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ABSTRACT

This document presents a sampling of unclassified, unlimited distribution (public release) NPS student theses and dissertations, NPS faculty reports, journal articles, and conference papers produced between 2005 and 2014. Thesis, dissertation, and faculty report citations were collated from Calhoun, the Dudley Knox Library's publicly accessible institutional archive (http://calhoun.nps.edu/public/) using the following search strategies:

Theses:
   'naval postgraduate school' AND (robot$ OR autonomous OR unmanned OR U?V OR A?V OR drone OR (remotely piloted))

Reports (Technical Reports):
   'naval postgraduate school' AND (robot$ OR autonomous OR unmanned OR U?V OR A?V OR drone OR (remotely piloted)) NOT (thesis or dissertation)
   where $ and ? are multi-character and single character truncators, respectively.

Journal Articles and conference paper citations were retrieved from these proprietary subscription databases, using the following search strategies:

Journal articles:
   Web of Science http://libproxy.nps.edu/login?url=http://isiknowledge.com/wos or http://isiknowledge.com/wos [subscription or IP access required]
   TS=(robot* OR autonomous OR unmanned OR U?$V OR A?$V OR drone* OR (remotely piloted)) AND AD=((USN OR Nav*) AND (NPS OR NPGS OR post*) AND (Monterey OR CA OR USA))

Journal articles and conference papers:
   Engineering Village 2 http://libproxy.nps.edu/login?url=http://www.engineeringvillage2.org or http://www.engineeringvillage2.org [subscription or IP access required]
   All fields: robot* OR autonomous OR unmanned OR drone* OR USV* OR AUV* OR UAV* OR UUV* OR UAS* OR UCAV* OR UCAS* OR UMV* or "micro air" or "micro vehicle" or uninhabited
   Author affiliation: Naval Post*
   where the * is a multi-character truncator

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TABLE OF CONTENTS

Contents

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THESES

2014

Bell, Timothy L. ***Sea-Shore Interface Robtic Design***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Advisor: Richard Harkins
http://hdl.handle.net/10945/42580
Abstract: An exoskeleton platform was developed, prototyped and tested for mobility performance in a beachfront environment. New platform, drive-train, motor-controller and wheel design were employed in the experiment. The objective was to improve on the shortcoming of previous NPS research. Three wheel-designs were tested during fixed pattern tests on grass, concrete and sand. Data suggests that, with regard to power consumption, there is a marginal difference on preferred wheel design. The sparse print round wheel showed promise in heavy vegetation; however, the WhegTM wheel proved to be the most versatile on various terrains. This suggests that a WhegTM wheel with improved round wheel characteristics would be optimal for various beachfront terrains.

Burke, Eric M. and Danny L. Ewing, Jr. ***Improving Warehouse Inventory Management Through RFID, Barcoding and Robotics Technologies***. MBA Professional Paper. Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2014.
Advisors: Nicholas Dew and Geraldo Ferrer
http://hdl.handle.net/10945/44556
Abstract: The purpose of this MBA project is to explore the potential value of combining automatic identification and robotics technology in order to improve asset visibility within a warehouse environment. The Defense Logistics Agency (DLA) experiences high costs associated with inventory inaccuracies and annual inventory audits. Our project examines technologies that could be used to improve the DLA's asset visibility. This study examines current industry applications of viable technologies in the marketplace and whether implementing these technologies would provide a sound economic solution. A cost–benefit analysis is included to determine the affordability of efficiencies that RFID and barcoding bring to warehouse operations. This analysis encompasses costs for systems purchase, implementation, and integration. Benefits are measured by determining cost savings in manpower requirements, increased efficiencies in order and restocking times, and improved accuracy in inventory management. The qualitative analysis addresses the advantages and disadvantages of an automatic identification system implementation. It also addresses future potential for the use of robots to improve inventory management. Ultimately, the project concludes that 2D barcoding far more cost effective within 10 years; however, both 2D barcoding and RFID can provide a positive return on investment.

Bumatay, Anthony A. and Grant Graeber. ***Achieving Information Superiority using Hastily Formed Networks and Emerging Technologies for the Royal Thai Armed Forces Counterinsurgency Operations in Southern Thailand***. M.S. in Network Operations. Monterey, California: Naval Postgraduate School, March 2014.
Thesis Co-Advisors: Brian Steckler and Edward Fisher
http://hdl.handle.net/10945/41353
Abstract: The southern Thailand provinces of Yala, Pattani, Narathiwat and Songkhla have seen a resurgence in Malay-Muslim violence since 2004. The scale and level of sophistication of the insurgent attacks have caused instability in the region and disruption in a country already marred by political turmoil. This thesis examines the history, trends in violence and actors behind the Malay-Muslim insurgency as well as the effectiveness of the Royal Thai Armed Forces'

counterinsurgency response. This is to create an analytical context that may be useful in the current Royal Thai Armed Forces (RTARF) approach in southern Thailand. This thesis also explores the applicability of network centric technologies such as hastily formed networks (HFN) as the backbone of a technological framework that will deliver information superiority to enable the Thai government to gain a tactical edge against the insurgent movement in southern Thailand. Along with the HFN concept, an overview of the emerging technologies that were demonstrated during the U.S.-Thailand Crimson Viper technology demonstration in Hat Yao, Thailand from August 19, 2013, are provided. This discussion will show how alternative power sources, social network analysis, persistent surveillance systems and unmanned vehicles, if integrated with HFN wireless ad hoc networking, provides an effective model to support the RTARF's counterinsurgency operations in southern Thailand.

Calibro, Taylor K. ***Obstacle Detection and Avoidance on a Mobile Robotic Platform Using Active Depth Sensing.*** M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Advisor: Xiaoping Yun
Second Reader: Zac Staples
http://hdl.handle.net/10945/42591
Abstract: The ability to recognize and navigate surrounding environments free from collision with obstacles has been at the forefront of mobile robotic applications since its inception. At the price of nearly one tenth of a laser range finder, the Xbox Kinect uses an infrared projector and camera to capture images of its environment in three dimensions. The objective of this thesis was to investigate if the Xbox Kinect can be utilized to detect thin or narrow obstacles that are often invisible to the P3-DX mobile robotic platform. We present an algorithm to process and analyze point cloud data from the Xbox Kinect sensor and transform it into a two-dimensional map of the surrounding environment for further use with the P3-DX. Obstacle avoidance scenarios were then performed using two separate algorithms: a narrow corridor following algorithm and a potential fields algorithm. The results demonstrate that in a structured testing environment, the Xbox Kinect can be used to detect and avoid narrow obstacles that are not immediately recognized by the onboard sonar array of the P3-DX.

Camacho, Nahum. ***Improving Operational Effectiveness of Tactical Long Endurance Unmanned Aerial Systems (TALEUAS) by Utilizing Solar Power***. Mechanical Engineer and M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Co-Advisors: Vladimir Dobrokhodov and Kevin D. Jones
Second Reader: Isaac Kaminer
http://hdl.handle.net/10945/42593
Outstanding Thesis Award
Abstract: This thesis develops, implements, and validates a hybrid energy-harvesting technique that enables extracting energy from the environment by utilizing convective thermals as a source of potential energy, and exploiting solar radiation for photovoltaic (PV) energy to achieve long endurance flight of an autonomous glider. The dynamic behavior of convective thermals, as well as their mathematical models, are studied to determine their motion, while the navigation task is simultaneously solved using a Bayesian search approach that is based on the prior knowledge of the 3D elevation. This study advances an existing technique for detection of thermals by implementing the online identification of the airplane sink rate polar. The glider's climb rate is optimized by implementing a modified thermalling controller, and its performance is compared to an existing method of centering in thermals. The integration of the energy extracted from the solar radiation is accomplished by the design of an Electrical Energy Management System (EEMS) that safely collects and distributes the energy onboard. The electrical energy is supplied by the semi-rigid mono crystalline silicon solar cells, which are embedded into the skin of the glider's wings without distorting the airfoil. To validate and verify the algorithms developed in MATLAB/Simulink, an interface to a high-fidelity pilot's training flight simulator was designed. Furthermore, the numerical algorithms were integrated onboard a prototype SB-XC glider

equipped with solar cells to enable the desired energy-harvesting technique. Flight test results verify the feasibility of the developed algorithms.

Campbell, Brenton. ***Human Robotic Swarm Interaction Using an Articifical Physics Approach***.
M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2014.
Thesis Co-Advisors: Timothy H. Chung and Richard M. Harkins
http://hdl.handle.net/10945/44531
Oustanding Thesis Award
Abstract: This thesis explores the use of an artificial physics framework to provide centralized control of a collection of agents in close proximity to a human operator. Based on the spatial separation between agents, agents to way-point, and agents to operator, the artificial physics framework calculates virtual forces that are summed and translated into velocity commands. The virtual forces are modeled after real physical forces such as gravitational and Coulomb, forces but are not restricted to them, for example, the force magnitude may not be proportional to one divided by separation distance squared. These virtual forces allow the collection of agents, or the swarm, to autonomously find the operator, create a formation, and navigate way-points. The operator has high-level control of the agents via a hand held-controller. This framework is applicable to a scenario where an operator in the field needs to work with several autonomous vehicles but is unable to devote a high-level of focus to controlling agent behavior.We implemented an artificial physics framework in two simulation environments and in physical indoor experiments with a team of three unmanned aerial vehicles. The results from the physical experiments show that an artificial physics-based framework is an effective way to allow multiple agents to follow a human operator inside a small arena with only minimal operator input.

Carey, Seamus B. ***Increasing the Endurance and Payload Capacity of Unmanned Aerial Vehicles with Thin-Film Photovoltaics***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Advisor: Sherif Michael
Second Reader: Alejandro Hernandez
http://hdl.handle.net/10945/42594
Abstract: Prior research has shown that the endurance of small unmanned aerial vehicles (UAV) can be significantly extended using thin film photovoltaic cells. The different power requirements of the RQ-11B Raven variants are explored in this thesis, and it is demonstrated that a CuInGaS2 (CIGS) solar array adhered to the wing of an RQ-11B not only extends the flight time but also expands the payload capacity of the platform. Power requirements and existing endurance of the digital variant of the RQ-11B were measured to establish a baseline of the platform's performance and validate previous research. A modular wing with an integrated CIGS array was then designed and constructed to be incorporated with the existing power circuitry of the platform. The baseline tests were repeated to determine the power generated by the array and supplied to the digital RQ-11B. It was shown that a solar integrated RQ-11B has a larger payload capacity and extended endurance, while still maintaining the modular and expeditionary nature of the existing platform. The concept of this research may be applied to all unmanned aerial platforms in order to expand their power generation to operate simultaneous or demanding payloads without stressing the existing power supply.

Chang, Ellen M. ***Defining the Levels of Adjustable Automony: A Means of Improving Resilience in an Unmanned Aerial System***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Advisor: Warren Vaneman
Second Reader: Oleg Yakimenko
http://hdl.handle.net/10945/43887
Abstract: This thesis investigates how to design in different levels of autonomy to improve the resilience of an unmanned aerial system (UAS) by applying the Function-specific Level of Autonomy Tool (FLOAAT) developed by NASA. This tool helps to define the levels of autonomy human-operators are comfortable with as well as assists designers in understanding how to

design in that level of autonomy. The thesis begins by reviewing past literature about resilience in engineered systems, defining terms pertaining to autonomy, introduces the concept of adjustable autonomy, and reviews the development supervisory control levels that define adjustable autonomy. It broadens the research that NASA performed and applies the tool to UAS functions. The extension of this thesis would lead to a more unified approach to defining levels of autonomy that can be adjusted for control of autonomous systems, and the development of components of software architecture that lead to greater systems resilience through integration of the human-operator in a way that is trusted. This effort is intended to create a foundation for human-centered automation to properly accommodate human-operator trust.

Davis, Robert B. *Applying Cooperative Localization to Swarm UAVs Using an Extended Kalman Filter*. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Co-Advisor: Timothy H. Chung and Duane T. Davis
http://hdl.handle.net/10945/43900
Abstract: Cooperative Localization (CL) is a process by which autonomous vehicles operating as a team estimate the position of one another to compensate for errors in the positioning sensors used by a single agent. By combining independent measurements originating from members of the team, a single estimate of increased accuracy will result. This approach has the potential to enhance the positional accuracy of an agent over use of a standard GPS, which would be essential for behaviors within a swarm requiring precision move-ments such as maintaining close formation. CL can also provide accurate positional information to the entire group when operating in an intermittent or denied GPS environment. In this thesis, a distributed CL algorithm is implemented on a swarm of Unmanned Aerial Vehicles (UAVs) using an Extended Kalman Filter. Using a technique created for ground robots, the equations are modified to adapt the algorithm to aerial vehicles, and then operation of the algorithm is demonstrated in a centralized system using AR Drones and the Robot Operating System. During tests, the positional accuracy of the UAV using CL improved over use of dead reckoning. However, the performance is not as expected based on the results noted from the referenced two-dimensional application of the al-gorithm. It is presumed that the sensors on-board the AR Drone are responsible. Since the platform is simply a low-cost solution to show proof-of-concept, it is concluded that the implementation of CL presented in this thesis is a suitable approach for enhancing positional accuracy of UAVs within a swarm.

Denevan, Thomas J. *Cost-Based Analysis of Unmanned Aerial Vehicles/Unmanned Aerial Systems in Filling the Role of Logistical Support*. M.S. in Management. Monterey, California: Naval Postgraduate School, December 2014.
Thesis Co-Advisor: Simona Tick and Douglas Brinkley
http://hdl.handle.net/10945/44549
Abstract: This thesis conducts a comparative cost analysis for using unmanned aerial vehicles (UAVs)/unmanned aerial systems (UASs) for logistical resupply purposes as opposed to the traditional logistical resupply resources. First, the thesis examines the types of UAVs in the U.S. Department of Defense (DOD) inventory as well as the traditional aircraft currently used for logistical purposes. Then, using a cost-based analysis, the thesis identifies possible logistical uses for selected UAVs based on specific capabilities and scenarios where the use of these systems would be most advantageous compared to traditional logistic resources. As the DOD continues to develop the emerging technologies of UAVs, the findings of this thesis may point to some immediate adaptations in the logistical resupply process that could result in cost savings.

Dillard, Chase H. ***Energy-Efficient Underwater Surveillance by Means of Hybrid Aquacopters***.
M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December
2014.
Thesis Co-Advisor: Vladimir Dobrokhodov and Kevin Jones
http://hdl.handle.net/10945/44551
Outstanding Thesis Award
Abstract: This thesis develops algorithms in support of a prototype hybrid air-water quadcopter
platform: the AquaQuad. We consider the scenario in which AquaQuads with underwater acoustic
sensing capabilities are tracking a submerged target from the surface of the ocean using sparse
distributed measurements. Multiple nonlinear estimation filters are evaluated for the tracking
scenario, resulting in the selection of the unscentedKalman filter (UKF). Geometric positioning
effects on estimators are explored through analysis of the horizontal dilution of precision metric.
The UKF is then implemented in real-time on quadrotors using time-difference of arrival pseudo-
measurements in an instrumented Vicon lab space. The AquaQuads will primarily drift, but
possess battery-limited flight capabilities. To increase on-station time, we seek to maximize use
of the environment. In addition to solar energy, we take advantage of ocean currents that
traditional autonomous platforms seek to reject. A novel sampling-based approach for path-
planning is therefore created and lab-tested. The new algorithm, Dead-Reckoning Rapidly-
Exploring Random Tree Star (DR-RRT*), combines the infinite-time optimality guarantees of
RRT* with the unique AquaQuad mobility requirements. The DR-RRT* develops obstacle-free
paths to a goal by linking brief flight and energy-efficient drift segments together, resulting in an
energy savings of 27 percent over direct flight.

Everly, Randall E. and David C. Limmer. ***Cost-effectivenss Analysis of Aerial Platforms and
Suitable Communications Payloads***. M.S. in Information Technology Management and Master
of Business Adminstration. Monterey, California: Naval Postgraduate School, March 2014.
Thesis Co-Advisors: Cameron MacKenzie and Glenn Cook
Second Reader: John Gibson
http://hdl.handle.net/10945/41375
Abstract: The goal of this research is to perform a cost-effectiveness analysis of selected aerial
platforms and suitable communication payloads for use as communication relays in support of
distributed military operations. Aerial platforms, for the purpose of this study, include UAVs,
towers and aerostats. A multi-objective analysis is utilized to compare dissimilar attributes
together among the alternatives. Cost data for each system considered is presented. To analyze
the cost-effectiveness of alternatives for different mission sets, three hypothetical scenarios are
used including disaster relief, long-range relay, and the tactical user. This research identifies the
most cost-effective aerial platforms and communication payloads for each scenario based on the
authors' preferences. Future decision makers can utilize this study as a decision tool to match
their own preferences.

Foster, Joseph D. ***Swarming Unmanned Aerial Vehicles (UAVs): Extending Marine Aviation
Ground Task Force Communications Using UAVs***. M.S. in Defense Analysis. Monterey,
California: Naval Postgraduate School, December 2014.
Thesis Advisor: John Dillard
Second Reader: Douglas Brinkley
http://hdl.handle.net/10945/44564
Abstract: Technological advances and research are pushing the application of unmanned vehicles
in exciting directions. This thesis emphasis is on cost estimation for a new unmanned aerial
vehicle (UAV) with swarm applications. The new swarm UAV theoretical can be designed to
emulate the current unmanned aerial system (UAS) mission, and expand upon the
communication relay mission. Small UASs have a line-of-sight capability limitation that leaves
room for improvement. The UAVs organic to the U.S. Marine Corps (USMC) are the primary focus
for this analysis because organic USMC UAVs are habitually small UAVs. The analysis will
determine a rough cost estimation range for a future AV with new technology. Based on the
adaptation of networking topologies and research, the communication relay mission is a feasible

capability to Peruse in future swarm UAVs. The analysis suggests that a swarm UAV is comparable in cost to legacy UAVs currently in service in the USMC.

Hermsdorfer, Kathryn M. ***Environmental Data Collection Using Autonomous Wave Gliders***. M.S. in Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, December 2014.
Thesis Advisor: Qing Wang
http://hdl.handle.net/10945/44577

Abstract: The Sensor Hosting Autonomous Remote Craft (SHARC), also known as Wave Glider, is an autonomous ocean vehicle powered by wave motion. This slow-moving platform makes long-term deployments and environmental data collection feasible, especially in data sparse regions or hazardous environments. The standard SHARC hosts a meteorological station (Airmar PB200) that samples air pressure, temperature, wind speed and wind direction at 1.12 m. The SHARC automatically transmits a 10-minute averaged data suite through an Iridium satellite link. In an effort to evaluate the SHARC default Airmar sensors and seek optimal sensors for air-sea interaction studies, NPS has developed an independent package of meteorological sensors, the NPS Met, for use on the SHARC. NPS Met measures pressure, air temperature, wind, SST, and relative humidity. This SHARC payload package was deployed three times in the Monterey Bay, along with a collocated drifting buoy (Marine Air-Sea Flux buoy, or MASFlux) with proven flux, mean, wave, and SST measurement for comparison and validation. This thesis will present analyses of data from the new mast and Airmar as compared to known, quality measurements from NPS MASFlux and NDBC buoy. Surface fluxes, evaporation duct heights and strength are derived from the SHARC measurements using the COARE algorithm.

Hewgley, Charles W., IV. ***Pose and Wind Estimation for Autonomous Parafoils***. PhD. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2014.
Disseration Supervisor: Roberto Cristi
http://hdl.handle.net/10945/43926

Abstract: This dissertation presents two contributions to the development of autonomous aerial delivery systems (ADSs), both of which advance the prospect of enabling an ADS to land on a moving platform, such as the deck of a ship at sea. The first contribution addresses the problem of estimating the target's position and velocity. A novel, dual-rate estimation algorithm based on Unscented Kalman filtering allows the ADS to use visual measurements from a fixed monocular sensor to estimate the target's motion even when the ADS's swinging motion in flight causes the target to be out of view. The second contribution addresses the problem of planning a landing trajectory considering winds in the vertical air mass between the target's height and the ADS's altitude. A wind model that assumes a logarithmic relationship between horizontal wind velocity and height in the air mass enables the ADS's guidance algorithm to plan a valid landing trajectory in the presence of these winds. This dissertation contains simulation results for the visual estimation algorithm that show that estimation errors are minimal after estimator convergence. Flight test results indicate that the wind modeling algorithm was useful for computing landing trajectories.

Hilger, Ryan Peter. ***Acoustic Communications Considerations for Collaborative Simultaneous Localization and Mapping.*** M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2014.
Thesis Advisor: Douglas Horner
Second Reader: Noel DuToit
http://hdl.handle.net/10945/44579

Abstract: This thesis considers the use of acoustic communications in reducing position uncertainty for collaborating autonomous underwater vehicles. The foundation of the work relies on statistical techniques for accurate navigation without access to GPS, known as Simultaneous Localization and Mapping (SLAM). Multiple AUVs permit increased coverage, system redundancy and reduced mission times. Collaboration through acoustic communications can minimize navigational uncertainty by permitting the group to benefit from locally discovered information.

However, the propagation of acoustic communications can be used to counter detect the system during naval operations. The thesis gives explicit consideration to tactical security in acoustic communications for a multi-AUV SLAM system. It provides initial techniques and analysis for minimizing communications between AUVs. The reduction is accomplished through a statistical method that allows for the estimation of the updated covariance matrices. Normally, SLAM techniques use expropioceptive (sonar and cameras) sensors and computer vision algorithms for the detection and tracking of navigational references. We propose a novel use of the acoustic modem as another sensor. It leverages the physical characteristics of underwater acoustic transmissions and the information transmitted in the signal to provide an additional measurement. We believe this is the first emphasis on minimizing communications within a multi-vehicle SLAM approach.

Jones, Courtney David. ***An Analysis of the Defense Acquisition Strategy for Unmanned Systems***. M.S. in Management. Monterey, California: Naval Postgraduate School, March 2014. Thesis Co-Advisors: Nicholas Dew and William Fast
http://hdl.handle.net/10945/41400
Abstract: In the past 12 years of sustained conflict, the Department of Defense (DoD) has procured thousands of unmanned systems, from ordnance disposal robots to airborne surveillance platforms to unmanned cargo helicopters. These assets have saved countless lives and have become critical to DoD strategy. The health of the U.S. robotics industry must become a national strategic imperative in order to maintain technology dominance. The cyclical nature of DoD funding inevitably results in industry expansion and consolidation. The unmanned systems industry will be subject to consolidation pressures. Keeping unmanned system cost-per-copy low is critical; thus, economies of scale should be highly valued. However, premature robotics industry consolidation could threaten innovation and competition that will be critical for the U.S. military to maintain its dominance. With impending budget reductions, there will be increasing pressure to narrow down on robotics technologies to achieve efficiencies and reduce costs. However, to maintain the health of the robotics industry, the acquisition strategy must be contingent on the evolution of industry. This thesis examines the defense robotics industry and historical technology S-curves for comparable industries and evaluates unmanned system acquisition strategies.

Juriga, Jacob T. ***Terrain Aided Navigation for REMUS Autonomous Underwater Vehicle***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2014. Thesis Advisor: Doug Horner
Second Reader: Noel DuToit
http://hdl.handle.net/10945/42654
Abstract: This research investigates the ability to create an undersea bathymetry map and navigate relative to the map. This is known as terrain aided navigation (TAN). In our particular case, the goal was for an autonomous underwater vehicle (AUV) to reduce positional uncertainty through the use of downward-looking swath sonar and employing TAN techniques. This is considered important for undersea operations where positioning systems such as GPS are either not available or difficult to put in place. There are several challenges associated with TAN that are presented: The image processing necessary to extract altitude data from the sonar image, the initial building of the bathymetry map, incorporating a system and measurement model that takes into consideration AUV motion and sensor uncertainty and near-optimal, real-time estimation algorithms. The thesis presents a methodology coupled with analysis on datasets collected from joint Naval Postgraduate School/National Aeronautical Space Administration experimentation conducted at the Aquarius undersea habitat near Key Largo, Florida.

Kubisak, Timothy D. *Investigation of Acoustic Vector Sensor Data Processing in the Presence of High Variable Bathymetry.* M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Advisor: Kevin B. Smith
Second Reader: Daphne Kapolka
http://hdl.handle.net/10945/42664
Abstract: Data has been collected on acoustic vector sensors mounted on autonomous underwater gliders in the Monterey Bay during 2012–2013. Previous processing work computed the acoustic vector intensity to estimate bearing to impulsive sources of interest. These sources included small explosive shots deployed by local fishermen and humpback whale vocalizations. While the highly impulsive shot data produced unambiguous bearing estimations, the longer duration whale vocalizations showed a fairly wide spread in bearing. In this work, causes of the ambiguity in bearing estimation are investigated in the context of the highly variable bathymetry of the Monterey Bay Canyon, as well as the coherent multipath interference in the longer duration calls. Sound speed data collected during the previous experimental effort, along with a three-dimensional bathymetric relief of the Monterey Bay Canyon, are incorporated into a three-dimensional version of the Monterey-Miami Parabolic Equation Model. Propagation results are computed over a frequency band from 336–464 Hz in order to provide predictions of pulse arrival structure. This data is analyzed using conventional pressure plane-wave beamforming techniques in order to highlight horizontal coupling caused by the canyon bathymetry. The data is also analyzed using the previously developed acoustic vector intensity processing string and shown to exhibit a qualitatively similar spread in the estimated bearing.

Lee, Joong Yang. *Expanded Kill Chain Analysis of Manned-Unmanned Teaming for Future Strike Operations*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Advisor: Timothy h. Chung
Second Reader: Ronald E. Giachetti
http://hdl.handle.net/10945/43944
Abstract: This study explores the concept of manned-unmanned teaming in the context of the joint capability areas and investigates the expanded kill chain for a manned and unmanned team for future strike operations. The study first elucidated capabilities that can be realized by manned-unmanned teams. A design reference mission for a manned-unmanned team (strike) operation was developed, enabling operational activity and functional analysis of the expanded kill chain. Simulation models were built to examine the time-efficiencies of the manned-unmanned teaming concept. This research used insights from the results of the models to explore alternatives in asset generation and systems link-up tactics. The analysis of strike operations cycle times that include total mission operations time, airborne time, and time to complete systems link-up provided data to generate recommendations. Besides identifying areas on which to focus efficiency improvement efforts, this study also proposes tactics and concept of operations to enhance the effectiveness of strike operations by manned-unmanned teams. This study reveals that fighter endurance is a limiting factor in manned-unmanned operations and proposes a synchronized launch or pre-launch establishment of communications and datalink as possible ways to mitigate these limiting factors.

Lowe, Donald R., Holly B. Story, and Matthew B. Parsons. *U.S. Army Unmanned Aircraft Systems (UAS)—A Historical Perspective to Identifying and Understanding Stakeholder Relationships*. Joint Applied Project. M.S. in Program Management. Monterey, California: Naval Postgraduate School, June 2014.
Advisor: Richard B. Doyle
http://hdl.handle.net/10945/42678
Abstract: This research is intended to advance understanding of relationships between unmanned aircraft systems (UAS) stakeholders and programs to allow the Army to increase efficiencies and reduce costs. It was found that the Army had never completed a formal UAS stakeholder identification and analysis. Internal and external stakeholders are identified here and fall within

categories of Army executive program leadership (e.g., Program Executive Office for Aviation), Army and service components (active, Guard, reserve forces), senior Army leadership (e.g., Headquarters, Department of Army), other federal and non-federal government entities (e.g., Congress), commercial interests (e.g., industry and academia), and other interested parties, such as the American people. An analysis of relationships affecting these stakeholders was conducted, including organizational beliefs and cultures, management of resources, policies and law and future UAS enhancements planned by the Army and industry partners. The most important problems found were inter-service and inter-branch disputes that shape UAS policies and procedures, forecasting for future UAS growth while managing costs and finding more efficient, less redundant ways to use current UAS capabilities, and safe integration into the national airspace system. This stakeholder analysis allows the Army to leverage the support of others for funding, resources, intellectual property, lessons learned and cooperation.

Margonis, Sotirios. ***Preliminary Design of an Autonomous Underwater Vehicle using Multi-Objective Optimization***. Mechanical Engineer, M.S. in Mechanical Engineering, and M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, March 2014.
Thesis Co-Advisors: Joshua Gordis and Tarek Abdel-Hamid
Second Reader: Fotis Papoulias
http://hdl.handle.net/10945/41415
Outstanding Thesis Award
Abstract: The aim of this work is to explore the applicability and usability of multi-objective optimization into various aspects of the design of an autonomous underwater vehicle (AUV). First, I begin with an introduction of the systems engineering design process and the background work for the multi-objective optimization process. Furthermore, I investigate and analyze the existing multi-objective optimization methods in decision making. I focus on various design aspects of an AUV such as the hull design, the weight distribution, the propulsion and, especially, the power supply technology. The objectives I used in the model are the minimization of the power needed to propel the vehicle and the maximization of both the weight of the energy section and the total range. Implementation of both the model and the optimization are carried out using Matlab, particularly the global optimization toolbox and the multi-objective genetic algorithm solver, whereas a special case of two objectives is implemented in Excel using Visual Basic and Excel solver. This research also explores the potential for a designer to use goals in the multi-objective optimization as well as approaches that let a designer choose one particular solution once all Pareto optimal solutions are found.

McMillan, Stuart I. and Jason G. McPhee. ***An Analysis of the First Fifteen Years of the Department of Defense Framework for Unmanned Ground Systems***. MBA Professional Paper. Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2014.
Thesis AdvisorS: Nicholas Dew and John T. Dillard
http://hdl.handle.net/10945/44613
Outstanding Thesis Award
Abstract: The Unmanned Ground Vehicle (UGV) program traces its roots back to Desert Shield and Desert Storm. At that time, warfighters observed the use of Unmanned Aerial Vehicles and recognized the potential for their ground use. Literature supporting this research focuses on UGV history, the Sigmoid Curve, associated push and pull factors, and the Department of Defense (DOD) Acquisition Strategy. DOD UGV master plans, which are used to conduct comparative analyses of programs, changes, and trends from year to year, examine the cost, schedule, and performance of all programs from 1991 to 2004. This research focuses on experienced schedule overruns, slippage, and the examination of characteristics leading to system success. This research also explains the relationship between push and pull factors and further outlines the evolution of UGV program requirements based on global conflicts and various mission types. This research clearly indicates that UGVs are created for force protection more than any other warfighting function.

Moore, Jeanie. ***Da Vinci's Children Take Flight: Unmanned Aircraft Systems in the Homeland***.
M.A. in Security Studies (Homeland Security and Defense). Monterey, California: Naval
Postgraduate School, March 2014.
Thesis Advisor: John Rollins
Second Reader: Robert Simeral
http://hdl.handle.net/10945/41420
Outstanding Thesis Award
Abstract: In 2015, the Federal Aviation Administration will open national airspace to unmanned
aircraft systems (UAS). Nonmilitary uses for UAS range from agriculture services to
entertainment purposes, and include tasks as mundane as inspecting gutters and as
consequential as fighting fires. Outside of the safety issues that accompany many breakthrough
technologies, the effort to integrate UAS into national airspace is enmeshed in political, legal and
economic policies that require careful navigation. Factors like cybersecurity and technological
advancements will continue to influence the way UAS can be used. This thesis provides an
orientation to the key considerations in UAS integration. Policy recommendations include early
stakeholder engagement; a national data protection law; no-fly zones around private residences;
clearly identifying UAS operators and owners; nonlethal payloads in national airspace; adapting
current surveillance laws to UAS; a single, national privacy law to facilitate the free flow of
commerce and coordination across state lines; a federal office in charge of monitoring data
privacy; accountability of data collectors; limited exemptions for activities conducted in the
interest of national security or to protect life and property; and managing cybersecurity risks.

Morisseau, Peter M. ***Coast Guard Maritime Security in the Underwater Domain***. MBA Professional
Paper. Master of Business Administration. Monterey, California: Naval Postgraduate School,
March 2014.
Thesis Co-Advisors: John Dillard and Gary Langford
http://hdl.handle.net/10945/44624
Abstract: The Coast Guard serves as the primary agency responsible for maritime domain
awareness (MDA) and transportation security under the Department of Homeland Security
through the Ports, Waterways, and Coastal Security (PWCS) mission. While significant
investments have been made in recent years for surface and air assets along with increased
command and control capabilities, little has been done to expand the PWCS mission to the
underwater domain. This thesis examines the need for the Coast Guard to develop MDA in the
underwater domain. This is accomplished by applying the fundamental processes from capability
gap analysis and analysis of alternatives (AoA), as would be necessary for initiating the
acquisition process. Through the gap analysis and AoA processes, the organization is able to
determine whether an operational need truly exists, whether current or emerging technology is
available to support a materiel solution, and whether there is the appropriate level of investment.
Ultimately, the intent of this thesis is to determine whether the Coast Guard has a validated
capability gap, and what opportunities exist to close the gap.

Murray, Kate L. ***Early Synthetic Prototyping: Exploring Designs and Concepts Within Games***.
M.S. in in Computer Science. Monterey, California: Naval Postgraduate School, December 2014.
Thesis Co-Advisor: Rudolph Darken and Brad Naegle
http://hdl.handle.net/10945/44627
Outstanding Thesis Award
Abstract: Early Synthetic Prototyping (ESP) is a process and set of tools that enable warfighters
to inform technology development and acquisition decisions by assessing emerging technologies
in a game environment. Collaborators in acquisition, science and technology, and industry can
develop models and scenarios for play and assessment. ESP allows an unbounded increase in
potentially disruptive ideas to be explored at minimal cost by inviting warfighters at all levels to
drive, define, and refine future systems. We conducted a study asking: (1) What feedback can be
gathered from game play? (2) Would that feedback be valuable? To this end, groups of military
officers were engaged in several scenarios to explore an unmanned vehicle concept called Robotic
Wingman. Through the game sessions, players expressed ideas on the characteristics of a

preferred interface and how to best employ Wingman. Using a game environment to explore design concepts early in the acquisition process can be applied to early requirement refinement and rudimentary tradeoff analysis. The encouraging results of this preliminary work demonstrate a strong potential to leverage game environments to explore revolutionary concepts to efficiently and effectively shape the future of the Department of Defense.

Naccarato, Vincent, Joong Yang Lee, Meng His Wu, Ittai Bar Ilan, James Efird, Benjamin Elzner, Darrell Morgan, Kayla Tawoda, Evan Wolfe, Wei Jun Goh, Sok Hiang Loo, Kok Wah Ng, Chee Siong Ong, Choon Ming Tan, Hock Woo Tan, Chung Siong Tng and Kangjie Yang. *The Distributed Air Wing*. Capstone Project, Cohort 20, Team Bravo. M.S. in Systems Engineering Analysis. Monterey, California: Naval Postgraduate School, June 2014.
Project Advisor: Timothy H. Chung
Second Reader: Jeffrey Kline
http://hdl.handle.net/10945/42717
Abstract: The development of advanced anti-access/area denial (A2AD) threats by potential adversaries presents a significant challenge to the United States Navy. The proliferation of these threats makes operating an aircraft carrier from contested waters a high-risk endeavor. If a carrier must be withheld from the battle or is put out of action, the entire capability of the air wing is lost. The Systems Engineering process was applied to this problem by exploring a concept called the Distributed Air Wing (DAW). This high-level concept includes various methods to distribute and disperse naval air capabilities from their centralized location on an aircraft carrier. This study outlines the development and analysis of three conceptual designs that fall under the concept of the DAW: a dispersed land and sea basing concept that utilizes carrier-borne Navy and Marine Corps aircraft, a seaborne unmanned aircraft courier system, and a carrier-based unmanned air-to-air vehicle. The analysis within shows that a mixture of these alternatives in varying degrees delivers the Fleet's most critical capabilities— Intelligence, Surveillance and Reconnaissance (ISR), Offensive/Defensive Counter Air, and Surface/Land Strike— with less risk than the current Carrier Air Wing (CVW) force structure and operational doctrine

Oncu, Mehmet and Suleyman Yildiz. *An Analysis of Human Causal Factors in Unammned Aerial Vehicle (UAV) Accidents.* MBA Professional Paper. Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2014.
Advisors: Edward H. Powley and Bryan J. Hudgens.
http://hdl.handle.net/10945/44637
Abstract: Human error has been identified as the major contributor in many severe aviation mishaps, even for accidents involving Unmanned Aircraft (UA) systems. The Department of Defense (DOD) has used the Human Factors Analysis and Classification System (HFACS) taxonomy successfully for ten years to discover the human error in UA mishaps. It is important not to ignore the indisputable human presence in UA and the possible human-related causal factors in UA mishaps so we might be better able to reduce and prevent possible incidents. HFACS with its four main and 19 subcategories is a useful framework for identifying which factors have arisen historically, and which of them should have priority. The results of this study reveals that among 287 causal factors attributed to 68 accidents, 65 percent of the factors were associated with humans. Moreover, this study also discloses that the rater who categorizes the factors can differently observe, understand, and interpret the findings of mishap investigation; thus, human error may even impact the categorization phase due to the rater's perception. The research concluded that even though HFACS carried out its functionality well, further study is needed to conduct intense statistical analysis with unlimited data and to validate HFACS with more case studies and various raters.

Ong, Chee Siong. ***Logistics Supply of the Distributed Air Wing***. M.S. in Modeling, Virtual Environments, and Simulation. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Advisor: Timothy Chung
Second Reader: Eugene Paulo
Outstanding Thesis Award
http://hdl.handle.net/10945/43969

Abstract: The use of the aircraft carrier has been the norm for delivering sizable amounts of air power swiftly to any part of the world. A capstone project, conducted by the system engineering curriculum, proposed to distribute the air assets from the aircraft carrier to multiple Expeditionary Airbases (EABs), which are land bases located within the operating theater. This thesis studies the logistical demands of the EABs, and adopts the Marine Aviation Logistics Support Program II (MALSP II) concept for the logistics supply of the Distributed Air Wing. Airship, fixed wing Unmanned Air Vehicle (UAV), and rotary wing UAV are explored as the main cargo transportation means. This thesis develops a vehicle routing optimization model to optimize the transportation fleet size and mix, and a discrete event simulation to analyze the logistics concept. Experiments are conducted to determine the feasibility and cost-effectiveness of using cargo UAVs, using cargo trucks as a reference for comparisons. All platforms achieved the three days' turnaround time, as stipulated by MALSP II. The airship is found to be the most cost-effective solution. Rotary wing and fixed wing UAVs deliver their supplies much faster, but are more suitable for quick response missions, instead of large cargo deliveries.

Patton, Scott A. ***A Comparison of Tactical Leader Decision Making Between Automated and Live Counterparts in a Virtual Environment***. M.S. in Modeling, Virtual Environments, and Simulation. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Advisor: Quinn Kennedy
Second Reader: Jonathan Alt
http://hdl.handle.net/10945/42705

Abstract: The use of responsible autonomous systems may not be far away. Prior to developing or using responsible autonomous systems, it may be important to know if tactical leaders would make different types of decisions with automated systems than they would make with a human live crew. This work attempts to determine if decisions, time to make decisions, and confidence in decisions differ when tactical leaders rely on an autonomous wingman or a live wingman. Virtual Battlespace Simulation 2 was used to provide the virtual environment in which 30 military personnel completed a simulated mission that entailed five decision points. Participants were randomly assigned to have an autonomous or live wingman. Decision patterns were compared to a standard based on Army Doctrine for mechanized infantry Bradley sections and subject matter experts. Results indicated no significant group difference in decisions made, time to make decisions, and confidence in decisions. However, significant group differences emerged in the aspects of the wingman that participants trusted most and least. Although most participants indicated that they would not trust autonomous wingmen in real combat, results suggest that participants would revert to doctrinal decisions when faced with an unambiguous situation with an unmanned system with which they had some experience.

Ramos, Nicole R. ***Assessment of Vision-Based Target Detection and Classification Solutions Using an Indoor Aerial Robot***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Advisor: Timothy H. Chung
Second Reader: Oleg A. Yakimenko
http://hdl.handle.net/10945/43984

Abstract: The role of unmanned aerial vehicles (UAVs) in military, commercial and recreational applications is continuously evolving as devel-opments in technology increase capabilities. The research herein presents an inexpensive computer-vision-based solution for detection and classification of a stationary target with a mobile aerial sensor as a prototyping platform. The main goal of this system is to use commercial-off-the-shelf and open-source components to

reduce design complexity to provide a legacy product for future develop-ment of specific capabilities. Color imagery collected during flight using a low-resolution camera is used to test the application of a simple algorithm against a commercially available and low cost sensor. Original image processing algorithms that leverage the existing body of works in the open-source community are developed and tested within the Systems Engineering construct. System architec-ture leverages a modular approach that can be easily modified and adapted to changing requirements and objectives. Conclusions are drawn and recommendations for further study and system development are presented.

Saadat, Muhammad K. ***The Drone Dilemma: Investigating the Causes of Controversy Between the United States and Pakistan***. M.A. in Security Studies (Combating Terrorism: Policy & Strategy). Monterey, California: Naval Postgraduate School, December 2014.
Thesis Advisor: Carolyn Halladay
Second Reader: Feroz H. Khan
http://hdl.handle.net/10945/44660
Abstract: The thesis examines the effects of U.S. drone strikes on Pakistan's politics, internal security, and relationship with the United States. It analyzes the perspectives of the United States and Pakistan within the realm of national interests, legal framework, and ethical aspects, as well as considers short-term benefits and long-term consequences. Whatever the tactical efficacy of drone strikes may be, they have contributed to anti-American feelings and a growing trust deficit between the United States and Pakistan, and adversely affected the actual cause of fighting terrorism. The thesis concludes that drones have not achieved significant success in the war on terror. The attacks have achieved tactical successes at a very heavy cost for Pakistan— and possibly to the detriment of the global war on terror. Drone operations have supplemented terrorist recruitment and resolve, pumped up anti-U.S. feeling in Pakistan and across the globe, and have set up dangerous precedents for countries potentially possessing other countries. The study offers a number of recommendations that are not new, but if followed can promote improvement at every tier.

Scott, Barry S. ***Strategy in the Robotic Age: A Case for Automous Warfare***. M.A. in Security Studies (Strategic Studies). Monterey, California: Naval Postgraduate School, September 2014.
Co-Thesis Advisors: Donald Abenheim and James Wirtz.
http://hdl.handle.net/10945/43995
Abstract: The advent of a Robotic Age in combat has set the stage for a renewed style of warfare: autonomous warfare. The outstanding feature of this new era is the arrival of robotics on the battlefield, but the significance of the new warfare style is that it mandates a shift in the way humans approach modern combat. In 2010, the Department of Defense restated autonomy as the single greatest theme for today's unmanned systems. Autonomy, however, has long been a theme in warfare and weapons; therefore, the concept should apply to both those who fight and to their machines. Autonomy is the current buzzword for improving technology, but increasing autonomy for the soldier or combatant is the defining characteristic of autonomous warfare. With a view to this development, this study suggests changes in the character of war, and proposes autonomous warfare as an operating concept that empowers, rather than replaces, humans in battle.

Shim, JooEon. ***Optimal Estimation of Glider's Underwater Trajectory with Depth-Dependent Correction Using the Navy Coastal Ocean Model with Application to Antisubmarine Warfare.*** M.S. in Physical Oceanography. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Advisor: Peter C. Chu
Second Reader: Chenwu Fan and Ronald Betsch
http://hdl.handle.net/10945/44002
Abstract: An underwater glider is a cost-effective underwater unmanned vehicle with high-endurance for oceanographic research or naval applications. Its navigation and localization accuracy are important because these accuracies provide spatiotemporally high resolution ocean

data with saving energy and time. The glider, however, is affected by the ocean currents because of its minimal velocity, which is due to its buoyancy-driven propulsion system. It also lacks of inexpensive and efficient localization sensors during its subsurface mission. Therefore, knowing its precise underwater position is a challenging task. This study attempts to develop a novel correction method for estimating a glider's optimal underwater trajectory. In four steps, it compares the corrected trajectories, which are developed using depth-averaged and depth-dependent correction methods using the Regional Navy Coastal Ocean Model (NCOM). The results suggest that the depth-dependent correction method is more accurate. This study for estimating a glider's underwater trajectory accurately would be beneficial to oceanographic research and naval applications, especially antisubmarine warfare (ASW) such as operating Intelligence, Surveillance, and Reconnaissance (ISR); operating littoral ASW; providing communication networks; and supporting tactical oceanography.

Smith, Montrell F. ***Converting a Manned LCU Into an Unmanned Surface Vehicle (USV): Aa Open Systems Architecture (OSA) Case Study***. M.S. in Systems Engineeing Management. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Advisor: Donald P. Brutzman
Second Readers: Richard D. Williams, III and Paul V. Shebalin
http://hdl.handle.net/10945/44004
Abstract: This thesis demonstrates the process by which the concepts of open systems architecture (OSA) might be applied within the context of an existing systems engineering methodology to result in a flexible system. This is accomplished by combining an existing systems engineering process model with OSA management and business principles to execute a successful asset-repurposing program. To demonstrate utility of this OSA approach to systems engineering management, this thesis analyzes an atypical asset-repurposing program: the conversion of a 1610 Class Landing Craft Utility to an unmanned surface vehicle. This thesis shows that OSA technical architecture is best implemented by defining high-level, business and technical flexibility requirements. This thesis argues that proper up-front architecting can balance non-recurring acquisition costs with future recurring lifecycle and modernization costs. A reference model and open standards are used to show the value of interface flexibility. This analysis makes the case for extending the useful service life of a Naval asset via repurposing rather than disposing of the asset, as is traditional. Furthermore, this analysis shows that strategic reuse or repurposing of assets represents an innovative alternative to the traditional sense of new-product acquisition, new-construction, and product modernization decisions.

Sözen, Volkan. ***Optimal Deployment of Unmanned Aerial Vehicles for Border Surveillance***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Advisor: Emily Craparo
Second Reader: Thomas Lucas
http://hdl.handle.net/10945/42729
Outstanding Thesis Award
Abstract: Border surveillance is an important concern for most nations wanting to detect and intercept intruders that are trying to trespass a border. These intruders can include terrorists, drug traffickers, smugglers, illegal immigrants, and others who represent a threat to national interests. Unmanned aerial vehicles (UAVs) allow for modernization and improvement of border surveillance. There are a number of advantages to using UAVs. Many UAVs can be controlled by a single operator, which reduces personnel costs; they are very fast and can patrol large regions; and they have wider regions of visibility than conventional surveillance methods, which increases the probability of detecting intruders. This thesis formulates mathematical models designed to find the best way to utilize a given fleet of UAVs by deciding their routes, altitudes, and speeds in order to maximize the probability of detecting intruders trying to trespass a given border. These models will enable decision makers to effectively acquire and employ a UAV fleet for border surveillance.

Stamey, Barcley W. *Domestic Aerial Surveillance and Homeland Security: Should Americans Fear the Eye in th Sky?* M.A. in Security Studies (Homeland Security and Defense). Monterey, California: Naval Postgraduate School, March 2014.
Thesis Advisor: Erik Dahl
Second Reader: Clay Moltz
http://hdl.handle.net/10945/41446

Abstract: Unmanned aircraft systems (UAS, also known as drones) are being increasingly more utilized in domestic law enforcement operations, enabling officers to maximize situational awareness from overhead while minimizing their exposure to danger. As the domestic airspace is scheduled to be fully drone integrated by 2015, growing concerns over national security and privacy issues have highlighted the capabilities and potential implications of using UAS on a national scale. This thesis examines the potential effectiveness of utilizing domestic aerial surveillance to increase homeland security while addressing how, and to what level, these programs should be federally overseen and regulated without infringing on Americans' civil liberties. This thesis argues that large-scale UAS operations by federal agencies are cost-inefficient and lack tangible results, while state and local agency operations, which employ smaller systems in more specific situations, are less expensive and more effective. Current U.S. law allows for aerial surveillance by law enforcement, but updating privacy legislation to account for modern technology should be considered. The Department of Homeland Security (DHS) needs to accelerate its working relationship with the Federal Aviation Administration (FAA) and its UAS approval process to establish and maintain privacy safeguards to ensure the highest level of national security while minimizing civil liberty infringement.

Stimpert, Sian E. *Lightening the Load of a USMC Rifle Platoon Through Robotics Integration*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, June 2014.
Thesis Co-Advisors: Alejandro Hernandez and Richard C. Milllar.
http://hdl.handle.net/10945/42733

Abstract: With the increase of the loaded weight that a Marine carries, the integration of robotics is a significant point of interest to the United States Marine Corps, especially to the Expeditionary Energy Office. Through the use of the agent-based modeling and simulation application, Pythagoras, robots are integrated into a Marine Expeditionary Unit's rifle platoon to alleviate the burden on each Marine. This study examines the rifle platoon's energy and power consumption, operational reach, and operational effectiveness for a scouting and patrolling mission. A systems engineering methodology results in a tradeoff analysis on the rifle platoon's success, relative to the number of integrated robots. Integrating six robots in a rifle platoon can improve the platoon's ability to fulfill its mission, while supporting the Marine Corps' energy strategy. In the context of energy initiatives, this research forms the baseline for investigating the impact of robot integration in Marine combat operations through simulations.

Terjesen, Steven. *Navigation System Design and State Estimation for a Small Rigid Hull Inflatable Boat (RHIB)*. Mechanical Engineering, M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Co-Advisors: Douglas Horner and Sean Kragelund
http://hdl.handle.net/10945/44016

Abstract: Autonomous operation of a small rigid hull inflatable boat (RHIB) is a complex problem that requires a robust network of sensors, controllers, processors, and actuators. Furthermore, autonomous navigation requires accurate state estimation, fusing and filtering data from an array of sensors to give the best possible estimates of attitude, position, and velocity. This thesis will address the hardware modifications and navigation state estimators used to configure the SeaFox Mk II RHIB for future autonomous operations. The study began with a RHIB capable of manual and remote-controlled operation. The proprietary controllers and processors were replaced with an open architecture system that enabled an autonomous mode of operation and data collection from a suite of global positioning satellite receivers and inertial measurement units. Multiple navigation state estimators were designed using the extended Kalman filter and several variants

of the unscented Kalman filter. Each filter was evaluated against simulated and actual sea trial data to determine its accuracy, robustness, and computational efficiency.

Tng, Chung Siong. ***Effects of Sensing Capability on Ground Platform Survivability During Ground Forces Maneuver Operations***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2014
Thesis Co-Advisor: Eugene P. Paulo and Douglas H. Nelson
Second Reader: Mark R. Stevens
http://hdl.handle.net/10945/44018
Avstract: The purpose of this thesis is to investigate the effects of sensing capability on ground platform survivability during ground force maneuver operations. Sensor classification probability of ground platforms and speed of unmanned aerial vehicles (UAV) are the factors being studied, and the Map Aware Non-Uniform Automata (MANA) agent-based simulation software was used to create a hypothetical Ground Force Maneuver Operation Scenario for this exploration. A tailored Waterfall systems engineering process model guided the study in identifying alternatives which, other than increasing armor thickness, can improve platform survivability during ground force maneuver operations. The Nearly Orthogonal Latin Hypercube was the Design of Experiment methodology used to determine the number of design points to be simulated, and the results generated from the multiple simulation runs were analyzed using regression analysis and partition tree analysis. The sensor classification probability of the Bradley M6 Linebacker and M1A2 Abrams Main Battle Tank, and the speed of UAV, were identified to be the three most significant factors affecting platform survivability. More importantly, the study provides decision makers with quantitative data, which can be used as references to determine the requirements for sensing capability enhancement programs.

Wanier, Blake M. ***A Modular simulation Framework for Assessing Swarm Search Models***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2014.
Thesis Advisor: Timothy H. Chung
Second Reader: James Eagle
http://hdl.handle.net/10945/44027
Abstract: The ability to utilize large numbers of unmanned systems as search agents allows the implementation of different search strategies that are not currently explored utilizing today's search decision support and analysis tools. This thesis develops a framework in MATLAB that allows the investigation of search strategies that utilize large numbers, or a swarm, of search agents. By implementing a modular design, multiple aspects of the search, such as tactics, searcher characteristics, and target characteristics, can easily be varied and analyzed. Utilizing JMP to perform statistical analysis, future design requirements can be refined in order to advise decision makers on possible alternatives and trade spaces for optimizing swarm search performance. Numerical studies demonstrate the ability to leverage the developed simulation and analysis framework to investigate three canonical swarm search models as benchmarks for future exploration of more sophisticated swarm search scenarios.

2013

Beach, Timothy M. ***Mobility Modeling and Estimation for Delay Tolerant Unmanned Ground Vehicle Networks***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2013.
Advisors: Preetha Thulasirama and Grace Clark
http://hdl.handle.net/10945/34624
Abstract: An ad hoc unmanned ground vehicle (UGV) network operates as an intermittently connected mobile delay tolerant network (DTN). The path planning strategy in a DTN requires mobility estimation of the spatial positions of the nodes as a function of time. The purpose of this thesis is to create a foundational mobility estimation algorithm that can be coupled with a cooperative communication routing algorithm to provide a basis for real time path planning in UGV-DTNs. In this thesis, we use a Gauss-Markov state space model for the node dynamics. The measurements are constant power received signal strength indicator (RSSI) signals transmitted from fixed position base stations. An extended Kalman filter (EKF) is derived for estimating of coordinates in a two-dimensional spatial grid environment. Simulation studies are conducted to test and validate the models and estimation algorithms. We simulate a single mobile node traveling along a trajectory that includes abrupt maneuvers. Estimation performance is measured using zero mean whiteness tests on the innovations sequences, root mean squared error (RMSE) of the state estimates, weighted sum squared residuals (WSSRs) on the innovations, and the posterior Cramer-Rao lower bound (PCRLB). Under these performance indices, we demonstrate that the mobility estimator performs effectively.

Blandin, Mathiew; Brux, Jeramy; Caraway, Christopher; Cook, Jamie; Fromille, Samuel; Haertel, David; Hall, Steven; Kish, John Paul; Szachta, Stephen. SE Cross-Campus Study (SEA 19A) ***2024 Unmanned Undersea Warfare Concept***. M.S. in Systems Engineering Analysis. Monterey, California: Naval Postgraduate School, June 2013.
Advisor: Timothy Chung
Second Reader: James Eagle
http://hdl.handle.net/10945/34733
Abstract: Potential adversaries throughout the world continue to acquire and develop sophisticated multi-layered, anti-access, area-denial (A2AD) systems. To maintain its maritime superiority, the United States must continue to innovate systems that are capable of operating in and defeating these A2AD environments. In particular, command of the undersea domain remains vital and will increasingly be critical in facing this future battle space. The challenges our nation faces, however, are not limited only to the technological capabilities of the warfighters, but also include a myriad of confounding constraints. In addition to the expected shortfalls of mission-ready assets, the Submarine Forces also must address significant pressures in defense spending. Nevertheless, unmanned undersea vehicles (UUVs) remain one of the top priorities of the Chief of Naval Operations, as UUVs serve as effective force multipliers, while greatly reducing risk, in critical missions in A2AD environments. This report presents the findings of analysis and assessment conducted by an integrated systems engineering and analysis team of military officer students at the Naval Postgraduate School. Their operationally driven tasking seeks to design a system-of-systems of unmanned and manned undersea vehicles to ensure undersea dominance both in the near term and into the next decade. The importance of the systems perspective to this study is reflected by the extensive engagement with many operational stakeholders, academic researchers, industry partners, and acquisitions programs across the Naval enterprise. The capability-based approach highlights the mission suitability of both currently fielded UUVs and also technologies realizable within the next decade. The capstone final report summarizes these critical insights and provides detailed recommendations to inform decision makers of the present to prepare for the undersea forces of the future.

Cabello, Carlos S. ***Droning On: American Strategic Myopia Toward Unmanned Aerial Systems.***
M.S. in Defense Analysis. Monterey, California: Naval Postgraduate School, December 2013.
Thesis Advisor: Bradley Jay Strawser
Second Reader: Robert O'Connell
http://hdl.handle.net/10945/38890
Abstract: Throughout the past decade of wars, the U.S. has deployed unmanned aerial systems, commonly referred to as drones, from Africa to Asia collecting intelligence and targeting adversaries. The nation now stands at a crossroad seeking to develop future American drone policy against an evolving threat while at the same time shaping global norms. The past decade of American drone use focused on short-term benefits, intelligence collection and lethal targeting, rather than on the long-term consequences of technology diffusion, or ethical and legal frameworks. Myopic drone strategies threaten to establish a global precedent that could undermine the stability of international relations, as state and non-state actors (SANSA) have begun to build, arm, and operate lethal unmanned systems at an alarming rate. Unmanned technology development and usage is outpacing international norms, regulations, and policies. These systems will usher in an era of unrestricted drone usage unless international regulations and standards are developed. This thesis examines whether American drone strategy is myopic and whether it is creating a dangerous international precedent. A qualitative analysis will identify the short-term benefits and long-term consequences of U.S. drone strategy, focusing on unmanned technology diffusion, ethical justifications, and legal frameworks. Examining American drone strategy can help explain why a myopic policy may be beneficial in the short-term, yet may increase threats to national interests in the long-term. The thesis concludes with an assessment of whether strategic myopia has already set a dangerous international precedent, which SANSA will use to justify their future drone programs.

Cena, James M. ***Power Transfer Efficiency of Mutually Coupled Coils in an Aluminum AUV Hull***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2013.
Thesis Co-Advisors: David Jenn and Alexander L. Julian
http://hdl.handle.net/10945/38895
Abstract: To charge the United States Navys Remote Environmental Measuring Units (REMUS) autonomous undersea vehicle (AUV) in situ requires the REMUS to mate with a docking station. There are two problems with this docking station. The docking system requires the REMUS to make electrical contact with the dock, which can lead to electrical shorting in an undersea environment. The dock is also designed to fit a single type of AUV. AUVs of different sizes require a new docking system. A different means of power transfer is required that can be used in a universal docking station. An inductive power transfer (IPT) system can be used in a universal docking station. In this report, we calculated the power transfer efficiency of an IPT system operating at 100 kHz using circular coils. These calculated results were then compared to three sets of measured efficiency data: an IPT system without ferrite tiles; an IPT system with the receiving coil attached to ferrite tiles; and an IPT system with the receiving coil/ferrite tile combination placed inside an aluminum AUV hull. Efficiency was poor, less than 10 percent with an air gap of 55 mm, when the receiving coil was placed inside the aluminum hull.

Choon, Junwei. ***Development and Validation of a Controlled Virtual Environment for Guidance, Navigation and Control of Quadrotor UAV***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisors: Oleg Yakimenko and Isaac Kaminer
http://hdl.handle.net/10945/37600
Abstract: This thesis is focused on the development of a six degrees of freedom (6DOF) simulation model of a commercial-off-the-shelf quadrotor. The dynamics of the quadrotor and its control strategy are described. The Geometric Dilution of Precision (GDOP) of the Autonomous Systems Engineering and Integration Laboratory (ASEIL) laboratory used in conducting the experiments is also analyzed. Simulation results are then verified with actual flight data. A direct method of calculus of variations is employed in the development of an algorithm for optimal

trajectory generation and collision-free flight. Using the differential-flatness characteristics of the system, the trajectory optimization is posed as a nonlinear constrained optimization problem in virtual domain, not explicitly related to the time domain. Appropriate parameterized functions employing an abstract argument, known as the virtual arc, are used to ensure initial and terminal constraints satisfaction. A speed factor maps the virtual to the time domain and controls the speed profile along any predetermined trajectory. An inner loop attitude controller was used to achieve almost global asymptotic attitude tracking for trajectory following. The trajectory generation and following algorithms were verified using the 6DOF simulation model through a simulated collision avoidance scenario.

Chua, Boon Heng. ***Integration of Multiple Unmanned Systems in an Urban Search and Rescue Environment***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, March 2013.
Thesis Advisor: Oleg Yakimenko
Second Reader: Mark Stevens
http://hdl.handle.net/10945/32805
Abstract: In view of the local, regional and global security trends over the past decade, the threats of disaster to the populace inhabiting urbanized areas are real and there is a need for increased vigilance. There can be multiple causes for urban disaster natural disasters, terrorist attack and urban warfare are all viable. This thesis focused on the event in which an urban search and rescue operation is required due to the aftermath of a terrorist activity. Systems engineering techniques were utilized to analyze the problem space and suggested a plausible solution. Application of unmanned vehicles in the scenario enhanced the reconnaissance, intelligence and surveillance capabilities of the responding forces, while limiting the exposure risk of personnel. One of the many challenges facing unmanned systems in a cluttered environment is a capability to rapidly generate reactive obstacle avoidance trajectories. A direct method of calculus of variations was applied for the unmanned platforms to achieve mission objectives collaboratively, and perform real-time trajectory optimization for a collision-free flight. Dynamic models were created to enable simulated operations within the thesis design scenario. Experiments conducted in an indoor lab verified the unmanned systems ability to avoid obstacles and carry out collaborative missions successfully.

Craft, Timothy L. ***The Systems Engineering Desighn of a Smart Forward Operating Base Surveillance System for Forward Operating Base Protection***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, June 2013.
Thesis Co-Advisors: Rachel Goshorn and Deborah Goshorn
http://hdl.handle.net/10945/34650
Abstract: Forward operating bases are vulnerable to terrorist activity due to their location and limited resources. Threat awareness under these conditions is paramount to the safety of the personnel and to mission accomplishment. In the absence of the manpower required to maintain complete and continuous monitoring of the FOBs surroundings, an automated surveillance system is needed. The Smart FOB Surveillance System (SFSS) employs a multi-agent behavior analysis and decision system with Swarm Intelligence (SI) through a network-centric systems engineering method of development to create a robust surveillance system. The SFSS provides the capability of an intelligence automated system for continuously monitoring areas for certain behaviors, linking individuals, predicting future behaviors, and taking appropriate action against them to eliminate threats and the possibility of future threats. Environments, such as insurgent urban areas, Forward Operating Bases, country borders, and other high-value target areas all require constant personnel behavior surveillance and monitoring. The SFSS utilizes a complex network of aerial, fixed and mobile terrestrial units, capable of identifying and processing audible, visual, and signal intelligence in order to determine personnel behavior in a given area of interest as well as recording and processing intelligence data. The focus is on creating a system to protect Forward Operating Bases (FOB) by providing continuous and autonomous surveillance and threat alerts. In this manner, a Smart FOB Surveillance System (SFSS) will be designed in this thesis using the systems engineering process.

Damron, David W. ***Tropical Cyclone Reconnaissance with the Global Hawk: Operational Thresholds and Characteristics of Convective Systems Over the Tropical Western United States***. M.S. in Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, December 2013.
Thesis Advisor: Patrick A. Harr
Second Reader: Barbara Scarnato
http://hdl.handle.net/10945/38913

Abstract: In a tropical cyclone (TC), in situ observations measure storm location, intensity, and structure. These parameters are valuable for initializing numerical models and providing forecasters with current conditions on which to base their forecast. Over the western North Pacific (WPAC), a lack of in situ observations in TCs is hypothesized to be one component that contributes to a recent leveling of forecast skill. In this study, the use of a Global Hawk (GH) unmanned aerial vehicle as an observing platform for TCs over the WPAC is examined. It is hypothesized that the GH can greatly benefit the Department of Defense by reducing the uncertainty in TC track forecasts, which has been mandated by the U.S. Pacific Command as a priority for increasing the area of sea maneuverability A limit to successful GH operations is the ability to operate at altitudes above typical cloud tops of WPAC TCs. A climatology of WPAC TC cloud-top heights and temperatures was examined to relate these parameters to storm characteristics. It is concluded that use of a GH for tropical cyclone reconnaissance in the WPAC is a viable option to provide in situ observations of tropical cyclone characteristics for improved model and operational forecasts.

Dengler, Judson J. ***An Examination of the Collateral Psychological and Political Damage of Drone Warfare in the FATA Region of Pakistan***. M.A. in Security Studies (Homeland Security And Defense). Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Fathali Moghaddam
Second Reader: David Brannan
http://hdl.handle.net/10945/37611

Abstract: This research will examine the collateral psychological and political damage of the United States drone warfare program on Pakistani society in the Federally Administered Tribal Areas (FATA), to determine if this is an effective, proactive homeland defense tactic. The use of drone aircraft by the United States government has increased worldwide since this evolving technology was first utilized in 2001. Each drone strike impacts militants, noncombatants, and ordinary civilians. The potential for collateral damage and civilian casualties may overshadow the tactical gain of even successful drone strikes by inspiring radicalization, and creating recruiting opportunities for militants. The findings of this research will recommend an alternative framework from which to evaluate the effectiveness of drone warfare based on the collateral psychological and political impact on society in this region. Traditional studies of drone warfare have tended to analyze from a tactical perspective. The examination of drone warfare, based on the damage done to the psychological experiences and political attitudes of FATA residents who may turn against the U.S., provides policy makers with the ability to better assess the impact of drone strikes on communities, and determine the optimal situation to leverage this lethal tactic, while minimizing negative outcomes.

Dimitriou, Georgios. ***Integrating Unmanned Aerial Vehicles into Surveillance Systems in Complex Maritime Environments***. M.S. in Modeling, Virtual Environments, And Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Quinn Kennedy
Second Reader: Thomas W. Lucas
Outstanding Thesis Award
http://hdl.handle.net/10945/37613

Abstract: One of the most important missions all Navies have is to constantly and sufficiently monitor their area of responsibility. This task becomes more challenging when a surveillance system operates in a complex environment with high traffic of merchant and fishing vessels and the existence of many islands. Potential tactics that targets might use increase the difficulty of

this task. Integrating Unmanned Aerial Vehicles (UAVs) into a surveillance system that consists of ground radars and surface ships might enhance the systems capabilities and mitigate its vulnerabilities. In this study, the extremely complex maritime environment of the Aegean Sea is modeled in the Map Aware Non Uniform Automata (MANA) agent-based simulation environment to explore the effectiveness of UAVs in those conditions. The results from almost 100,000 simulated Intelligence, Surveillance, and Reconnaissance missions are analyzed using descriptive statistics, ANOVA, stepwise regression, and partition trees. It was found that by integrating one or two UAVs into a traditional surveillance system, it becomes more efficient in the detection and persistent surveillance of enemies and neutral targets. The most important factors that affect the surveillance systems performance are the detection capabilities of its sensors, the communication accuracy, and the enemys counter-detection capability. Thus, Greece and other countries with similar geographical characteristics should deploy UAVs in a maritime surveillance role.

Fitzgerald, Jessica L. ***Characterization Parameters for a Three Degree of Freedom Mobile Robot.*** M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2013.
Thesis Advisor: Richard Harkins
Second Reader: Andres Larraza
http://hdl.handle.net/10945/38929
Abstract: Control and Navigation logic was developed for a 3-Degree of Freedom Surf-Zone Robot to assist in the identification and characterization of platform parameters for use in the Shuey Dynamic Model. These parameters included, primarily platform rotational inertia and wheel slip. Data was collected in various track scenarios including benign flat terrain and more complicated beach runs. Track lengths spanned short straight paths of no more than 10 meters to full-run point-to-point autonomous navigation paths of up to 80 meters. The longer runs included turns of up to 180 degrees and terrain inclines of 2 degree or less. As expected the Shuey model proved reliable for short runs of no more than 10 meters. For long length runs in the beach environment the Dynamic Model diverged quickly. This is attributed to, primarily, wheel slip conditions and the fact that the Shuey Model is open loop. Motor current was monitored under load conditions to identify wheel slip and simple algorithms were implemented to account for this with little success. However, closed loop heading input resulted in significant improvement to the model

Fritz, James R. ***Computer-aided Detection of Rapid, Overt, Airborne, Reconnaissnace Data with the Capability of Removing Ocean Noises***. M.S. in Joint Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, December 2013.
Thesis Co-Advisors: Peter Chu and Chenwu Fan
Second Reader: Ronald E. Betsch
http://hdl.handle.net/10945/38932
Abstract: There have been three times more attacks to naval ships using sea mines than all other forms combined. Sea mines have always been viewed upon as underhanded and unchivalrous, yet they provide a weaker navy the capability to stall and damage a vastly superior navy. Utilizing unmanned sensors to detect sea mines is the goal of the navy for the future. Computer-aided detection (CAD) of sea mines is much faster and more consistent than a human operator, yet it is not currently being utilized by any of our mine countermeasure assets. Although there are many studies that have incorporated computer aided detection and classification algorithms with sonar imagery for mine warfare, few have used Light Detection and Ranging (LIDAR). During an amphibious assault scenario the ability to land assets quickly and mitigate risk is vital to the success. This thesis analyzes Rapid Overt Aerial Reconnaissance data from an Office of Naval Research experiment by Fort Walton Beach, FL. The CAD algorithm that was developed consistently detects sea mines in LIDAR data while having a manageable false alarm rate.

Gaerther, Uwe. ***UAV Swarm Tactics: An Agent-based Simulation and Markov Process Analysis***.
M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2013.
Thesis Advisor: Timothy H. Chung
Second Reader: Michael Atkinson
Outstanding Thesis Award
http://hdl.handle.net/10945/34665
Abstract: The rapid increase in the use of unmanned aerial vehicles (UAVs) in recent decades
lead to their potential use as saturation or swarm threats to Allied Forces. One possible counter
measure is the design and deployment of a defensive UAV swarm. This thesis identifies a future
concept of swarm-versus-swarm UAV combat, focusing on the implications of swarm tactics and
identifies important factors for such engagements. This work provides initial key insights through
significant modeling, simulation, and analysis. The contributions of the presented work include
the design of an agent-based simulation and the formulation of an associated analytical model.
The agent-based simulation allows for the UAV to be modeled as an agent that follows a simple
rule set, which is responsible for the emergent swarm behavior relevant to defining swarm
tactics. A two-level Markov process is developed to model the air-to-air engagements, where the
first level focuses on one-on-one combat while the second level incorporates the results from the
first and explores multi-UAV engagements. Tactical insights obtained from this study can be
contrasted with tactics for manned air combat, which highlights the potential need to develop
new tactics for unmanned combat aviation as well as for swarm scenarios. Additional analysis
performed in this thesis provides further tactical recommendations and outlines multiple avenues
of future study.

Harrop, John P. ***Improving the Army's Joint Platform Allocation Tool (JPAT)***. M.S. in Operations
Research. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Emily Craparo
Second Reader: Christopher Marks
http://hdl.handle.net/10945/37635
Abstract: The U.S. Army's joint platform allocation tool (JPAT) is an integer linear program that
was developed by the Army's Training and Doctrine Command Analysis Center and the Naval
Postgraduate School to help inform acquisition decisions involving aerial reconnaissance and
surveillance (R&S) resources. JPAT evaluates inputs such as mission requirements, locations of
available equipment, and budgetary constraints to determine an effective assignment of
unmanned aerial R&S assets to missions. As of September 2013, JPAT is solved using a rolling
horizon approach, which produces a sub-optimal solution, and requires substantial computational
resources to solve a problem of realistic size. Because JPAT is an integer linear program, it is a
suitable candidate for using decomposition techniques to improve its computational efficiency.
This thesis conducts an analysis of multiple approaches for increasing JPATs computational
efficiency. First, we reformulate JPAT using Benders decomposition. Then, we solve both the
original and decomposed formulations using the simplex and barrier algorithms with multiple size
datasets. In addition, we experiment with an initial heuristic solution and other techniques in our
attempts to improve JPATs runtime. We find that while Benders decomposition does not result in
significant improvements in computation time for the instances considered in this thesis, initial
solution heuristics and other modifications to the model improve JPATs performance.

Horner, Douglas. ***A Data-driven Framework for Rapid Modeling of Wirelss Communication
Channels***. PhD. in Computer Science. Monterey, California: Naval Postgraduate School,
December 2013.
Disseration Supervisor: Geoffrey Xie
http://hdl.handle.net/10945/38947
Abstract: Accurate estimation and prediction of wireless signal strength holds the promise to
improve a wide variety of applications in network-ing and unmanned systems. Current estimation
approaches use either simplistic attenuation equations or detailed physical models that provide
limited accuracy and may require a lengthy period of environmental assessment and
computation. This dissertation presents a new, data-driven, stochastic framework for rapidly

building accurate wireless connectivity maps. The framework advances the state of the art in three aspects. First, it augments the classic spatial interpolation procedure known as Kriging with a complementary additive approach to capture the typical anisotropic nature of wireless channels in cluttered environments. Second, it includes a technique for rapidly creating and maintaining a connectivity map in near real-time through the use of a spatial Bayesian recursive filter. Third, it introduces a novel methodology to adapt the resolution of a connectivity map based on the spatial characteristics and the quantity of available sample measurements. Detailed analyses, using several datasets collected recently in the Monterey Harbor, have confirmed the power and agility of the proposed approach.

Ironhill, Christopher, Bryan Otis, Frederick Lancaster, Angel Perez, Diana Ly, Nam Tran. *Small Tactical Unmanned Aerial System (STUAS) Rapid Integration and Fielding Process (RAIN)*. Team RAIN/Cohort 311-101A4/121A4 M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisors: Rama Gehris and Bonnier Young
http://hdl.handle.net/10945/37705
Abtract: The Department of the Navy (DoN) maintains an inventory of Small Tactical Unmanned Aircraft Systems (STUAS). These systems are designed for payload modularity to support user selection of multiple mission configurations in order to meet any unique mission need. Numerous mission ready payloads have been developed for each system, and only need to be integrated in order to become part of the fielded unmanned aerial system (UAS) configuration. Unfortunately, the DoN does not have a method that maintains sufficient systems engineering (SE) discipline to rapidly integrate and field new mission configurations to the fleet in support of aggressive schedules and urgent user needs. The typical fielding time frame can range from 24 to 36 months, instead of the desired 6 to 18 months. Furthermore, without a sufficient SE approach, risk to mission success is not well understood. This paper captures all applicable requirements for fielding a new capability onto an existing UAS, and using an SE approach, outlines a process to rapidly integrate payloads DoN system. The process identified provides a comprehensive list of integration requirements; a cost, schedule, and performance trade-off analysis; technical risk associated with each tradeoff option; and recommendations on how to best support a rapid fielding timeline.

Justice, Joel M. *Active Shooters: Is Law Enforcement Ready for a Mumbai Style Attack?* M.A. in Security Studies (Homeland Security And Defense). Monterey, California: Naval Postgraduate School, September 2013.
Thesis Co-Advisors: David Brannan and Patrick Miller
http://hdl.handle.net/10945/37645
Abstract: Between April 16, 2007, and December 14, 2012, the United States has seen 25 mass shootings, seven of which occurred in 2012. A report by United States Department of Homeland Security, in 2009, suggested that the United States will be the target of a terrorist act that could cause a high number of casualties. The November 26, 2008, attack on Mumbai is a transparent example of how determined terrorists, trained to die fighting, can bring a large metropolitan city to its knees. It is entirely probable that Mumbai-type attacks could occur in the United States. Since the local law enforcement respond to attacks in progress, any active shooter event would be handled by the local jurisdiction. Many law enforcement agencies have begun to incorporate tactical plans to respond to Mumbai-type terrorist attacks. This thesis focused on police preparedness of select large metropolitan law enforcement agencies for potential Mumbai-type terrorist attacks. A comparative analysis of these police agencies was conducted, which showed that the frequency of training was found to be varying and inadequate by these agencies. A similar concern was that none of the agencies had equipped all the police officers with rifles, which were deemed critical to engage well-equipped active shooters. It is the conclusion of the thesis that gaps in preparedness exist and law enforcement organizations have room for improvement. It was also concluded that agencies need to enhance communication capability between neighboring jurisdictions and focus on triage of the victims during the early stages of attacks when medical personnel would be unable to approach.

Kim, Kyungnho. *Integrating Coordinated Path Following Algorithms to Mitigate the Loss of Communication Among Multiple UAVs*. M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, March 2013.
Thesis Advisor: Raymond R. Buettner
Co-Advisors: Vladimir N. Dobrokhodov and Kevin D. Jones
http://hdl.handle.net/10945/32848

Abstract: The thesis addresses the problem of mid-air collision avoidance among multiple Autonomous Unmanned Aerial Vehicles (UAVs) capable of communicating their flight states across a time-varying communication network. The UAVs capabilities to (a) follow a given path and to (b) exchange and coordinate their relative position while on the path are considered the key factors enabling the time-critical coordination that in turn guarantees the safety of flight. The thesis is based on the key results of the recently developed concept of Coordinated Path Following (CPF) for multiple autonomous agents. While the path-following methodology is adapted without modification, the information exchange over the time-varying communication network and its impact on the performance of coordination was analyzed in a comparative study. The impact of the time-varying information flow is represented by the loss of link ratio, which is the ratio of time without information exchange to the nominal timeframe of communication in a given bidirectional network. The particular coordination metrics utilized are the coordination error (difference between the relative positions of UAVs on the paths) and the Euclidian distance between the UAVs (space separation). On the other hand, the control effort necessary to achieve the desired coordination is represented by the level and variation of the commanded velocity profile. The particular goal of the numerical study was to understand the amount of control effort required to achieve the desired separation of UAVs capable of exchanging a minimum number of parameters over a degrading communication network.

Kiremitci, Huseyin. *Satellite Constellation Optimization for Turkish Armed Forces*. M.S. in Space Systems Operations. Monterey, California: Naval Postgraduate School, March 2013.
Thesis Advisor: J.Scott Matey
Second Reader: Alan Scott
http://hdl.handle.net/10945/32849

Abstract: Advancing technologies in smallsats provide remote sensing and communications capabilities achievable with a constellation of satellites at a reasonable cost to meet military needs. Like any other nation looking for a cheap but effective solution in that area, Turkey might also benefit from a replacement of its remote sensing assets. Currently Turkish Armed Forces rely on a limited number of reconnaissance aircraft and Unmanned Aerial Vehicles, which do not provide real-time or near real-time remote sensing capabilities. Near real-time remote sensing needs for the Turkish warfighter dictates Turkish Armed Forces reach that capability as soon as possible. Likewise, replacing its conventional communication radios with satellite communication devices would also fulfill warfighter needs. While current communication devices have physical limitations in Turkeys mountainous terrain and the surrounding seas, satellite communication capability would provide wider coverage and for specific frequencies might provide better resistance to jamming and interference too. For the benefit of Turkish Armed Forces communications needs, a satellite constellation must be optimized such that effective coverage will be achieved with the least number of satellites to provide a reasonable cost. In this study, Satellite constellation optimization for the Turkish Armed Forces will be achieved by using Analytical Graphics, Inc.s Systems Tool Kit software for simulation and analysis of several possible communications and remote sensing satellite constellations covering Turkish territory and surrounding seas.

Lim, Zhifeng. *The Rise of Robots and the Implications for Military Organizations*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisors: Gary O. Langford and Douglas H. Nelson
http://hdl.handle.net/10945/37662

Abstract: This thesis explores the reasons for the inevitability of the extensive use of robots in military organizations, projects the adoption timeframe for robots in military organizations,

proposes how robots might evolve, assesses the impact of robots on military organizations and suggests the way forward for military organizations to facilitate the adoption of robots. Macro environmental trends suggest that the use of robots is the way forward for military organizations. The thesis projects that the adoption rate of robots will pick up from this point forward and will reach market saturation in a matter of decades. The use of robots has physical, functional, and behavioral implications for military organizations, and their increasing numbers will affect how militaries are organized and alter the existing organizational processes in the long term. Military organizations will benefit from a better understanding of the impact of robots and the resulting challenges. Taking the necessary steps to mitigate the challenges and facilitate the evolutionary transition for the military organizations will allow these organizations to reap the benefits of robots and to operate effectively in the changing macro environment.

Lucas, Andrew R. *Digital Semaphore: Technical Feasibility of QR Code Optical Signaling for Fleet Communications.* M.S. in Systems Technology (Command, Control & Communications). Monterey, California: Naval Postgraduate School, June 2013.
Thesis Advisor: Don Brutzman
Second Readers: Ray Buettner and Jeff Weekley
Outstanding Thesis Award
http://hdl.handle.net/10945/34699
Abstract: In recent decades, optical LOS communications such as flag semaphore or flashing light have atrophied to the point where, if they are required, U.S. Naval forces are at a distinct disadvantage. RF communications have become critical to nearly all operations, but this capability comes at the cost of disclosing the location of operations. Depending on the platform, these RF communications can become a critical vulnerability. EMCON attempts to minimize this vulnerability through the elimination of any RF emissions from a ship, but communication requirements in recent years have essentially prevented a complete suppression of RF emissions. This work proposes mitigating emissions vulnerability by utilizing a new method of optical communications at LOS visual ranges reminiscent of flag semaphore. Tactical QR code communications streaming digital data through optical signaling has the potential to provide tactical communications at a moderate range, allowing critical communications to be relayed to and from off-ship platforms. Additional technological advances can be used to overcome current range, security, reliability, and throughput barriers. This project demonstrates how a combination of essential technical capabilities can be used to establish a QR code communications system as a potentially useful approach for tactical operations.

McMullen, Eric L. and Brian Shane Grass. *Effects of UAV Supervisory Control on F-18 Formation Flight Performance in a Simulator Environment*. M.S. in Modeling, Virtual Environments, and Simulation (Moves). Monterey, California: Naval Postgraduate School, March 2013.
Thesis Advisors: Ji-Hyun Yang and Quinn Kennedy
Second Reader: Joseph Sullivan
http://hdl.handle.net/10945/32870
Abstract: Continual advances in technology, along with increased cockpit workload particularly the shift from two-seat to single-seat fighters to save money and reduce risk to lifepush the limits of human mental capacity. Additionally, there is interest within the military aviation community to integrate Unmanned Aerial Vehicle (UAV) control into the cockpit in order to expand force projection capability. This study compared the effects on formation flight performance of two different secondary tasks, specifically a traditional secondary task such as target prosecution with an electro-optical Forward Looking Infra-Red (FLIR) pod, and a futuristic secondary task such as UAV supervisory control. A total of 34 military fighter aviators volunteered to fly three five-minuteF-18 simulator sessions in close formation with no secondary task, and then treated with each of the two secondary tasks. Results provided clear indication that the futuristic task was significantly more challenging than the traditional task, and that both secondary tasks significantly increased the average mean following distance and variance compared to the undistracted flying baseline scenario. Additionally, we found no evidence that increased flight experience (total flight hours) significantly improved performance of the prescribed primary task

when treated with the futuristic task distraction. Knowledge gained from the results could contribute to improved crew resource management (CRM) and pilot workload management as well as flight safety resulting from the modification of flight procedures based on known effects of distractions in the cockpit.

Ozcan, Begum Y. ***Effectiveness of Unmanned Aerial Vehicles in Helping Secure a Border Characterized by Rough Terrain and Active Terrorists***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2013.
Thesis Advisor: Thomas W. Lucas
Second Reader: Jeffrey Appleget
Outstanding Thesis Award
http://hdl.handle.net/10945/34717
Abstract: Border security is of great importance to most countries. Turkey has been in conflict with terrorist groups since the 1980s. Up to now, more than 40,000 people have been killed, including Turkish soldiers and civilians. The porosity and openness of Turkeys Iraq border, combined with the rugged topography of the region, creates a passage for terrorist groups to move materiel and personnel. Technical capabilities of Unmanned Aerial Vehicles UAVs can be used to improve coverage along borders. However, their effectiveness is highly dependent on the characteristics of the region. In this study, 87 km of the Turkey-Iraq border is modeled in Map Aware Non Uniform Automata (MANA) to examine the potential impact of UAVs on detecting and classifying terrorists seeking passage from Northern Iraq into Turkey. The results from the 103,200 simulated terrorist incursions are analyzed using descriptive statistics, stepwise linear regression, lasso regression, regression trees, and random forests. The use of UAVs is found to be efficient in the detection and classification of terrorists in this region. The analysis techniques reveal that the most significant factors are the UAVs detection and classification performance, as well as the terrorists counter detection capabilities. Thus, Turkey (and countries trying to secure similar terrain) should purchase (or build) and employ hard-to-detect UAVs with sophisticated sensors.

Richter, Stephen P. ***Digital Semaphore: Tactical Implications of QR Code optical Signaling for Fleet Communications***. M.S. in Systems Technology (Command, Control & Communications). Monterey, California: Naval Postgraduate School, June 2013.
Thesis Co-Advisors: Don Brutzman and Ray Buettner
Second Reader: Jeff Weekley
Outstanding Thesis Award
http://hdl.handle.net/10945/34727
Abstract: This thesis focuses on potential tactical uses of Quick Response (QR) codes for optical signaling. It examines visual communications methods used effectively by the fleet throughout history, both during peace and wartime operations. Due to the advent of new technology, radio frequency line-of-sight (RF LOS) communications have come to the forefront of current operations, leaving the fleet vulnerable when conducting operations in an emissions controlled (EMCON) environment. In addition, the use of QR codes can circumvent the issues associated with Hazards of Electromagnetic Radiation to Ordinance (HERO) as well as provide a new effective method for conducting Identification Friend Foe/Neutral (IFFN). The ultimate goal of this thesis is to initiate new efforts that provide the fleet with an option for a new visual communication method. The need for a reliable visual line-of-sight (LOS) communications method has become apparent. This work proposes the tactical use of QR codes for visual communications, conveniently described as Digital Semaphore. QR codes have the ability to become the newest and most effective method of visual communication, replacing older, less effective forms. This thesis examines the use of various sensors and cameras to read and decode QR codes, and also proposes new practical uses of QR codes for communications on board ships, aircraft, and unmanned vehicles. Prototype software is provided as an initial-candidate QR Tactical Decision Aid (TDA). The ultimate goal of this thesis is to provide the fleet with an option for a visual communications method that allows ships and other units operating in a tactical

emissions controlled environment to minimize communications vulnerability and maximize operational effectiveness.

Sagir, Yavuz. ***Dynamic Bandwidth Provisioning using Markov Chain Based on RSVP***. M.S. in Electronic Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Preetha Thulasiraman
Second Reader: Joshua D. Green
http://hdl.handle.net/10945/37708
Abtract: An important aspect of wireless communication is efficiency. Efficient network resource management and quality of service (QoS) are parameters that need to be achieved especially when considering network delays. The cooperative nature of unmanned ground vehicle (UGV) networks requires that bandwidth allocation be shared fairly between individual UGV nodes, depending on necessity. In this thesis, we study the problem of dynamic bandwidth provisioning in a UGV network. Specifically, we integrate the use of a basic statistical model, known as the Markov chain with a widely known, network bandwidth reservation protocol, known as the Resource Reservation Protocol (RSVP). The Markov chain results are used with RSVP to identify specific bandwidth allocation requirements along a path such that data transmission along that path is successful. Using a wireless simulation program known as Qualnet, we analyze the bandwidth efficiency and show that this algorithm provides higher bandwidth guarantees and better overall QoS when compared with solely using RSVP in wireless communication networks.

Santiago, Mariela I. ***Systems Engineering and Project Management for Product Development: Optimizing Their Working Interfaces***. M.S. in Systems Engineering Management. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: John Osmundson
Second Reader: Gary Langford
http://hdl.handle.net/10945/37709
Abstract: This work discusses common issues that occur from the inadequate integration of systems engineering into the project management process. In so doing, this work is shaped by the following questions: What are the most common conflicts between Program Management and Systems Engineering during product development? Where in the product development cycle do conflicts occur? How can the conflicts be mitigated? This work identified three main conflicts within the product development process of the four case studies, the Hubble telescope, the Mars Polar Lander, the Demonstration of Autonomous Rendezvous Technology (Program, and the Constellation program. The three main problems are insufficient systems engineering in the product development process, insufficient budget and tight schedule, and inadequate risk management. These three issues eventually led to the mishaps and failures of the case studies examined in this thesis. This work proposes that, in order to mitigate conflicts in the integration of project management and systems engineering, systems engineers and project management should be able to have a common language, understand each others objectives, and understand how these objectives benefit both the product and the project. Therefore, its recommendations are that systems engineers be trained in project management and project managers be trained in systems engineering and that this training should include risk management. In this case, risk management is the common language between systems engineering and project management.

Severinghaus, Robert N. ***Improving UXS Network Availability with Asymmetric Polarized MIMO***. PhD in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2013.
Dissertation Co-Supervisors: Murali Tummala and John McEachen
http://hdl.handle.net/10945/34740
Abstract: To improve the efficiency of communications among unmanned systems, the research focused on the novel use of asymmetric polarized MIMO and network availability. The dissertation objective was to maintain the highest network availability for a mobile ad hoc network with heterogeneous communication capabilities. Using a hybrid dual-polarized Rayleigh fading channel

model, asymmetric antenna configurations were studied in simulation for bit error rate and capacity. For a 11 configuration, polarization reciprocity was used to exploit the polarized channel knowledge, thereby maximizing received uplink power. The optimum gains to maximize uplink capacity were also derived for varying channel cross-polarization values. Larger configurations of 21 and 22 were investigated, including overlays of orthogonal space-time block coding, which improved diversity performance in the polarized channels. Extending these link results to realistic scenarios with unmanned systems, a reference point group mobility model including large-scale propagation was proposed to compute the network availability. Another scenario detailed robot exploration of unknown environments, which included large-scale path loss models. While deploying the network, the factors of exploration strategies, signal thresholds and routing were shown to impact the availability metric. Lastly, four extensible formation models were analyzed for their influence on network availability.

Stevens, Timothy S. ***Analysis of Nondeterministic Search Patterns for Minimization of UAV Counter-Targeting***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, March 2013.
Thesis Advisor: Timothy H. Chung
Second Reader: Michael Atkinson
Outstanding Thesis Award
http://hdl.handle.net/10945/32905
Abstract: In an attempt to mitigate the expanding counter-UAV capabilities of adversary countries developed in response to the United States_ increased reliance on these platforms, we apply a nondeterministic search pattern to a finite area searcher. By implementing a Levy distribution on search leg lengths we analyze the trade-offs between efficiency and evasiveness of the searcher, comparing the expected time to target detection for a given set of Levy parameters to a probabilistic time to counter-targeting based on intelligence driven enemy capability. The culmination of this thesis is the development of a robust simulation tool, capable of modeling various parameters on both searcher and search area, the output of which is a quantifiable estimate on the probability of mission success.

Stiles, Zachariah H. ***Dynamic Towed Array Models and State Estimation for Underwater Target Tracking***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Co-Advisors: Robert G. Hutchins and Xiaoping Yun
http://hdl.handle.net/10945/37725
Abstract: The ability of Towed Linear hydrophone Arrays (TLA) to detect submarine-emitted narrow band tonals makes them the submarine tracking sensor of choice. Recent TLA improvements allow surface ships, Unmanned Underwater Vehicles (UUVs), Unmanned Surface Vehicles (USVs), and submarines alike to detect modern submarines by towing arrays. Allowing the full spectrum of Navy assets access into the Anti-submarine Warfare (ASW) arena is vital to countering future submerged threats. The generation of dynamic TLA and state estimation models in Simulink is detailed in this thesis. The dynamic TLA model receives user-specified TLA parameters and performs Dolph-Chebyshev optimization to form a set of beams which are steered for tracking. The TLA parameters can be specified to meet the needs of the towing vehicle, whether it is a submarine, ship, USV or UUV. The state estimation model uses outputs received from a mobile platform towing an array to estimate the target state. The state estimation model uses both bearing-only and Doppler-bearing Extended Kalman Filters to estimate target state. These models provide a basic platform which can be used to enhance ASW capabilities. Specifically, the models can aid in determining optimal future ASW-asset allocation, improving TLA tracking algorithms, and improving information presented to submarine operators.

Streenan, Andrew T. ***Diver Relative UUV Navigation for Joint Human-Robot Operations***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Noel Du Toit
Second Reader: Doug Horner
http://hdl.handle.net/10945/37726

Abstract: A novel application for Autonomous Underwater Vehicles (AUVs) is considered here: a robotic diver assistant that enables close-quarters robotic operations with human divers. A robotic diver assistant has the potential to improve the efficiency, effectiveness and safety of diver operations. The robot diver assistant must share the operating environment with human divers, navigate relative to the environment to reach a specified site location (along with moving divers), and then maneuver among the mostly static divers as they perform their tasks on location. The robot operates in three unique scenarios: station-keeping, diver-following (shadowing), and diver-leading (vectoring). Various strategies for navigating among divers while ensuring diver safety are investigated. A reactive strategy, based on potential fields, is investigated and applied to station-keeping and diver-following. A deliberative approach, which plans the robots motion over a finite horizon, is presented for diver leading. These approaches are applied to the SeaBotix vLBV300 platform for which a simulator is developed based on a decoupled motion model for the platform, as well as experimental results in a controlled test tank.

Taranto, Matthew T. ***A Human Factors Analysis of USAF Remotely Piloted Aircraft Mishaps***. M.S. in Human Systems Integration. Monterey, California: Naval Postgraduate School, June 2013.
Thesis Advisors: Michael E. McCauley and Christian (Kip) Smith
Second Reader: Chad W. Seagren
http://hdl.handle.net/10945/34751

Abstract: As the effort to demonstrate the viability and effectiveness of Remotely Piloted Aircraft (RPA) systems continues, there is an increasing demand for improved total system performance; specifically, reduced mishap rates. The USAF MQ-1 and MQ-9 have produced lifetime mishap rates of 7.58 and 4.58 mishaps per 100,000 flight hours, respectively. To improve the understanding of RPA mishap epidemiology, an analysis was completed on USAF MQ-1 and MQ-9 RPA mishaps from 2006-2011. The dataset included 88 human error-related mishaps that were coded using the DoD Human Factors Analysis and Classification System. The specific research question was: Do the types of active failures (unsafe acts) and latent failures (preconditions, unsafe supervision, and organizational influences) differ between the MQ-1 and MQ-9 when operated with the same Ground Control Station (GCS)? The single inclusion of Organizational Climate (organizational influence) in the Level II logistic regression model suggests that there is not a statistically significant difference in RPA-type mishaps with regard to human error. These results suggest that human performance requirements should be coupled to the GCS and not aircraft type. The models have the promise to inform RPA certification standards and future system designs.

Teo, Harn Chin. ***Closing the Gap Between Research and Field Applications for Multi-UAV Cooperative Missions***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Oleg Yakimenko and Paul Montgomery
Second Reader: Gary Langford
http://hdl.handle.net/10945/37730

Abstract: The ability to fly multiple unmanned aerial vehicles (UAVs) in collaboration has the potential to expand the scope of feasible UAV missions and could become the backbone of future UAV missions. However, despite having garnered significant research interest, there is no indication that systems supporting collaborative operation of multiple UAVs are close to achieving field deployment. The challenge of successfully deploying a quality system is inherently complex, and systems engineering offers an approach to handle the complexities. Effective application of systems engineering requires both knowledge breadth and depth. This thesis presents the results of a consolidation of information intended to support the conduct of systems engineering

activities; and describes an experiment to ascertain the sensitivities of some key operational parameters, e.g., acquisition, pointing, and tracking. The experiment was conducted using Automatic Dependent SurveillanceBroadcast (ADS-B) and visual tracking equipment employing state-of-the-art technology to understand the operating challenges and requirements of using this equipment to provide situational awareness for a UAV pilot.

Teters, James C.,II. ***Enhancing Entity Level Knowledge Representation and Environmental Sensing in COMBATXXI Using Unmanned Aircraft Systems.*** M.S. in Modeling, Virtual Environments, And Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Imre Balogh
Second Reader: Peter Nesbitt
http://hdl.handle.net/10945/37732
Abstract: Current modeling and simulation techniques may not adequately represent military operations using unmanned aircraft systems (UAS). A method to represent these conditions in a combat model can offer insight to the use and application of UAS operations, as well as understanding the sensitivity of simulation outcomes to the variability of UAS performance. Additionally, using combat model simulations that do not represent UAS behavior and conditions that cause this variability may return misleading or incomplete results. Current approaches include explicit scripting of behaviors and events. We develop a proof of principle search, targeting, and acquisition (STA) model for use with UAS within COMBATXXI, leveraging existing STA research conducted at the MOVES Institute at the Naval Postgraduate School. These dynamic behaviors are driven by events as they unfold during the simulation run rather than relying on preplanned events as in the scripted approach. This allows these behaviors to be highly reusable since they do not contain scenario or incident specific information. We demonstrate the application of the new STA model in a tactical convoy scenario in COMBATXXI. A design of experiments and post analysis quantifies the sensitivity of the measures of effectiveness of success to conditions contributing to variability in UAS performance.

Weiss, Joshua D. ***Real-time Dynamic Model Learning and Adaptation for Underwater Cehicles***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2013.
Thesis Advisor: Noel du Toit
Second Reader: Douglas Horner
http://hdl.handle.net/10945/37741
Abstract: Precision control of unmanned underwater vehicles (UUVs) requires accurate knowledge of the dynamic characteristics of the vehicles. However, developing such models are time and resource intensive. The problem is further exacerbated by the sensitivity of the dynamic model to vehicle configuration. This is particularly true for hovering-class UUVs since sensor payloads are often mounted outside the vehicle body. Methods are investigated in this thesis to learn the dynamic model for such a hovering-class UUV in real time from motion and position measurements. Several system identification techniques, including gradient estimation, Bayesian estimation, neural network estimation, and recursive linear least square estimation, are employed to estimate equations of motion coefficients. Experimental values are obtained for the surge, sway, heave, and yaw degrees of freedom. Theoretical results are obtained for the roll and pitch degrees of freedom. The experimentally obtained model is then compared to the true vehicle behavior.

Wodele, Ryan. ***Business Case Analysis of the Special Operations Air Mobility Vehicle***. Master of Business Administration. MBA Professional Report. Monterey, California: Naval Postgraduate School, December 2013.
Advisors: Stephen Hansen, Mina Pizzini and Bryan Hudgens
http://hdl.handle.net/10945/39038
Abstract: Special Operations Air Mobility Vehicle (SOAMV) is the military term used to describe the Weight Shift Control (WSC) aircraft. The WSC aircraft is a type of Light-Sport aircraft that has

certain characteristics that distinguish it from the more vague aircraft industry segment of Light-Sport aircraft. The WSC aircraft consists of three major, but simple parts: the wing, the carriage, and the pilot. Everything about this aircraft is based on simple, portable, and inexpensive concepts with very little use of modern technology. This keeps the costs down and maximizes the basics of aviation, to include calling on the skills and training of the pilot. Several manufacturers produce this commercial aircraft. They are Air Creation USA, Airborne, Evolution, Concept Aviation, Manta Aircraft S.A., and Northwing Design. This project has three objectives: (1) describe the WSC aircraft and its capabilities. Assess its benefits and costs relative to the V-22 Osprey, the newest troop transport helicopter, and the US Air Force (USAF) Predator, an Unmanned Aerial Vehicle Drone; (2) perform an industry analysis of the WSC training and aircraft sales industry; and (3) determine the expected government training capabilities and costs.

Zorn, James B. *A Systems Engineering Analysis of Unmanned Maritime Systems for U.S. Coast Guard Missions*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, June 2013.
Thesis Advisor: Timothy H. Chung
Second Reader: Mark Stevens
Outstanding Thesis Award
http://hdl.handle.net/10945/34766

Abstract: The U.S. Coast Guard is uniquely suited to utilize multi-mission unmanned maritime systems (UMS) to maintain its leading role in maritime safety, security and stewardship. Current UMS technological capabilities coupled with USCG mission needs motivate an analysis of proposed USCG UMS through a systems engineering methodology. This work begins by decomposing the capability needs for USCG UMS by developing a series of concepts of operations (CONOPS) in a "solution neutral" context. Following capabilities analysis, multi-mission commonalities help derive three USCG UMS alternatives: (1) Cutter-Based Tactical UUV, (2) Shore-Based Harbor/Coastal UUV/USV, and (3) Operational Offshore USV. These alternatives and their respective system architectures provide a design concept for near- to mid-term (5-10 year) acquisition. Finally, feasibility analysis reviews key system enablers (such as technology, capability, policy, and supportability and manpower) for the alternatives to justify a realistic integration timeline. Recommendations for technology investments, enhanced UMS partnerships, USCG unmanned system policies and organizational knowledge are provided to reduce delays and to accelerate delivery of needed capabilities to the field. This study lays the foundation for future strategic planning of USCG UMS (i.e., a USCG UMS Roadmap) while providing additional motivation for USCG unmanned systems in general.

2012

Acton, Brian E. and David L. Taylor. ***Autonomous Dirigible Airships: a Comparative Analysis and Operational Efficiency Evaluation for Logistical Use in Complex Environments***. Master of Business Administration. MBA Professional Report. Monterey, California: Naval Postgraduate School, June 2012.
Advisors: John Khawam and Jeffrey Kline
http://hdl.handle.net/10945/7299
Abstract: The fiscal year 2012 budget resolution forced many agencies to significantly reduce their budget spending and adhere to stricter budgetary policies. The one agency that was hit the hardest was the Department of Defense; it was forced to reduce its budget by $10 trillion over a span of 10 years. With the ongoing War on Terror, the Department of Defense estimated in 2010 that the cost of maintaining a single soldier in a wartime environment grew exponentially to well over $1 million per soldier. The U.S. involvement in Iraq and Afghanistan started a major shift, from using manned vehicles to using unmanned vehicles, also known as autonomous vehicles. These autonomous vehicles can be controlled remotely via satellite or radio signals. Currently, the majority of unmanned vehicle usage is in autonomous unmanned aerial vehicles (UAVs) that provide air surveillance, reconnaissance, and assault purposes across all services. This major shift to autonomous vehicles has kept a large number of troops out of dangerous environments such as Iraq and Afghanistan, has reduced the risk of losing soldiers lives, and, at the same time, has reduced the costs of keeping soldiers in these dangerous environments for long periods of time. The purpose of this project is to provide a comparative analysis and operational efficiency evaluation of current and in-development airships, or dirigibles, to expand the UAVs capability as a viable logistic support platform. This project demonstrates that airships, manned or unmanned, can reduce costs, particularly important with the current budgetary concerns throughout the Department of Defense. The expanded use of airships for logistics could benefit all services due to their flexibility, lift capability, interoperability, and lower cost.

Adams, Jerrod C. ***An Interpolation Approach to Optimal Trajectory Planning for Helicopter Unmanned Aerial Vehicles.*** M.S. in Applied Mathematics. Monterey, California: Naval Postgraduate School, June 2012.
Thesis Advisor: Wei Kang
Second Reader: Hong Zhou
http://hdl.handle.net/10945/7300
Abstract: This thesis explores numerical methods to provide real-time control inputs to achieve an optimal trajectory which minimizes the time required for a Helicopter Unmanned Aerial Vehicle (HUAV) to reorient to a given target. A library of optimal trajectories is populated using a pseudo spectral computational algorithm applied to the mathematical model developed by the National University of Singapore and Singapore Department of Defense to simulate flight characteristics for their HeLion small scale HUAV system. The model is a complex system of non-linear differential equations fifteen state variables and four control variables used to simulate the aerodynamic forces on the HUAV. Then, using the library of optimal trajectories for known target locations, we apply interpolation methods to provide control inputs in order to intercept an attack heading to a target more quickly than an online, full scale optimization approach. All simulations in this thesis are modeled using the MATLAB program.

Atkinson, Robert E., III. ***Tropical Cyclone Reconnaissance over the Western North Pacific with the Global Hawk Operational Requirements, Benefits, and Feasibility***. M.S. in Meteorology and Oceanography. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: Patrick A. Harr
Second Reader: Jeff Kline
http://hdl.handle.net/10945/17315
Abstract: Over the North Atlantic Ocean, an operational manned aircraft-based tropical cyclone (TC) reconnaissance program is conducted by the United States Air Force. However, no such

program is conducted over the western North Pacific (WPAC), where the maximum annual number of TCs occurs. Rather, remotely-sensed observations from satellites provide data on TC characteristics. While operational forecasts of TC track over the WPAC have improved, the rate of improvement has declined, and no such decline has been observed over the North Atlantic. In this study, the declining rate of improvement in WPAC forecast accuracy is examined relative to the lack of direct observations. The capabilities of manned-aircraft are compared with use of a Global Hawk unmanned aerial system for use as an observing platform. This is proposed in view of a declining capability in satellite data coverage. Current Global Hawk programs are reviewed with respect to requirements for operational tropical cyclone reconnaissance over the western North Pacific. A multi-year demonstration project is proposed to obtain in situ observations of TC location and intensity. The observation impacts on improved tropical cyclone forecasts will be assessed such that a positive impact will lead to recommendation of a Global Hawk for operational tropical cyclone reconnaissance.

Barker, William P. ***An Analysis of Undersea Glider Architectures and an Assessment of Undersea Glider Integration into Undersea Applications***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: John Osmundson
Second Reader: Steven Bousquet
http://hdl.handle.net/10945/17320
Abstract: Currently, buoyancy driven underwater gliders are deployed globally to gather oceanographic data from across the worlds oceans. This thesis examines the utility of underwater gliders within the context of providing additional U.S. Navy capabilities. An extensive survey of available underwater gliders was undertaken and the resultant survey pool of ten gliders down selected to five gliders of fixed wing configuration. A comprehensive architectural analysis was then conducted of seven key architectural attributes of the five selected gliders. The architectural analysis compared various implementations of the key architectural attributes relative to desirable traits and capabilities for a notional U.S. Navy glider. Following the architectural analysis a proposed architecture for a U.S. Navy underwater glider was developed which includes a compendium of best features gleaned from the architectural analysis. Drivers and rationale for selection of specific key architectural attributes and features are also provided. Additionally, a comparison of constraints and capabilities of underwater gliders is provided. Finally, a comparison of the current and proposed capabilities of underwater gliders versus other Autonomous Undersea Vehicles, specifically Unmanned Undersea Vehicles, is proffered.

Bateman, Travis K. ***Design and Laboratory Implementation of Autonomous Optimal Motion Planning for Non-holonomic Planetary Rovers***. M.S. in Astronautical Engineering. Monterey, California: Naval Postgraduate School, December 2012.
Thesis Co-Advisors: Mark Karpenko and I. Michael Ross
http://hdl.handle.net/10945/27791
Abstract: This work investigates the challenge of designing and implementing minimum-time trajectories for an autonomous, non-holonomic, planetary rover. The optimal trajectories were implemented at the Control and Optimization Laboratories with a TRAXXAS remote controlled vehicle modified to enable autonomous operations. These modifications include the addition of an ArduPilot controller into the architecture of the vehicle. The ArduPilot controls the inputs to the drive motor and steering servos to implement the trajectory commands generated by the trajectory optimization tool, DIDO. The challenging problem of parallel parking was used to evaluate a canonical maneuvering scenario and illustrate a procedure for motion planning that could be used for guiding a planetary rover. Three cases were evaluated with different starting points to illustrate the difficulties associated with controlling a non-holonomic vehicle. The starting points were located in front of, next to, and behind the parking space. In addition to each case, three scenarios were evaluated for complexity no cars, two cars parked with an ideal amount of space between them, and two cars parked with minimal space between them. A VICON motion capture system was used measure the vehicle trajectory in experiments.

Beach, Joseph N. ***Integration of an Acoustic Modem onto a Wave Glider Unmanned Surface Vehicle***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, June 2012.
Thesis Advisor: Joseph A. Rice
http://hdl.handle.net/10945/7308
Abstract: This thesis examines the possibility of integrating an acoustic modem onto a Wave Glider with the goal of providing a bidirectional communications gateway for submerged sensors, platforms, and networks. The Wave Glider unmanned surface vehicle continuously harvests energy from the environment and is able to hold station without needing to refuel. A unique two-body architecture and wing system directly converts wave motion into thrust, and solar panels provide electricity for sensor payloads. Data messages are transmitted to shore via satellite, and the continuous surface presence means that data can be delivered in real time as it is collected. The objective of this thesis is to identify the best location for an acoustic modem on the Wave Glider, considering the factors of hydrodynamic drag on the vehicle and acoustic performance of the modem.

Chua, Chee Nam. ***Integration of Multiple UAVs for Collaborative ISR Missions in an Urban Environment***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisors: Oleg Yakimenko and Fotis Papoulias
Second Reader: Gerard Leng
http://hdl.handle.net/10945/17343
Abstract: Military conflicts are shifting from jungles and deserts to cities. This is because terrorists, insurgents, and guerillas find these areas provide a rich target environment and good hideouts. With the use of UAVs, urban threats can be tracked and targeted effectively. However, in an urban environment where there is little or no GPS signals and many obstacles, navigation of UAVs is a major challenge. Multiple UAVs can be employed to share sensor information to counter these challenges and to perform Intelligence, Surveillance, and Reconnaissance (ISR) missions with greater ground coverage and better success rates. This thesis explored the various types of UAVs deployed for urban operations and investigated the trends of the UAVs in terms of their parameters such as weight, altitude, speed, and sensor suite. The challenges and requirements for interoperability of multi-UAV operations in urban environments were also discussed. A direct-method-based control system for multiple UAV collaboration and obstacle collision avoidance was proposed. The UAVs were able to share and integrate their sensors information for joint cooperation. A dynamic model was developed for the simulation testing of the algorithm. Following that, physical experiment was carried out in an indoor environment on Quanser QBall-X4 UAV to evaluate the results.

Day, Michael. ***Multi-Agent Task Negotiation Among UAVs to Defend Against Swarm Attacks***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, March 2012.
Thesis Co-Advisors: Timothy H. Chung and Chris Darken
http://hdl.handle.net/10945/6784
Abstract: This research involves a multi-agent based simulation modeling a large swarm of adversarial UAVs attacking a surface target and groups of friendly UAVs responding to thwart the attack. Defense systems need to cooperatively negotiate which enemy systems to engage to maximize the number of aggressor systems destroyed. Using optimal centralized task assignment methods as a baseline, various distributed methods are examined for efficiency and effectiveness. Our findings indicate that the optimality of distributed methods does approach that of centralized methods, though further study is warranted in future simulations with additional constraints, and in field experimentation with physical UAVs. We further find that the number of defender agents, the effectiveness of their weapon systems, and their speeds contribute significantly to the defender swarm's effectiveness.

Dono, Thomas F. *Optimized Landing of Autonomous Unmanned Aerial Vehicle Swarms. M.S. in Operations Analysis*. Monterey, California: Naval Postgraduate School, June 2012.
Thesis Advisor: Timothy Chung
Second Reader: Chad Seagren
Outstanding Thesis Award
http://hdl.handle.net/10945/7331

Abstract: This research explores a future concept requiring the efficient and safe, landing and recovery of a swarm of unmanned aerial vehicles (UAVs). The presented work involves the use of an overarching (centralized) airspace optimization model, formulated analytically as a network-based model with side constraints describing a time-expanded network model of the terminal airspace in which the UAVs navigate to one or more (possibly moving) landing zones. This model generates optimal paths in a centralized manner such that the UAVs are properly sequenced into the landing areas. The network-based model is grown using agent based simulation with simple flocking rules. The resulting solution is compared to another agent-based model which uses similar avoidance rules for the landing of these UAVs, exploring the benefit of distributed computation and decision-making characteristic of swarming models. Relevant measures of performance include, e.g., the total time necessary to land the swarm. Extensive simulation studies and sensitivity analyses are conducted to demonstrate the relative effectiveness of the proposed approaches.

Futch, Thomas D. *An Analysis of the Manpower Impact of Unmanned Aerial Vehicles on Subsurface Platforms*. M.S. in Management. Monterey, California: Naval Postgraduate School, March 2012.
Thesis Co-Advisors: Bill Hatch and Chad W. Seagren
http://hdl.handle.net/10945/6795

Abstract: Currently the submarine force is exploring two possible UAVs, Switchblade and ScanEagle. Each brings capabilities to the submarine to allow safer operations while continuing to perform the required mission. The constantly changing operational environment has forced all elements of the military to adapt and overcome. The submarine force is tasked with more missions and less support than ever before. As a result the ability to adapt and overcome has create a need for additional capabilities in the form of unmanned aerial vehicles (UAVs). A manpower analysis was conducted to identify requirements necessary for submarine launched UAV operations. Current surface launched UAV Navy Enlisted Classification (NEC) codes were used as a comparison for the analysis. Currently these NECs are only available to aviation source ratings. Analysis shows that there are several submarine specific ratings that have the same knowledge entry requirements as the aviation source ratings that are eligible to operate UAVs. Furthermore, research showed that based on the simplicity of operation of Switchblade and ScanEagle, that no additional manpower requirements are necessary. Specifically, on all classes of submarines, Switchblade can be launched and flown with no additional watchstations manned, compared to a standard mission watchbill. Also, with ScanEagle, SSGN class submarines require no additional watchstanders once the UAV is launched, and airborne than would be required for a normal mission watchbill. Incorporating UAVs into the arsenal of a submarine is a vital requirement that needs accomplished. This research recommends the creation of a specific NEC for the submarine force to identify UAV operators.

Gromadski, Christopher R. *Extending the Endurance of Small Unmanned Aerial Vehicles Using Advanced Flexible Solar Cells*. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2012.
Thesis Advisor: Sherif Michael
Second Reader: Rudolf Panholzer
http://hdl.handle.net/10945/27836

Abstract: Most currently fielded small unmanned aerial vehicles (SUAV) have flight times limited to 90 minutes due to battery life and are often forced to work in teams of multiple craft to provide tactical level units with continuous observation of the battlefield. Continuous operations additionally place a strain on logistics trains by requiring either more batter-ies or fuel to support

recharging. Prior theses have examined the ability of solar cells to extend the flight endurance and capabilities of SUAVs during peak sunlight conditions. This research demonstrated the viability of augmenting the onboard power supply with advanced thin-film photovoltaic (TFPV) cells made of copper-indium-gallium sele-nide (CIGS) over a longer period of time. The additional source of power will reduce, at times even eliminate, the demand on the lithium polymer batteries of a Raven SUAV as sunlight conditions change throughout the day. All components used in construction were commercially available, including foam wings that closely resembled the air-foil of a Raven SUAV with increased surface area. The laboratory tests used standard operating procedures from the operators manual and input from the training community to accurately simulate flight conditions and field use. This research demonstrates that degraded components and non-ideal sunlight conditions still provide a significant improvement over the original system for a minimal cost in money and weight. The approach is relevant to the use of the system in austere combat zones which require results in conditions that are rarely ideal. The research additionally ap-plied projections to the capabilities of the augmenting circuitry on unmodified Raven wings and Puma SUAVs.

Hajri, Riadh. *UAV to UAV Target Detection and Pose Estimation*. M.S. in Systems Technology. Monterey, California: Naval Postgraduate School, June 2012.
Thesis Advisor: Timothy H. Chung
Second Reader: Raymond Buettner
http://hdl.handle.net/10945/7351
Abstract: The objective of this thesis is to investigate the feasibility of using computer vision to provide robust sensing capabilities suitable for the purpose of UAV to UAV detection and pose estimation using affordable CCD cameras and open coding libraries. We accomplish this by reviewing past literature about UAV detection and pose estimation and exploring comparison of multiple state-of-the-art algorithms. The thesis presents implementation studies of detection approaches including color-based detection and component-based detection. We also present studies of pose estimation methods including the PosIt algorithm, homography-based detection, and the EPFL non-iterative method. The thesis provides a preliminary strategy for detecting small UAVs and for estimating its six degree of freedom (6DOF) pose from image sequences within the prescribed airspace. Discussion of its performance in processing synthetic data is highlighted for future applications using real-life data sets.

Heiss, Kevin L. *A Cost Benefit Analysis of Fire Scout Vertical Takeoff and Landing Tactical Unmanned Aerial Vehicle (VTUAV) Operator Alternatives.* M.S. in Management. Monterey, California: Naval Postgraduate School, March 2012.
Thesis Advisor: Bill Hatch
Second Reader: Ben Roberts
http://hdl.handle.net/10945/6806
Abstract: A cultural debate exists to determine if the MQ-8B Fire Scout Vertical Takeoff and Landing Tactical Unmanned Aerial Vehicle (VTUAV) should be operated by rated pilots, commissioned officers, or enlisted personnel. Each military service has historically treated this issue differently. The U.S. Navy currently requires rated pilots to fly Fire Scout, the U.S. Army and Marine Corps allow enlisted personnel to fly their Shadow Unmanned Aerial Vehicle (UAV), and the Air Force only allows rated pilots to fly their UAV systems. Technology has advanced rapidly in the area of UAVs as they have advanced from being remotely piloted aircraft to now being completely autonomous. This research examined the Air Vehicle Operator (AVO) requirements for autonomous vehicles such as Fire Scout and will demonstrate that the U.S Navy should create a pilot program that trains enlisted personnel to operate Fire Scout. This research identifies the costs and benefits associated with each type of prospective operator alternativerated pilots, commissioned Surface Warfare Officers (SWO), and Operations Specialist (OS) enlisted personnel. By utilizing enlisted AVOs vice rated pilots, training costs will be found to be reduced from millions to tens of thousands, annual amortized manning costs will be cut by more than half, and total cost savings will be found to be on the order of a billion dollars over a ten-year period. The research will also identify both tangible and intangible benefits by allowing

enlisted personnel to become Fire Scout AVOs. Benefits are identified relating to training time, manning constraints, physiological constraints, culture, and safety. Furthermore, this research will summarize current Knowledge, Skills, and Abilities (KSA) necessary to operate an autonomous air vehicle such as Fire Scout.

Huang, Chung-Huan. ***Design and Development of Wireless Power Transmission for Unmanned Air Vehicles.*** M.S. in Electronic Warfare Systems Engineering and M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: David C. Jenn
Second Reader: Ric Romero
http://hdl.handle.net/10945/17380
Abstract: This thesis is an exploration of microwave wireless power transmission (WPT) for micro-air vehicles (MAVs). WPT, converting radio frequency (rf) power into usable direct current (dc) power, can be implemented with a rectifying antenna, or rectenna. The emphasis of this thesis is on the simulation of rectenna efficiency and measurement of experimental hardware. In this thesis, power reflection in the rectifier matching circuit was investigated by a series of simulations using Agilent Advanced Design System (ADS). Tuning elements were added and adjusted in order to optimize the efficiency. A maximum efficiency of 57 per cent was obtained at 10 gigahertz (GHz) with 200 mW input to the rectenna. A full-wave rectenna was built and hardware experiments were conducted to measure the efficiency of the WPT and characterize the behavior of the circuit. The design is optimized for an input power of 200 mW but, because of hardware limitations, only low-input power levels (about 1 mW) could be tested. A comparison of measurement and simulation results is given, and possible reasons for the differences are discussed.

Hurban, Michael A. ***Adaptive Speed Controller for the SeaFox Autonomous Surface Vessel***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2012.
Thesis Co-Advisors: Vladimir Dobrokhodov, Douglas Horner and Sean Kragelund
http://hdl.handle.net/10945/6811
Abstract: The thesis addressed the control system development for a high-speed surface vessel. In particular, the work utilized modern adaptive control techniques to design a speed following controller for the SeaFox ASV; the vehicle features three distinct speed, regimes including the displacement, rapid transition and planing regimes. The study started with the collection of experimental data required to characterize the operating modes and the inherent nonlinear phenomena of the high-speed ASV. Then, it proceeded to system identification study with an objective to develop a mathematical model of the vehicle thus aiming to represent the ASVs speed dynamics at various regimes and to facilitate control system development. After completing the model development, three speed following controllers were designed A classical Proportional-Integral-Derivative (PID), a nonlinear Model Reference Adaptive (MRAC) and a L1 Adaptive Controller. The motivation behind the choice of three different controllers is two-fold. First, comparison of the linear and nonlinear control approaches is desired to better illustrate the achievable control architecture limitations. Second, comparing two types of nonlinear adaptive control architectures allowed the selection of the best control algorithm for operating the ASV speed in the presence of highly non-linear dynamics and significant disturbances acting on it. Furthermore, each controller is integrated with the SeaFox mathematical model and implemented with and without realistic operational disturbances. This provided a basis for objective comparison among the controllers and gave a means to demonstrate their relative robustness and performance characteristics. Finally, the MRAC and the PID controller were implemented onboard the actual SeaFox ASV and tested in numerous sea-trials under natural conditions to once again demonstrate the advantages and limitations of the chosen control architectures.

Jacobi, Loren, Rick Campbell, Chee Nam Chau, Chin Chuan Ong, Szu Hau Tan, Hock Hin Cher, Cory Alexander, Christien Edwards, Anner Diukman, Sze Yi Ding, Matthew Hagstette, Howe Leng Kwek, Adam Bush, Matt Meeks, Kine Yin Tham, Mei Ling Ng, Ing Kang Yeo, Yew Kok Loke. ***Tailorable Remote Unmanned Combat Craft***. Systems Engineering Analysis Cohort 18, Team B. M.S. in Systems Engineering Analysis. Monterey, California: Naval Postgraduate School, June 2012.
Capstone Project Advisor: Gary Langford and Timothy Chung
http://hdl.handle.net/10945/15434
Abstract: U.S. military and civilian vessels are critically vulnerable to asymmetric threats in littoral environments. Common asymmetric weapons such as Anti-Ship Cruise Missiles (ASCM), Low Slow Flying (LSF) aircraft and Fast Attack Craft (FAC) / Fast Inshore Attack Craft (FIAC) threaten U.S. strategic goals and can produce unacceptable losses of men and material. The SEA-18B team presents an operational concept for a family of Unmanned Surface Vessels USV) capable of defending ships from asymmetric swarm attacks. This USV, the Tailorable Remote Unmanned Combat Craft (TRUCC), can operate in concert with the next generation of capital surface vessels to combat this critical threat with maximum efficiency. Critical performance criteria of the TRUCC family were determined through agent-based simulation of a Straits of Hormuz Design Reference Mission. Additional models addressed ship synthesis and operational availability. A Technology and Capability Roadmap outlines areas of interest for investment and development of the next-generation USV. Interim technology and capability milestones in the Roadmap facilitate incremental USV operational capabilities for missions such as logistics, decoy operations and Mine Warfare. The TRUCC operational concept fills a critical vulnerability gap. Its employment will reduce combat risk to our most valuable maritime assets: our ships and our Sailors.

Jones, Levi. ***Coordination and Control for Multi-Quadrotor UAV Missions***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2012.
Thesis Advisor: Oleg Yakimenko
Second Reader: Noel Du Toit
http://hdl.handle.net/10945/6816
Abstract: This thesis is centered upon an optimal trajectory generation algorithm that allows real-time control for cooperation of multiple quadrotor vehicles for intelligence, surveillance, and reconnaissance missions with minimal user input. The algorithm is designed for an indoor environment where global positioning system data is unavailable or unreliable, forcing the vehicles to obtain position data using other sensors. This thesis specifies the lab setup and well as the control approach used. Data acquired from two experiments is included to demonstrate the effectiveness of the control approach. The control approach described within allows for a fully autonomous system with user input required only at the initiation of a mission. The algorithm blends trajectory planning, trajectory following, and multi-vehicle coordination to achieve the goal of autonomy. The focus of the thesis was on trajectory generation and multi-vehicle coordination, while leveraging existing trajectory following controller implementations. The trajectory generation is accomplished with a direct transcription of the optimization problem that leverages inverse dynamics and separates spatial and temporal planning. The vehicle motion is constrained, and simplifying multi-vehicle coordination assumptions allow for the efficient solution and execution of the problem.

Kaptan, Ali. ***Net-centric Controlled Distributed Stand-in-Jamming using UAVs Transmission Losses and Range Limitations Due to Geo-localization Problem over Turkish Geography***. M.S. in Electronic Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Co-Advisors: David Jenn and Edward Fisher
http://hdl.handle.net/10945/17382
Abstract: Network Centric Warfare (NCW) and swarming have become very important operational terms parallel to the improvements in wireless network technologies. These relatively new concepts are being widely used in many operational applications. The main purpose of this

research effort is to examine the metrics of NCW, and the use of unmanned aerial vehicle (UAV) swarms in electronic attack (EA) missions. UAVs have already been used in many military operations. Swarming a number of small UAVs in a distributed beamforming approach to have the desired operational effect is the current popular research area. Distributed beamforming and swarm behavior of self-synchronized autonomous UAVs are investigated in this study. Two simulation scenarios were created and implemented to show the effectiveness of EA against radars and wireless communication links. In reality, EA against a single node in a network, such as a radar or communication link, is unlikely to be successful by itself, however simulation results showed that the decision making process of the enemy network and OODA (Observe, Orient, Decide, Act) cycle is directly vulnerable to jamming.

Kolar, Ramesh. ***Business Case Analysis of Medium Altitude Global ISR Communications (MAGIC) UAV System***. Master of Business Administration. Monterey, California: Naval Postgraduate School, June 2012.
Thesis Advisor: Daniel Nussbaum
Thesis Co-Advisor: Raymond Franck
http://hdl.handle.net/10945/7369
Abstract: This study is a business case analysis of a Medium Altitude Global ISR Communication (MAGIC) UAV system. The MAGIC platform is analyzed together with three other medium-altitude ISR platforms. A cost model for RDT and E and O and S for the MAGIC is developed based on historical data. A baseline case for MAGIC is then developed with Average Production Unit Cost (APUC) of $17M, RDT and E cost of $510M, and discount factor of 0.025 for the analysis. A Net Present Value of Life Cycle Cost (NPVLCC) and a return ratio as defined by the ratio of the NPVLCC of alternative platforms to the NPVLCC of MAGIC are used in the analysis. Results are presented for 500, 1000, 2000, and 3000 nm ranges. MAGIC outperforms Reaper and Global Hawk, while Predator outperforms MAGIC at the 500 nm. MAGIC outperforms all others in the 1000, 2000 and 3000 nm range. The analysis is extended to cover other payloads for the same ranges. The results show that MAGIC is favored over Reaper for 1000 nm and 2000 nm range, and the return ratio is marginal for 500 nm. MAGIC is favored in all ranges when compared with Global Hawk.

Larkins, Colin G. ***The EP-3E vs. the BAMS UAS: An Operating and Support Cost Comparison***. M.S. in Information Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: Raymond Buettner
Second Reader: William Robinette
http://hdl.handle.net/10945/17395
Abstract: The battlefield is constantly changing and the need for swift, persistent intelligence, surveillance and reconnaissance (ISR), has increased the focus on the use of unmanned aerial vehicles (UAVs) to help meet collection requirements. Certain UAVs can have longer dwell and on-station times than manned vehicles, with some UAVs capable of dwell times in excess of 20 hours. UAVs have an additional benefit of eliminating some of the risks associated with manned aircraft conducting ISR missions. Consequently, UAVs have been closely reviewed as a replacement craft for several manned ISR aircraft and have taken increasing roles in the world of ISR. Given an uneven record of success in the implementation of UAS, and Congressional concerns regarding the relative cost of UAV programs, the purpose of this thesis is to reexamine, compare and analyze the Operating and Support (O and S) costs for both the EP-3E ISR aircraft with the Broad Area Maritime Surveillance (BAMS) Unmanned Aerial System (UAS) that the Chief of Naval Operations (CNO) has declared to be the primary system to replace the EP-3E capability. This comparison includes all costs from initial system deployment through the end of the platforms service life. This thesis uses the revised O and S cost methodology in accordance with Department of Defense (DoD) Instruction 5000.2, Operation of the Defense Acquisition System. In addition, a typical O and S comparison, this thesis modifies the existing BAMS O and S costs to account for the additional costs of bandwidth, ground station support, collection sites, and risks as they apply to the BAMS UAS. These factors were not adequately considered in the original O

and S analysis. Once the analysis and comparison is completed, a recommendation is made as to whether or not the decision to replace the EP-3E ISR system with the BAMS UAS should be revisited.

Martin, Michael. ***Global Versus Reactive Navigation for Joint UAV-UGV Missions in a Cluttered Environment.*** M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2012.
Thesis Advisor: Oleg Yakimenko
Second Reader: Roberto Crisit
http://hdl.handle.net/10945/7380
Abstract: This thesis presents the coordination of an unmanned, multi-vehicle team that navigates through a congested environment. A novel approach is outlined that enables the control of multiple vehicles based on both computer vision and optimal trajectory algorithms. Various sensors are used to achieve localization in the indoor environment in lieu of global positioning data. Specifically, a Quanser Qball quadrotor is equipped with a downward-looking camera and sonar altimeter, while a Quanser Qbot ground vehicle is outfitted with sonar and infrared range finders. This equipment is complemented by an Optitrack motion-capture system. Using conventional image-processing techniques, the birds-eye images supplied by the quadrotor provide information regarding the dynamic environment that surrounds the ground vehicle. The ground vehicle can then produce a global, optimal trajectory, assuring collision-free operations. The optimization problem is addressed by applying the Inverse Dynamics in the Virtual Domain (IDVD) method that uses both the inverse kinematics of the ground vehicle and obstacle information. Furthermore, the IDVD method enables the separation of spatial and temporal planning. As verification of the results of this research, the developed approach for path planning is executed in a fully controlled lab environment and then compared with a sonar-based, reactive obstacle avoidance technique.

Medford, Christopher M. ***The Aerodynamics of a Maneuvering UCAV 1303 Aircraft Model and its Control through Leading Edge Curvature Change***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: M.S. Chandrasekhara
Second Reader: G.V. Hobson
http://hdl.handle.net/10945/17417
Abstract: This study investigates the aerodynamic effects of modifying the leading edge on an unmanned combat air vehicle (UCAV) 1303. Literature suggests that leading edge accelerations are reduced for rounder leading edges and stall characteristics are altered. These phenomena are examined using the previously tested 1/72 scale model with a 47-degree leading edge sweep and a cranked trailing edge delta wing with fuselage. The study consists of both flow visualization and aerodynamic force and moment measurements. The model is maneuvered in the NPS water tunnel where a five-component strain gage load balance system measures the forces experienced by it. The model is pitched at different rates with different degrees of yaw for these studies. This process is repeated for a modified leading edge with a radius double the baseline. Preliminary results show that the rounded leading edge acted as expected, alleviating signs of tip-stall in the normal force distribution and smoothing pitch-breaks in the pitching moment distribution. Rolling moment was shown to increase with angle of attack for the modified leading edge case.

Menjivar, Jose D. ***Bridging Operational and Strategic Communication Architectures Integrating Small Unmanned Aircraft Systems as Airborne Tactical Communication Vertical Nodes***. M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: Douglas J. MacKinnon
Second Reader: John H. Gibson
http://hdl.handle.net/10945/17418
Abstract: The United States Department of Defense enterprise communication architectures are presently designed to support large-scale fixed organizations and rely primarily on satellite

mediums. However, they are inadequate in tactical level environments, and are not readily available nor affordable to support multiple operators in various tactical locations. Incorporating Small-Unmanned Aircraft Systems (UAS) with communication repeaters could expand local mobile ad-hoc networks coverage for users in communications degraded environments and reduce satellite dependency. The proof of concept is focused on leveraging existing Government Off The Shelf (GOTS) technology with ever increasing Small-UAS functionality to explore the potential reduction of communication inadequacies in tactical environments. Through the efforts of this thesis, the goal is to extend and enhance beyond line of sight (BLOS) and on-the-move communications at the small unit level. The findings provide face validation that Small-UAS equipped with a communication payload can provide these services that enhance voice transmissions, and thus, enable TCP/IP data transfer in communication degraded environments without interfering with the Small-UAS primary ISR function or airworthiness. Future efforts in this line of inquiry may also inform the use of multiple Small-UAS to extend the networks and autonomous operations, and perhaps, eliminate the requirement for a ground Small-UAS operator.

Pham, Loc V., Brandon Dickerson, James Sanders, Michael Casserly, Vicente Maldonado, Demostenes Balbuena, Stephen Graves, Bhavisha Pandya. *UAV Swarm Attack: Protection System Alternatives for Destroyers*. Systems Engineering Project Report. Cohort 311-1120 Team Crane M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, December 2012.
Thesis Co-Advisors: Paul V. Shebalin and Bonnie Young
http://hdl.handle.net/10945/28669
Abstract: The Navy needs to protect Destroyers (DDGs) from Unmanned Aerial Vehicle (UAV) attacks. The team, focusing on improving the DDG's defenses against small radar cross section UAVs making suicide attacks, established a DRM, identified current capability gaps, established a functional flow, created requirements, modeled the DDG's current sensing and engagement capabilities in Microsoft Excel, and used Monte Carlo analysis of 500 simulation runs to determine that four out of eight incoming IED UAVs are likely to hit the ship. Sensitivity analysis showed that improving weapon systems is more effective than improving sensor systems, inspiring the generation of alternatives for improving UAV defense. For the eight feasible alternatives the team estimated cost, assessed risk in accordance with the requirements, simulated performance against the eight incoming UAVs, and performed cost benefit analysis. Adding CIWS mounts is the most cost effec-tive alternative, reducing the average number of UAV hits from a baseline of 3.82 to 2.50, costing $816M to equip the 62-DDG fleet for a 12-year life cycle. Combining that with upgraded EW capabilities to jam remote-controlled UAVs reduces the hits to 1.56 for $1844M, and combining those with decoy launchers to defeat the radar-seeking Harpy UAVs reduces the hits to 1.12 for $2862M.

Rogers, Darren J. *GSM Network Employment on a Man-Portable UAS*. M.S. in Information Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Co-Advisors: Raymond R. Buettner and Kevin D. Jones
http://hdl.handle.net/10945/17449
Abstract: There are numerous national systems that offer communications support with enhanced capabilities to support ISR. For the tactical unit, it can be challenging and cumbersome to deal with national systems that may or may not be able to provide near real-time support due to other, high priority tasking. The deployment of a low-cost GSM communications support system with enhanced capabilities (CSSEC) to support intelligence, surveillance and reconnaissance (ISR), which a tactical unit could have organically, would relieve the warfighter of having to depend on national assets and processes. Employing a CSSEC system on a man-portable or small UAS would allow the range of the system to be greatly extended, as opposed to a ground-based system which may be difficult to operate in a high-threat environment. Commercial off-the-shelf (COTS) hardware is readily available and easily acquired. With a CSSEC deployed on a UAS, a tactical unit conducting ground operations would not be geographically constrained to a specific

location to conduct ISR. Nor would they draw attention to the unit in having to set up antennas and other equipment on a building or outpost. Leveraging COTS hardware and open-source software will keep overall cost low without having to deal with software licensing requirements associated with proprietary systems.

Rochholz, Timothy W. ***Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks.*** M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Co-Advisors: Joseph A. Rice and Timothy H. Chung
http://hdl.handle.net/10945/17448
Abstract: By analyzing data from a long-duration deployment of four wave-powered unmanned surface vehicles called Wave Gliders, an assessment of operating characteristics informs the potential utility of the Wave Glider in an undersea distributed network as a replacement for a moored communications gateway buoy. Specifically, the wave-powered propulsion system is analyzed to assess endurance, operability, and application in an underwater distributed network as the gateway node. The results of the study serve to identify the parameters for an experiment designed to test the Wave Glider as a station-keeping gateway node.

Savage, Marta K. ***Design and Hardware-in-the-loop Implementation of Optimal Canonical Maneuvers for an Autonomous Planetary Aerial Vehicle***. M.S. in Astronautical Engineering. Monterey, California: Naval Postgraduate School, December 2012.
Thesis Co-Advisors: Mark Karpenko and I. Michael Ross
http://hdl.handle.net/10945/27898
Abstract: A truly autonomous aerial vehicle is required for conducting aerial missions at distances great enough to cause time lag in communications, such as on other planets. This level of autonomy also reduces the requirement for trained UAV pilots to fly round-the-clock missions. Development of optimal canonical maneuvers is a step towards achieving real-time optimal trajectory generation and more fully autonomous aircraft capable of independent and efficient flight maneuvering. This thesis develops a model of the MONARC aerial vehicle and sets up the optimal control problem for generating canonical maneuver profiles. The DIDO optimal control software is used in order to generate time-optimal trajectories for flight implementation on the MONARC test bed. The ability of the MONARC to fly the optimal trajectories is verified using a 6DOF SIMULINK model. Several canonical maneuvers were developed and optimized to generate trajectories for multiple flight scenarios. One of these cases is analyzed for implementation as part of a Hardware-in-the-Loop (HIL) simulation. This HIL test will verify that the optimization model has sufficient fidelity to be used to generate optimal trajectories that can be physically flown by the MONARC.

Shuey, Eric and Mika Shuey. ***Modeling and Simulation for a Surf Zone Robot***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2012.
Thesis Co-Advisors: Richard Harkins and Timothy H. Chung
Outstanding Thesis Award
http://hdl.handle.net/10945/27905
Abstract: A kinematic and dynamic model for a three degree-of-freedom surf zone robot is developed and tested with a physical test platform and with a simulated robot in Robot Operating System. Derived from Lagrangian mechanics and relying on angular wheel velocities from encoders, the model successfully demonstrates accurate prediction of motion on simple terrain. The application of the model to future platforms is analyzed and a broad examination of the current state of surf zone robotic systems is provided. An in-depth discussion of the potential improvements to the model is made and the critical work still needed to realize a complete and deployable surf zone platform is described for future study.

Soylu, Umit. ***Multi-Target Tracking for Swarm vs. Swarm UAV Systems***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: Timothy H. Chung
Second Reader: Joel Young
Outstanding Thesis Award
http://hdl.handle.net/10945/17462
Abstract: Unmanned systems, including unmanned aerial vehicles (UAVs), are developing technologies that are becoming increasingly important. This thesis provides a model for generating a common operational picture (COP) for unmanned systems that is applicable in today's technology, and presents results and analysis based on simulation studies. This thesis specifically investigates a swarm versus swarm unmanned systems scenario in which opposing teams of UAVs approach each other. Different methodologies for generating a COP from the perspective of a given team are investigated, and a simulation is designed to explore the performance of the selected strategies for performing multi-target tracking. The results of the simulation show the performance of the presented approach where targets are assumed in the field of view of the tracking agents, false detections may or may not be present, and all entities maneuver according to nondeterministic motion models.

Tham, Kine Yin. ***Study of Command and Control (C&C) Structures on Integrating Unmanned Autonomous Systems (UAS) into Manned Environments***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: Gary Langford
Second Reader: John Osmundson
http://hdl.handle.net/10945/17468
Abstract: The use of unmanned systems in the military has been growing. Although the technologies and associated capabilities of unmanned autonomous systems (UAS) continue to progress rapidly, comparatively little has been considered about how these systems will impact a future operating environment. This thesis used scenario planning, specifically a slice-of- time scenario planning, to explore the future operating environment and examined integrating UAS into the current manned environment. This thesis highlighted a few technologies which will shape the future of unmanned systems. The thesis also explored a case study based on STARFISH Project by the Acoustic Research Laboratory (ARL), a laboratory within the Tropical Marine Science Institute (TMSI) of the National University of Singapore (NUS), and derived a proposed roadmap for integrating unmanned systems into the manned environment.

Van Bourgondien, Jeffery. ***Analysis of the Sustainment Organization and Process for the Marine Corps RQ-11B Raven Small Unmanned Aircraft System (SUAS).*** MBA Professional Report. Master of Business Administration. Monterey, California: Naval Postgraduate School, March 2012.
Advisors: David F. Matthews and Raymond E. Franck
http://hdl.handle.net/10945/6883
Abstract: The purpose of this study is to outline and analyze the acquisition and sustainment process for the current U.S. Marine Corps RQ-11B Raven Digital Data Link small unmanned aerial system program. The current sustainment of the Marine Corps Raven evolved from the support employed for its predecessor analog variant in 2008, which was originally supported by Marine organic assets below depot-level maintenance requirements. The Ravens manufacturer, AeroVironment Inc., now stations a field service representative in theater and has been since around June 2011 under a contractor logistics support contract after the Marine Corps struggled to implement organic support and sustain its Ravens at the organizational and intermediate levels. This report serves as a case study for insights into the acquisition strategies for future unmanned systems. I explore the advantages and limitations of organic versus contractor support options in the form of monetary, organizational, and logistical resource allocation by analyzing the spectrum of solutions throughout the supply and maintenance constructs. The analysis covers both operational and sustainment perspectives through the lens of doctrine, organization, training, material, leadership and education, personnel, and facilities implications.

Wallace, John A. *Integrating Unmanned Aircraft Systems into Modern Policing in an Urban Environment*. M.A. in Security Studies (Homeland Security and Defense). Monterey, California: Naval Postgraduate School, September 2012.
Thesis Advisor: Patrick Miller
Second Reader: Nadav Morag
http://hdl.handle.net/10945/17474
Abstract: This thesis examines the possibilities and advantages of incorporating the use of unmanned aircraft systems (UAS) into operational use by local public safety agencies. The use of UAS has become a vital tool for the military but still has not become a tool used by domestic police forces. This thesis explores the options of using this type of technology, such as an economical alternative or enhancement to existing aviation programs and better situational awareness for tactical operations. In addition, to reviewing issues and concerns related to privacy considerations; this thesis addresses program implementation, creation of best practices policy and procedures, benefits to community safety, and flight regulations and restrictions under the oversight of the Federal Aviation Administration (FAA).

Wiseman, Adam. *Autonomous Underwater Vehicle Planning for Information Exploitation*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2012.
Thesis Co-Advisors: Douglas Horner and Oleg Yakimenko
http://hdl.handle.net/10945/6890
Abstract: The ability of an Autonomous Underwater Vehicle (AUV) to dynamically plan safe routes and maneuvers in dangerous environments is directly relevant for the future of the use of AUVs in the exploration and exploitation of the underwater environment, specifically the littorals and inland waters. This thesis builds upon the existing body of knowledge of the REMUS AUV dynamics and kinematics and develops a control scheme for a real-time optimized vehicle trajectory that will permit continuous and autonomous collection and exploitation of external sensor data, which will facilitate full 360-degree, 2-dimensional mapping of the underwater environment surrounding the vehicle while preventing the vehicle from coming into contact with mapped objects in the water. The developed control schema will seek to generate a trajectory in real-time that optimizes a key parameter of interest, the Information Gain, while minimizing a specified cost function of constraints, such as kinematic limits and obstacle avoidance criteria.

Yau, Meng Wee Joses. *Localization of Surface or Near-Surface Drifting Mines for Unmanned Systems in the Persian Gulf*. M.S. in Physical Oceanography. Monterey, California: Naval Postgraduate School, June 2012.
Thesis Co-Advisors: Peter C. Chu and Timothy H. Chung
Second Reader: Ronald E. Betsch
http://hdl.handle.net/10945/7436
Abstract: This thesis investigates the combined use of ocean models, such as idealized surface current flows, and search models, including expanding area and discrete myopic search methods, to improve the probability of detecting a near-surface, drifting object over time. Enhanced search effectiveness is facilitated by the use of robotic search agents, such as a tactical unmanned underwater vehicle (UUV) or unmanned aerial vehicle (UAV), leveraging simulation methods to inform the search process. The presented work investigates the impact of using nave versus optimized search patterns on localizing a drifting object, including a surrogate ocean model using idealized flow as well as historical data sets with Weibull-distributed perturbations. Numerical studies and extensive analysis using different permutations of model parameters (including the relative speed of the drifting object, time late in the searcher's arrival to the search area, sensor sweep width, and duration of the search mission) identify the significant factors affecting the overall probability of detection. Such insights enable further explorations using empirical datasets for specific oceanographic regions of interest.

2011

Actkinson, John Ira. ***Minesweeping for Pressure Actuated Mines by Air Injection into a Water Column***. M.S. in Engineering Acoustics. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Bruce Denardo
Second Reader: Daphne Kapolka
http://hdl.handle.net/10945/5493
Abstract: The U.S. Navy historically has not had an adequate means to remotely pressure sweep for mines at reasonable speeds and cost, and this is still the case. The Navy has addressed such threats, but countermeasures are time consuming and considered to be very resource intensive. During this thesis two sets of data were collected in tow tank experiments using two different sizes of Bubble Squid apparatus. This thesis is a continuation of work already completed by Lieutenant Jeffery Murawski from December 2009. This continuation was able to extend the proof-of-concept with larger scale tow-tank testing at NPS. Further testing with the much larger three-meter Bubble Squid apparatus culminated in experiments conducted in March 2010 at the David Taylor Research Basin in Carderock, MD. The data that was collected and analyzed in this thesis will show that the Bubble Squid apparatus is a viable concept for solving the pressure influence minesweeping capability gap.

Ardhaoui, Mejdi Ben. ***Implementation of Autonomous Navigation and Mapping Using a Laser Line Scanner on a Tactical Unmanned Aerial Vehicle***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, December 2011.
Thesis Advisor: Timothy H. Chung
Second Reader: Duane Davis
http://hdl.handle.net/10945/10728
Abstract: The objective of this thesis is to investigate greater levels of autonomy in unmanned vehicles. This is accomplished by reviewing past literature about the developing of components of software architecture that are necessary for unmanned systems to achieve greater autonomy. The thesis presents implementation studies of existing sensor-based robotic navigation and mapping algorithms in both software and hardware, including a laser range finder, on a quadrotor unmanned aerial vehicle platform for real-time obstacle detection and avoidance. This effort is intended to lay the groundwork to begin critical evaluation of the strengths and weaknesses of the MOOS-IVP autonomy architecture and provide insight into what is necessary to achieve greater levels of intelligent autonomy in current and future unmanned systems.

Chan, Chung Wei. ***Investigation of Propagation in Foliage using Simulation Techniques***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2011.
Thesis Advisor: David C. Jenn
Second Reader: Vic Romero
http://hdl.handle.net/10945/10577
Abstract: In a foliage environment, radio wave propagation is subjected to fading on both large-scales and small-scales that impair the quality and reliability of data link transmission. This has implications in many military applications. An example is the performance of communications links and unmanned aerial vehicle radio links when the ground forces are operating in foliage environments. The purpose of this research is to evaluate some simple models for propagation of radio waves in foliage using an electromagnetic field simulation application. The three dimensional (3D) electromagnetic field simulation application, CST Studio Suite, was used in the modeling and simulation process. Specifically, the CST Microwave Studio module was used to model the forest using dielectric blocks. Various combinations of forest dimensions, material dielectric parameters and antenna placements were simulated to obtain propagation models of radio waves in foliage environment. The simulation models are compared to three empirical models presented in the literature for propagation in foliage environment. Using the simulation model, we examined the coverage diagram for a transmitter antenna immersed in foliage. The

results show that the proposed simulation models provide a rough approximation to radiowave propagation in an actual rainforest environment. Based on the simulated results, the path loss in foliage is affected by the forest's electrical characteristics, the height of the transmitter and the height of receiver.

Chin, Chee Keen. ***Extending the Endurance, Missions and Capabilities of Most UAVS Using Advanced Flexible***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, March 2011.
Thesis Advisor: Sherif Michael
Second Reader: Rudolf Panholzer
http://hdl.handle.net/10945/5824
http://handle.dtic.mil/100.2/ADA576544

Abstract: The extension of flight time for military miniature unmanned aerial vehicles (UAVs) has been demonstrated through the implementation of thin-film photovoltaic (TFPV) cells. Currently, most electric mini-UAVs are powered by high energy density lithium-ion or lithium polymer batteries; however, the flight endurance is usually limited between 60 to 90 minutes before requiring a forced recovery to replace exhausted batteries. In this thesis, the viability of extending flight endurance by complementing the on-board battery source of a mini-UAV using advanced TFPV cells made of copper-indium-gallium di-selenide (CIGS) semiconductor materials is considered. In order to achieve a higher efficiency, the simulation and testing phase incorporates the use of a DC-to-DC converter and a maximum power point tracking device or algorithm to provide the desired output voltage and deliver maximum power from the TFPV cells to the battery and load. In addition to investigating the application of TFPV cell technology, development of new high power/energy density batteries and fuel cells technologies, as well as the potential benefit of applying less mature, high-efficiency photovoltaic cells to military UAVs are also considered.

Cobb, Brandon J. ***Adaptive Discrete Event Simulation for Analysis of Harpy Swarm Attack***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Arnold Buss
Second Reader: Jeffrey Kline
http://hdl.handle.net/10945/5501

Abstract: Harpy swarm attacks are a new type of threat designed for Suppression of Enemy Air Defenses. Research into combating Harpy swarm attacks has been conducted but the simulation software used to date, Naval Simulation System, is inadequate for future research. A new and mission-focused simulation tool is necessary in order to advance research in defensive tactics against Harpy and other unmanned aerial vehicle threats (UAV). This research develops a simulation model for a Harpy swarm attack using Simkit to meet the need for a mission specific analytical tool. The base model consists of a user-defined Harpy patrol area and a ship traversing the area on a course and speed also defined by the user. A total of 16 parameters are defined and implemented. The model records the time any Harpy impacts the ship to provide data for the response variable, the number of Harpy hits on the ship. Main effect and full factorial regressions were performed as well as a partition tree to determine which parameters had the most significance on the number of Harpies which hit the ship. These model characteristics and future enhancements will provide researchers the ability to assess alternative anti-UAV swarm tactics.

Darnell, Bart W. ***Unmanned Aircraft Systems: A Logical Choice for Homeland Security Support***. M.A. in Security Studies (Homeland Security and Defense). Monterey, California: Naval Postgraduate School, December 2011.
Thesis Advisor: Erik Dahl
Second Reader: Clay Moltz
http://hdl.handle.net/10945/10587

Abstract: Unmanned aircraft systems (UAS) have been part of aviation from the beginnings of manned aviation and have become a vital tool of our overseas military and national security operations. Public and private sector interest continues to grow for UAS to be used in a variety of

domestic missions, such as border patrol, law enforcement, and search and rescue. With growing concerns over issues, such as border security and critical infrastructure protection, it would seem that UAS would be a logical choice for increased homeland security support, and yet they remain only in limited use. This thesis examined why UAS are not widely used domestically for homeland security support and found that their sluggish integration into the National Airspace System stems from a perceived flight safety risk. However, UAS operations have improved; systems, such as the Predator have flight safety trends equivalent to that of some manned aircraft. Nevertheless, government, private industry, academia, and other UAS stakeholders should continue to work together to further UAS safety. Specifically, they should collaborate to improve UAS component reliability, develop aviation regulations and standards to account for peculiar UAS characteristics, and improve public perception.

Doherty, Sean Michael. ***Cross Body Thruster Control and Modeling of a Body of Revolution Autonomous Underwater Vehicle***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2011.
Thesis Advisor: Douglas Horner
Second Reader: Oleg Yakimenko
http://hdl.handle.net/10945/5728
http://handle.dtic.mil/100.2/ADA543855
Abstract: Cross body thrusters permit a body of revolution Autonomous Underwater Vehicle to retain the energy efficiency of forward travel while increasing the ability to maneuver in confined areas such as harbors and piers. This maneuverability also permits more deliberate underwater surveys using a fixed, mounted forward and downward looking sonar. This work develops the necessary hydrodynamic coefficients, using methods applied to earlier vehicles, to develop a valid computer simulation model. Additionally, this work develops a polynomial regression translating thruster input in RPM to an applied force output, which is incorporated into the vehicle model. This model is then employed to examine the response and control, specifically at low speed, of a body-of-revolution Autonomous Underwater Vehicle equipped with off-axis cross-body thrusters. These results are then utilized to develop a series of PID controllers for use onboard the REMUS Autonomous Underwater Vehicle.

Emmersen, Tracy, Ng Kiang Chuan, David Chiam, Ong Zi Xuan, Perh Hong Yih Daniel, Koh Wee Yung, Wes Wessner, Jon Saburn, Lim Choon Wee, Wong Chee Heng, Christian Silvestrini, Lu Zheng Liang, Phil Castaneda, Sor Wei Lun, Pek Wee Kok, Jim Drennan, Teo Yong Kiong; Tan Yick Fung, Scott Harvey, William Walker, Wee Hong Chuan, Matt Malinowski, Kelvin Zhu, Thomas Mills, Chang Chung Wei. ***Advanced Undersea Warfare Systems***. MSSEA in Systems Engineering. SEA Cohort 17, Team B. NPS-SE-11-004. Monterey, California: Naval Postgraduate School, Department of Systems Engineering, June 2011.
Capstone Project Advisor: John Osmundson
http://hdl.handle.net/10945/6959
Abstract: Over the next twenty years, the proliferation of threats in the undersea environment will likely challenge the platform-centric model that the United States Navy uses to maintain dominance in Undersea Warfare (USW). Meanwhile, rapidly maturing technologies offer greater capabilities to potential adversaries around the world. Such a paradigm creates an imperative for the Navy to harness emerging technologies to maintain USW dominance amid a dynamic threat environment, while balancing cost, risk, and required performance. This systems engineering analysis develops Advanced Undersea Warfare Systems (AUWS) that provide a technological and tactical advantage based on the needs of the war-fighter. Following critical analysis of the numerous possible alternatives for performing the necessary Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) and prosecution and an objective screening process, four system architectures, and associated operational concepts, are selected for detailed analysis. From cost, risk, and performance analyses, superior AUWS concepts are shown to be flexible, scalable, and tailorable systems that balance critical need areas. This analysis highlights the need for new warfare systems that can meet future challenges to the traditional platform-centric model for USW dominance. Using the

results and recommendations in this analysis will allow the Navy to deploy capabilities that effectively and efficiently meet future operational needs.

Fodera, Christopher M. *Transitioning the Tactical Marine Corps to IPv6*. M.S. in Information Sciences. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Alex Bordetsky
Second Reader: David Cabrera
http://hdl.handle.net/10945/5602
Abstract: As communication in tactical arenas continues to trend from serial to Internet Protocol (IP) based, the necessity for tactical programs of record to embrace IP communications becomes more and more imperative. While many Marine Corps tactical communications programs of record already recognize this trend and its significance, some are affected more heavily than others. Numerous advantages exist for transitioning from Internet Protocol version 4 to Internet Protocol version 6, and a top-down transition makes most sense for deployed and deploying units, the Data Distribution System-Modular is the system best suited to take on this role. The Naval Postgraduate School's Center for Network Innovation and Experimentation (CENETIX) and Tactical Network Topology (TNT) field experimentation program, along with the Marine Corps Tactical Systems Support Activity (MCTSSA), can take on this task of transitioning the Tactical Marine Corps to IPv6.

Halle, Steven and Jason Hickle. *The Design and Implementation of a Semi-Autonomous Surf-Zone Robot Using Advanced Sensors and a Common Robot Operating System*. M.S. in Physics. Monterey, California: Naval Postgraduate School, June 2011.
Thesis Co-Advisors: Richard Harkins and Timothy H. Chung
http://hdl.handle.net/10945/5690
Abstract: A semi-autonomous vehicle, MONTe, was designed, modeled and tested for deployment and operation in a surf-zone coastal environment. The MONTe platform was designed to use unique land based locomotion that incorporates wheel-legs(WhegsTM) and a tail. Semi-autonomy was realized with data from onboard sensors and implemented through open source Robot Operating System (ROS), hosted on an Ubuntu Linux based processor. Communications via IEEE 802.11 protocols proved successful for data telemetry in line of site operations. Basic mobility and tail control of the platform was modeled in Working Model 2D. Field tests were successfully conducted to demonstrate mobility and semi-autonomous waypoint navigation. Future developments will look to improve the overall design and test water borne mobility, navigation, and communication.

Hong, Bryan Y. *An Effective Noise Filtering Method for Mine Detection*. M.S. in Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Peter Chu
Second Reader: Ronald E. Betsch
http://hdl.handle.net/10945/5576
Abstract: Automatic detection of sea mines in coastal regions is difficult due to highly varying sea bottom conditions present in the underwater environment. Detection systems must be able to discriminate objects that vary in size, shape, and orientation from naturally occurring and man-made clutter. Additionally, these automated systems must be computationally efficient to be incorporated into Unmanned Aerial Vehicle (UAV) sensor systems characterized by high sensor data-rates and limited processing abilities. Commonly used noise filters largely depend on the window (or neighborhood) size, which makes the mine detection ineffective. Using the bi-dimensional empirical mode decomposition (BEMD) analysis, an effective, robust sea mine detection system can be created. A family of decomposed images is generated and applied to optical lidar image data from the Rapid, Overt, Airborne, Reconnaissance (ROAR) experiment supplied by Naval Surface Warfare Center, Panama City. These decompositions project key image features, geometrically defined structures with orientations, and localized information into distinct orthogonal components or feature subspaces of the image. Application of the BEMD method to the analysis on side scan sonar data is also provided. Accurate detection and classification of

mines is time consuming and requires divers or Autonomous Underwater Vehicles (AUV) in the water. The navy continues to pursue more expedient methods in mine countermeasures, and with airborne lidar, a surf zone (SZ) and landing zone can be quickly surveyed for possible mines. In the near surf zone, all possible mines can be quickly neutralized by dropping guided munitions, eliminating the need to send divers or AUVs to verify contacts. Still, the need for improved methods of detection and classification is needed. BEMD, a relatively new method of signal analysis developed about fifteen years ago, was tested on lidar imagery from the ROAR experiment to look for any improvements in detecting and classifying mines.

Jurta, Daniel and Bryan Pettigrew, Adam Dye, Joshua Hodge, James Mullen, and Grant Schweikert. ***MQ-8B Fire Scout UAV Manning Cost Benefit Analysis***. Executive Master of Business Administration. Monterey, California: Naval Postgraduate School, September 2011.
Senior Consultant: Frank R. "Chip" Wood
http://hdl.handle.net/10945/7070
Abstract: EXECUTIVE SUMMARY: At the request of the Intelligence, Surveillance, and Reconnaissance Task Force, the Naval Air Systems Command's program office for Multi-Mission Tactical Unmanned Aerial Systems (UAS)—also known as PMA-266, began MQ-8B flight operations in Afghanistan. Due to the importance and short notice of this request, the initial manning and support measures for the Fire Scout detachment has relied heavily on contractors. In an effort to refine and redirect the future manning of Fire Scout detachments, PMA-266 asked the Washington DC Naval Postgraduate School Consulting Group to evaluate three different courses of action (COAs) detailing manning options for deployment of the MQ-8B Fire Scout for the next year. The three COAs were: 1) Manning with a military component 2) Manning with NGC contract services 3) Manning through a third party contractor. This report recommends that PMA-266 use the military component COA to the maximum extent possible. In addition to annual cost savings of over $10M, a military component provides greater mission-focus and flexibility inherent in a military chain of command as compared to a contract manning structure. The Navy would also benefit by obtaining operational UAS experience as it looks to develop an unmanned aviation community. The experience gained could be used to develop Navy instructors for operator and maintenance training instead of continuing to rely on contract support for these requirements.

Kilitci, Serkan, and Muzaffer Buyruk. ***An Analysis of the Best Available Unmanned Ground Vehicle in the Current Market with Respect to the Requirements of the Turkish Ministry of National Defense***. Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2011.
Advisors: John T. Dillard and Kathryn Aten
http://hdl.handle.net/10945/10633
Abstract: Today, Unmanned Ground Vehicles (UGVs) provide significant supporting capabilities in military operations worldwide. When UGVs are used to their full potential, the number of casualties is decreased and the combat effectiveness of warfighters is increased. UGVs are being developed in different sizes to meet different mission capability requirements. The employment of available UGVs and the development of new UGV capabilities have been rising steadily. Countries have started giving more importance to UGVs, and they are now being employed all over the world. The Turkish Ministry of National Defense (MND) can use the advantages of UGVs in a number of ways to assist in its efforts against terrorist activities. The purpose of this MBA project is to conduct an analysis of the best available UGV in the current market with respect to the requirements of the Turkish MND. After providing some background and market research on UGVs, we will explore their capabilities and their capability gaps in regard to the requirements of the Turkish MND. In the end, this project will determine the best available near-term UGV for the Turkish MND by employing the Analysis of Alternatives (AoA) method of the U.S. Defense Acquisition System.

Larkin, Matthew S. ***Brave New Warfare: Autonomy in Lethal UAVS***. M.S. in Management
Monterey, California: Naval Postgraduate School, March 2011.
Thesis Co-Advisors: George Lucas and William Hatch
http://hdl.handle.net/10945/5781
http://handle.dtic.mil/100.2/ADA543725
Abstract: The Department of Defense (DoD) is making significant strides to develop and deploy unmanned vehicles in a variety of environments. Specifically, the Secretary of the Navy is sponsoring a new program, Consortium for Robotics and Unmanned Systems Education and Research ("CRUSER"), at the Naval Postgraduate School to enhance the ability to address unmanned vehicle research in a systematic manner. The area of research in this thesis strives to position the technological advancements within an ethical framework that will guide the development and use of these technologies. Autonomous platforms may bring significant advantages and enhance our abilities for mission accomplishment. This project concludes that they are best deployed in conventional conflicts, and may have more limited and problematic uses during irregular warfare and COIN operations. Laws pertaining to the deployment of autonomous and unmanned platforms are unclear and need to be strengthened on an international scale. Furthermore, the questions regarding what are permissible uses of autonomous platforms should also include future operators and personnel involved in the acquisition and engineering of these platforms, and should not be left solely in the hands of lawyers and diplomats. The combination of autonomy and lethality is found to work best when limited to the targeting of an enemy's weapons systems and aircraft in highly scripted environments rather than enemy combatants and personnel themselves.

Lednicky, Eric J. ***Analytically Quantifying Gains in the Test and Evaluation Process through Capabilities-based Analysis***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Rachel T. Silvestrini
Second Reader: Harrison C. Schramm
http://hdl.handle.net/10945/5578
Abstract: Military operating environments are increasingly diverse and technically challenging. Fielding relevant weapons systems to meet the demands of this environment is increasingly difficult, prompting policy shifts that mandate a focus on systems capable of combating a wide threat range. The Capabilities-Based Test and Evaluation (CBT&E) construct is the Department of the Navy's effort to concentrate on integrated system design with the objective of satisfying a particular operational response (capability) under a robust range of operating conditions. One aspect of CBT&E is the increased employment of advanced mathematical and statistical techniques in the Test and Evaluation (T&E) process. This study illustrates advantages of incorporating these invaluable techniques, like Design of Experiments (DOE) and Modeling and Simulation (M&S), within the T&E process. We also suggest a general methodology for approaching test plan design, presented via a notional scenario in which a complex system must defend a forward outpost. We found through statistical analysis that the application of DOE concepts to the System Under Test (SUT) throughout three primary phases of T&E quantifiably improved the accomplishment of the selected Measure of Effectiveness (MOE).

Liu, Chun-Yi. ***An Improved Rectenna for Wireless Power Transmission for Unmanned Air Vehicles***. M.S. in Electronic Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: David C. Jenn
Second Reader: Ric Romero
http://hdl.handle.net/10945/5561
Abstract: This thesis continues an NPS project related to wireless power transmission for micro air vehicles (MAVs). The conversion of radio-frequency (rf) power into usable direct-current (dc) power is performed by a rectifying antenna, or rectenna. The emphasis of this thesis is the simulation and experimental study of various rectenna designs to determine which best provides high efficiency, stable output power, and lightweight design. The analysis of rectenna design

focuses on four subsystems: (1) the receiving antenna, (2) the matching sections, (3) the rectification, and (4) the post-rectification filter. Based on the findings of this research, the ultimate rectenna design implements a half-wave dipole antenna that performs full-wave rectification with two diodes. The post-rectification filter is implemented by a capacitor to obtain stable dc power. The final design achieved an efficiency of nearly 66% for input power in the range of 200 mW.

Milionis, Georgios. ***A Framework for Collaborative Quadrotor - Ground Robot Missions***. M.S. in Applied Physics and Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2011.
Thesis Advisor: Oleg Yakimenko
Thesis Co-Advisor: Richard Harkins
http://hdl.handle.net/10945/10654
Abstract: The thesis proposes a real-time control algorithm for the cooperation of a joint team consisting of a Quadrotor and a Ground robot for coordinated ISR missions. The intended application focuses on indoor environments, where Global Positioning System signals are unreliable or simply unavailable so that the control algorithms must rely on local sensor information. The thesis describes the appropriate set up of the lab and includes simulations using a full dynamic model of the quadrotor and robot, demonstrating the suitability of the implemented and the proposed control scheme into a waypoint navigation scenario. The implemented controller uses the Linear Quadratic Regulator method imposed into five different channels; pitch, roll, yaw, x-y position and height, configured to the appropriate gains for smoother following of the trajectory. The proposed control scheme incorporates three key aspects of autonomy; trajectory planning, trajectory following and collaboration of the two vehicles. Using the differentially-flat dynamics property of the system, the trajectory optimization is posed as a non-linear constrained optimization within the output space in the virtual domain, not explicitly related to the time domain. A suitable parameterization using a virtual argument as opposed to time is applied, which ensures initial and terminal constraint satisfaction. The speed profile is optimized independently, followed by the mapping to the time domain achieved using a speed factor.

Miller, Glenn A. ***Evaluation of HRI Payloads for Rapid Precision Target Localization to Provide Information to the Tactical Warfighter***. M.S. in Information Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Kevin Jones
Second Reader: Ray Buettner
http://hdl.handle.net/10945/5512
Abstract: High Resolution Imagery (HRI) with precise location and targeting data for the warfighter has become an integral part in today's asymmetric warfare environment. This thesis conducted practical testing of systems and employed qualitative research methods to evaluate HRI payloads for SUAS to provide rapid precision target localization to the warfighter. The research attempted to evaluate new HRI systems integration with the current SUAS's to produce accurate or reduced error images for intelligence and targeting data. The targeting solutions were to be evaluated against those calculated solutions achieved on a manned aircraft. This part of the evaluation was not completed due to the discovery of radio frequency noise interference induced by systems modifications required to fit the small confines of the SUAS platform. Targeting solution research was conducted using archival images from a manned flight mission. Once the system and technology is modified to eliminate the radio frequency noise there is a high probability of successfully proving the desired capability.

Munoz, Mauricio F. ***Agent-Based Simulation and Analysis of a Defensive UAV Swarm Against an Enemy UAV Swarm***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2011.
Thesis Advisor: Timothy H. Chung
Second Reader: Michael P. Atkinson
http://hdl.handle.net/10945/5700
http://handle.dtic.mil/100.2/ADA547892

Abstract: Unmanned systems, including unmanned combat aerial vehicles (UCAVs), are increasingly important in military operations. Given the growth of unmanned systems technology worldwide, these systems may increasingly pose a real threat to U.S. and Allied forces in the near future. This thesis proposes a future concept of employing a defensive UCAV swarm, launched from a friendly sea-based platform. To simulate this defensive swarm system, an agent-based simulation model was developed, and appropriate designs of experiments and statistical analyses were conducted. The investigated factors were drawn from the literature review to create several experimental designs with the objective of identifying the significant design factors of the Blue UCAV system. The result of the analysis shows that only five of the eleven candidate factors analyzed are significant, which can be used to inform the engineering specification of preliminary requirements for potential future development.

Pawlenko, Matthew. ***Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV).*** M.S. in Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisors: Philip A. Durkee and K.Todd Holland
http://hdl.handle.net/10945/5466

Abstract: In many places that U.S. forces operate, there exists an insufficient amount of data regarding river water depths, which is a necessity for safe operational planning. Satellite sensors and airborne manned platforms have been used for bathymetric derivation, but are not in abundance, nor do they have the spatial resolution required to examine smaller rivers. Using Unmanned Aerial Vehicles (UAV), this research examines the feasibility of using a ratio method with digital imagery to derive water depths, as well as a simpler polynomial regression to create a lookup table for use in the field. The results show that the ratio method of Red to Blue had higher correlation than Red color band on its own, and that the simple polynomial regression using a ratio of Red to Blue had higher correlation than more widely accepted methods. However, both methods are limited by a maximum depth, which is defined as the point where color no longer changes with depth. All depths beyond this point appear as this maximum depth. These findings show that using imagery from UAVs for bathymetric derivation could be a feasible alternative to accepted satellite imagery methods, but further research is needed to demonstrate operational utility.

Payton, Leslie T. ***The Future of Unmanned Aircraft Systems in Support of the Marine Expeditionary Unit***. M.S. in Management. Monterey, California: Naval Postgraduate School, December 2011.
Thesis Advisor: Daniel Nussbaum
Second Reader: Don Summers
http://hdl.handle.net/10945/10667

Abstract: The USMC Marine Expeditionary Unit (MEU) is commonly referred to as "the nation's 911 force." It must be capable of executing a full spectrum of missions from low-intensity humanitarian assistance and noncombat evacuations to high-intensity major combat operations. The structure and equipment are designed around this multimission requirement. However, the USMC owns the fixed-winged Shadow unmanned aircraft system (UAS), and is in the process of acquiring a small fixed-wing UAS, the small tactical UAS (STUAS) to provide intelligence, surveillance, and reconnaissance. The USMC is also researching a cargo resupply UAS based on helicopter technology. The USMC focus on single mission UAS does not fit with the MEU's mission requirements. This thesis will examine MEU mission requirements and recommend a UAS

capability set that best supports MEU operations. From this recommended set of requirements, the thesis will use a cost analysis to determine a future UAS program of record.

Peterson, Troy M. and Jason R. Staley. ***Business Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF).*** Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2011.
Advisors: Raymond E. Franck and Daniel A. Nussbuam
http://hdl.handle.net/10945/10672
Abstract: Based on our analysis K-MAX is an attractive alternative to current methods of resupply. These findings led to our conclusion that the K-MAX is a program worthy of DoD investment and becoming a program of record. The concept for the utilization of unmanned aircraft system (UAS) capability in support of logistics in operation enduring freedom (OEF) is in response to a United States Marine Corps urgent needs requirement. This capability significantly decreases the ground convoy requirement. In addition, the introduction of UAS would reduce American forces' exposure to exterior enemy threats while conducting resupply missions. The Cargo UAS (CUAS) program is a Naval Air Systems Command (NAVAIRSYSCOM) initiative. The Marines' main interest in the program is the ability to have a system that can operate autonomously beyond line of sight with GPS en route waypoint navigation and be controlled remotely at designated cargo delivery locations. The purpose of this study is to estimate potential cost savings in the form of resource human life valuations. This study conducts a business case analysis (BCA) comparing the estimated costs of the UAS program to the current methods for providing logistical support through traditional ground convoys, fixed and rotary wing assets.

Rice, Marshall, Rahul Petrie, Daniel Reese, Kurtis Hoots, Robert Taylor, Drew Nash, Jonathan Trdan-Schmidt, Thuan Huynh, and Bunny Cooper. ***United States Navy Oceanic Armed Reconnaissance System***. MSSE & MSES. NPS-SE-11-017. Monterey, California: Naval Postgraduate School, 2011.
Project Advisors: Mark M. Rhodes and Josephy W. Sweeney III
http://hdl.handle.net/10945/6967
Abstract: A student team at the Naval Postgraduate School studied the need for, and development of, a system that effectively and economically deters piracy in an area of interest. The system's proposed area of operation is the Gulf of Aden, but the system may be deployed to any operational theater where piracy threatens maritime commerce. Piracy and hijacking of ships off the Somali Coast have grown tenfold since 2006. In response to this growing problem, the U.S. Navy, along its with allies, formed Combined Task Force 151 (CTF-151) to protect approximately 33,000 merchant vessels transiting through this area daily. CTF-151 patrols the Internationally Recommended Transit Corridor (IRTC) in the Gulf of Aden and because of this, Somali pirates have begun to migrate away from the IRTC and CTF-151 patrols. For this reason, the team studied the use of UAV technology that allowed for broader area of piracy surveillance and detection. The system that was conceived and analyzed was the Oceanic Armed Reconnaissance System (OARS). The OARS Basic alternative, when analyzed against CTF-151, was found to be the most cost effective system. This OARS Basic system is comprised of a Littoral Combat Ship (LCS) as a host vessel, ScanEagle UAVs, an SH-60 Helicopter, and Zodiac Rigid Hulled Inflatable Boats (RHIB).

Slatt, Michael. ***Development and Testing of a Hybrid Wheg^{TM}-mobile Platform for Autonomous Surf-zone Operations***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2011.
Thesis Advisor: Richard Harkins
Second Reader: Peter Crooker
http://hdl.handle.net/10945/10695
Abstract: Mobility Over Non-Trivial Terrain (MONTe) is a hybrid (wheel-leg) WhegTM-mobile platform created for two purposes. The first purpose is to verify the simulated benefits of adapting previous six-legged Wheg robotic platforms to a four-legged Wheg amphibious design

with a tail. The second purpose is to provide a platform to continue autonomous design and testing in the amphibious environment. In addition, the challenges of previous NPS surf-zone designs are investigated as well as the new challenges of making an amphibious platform to include the following: suspension system, drivetrain, tail integration, environmental control for subsystems, power distribution system and water-borne operation.

Snyder, Derek J. ***Design Requirements for Weaponizing Man-Portable UAS in Support of Counter-Sniper Operations***. M.S. in Information Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Co-Advisors: Raymond R. Buettner and Kevin D. Jones
http://hdl.handle.net/10945/5543
Abstract: The sniper is a highly successful tool used by the enemy to create both physical and psychological effects on U.S. and Coalition forces. A single enemy sniper can pin down an entire company-sized element for an extended period of time, resulting in measurable disruptions in operations. This threat is as old as the rifle itself but has been somewhat shadowed by the proliferation of the Improvised Explosive Device (IED) over the past few years. Nevertheless, many resources are being dedicated to counter-sniper technology to include: permanently mounted radar systems, vehicle mounted systems, and shot detection systems worn by the individual Soldier to identify the point of origin (POO) of the small arms fire and thus the location of the sniper. This location is extremely helpful information, but knowledge of the sniper's location alone will not always be enough to regain freedom of maneuver. If the sniper is free to target, his target is not free to maneuver. This thesis explores the design requirements of weaponizing man-portable UAS at the tactical level in support of counter-sniper operations so that the sniper is not free to operate without risk. These systems are already commonly deployed on the battlefield, and if a scalable weapons system capability can be provided, it will immediately reduce the effectiveness of the adversary snipers.

Sosebee, Philip D. ***Flow Visualization and Detailed Load Measurements Over a Maneuvering UCAV 1303***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2011.
Thesis Advisor: M.S. Chandrasekhara
Second Reader: G.V. Hobson
http://hdl.handle.net/10945/5743
http://handle.dtic.mil/100.2/ADA543022
Abstract: The unsteady aerodynamic performance of a maneuvering 1/72nd scale model of an unmanned combat air vehicle (UCAV) 1303 geometry has been studied in the Naval Postgraduate School water tunnel. Despite the numerous past publications on UCAV flows, none pertains to the UCAV maneuvering characteristics. Due to its nonslender wing, the flow features over the chosen aircraft are unique in that both features of highly yawed wings and of delta wings are present. Even though the speeds and Reynolds numbers are low in a water tunnel, the results of the present studies attest to the suitability of a water tunnel for performing such studies. Force measurements taken at various Reynolds numbers, model attitudes and maneuvering rates for comparison proved to be valid for data comparison to potential flight scenarios. The UCAV 1303 model has a 47 degrees leading edge sweep and a cranked trailing edge delta wing with a fuselage. Pitching and rolling maneuvers were performed in various combinations to demonstrate the real flight conditions of a maneuvering UCAV. A five-component strain-gage and flow monitoring software were used to determine force and moment coefficients in real time. These coefficients were analyzed and compared to previous flow visualization tests to correlate the various flow features recorded during that phase of the study, and to determine the overall stability of a delta wing UCAV. These plots demonstrate what is seen visually at Reynolds numbers from 1.17×10^4 to 2.94×10^4. Where the pitch break occurs on the wings during maneuvers is correlated and dependent on Reynolds number, as initially suspected. Performing unsteady maneuvers helped in retaining the approximate linear variation of lift coefficient to higher angles of attack. Roll maneuvers produced oscillatory side forces and moments at high angles of attack and roll, indicating potentially serious unsteady forces.

Suh, George Y. ***Shear and Stability at the Base of the Mixed Layer in the Arctic Ocean: The Role of Inertial Motions***. M.S. in Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, March 2011.
Thesis Advisor: Timothy Stanton
Second Reader: William Shaw
http://hdl.handle.net/10945/5751
http://handle.dtic.mil/100.2/ADA543824

Abstract: The Arctic environment changed significantly over recent decades and declines in perennial sea ice and thickness concentrations have been frequently observed. Current predictive models providing researchers with conservative estimates of sea ice concentrations, the lack of observations and understanding of the physical processes that promote changes in sea ice create inaccuracies that need to be improved. A fusion of buoy observations, satellite derived ice concentrations, and modeled wind data are made in this thesis to provide a better insight into sea ice inertial motions and its influence on the processes that occur in the Arctic Ocean mixed layer and to investigate whether these processes can be parameterized to improve predictive models. Observations made in the Canadian Basin and the Transpolar Drift by high resolution Autonomous Ocean Flux Buoys (AOFBs), SSMI and AMSR-E satellite derived ice concentrations, and ERA-Interim winds are used to examine the relationships between winds, ice coverage and sea ice inertial oscillations. Data collected from AOFBs and collocated Ice-Tethered Profilers (ITPs) are analyzed to investigate whether ocean mixed layer inertial oscillations contribute to shear instability at the base of the mixed layer, which serves as a mechanism for vertical transport of heat in water masses underlying the mixed layer. Results show that simple linear regression models cannot explain the relationship between inertial sea ice velocities and modeled winds. However, they do indicate that the magnitude of the inertial sea ice velocities during summers is greater when compared to winter. Analysis further reveals a relationship between sea ice inertial oscillations and sea ice concentrations. We conclude that parameterizing the conditions that permit significant inertial motions in terms of changing areal ice conditions is viable. Inertial oscillations generated in the Arctic Ocean mixed layer do contribute significantly to the instability at the base of the mixed layer, especially during summers. However, comparisons of dynamic instability at the base of the mixed layer to satellite derived sea ice concentrations reveal no conclusive relationship.

Tuggle, Christopher K. ***The Use of Autonomous Vehicles for Spatially Measuring Mean Velocity Profiles in Rivers and Estuaries***. M.S. in Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Jaime MacMahan
Second Reader: Ed Thornton
http://hdl.handle.net/10945/5538

Abstract: Autonomous vehicles (AVs) are commonly used in oceanic and more recently estuarine and riverine environments because they are small, versatile, efficient, moving platforms equipped with a suite of instruments for measuring environmental conditions. However, moving vessel observations, particularly those associated with Acoustic Doppler Current Profiler (ADCP) measurements, can be problematic owing to instrument noise, flow fluctuations, and spatial variability. A range of ADCPs manufactured by different companies were integrated onto an Unmanned Surface Vehicle (USV), an Unmanned Underwater Vehicle (UUV), and some additional stationary platforms, and were deployed in a number of natural riverine and estuarine environments to evaluate the quality of the velocity profile over the depth, minimum averaging time interval requirements and AV mission planning considerations. An appropriate averaging window, T*, was determined using the Kalman Algorithm with a Kalman gain equal to 1%. T* was found to be independent of depth, flow velocity, and environment. There was no correlation (R2=0.18) for T* between flow magnitude and direction. Results from all measurements had a similar T* of approximately 3 minutes. Based on this, an averaging window of 4 minutes is conservatively suggested to obtain a statistically confident measure of the mean velocity profile.

Tyree, Michael G. ***Initial Design and Concept of Operations for a Clandestine Data Relay UUV to Circumvent Jungle Canopy Effects on Satellite Communications.*** M.S. in Information Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Raymond Buettner
Second Reader: Sean Kragelund
http://hdl.handle.net/10945/5537

Abstract: Communications within jungle environments has always been a difficult proposition. This is especially true of collection assets beneath triple canopy jungle that need to communicate with overhead national assets. The traditional methods of countering the negative effects of the canopy on EM signals have been to increase the power to offset the losses, or to utilize new, more canopy transparent portions of the EM spectrum. However, there are complications with both of these methods. Simply increasing transmitted power increases the drain on the system's power supply, thus lowering effective on-station time. Shifting to a different portion of the EM spectrum can negatively affect the transmission rate of the system and requires specialized equipment such as antennas and modulators. This work addresses the issue by designing a semi-autonomous UUV, which will clandestinely relay data from the embedded jungle systems to overhead national assets. Rather than trying to punch through the canopy directly, the proposed UUV will take advantage of the fact that most jungle water ways have, at the very least, a thinner canopy overhead if not a clear view of the sky for less lossy satellite communications. This shifts the primary communications from an Earth-Sky problem to a lateral wave model where the communications travels parallel to the canopy. While the jungle is still not an ideal medium for communications, other methods can be used to address these losses. The proposed UUV will be designed to be cheap and constructed from existing systems. It will also be small, and lightweight, enough to be delivered and deployed in theater via aircraft, boats, and operators on the ground. Additionally it will be capable of long on station times due to the ability recharge on station.

Walliser, James C. ***Trust in Automated Systems: The Effect of Automation Level on Trust Calibration***. M.S. in Human Systems Integration. Monterey, California: Naval Postgraduate School, June 2011.
Thesis Advisor: Lawrence G. Shattuck
Second Reader: Robert L. Shearer
http://hdl.handle.net/10945/5628
http://handle.dtic.mil/100.2/ADA547808

Abstract: Automated systems perform functions that were previously executed by a human. When using automation, the role of the human changes from operator to supervisor. For effective operation, the human must appropriately calibrate trust in the automated system. Improper trust leads to misuse and disuse of the system. The responsibilities of an automated system can be described by its level of automation. This study examined the effect of varying levels of automation and accuracy on trust calibration. Thirty participants were divided into three groups based on the system's level of automation and provided with an automated identification system. Within the Virtual Battlespace 2 environment, participants controlled the video feed of an unmanned aircraft while they identified friendly and enemy personnel on the ground. Results indicate a significant difference in the ability to correctly identify targets between levels of automation and accuracy. Participants exhibited better calibration at the management by consent level of automation and at the lower accuracy level. These findings demonstrate the necessity of continued research in the field of automation trust.

Watts, Bryan D. ***Integration of Control Algorithms for Quadrotor UAV's Using an Indoor Sensor Environment***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Advisor: Isaac Kaminer
Second Reader: Vladimir Dobrokhodov
http://hdl.handle.net/10945/5529
Abstract: This thesis develops an architecture that facilitates the design and indoor testing of control algorithms implemented onboard quadrotor UAV's using an ultra-wideband (UWB) indoor positioning solution from Ubisense. Initially, details are provided on basic quadrotor dynamics, the setup of the indoor sensor environment, and the communication scheme. A thorough analysis is conducted on the accuracy and estimation lag of Ubisense UWB sensors for providing indoor position information to the quadrotor. Once this framework is established, the focus is placed on design and experimental validation of the altitude hold control algorithm. The observer used is a discrete Kalman filter that minimizes the covariance of position and acceleration measurement inputs to produce a smooth estimation of states (position, velocity and acceleration). These estimated states are then fed into a modified PD plus Integral controller to produce quadrotor thrust commands for given altitude step commands. Results indicate that the technology used is capable of maintaining a UAV's altitude within an error margin of +/-13.3 cm, but the relatively slow update rate of the Ubisense system limits the possibility of more complex and aggressive maneuvers.

Zaborowski, Robert Michael. ***Onboard and Parts-based Object Detection from Aerial Imagery***. M.S. in Modeling, Virtual Environments, and Simulation (MOVES) and M.S. In Computer Science. Monterey, California: Naval Postgraduate School, September 2011.
Thesis Co-Advisors: Mathias Kölsch and Chris Darken
http://hdl.handle.net/10945/5523
Abstract: The almost endless amount of full-motion video (FMV) data collected by Unmanned Aerial Vehicles (UAV) and similar sources presents mounting challenges to human analysts, particularly to their sustained attention to detail despite the monotony of continuous review. This digital deluge of raw imagery also places unsustainable loads on the limited resource of network bandwidth. Automated analysis onboard the UAV allows transmitting only pertinent portions of the imagery, reducing bandwidth usage and mitigating operator fatigue. Further, target detection and tracking information that is immediately available to the UAV facilitates more autonomous operations, with reduced communication needs to the ground station. Experimental results proved the utility of our onboard detection system a) through bandwidth reduction by two orders of magnitude and b) through reduced operator workload. Additionally, a novel parts-based detection method was developed. A whole-object detector is not well suited for deformable and articulated objects, and susceptible to failure due to partial occlusions. Parts detection with a subsequent structural model overcomes these difficulties, is potentially more computationally efficient (smaller resource footprint and able to be decomposed into a hierarchy), and permits reuse for multiple object types. Our parts-based vehicle detector achieved detection accuracy comparable to whole-object detection, yet exhibiting said advantages.

2010

Archontakis, Andreas. ***Assessing the Flight Quality of a Large UAV for SensorsGround Robots Aerial Delivery***. M.S. in Information Warfare. Monterey, California: Naval Postgraduate School, September 2010.
Thesis Co-Advisors: O. Yakimenko and A. Bordetsky
Second Reader: P. Ateshian
http://hdl.handle.net/10945/5116
http://handle.dtic.mil/100.2/ADA531461
Abstract: The new goal for unmanned aerial systems will be to find creative methods of keeping the cost low and still maintain effectiveness. This thesis discusses the importance of UAVs over the last few years, suggests the development of a low-cost, large UAV, and evaluates the results. We also examine the idea of a platform for deploying multiple aerial-delivery, parafoil-based systems and discuss scenarios for the improvement of the collaboration of the large UAV with the Snowflake project.

Burkamshaw, Leon Keith. ***Towards a Low-Cost Quadrotor Research Platform***. M.S. in Software Engineering. Monterey, California: Naval Postgraduate School, March 2010.
Thesis Advisor: Douglas Horner
Second Reader: James B. Michael
http://hdl.handle.net/10945/10540
http://handle.dtic.mil/100.2/ADA518360
Abstract: Two aspects of currently available Miniature UAVs (MUAVs) that limit the adoption of this technology for civil and research purposes are the high cost and closed design philosophy. This thesis attempts to solve these problems by presenting an open source design that is focused on low-cost, while maintaining a reasonable level of performance. The use of Commercial Off-The-Shelf (COTS) equipment is maximized where possible to reduce development time and cost. A novel approach used by this design is the use of a Nintendo Wii MotionPlus device as an Inertial Measurement Unit (IMU). This mass produced COTS part provides a three degree of freedom IMU for minimal cost. All software is of a modular design to ease understanding and facilitate improvements. To reduce development time, and to help discover requirements, a Rapid Application Development (RAD) methodology has been adopted that is suitable for implementation by a single developer. Software prototypes are constructed and iteratively built upon to discover more requirements. At the completion of each phase, testing is performed. Once a suitable level of maturity has been reached, the software prototype is rolled into the main build. Flight-testing is performed at the completion of the design along with a quantitative measure of flight stability.

Byers, Kenneth. ***Situational Awareness for Surveillance and Interdiction Operations (SASIO): Tactical Installation Protection***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, March 2010.
Thesis Advisor: Timothy H. Chung
Second Reader: Rachel T. Johnson
Outstanding Thesis Award
http://hdl.handle.net/10945/5383
http://handle.dtic.mil/100.2/ADA518377
Abstract: Security of a Forward Operating Base (FOB) is of high interest and operational importance to the U.S. military and allied forces. The Situational Awareness for Surveillance and Interdiction Operations (SASIO) model simulates the operational tasking of a single Unmanned Aerial Vehicle (UAV) and a ground-based interceptor that are designed to search, identify, and intercept potential hostile targets prior to reaching the FOB. This thesis explains the SASIO model and its implementation in JAVA. This theoretical model leverages Design of Experiments (DOE), which varies multiple characteristics of the system to explore insights for the tactical employment of UAV and interceptor to combat potential hostile actions against a predefined area of interest.

Designed screening simulation experiments identifies influential factors to provide guidance for tactical employment of Blue Force assets, as well as provide alternative means to influence Red force behavior in a beneficial manner. This thesis analyzed the effects of the influential factors with respect to the percentage of threats interdicted, time to acquire threats, and mean distance away from the FOB that the threats were interdicted. Through analytical techniques, a quantifiable measure of the employment strategy for the UAV and ground-based interceptor was achieved.

Coba, Javier V. ***Application of Copper Indium Gallium Diselenide Photovoltaic Cells to Extend the Endurance and Capabilities of the Raven RQ-11B Unmanned Aerial Vehicle***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2010.
Thesis Advisor: Sherif Michael
Second Reader: Todd Weatherford
http://hdl.handle.net/10945/5118
http://handle.dtic.mil/100.2/ADA531540
Abstract: Prior thesis work has demonstrated the possibility of extending the flight time of military Small Unmanned Aerial Vehicles (SUAV) by 200% with the implementation of thinfilm photovoltaic (TFPV) cells. In this thesis, we investigate how thin-film photovoltaic cells, made out of Copper Indium Gallium Di-Selenide (CIGS) semiconductor materials and mounted on the wings of the Raven RQ-11B SUAV, provide sufficient electrical power to fully operate the UAV for extended periods of time. This research focuses on extending the flight time of the Raven RQ-11B and on minimizing its sole dependence on lithium-ion batteries. This research will also demonstrate that increasing the size of the wings, adding a DC to DC power converter, and using a Maximum Power Point Tracker (MPPT) will enable the Raven RQ-11B to keep its lithium-ion battery charging continuously, while operating under varying daylight conditions. Additionally, this research will investigate the advantage of enabling systems on the ground to "self-charge." This will enable tactical units to operate in any field, to include areas where power sources are unavailable.

Davis, Cledo L. ***The Systems Integration of Autonomous Behavior Analysis to Create a "Maritime Smart Environment" for the Enhancement of Maritime Domain Awareness***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, June 2010.
Thesis Co-Advisor: Rachael Goshorn and Deborah Goshorn
http://hdl.handle.net/10945/5352
http://handle.dtic.mil/100.2/ADA524661
Abstract: Maritime Domain Awareness (MDA) is a very challenging mission area in an ever-increasing net-centric environment, which is inundated with data from many highly advanced, capable sensors and communication suites. With all these technological data collection and dissemination advances, the information available is just too voluminous for humans alone to process and react to manually, sifting the "wheat from the chaff," and be expected to accomplish effective operational decision making regarding maritime threats to national security, as well as to international peace and trade on the high seas. This thesis addresses MDA Joint Integrating Concept capability gaps, MDA-003C and MDA-004C, for aggregating, analyzing and displaying maritime information in order to understand the maritime environment to identify threats and predicting activity within the maritime domain. Applying the Systems Engineering process, the concept, requirements analysis, architectures, and system design and validation description for a systems integration solution is presented. The proposed implementation entails integrating autonomous behavior analysis capability that utilizes syntactical grammar-based spatial-temporal behavior classifications within existing Net-Centric MDA environments. In attestation to this implementation, this thesis describes the research conducted on a demonstrable proof-of-concept laboratory system, the Watchman Maritime Smart Environment System, whose representative architecture for specific autonomous behavior analysis implementation is provided.

DeDeaux, Cedric N. *Energy Capture Module (ECM) for Use in Unmanned Mobile Vehicles (UMVS) with a Specific Study of the Draganflyer X6 UAV*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2010.
Thesis Co-Advisors: Robert Harney and Rachel Goshorn
Second Reader: Mark Stevens
http://hdl.handle.net/10945/5172
http://handle.dtic.mil/100.2/ADA531569

Abstract: Unmanned drones, robots, and vehicles are often chosen to perform tasks in harsh and dangerous environments. Autonomous vehicles are ideal in tactical situations when these vehicles can perform functions for warfighters when the risk to human life is significantly too high. In particular, unmanned aerial vehicles (UAVs) have become a common staple of military operations. Common sizes range from slingshot-launched spy bots to global guardians. Small UAV of all types have limited mission endurance due to volume and weight constraints of their energy storage and power sources. In many cases, UAVs are limited in the extent to which they could provide tactical advantage because of their need to be recharged or refueled. Even with the use of highly efficient energy and power sources, it is extremely difficult to design a feasible energy system that will provide power for prolonged duration missions. A method, energy capture, exists to provide recharging of an energy source remotely. By utilizing electromagnetic waves, energy can be transmitted wirelessly over great distances. This method has been implemented in several forms today, and shows promise as a possible way to provide for much greater UAV mission endurance. An Energy Control Module (ECM) is proposed as a scalable and Modular Open System (MOS) design concept that can utilize either a tuned laser photovoltaic cell or a microwave receiver to convert received electromagnetic energy to maintain the onboard UAV platform battery charged. The ECM can utilize ground or shipboard based power supply to wirelessly transmit power to a UAV. This thesis presents a study of the characteristics needed for an ECM that allows a small UAV platform to remain on station and perform its designed functions while recharging its energy source for prolonged duration missions.

French, Daniel W. *Analysis of Unmanned Undersea Vehicle (UUV) Architectures and an Assessment of UUV Integration into Undersea Applications*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2010.
Thesis Advisor: John S. Osmundson
Second Reader: James S. Griffin
http://hdl.handle.net/10945/5111
http://handle.dtic.mil/100.2/ADA531528

Abstract: There are prominent unmanned undersea vehicle (UUV) systems existing in the commercial marketplace today, but these systems have a relatively small role and presence in U.S. Navy application. This thesis suggests what existing commercially available UUV system architectural attributes could be used now in U.S. Navy applications. After a survey of multiple existing commercial UUV systems, five of the prevalent systems in the marketplace were selected for analysis and comparison of their system architecture. This thesis included a comprehensive architectural analysis on seven specific architectural attributes of these UUV systems. Other UUV systems were also analyzed to support specific system architecture discussion. Major architecture considerations were made by the UUV system designers and likely drivers of existing system attributes were discussed as well as the benefits and disadvantages of these system attributes. Finally, based on the material and findings of the thesis, recommendations for a notional UUV system design and architecture for the U.S. Navy was presented.

Fry, Jered N. and Steven E. Tutaj. *A Business Case Analysis for the Vulture Program*. MBA Professional Report. Monterey, California: Naval Postgraduate School, December 2010.
Advisors: Daniel A. Nussbaum and Alan J. Laverson
http://hdl.handle.net/10945/10488
http://handle.dtic.mil/100.2/ADA536326

Abstract: The Vulture program is an initiative being developed by the Defense Advanced Research Projects Agency (DARPA). The end goal of the Vulture program is to develop a high

altitude long endurance (HALE) unmanned aerial vehicle (UAV) that is capable of maintaining a 1,000-pound payload on station for five years. The DARPA goals for the Vulture program include, at a minimum, the development and demonstration of advanced reliability technologies for the proposed future Vulture system. It is envisioned that Vulture will provide affordable, persistent coverage over an area of interest for surveillance and communications relay missions. The purpose of this study is to estimate the potential cost savings and identify other benefits associated with the potential operational use of Vulture. This study conducts a business case analysis (BCA) comparing the estimated costs of the Vulture program to those of the Global Hawk and Global Observer systems. Sensitivity analyses are performed on the cost variables, as well as a general risk assessment for Vulture.

Gatzke, Benjamin Thomas. ***Trajectory Optimization for Helicopter Unmanned Aerial Vehicles (UAVs)***. M.S. in Applied Mathematics. Monterey, California: Naval Postgraduate School, June 2010.
Thesis Advisor: Wei Kang
Second Reader: Hong Zhou
http://hdl.handle.net/10945/5315
http://handle.dtic.mil/100.2/ADA524550
Abstract: This thesis explores the numerical methods and software development for optimal trajectories of a specific model of Helicopter Unmanned Aerial Vehicle (UAV) in an obstacle-rich environment. This particular model is adopted from the UAV Laboratory of the National University of Singapore who built and simulated flights for an X-Cell 60 small-scale UAV Helicopter. The code, which allowed the team to simulate flights, is a complex system of non-linear differential equations-5 state variables and four control variables-used to maneuver the state trajectories. This non-linear model is incorporated into a separate optimization algorithm code, which allows the user to set initial and final time conditions together with various constraints, and, using the same variable scheme, optimize a trajectory. The optimal trajectory is defined by using a cost function-the performance measure-and the system is subject to a set of constraints (such as mechanical limitations and physical three-dimensional obstacles). Simulations conclude that solutions are readily obtained; however, it is still very difficult to derive trajectories that are truly optimal, and our work calls for more future research in computational programs for optimal trajectory planning. All simulations in this thesis are modeled using the MATLAB program.

Gill, Travis J. ***Carrier Air Wing Tactics Incorporating the Navy Unmanned Combat Air System (NUCAS)***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, March 2010.
Thesis Advisor: Susan M. Sanchez
Second Reader: Douglas E. Otte
http://hdl.handle.net/10945/5364
http://handle.dtic.mil/100.2/ADA518620
Abstract: The United States Navy has established a Program Office for Acquisition, PMA-268, to develop the Navy Unmanned Combat Air System (NUCAS). The NUCAS will be a fighter-sized aircraft capable of a variety of missions including deep-strike, Intelligence Surveillance and Reconnaissance (ISR), Time Sensitive Targeting (TST) and Air-to-Air Refueling (AAR).The NUCAS will offer new capabilities to the operability of a Carrier Air Wing (CAW). Potential benefits include improvements in combat sortie completion rate for manned aircraft such as the F/A-18 Super Hornet and the F-35C Lighting II Joint Strike Fighter (JSF). In this thesis, we evaluate a strike scenario that focuses on the coordination of the NUCAS, the F/A-18 Super Hornet,and the F-35C Lightning II. We construct a simulation model of the scenario, and use a designed experiment to run 12,000 simulated coordinated strike events. We then use a variety of statistical and graphical tools to evaluate the result in order to determine the quantity of aircraft required for mission success, and operational factors necessary to limit friendly aircraft losses. The results indicate that a division of four NUCAS aircraft is advantageous, in terms of achieved high target casualty rates and high blue survivability rates. The results also highlight the necessity of stealth technology requirements in future aircraft development.

Gray, Stephen C. ***Leveraging Naval Riverine Forces to Achieve Information Superiority in Stability Operations***. M.S. in Information Systems Management. Monterey, California: Naval Postgraduate School, December 2010.
Thesis Advisor: R.Mitchell Brown III
Second Reader: Karl D. Pfeiffer
http://hdl.handle.net/10945/5075
http://handle.dtic.mil/100.2/ADA536372
Abstract: The conflicts of Iraq and Afghanistan have provided an undeniable storyline: U.S. forces can conduct a conventional mission better than any in the world, but that mission, accomplished in short order, leaves behind a situation for which conventional forces and equipment are ill-prepared. This situation requires a new mission: Stability Operations. The blue-water is not where these 21st century conflicts will likely take place, and forces such as the U.S. Navy Riverines are among the many forces that provide a capability to integrate and communicate with local populations that cannot be matched by blue-water forces. While the riverine force's mission set is one that could become heavily utilized in stability operations, the ability to conduct those missions is currently hindered by a lack of implementation of information technology. The current disadvantages that greatly increase operational risk include a reduced capability to engage the population, reduced situational awareness, and limited communication reach-back capability. A riverine force properly equipped with and trained with biometric, unmanned, and information sharing systems would provide the NECC, and U.S. Navy as a whole, a more comprehensive ability to conduct stability operations in brown-water areas, something no other conventional Navy unit can currently accomplish.

Ireland, Robert D. ***Autonomous Vehicle Systems : Implications for Maritime Operations, Warfare Capabilities, and Command and Control***. M.S. in Systems Technology. Monterey, California: Naval Postgraduate School, June 2010.
Thesis Advisor: Shelley P. Gallup
Second Reader: Douglas J. MacKinnon
http://hdl.handle.net/10945/5284
http://handle.dtic.mil/100.2/ADA524742
Abstract: Military operations within the last decade have seen enormous growth in the fielding and utilization of unmanned tele-operated vehicles in the air, ground, and maritime domains. With advances in computing and processing technology, these vehicles and systems are becoming increasingly autonomous in nature and will continue to evolve in the future, significantly impacting the warfighter and the battlespace. A great deal of research and development (R&D) is currently underway by the Department of Defense (DoD), as well as in industry and academia, in the field of autonomous systems. As the technology in this area rapidly advances, comparatively little is known about how these systems will affect our future organizational and Command and Control (C2) architectures, or their implications for the future of warfare in general. This thesis catalogues the current and emerging technologies associated with these systems, within the context of the capabilities they bring to the warfighter. From this baseline, an analysis of future capabilities is conducted against selected maritime operations as identified in the Navy Tactical Task List (NTTL). Impact to organizational performance is analyzed using the Congruence Model, and possible implications are drawn about the near-term future of naval operations and organizational change.

Jacobson, Kevin Robert. ***The Littoral Combat Ship (LCS) Surface Warfare (SUW) Module: Determining the Best Mix of Surface-to-Surface and Air-to-Surface Missiles***. M.S in Modeling, Virtual Environments, and Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2010.
Thesis Advisor: Michael McCauley
Second Reader: Curtis Blasi
http://hdl.handle.net/10945/5207
http://handle.dtic.mil/100.2/ADA531553
Abstract: Asymmetric threats pose increasing challenges to the United States Navy in littoral

environments. To address the Navy's need for a new platform to serve in this area, the Littoral Combat Ship (LCS) was designed and put into service. What still has yet to be determined is what surface-to-surface capability the LCS will have as well as what air-tosurface capability the LCS helicopter/unmanned aerial vehicle (UAV) will have. This study uses freely available data to build a simulation utilizing an agent-based modeling platform known as MANA. The simulation is exercised over a broad range of different weapon systems types with their capabilities ranged across the spectrum of possibilities based on their effectiveness as well as potential difficulties in targeting small boat threats. Using linear regression and partition trees, an analysis is performed on the resulting dataset to address the research question. The results show that the NLOS system is the best surface-to-surface missile system for the LCS as long as the expected rate of fire is obtained. The best air-tosurface missile system is either APKWS or LOGIR, depending on which can obtain a rate of fire of one missile every nine seconds or faster. Lastly, the rate of fire has been shown to be the most important factor in determining the effectiveness of the different missiles.

Kaya, Fevzi Aytac. ***Development of a Receiver Processor for UAV Video Signal Acquisition and Tracking Using Digital Phased Array Antenna***. M.S. in Electronic Warfare Systems Engineering and Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2010.
Thesis Advisor: David C. Jenn
Second Reader: Terry Smith
http://hdl.handle.net/10945/5221
http://handle.dtic.mil/100.2/ADA531560

Abstract: Air dominance is a key factor concerning today's warfare. Obtaining air dominance requires having a high degree of situational awareness. Unmanned aerial vehicles (UAVs) have gained popularity for surveillance and reconnaissance missions and provide situational awareness to ground-based military units. During operations it is necessary to maintain an uninterrupted data and control link between the UAV and the ground control station (GCS). This requires GCS antennas with signal-tracking capability. The work on this research was based on an ongoing project that originally started in 2002. The ultimate purpose is to design and build a digital phased-array antenna system that can automatically acquire, track, demodulate and decode video signals from a UAV using commercial-off-the-shelf (COTS) equipment. Previous work done includes integration of hardware components and development of software modules that allow the array system to auto-track signals from a UAV as well as decode the video signals in a standard format. The research in this thesis focused on allowing the system to demodulatethe video signals acquired by the digital tracking array. The baseband demodulation technique implemented was previously tested with video signals. A new technique utilizing tangent-type demodulation of signals was also implemented and tested using a bench-top test setup.

Lawler, Paul P. ***Cost Implications of the Broad Area Maritime Surveillance Unmanned Aircraft System for the Navy Flying Hour Program and Operation and Maintenence Budget***. Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2010.
Thesis Co-Advisors: Lawrence Jones and John Mutty
http://hdl.handle.net/10945/5059
http://handle.dtic.mil/100.2/ADA536476

Abstract: The 21st century has ushered in an era of new maritime challenges for the U. S. Navy, requiring the ability to maintain situational awareness over the world's maritime domain. The need for global Maritime Domain Awareness (MDA) has highlighted gaps in existing organic Intelligence, Surveillance, and Reconnaissance (ISR) collection capabilities within the Navy. To fill this capability gap, the Navy has initiated a recapitalization plan of its airborne ISR force to leverage the technological capabilities of unmanned systems, of which the Broad Area Maritime Surveillance (BAMS) Unmanned Aircraft System (UAS) is an integral part. The purpose of this thesis is to identify and analyze the cost implications of the acquisition of the BAMS UAS for the Navy's Flying Hour Program (FHP) and the Operation and Maintenance, Navy (OMN) budget by

developing an Operations and Support (O&S) cost estimation methodology for the BAMS UAS. Additionally, this thesis analyzes some of the financial and support impacts of this weapon system within the context of the funding challenges the Navy will face in managing the FHP and OMN budget accounts in the near future.

Morrison, Richard B. *Fiducial Marker Detection and Pose Estimation from LIDAR Range Data*. M.S. in Modeling, Virtual Environments, and Simulation (MOVES). Monterey, California: Naval Postgraduate School, March 2010.
Thesis Co-Advisors: Mathias Kölsch and Timothy H. Chung
Outstanding Thesis Award
http://hdl.handle.net/10945/5411
http://handle.dtic.mil/100.2/ADA518637
Abstract: Light Detection and Ranging (LIDAR) systems are three dimensional (3D) imaging sensors applied for mapping terrain, measuring structural dimensions, and navigating robots. Pulsed laser rangefinders provide precise range measurements that require an estimate of sensor pose for transformation into world coordinates. Pose information is frequently provided with extrinsic sources such as Global Positioning System (GPS) or an Inertial Measurement Unit (IMU). Unreliable signal availability for GPS in military environments and the high cost of IMUs limit the employment of these extrinsic sources. Determining pose intrinsically by detecting landmarks in the environment within the sensor data is more ideal. Fiducial markers with known geometric dimensions and orientation provide a means of estimating LIDAR pose and registering data. Presented is a method for landmark detection and pose estimation within range data. Cylinder, cone, and sphere geometries are assessed for use as fiducial markers. The detection algorithm extracts geometric features from LIDAR point data and tests for fit to a fiducial marker model. Geometric feature extraction compresses the data set and leads to a potential intrinsic registration method using environment and marks. The detection accuracy and pose estimation precision are examined with terrestrial LIDAR range data captured in various outdoor street environments.

Muratore, Mark J. *Effective Teaming of Airborne and Ground Assets for Surveillance and Interdiction*. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2010.
Thesis Co-Advisors: Timothy H. Chung and Rachel T. Johnson
Second Reader: Chad W. Seagren
http://hdl.handle.net/10945/5267
http://handle.dtic.mil/100.2/ADA524744
Abstract: As Unmanned Aerial Vehicles (UAVs) become more prevalent on the battlefield, ground forces will have to increasingly rely on them for intelligence, surveillance, and reconnaissance (ISR), as well as target marking, and overwatch operations. The Situational Awareness for Surveillance and Interdiction Operations (SASIO) simulation analysis tool uses Design of Experiments (DOX) to study of aspects of UAV surveillance characteristics in conjunction with ground-based interdiction teams. The goal is to reduce the time required to intercept and capture targets of interest. Through screening analysis, significant factors can be determined to build a model that will provide a ground commander with insights to aid in the tactical employment of his assets. We will examine different teaming strategies and coordination measures between searching and interdicting assets in order to study the effectiveness of the interdictor possessing an organic, tracker UAV. The objective of this research is to quantify the benefit or penalty of an additional UAV asset that is organic to a quick reaction force, in the context of the overall surveillance and interdiction operation.

Quincy, Keith E., Jamarr J. Johnson, Michael G. Moran, Drew J. Nilsson, and Bradley G. Thompson, etal. ***An Integrated Command and Control Architecture Concept for Unmanned Systems in the Year of 2030***. Integrated Project Report NPS-SE-10-003 M.S. of Science in Systems Engineering. NPS-SE-10-003 Monterey, California: Naval Postgraduate School, June 2010.
Project Advisor: Gary Langford
http://hdl.handle.net/10945/5244

Abstract: U.S. Forces require an integrated Command and Control Architecture that enables operations of a dynamic mix of manned and unmanned systems. The level of autonomous behavior correlates to: 1) the amount of trust with the reporting vehicles, and 2) the multi-spectral perspective of the observations. The intent to illuminate the architectural issues for force protection in 2030 was based on a multi-phased analytical model of High Value Unit (HVU) defense. The results showed that autonomous unmanned aerial vehicles are required to defeat high-speed incoming missiles. To evaluate the level of autonomous behavior required for an integrated combat architecture, geometric distributions were modeled to determine force positioning, based on a scenario driven Detect-to-Engage timeline. Discrete event simulation was used to schedule operations, and a datalink budget assessment of communications to determine the critical failure paths in the the integrated combat architecture. The command and control principles used in the integrated combat architecture were based on Boyd's OODA (Obseve, Orient, Decide, and Act) Loop. A conservative fleet size estimate, given the uncertainties of the coverage overlap and radar detection range, a fleet size of 35 should be anticipated given an UAV detection range of 20km and radar coverage overlap of 4 seconds.

Stubblefield, Philip N. ***Security Enhancement of Littoral Combat Ship Class Utilizing an Autonomous Mustering and Pier Monitoring System***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, March 2010.
Thesis Co-Advisors: Rachel Goshorn and Deborah Goshorn
Second Reader: Mark Stevens
http://hdl.handle.net/10945/5418
http://handle.dtic.mil/100.2/ADA518711

Abstract: Littoral Combat Ships (LCS) are designed and built to have minimum crew sizes thus, while the ship is in port, there are fewer crewmembers to facilitate pier monitoring, security, and conducting mustering of personnel. The crew of LCS ships presently have too many responsibilities to ensure 100% coverage of the Pier area 100% of the time, and cannot manually maintain a real time muster of all ships personnel. This lack of coverage and situational awareness could make LCS ships vulnerable to terrorist attacks or terrorist monitoring. This thesis addresses the capability gap for complete and automated personnel mustering and situational awareness in the pier area for LCS class ships. Through applying the Systems Engineering process, the concept, external systems diagram, requirements, and functional architectures for a generic solution are proposed. The proposed solution is an autonomous system utilizing facial recognition software to maintain a muster of the ship's crew, while in parallel monitoring the pier area, looking for any known person of interest (e.g., terrorists) and providing appropriate alerts. Additionally, this thesis provides a demonstrable proof-of-concept prototype system solution, named Pier Watchman. Its instantiated physical architecture of a specific autonomous solution to pier monitoring and personnel mustering is provided.

Tozzi, Michael Jay. ***Development and Implementation of Low Cost Mobile Sensor Platforms within a Wireless Sensor Network***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2010.
Thesis Advisor: Rachel Goshorn
Second Reader: Duane Davis
http://hdl.handle.net/10945/5232
http://handle.dtic.mil/100.2/ADA531598

Abstract: Sensor networks are used throughout the government and industry for a wide variety of purposes. Mobile Sensor Platforms (MSPs), from surface combatant vessels to unmanned aerial vehicles, have been integrated into these sensor networks since their inception. Unmanned

MSPs currently used in sensor networks have two major drawbacks: They are extremely expensive and they require the control of a human operator. Remote controlled unmanned systems currently do not eliminate risk to personnel entirely, because they are typically too expensive to be considered expendable. If these standard unmanned systems are downed in a hostile environment, their recovery is often attempted by personnel on the ground; thus, still risking human lives. The military is exploring the use of low-cost unmanned MSPs to eliminate the need to risk personnel in their recovery. One of the greatest expenses in the life cycle of any system is operator cost. To reduce or eliminate operator cost, a platform must be autonomous. Though algorithms exist for adding autonomous capabilities to a mobile platform, such algorithms are typically designed for robust systems with a great deal of processing power. Low-cost systems are typically limited in capability by a low-processing power CPU. For this reason, small footprint alternatives to existing autonomous control algorithms must be developed to truly implement a low-cost MSP. This thesis applies the systems engineering process to developing a generic system solution for the need of a low-cost MSP, with concept of operations, external systems diagram, generic requirements, functional architecture and decompositions developed. The proposed generic system solution is then further designed in a scoped environment and implemented as a proof of concept prototype.

Vandenberg, Troy D. *Manning and Maintainability of a Submarine Unmanned Undersea Vehicle (UUV) Program: A Systems Engineering Case Study*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2010.
Thesis Advisor: Clifford Whitcomb
Second Reader: W.G. "Jerry" Ellis
http://hdl.handle.net/10945/5226;
http://handle.dtic.mil/100.2/ADA531594
Abstract: The purpose of this thesis is to study the manning and maintainability requirements of a submarine unmanned undersea vehicle (UUV) program. This case study reviews current commercial and military applications of UUVs and applies their principles to the missions of the Navy's submarine force. Past and current UUV efforts are lacking requirements documents and the formal systems engineering process necessary to produce a successful program of record. Therefore, they are not being funded for use by the war-fighter. The Navy must develop formal concepts of operations (CONOPS) for the missions and systems that it wants to produce and allow industry to begin development for a formal future UUV program. Furthermore, the military has developed countless unmanned systems that have been developed for use in the water, on the ground and in the air, from which the Navy can apply important lessons learned. Lastly, analysis suggests that the Navy should continue to support the use of a submarine detachment for operation and maintainability of future vehicle programs.

Williams, Edward O. *Surveillance and Interdiction Models : A Game-Theoretic Approach to Defend Against VBIEDS*. M.S. in Defense Analysis. Monterey, California: Naval Postgraduate School, June 2010.
Thesis Advisor: Timothy H. Chung
Second Reader: Frank Giordano
http://hdl.handle.net/10945/5329;
http://handle.dtic.mil/100.2/ADA524793
Abstract: This thesis develops a model for surveillance and interdiction operations by combining a tactical Unmanned Aerial Vehicle (UAV) to detect a threat with a ground force to interdict that threat. The scenario models the defense of a fixed facility such as a Forward Operating Base against an enemy attack in the form of a Vehicle Borne Improvised Explosive Device (VBIED). UAVs are increasingly more important in the military, and significant improvements in quantity and capability allow even tactical units to employ this tool, yet little research has been done on effective employment techniques at this level. Additionally, VBIEDs are a significant threat, but the primary counter-VBIED technique is simply hardened perimeter defenses, and little work has been done to detect and interdict a VBIED before it reaches the target. This research project addresses both deficiencies. Through spreadsheet and decision theory analysis, the factors that

impact UAV and ground force employment are examined and effective strategies to employ the two together are considered. Then through Game Theory, the strategic interactions between attack and defender are modeled to examine how changes in the conditions can impact the optimal strategy choices for each side.

Yeh, ShihYuan. ***Development of a Digital Tracking Array with Single-Channel RSNS and Monopulse Digital Beamforming***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2010.
Thesis Co-Advisors: David C. Jenn and Roberto Cristi
http://hdl.handle.net/10945/4956;
http://handle.dtic.mil/100.2/ADA536483
Abstract: Unmanned aerial vehicles (UAVs) are widely used in military applications, and one of the most common missions is remote sensing. Remote sensing requires UAVs equipped with different kinds of sensors. Information collected by remote sensors must be transmitted back to a ground control station (GCS) to conduct analysis. The majority of UAVs are controlled directly by GCS personnel using radio frequency (RF), line-of-sight (LOS) links. The ground antenna must acquire and then track the UAV signal. A digital phased array allows signal processing functions to be performed in the antenna processor as well as beamforming and tracking. The development of a digital tracking array with single-channel robust symmetrical number system (RSNS) and monopulse digital beamforming (DBF) to track a UAV's transmitted signal is described in this thesis. The RSNS is used as the direction finding (DF) algorithm and can provide high angle resolution with two closely spaced elements. However, as is typical for an array, the angle accuracy is reduced at the two ends of the field-of-view (FOV). The monopulse DBF is used to precisely track the signals. The monopulse tracking technique provides precise angle accuracy within a FOV of approximately ±45. The tracking system is developed in LabView, and the performance of a six-element prototype array is demonstrated by measurement in an anechoic chamber.

2009

Baravik, Keith Andrew. ***Object Localization and Ranging Using Stereo Vision for Use on Autonomous Ground Vehicles***. M.S. in Physics. Monterey, California: Naval Postgraduate School, June 2009.
Thesis Co-Advisor: Richard Harkins and Nancy Hagel
http://hdl.handle.net/10945/4701
http://handle.dtic.mil/100.2/ADA501221
Abstract: This thesis integrates stereo-vision into existing NPS robot architecture. It demonstrates that image cross correlation can be used to measure ranges as theory predicts. It also demonstrates that objects can be ranged and stored into a database map for later use as common reference points in position determination. Small Unmanned Ground Vehicles (UGV), developed using commercial-off-the-shelf (COTS) technologies are of particular interest for this robotic vision application. To perform their designated missions, these devices require accurate position information. Most devices will determine that position using a Global Positioning System (GPS) receiver; however, the signal is vulnerable to jamming and becomes degraded when not provided a clear view of the sky. Similarly, the error in dead reckoning (DR) systems increases with time if not reset using a known reference. The fusion of stereo vision technology with GPS and DR systems is ideal for use in the design of a command and control module of an unmanned vehicle that is capable of operating autonomously in an environment where traditional position determination loses satellite signals or requires a known reference point to reset uncertainty in position.

Beales, Brian O. ***F-22 Versus UCAV: Fixing Today's Deficiencies Leaves Questions about Tomorrow's Dominance***. M.A. in Security Studies (Homeland Security and Defense) Monterey, California: Naval Postgraduate School, December 2009.
Thesis Co-Advisors: Robert E. Looney and Robert M. McNab
http://hdl.handle.net/10945/4388
http://handle.dtic.mil/100.2/ADA514321
Abstract: This thesis evaluates the U.S. government's decision to end F-22 production and shift procurement focus toward firstgeneration Unmanned Combat Aerial Vehicles (UCAV). Over the last eight years since September 11, 2001, the U.S. military has been in a constant asymmetric battle with violent extremists. UCAVs, like the MQ-1 and MQ-9, have provided a persistent air power presence and have grown in popularity because of their low cost and versatility. At the same time, the F-22 has seen no direct combat action, and has been characterized by cost overruns and significantly overwhelming capabilities. The question becomes has this shift in procurement to solve irregular warfare deficiencies today introduced issues concerning tomorrows dominance for the USAF? The evaluation of this decision involves three subareas that provide a necessary foundation to answer the main research questions: the global defense-spending environment; analysis of manned versus unmanned flight including cost implications; and an aircraft effectiveness comparison across a broad threat spectrum. While it is apparent that UCAVs are less expensive and able to provide a persistent presence in today's threat environment, the decision to shut down production of the F- 22 decreases the USAF's ability to defend the Homeland against a full spectrum of potential threats.

Brown, Bronchae M. and Brian L. P. Schulz. ***The Effects of the Joint Multi-Mission Electro-Optical System on Littoral Maritime Intelligence, Surveillance, and Reconnaissance Operations***. M.S. in Information Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Douglas MacKinnon
Second Reader: Brian Wood
http://hdl.handle.net/10945/4638
http://handle.dtic.mil/100.2/ADA509154
Abstract: The United States Department of Defense finds itself in a period of reduced resources

and growing requirements. In the field of Intelligence, Surveillance, and Reconnaissance (ISR), there have been calls for both manpower and system cuts, while collection requirements continue to increase. One proposed method for maximizing ISR collection efforts is the development of multi-mission capable collection equipment. In support of this concept, BAE Systems has developed the Joint Multi-Mission Electro-optical System (JMMES). Designed for potential use on both manned and unmanned aircraft, JMMES is capable of multi-mission integration and target prosecution without the need to exchange system components or system operator, thus increasing flexibility, responsiveness, and capabilities, while reducing manning and cost requirements. JMMES incorporates multi-spectral technology and advanced search algorithms to enhance autonomous collection capabilities. Our thesis investigates how a JMMES equipped SH-60 variant aircraft affects U.S. ISR capabilities in the littoral regions, specifically in the areas of Anti Submarine Warfare (ASW), Surface Warfare (SUW), Maritime Interdiction Operations (MIO), and Search and Rescue (SAR). We teamed with the faculty research group in conducting JCTD test flights during Trident Warrior 2009. Utilizing both quantitative and qualitative results and analysis from the exercise flights and post-flight surveys, we developed an organizational simulation model, using VDT, to evaluate the benefits of JMMES.

Chua, Weng Heng. *Flow Visualization Studies Over a UCAV 1303 Model*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2009.
Thesis Advisor: M.S. Chandrasekhara
http://hdl.handle.net/10945/4757
http://handle.dtic.mil/100.2/ADA501642
Abstract: This study is a qualitative documentation of the main flow features that affect the aerodynamic performance under steady and unsteady maneuver conditions. The relevant fluid flow physics is not available presently and, hence, this thesis concentrated on generating those critical details. Towards this goal, model studies were conducted on the United States Air Force (USAF) geometry, described as same UCAV 1303, which is essentially a flying wing in the Naval Postgraduate School (NPS) water tunnel using dye-flow visualization technique. This study adapted the UCAV model 1303 for the NPS water tunnel by incorporating multiple ports for dye injection and was manufactured using rapid prototyping techniques. To obtain conditionally sampled flow images, especially for unsteady flow conditions, special phase locking circuitry was designed, fabricated and integrated with high resolution digital cameras and tunnel flow monitoring software. Flow visualization images at various Reynolds numbers, model attitudes and pitch rates were obtained. Strong vortical flow was observed as expected for a 47 degree delta-wing. The shallow sweep angle and tail-less geometry seemed to present some unusual aerodynamic characteristics in regard to vortex bursting.

Dobrydney, John F. *IPv6 Tactical Network Management*. M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Alex Bordetsky
Second Reader: Michael Clement
Outstanding Thesis Award
http://hdl.handle.net/10945/4574
http://handle.dtic.mil/100.2/ADA509120
Abstract: Current and emerging technologies and equipment, such as unmanned aerial vehicles, ground sensors, networked radios, operator-worn sensor vests, and nanotechnology applications offer warfighters unprecedented command and control and information detection capabilities, yet the use of this technology has not been fully realized. The current protocol, IPv4, is incapable of providing enough addresses due to a depletion of IPv4 address space. IPv6, however, offers unprecedented network support for tactical-level sensor and communications assets in terms of increased address space, Quality of Service (QoS), flexibility, and security. The Department of Defense is transitioning from IPv4 to IPv6 in order to capitalize on IPv6's expanded capabilities. However, one unresolved area is proper IPv6 network management. Currently, the majority of the configuration and operational knowledge is in the mind of a very few individuals. The expertise currently available must be developed for application by the tactical network manager

operating out on the edge of the network, in order to properly administer both an IPv4/IPv6 dual stacked network during the phased protocol transition and a purely native IPv6 network. Second, IPv6 features a robust Quality of Service (QoS) capability previously unavailable through IPv4, which requires research to determine the optimum configuration to support the warfighter's diverse requirements.

Erdemli, Mustafa Gokhan. ***General Use of UAS in EW Environment--EW Concepts and Tactics for Single or Multiple UAS Over the Net-Centric Battlefield***. M.S. in Electronic Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Co-Advisors: Edward Fisher and Wolfgang Baer
http://hdl.handle.net/10945/4512
http://handle.dtic.mil/100.2/ADA508909
Abstract: With the development of technology, Electronic Warfare has been increasing for decades its importance in modern battles. It can even be referred to as the heart of today's net-centric battlefield. Unmanned Aerial Systems are gaining more importance every single day. Nations are working on more complex and more effective UAS in order to accomplish missions that are very difficult, or even impossible for manned aircraft. Electronic Warfare missions are often dangerous and risky. Mounting Electronic Warfare equipment on a UAS and using it to conduct the EW mission is the most rational solution, since it does not endanger human life. This thesis will examine the possible ways in which UAS can be paired with EW equipment. These two technologies can be integrated into a single mission over the net-centric battlefield. Furthermore, this thesis will try to explain the concepts and tactics required to use these integrated technologies more effectively. At the end of the thesis, a scenario will be run to help the reader understand the applicability of these tactics in the real environment.

Featherstone, Ralph L. ***Determination of Critical Factors in Unmanned Casualty Evacuation in the Distributed Environment***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2009.
Thesis Advisor: Gary Horne
Second Reader: Segio Posadas
http://hdl.handle.net/10945/4718
http://handle.dtic.mil/100.2/ADA501188
Abstract: The current battlefield is changing rapidly. Combat operations against irregular forces are set in a dispersed, non-linear battlefield. Vast distances between small units such as the infantry squad, and the distances from these small elements to their supporting organizations, pose unique challenges. Casualty evacuation is an evolving challenge. The goal of casualty evacuation is to transport an injured Marine from the point of injury to a medical care facility. Increased dispersion results in longer distances from the point of injury to medical care facilities with a corresponding increase in the delay between the time of injury and lifesaving surgical care. The non-linear aspects of this battlefield increase the threat to aircraft crews and platforms conducting casualty evacuation Unmanned aerial systems offer an alternative means of air casualty evacuation. This alternative may provide time-critical response while reducing threat to aircraft crews. The thesis determined the probability distribution of mission completion times and identified the most influential factors on mission success.

Fitzpatrick, Christian R. ***Integration of Robotics and 3D Visualization to Modernize the Expeditionary Warfare Demonstrator (EWD)***. M.S. in Modeling, Virtual Environments, and Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2009.
Thesis Co-Advisors: Don Brutzman and Amela Sadagic
Outstanding Thesis Award
http://hdl.handle.net/10945/4520
http://handle.dtic.mil/100.2/ADA510015
Abstract: In the summer of 2008, the Commandant of the Marine Corps (CMC) released a message to all Marines and Sailors detailing plans to revitalize U.S. naval amphibious competency. Current responsibilities in Iraq and Afghanistan have significantly reduced available

training time causing overall amphibious readiness to suffer. In response, this thesis evaluates 3D visualization techniques and other virtual environment technologies available to support these mission-critical training goals. The focus of this research is to modernize the Expeditionary Warfare Demonstrator (EWD) located aboard Naval Amphibious Base (NAB) Little Creek, Virginia. The EWD has been used to demonstrate doctrine, tactics, and procedures for all phases of amphibious operations to large groups of Navy, Marine Corps, Joint, Coalition and civilian personnel for the last 55 years. However, it no longer reflects current doctrine and is therefore losing credibility and effectiveness. In its current configuration, the EWD is limited to a single training scenario since the display's ship models rely on a static pulley system to show movement and the terrain display ashore is fixed. To address these shortfalls, this thesis first recommends the usage of the wireless communication capability within Sun's Small Programmable Object Technology (SunSPOT) to create robotic vehicles to replace the current ship models. This enables large-group visualization and situational awareness of the numerous coordinated surface maneuvers needed to support Marines as they move from ship to shore. The second recommendation is to improve visualization ashore through the creation of Extensible 3D Graphics (X3D) scenes depicting high-fidelity 3D models and enhanced 3D terrain displays for any location. This thesis shows how to create these scenes and project them from overhead in order to modernize the gymnasium-sized EWD into an amphibious wargaming table suitable for both amphibious staff training and operational planning. Complimentary use of BASE-IT projection tables and digital 3D holography can further provide smallgroup, close-up views of key battlespace locations. It is now possible to upgrade an aging training tool by implementing the technologies recommended in this thesis to support the critical training and tactical needs of the integrated Navy and Marine Corps amphibious fighting force.

Francis, Michael R. ***DIDO Optimization of a Lunar Landing Trajectory with Respect to Autonomous Landing Hazard Avoidance Technology***. M.S. in Space Systems Operations. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Daniel W. Bursch
Second Reader: James H. Newman
http://hdl.handle.net/10945/4508
http://handle.dtic.mil/100.2/ADA508813
Abstract: In this study, the current and expected state of lunar landing technology is assessed. Contrasts are drawn between the technologies used during the Apollo era versus that which will be used in the next decade in an attempt to return to the lunar surface. In particular, one new technology, Autonomous Landing Hazard Avoidance Technology (ALHAT) and one new method, DIDO optimization, are identified and examined. An approach to creating a DIDO optimized lunar landing trajectory which incorporates the ALHAT system is put forth and results are presented. The main objectives of the study are to establish a baseline analysis for the ALHAT lunar landing problem, which can then be followed up with future research, as well as to evaluate DIDO as an optimization tool. Conclusions relating to ALHAT-imposed ConOps (Concept of Operations), sensor scanning methods and DIDO functionality are presented, along with suggested future areas of research.

Holland, Courtney L. ***Characterization of Robotic Tail Orientation as a Function of Platform Position for Surf-Zone Robots***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, June 2009.
Thesis Advisor: Richard HarkinS
Second Reader: Peter Crooker
http://hdl.handle.net/10945/4782
http://handle.dtic.mil/100.2/ADA502235
Abstract: The Naval Postgraduate School Small Robot Initiative is an ongoing effort to develop autonomous robotic platforms for military applications. The latest design in this series, a quadruped robot with a tail for stability and obstacle climbing, is currently under development in collaboration with Case Western Reserve University. Tail orientation as a function of robot platform attitude is tested for angle of bank climbs at 10 and 15 degrees. Data indicate that

although the platform induced noise is significant, tail orientation can be successfully managed with proper PID feedback mechanisms, including tail position as a function of platform attitude. Gross control of the tail used as an assist for climbing is validated in this experiment. More sophisticated filter algorithms are indicated for fine tuned tail control, including but not limited to the Kalman filter.

Hurd, William R. ***Application of Copper Indium Gallium Diselenide Photovoltaic Cells to Extend the Endurance and Capabilities of Unmanned Aerial Vehicles***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Sherif Michael
Second Reader: Todd Weatherford
http://hdl.handle.net/10945/4539
http://handle.dtic.mil/100.2/ADA508880
Abstract: In this thesis, we investigate the advantages of modifying current military Unmanned Aerial Vehicles (UAV) with available thinfilm photovoltaic (PV) cells to increase their endurance, and/or capabilities. The approach taken was to explore available off-theshelf flexible solar technology and to integrate it in a proof-of-concept model for testing and analysis. A physically similar commercially available battery-powered plane was used to demonstrate the materials and methods by which the RQ-11B (Raven) Small Unmanned Aerial Vehicle (SUAV) could be modified. This research extends academic and private pursuit of solar flight to near-term improvement of military SUAV. Besides increasing on-station time of reconnaissance assets, this research also displays the additional advantage of enabling systems on the ground to "self-charge." This will enable tactical units to operate further afield, untethered from conventional power sources. Beyond the proof-of-concept, findings are extended to other potential military uses and greater improvement through new or modified UAV design.

Hurni, Michael Anthony. ***An Information-Centric Approach to Autonomous Trajectory Planning Utilizing Optimal Control Techniques***. PhD. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Dissertation Supervisor: I.Michael Ross
http://hdl.handle.net/10945/10469
http://handle.dtic.mil/100.2/ADA509422
Abstract: This work introduces a new information-centric pseudospectral optimal controlbased algorithm for autonomous trajectory planning and control of unmanned ground vehicles with real-time information updates. It begins with a comprehensive study and comparison of the various path planning methods currently in use. It then provides an analysis of the optimal control method, including vehicle and obstacle modeling techniques, several different problem formulations, and a number of important insights on unmanned ground vehicle motion planning. The new algorithm is then utilized on a collection of motion planning scenarios with varying levels of information; the performance of the planner and the solution accuracies under these varying levels of information are studied for both single and multi-vehicle scenarios. The multi-vehicle scenarios compare and contrast centralized, decentralized, decoupled, coordinated, cooperative, and prioritized control methods. Finally, the versatility of the planner (and the optimal control technique) is demonstrated, as it is used as both a path follower and trajectory planner in a collection of scenarios, including multi-vehicle formations and sector keeping.

Lee, Han Chuan. ***Robustness of Control Laws Implemented in Visual Based Target Tracking System***. M.S. in Engineering Science (Mechanical Engineering). Monterey, California: Naval Postgraduate School, December 2009.
Thesis Co-Advisors: Issac I. Kaminer and Vladimir N. Dobrokhodov
http://hdl.handle.net/10945/4502
http://handle.dtic.mil/100.2/ADA514273
Abstract: The previously developed guidance law implemented onboard the Small Unmanned Aerial Vehicle (SUAV) relies exclusively on the information from the image processing software and allows the performance of coordinated SUAV guidance and vision-based target tracking and

motion estimation. This enables "passive only" coordinated tracking of noncooperative targets. An analysis of the system performance shows that the developed target tracking law demonstrates poor range holding capability when the target performs evasive maneuvers. Therefore, a new guidance law has been formulated by resolving SUAV dynamics with respect to the moving target frame, as opposed to the inertial frame in previous formulation. This simple modification results in theoretically achievable perfect range holding capability for the price of requiring the target motion information to be known. As a result, this new modification is based on the assumption of known target states, which in turn requires an implementation of a target motion estimator. An obvious tradeoff in performance of the "passive only" and "estimator based" target tracking systems is investigated in this thesis under realistic conditions including target loss events. This work extends previous results by investigating the performance of both guidance laws to the variation in target velocity and frequency of tracking loss events. The results obtained are based on the high fidelity 6DOF simulation implemented in SIMULINK, and analyzed using the multi-criteria optimization methodology introduced in the previous work. The results show that both guidance laws suffer predictable degradation in performance when subject to the external disturbances and tracking loss events. However, in the absence of tracking loss events, the new guidance law suffers less degradation in performance as compared to the old guidance law. When "frequency" of tracking loss events is low (less than 12%), the new guidance law is still able to provide better performance than the old guidance law As the "frequency" of tracking loss events increases further (between 12% to 25%), the performance of the new guidance law starts rapidly degrading, converging to that of the initial system; the target estimator is no longer able to provide a good prediction of the target velocity and heading to the guidance law.

Letourneau, Jon P. ***Incorporating Multi-Criteria Optimization and Uncertainty Analysis in the Model-Based Systems Engineering of an Autonomous Surface Craft***. M.S. in Systems Engineering and Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Co-Advisors: Cliff Whitcomb and Fotis Papoulias
Outstanding Thesis Award
http://hdl.handle.net/10945/4549
http://handle.dtic.mil/100.2/ADA509934
Abstract: This thesis presents an effective methodology and tool set, that explicitly considers technological uncertainty, to enable design, development, and assessment of alternative system concept architectures for an autonomous unmanned surface vessel (USV) in a system of systems (SoS) context. Complex system designs often fail due to poor communication of customer needs and inadequate understanding of the overall problem. This frequently results in the design team missing the mark in transforming requirements into a successful conceptual design. Effective system design requires a defined, flexible, and structured context within which new technological ideas can be judged. Alternative physical architectures are then modeled, simulated, and compared to find the "best" solution for further examination. This thesis uses model-based systems engineering (MBSE) principles to develop a multi-criteria decision making (MCDM) model that allows designers to perform a solution neutral investigation of possible alternative physical architecture concepts. This ensures a consistent quantitative evaluation of warfighting capability, suitability, effectiveness, technology maturation, and risk before and during a program execution. This effort is in support of an extended program to design a system of unmanned systems intended to provide the DoD with a coordinated, multi-domain, multi-mission, autonomous security and warfighting asset.

Lintz, William A. ***Radio Frequency Signal Reception Via Distributed Wirelessly Networked Sensors Under Random Motion***. PhD. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Disseration Supervisors: John McEachen and Murali Tummala
http://hdl.handle.net/10945/10472
http://handle.dtic.mil/100.2/ADA509303
Abstract: This research investigates the reception of radio frequency signals using wirelessly

networked autonomous sensor nodes under random motion. Emphasis is placed on investigating effects of random motion on sensor array beamforming. Novel techniques to conduct array operations in spite of the node motion are offered. Conflicting priorities of energy consumption and array operational requirements are addressed to demonstrate performance of the proposed solutions. The issues of node management in a beamforming application, degradation of beamforming performance due to element motion, the need for a weight reset time determination method, and the effect of unsteady element orientation in network communications are explored for system implementation. Examination of Doppler shift due to node motion demonstrated that its impact is negligible on beamforming performance. The management system proposed for the wireless sensor network enabled sensor operation while preserving node energy. Analysis of independent node motion on beamforming performance produced a relationship between motion and gain percent change on aim point. A novel methodology was offered to determine weight reset times with elements in motion. Investigation of unsteady antenna orientation produced an innovative method to mitigate communications degradation. Each proposal proved superior to alternate approaches in terms of performance and energy conservation.

Marsh, Christopher D. *Counter Piracy : A Repeated Game with Asymmetric Information*. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Kyle Y. Lin
Second Reader: Timothy H. Chung
http://hdl.handle.net/10945/4542
http://handle.dtic.mil/100.2/ADA508889
Abstract: This thesis presents a model of a counter-piracy operation, where a task force has one operational asset (a destroyer) and one reconnaissance asset (an unmanned aerial vehicle) to reduce piracy in a large region. The region is divided into small areas, and each day the pirates operate in one area to hijack commercial vessels to collect ransoms. The information is asymmetric to the two players. The pirates know which area is more profitable, but the task force does not. The task force can use the operational asset to prevent piracy, and the reconnaissance asset to collect information on the profitability of each area. The pirates want to maximize their income over a thirty-day period, while the task force wants to minimize it. The numerical experiments quantify the value of the operational asset and the reconnaissance asset in this counter-piracy operation.

McBride, Marlon and Mustafa Masacioglu. *Control Based Mobile Ad Hoc Networking for Survivable, Dynamic, Mobile Special Operation Force Communications*. M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Alex Bordetsky
Second Reader: Michael Clement
http://hdl.handle.net/10945/4592
http://handle.dtic.mil/100.2/ADA508885
Abstract: In the next generation of wireless communication systems, there will be a need for the rapid deployment of independent mobile users. Significant examples include establishing survivable, efficient, dynamic mobile communication for tactical Special Operation Force (SOF) networks, as well as SOF units that are ad hoc networking with first responders conducting emergency/rescue and disaster relief operations. Such network scenarios cannot rely on centralized and organized connectivity, and should instead employ applications of newly developing Control Based Mobile Ad Hoc Networking (CBMANET). In a CBMANET environment, an autonomous collection of mobile users communicate over relatively bandwidth constrained wireless links by taking benefit of nodes mobility and topology control in combination with mobile platform switching. The network is decentralized. All network activity, including discovering the topology and delivering messages, must be executed by the nodes themselves (i.e., routing functionality will be incorporated into mobile nodes). Harnessing the tremendous flexibility and efficiency of CBMANET would allow for better control and protection of ad hoc mobile networks.

Therefore, we need to work tirelessly to improve our capabilities in the three aforementioned control spaces.

McChesney, Nevin A. ***Three-Dimensional Feature Reconstruction with Dual Forward Looking Sonars for Unmanned Underwater Vehicle Navigation***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, March 2009.
Thesis Co-Advisors: Doug Horner and Roberto Cristi
Outstanding Thesis Award
http://hdl.handle.net/10945/4788
http://handle.dtic.mil/100.2/ADA496699

Abstract: Unmanned Underwater Vehicles frequently rely on two-dimensional sensors for information about their surroundings. These sensors do not provide adequate information for obstacle avoidance in cluttered maritime environments. To address that issue, a threedimensional reconstruction of the environment utilizing occupancy grids and a prototype forward looking sonar will be considered. Providing the vehicle with three-dimensional views of the environment will allow for optimal route planning and an increase in successful missions in complex environments.

McGrew, Timothy M. ***Army Aviation Addressing Battlefield Anomalies in Real Time with the Teaming and Collaboration of Manned and Unmanned Aircraft***. M.S. in Defense Analysis. Monterey, California: Naval Postgraduate School, December 2009.
Thesis Advisor: Alex Bordetsky
Second Reader: Brian Greenshields
http://hdl.handle.net/10945/4485
http://handle.dtic.mil/100.2/ADA514384

Abstract: This thesis focuses on determining the effectiveness of a new and innovative concept or Tactic, Technique and Procedure (TTP) for army aviation by teaming Manned and Unmanned (M/UM) aircraft in the conduct of Reconnaissance, Surveillance, and Target Acquisition (RSTA) operations in the Contemporary Operating Environment (COE). M/UM aircraft teaming is described, as well as the evolution of the Unmanned Aerial Vehicle (UAV) and the technology applications they bring to bear. M/UM aircraft teaming as a TTP is examined in two case studies: (1) The 25th Combat Aviation Brigade's (CAB) use of the TTP during a 15-month deployment to MND-N during OIF 06-08, and (2) The Battle of Sadr City, March-April 2008, in which a highly successful large, joint and combined arms operation was conducted. A series of experiments conducted at Camp Roberts, CA by the NPS-lead CENETIX team is reviewed that investigated using M/UM aircraft teaming and collaboration in the ad-hoc mesh networking environment. This thesis also describes a game theory model for M/UM aircraft teaming in the conduct of Counter-IED operations.

McGuire, Michael. ***The Integration of the Naval Unmanned Combat Aerial System (N-UCAS) into the Future Naval Air Wing***. Masters in Business Administration. Monterey, California: Naval Postgraduate School, December 2009.
Thesis Co-Advisors: John Mutty and Daniel Nussbaum
http://hdl.handle.net/10945/4484
http://handle.dtic.mil/100.2/ADA514238

Abstract: This MBA Project investigates the use of unmanned vehicles, specifically the Navy-Unmanned Combat Air System (N-UCAS), which can be employed and deployed in novel ways to gain access in the access denied surface domain due to the proliferation of anti-ship ballistic missiles. The capabilities of N-UCAS, coupled with a new employment/deployment model, have the potential to allow the Navy to maintain the forecasted capacity of the future power projection fleet while reducing the number of carriers. The savings from the reduction in the carrier fleet could allow smaller crafts, such as the Joint High Speed Vessel (HSV) and the Littoral Combat Ship (LCS), to be procured in larger numbers to aid in the shortfalls that the current Naval Force has in Maritime Security and Cooperative Engagement (MSCE) capacity.

McLain, Brian K. ***Steady and Unsteady Aerodynamic Flow Studies Over a 1303 UCAV Configuration***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: M.S. Chandrasekhara
Second Reader: G.V. Hobson
Outstanding Thesis Award
http://hdl.handle.net/10945/4589
http://handle.dtic.mil/100.2/ADA509242

Abstract: This study generated new information through qualitative documentation of the main flow features and direct measurements of the aerodynamic performance of a tailless, unmanned combat air vehicle (UCAV) 1303 configuration under both steady and unsteady maneuvering conditions. Photographic evidence of flow features, measurements of large-scale flow effects, and that of forces and aerodynamic coefficients during static and dynamic pitch, roll and yaw maneuvers were obtained. Flow visualization images and force measurements were taken at various Reynolds numbers, model attitudes and pitch rates for comparison. A 1/72nd-scale model with a 47-degree leading edge sweep and a cranked trailing edge delta wing with a fuselage was investigated in the NPS water tunnel. Phase locked, high-resolution flow images were obtained using a five color dye injection system over the maneuvering model. Both static and dynamic pitch-up, roll and yaw maneuvers were considered. Additionally, a five-component strain gage and flow monitoring software were employed to record, in real time, yawing, pitching and rolling moment information and derive the aerodynamic force and moment coefficients for selected maneuver conditions. Flow visualization revealed the presence of a strong spanwise flow at low angles of attack and strong vortical flow structures at larger angles of attack, as can be expected, but not clearly established earlier, for such low sweep angle wings. It also indicated that the vortical structures and reverse flow were highly Reynolds-number dependent. Normal force and pitching moment load data correlated well with trends observed for low sweep angle delta wings, but unexpected side force, yawing moment and rolling moment variations were observed, which were attributable to asymmetrical vortical flow behavior on the tailless UCAV geometry.

Miranda, Ricardo E. ***Development of a Nonlinear 6-Degree of Freedom Miniature Rotary-Wing Unmanned Aerial Vehicle Software Model and PID Flight Path Controller using Mathworks Simulink Simulation Environment***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Robert G. HutchinS
Co-Advisors: Vladimir Dobrokhodov and Ioannis Kitsios
http://hdl.handle.net/10945/4586
http://handle.dtic.mil/100.2/ADA509244

Abstract: This paper describes the development of a 6-degree of freedom (6-DOF), nonlinear, miniature rotary-wing unmanned aerial vehicle (RW UAV) simulation environment using MathWorks Simulink simulation software. In addition to the modeling process, this research also conducts flight-path controller design using Proportional-Derivative (PD) control techniques. This model's development is motivated by the desire to enable a rapid prototyping platform for design and implementation of various flight control techniques with further seamless transition to the hardware in the loop (HIL) and flight-testing. The T-Rex Align 600 remote controlled helicopter with COTS autopilot was chosen as a prototype rotary UAV platform. The development of the nonlinear simulation model is implemented starting with extensive literature review of helicopter aerodynamics and flight dynamics theory and applying the mathematical models of the helicopter components to generate helicopter inertial frame motion simulations from operator commands. The primary helicopter components modeled in this thesis include the helicopter main rotor inflow, thrust, flapping dynamics, as well as the tail rotor inflow and thrust responses. The inertial frame motions are animated using the Flight Gear Version 0.9.8 software. After obtaining simulations with verifiable results, the nonlinear model is linearized about the hovering flight condition and a linear model is extracted. Lastly, the PD controller is designed and flight path software in the loop (SIL) test results are presented and explained. The SIL tests are conducted for autonomous flight along specified rectangular and figure-8 flight paths.

Raymer, Michael K. *A Comparative Analysis of the Army MQ-8B Fire Scout Vertical Takeoff Unmanned Aerial Vehicle (VTUAV) and Navy MQ-8B Manpower & Training Requirements*. M.S. in Management. Monterey, California: Naval Postgraduate School, March 2009.
Thesis Co-Advisors: Bill Hatch and Cary Simon
http://hdl.handle.net/10945/10460
http://handle.dtic.mil/100.2/ADA497197
Abstract: The recent increased urgency to combat terrorism and asymmetric threats, combined with the environment in which field troops are forced to operate has created a unique demand for non-standard war fighting capabilities. Beginning in 2004, the U.S. Navy, in a joint effort with the U.S. Army, began jointly testing and evaluating the Northrop Grumman MQ-8B Fire Scout Vertical Take Off Unmanned Aerial Vehicle (VTUAV). This platform has shown very promising early results in testing and is slated for implementation on the Navy's newest Littoral Combat Ship (LCS). A manpower analysis of the Fire Scout MQ-8B was conducted to identify requirements applicable to operating the platform aboard LCS. Current Army MQ-8B manning was described and used to compute a baseline model determining best mix of manpower requirements needed to implement Fire Scout at sea. Accurate identification of manpower requirements and training for Fire Scout operators, technicians and support personnel will eventually diminish reliance on civilian contractors, and provide the opportunity for joint military operability. The Army MQ-8B Fire Scout training program was analyzed to compare the suitability and feasibility of Navy training for operators and technicians. Currently, there is no Navy training program in place to train Fire Scout operators and technicians to support LCS.

Richard, Mark G. *Cooperative Control of Distributed Autonomous Systems with Applications to Wireless Sensor Networks*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2009.
Thesis Co-Advisors: Deok Jin Lee and Isaac I. Kaminer
http://hdl.handle.net/10945/4742;
http://handle.dtic.mil/100.2/ADA501360
Abstract: This thesis extends previously developed self-tuning adaptive control algorithms to be applied to a scenario where multiple vehicles autonomously form a communication chain which maximizes the bandwidth of a wireless sensor network. In the simulated scenario, multiple unmanned aerial vehicles are guided to positions that optimize communication links between multiple ground antennas. Guidance is provided by a self-tuning extremum controller, which uses adaptive techniques to autonomously guide a vehicle to the optimal location with respect to a cost function in an uncertain and noisy environment. In the case of high-bandwidth communication, this optimal location is the point where signal-to-noise ratio is maximized between two antennas. Using UAVs as relay nodes, an optimized communication chain allows for greater communication range and bandwidth across a network. Control system models are developed and tested using computer and hardware-in-the-loop simulations, which will be validated with a flight test at a future date.

Rozen, Nir. *Sensor Interceptor Operational Policy Optimization for Maritime Interdiction Missions*. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, December 2009.
Thesis Advisor: Johannes O. Royset
Second Reader: Moshe Kress
Outstanding Thesis Award
http://hdl.handle.net/10945/4370
http://handle.dtic.mil/100.2/ADA514426
Abstract: Maritime Interdiction Missions (MIM) are of great interest and high operational importance to the U.S. Navy, the U.S. Coast Guard, and allied forces. The MIM scenario discussed in this thesis includes an area of interest with multiple neutral and hostile vessels moving through this area, and an interdiction force consisting of an unmanned aerial vehicle (UAV) and an intercepting vessel, whose objectives are to search, identify, and intercept hostile vessels within

a given time frame. In this thesis, we develop Stochastic Dynamic Programming models, which represent the MIM scenario. While a theoretical method of producing an optimal decision policy for the interdiction force is presented in this thesis, it is shown that such computation is intractable. The models developed in this study are used to analyze and evaluate the performance of a heuristic decision policy that we recommend to be applied by the interdiction force. Based on a numerical case study, which includes several representative MIM scenarios, we show that the number of intercepted hostile vessels following the heuristic decision policy is at least 60% of the number of hostile vessels intercepted following the optimal decision policy. Based on the results of the heuristic performance in the numerical case studies, we recommend the implementation of our suggested heuristic in an operational decision aid for Maritime Interdiction Missions.

Tan, I-Hsiang Leslie and Devieash James Pandya. ***UAV Digital Tracking Array Design, Development and Testing.*** M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2009.
Thesis Advisor: David C. Jenn
Second Reader: Phillip E. Pace
http://hdl.handle.net/10945/4352
http://handle.dtic.mil/100.2/ADA514423
Abstract: This thesis carried out the design and development of an integrated array and receiver processor that utilizes advanced techniques of Robust Symmetric Numeric System (RSNS) and monopulse Digital Beamforming (DBF) to accurately track a UAV using commercial-off-the-shelf (COTS) equipment. This was based on previous work done using virtual spacing RSNS and digital beamforming to extend the method to a functional six element array with direction finding and tracking capability. The six element antenna array and direct-conversion receiver were developed and tested to retrieve a FM-modulated video signal encoded using the NTSC format. This thesis addresses system-evel design tradeoffs, as well as hardware and software design, development and testing. A bench top test was conducted to test the functionality of the NTSC decoding and FM software modules developed and a comprehensive test was done in an anechoic chamber to characterize the array's capability in DF using RSNS and monopulse DBF.

Thompson, Scott R. ***Displacement of Tethered Hydro-Acoustic Modems by Uniform Horizontal Currents***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2009.
Thesis Co-Advisors: Fotis Papoulias and Joseph Rice
Outstanding Thesis Award
http://hdl.handle.net/10945/4316
http://handle.dtic.mil/100.2/ADA514338
Abstract: Undersea sensors often include an acoustic modem buoyed above a seabed mooring or suspended beneath a surface buoy. In both cases, a vertical cable is subjected to horizontal water currents. This theses examines the two cases, the first characterized by a cable moored to the bottom of the ocean with a buoyant end, and the second being a cable suspended or towed from a surface buoy or Unmanned Surface Vehicle (USV) with a weighted end. The equations of motion are similar, as both cases have an object affixed to the free end of the cable and the other end fixed to a stable point. A physics-based algorithm in MATLAB models the effects of drag and buoyancy on the cable and predicts the steady-state shape of the cable.

Tsai, Yen-Chang. ***Development of the Phase Synchronization Circuit for Wirelessly Distributed Digital Phased Array***. M.S. in Electronic Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: David C. Jenn
Second Readers: Robert D. Broadston and Jiheon Ryu
http://hdl.handle.net/10945/4611
http://handle.dtic.mil/100.2/ADA509254
Abstract: The Wirelessly Distributed Digital Phased Array (WDDPA) is an ongoing research

program at the Naval Postgraduate School (NPS) which has numerous possible applications in radar and communication systems. The WDDPA incorporates many array elements randomly or nonuniformly in the environment or on a platform. Array elements are synchronized and controlled over a wireless channel. Compared to conventional phased array systems, its advantages are adaptability, survivability and flexibility. Phase synchronization is a critical component of the WDDPA development. The common phase reference is vital to steer the beam and control the radiation pattern for the phased array system. The objective of this paper is to improve the WDDPA synchronization operation. Previous hardware and software architectures were replaced or modified to improve the accuracy and speed of the phase synchronization. A series of experiments, first for hardwired channels, then for wireless channels, were conducted successfully to verify the synchronization operation for two elements. Several problems with the circuit were diagnosed and then addressed. The overall performance of the improved synchronization circuit for the demonstration array was satisfactory, allowing phases to be synchronized within 20° wirelessly. The architecture for the potential successor of the synchronization circuit is introduced. It is more flexible and robust than the current circuit and thus more desirable for future applications of the WDDPA.

Valle, Antonio. ***Feasibility of Developing Academic Laboratories using a Low-Cost Robot***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2009.
Thesis Advisor: Xiaoping Yun and Alexnader Julian
http://hdl.handle.net/10945/4599
http://handle.dtic.mil/100.2/ADA509252
Abstract: The objective of this research was to investigate the feasibility of developing new academic laboratories for an introductory robotics course at the Naval Postgraduate School (NPS) using low-cost commercially-available robots. In particular, this research used a desktop computer with Fedora 8 Linux operating system, a wireless network and the Garcia robot from Acroname Incorporated. The Garcia robot is a wheeled robot that has many onboard devices, such as encoders, infrared sensors, and a laser range finder with the capability of further expansion. The investigation of the feasibility of developing laboratories using a low-cost commercially-available robot yielded mixed results. The positive results were that a lowcost robot, the Garcia, was found to be a flexible and powerful academic tool. The Garcia robot allowed for the development and implementation of a collection of laboratories to ensure that basic robotic functions are understood. The drawbacks were that the Garcia robot was difficult to start due to the lack of proper documentation. Also, the selected host configuration limited the Garcia's performance because the configuration injected an initial latency of 15 to 20 seconds. The latency was noted when communicating with the robot and the laser simultaneously.

Whiteman, Shannon J. ***Improving Situational Awareness in the Counter-IED Fight with the Utilization of Unmanned Sensor Systems***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, June 2009.
Thesis Advisor: Eugene Paulo
Second Reader: Mark Rhoades
http://hdl.handle.net/10945/4668
http://handle.dtic.mil/100.2/ADA501551
Abstract: An organized and thorough systems design framework is necessary to successfully address large-scale, complex problems, such as the utilization of unmanned sensor technologies to provide situational awareness (SA) in the counter-improvised explosive device (C-IED) fight. An appropriate systems engineering design process was used to develop such a framework, as the completion of the first two phases - problem definition and solution design - provides a basis for analysis of alternatives and a design recommendation. This process generated the following problem statement: Design a system that, through the use of unmanned sensors, provides effective and efficient SA to the commander in a C-IED scenario. By effective, the system must maximize the ability to process sensor imagery and detect, classify, identify, and counter IEDs. To be efficient, the system must address important characteristics of operational suitability and survivability. Thus, providing SA, maximizing operational suitability, and maximizing Soldier

survivability are the primary objectives in the effective and efficient employment of unmanned sensors in C-IED. Three physical alternatives were generated and synthesized: baseline, near-term, and long-term. Each alternative consisted of a combination of sensors, satellites, and unmanned systems to ensure that the top-level SA functions are addressed. Each alternative's basic specifications, battlefield flow (highlighting each unmanned sensor's use for observe, process information, and understanding the environment), and drawbacks are addressed.

Yildiz, Bahri. ***Exploration of the Use of Unmanned Aerial Vehicles Along with Other Assets to Enhance Border Protection***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2009.
Thesis Advisor: Gary E. Horne
Second Reader: Thomas Anderson
http://hdl.handle.net/10945/4671
http://handle.dtic.mil/100.2/ADA501385
Abstract: Border protection is a vital national security issue for most countries. The U.S. Customs and Border Protection (CBP) is responsible for protecting the borders of the U.S. from terrorism, human and drug smuggling and illegal migration. The U.S. CBP improves manpower, technology and infrastructure along the border through various projects. In this study, part of the Tucson sector in Arizona is modeled in an agent-based model (MANA) to explore the effects of using a hand-launched, mini Unmanned Aerial Vehicle (miniUAV) along with other assets, such as Border Patrol (BP) agents, surveillance towers, the Predator B, seismic sensors and communication centers. The results from the runs of different scenarios, created by a Nearly-Orthogonal Latin Hypercube (NOLH) design, are analyzed using comparison tests, linear regression, and regression trees. As a result, the use of miniUAVs is found to be beneficial in capturing the illegal entrants in this analysis and thus could potentially provide more secure borders. Adequate manpower, in this case BP agents, and a reliable communication web to compose a Common Operational Picture (COP) emerge as the most important factors regarding border protection in this analysis.

2008

Abbott, Benjamin P. ***Littoral Combat Ship (LCS) Mission Packages : Determining the Best Mix***.
M.S. in Operations Research. Monterey, California: Naval Postgraduate School, March 2008.
Co-Advisors: Thomas W. Lucas and Jeffrey Kline
Second Reader: Michael R. Good
Outstanding Thesis Award
http://hdl.handle.net/10945/4291
http://handle.dtic.mil/100.2/ADA479783

Abstract: The threat of a large fleet engagement in the open ocean is currently over shadowed by the asymmetric challenges presented by state and non-state actors using the littorals for illicit purposes. Unlike traditional multi-mission combatants, the Littoral Combat Ship (LCS) is a focused mission platform significantly less capable of handling simultaneous missions, whether they are planned or not. However, when deploying LCS as a squadron, a Combatant Commander may select to equip multiple LCS platforms with a mix of focused mission packages to ensure operational success across the broad range of challenges associated with littoral warfare. Through the use of simulation, design of experiments, and data analysis, this thesis simulated 41,195 littoral operations to address how many LCS should comprise an employed squadron, what the composition of a squadron should be, and how sensors and weapon systems contribute to the effectiveness of an employed squadron. The results indicate that a squadron size of six to ten LCS produces the best results, and that a compositional rule of thumb of five LCS for the primary threat and two LCS for the secondary threat applies to each warfare area. Lastly, the number of casualties suffered in each warfare area reinforces the danger associated with littoral combat and serves as a reminder that close engagement, while necessary, carries a cost.

Addison II, William F. ***Autonomous Underway Replenishment at Sea for Riverine Operations***.
M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2008.
Thesis Advisors: Fotis Papoulias and Oleg Yakimenko
http://hdl.handle.net/10945/4278
http://handle.dtic.mil/100.2/ADA479664

Abstract: Currently the United States Navy is making a small footprint in the world's littoral regions with the help of the United States Marine Corps. In Iraq, the Marine Corps is actively conducting Riverine operations, however they are overly tasked and in need of permanent replacement by the United States Navy. In order to alleviate the Marine Corps, the Naval Expeditionary Combat Command with its Riverine Squadrons will soon take over these Riverine operational commitments in order to reestablish supremacy throughout the Riverine environment. With this in mind, the Chief of Naval Operations, Center for Naval Analyses requirements, System Engineering Analysis (SEA- 11) class of 2007 developed a concept of operations (CONOPS) which the Total Ships System Engineering (TSSE) class of 2007 used to develop a prototype platform, which met all initial design requirements. In order to take full advantage of this prototype platform, every effort was taken in order to minimize the number of crew members on station at any given time. The purpose of this thesis is to demonstrate the use of the direct method, which will allow the Specialized Command and Control Craft (SCCC) to conduct a fully autonomous Underway Replenishment at Sea (UNREP) with a standard supply vessel. The direct method approach allows for a smooth path is created instead of using waypoint navigation. Additionally, this method allows for real-time updates at (1Hz).

Agpaoa, Roy; Cawley, Matthew; Cossey, Chad; Galvan, Jose; Giang, Alan; Hanchinamani, Joseph; Ikeda, Jeffrey; Kenney, John; Magnusson, Lance; Martinez, Christopher; Newberry, Mike; Raymond, Eldridge; Rykala, John; Watts, Jason; Wood, Micheal. ***Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission Capability*** : *By Keyport MSSE Cohort*. NPS-SE-08-003. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, June 2008.
Project Advisors: E.P. Paulo and M.M. Rhoades
http://hdl.handle.net/10945/6935
http://handle.dtic.mil/100.2/ADA483334
Abstract: The Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission Module project applies established systems engineering principles and processes to the design of an ASW payload module that examines the capability of the HAMR to perform persistent ASW mission support. Critical system functions and objectives are identified and are assigned appropriate quantitative metrics. Additionally, three alternative architectures are generated and evaluated using the appropriate metrics based on results from modeling using Naval Systems Simulation (NSS). Manning is considered as a key stakeholder parameter and is included as an evaluation concern. The alternatives are also compared through the examination of life cycle costs. The recommendation to the stakeholders based on the research and results is an unmanned ASW sensor platform that uses other ASW assets for prosecution.

Alver, Yücel and Murat Özdoğan. ***Mission Assignment Model and Simulation Tool for Different Types of Unmanned Aerial Vehicles***. M.S. in Modeling, Virtual Environments, and Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2008.
Thesis Advisor: Arnold Buss
Second Reader: Enver Yücesan
http://hdl.handle.net/10945/3929
http://handle.dtic.mil/100.2/ADA488782
Abstract: The use of unmanned aerial vehicles on the battlefield becomes more and more important every day. Parallel to this growing demand, there is a need for robust algorithms to solve the mission assignment problem in an optimum way. There are several tools for solving the assignment problem and testing the results to evaluate the robustness of the proposed algorithm. For most of the models, input factors are limited to the most important ones to make the process simpler. The aim of this thesis is to create an optimal solution for the assignment problem and test its robustness with a stochastic simulation tool. To accomplish the goals more factors, such as ground abort rates of the UAVs and the area weather risk levels are added. These factors, which were typically excluded from previous studies, are incorporated to make the model more realistic. The analysis and the results proved that the assignment algorithm works well and creates plausible results.

Cascio, Joseph A. ***Optimal Path Planning for Multi-Arm, Multi-Link Robotic Manipulators***. M.S. Astronautical Engineering. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Advisor: I.M. Ross
Second Reader: A.D. Scott
http://hdl.handle.net/10945/3687
http://handle.dtic.mil/100.2/ADA547109
Abstract: This work investigates the problem of robotic arm control with the goal of achieving given performance requirements by solving for the optimal joint trajectories and corresponding controls for tasks, such as point-to-point positioning. The resulting optimal control problem is highly nonlinear and constrained due to the nonlinearities in the robotic arm dynamics and kinodynamic constraints including limits on joint velocities and actuator torques. This thesis illustrates the applicability of pseudospectral methods to solve the optimal path planning problem for a system of multi-link, multi-degree of freedom robotic arms. The optimal control problem is defined in standard form and solved using the software package DIDO. Pontryagin's Minimum Principle is used to verify that the proposed solution satisfies the necessary conditions for optimality. A particularly challenging aspect that is explored is the optimal motion of multiple

arms conducting independent tasks with the risk of collision. Collision avoidance can be achieved by modeling appropriate path constraints. The processes for optimal trajectory planning are developed for a single two degree-of-freedom manipulator conducting point-to-point positioning and extended to include dual three degree-of-freedom manipulator maneuvers employing collision avoidance. The results demonstrate the suitability of pseudospectral techniques to solving the minimum time and minimum control maneuvers for robotic arms. The employment of collision avoidance techniques will facilitate continued research in autonomous robotic motion planning using optimal control criteria in multiple arm systems.

Chua, Choon Seong. ***Generic UAV Modeling to Obtain Its Aerodynamic and Control Derivatives***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Co-Advisors: Anthony J. Healey and Oleg A. Yakimenko
http://hdl.handle.net/10945/3817
http://handle.dtic.mil/100.2/ADA493999
Abstract: This thesis deals with two different software packages to obtain the aerodynamic and control derivatives for a generic unmanned air vehicle (UAV). These data has a dual application. Firstly, it is required in the Mathworks' Simulink 6-degree-of-freedom model of a generic unmanned air vehicle to develop a robust controller and do a variety of trade-offs. Secondly, is also needed to tune the parameters of the existing real-time controllers such as a Piccolo autopilot. The first approach explored in this thesis involves using the LinAir software program developed about a decade ago at Stanford University, the second one relies on the Athena Vortex Lattice package developed at Massachusetts Institute of Technology. The thesis applies two aforementioned packages to generate the aerodynamic data for two different-size UAVs, SIG Rascal and Thorpe Seeop P10B, emphasizing advantages and pitfalls of each approach, and further compares the obtained data with that of some other UAVs such as BAI Aerosystems Tern and Advanced Ceramics Corp. Silver Fox. The thesis ends with some computer simulations based on the obtained aerodynamic data.

Clem, Doyne Damian. ***Logistically-Constrained Asset Scheduling in Maritime Security Operations***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2008.
Thesis Advisor: Johannes O. Royset
Second Reader: W. Matthew Carlyle
http://hdl.handle.net/10945/3938
http://handle.dtic.mil/100.2/ADA488619
Abstract: Operational commanders and planners are challenged with maintaining fleet presence in many environments with limited resources. To add to this challenge, there are further constraints placed upon assets allocated to a given operational commander such as replenishments at sea, multinational exercises, diplomatic port visits, and predetermined in-chop and out-chop dates. In the case of the Combined Maritime Force (CMF), which operates in the FIFTH FLEET Area of Responsibility, these constraints are further magnified by the fact that ships under his or her operational command are from as many as ten different coalition nations at any given time. Furthermore, command of the CMF rotates between these coalition nations, increasing the propensity for inconsistent and sub-optimal resource allocation. This thesis develops a scheduling tool, Coalition Resource Allocation for Maritime Security (C-RAMS), that is capable of quickly producing a schedule that optimizes a given measure of effectiveness for assets assigned to the CMF. This C-RAMS tool accounts for logistics requirements and allows a commander to set priorities within various sub-regions, types of assets, and specific time periods. We illustrate how C-RAMS provides such an optimal schedule and also provides insights into interactions between different priorities and ship types, including those which may be interpolated for future force configurations, through the use of Visual Basic with an Excel 2003 user interface.

Collier, Corey M. and Jeffrey C. Kacala. ***A Cost-Effectiveness Analysis of Tactical Satellites, High-Altitude Long-Endurance Airships, and High and Medium Altitude Unmanned Aerial Systems for ISR and Communication Missions***. M.S. in Space Systems Operations. Monterey, California: Naval Postgraduate School, September 2008.
Thesis Advisor: William J. Welch
Second Reader: Charles M. Racoosin
http://hdl.handle.net/10945/3934
http://handle.dtic.mil/100.2/ADA488904

Abstract: Before 1991, the United States military's demand for additional communications bandwidth and timely intelligence was rising rapidly. Since then, with the advent of the Global War on Terrorism, it has increased substantially. To address this growing need, the Department of Defense has focused its acquisition and procurement efforts on obtaining new communications and intelligence, surveillance, and reconnaissance (ISR) platforms that can help lessen shortfalls and possibly exploit new, untapped resources. Recently, there has been an increasing focus on new technology, such as tactical satellites or high-altitude long-endurance airships, as a way to increase communications and intelligence collection capacities. Likewise, advances in the capabilities of medium-altitude and high-altitude unmanned aerial systems have resulted in a more prominent role for them on today's battlefield. Each of these vehicles has a unique niche in today's military, but the increasing capabilities of each are beginning to create some overlap in their uses. This study will conduct a cost-effectiveness analysis on these systems for use as a persistent communications and ISR platform. In particular, it will measure the effectiveness of each for comparison, and will offer possibilities to increase the overall effective use of the three together to maximize performance and cost.

Demirel, Ibrahim. ***Aircraft Pilot Situational Awareness Interface for Airborne Operation of Network Controlled Unmanned Systems (US).*** M.S. in Information Technology Management . Monterey, California: Naval Postgraduate School, March 2008.
Thesis Co-Advisor: Alex Bordetsky and Eugene Bourakov
http://hdl.handle.net/10945/4250
http://handle.dtic.mil/100.2/ADA479681

Abstract: This thesis research is focused on Network Centric Operations with Unmanned Systems (US). It specifically focuses on the currently underdeveloped area of aircraft pilot decision support for operating USs, including Unmanned Aerial Vehicles (UAV), Unmanned Ground Vehicles (UGV) and Unmanned Surface Vehicles (USV), over the network from the board of an aircraft. Building on Landreth and Glass's thesis on controlling UAV over the network, including from another manned aircraft, this thesis aims to ease implementation and usage of the, SA interface. The SA interface enables the operator to be aware of what is going on around the Unmanned System while it is being operated from a remote location, and to react in the best possible way within a reasonable amount of time. The Rascal UAV interface was reviewed, SA-related problems were identified, and solutions to those problems were proposed. After our studies we proposed eight possible solutions to implement, and one of them is implemented and used. However, due to some problems, we could not test all our solutions.

Emir, Ender. ***Implementation and Evaluation of an INS System using a Three Degrees of Freedom MEMS Accelerometer***. M.S. in Physics. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Advisor: Richard Harkins
Second Reader: Brett Borden
http://hdl.handle.net/10945/3853
http://handle.dtic.mil/100.2/ADA493702

Abstract: Position determination is one the most important aspects of navigation for an autonomous vehicle and can be accomplished through a variety of methods. Advances in Global Positioning System (GPS) technology, improved accuracy by a Wide Area Augmentation System (WAAS), wider coverage, easy integration and low cost, make GPS the most preferable alternative for the navigation of autonomous vehicles. However, an autonomous vehicle must be

able to navigate and determine its position on earth without external navigation aids such as GPS, Loran and Transit. A method of inertial navigation, called dead reckoning, where the robot calculates its position from a known reference position through using laser range finders, gyros, shaft encoders and accelerometers, becomes more important for navigation with no external aids. This thesis examines the navigation ability for robots using a three degree of freedom accelerometer, which can sense the instantaneous accelerations in three dimensions. Tests and results of the accelerometer as an inertial system for a mobile robot are implemented in 1-D and 2-D. The results demonstrated that Crossbow MEMS accelerometer can be used for a distance of 10 meters for mobile robot navigation with different levels of errors according to the path followed in 2-D.

Gregory, Jr., Robert H. *Army Transformation and the Future Combat System*. M.A. in Security Studies (Defense Decision-Making). Monterey, California: Naval Postgraduate School, March 2008.
Thesis Advisor: Daniel Moran
Second Reader: James Wirtz
http://hdl.handle.net/10945/4205
http://handle.dtic.mil/100.2/ADA479911
Abstract: This thesis examines current efforts to transform the U.S. Army to face new challenges. The Army's transformation is based on the development of the Future Combat System (FCS), initiated in 1999. The FCS consists of eight new manned vehicles, various unmanned sensors, robotic vehicles, and remote controlled missiles, all connected by a common network. Critics of the Army's transformation contend that this equipment and associated doctrine is based on traditional Cold War scenarios rather than the types of challenges the Army is likely to face. This thesis examines whether the FCS is influenced by traditional preferences for certain types of doctrine, equipment, and capabilities. To do this, the development of the Army's current capabilities, through past reforms, is first described. Second, the influence of tradition on the development of future capabilities is examined. Third, the potential for FCS to achieve its design goals is measured in both technical and strategic terms. Fourth, the manner in which FCS capabilities relate to irregular warfare is examined from the perspective of the Army's combat arms branches. Finally, considering the significance of institutional culture and past reforms, this thesis determines if outdated traditional considerations influence current Army transformation efforts.

Hedderly, James W. *A Seakeeping Study on the Autonomous Sustainment Cargo Container Delivery System*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2008.
Thesis Advisor: Fotis Papoulias
http://hdl.handle.net/10945/4229
http://handle.dtic.mil/100.2/ADA479942
Abstract: An increasing emphasis has recently been placed with fighting non-national and irregular forces. Single entity attacks on shipping and transportation units have replaced attacks on fortified or established military positions. The supply chain from sea to shore has become the target of opportunity to disrupt the Global War on Terrorism and put further lives in danger. Autonomous containers will play an essential role to deliver logistical supplies to waterborne littoral vessels in order to maintain station and complete military operations all while eliminating the threat to human life as the containers will be programmed to deliver supplies to a specified local in a reasonable timetable; vessels such as Riverine Warfare patrol craft, Special Operations craft and Coast Guard search and rescue boats and their crews. The research to be conducted will focus on the seakeeping characteristics of an autonomous sustainment cargo container and the feasibility of its deployment. Established geometric data will be used along with changing loading characteristics and ride effects. The in depth analysis will be focused on the responses of the container in varying sea conditions and at varying loads to see if further refinement of the design or policies concerning loading and deployment may be required.

Hough, George C. ***Wireless Robotic Communications in Urban Environments: Issues for the Fire Service***. M.A. in Security Studies (Homeland Defense and Security). Monterey, California: Naval Postgraduate School, March 2008.
Thesis Advisor: Richard Bergin
Second Reader: Kate Remley
http://hdl.handle.net/10945/4232
http://handle.dtic.mil/100.2/ADA479946

Abstract: Firefighters are tasked with conducting search and rescue operations at incidents ranging from minor smoke conditions to multi-agency disasters. In each instance, a rapid risk assessment must be conducted based on preliminary dispatch information. Small, lightweight "man portable" robots are a natural fit for gaining improved situational awareness, yet few have been employed for this application. The problems encountered in using wireless robots in urban environments are among the primary reasons. This thesis focuses on the wireless link between the robot and the firefighter employing it. The work presented is useful for policy makers in allocating public safety spectrum, firefighters in pre-planning responses, and engineers for designing relevant control systems. While the arguments rest on a technical footing of test data and models, the paper is written primarily for a non-technical audience. A technology acceptance model is developed for employing robots wirelessly. Test data is presented showing the debilitating effects of interference from employing multiple robots concurrently. Models are applied to predict signal loss in tunnels and urban environments, and results indicate an optimal frequency range exists between 500 MHz and 1 GHz. A case is presented to allocate spectrum in this range using a priority access protocol.

Kam, Khim Yee. ***High Bandwidth Communications Links between Heterogeneous Autonomous Vehicles using Sensor Network Modeling and Extremum Control Approaches***. M.S. in Engineering Science (Mechanical Engineering). Monterey, California: Naval Postgraduate School, December 2008.
Thesis Co-Advisor: Isaac I. Kaminer and Deok Jin Lee
http://hdl.handle.net/10945/3833
http://handle.dtic.mil/100.2/ADA494117

Abstract: In future network-centric warfare environments, teams of autonomous vehicles will be deployed in a coorperative manner to conduct wide-area intelligence, surveillance and reconnaissance (ISR) missions in a tactical environment. The operational range of these survey vehicles is usually limited by the line-of-sight (LOS) and/or bandwidth constraints of the communication system. To increase the operational range and to allow real-time transmission of data back to the command station, autonomous vehicles configured with high bandwidth communication system are positioned between the command station and the survey vehicles acting as communication relay vehicles and flying sensors. This will allow the survey vehicles to transfer their data back to the command station on the move, thus improving the efficiency of the missions. In this thesis, an autopilot guidance and control algorithm was developed that will allow the relay vehicles to reposition themselves autonomously to maintain an optimal loitering flight path to maximize the quality of the communication link between the command station and survey vehicle. The main contributions of this thesis are two-fold. First, a communication propagation model was developed to predict the signal-to-noise (SNR) ratio of the communication link, which is used as a reference SNR signal for the UAVs. Second, the communication model was then integrated into a feedback control loop to formulate a new real-time adaptive controller, which is based on an extremum seeking approach with a gradient-based controller, to drive the relay vehicle to an optimal loitering path using SNR as the cost function.

Kandasamy, Jaya Kumar. ***Stabilization System for Camera Control on an Unmanned Surface Vehicle***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Advisor: Anthony J. Healey
http://hdl.handle.net/10945/3832
http://handle.dtic.mil/100.2/ADA493888
Abstract: SeaFox is an unmanned surface vehicle (USV) primarily used for maritime security operations. Currently, a remotely operated vision based camera is used to track a particular target whilst the USV approaches the intended target. While the USV is in motion, the hydrodynamic forces and mechanical vibrations makes it difficult for the operator to lock on to the target at all times. This thesis addresses this issue through the development of a self compensated motion controller that uses geo-pointing to track and lock onto a target at all times. The disturbance data as captured by the onboard IMU sensor is used to establish parameters for the compensator. The compensated pan tilt angles are fed to the vision based camera through a PID controller. The controller developed will enable the vision based camera system to autonomously track the intended target independently of the motion of the USV.

Kistner, Patrick B. and David M. Crescitelli. ***Enhanced Detection of Orthogonal Radar Waveforms using Time-Frequency and Bi-Frequency Signal Processing Techniques***. M.S. in Information Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September 2008.
Thesis Advisor: Phillip E. Pace
Second Reader: Terry E. Smith
http://hdl.handle.net/10945/3931
http://handle.dtic.mil/100.2/ADA488979
Abstract: This thesis investigates the periodic autocorrelation function (PACF) and periodic ambiguity function (PAF) for orthogonal continuous waveform (CW) modulations used in netted low probability of intercept (LPI) radar. Three orthogonal polyphase sequences and one frequency coding sequence are examined and their PACF and PAF characteristics are quantified. The Wigner-Ville distribution (WVD) and quadrature mirror filter bank (QMFB) timefrequency signal processing techniques and the cyclostationary bi-frequency technique (often used in non-cooperative intercept receivers) are used to detect the orthogonal CW signals and extract their parameters. The results shows that a combination of the techniques used were able to extract the basic signal parameters of bandwidth and code period from the polyphase waveforms and also the frequency hop slots and code length from the frequency coding sequence. The concept of using a swarm of unmanned aerial vehicles (UAV) is examined from the viewpoint of a coordinated group of netted intercept receivers in search of an LPI radar network.

Kocaman, Ibrahim. ***Distributed Beamforming in a Swarm UAV Network***. M.S. in Electronic Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, March 2008.
Thesis Advisor: David Jenn
Second Reader: Terry Smith
http://hdl.handle.net/10945/4215;
http://handle.dtic.mil/100.2/ADA479952
Abstract: The use of wireless communication techniques and network centric topologies with unmanned aerial vehicles (UAV) within modern warfare concepts makes it possible to utilize new distributed beamforming applications. The objective of this research is to combine the concept of wireless beamforming in opportunistic random arrays with the concept of swarm UAVs. A considerable amount of research has already been done about the feasibility and advantages of opportunistic arrays for a single platform. Distributed beamforming techniques are widely applied by many researchers. The use of swarm UAV concepts for a widely dispersed wirelessly networked opportunistic array may anticipate many advantages over single platform-borne opportunistic arrays. Major challenges are synchronization and localization, which are caused by the mobile structure of the proposed network topology. Possible solutions to these problems are proposed. In this thesis the use of swarm UAVs for jamming is analyzed. Closed form expressions

for jamming power versus the number of UAVs, ranges, degree of transmitter coherence, and quality of beamforming are derived. It was found that even for low quality beamforming (large phase errors, or poor synchronization) significant improvements in system performance is still achievable.

Kurkcu, Coskun and Kaan Oveyik. *U.S. Unmanned Aerial Vehicles (UAVS) and Network Centric Warfare (NCW) : Impacts on Combat Aviation Tactics from Gulf War I through 2007 Iraq*. M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, March 2008.
Thesis Co-Advisors: Cary simon and Terry Smith
http://hdl.handle.net/10945/4211
http://handle.dtic.mil/100.2/ADA480077
Abstract: Unmanned, aerial vehicles (UAVs) are an increasingly important element of many modern militaries. Their success on battlefields in Afghanistan, Iraq, and around the globe has driven demand for a variety of types of unmanned vehicles. Their proven value consists in low risk and low cost, and their capabilities include persistent surveillance, tactical and combat reconnaissance, resilience, and dynamic re-tasking. This research evaluates past, current, and possible future operating environments for several UAV platforms to survey the changing dynamics of combat-aviation tactics and make recommendations regarding UAV employment scenarios to the Turkish military. While UAVs have already established their importance in military operations, ongoing evaluations of UAV operating environments, capabilities, technologies, concepts, and organizational issues inform the development of future systems. To what extent will UAV capabilities increasingly define tomorrow's missions, requirements, and results in surveillance and combat tactics? Integrating UAVs and concepts of operations (CONOPS) on future battlefields is an emergent science. Managing a transition from manned- to unmanned and remotely piloted aviation platforms involves new technological complexity and new aviation personnel roles, especially for combat pilots. Managing a UAV military transformation involves cultural change, which can be measured in decades.

Kwok, Yew Heng. *A Methodological Approach for Conducting a Business Case Analysis of Zephyr Joint Capability Technology Demonstration (JCTD)*. M.S. in Operations Security. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Advisor: Daniel Nussbaum
Second Reader: Alex Bordetsky
http://hdl.handle.net/10945/10291
http://handle.dtic.mil/100.2/ADA494056
Abstract: Zephyr, a high altitude long endurance (HALE) solar powered, unmanned aerial vehicle (UAV) is thus identified as a Joint Capability Technology Demonstration (JCTD) candidate. This program is managed by the Office of Secretary of Defense (OSD) and is sponsored by United States Central Command (USCENTCOM) and United States European Command USEUCOM. This program aims to accelerate the development and operational evaluation of the Zephyr concept so that the system can transit to production and be deployed in the field to address military needs in the quickest possible time. The objective of this study is to analyze the Return on Investment (ROI) of the Zephyr system. This is achieved by developing a model to carry out a Business Case Analysis (BCA) of JCTDs, including defining the methodical structure required in the business case report conducting Zephyr JCTD BCA, with a baseline analysis, followed by sensitivity, as well as a quality risk assessment for Zephyr system. The BCA compares the life cycle costing with that of the Global Observer, a liquidhydrogen fuelled UAV, in operational scenarios over a period of 15 years.

Masek, Theodore. ***Acoustic Image Models for Navigation with Forward-Looking Sonars***. M.S. in Software Engineering. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Advisor: Mathias Kölsch
Second Reader: Kevin Squire
http://hdl.handle.net/10945/3754
http://handle.dtic.mil/100.2/ADA494074
Abstract: Cost and miniaturization of autonomous unmanned vehicles (AUV) drive component reuse and better sensor data analysis. One such component is the forward looking sonar (FLS) which can be used for obstacle avoidance and to extract vehicle state information. However, autonomous feature extraction of images from the FLS is difficult due to the noise inherent in the sensor and the sensor's susceptibility to interference from other acoustic devices. This thesis investigated techniques to detect and classify common acoustic noise artifacts and common objects in a single frame. Other techniques require three or more frames to filter objects from other noise sources. A combination of probabilistic and template-based models were used to successfully detect and classify acoustic noise and objects. One common noise source is the micro modem which was detected 100% of the time with 1% false positives. Objects such as the ocean floor were correctly classified more than 93% of the time in most sites. Due to the short development time frame, the software was developed with a two-stage approach. First, a high level scripting language was used for rapid prototyping of different classification techniques. In order to meet the time-constrained requirements of the target software, the classification algorithms were encapsulated as C++ classes in an object oriented design once the desired techniques were identified.

McCadden, Kevin K. and Christopher A. Nigus. ***Allocation of UAV Search Efforts using Dynamic Programming and Bayesian Updating***. M.S. in Applied Science (Operations Research). Monterey, California: Naval Postgraduate School, June 2008.
Thesis Advisor: Johannes O. Royset
Second Reader: Moshe Kress
Outstanding Thesis Award
http://hdl.handle.net/10945/4112
http://handle.dtic.mil/100.2/ADA483499
Abstract: As unmanned aerial vehicle (UAV) technology and availability improves, it becomes increasingly more important to operate UAVs efficiently. Utilizing one UAV at a time is a relatively simple task, but when multiple UAVs need to be coordinated, optimal search plans can be difficult to create in a timely manner. In this thesis, we create a decision aid that generates efficient routes for multiple UAVs using dynamic programming and a limited-lookahead heuristic. The goal is to give the user the best knowledge of the locations of an arbitrary number of targets operating on a specified graph of nodes and arcs. The decision aid incorporates information about detections and nondetections and determines the probabilities of target locations using Bayesian updating. Target movement is modeled by a Markov process. The decision aid has been tested in two multi-hour field experiments involving actual UAVs and moving targets on the ground.

McKeehan, Zachary D. ***Vision-Based Interest Point Extraction Evaluation in Multiple Environments***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, September 2008.
Thesis Co-Advisors: Mathias Kölsch and Kevin Squire
http://hdl.handle.net/10945/3952
http://handle.dtic.mil/100.2/ADA488890
Abstract: Computer-based vision is becoming a primary sensor mechanism in many facets of real world 2-D and 3-D applications, including autonomous robotics, augmented reality, object recognition, motion tracking, and biometrics. Vision's ability to utilize non-volatile features to serve as permanent landmarks in motion tracking provides a superior basis for applications such as initial self-localization, future re-localization, and 3-D scene reconstruction and mapping. Furthermore, the increased reliance of the United States armed forces on the standoff warfighting capabilities of unmanned and autonomous vehicles (UXV) in, on, and above the sea, necessitates

better overall navigation capabilities of these platforms. Towards this end, we draw upon existing technology to measure and compare current visual interest point extractor performance. We utilize an inventory of extractors to define and track interest points through physical transformations captured in images of various scene classifications. We then perform a preliminary determination of the best-suited extraction descriptor for each visual scene given multi-frame interest point persistence with maximum viewpoint invariance. Our research contributes an important cornerstone towards the validation of precision, vision-based navigation, thereby increasing UXV performance and strengthening the security of the United States and her allies worldwide.

Moose, Robert G. ***Covering the Homeland: National Guard Unmanned Aircraft Systems Support for Wildland Firefighting and Natural Disaster Events***. M.A. in Security Studies (Homeland Security and Defense). Monterey, California: Naval Postgraduate School, December 2008.
Thesis Advisor: James J. Wirtz
Second Reader: Timothy J. Doorey
http://hdl.handle.net/10945/3752
http://handle.dtic.mil/100.2/ADA493900
Abstract: Over the past decade, the United States Government has had to cope with increasingly severe large-scale natural disasters. The 2004 hurricane season alone caused 167 deaths and an estimated $4.6 billion in damages. The following year, Hurricane Katrina took 1,330 lives and caused an estimated $9.6 billion in damages. The 2007 fire season saw over 85,000 wildland fires consume more than 9.3 million acres. In Southern California alone, wildfires forced over half a million people to evacuate their homes, destroyed over 3,079 structures, and caused over $1.8 billion in damages. This thesis examines the possible nontraditional and creative use of unmanned aircraft systems to mitigate the threat and effects of natural disasters, assist with search and rescue, and aid postdisaster recovery efforts. This work investigates the use of National Guard unmanned aircraft systems to provide lead agencies support prior to, during, and following major disaster incidents. The thesis also explores the benefits and challenges to setting up National Guard units operating unmanned aircraft systems within the United States equipped with specialized sensors in a similar fashion to the National Guard modular airborne firefighting system, and offers subjects for follow on research.

Ong, Chee Wei. ***A Discovery Process for Initializing Ad Hoc Underwater Acoustic Networks***. M.S. in Engineering Acoustics. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Advisor: Joseph A. Rice
Second Reader: John C. McEachen
http://hdl.handle.net/10945/3774
http://handle.dtic.mil/100.2/ADA493816
Abstract: Seaweb is an underwater acoustic wide-area network connecting autonomous, distributed nodes. Prior iterations of Seaweb relied on operator intervention to initialize and manually configure the network routes. This thesis implements a network discovery process that enables a field of spontaneously deployed, ad hoc nodes to auto-configure for networking purposes. Network routing is initialized as nodes in the network are discovered, with routes chosen according to comparative evaluation of a cost function for all candidate routes. The implemented network discovery process is tested using computer simulation and sea trial data. The resultant network routes obtained upon completion of the ad hoc network discovery process are compared with those derived from Dijkstra's algorithm. It is concluded that the network discovery process always produces a shortest-path route from a master node to any other discovered nodes in the network. Sensitivity studies on the route cost evaluation function are performed, and an alternative network discovery scheme is discussed.

Parsley, Randall S. ***Creating an Effective Multi-Domain Wide-Area Surveillance Platform to Enhance Border Security***. M.A. in Security Studies (Homeland Security and Defense). Monterey, California: Naval Postgraduate School, March 2008.
Thesis Co-Advisors: Richard Bergin and Nadav Morag
http://hdl.handle.net/10945/4194
http://handle.dtic.mil/100.2/ADA479947
Abstract: North American Aerospace Defense Command (NORAD) and United States Northern Command (USNORTHCOM) lack persistent, multi-domain, wide-area surveillance (WAS) to conduct their assigned homeland defense and homeland security missions. Wide-area surveillance allows military operators to see vast expanses of the homeland. For example, it is the difference between a view of Texas and a view of the broad U.S. southern border - from Texas to California. With WAS, the Department of Defense (DOD) would have access to the big picture. Without WAS, gaps in radar coverage could allow potential terrorists or people transporting drugs into the United States - to cross the border undetected. DOD or Customs would never see them. This thesis examines how NORAD-USNORTHCOM could and must achieve consistent, wide-area surveillance for the U.S. borders, both southern and northern. This can be achieved by combining the existing manned and unmanned radars with Over-the-Horizon Radars capabilities. By combining all three systems to form a family of radar surveillance systems, working as one consistent radar surveillance system, NORADUSNORTHCOM will be more effective in homeland defense and homeland security missions.

Pearson, John L. ***Optimizing Unmanned Aircraft System Scheduling***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2008.
Thesis Advisor: W. Matthew Carlyle
Second Reader: Sergio Posadas
http://hdl.handle.net/10945/4046
http://handle.dtic.mil/100.2/ADA483449
Abstract: Unmanned Aircraft Systems (UASs) are critical for future combat effectiveness. Military planners from all branches of the Department of Defense now recognize the value that real time intelligence and surveillance from UASs provides the battlefield commander. The Operations Analysis Division of the Marine Corps Combat Development Command is currently conducting an Overarching Unmanned Aircraft Systems study to determine future force requirements. Current analysis is conducted through the use of the Assignment Scheduling Capability for Unmanned Air Vehicles (ASC-U) and several specially designed heuristics. The Unmanned Aircraft System Scheduling Tool (UAS-ST) combines these capabilities into one model and addresses several issues associated with ASC-U. UAS-ST allows the user to control all aspects of the UAS, define a scenario, and then generates a flight schedule over a known time horizon based on those inputs. All missions are assigned a user defined value and the total schedule value is reported. The user can then quickly change a parameter of the UAS, re-solve the model, and see the impact their proposed change has on the overall value of the schedule attained. Therefore, UAS-ST is a tool for analyzing the value of future changes in UAS structure.

Rippeon, Ryan. ***Clandestine Message Passing in Virtual Environments***. M.S. in Computer Science and M.S. in Modeling, Virtual Environments and Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2008.
Thesis Co-Advisors: Gurminder Singh and Joseph Sullivan
http://hdl.handle.net/10945/3967
http://handle.dtic.mil/100.2/ADA488794
Abstract: Virtual Environments (VEs) present a new challenge for government officials attempting to monitor computer networks for terrorist communication. VEs bring new dimensions to online communication through visual appearance and state maintaining servers. In this thesis, various VEs will be explored to study what current abilities and usage patterns exist. Once characteristics of the VEs are established, clandestine methods for passing information will be developed along with proof of concepts. Visual cues, steganography and autonomous bots will be examined. Monitoring techniques are then discussed to attempt observation and analysis of this information

at various levels. The expectation is that these results will improve awareness and solidify an understanding of the more surreptitious capabilities present in these networked environments.

Scioletti, Michael S. ***A Heuristic Algorithm for Optimized Routing of Unmanned Aerial Systems for the Interdiction of Improvised Explosive Devices***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2008.
Thesis Advisor: Johannes O. Royset
Second Reader: W. Matthew Carlyle
Outstanding Thesis Award
http://hdl.handle.net/10945/4001
http://handle.dtic.mil/100.2/ADA483643

Abstract: Improvised explosive devices (IEDs) are effective weapons for insurgents targeting conventional military and security forces. Real-time information gathering about likely use of such weapons is one approach to reduce the effectiveness of IEDs. Unmanned aerial system (UASs) may provide the information gathering capability commanders need to interdict IEDs. Currently, UASs are not systematically utilized in that capacity. This research develops a routing tool that uses column-generation techniques and a greedy algorithm to route UASs through suspected IED locations for the purpose of IED interdiction as it transit to and from command directed missions. In empirical studies of data sets with up to 125 IED locations and missions, the routing tool provides optimal or near-optimal solutions in all instances tested. The tool produces de-conflicted routes for up to three UASs within five minutes of computing time.

Sebalj, Derek. ***Single Operator Control of Multiple Uninhabited Air Vehicles : Situational Awareness Requirement***. M.S. in Modeling, Virtual Environments and Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2008.
Thesis Advisor: Michael McCauley
Second Reader: Anthony Ciavarelli
http://hdl.handle.net/10945/3964
http://handle.dtic.mil/100.2/ADA489080

Abstract: Militaries around the world, as well as other government agencies, are increasingly using uninhabited vehicles to perform dull, dirty and dangerous work. In the United States, laws currently mandate their increasing use throughout the armed services, with set percentages of overall vehicle fleets. Currently, teams of people operate these vehicles, especially Uninhabited Air vehicles (UAVs). For example, n:1, where n is the number of operators and n > 1. The ultimate goal, and the object of much research, is the technology to lower, or even invert the control ratio from many people to one vehicle to one operator of several vehicles, e.g., 1:m, where m is the number of vehicles and m > 1. While the technology to automate these vehicles continues to progress at a rapid pace, less attention has been paid to the Human Factors aspect. Theoretically, technology exists to enable single operator control of multiple UAVs; however, the human operator must interact with the vehicle, especially if the vehicle will be used to apply deadly force. What information does the operator readily need to make these critical decisions? How will the human operators be able maintain the situational awareness of all vehicles under their control and make informed decisions as to their employment in dynamic situations? One possible aid to maintaining Situational Awareness is an overall Situational Awareness display that gives an overview of the vehicle locations, both geographically and in relation to one another. The question to be answered is whether this display adds useful information to the operator without further straining the operator's limited attention resources. Experiment participants were tasked to provide supervisory control of four simulated UAVs in a simulated environment and make tasking decisions for the UAVs based on static ground targets that required investigation. Accuracy of situational awareness information was measured with and without the additional Situation Awareness display to determine the net benefit of adding an additional display to the operator's station. Results indicate that the Situational Awareness diplsay helped the UAV pilot make more accurate decisions regarding the UAV in closest proximity to a target requiring reinvestigation. Contrary to expectations, the SA display did not increase the speed of decision making for re-assigning the UAVs to a target of interest. The results support the conclusion that

operators of multiple UAVs should have some form of Situational Awareness display to aid in determining the UAVS location geopgraphically and in relation to other UAVs and search objects.

Soh, Mun Lok Bernard. *Hardware in the Loop Implementation of Adaptive Vision Based Guidance Law for Ground Target Tracking*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Co-Advisors: Vladimir N. Dobrokhodov and Kevin D. Jones
http://hdl.handle.net/10945/3707
http://handle.dtic.mil/100.2/ADA494070
Abstract: An adaptive guidance law of a Vision Based Target Tracking (VBTT) system was previously developed and implemented onboard a Small Unmanned Aerial Vehicle (SUAV) in order to track a ground target moving with a constant velocity. This work extends previous results by considering scenarios where the variation of target velocity, in both magnitude and direction, is used to excite the feedback control law for further robustness analysis. This provides essential insight on the sensitivity of the performance criteria indicated by the range holding capability, navigation error and the convergence speed of the guidance law. In addition, this thesis addresses the robustness of the SUAV guidance law to the generalized time delay in feedback due to, for example, data processing or communications lag. This thesis also extends the previously obtained results by introducing a multi-criteria optimization technique. The results obtained are first based on the numerical simulations implemented in SIMULINK and then in high fidelity HIL simulation environment with Piccolo Plus AP in the control loop. Initial steps in developing Vision Based HIL environment incorporating TASE gimbal, Piccolo Plus AP, Pan-Tilt unit and image processing software are presented. The work also includes motivation for the development, an overview of the existing technologies, and initial implementation of low-level driving mechanism (drivers) for the realistic representation of the real-world environment.

Sonmezocak, Erkan and Senol Kurt. *Optimum Route Planning and Scheduling for Unmanned Aerial Vehicles*. Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Co-Advisors: Aruna Apte and Susan Heath
http://hdl.handle.net/10945/3831
http://handle.dtic.mil/100.2/ADA494126
Abstract: New threat perceptions have extended the sense of self-defense to include preemptive strikes if a threat is going to occur. For its part, the military should have high Intelligence, Surveillance, and Reconnaissance (ISR) capabilities to implement this strategy. UAVs play an important role as the most effective way of providing high quality ISR in today's modern wars. The route planning of UAVs is the most critical and challenging problem of wartime. This thesis will develop three algorithms to solve a model that produces executable routings in order to dispatch three Unmanned Aerial Vehicles (UAV) to complete 20 different missions in different locations. These algorithms seek to maximize the bonus points that are paired with the targets, representing the priority of the missions. By this definition, the problem can be classified as a Multiple Tour Maximum Prize Collection Problem (MTMPC). MTMCP is closely related to the classical Traveling Salesman and Vehicle Routing Problems with the difference that not all nodes can be visited in the available time. Each node is assigned a bonus point value representing the priority of that mission, and the objective of the MTMCP is to determine the nodes to be visited to maximize the collected bonus points.

Tham, Kine Seng. *Enhancing Combat Survivability of Existing Unmanned Aircraft Systems*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, December 2008.
Thesis Co-Advisors: Gary Langford and Ravi Vaidyanathan
http://hdl.handle.net/10945/3734
http://handle.dtic.mil/100.2/ADA494136
Abstract: The importance of Unmanned Aircraft Systems (UAS) to warfighters has been growing. Each loss (regardless of whether the entire UAS or parts of it) has become more expensive and unaffordable in both an operational and monetary sense. An unmanned aircraft (UA) loss may

mean that critical missions cannot be performed and millions of dollars of investments on the UA lost. As most existing UAS were designed to be inexpensive and expendable, there is a need to enhance their combat survivability. Combat survivability is the capability of UAS to avoid or withstand a man-made hostile environment. This thesis explored how to enhance the combat survivability of existing UAS. Potential survivability enhancement options are identified. These options include changes in tactics, improving the situation awareness of the operator, equipping the UA with the capability to counter an incoming threat, improving the payload performance, improving resistance of the data link to jamming. The technology behind these options as well as the favorable and unfavorable factors of the options are studied and discussed. This thesis also proposed a process for selecting the "best" solution from survivability enhancement alternatives. This thesis used systems engineering methodology to enhance the survivability of existing UAS.

Upperman, Teresa Lynn Odom. ***Elint Signal Processing using Choi-Williams Distribution on Reconfigurable Computers for Detection and Classification of LPI Emitters***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, March 2008.
Thesis Co-Advisors: Douglas J. Fouts and Phillip E. Pace
http://hdl.handle.net/10945/4156
http://handle.dtic.mil/100.2/ADA486152
Abstract: This thesis documents the use of the SRC-6 Reconfigurable Computer for use in analyzing low probability of intercept (LPI) signals using the Choi-Williams distribution. The SRC-6 is a reconfigurable computer manufactured by SRC Computers, Inc. which allows the user to tailor both the software and the hardware to a specific task. This increases the speed at which the task can be accomplished making it useful for applications in electronic intelligence (ELINT). The Choi-Williams distribution is a mathematical technique that was first created using MATLAB and then converted to C code for use on the SRC-6. The purpose of this study is to investigate the feasibility of using a reconfigurable computer for ELINT applications and the timely detection and classification of LPI signals. This thesis is part of a larger study to use reconfigurable computers for the autonomous detection and classification of LPI signals.

2007

Ball, Gregory P. ***MAJIC : A Java Application for Controlling Multiple, Heterogeneous Robotic Agents***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, September 2007.
Thesis Co-Advisors: Craig Martell and Kevin Squire
http://hdl.handle.net/10945/3339
http://handle.dtic.mil/100.2/ADA473693
Abstract: Current capability to command and control a team of heterogeneous robotic agents is limited by proprietary command formats and operating systems. A specific challenge in this context is the specification, the programming, and the testing of software for such a wide variety of mobile robot teams. This work explores the applicability of an application program interface (API), called the Multi-Agent Java Interface Controller (MAJIC), that supports command, control, and coordination of heterogeneous robot teams. MAJIC encapsulates scripted commands, preprogrammed behaviors, and simultaneous, multi-agent control. By exploiting the powerful techniques of polymorphism and object-oriented programming, a generic MajicBot class will provide the necessary level of abstraction between the user and the proprietary architectures. Utilizing the technique of inheritance, future NPS students will be able to extend the generic class in order to easily add new robot-specific libraries. Students will also be able to utilize the existing libraries to program and test their own robot behaviors in real-world environments utilizing the MAJIC package. A final display of the versatility and power of programming behaviors within the MAJIC software architecture is demonstrated by a series of example programs conducted on a team of robots consisting of a Sony Aibo, a Mobile Robots Pioneer, and a K-Team Hemisson.

Casias, Juan Francisco. ***Performance of Wireless Unattended Sensor Networks in Maritime Applications***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: John C. McEachen
Second Reader: Weilian Su
http://hdl.handle.net/10945/3497
http://handle.dtic.mil/100.2/ADA470042
Abstract: Wireless, unattended sensor networks offer a superior monitoring capability with unparalleled flexibility. Traditional systems are typically restrictive in the rigidity of their positioning and topological design requirements. Ongoing research continues to expand the potential for the use of these un-tethered and autonomous systems ranging from the mundane, monitoring soil conditions for agricultural crops, to the extreme of military operations, providing valuable intelligence to commanders in a variety of battlespace conditions. This thesis investigated the use of this type of system in what may be the most hostile of environmental conditions from a wireless networking and communications point of view, the water. The network will be required to organize, establish and maintain itself in a variety of dynamic conditions in or on the water. Commercial off-the-shelf products developed by Crossbow Technologies were used in developing the wireless, unattended sensor network consisting of single and multiple nodes. Nodes were tested on a solid ground surface, on the surface of the water, below the surface of the water (not submerged), and fully submerged. The most significant findings were attained with regard to range. Other findings with regard to link quality, network formation, and network stability support results attained in previous research.

Chng, Kim Chuan. ***Determining a Cost-Effective Mix of UAV-USV-Manned Platforms to Achieve a Desired Level of Surveillance in a Congested Strait***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Co-Advisors: Patricia A. Jacobs and Donald P. Gaver
Second Reader: Wayne P. Hughes, Jr.
http://hdl.handle.net/10945/3061
http://handle.dtic.mil/100.2/ADA475836
Abstract: This thesis develops concepts of operations (CONOPS) and analytical models to determine the surveillance assets for a congested strait. Two maritime security threats (Reds) are a hijacked large ship carrying dangerous cargo or a SB manned by terrorists attempting to cause damage to other vessels or the port. The Red SB can either conduct a direct attack or a sneak attack by hiding among other neutral SBs. The defense force consists of shore-based sensors, unmanned aerial vehicles (UAVs), unmanned surface vehicles (USVs), and patrol craft (PC). The shore-based radar and the UAVs classify unidentified vessels as suspicious or not suspicious and suspicious SB must be inspected by a USV or PC. Analytical models are introduced to analyze requirements for numbers of surveillance assets and to assess the effectiveness of the CONOPS to achieve a desired probability of detecting and intercepting the threat. They incorporate both differential equations and probabilistic arguments. Results indicate that if the UAVs generate many false positives then the USVs and PCs have a higher workload which decreases the probability of detecting a threat. USVs and PCs should give a high priority to inspecting suspicious SBs rather than identifying unsuspicious SBs to achieve a higher probability of detecting a threat.

Dolbec, Michael R. ***Velocity Estimation using Forward Looking Sonar***. M.S. in Engineering Science. Monterey, California: Naval Postgraduate School, March 2007.
Thesis Advisor: Doug Horner
Associate Advisor: Mathias Kölsch
http://hdl.handle.net/10945/3558
http://handle.dtic.mil/100.2/ADA467123
Abstract: The thesis investigates a method to estimate the forward velocity and heading rate of an autonomous underwater vehicle (AUV). Through relatively new technologies small AUVs are now able to mount a Forward Looking Sonar (FLS) on the vehicle's nose. This can be used for obstacle avoidance and feature based navigation. The sensor can also be used to estimate motion of the AUV, which can be useful for undersea navigation. The thesis focuses on a template matching technique used in computer vision. Two sequential sonar images are compared with the goal of finding the rotation and translation that best correlates the first to the second sonar image. The transformation which maximizes the correlation coefficient is then converted to forward velocity and heading rate through motion analysis. Experimentation shows that the method provides accurate estimates for both the forward velocity and heading rate of the AUV. Accuracy of the estimates for forward velocity was at the limitation of the resolution of the sonar. Using velocities estimated through image processing applied to FLS images entirely with software, the weight and energy resources currently required by standard measurement techniques could be used to increase the vehicles endurance or for additional payload capacity. Another benefit would be the reduction in acoustic and electrical interference with the FLS and side scan sonar, which would improve the vehicle's obstacle avoidance and mine-hunting capability. The vehicle could become more flexible in its capability to support additional roles vice specific missions. This method holds the promise for permitting smaller AUVs with a FLS to navigate undersea more accurately.

Foutzitzis, Evangelos K. ***Multiple Assets Position Determination in a 3-Dimensional Environment using the APRS Protocol***. M.S. in Electronic Warfare Systems Engineering. Monterey, California: Naval Postgraduate School, September2007.
Thesis Advisor: Andrew A. Parker
Second Reader: James F. Ehlert
http://hdl.handle.net/10945/3280
http://handle.dtic.mil/100.2/ADA474028

Abstract: Increased situational awareness in the battlefield is one of the main objectives in today?s operations and applies to all levels of commands. Several attempts have been made to use tracking devices for detecting and continuously updating the positional data of friendly assets on a map. Current applications like Falcon View fulfill their objective in presenting the location of targets of interest on a digital mapping environment. Falcon View is a geographic information system (GIS) used extensively by DoD for mission planning purposes. When the requirement is to track airborne assets such as aircraft or unmanned aerial vehicles (UAVs), none of the current applications can present the results in three-dimensions. Instead they project the received tracks on the ground in 2-dimensions creating a false or impaired perspective of the true tactical situation. This thesis develops and tests a software application in a plug-in form integrated into the open-source NASA World Wind mapping engine. The application is designed to determine the tracks of both airborne and ground-moving assets in three dimensions. It also tests the concept in a real-world environment and verify the impact it has on situational awareness at various command levels.

Freye, Jeffrey T. ***Design of Experiment Analysis for the Joint Dynamic Allocation of Fires and Sensors (JDAFS) Simulation***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Thomas W. Lucas
Second Reader: Darryl K. Ahner
http://hdl.handle.net/10945/3365
http://handle.dtic.mil/100.2/ADA470129

Abstract: The U.S. Army Training and Doctrine Command (TRADOC) Analysis Center's Joint Dynamic Allocation of Fires and Sensors (JDAFS) model, a low-resolution, Discrete Event Simulation Model with embedded optimization enables the analysis of many scenarios and factors to explore Joint Intelligence, Surveillance, and Reconnaissance (ISR) missions. JDAFS is a powerful model that combines both discrete event simulation and the optimization of a linear objective function to generate realistic, reasonable, and consistent solutions to difficult ISR scheduling problems. Given a scenario and a mix of ISR platforms, JDAFS optimizes a flight schedule and executes the missions. This research develops a Joint ISR scenario, explores scenario simulation results, and provides a proof-of-principle analysis that aids in the ISR decision making process. This study examines 274 design points in each of two scenarios, a non-penetrating scenario that allows only standoff collection and a penetrating scenario that allows country of interest overflight. The use of an efficient design of experiment methodology enables the exploration of the interior and exterior of the response surface for the two experimental scenarios. Analysis of the simulation output suggests that the optimization interval significantly impacts total coverage. In the nonpenetrating scenario, shorter optimization intervals ensure better coverage; however, in the penetrating scenario, longer optimization intervals provide for improved coverage. The disparity is explained by reduced likelihood of assignment saturation in the penetrating scenario due to the increased number of mission areas. Sensor range, sensor package configuration, and platform dwell time also affect the level of coverage. This is clearly demonstrated by the superior coverage provided by the most capable ISR platforms.

Gkionis Charalampos. ***Linear and Planar Array Formation in Wireless Sensor Networks***. M.S. in
Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Murali Tummala and John McEachen
Second Reader: T. Owens Walker III
http://hdl.handle.net/10945/3436
http://handle.dtic.mil/100.2/ADA470075
Abstract: Wireless sensor networking (WSN) is a relatively new field of research with many
applications, both military and commercial. In the military applications, WSNs could be used in
hostile environments to minimize the need for human presence. A WSN consists of a large
number of small sensor nodes that are deployed in an area of interest for collecting information.
A subgroup of nodes then collaborate their transmissions to achieve beamforming. The
information collected by the WSN is relayed to an unmanned aerial vehicle (UAV), which is
synchronized with the transmission beam of the network. In this study, the positioning of the
nodes in a WSN is investigated with the main object to propose a method to find the best
combination of nodes for beamforming given a random distribution in the sensor field.
Additionally, the method is expandable in two dimensions and capable of forming a planar
antenna array which will improve the beamforming gain. A simulation model was developed in
MATLAB code to study the formation of linear and planar antenna array of nodes. The existing
iterative technique in the formation of a linear antenna array is compared with the proposed and
the results showed an improvement in linearity.

Griffith, Christopher M. ***Unmanned Aerial Vehicle-Mounted High Sensitivity RF Receiver to
Detect Improvised Explosive Devices***. M.S. in Information Warfare Systems Engineering.
Monterey, California: Naval Postgraduate School, September 2007.
Thesis Advisor: Lonnie A. Wilson
Second Reader: Ray A. Elliot
http://hdl.handle.net/10945/3303
http://handle.dtic.mil/100.2/ADA474013
Abstract: Improvised Explosive Devices (IEDs) are increasing in complexity and lethality. A RE
system is needed to detect the presence of RF IEDs. This thesis describes the evolution of a
proven ground-based RF detection system. It is designed to collect unintended radio frequency
emissions from the IED's RF triggers and receivers. Modification of the ground-based version
allowed placing this RF system into an airborne platform. The detection range and corresponding
time to react to a possible threat is dramatically improved. Increased time provides greater
protection for the front line troops that are primary targets of RF IEDs, hence reducing the
casualties of U.S. troops. Field testing and technical feasibility demonstrations are conducted
using a NPS-owned TERN UAV at McMillan Airfield located at Camp Roberts, CA. The research
conducted for this thesis primarily deals with the implementation and testing of this RF system
onto UAVs. Several additional benefits make this RF system useable over a wide range of
applications.

Herkamp, John Frederick. ***Deployment of Shaped Charges by a Semi-Autonomous Ground
Vehicle***. M.S. in Physics. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Richard Harkins
Second Reader: Peter Crooker
http://hdl.handle.net/10945/3432
http://handle.dtic.mil/100.2/ADA470035
Abstract: Neutralization of remotely operated Improvised Explosive Devices (IEDs) is a dangerous
task risking human lives on a daily basis. BigFoot seeks to replace the local human component by
deploying and remotely detonating shaped charges to destroy IEDs. This research developed a
platform that can autonomously navigate GPS waypoints, avoid obstacles, and provide remote
user controls for an onboard robotic arm to deploy and remotely detonate shaped charges.
BigFoot incorporates improved communication range over previous Autonomous Ground Vehicles
and an updated user interface that includes controls for the arm and camera by interfacing
multiple microprocessors. BigFoot is capable of avoiding static and mobile obstacles as well

handling most surfaces with minor slopes. BigFoot continues to be somewhat limited by communications range and GPS availability. However, BigFoot is an ideal platform for relatively short range deployment to neutralize roadside IEDs.

Hui, Kok Meng Edmund. *Digital Tracking Array for FM Signals Based on Off-the-Shelf Wireless Technologies*. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: David C. Jenn
Second Reader: Robert D. Broadston
http://hdl.handle.net/10945/3159
http://handle.dtic.mil/100.2/ADA475975
Abstract: The purpose of this research is to design a digital phased array for receiving and tracking a 2.4 GHz FM video signal from an unmanned air vehicle. The tracking is done using a monopulse technique. Various numbers of elements were simulated to access the pattern coverage. The beamforming and demodulation are performed digitally by a computer. Several antenna architectures were studied and the requirements for hardware components such as the analog-to-digital converters and amplifiers are specified. Several methods for generating the carrier signal for the local oscillator are also discussed. They include an independent local oscillator, a voltage controlled oscillator with feedback (i.e., a phased locked loop) and mixing with a phase shifted copy of the received signal (Bilotti's method).

Jun, Hyun Il. *The Implementation and Testing of a Robotic Arm on an Autonomous Vehicle*. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: Richard Harkins
Second Reader: Peter Crooker
http://hdl.handle.net/10945/3157
http://handle.dtic.mil/100.2/ADA475886
Abstract: An articulated arm with three degrees of freedom is implemented and tested on an autonomous robot. Kinematic equations of motion for the arm are modeled and tested. A communication architecture is successfully implemented for wireless manual control of the arm. Visual and thermal cues are realized with an onboard camera and a collocated thermal sensor. Future work suggests investigations for full autonomous arm control without manual operator intervention based on sensor cues and visual scene correlation.

Knight, Anthony G. and Aaron B. Luck. *Tactical Space: Beyond Line of Sight Alternatives for the Army and Marine Corps Ground Tactical Warfighter*. M.S. in Space Systems Operations. Monterey, California: Naval Postgraduate School, September 2007.
Thesis Advisor: William Welch
Second Reader: Alan Scott
http://hdl.handle.net/10945/3262
http://handle.dtic.mil/100.2/ADA473940
Abstract: United States Army and Marine Corps ground tactical warfighters find themselves conducting operations across greater distances and with more autonomy from their higher commands than ever before. As their areas of operations become larger in modern conflicts, and distributed operations become more the norm, deficits in the tactical warfighter?s ability to conduct beyond line of sight (BLOS) communications, intelligence, surveillance, and reconnaissance (ISR), blue force tracking and situational awareness (BFT/SA), and position, navigation, and timing (PNT) become more noticeable and dangerous. The capabilities existing in the tactical space this warfighter operates within and from where he is supported cannot meet his needs now, nor will they likely meet his needs in the future. While upgrades and expansion of current satellite and unmanned aerial system (UAS) architectures will expand these BLOS capabilities, it is not likely they will increase sufficiently to reduce the deficit in support. A new regime, the High Altitude Area of Interest (HAAI) also known as near space, provides potential capabilities specifically tailored to the tactical warfighter. This thesis reviews the BLOS requirements of the tactical warfighter, identifies the current and future deficits in each area, and

identifies emerging areas of support. It then provides recommendations on further development of integrated architectures spanning multiple regions, to provide efficient, persistent, and sufficient BLOS capabilities to the tactical warfighter.

Lalis, Vasileios. ***Exploring Naval Tactics with UAVs in an Island Complex using Agent-Based Simulation***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Thomas w. Lucas
Second Reader: Kyle Lin
http://hdl.handle.net/10945/3443
http://handle.dtic.mil/100.2/ADA471061
Abstract: The benefits of Unmanned Aerial Vehicles (UAV) at sea are undisputed. The amount and speed of the incoming information from a UAV, combined with its maneuverability and "time-on-task" capability, are assets to any navy. For the Greek Navy, the main local operation area is the Aegean and Ionian Sea. As Greece lies between three continents (Europe, Asia, Africa), there is a great deal of sea traffic and potential illegal activities, such as smuggling, exploitation of illegal immigrants, and possible terrorist activity. The scope of this study is to explore naval tactics with UAVs in an island complex using Agent-Based Simulation. MANA (Map Aware Non-uniform Automata) software, used in this study, provides a visual and realistic background to conduct simulations of real operations involving many different entities. This thesis demonstrates that this type of software can rapidly produce, explore and check simulated naval tactics before actual implementation. It also shows how the UAV's technology plays a key role in a search and detection operation, whereas the enemy must rely mostly on his tactics.

Lee, Shay Liang. ***Force Protection Via UGV-UVA Collaboration : Development of Control Law for Vision Based Target Tracking on SUAV***. M.S. in Mechanical Engineering and M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Co- Advisors: Vladimir N. Dobrokhodov and Richard Harkins
http://hdl.handle.net/10945/3102
http://handle.dtic.mil/100.2/ADA475930
Abstract: The Naval Postgraduate School UAV Laboratory developed a Small Unmanned Aerial Vehicle (SUAV) equipped with a Vision Based Target Tracking (VBTT) system as part of its Tactical Network Topology field experimentation program. The VBTT system includes a miniaturized gimbaled camera that allows autonomous target tracking while providing concurrent estimates of target motion including its position, velocity and heading. Using the current control law, the speed of convergence and the range-holding performance have been found to deteriorate as target speed increases. The aim of this thesis is to elaborate on the existing control law in order to achieve better performance. Employing a new and novel algorithm from the Lyapunov Stability Analysis, for the purpose of adjusting the feedback gain, is proposed in this thesis; to that end a control law with adjustable gain can be easily implemented based on UAV-Target kinematics to optimize UAV performance. The performance of the newly adjustable gain control law is tested in both SIMULINK model and Hardware-In-the-Loop simulations to verify any improvement in performance over the constant gain control law. Principal results offer improved SUAV target-tracking performance with no additional hardware costs.

Lim, Han Leong. ***Network Payload Integration for the Scan-Eagle UAV***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: Anthony J. Healey
http://hdl.handle.net/10945/3117
http://handle.dtic.mil/100.2/ADA475874
Abstract: With the increasing maturity of Mesh network technology, it is inevitable that we exploit the synergistic capabilities in networking of autonomous vehicles [1]. The interconnectivity enables the sharing or dissemination of information between various nodes and has the capability to enhance communication range between a Ground Control Station (GCS) and autonomous aircraft which can then be expanded to several GCSs, or in a networked combination of

Unmanned Aerial Vehicle (UAV), Unmanned Ground Vehicle (UGV) and Unmanned Surface Vehicle (USV) [2]. This thesis discusses the setup of the Mesh network between the ScanEagle GCS and the ScanEagle UAV. It describes the modifications on the high gain antenna and the integration of an ITT Mesh card radio into the ScanEagle. A study of the results conducted in Panama City to understand the limitations and constraints of several Mesh nodes operating within a specified area is described, together with a discussion of the results and recommendations for further work.

Lim, Thiow Yong Dennis. ***A Methodological Approach for Conducting a Business Case Analysis of the Global Observer Joint Capability Technology Denomstration (JCTD)***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: Daniel Nussbaum
Second Reader: Kyle Lin
http://hdl.handle.net/10945/3114
http://handle.dtic.mil/100.2/ADA475934
Abstract: The Global Observer is a Joint Capability Technology Demonstration (JCTD) initiative that is being managed by the United States Special Operations Command (US SOCOM). The JCTD Program seeks to accelerate the development and operational evaluation of mature advanced technologies to rapidly transition the new capability to military operations. The Global Observer is a liquid-hydrogen powered unmanned aircraft system that has been designed for deployment as a stratospheric satellite. It will provide an affordable, persistent presence over any designated area of interest for surveillance and communications relay missions. The purpose of this study is to analyze the cost savings, as well as the other benefits associated with the operational deployment of the Global Observer. This thesis will (1) Develop a model for performing business case analyses of JCTDs, including defining the methodical structure required in the business case report; and (2) Conduct the Global Observer JCTD business case analysis, including a baseline analysis and a comprehensive sensitivity analysis based on a developed operational scenario with 6 designated areas of operations, while comparing the performance with an existing analogous system, i.e., the RQ-4 Global Hawk.

McCamish, Shawn B. ***Distributed Autonomous Control of Multiple Spacecraft during Close Proximity Operations***. PhD in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2007.
Disseration Supervisors: Xiaoping Yun and Marcello Romano
http://hdl.handle.net/10945/10213
http://handle.dtic.mil/100.2/ADA475928
Abstract: This research contributes to multiple spacecraft control by developing an autonomous distributed control algorithm for close proximity operations of multiple spacecraft systems, including rendezvous and docking scenarios. The proposed control algorithm combines the efficiency of the Linear Quadratic Regulator (LQR) and the robust collision avoidance capability of the Artificial Potential Function (APF) method. The LQR control effort serves as the attractive force toward goal positions, while the APF-based repulsive functions provide collision avoidance for both fixed and moving obstacles. The combination of the LQR and APF control logics, referred to as the LQR/APF control algorithm, yielded promising results as demonstrated by the numerous multiple spacecraft maneuver simulations reported in this dissertation. In order to validate the proposed control approach, a multiple spacecraft model validation and visualization technique was developed using a versatile MATLABSatellite Toll Kit (STK) interface to propagate the spacecraft models, compare against STK generated ephemeris, and animate for analysis. The MATLAB-STK interface efficacy was demonstrated during the evaluation and analysis of the innovative LQR/APF multiple spacecraft control algorithm. The LQR/APF multiple spacecraft close proximity control algorithm was developed, refined, and thoroughly simulated using high fidelity six Degree of Freedom (DOF) spacecraft models. In order to evaluate the stability and robustness of the control approach a Monte-Carlo simulations set was run. The LQR/APF control algorithm was further evaluated by virtual hardware-in-the-loop implementation at the NPS Spacecraft Robotics Laboratory. The laboratory hosts the Autonomous Docking and Spacecraft Servicing

testbed which allows for on-the-ground testing of close proximity multiple spacecraft control concepts.

McVicker, Michael Charles. ***Effects of Different Camera Motions on the Error in Estimates of Epipolar Geometry between Two Dimensional Images in Order to Provide a Framework for Solutions to Vision Based Simultaneous Localization and Mapping (SLAM)***. M.S. Computer Science. Monterey, California: Naval Postgraduate School, September 2007.
Thesis Co-Advisors: Mathias Kölsch and Kevin Squire
http://hdl.handle.net/10945/3251
http://handle.dtic.mil/100.2/ADA474386
Abstract: This thesis explores the effect camera motion and feature tracking have on the estimations of an epipolar geometry at different stages of a 3D reconstruction and relates the findings to a framework for vision based Simultaneous Localization and Mapping (SLAM). Although there have been previous attempts to determine the quality of algorithms that calculate a fundamental matrix, both robust and linear, we have found no study that explores the relationship between camera motion, or likewise the different types of parallax, and errors in the epipolar geometry between two images as defined by an estimated fundamental matrix. The interest comes from the fact that there are claims to this end made by two prominent textbooks in this area. By using synthetic scenes that are projected with and without noise by camera matrices that define different camera motions between the projections we are able to isolate the three different type of parallax that can be experienced between projections; no parallax shift from rotational movement, a high amount of parallax shift from translational movement in the camera's xy-plane, a high amount of parallax shift from translational movement along the camera's optical axis (z-plane). We also studied an unconstrained movement with components of each of the previous three types. The different camera motions are equivalent to different motions a robot would experience when performing SLAM, specifically, rotational, lateral, forward and unconstrained motions. There are multiple experiments that explore the effect motion has at every stage of a projective reconstruction algorithm.

Monroe, Dennis W. ***Navy Requirements for Controlling Multiple Off-Board Robots Using the Autonomous Unmanned Vehicle Workbench***. M.S. in Modeling, Virtual Environments and Simulation (MOVES). Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Don Brutzman
Second Readers: Jeff Weekley and Terry Norbraten
http://hdl.handle.net/10945/3446
http://handle.dtic.mil/100.2/ADA471375
Abstract: The Autonomous Unmanned Vehicle Workbench (AUVW) is an ongoing project at NPS that allows rehearsal, real-time control, and replay of diverse autonomous unmanned vehicle (AUVs) missions. The AUVW increases the situational awareness of operators while allowing operators to learn valuable insights in a robots performance before, during, and after a mission. This thesis examines a variety of strategic authoritative plans for autonomous vehicles to determine functional mission requirements that autonomous vehicles are expected to be performing in the near future. Excellent agreement on tactical needs and requirements was found among these diverse documents. A series of exemplar missions corresponding to specific requirements are presented as a way to explore and evaluate different tactical capabilities. These missions are then compared to the current capabilities of the AUVW by planning, running, and evaluating them in the workbench. Although the AUVW is a powerful tool it still lacks some functionality to make it tactically usable. Nevertheless, perhaps two thirds of the necessary capabilities are already supported in the workbench and further capabilities can be feasibly integrated. The result of this work is a roadmap for future work to add functionality so that the workbench can thoroughly perform user tasks in all mission areas.

Nachmani, Gil. ***Minimum-Energy Flight Paths for UAVs using Mesoscale Wind Forecasts and Approximate Dynamic Programming***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: Johannes O. Royset
Second Reader: Kevin Jones
Outstanding Thesis Award
http://hdl.handle.net/10945/3150
http://handle.dtic.mil/100.2/ADA475882

Abstract: Fuel or battery consumption of unmanned aerial vehicles (UAVs) can be improved by utilizing or avoiding air currents. This thesis adopts a network modeling approach to formulate the problem of finding minimum energy flight paths. The relevant airspace is divided into small regions using a grid of nodes, inter-connected by arcs. A function, representing energy cost, is defined on every arc in terms of the solution of a constrained nonlinear program for the optimal local airspeed to fly in a given wind field. Then, shortest-path models are implemented on the network to find the optimal paths from an origin to a destination. Five models are studied and they correspond to cases of pre-planning of flight routes and dynamic updating of routes during the course of the flight. These models use three-dimensional grids of forecasted wind currents, produced by the Naval Research Laboratory's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) with horizontal resolution of 1 km. One of the shortest-path models, a stochastic-dynamic model, assumes real-time measurement capabilities of the wind velocity in the vicinity of the UAV, through its GPS-INS system, and provides updated waypoints to follow after every measurement. For each model, the energy costs of the shortest-path solutions for 1000 randomized missions over a Nevada test site are simulated and compared to the energy costs of straight-line paths. For a 100 kg UAV, the dynamic model produces an average reduction of 15.1% in the energy consumption along 40 km long round trips, and an average reduction of 30.1% under windy conditions with average wind speeds larger than 15 m/s. A stochastic-dynamic model for maximum duration, solved using a heuristic algorithm, achieves an average increase of 32.2% in the flight duration for a 100 kg UAV.

Nader, Cesar E. ***An Analysis of Manpower Requirements for the United States Marine Corps Tiers II & III Unmanned Aerial Systems Family of Systems Program***. Master of Business Adminstration. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Bill Hatch
Second Reader: Cary Simon
http://hdl.handle.net/10945/3465
http://handle.dtic.mil/100.2/ADA471381

Abstract: This research was conducted to examine the quantitative and qualitative component requirements for the Tier II and Tier III of the United States Marine Corps Unmanned Aerial Systems Program. The main objective of this research is to develop a proposed manpower structure for a composite squadron in order to improve current UAS capabilities while minimizing manpower requirements. This was accomplished by conducting an independent assessment of manpower requirements of the different strategies being considered under the Unmanned Aerial Systems Family of Systems (UAS FoS) for the Marine Corps for the Tier II and III. In the final analysis, the research recommends the consolidation of the Tiers II and III to form a composite UAV squadron, reduce the logistics footprint by relegating the support mission to the MWSS and the MALS, and combining operational and maintenance billets within the current VMU structure to consolidate manpower requirements and optimize UAS force structures.

Oliver, Derek M. ***An Alternative Optimization Model and Robust Experimental Design for the Assignment Scheduling Capability for the Unmanned Aerial Vehicles (ASC-U) Simulation***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: susan M. Sanchez
Second Reader: Darryl K. Ahner
Outstanding Thesis Award
http://hdl.handle.net/10945/3400
http://handle.dtic.mil/100.2/ADA473318

Abstract: The Modeling, Virtual Environments, and Simulations Institute (MOVES) and the United States Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC) at the Naval Postgraduate School, Monterey, California, developed the Assignment Scheduling Capability for Unmanned Aerial Vehicles (ASC-U) discrete event simulation to aid in the analysis of future U.S. Army Unmanned Aerial Vehicle (UAV) requirements. TRAC selected ASC-U to provide insight into the programmatic decisions addressed in the U.S. Army UAV-Mix Analysis that directly affects future development and fielding of UAVs to include the Future Combat System. ASC-U employs a discrete event simulation coupled with the optimization of a linear objective function. At regular intervals, ASC-U obtains an optimal solution to an assignment problem that assigns UAVs to mission requirements that are available or will be available at some time in the future. This thesis presents an alternative optimization model, explores 23 simulation factors, and provides sensitivity analysis for how UAV coverage may degrade in the presence of adverse random events. Integer programming, experimental design, and an innovative Optimized Flexible Latin Hypercube (OFLH) design are used to evaluate a representative sample from an Army 2018 scenario. The conclusions suggest the following: the alternative optimization model developed in this thesis can successfully maximize ASC-U value without the use of a heuristic; smaller optimization intervals do not guarantee higher total value when the heuristics are included; to maximize total value, Early Return should be set to FALSE and Secondary Areas should be set to TRUE; an OFLH is valuable for robust analysis of simulation models containing many factors; and as the model factors change over predefined ranges, the solution quality is consistent.

Papadopoulos, Themistoklis. ***Probability Modeling of Multi-Type Autonomous Unmanned Combat Aerial Vehicles Engaging Non-Homogeneous Targets Under Imperfect Information***. M.S. in Modeling, Virtual Environments and Simulation (MOVES). Monterey, California: Naval Postgraduate School, March 2007.
Thesis Advisor: Moshe Kress
Second Reader: Kyle Lin
http://hdl.handle.net/10945/3622
http://handle.dtic.mil/100.2/ADA467498

Abstract: UCAVs are advanced weapon systems that can loiter autonomously in a pack over a target area, detect and acquire the targets, and then attack them. Modeling these capabilities in a specific hostile operational setting is necessary for addressing weapons design and operational issues. While much attention has been given to the engineering and technological aspects of UCAV developments, there are very few studies on operational concepts for these weapon systems and their effectiveness and efficiency. This thesis builds probability models (Markov Chains) that describe UCAV operations, defines Measures of Effectiveness (MOEs) for the engagement performance, maps the functional relations between the parameters and the MOEs, and obtains insights regarding the design of the UCAVs and their tactical employment. The models are used to conduct extensive numerical analysis, based on experimental design concepts and traditional sensitivity analysis. The main focus of the analysis is to investigate optimal and robust mixes of UCAVs of different types, with respect to the MOEs. While in most cases, extreme-point solutions are optimal, there are cases where a balanced UCAV mix is better.

Papalexidis, Nikolaos. ***Distributed Algorithms for Beamforming in Wirless [Sic] Sensor Networks***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Co-Advisors: Murali Tummala and John C. McEachen
Thesis Committee Members: Roberto Cristi and Weilian Su
http://hdl.handle.net/10945/3397
http://handle.dtic.mil/100.2/ADA473271
Abstract: Sensor nodes in a wireless sensor network (WSN) can establish a link with a UAV by using beamforming techniques to form a random array with position errors. The position errors' effect in the array performance is examined using a MATLAB-based simulation model. In order to spread the processing and communication load among the nodes, two new distributed algorithms for beamforming in WSN, based on the least squares (LS) approximation of the desired array response, are proposed. The first is a distributed implementation of the QR decomposition, and the second is an iterative method for solving the LS problem. Results indicate that the processing load is effectively shared among the nodes. Especially, in the second approach, the processing load can be lower than that of the centralized approach, depending on the algorithm's convergence. For both algorithms, the tradeoff for the ability to spread the processing load is the increased communication cost, which could cause an overall increase in the total power consumption in the network. However, the average power per participating sensor node is still lower than that required by the cluster head in the centralized approach. Consequently, the network's susceptibility to failures due to excessive power consumption is greatly reduced.

Poulin, Robert J. ***Mapping Autonomous System's Router Level Topology in IPv6***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Co-Advisors: Geoffrey Xie and John Gibson
http://hdl.handle.net/10945/3412
http://handle.dtic.mil/100.2/ADA473429
Abstract: The core of the Internet is composed of many independent and mutually exclusive collections of routers, called Autonomous Systems, which are responsible for moving traffic between communicating end-systems, or hosts, regardless of the relative location of those hosts. The complexity of the internal composition of these autonomous systems is such that accurate documentation of their topology, reference to as mapping, is difficult and prone to error. Developing automated support for this effort remains an area of active research, the potential benefit of which is the ability to actively monitor the health of the Internet across these autonomous systems making it possible to identify critical infrastructure chokepoints before their failure adversely impacts the network or national security. The Internet is in the process of transitioning to a new version of the Internet Protocol, the fundamental protocol that melds the heterogeneous networks worldwide into a single cooperative whole. Tools, techniques, and tactics developed for the current version, IPv4, may hold promise for adaptation to support the new version, IPv6. This thesis explores several of the IPv4 techniques that hold promise for adaptation and provides an implementation as a proof-of-concept.

Reber, Daniel N. ***Optimized Routing of Unmanned Aerial Systems for the Interdiction of Improvised Explosive Devices***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2007.
Thesis Advisor: Johannes O. Royset
Second Reader: Robert F. Dell
Outstanding Thesis Award
http://hdl.handle.net/10945/3242
http://handle.dtic.mil/100.2/ADA474352
Abstract: As of September 2007, improvised explosive devices (IED) account for 43% of U.S. casualties in Iraq - the largest single cause of death. One reason for their high rate of effectiveness is that they are extremely difficult to detect. This research develops a tool for selecting routes that will best employ unmanned aerial systems (UAS) for the purpose of detecting IED or related activity. We refer to this tool as IED Search Optimization Model (ISOM).

ISOM - which uses prediction model results as an underpinning - accounts for factors such as winds, sensor sweep-width, and aircraft deconfliction. We formulate the problem as an Integer Program and optimally solve it to select the best routes. Initial evaluation of ISOM through field experiments with actual UAS suggest that the tool produces realistic routes which can be flown in the expected amount of time. Furthermore, these routes result in a 42% increase in the likelihood of achieving a detection opportunity over searching nodes in a random manner. ISOM could be implemented as a "reach-back" capability with an analyst providing daily routes for tactical operators.

Richerson, John Paul. *The Extension of Wireless Mesh Networks Via Vertical Takeoff and Landing Unmanned Aerial Vehicles*. M.S. in Operations Analysis. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Co-Advisors: James Eagle and James Ehlert
Second Reader: Kyle Lin
http://hdl.handle.net/10945/3132
http://handle.dtic.mil/100.2/ADA475876
Abstract: The evolution of integrated circuits, wireless communications, and data networking makes wireless networks practical for military and law enforcement applications. The objective of this thesis is to test and to evaluate network performance and suitability of an 802.11 wireless access point enabled vertical takeoff and land (VTOL) unmanned aerial vehicle (UAV) functioning as an airborne sensor and communications relay platform. Also, by identifying the production process of a COTS Remote Controlled Helicopter equipped with a wireless access point, a system comprised of discrete technologies and production steps can be defined to gain insight into defeating an Aerial Improvised Explosive Device (AIED). Understanding the true capabilities of a small VTOL UAV, its applicability to a wireless network, and the production system associated with the manufacture of an AIED will allow proper planning, application and utilization in support of security and Force Protection missions and scenarios.

Rogers, John Henrik. *A New Sufficient Condition for Robust Interdomain Routing*. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Geoffrey Xie
Second Reader: John Gibson
http://hdl.handle.net/10945/3408
http://handle.dtic.mil/100.2/ADA473414
Abstract: Border Gateway Protocol (BGP) is currently the only interdomain routing protocol employed on the internet. It allows tens of thousands of Autonomous Systems (ASes) to exchange routing information while implementing economic and organizational policies. However, conflicting policies between ASes can cause routing instability and/or unpredictable routing solutions. A system of routers is robust if routing tables always converge predictably, despite router and link failures. We pursue an approach to guarantee BGP robustness through operational guidelines. Existing guidelines for BGP robustness are essentially geared toward satisfying the same sufficient condition for BGP robustness developed by Griffin and Wilfong. In this thesis, we first show that there exists a weaker sufficient condition for BGP robustness. We then discuss how new guidelines for configuring BGP with a guarantee of robustness may be derived from this new condition. Additionally, we compare various models of BGP behavior and show that the models do not always have equivalent results and sometimes have completely different behavior.

Schenk, Michael A. *Real-Time Implementation of an Asynchronous Vision-Based Target Tracking System in an Unmanned Aerial Vehicle*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Isaac I. Kaminer
Second Reader: Vladimir N. Dobrokhodov
http://hdl.handle.net/10945/3529
http://handle.dtic.mil/100.2/ADA473354
Abstract: Currently, small unmanned aerial vehicles developed by NPS have been able to locate

and track stationary and moving targets on the ground. New methods of continuous target tracking are always being developed to improve speed and accuracy, ultimately aiding the user of the system. This thesis describes one such method, utilizing an open loop filter as well as an external correction source: Perspective View Nascent Technologies (PVNT). While the PVNT correction can theoretically improve the accuracy from 20-30 meters to 1-2 meters, it does have a disadvantage in that the target position updates are delayed anywhere from 1-10 seconds. In order to account for the delay, an asynchronous filter is used to update the target position data given the external position correction from PVNT. Two cases have been tested including the general filter and one that utilizes a road model in the calculations. While an earlier thesis developed the basic simulation for the system, this thesis discusses improvements and corrections to the simulation model as well as the necessary steps for real-time implementation.

Seguin, John M. ***Simulating Candidate Missions for a Novel Glider Unmanned Underwater Vehicle***. M.S. in Information Systems and Operations. Monterey, California: Naval Postgraduate School, March 2007.
Thesis Advisor: Don Brutzman
Second Readers: Ray Jones and Richard Willaims
http://hdl.handle.net/10945/3664
http://handle.dtic.mil/100.2/ADA467375
Abstract: Unmanned Underwater Vehicles (UUVs) are becoming ubiquitous in the framework of U.S. Navy operations. According to the U.S. Navys UUV Master Plan (2004), research and development will expand UUV capabilities that enable diverse roles from Intelligence, Surveillance, and Reconnaissance (ISR) and Mine Countermeasures to Anti-Submarine Warfare (ASW) and Information Operations (IO). However, typical UUVs are severely limited in operational characteristics such as endurance and range which prevents their use conducting certain missions. A novel UUV is currently being designed that is projected to support significantly greater endurance and range characteristics. This UUV is called Seadiver and is being designed by Institute of Engineering Science of Toulon, France with support from Naval Postgraduate School. It is a low-cost glider UUV which generates propulsion not with propellers or jet pumps, but rather by controlling its buoyancy. This method of propulsion is quite efficient and maybe capable of autonomous operation up to 30 days with a range of around 700 nautical miles. A UUV with such endurance and range exposes military missions previously impractical for UUVs especially when used in concert as an array of many UUVs. This thesis creates a simulation using NPS-produced software simulation tools Simkit, Viskit and AUV Workbench that analyzes the capabilities and effectiveness of Seadiver UUVs conducting missions of tactical interest.

Sjoberg, Eric J. ***Autonomous Coordination and Online Motion Modeling for Mobile Robots***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, September 2007.
Thesis Co-Advisors: Kevin Squire and Craig Martell
http://hdl.handle.net/10945/3206
http://handle.dtic.mil/100.2/ADA474495
Abstract: Robots are rapidly becoming more involved in everyday military operations. As robots become more capable, their tasks will increase to include such roles as exploring enemy controlled buildings and caves. The goal of this thesis is to explore methodologies that allow robots to operate more autonomously. The first goal is to develop an algorithm that allows groups of robots to construct controlled formations with only local information. Experiments investigate the ability of this algorithm to handle obstacles, dynamic conditions, and varying number of robots. The second goal of this work is to demonstrate a method by which a robot can automatically determine how it is moving. Experiments demonstrate the ability of the algorithm to learn new models given models from other surfaces and robots. This work facilitates further research into creating complex formations using only local information and in fully automating current Simultaneous Localization And Mapping (SLAM) applications.

Smeltz, Jeremy M. and Andrew J. Valerius. ***Sensor Failure Detection through Introspection***. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Co-Advisors: Craig Martell and Kevin Squire
http://hdl.handle.net/10945/3518
http://handle.dtic.mil/100.2/ADA473472
Abstract: The advancement of robot technology holds many opportunities for military applications. One area of research being done is simultaneous localization and mapping (SLAM). SLAM uses a robot's sensors to generate a map of the area while maintaining its current position within that map. SLAM research is built upon the assumption that all of the sensors are working correctly. Since field conditions are likely to cause erratic sensor function due to damage or inclement weather conditions, this assumption must be addressed. The goal of our research is to discover methods of effectively performing self-diagnostic checks on robots to detect failures and malfunctions in sensors. There has been little work in the area of error detection in sensors, and what little work has been done has limited applications. This thesis will perform a series of experiments using a variety of different error detection techniques. It is our hope that the methods developed will prove to be applicable to a variety of real world systems.

Smuda, William James. ***Rapid Prototyping of Robotic Systems***. Ph.D in Software Engineering. Monterey, California: Naval Postgraduate School, June 2007.
Disseration Supervisor: Mikhail Auguston
http://hdl.handle.net/10945/10225
http://handle.dtic.mil/100.2/ADA473433
Abstract: This effort describes a systems engineering approach to the design and implementation of software for prototyping robotic systems. Developing networked robotic systems of diverse physical assets is a continuing challenge to developers. Problems often multiply when adding new hardware/software artifacts or when reconfiguring existing systems. This work describes a method to create model-based, graphical domain-specific languages. Domain-specific languages use terms understandable to domain engineers as well as abstract software engineering decisions. This methodology enables domain engineers to create quality executable prototypes without being versed in the intricacies of software engineering.

Stracker, Matthew C. ***An Operational Manpower Analysis of the RQ-8 Fire Scout Vertical Take-Off Unmanned Aerial Vehicle (VTUAV)***. M.S. in Management. Monterey, California: Naval Postgraduate School, September 2007.
Thesis Advisor: Bill Hatch
Second Reader: Ben Roberts
http://hdl.handle.net/10945/3208
http://handle.dtic.mil/100.2/ADA474494
Abstract: In August of 2001 the Secretary of the Navy announced the Navy would expand the work and experimentation in unmanned vehicle systems. After the events of September 11 this was accelerated with the increased urgency to combat terrorism and asymmetric threats. The U.S. Navy is currently undergoing testing and evaluation of the Fire Scout Vertical Take-Off Unmanned Aerial Vehicle (VTUAV) and its integration into the fleet. An in depth analysis of the Fire Scout's manpower requirements is necessary as part of total force integration. At the present time, the Navy only utilizes aviation ratings by requirement and assignment as unmanned aerial system operators, unlike the Army and Marine Corps. Therefore, the Littoral Combat Ship manpower requirements exceed the Navy's target of 25 persons for the combined RQ-8B and SH-60 air detachment. Analysis shows a possible remedy to this problem is to allow non-aviation ratings the opportunity to operate the Fire Scout. This change in policy and occupational standards would generate greater operational capability and personnel flexibility for this newly acquired air ship and surface platform. Specifically, occupational research showed the Aviation Administrationman (AZ) rating is no more qualified to operate a Fire Scout VTUAV than the Operations Specialist (OS) rating. In fact, it can be argued that an OS is better qualified according to occupational standards to operate the Fire Scout. Therefore, one of the

recommendations of this research is to add Operational Specialist as a source rating to NECs 8363 and 8364 immediately.

Teng, Choon Hon Adrian. ***Design and Performance Evaluation Study of a Prototype of a Tactical Unmanned Aerial Vehicle***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Co-Advisors: Kevin D. Jones and Vladimir N. Dobrokhodov
http://hdl.handle.net/10945/3043
http://handle.dtic.mil/100.2/ADA475917
Abstract: This thesis aims to provide a low-cost solution through integrating commercial off-the-shelf (COTS) technologies to produce a prototype of a "Tactical Unmanned Combat Aerial Vehicle UCAV" system that can be utilized by the front-line ground units in the near future. The Tactical UCAV is designed to enhance the information collection and autonomous precision strike capability of the ground units. The Tactical UCAV can also be deployed as sensor nodes as part of a larger global information grid in a networkcentric warfare operation. The proposed Tactical UCAV system is comprised of a Hunter Unmanned Aerial Vehicle (HUAV), which primarily carries high resolution sensors and communication devices and is used as a mother-ship for smaller "Killer UAVs (KUAV)." The KUAV carries a mission specific set of instruments; it can be a sensor or a warhead or both depending on the desired end results. After the target is acquired by the HUAV, the target information will be transferred to the KUAV. The KUAV can then be launched in close proximity of the target with the target position update from the HUAV. This thesis will focus on the development of a prototype KUAV and the integration of the prototype with the existing HUAV "Rascal" developed and operated by the Naval Postgraduate School (NPS). The KUAV and the HUAV will form the Tactical UCAV system.

Toh, Leng Huei. ***A Follow-Up Study on Wireless Power Transmission for Unmanned Air Vechicles [Sic Vehicles]***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: David C. Jenn
Second Reader: Michael A. Morgan
http://hdl.handle.net/10945/3039
http://handle.dtic.mil/100.2/ADA475913
Abstract: This thesis was a continuation in part of a NPS project relating to microwave wireless power transmission for micro air vehicles (MAVs). The concept of using microwaves for transferring power in free space has existed since the beginning of the 20th century. The emphasis of this thesis is the experimental study of powering micro air vehicles via the use of using a microstrip rectenna (rectifying antenna) at 10 GHz. A microstrip rectenna was built and experiments were conducted to measure the efficiency of the rectenna elements. The conversion of radio frequency (RF) power into usable DC power was performed by a rectenna. Its function could be broken down into the following four stages: reception of radio frequency (RF) power, prerectification filtering, rectification, and post-rectification filtering. A rectenna model based on past research by NPS students was simulated, built, and tested. The analysis and findings of the rectenna model were presented, with suggested improvements highlighted.

Tzellos, Konstantinos. ***Filter Bank Approach to the Estimation of Flexible Modes in Dynamic Systems***. M.S. in Electrical Engineeing. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Roberto Cristi
Second Reader: Xiaoping Yun
http://hdl.handle.net/10945/3467
http://handle.dtic.mil/100.2/ADA473493
Abstract: The problem of estimating frequencies of sinusoids buried in noise has been great interest in both military and civilian applications. In particular, in Control Systems with flexible appendages the sinusoidal vibrations can cause instabilities and degrade performance of the overall system. In this thesis the problem of identifying frequencies disturbances in flexible

systems using advanced Digital Signal Processing techniques such as filter banks and Quadrature Mirror Filters is addressed. In a number of situations there is a need to design a controller for a system with flexible modes. In particular, space applications solar panels and robotic arms introduce flexible modes in the system which degrades the performance. In these kinds of applications, the frequencies of flexible modes can not be modeled accurately a priori and they can change according the operating conditions. The proposed approach is tested by computer simulations.

Vincent, Patrick J. ***Energy Conservation in Wireless Sensor Networks***. Ph.D in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2007.
Disseration Supervisor: Murali Tummala
http://hdl.handle.net/10945/10228
Abstract: This dissertation presents a system-level approach for minimizing the power expended in achieving communication between a ground-based sensor network and an overhead Unmanned Aerial Vehicle (UAV). A subset of sensor nodes, termed a transmit cluster, aggregates data gathered by the network and forms a distributed antenna array, concentrating the radiated transmission into a beam aimed towards the UAV. We present a method for more uniformly distributing the energy burden across the sensor network, specifying the time that should elapse between reassignments of the transmit cluster and the number of hops that should be placed between successive transmit clusters. We analyze the performance of two strategies for reconfiguring the communication burden between the sensor network and the UAV in order to bring the UAV and the sensor network's beam into alignment quickly, while minimizing the energy expenditure. We analyze the optimal number of nodes that should participate in a beamforming process in order to minimize the energy expended by the network, and we provide a framework to analyze the minimum energy expended in a simple beamforming algorithm. Finally, we analyze the probability that an arbitrarily selected sensor node is connected to a specified number of other nodes and we present an algorithm for the formation of near-linear arrays given random placement of nodes.

Volland, Kirk N. ***Design, Construction and Testing of a Prototype Holonomic Autonomous Vehicle***. M.S. Applied Physics. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: Richard Harkins
Second Reader: Peter Crooker
http://hdl.handle.net/10945/3033
http://handle.dtic.mil/100.2/ADA475739
Abstract: United States Department of Defense (DoD) autonomous vehicle efforts have concentrated research in areas that support development of unmanned ground and air battlefield vehicles. Little attention has been paid to applying robotics to automate routine tasks. A robotic solution consisting of a prototype holonomic vehicle is proposed to search for, detect, and remove debris that could cause foreign object damage (FOD) to turbine-engine aircraft operated from ships. Holonomic, or omnidirectional, motion was realized by solving the system of equations governing the vehicle's motion atop a plane surface. Translational motion without chassis rotation was achieved through motion control using a single board computer, a pulse width modulation (PWM) and optical isolation circuit, and a low-cost inertial measurement unit (IMU). Obstacle detection and avoidance was realized by constructing a microprocessor-controlled scanning ultrasonic sonar detector head and controller circuit. The sonar detector demonstrated 360 (degrees) coverage and centimeter resolution. Rudimentary autonomous operation and wireless manual control via a Java graphical user interface (GUI) were achieved in an indoor environment.

Williamson, Todd A. ***Modeling and Implentation of PID Control for Autonomous Robots***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Richard Harkins
Second Reader: Peter Crooker
http://hdl.handle.net/10945/3470
http://handle.dtic.mil/100.2/ADA473631

Abstract: PID control is optimized here to control the course of a small autonomous robot for military applications. A Visual Basic program was written to model the robot response to the controller and provide a method of optimization. The computer model is based on empirical data gathered through testing. Controller theory, robot mechanics, and hardware implementation are all discussed as they relate to the ability of the robot to get from one location to another along an efficient path. The controller was tuned to provide optimal direction control and the model was evaluated for accuracy. The robot completed a 170 degree pivot turn in 4.0 seconds and a 170 degree differential turn in 5.1 seconds. The time predicted by the model for the each turn was within 10% of what the robot did.

Wolf, Rebecca E. ***Observations and Modeling of the Shelf Circulation North of the Monterey Bay during August 2006***. M.S. Physical Oceanography. Monterey, California: Naval Postgraduate School, June 2007.
Thesis Advisor: Steven R. Ramp
Second Reader: Leslie K. Rosenfeld
http://hdl.handle.net/10945/3469
http://handle.dtic.mil/100.2/ADA473639

Abstract: In August of 2006 the Adaptive Sampling and Prediction (ASAP) experiment was conducted near the northern Monterey Bay. Multiple assets including aircraft, autonomous vehicles, moorings, and numerical models were used to gain a better understanding of three-dimensional upwelling centers. Data were collected at two separate mooring locations using Acoustic Doppler Current Profilers (ADCPs) during the experiment. The focus of this thesis is to determine the effects of local wind forcing on the ocean circulation and provide a comparison between the data collected at the mooring locations and numerical predictions for the region. Upwelling and relaxation events are used as the basis for understanding the local wind forcing. Upwelling typically results in equatorward flow while relaxation events typically result in poleward flow. Several different types of analyses were used to determine the effects of the local wind forcing. A visual analysis was performed with stick vector plots and component plots of the rotated time series that compared the wind with the data from the water column. Two methods of cross correlation, component correlations and vector correlations, were exploited as well as a spectral analysis of the wind and ADCP data. Finally the coherence and phase between the wind and currents were examined. Based on the analysis it became evident that the currents were forced by both wind and non-local events such as eddies, meanders, and the large-scale alongshelf pressure gradient. Associated with the ASAP experiment, the Harvard Ocean Prediction System (HOPS), the Regional Ocean Modeling System (ROMS), and the Navy Coastal Ocean Model (NCOM) provided nowcasts that were compared with the mooring data to determine their accuracy and precision. Overall, in the beginning of August the models provided reasonable representations of the flow patterns at the mooring locations. The prediction error increased towards the end of August which was possibly related to data assimilation techniques and more non-local forcing at that time. The military application of this thesis is that accurate current prediction by ocean models will benefit amphibious operations, special warfare operations, and mine warfare in the littoral zone.

Yeh, Mingtze. ***Throughput Evaluation of an Autonomous Sustainment Cargo Container System***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2007.
Thesis Advisor: Fotis Papoulias
http://hdl.handle.net/10945/3024
http://handle.dtic.mil/100.2/ADA475748

Abstract: With the development of new concepts in military operations and reductions in manpower of our military forces, the promotion of autonomous systems has been pushed to the forefront. Autonomous containers will play an essential role in the ability to deliver logistical supplies to waterborne littoral vessels enabling them to maintain station and complete there military operations while reducing the threat to personnel. Programmed to deliver supplies to a specified local in a reasonable timetable, these containers will play an essential role to vessels such as Riverine Warfare patrol craft, Special Operations craft and Coast Guard search and rescue boats. Development of a successful autonomous system that can deliver logistical supplies in littoral human threat arenas would serve as an immense reduction in logistical supply costs. The research that is to be conducted will focus on the unique characteristics of an autonomous sustainment cargo container and its throughput evaluation. Use of geometric data and static stability is analyzed and compared. In depth analysis primarily focuses on the hull characteristics of the container and whether subtle alterations to the bow and stern units reduce the resistance and increase the efficiency of the deliverability rate of the autonomous system.

Zirkelbach, Thomas. ***Pictorial Display Design to Enhance Spatial Awareness of Operators in Unmanned Aviation***. M.S. in Modeling, Virtual Environments and Simulation (MOVES). Monterey, California: Naval Postgraduate School, March 2007.
Thesis Advisor: Michael E. McCauley
Second Reader: Anthony P. Ciavar
http://hdl.handle.net/10945/3568
http://handle.dtic.mil/100.2/ADA467707

Abstract: In aviation, spatial awareness and spatial orientation are essential for performing the task of recovering from an unusual attitude. Degraded spatial awareness, particularly in extreme flight situations, may lead to lower operational effectiveness and to loss of equipment and, in manned aviation, loss of life. Therefore, inprovements in spatial awareness in complex 3D environments, including both manned and unmanned aviation. The main goal of this thesis was to determine whether a new prototype display design, called WEBER-Box, is a useful alternative or supplement to traditiona flight instruments for unmanned aviation. In addition we combined the traditional flight instrument as well as the WEBER_Box with a color-coded indication when the aircraft entered an unusual attitude. In this experiment, the participants executed typical tasks of a UAV-operator. We investigated the influence of the WEBER-Box on UAV operator's orientation performance. The important results can be summarized as follows: 1. significant improvement in correctly solving the orientation tasks, 2. significant reduction in time to solve orientation tasks, 3. color coded indication of unusual attitude significantly decreased the response time and reduced the error, 4. the proposed display design was accepted, interpreted, and and used to solve 3D-orientation tasks efficiently.

2006

Beaver, James W., Andrew D. Bucher, Richard W. Byers, Jennifer M. Free, Pedro R. Mercado, and Tristan V. Oliveria. ***Systems Analysis of Alternative Architectures for Riverine Warfare in 2010***. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Co-Advisors: Eugene Paulo and Richard Williams
http://hdl.handle.net/10945/2361
http://handle.dtic.mil/100.2/ADA460370

Abstract: This thesis analyzed the Navy's proposed Riverine Force (RF) structure and capabilities of 2006. Systems Engineering and Analysis cohort 10 (SEA10) developed a cost-effective system of systems which increased battlespace awareness and situational responsiveness for 2010. Riverine missions were decomposed into their functional, physical, and operational architectures using the detect-to-engage sequence. This analysis determined critical RF functions. Critical functions detect and engage were then physically represented by feasible force package alternatives that augmented the baseline RF. SEA10 analyzed these alternatives using agent based models to identify baseline RF capability gaps and provide insights into possible solutions. Reduction of modeling data indicated the baseline force was as effective as some upgraded force packages depending on the measure of performance (MOP) or scenario structure under scrutiny. Sensor augmentation demonstrated significant improvements to baseline performance by increasing battlespace awareness. Weapon augmentation alone did not significantly improve baseline performance by increasing situational responsiveness. Combined sensor-weapon augmentation performed well across all MOP and scenarios. The Unmanned Surface Vehicle (USV) was the most cost-effective alternative. Dedicated helicopter support demonstrated the best performance overall, but was the most costly alternative.

Bessemer, William G. ***Transitioning to Unmanned Combat Aerial Vehicles***. M.S. in Information Operations. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: Robert O'Connell
Second Reader: Anna Simons
http://hdl.handle.net/10945/2361
http://handle.dtic.mil/100.2/ADA456959

Abstract: The Air Force is currently developing Unmanned Combat Aerial Vehicles (UCAV). The UCAV is projected for initial testing by 2010. However, after reviewing the Office of Secretary of Defense's Unmanned Aircraft Systems Roadmap for 2005 2030; obtaining squadrons of UCAVs will cost billions of dollars and require decades to produce. The United States cannot afford to wait decades for unmanned weapons. Technology is spreading fast. Third world countries without stable economies and non-state actors are able to obtain/develop sophisticated weapons that are capable of destroying tactical aircraft. With sophisticated weapons easily obtainable, the risk of losing people in air combat is increasing significantly and that in turn is creating a level playing field for potential U.S. adversaries. Unmanned weapons technology can help America retain its military edge. However, since unmanned warfare capability is still decades away and is a multi-billion dollar project, America needs a quick fix. This study will argue that the most effective way to decrease risk-of-life and budget costs is to introduce F-16 Unmanned Aerial Systems (UAS) aircraft for combat. This thesis will answer the question: How can the government seize the unmanned aircraft advantages and decrease defense spending until the UCAV is operational? The answer to this question will illustrate how an effective F-16 UAS force can synchronize resources to properly complete UCAV development while instantly reducing risk of life.

Chin, Chee Kian. ***Experimental Investigation of Pitch Control Enhancement to the Flapping Wing Micro Air Vehicle***. M.S. in Engineering Science (Mechanical Engineering). Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Kevin D. Jones
Second Reader: Christopher Brophy
http://hdl.handle.net/10945/2497
http://handle.dtic.mil/100.2/ADA462357

Abstract: The mechanical pitching characteristic of the NPS flapping-wing Micro Air Vehicle (MAV) developed by Professor Kevin D. Jones are studied experimentally through the use of constant temperature anemometry and force balance techniques. The MAV without the main fixed-wing is placed in a laminar flow field within a low speed wind tunnel with the wake after the flapping wings characterized with a constant temperature anemometer and thrust generation measured by a load cell at various neutral angles, flapping frequencies and free stream velocities. The experiments seek to determine the effects on the MAV propulsion when the neutral angle of attack of the flapping wings is varied. Flow visualization is also performed to better enhance understanding of the flow field across the pitched flapping wings.

Davis, Duane T. ***Design, Implementation and Testing of a Common Data Model Supporting Autonomous Vehicle Compatibility and Interoperability***. Ph.D. in Computer Science. Monterey, California: Naval Postgraduate School, September 2006.
Disseratation Supervisor: Don Brutzman
http://hdl.handle.net/10945/10150
http://handle.dtic.mil/100.2/ADA457026

Abstract: "Current autonomous vehicle interoperability is limited by vehicle-specific data formats and support systems. Until a standardized approach to autonomous vehicle command and control is adopted, true interoperability will remain elusive. This work explores the applicability of a data model supporting arbitrary vehicles using the Extensible Markup Language (XML). An exemplar, the Autonomous Vehicle Command Language (AVCL), encapsulates behavior-scripted mission definition, goalbased mission definition, inter-vehicle communication, and mission results. Broad applicability is obtained through the development of a behavior set capturing arbitrary vehicle activities, and automated conversion of AVCL to and from vehicle-specific formats. The former uses task-level behaviors suitable for mission scripting and goal decomposition. Translations use the Extensible Stylesheet Language for Transformation, XML data binding, context-free language parsing, and artificial intelligence machine learning and search techniques. Translation capability is demonstrated through mappings of AVCL to and from multiple vehicle-specific formats. A final demonstration of the power of a common autonomous vehicle data model is provided by the implementation of a hybrid control architecture. The model's vehicle-independence and the ability to generate vehicle-specific data are leveraged in the design of an architecture that provides increased autonomy by augmenting a vehicle's existing controller. The utility of this architecture is demonstrated through implementation on the Naval Postgraduate School's ARIES Unmanned Underwater Vehicle."--p. i.

DeVane, John C. ***Applicability of Unmanned Aerial Systems to Homeland Defense Missions***. M.A. in Security Studies (Homeland Security and Defense). Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Craig Hooper
Second Reader: Brian Greenshields
http://hdl.handle.net/10945/2509
http://handle.dtic.mil/100.2/ADA462422

Abstract: Battlefield success of Unmanned Aerial Systems (UAS) prompted Department of Defense and Department of Homeland Security leaders to examine their possible applicability to homeland defense missions within the National Strategy for Homeland Security. The National Strategy for Homeland Security incorporates all levels of government to include law enforcement agencies and the military, the predominant owner and operator of UASs. The military, however, is restricted in its domestic role by the Posse Comitatus Act, and is therefore limited in its

domestic employment of UASs. In order to determine the applicability of UASs to homeland defense missions, it is necessary to examine the capabilities of available UASs, to match them with mission requirements, and determine the legality of where they can be used and who can operate them. A policy that places combat UAS capability with Title 10 military forces and homeland defense mission capability with Title 32 and law enforcement agencies will fulfill the goals stated in the national strategy and function within the current legal framework.

Dunbar, Thomas W. ***Demonstration of Waypoint Navigation for a Semi-Autonomous Prototype Surf-Zone Robot***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, June 2006.
Thesis Co-Advisors: Richard Harkins and Ravi Vaidyanathan
http://hdl.handle.net/10945/2756
http://handle.dtic.mil/100.2/ADA451347
Abstract: The objective of the Small Robot Technology (SMART) initiative at the Naval Post Graduate School (NPS) is to develop robots for military uses. One of the goals of this program is to create a surf--zone reconnaissance robot to do beachhead surveillance and mine detection. To this end, a prototype robot was created to test the locomotion and navigation functions which will be used on the surf--zone robot. This work consisted of redesigning the steering mechanism, strengthen the structure, improving the electrical distribution and upgrading the communications hardware. Several tests were conducted on both grass and soft sand to evaluate the performance of the locomotion system and the navigation software. The results demonstrated that the robot functions best in soft sand as expected. However, several serious mechanical design flaws were noticed in the body construction and mechanical systems. These flaws, while not detrimental, did negatively impact the performance of the system. Finally, some suggestions for improving future prototypes are discussed.

Eikenberry, Blake D. ***Guidance and Navigation Software Architecture Design for the Autonomous Multi-Agent Physically Interacting Spacecraft (AMPHIS) Test Bed***. M.S. in Astronautical Engineering and Astronautical Engineer Degree. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Marcello Romano
Second Reader: Oleg Yakimenko
http://hdl.handle.net/10945/2349
http://handle.dtic.mil/100.2/ADA477319
Abstract: The Autonomous Multi-Agent Physically Interacting Spacecraft (AMPHIS) test bed examines the problem of multiple spacecraft interacting at close proximity. This thesis contributes to this on-going research by addressing the development of the software architecture for the AMPHIS spacecraft simulator robots and the implementation of a Light Detection and Ranging (LIDAR) unit to be used for state estimation and navigation of the prototype robot. The software modules developed include: user input for simple user tasking; user output for data analysis and animation; external data links for sensors and actuators; and guidance, navigation and control (GNC). The software was developed in the SIMULINK/MATLAB environment as a consistent library to serve as stand alone simulator, actual hardware control on the robot prototype, and any combination of the two. In particular, the software enables hardware-in-the-loop testing to be conducted for any portion of the system with reliable simulation of all other portions of the system. The modularity of this solution facilitates fast proof-of-concept validation for the GNC algorithms. Two sample guidance and control algorithms were developed and are demonstrated here: a Direct Calculus of Variation method, and an artificial potential function guidance method. State estimation methods are discussed, including state estimation from hardware sensors, pose estimation strategies from various vision sensors, and the implementation of a LIDAR unit for state estimation. Finally, the relative motion of the AMPHIS test bed is compared to the relative motion on orbit, including how to simulate the on-orbit behavior using Hill's equations.

Furukawa, Tyler H. ***Reactive Obstacle Avoidance for the REMUS Autonomous Underwater Vehicle Utilizing a Forward Looking Sonar***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2006.
Thesis Advisor: Anthony J. Healey
Second Reader: Douglas Horner
http://hdl.handle.net/10945/2779
http://handle.dtic.mil/100.2/ADA451353

Abstract: One day fully autonomous AUV's will no longer require human interactions to complete its missions. To make this a reality, the AUV must be able to safely navigate in unfamiliar environments with unknown obstacles. This thesis builds on previous work conducted at NPS's Center for AUV Research to improve the autonomy of the REMUS class of AUVs with an implemented FLS. The first part of this thesis deals with accurate path following with the use of look-ahead pitch calculations. With the use of a SIMULINK model, constraints surrounding obstacle avoidance path planning are then explored, focusing on optimal sensor orientation issues. Two path planning methods are developed to address the issues of a limited sonar field of view and uncertainties brought on by an occlusion area. The first approach utilizes a pop-up maneuver to increase the field of view and minimize the occlusion area, while the second approach creates a path with the addition of a spline. Comparing the two methods, it was concluded that spline addition planner provided a robust optimal obstacle avoidance path and along with the look-ahead pitch controller completes the design of a "back-seat driver" to improve REMUS's survivability in an unknown environment.

Gayle, Wayne H. ***Analysis of Operational Manning Requirements and Deployment Procedures for Unmanned Surface Vehicles Aboard US Navy Ships***. Master of Business Administration. Monterey, California: Naval Postgraduate School, March 2006.
Thesis Advisor: Bill Hatch
Second Reader: Cary Simon
http://hdl.handle.net/10945/2900
http://handle.dtic.mil/100.2/ADA445406

Abstract: This research was conducted per a Navy Warfare Development Center request that the Naval Postgraduate School update the Navy's TACMEMO: Integration of UVs into Maritime Missions TM 3-22-5-W. Unmanned Surface Vehicles (USVs) are expected to becoming an integral part of the Navy's maritime mission. To incorporate USVs into the fleet, manpower issues must be identified and resolved, i.e., manning requirements supporting USV operations; and analysis of the rate/rating, skill sets, training and procedures required to operate and maintain USVs. The methodology included Navy lessons learned, operation evaluation reports, and technical documentations from past and ongoing fleet employment of USVs to identify manning issues. Research findings included: current USV launch-and-recovery systems on host ships are personnel intensive compared to other available systems; knowledge, skills and abilities required of USV support personnel are identified within the BM, EM, EN, ET (Surface), GM, IT, OS, STG (Surface) rating occupational standards, and it would be easier to train personnel from these ratings for USV support; and a formal training path should be established for USV operators. In consonance with Navy Human Capital direction, naval platforms must operate with reduced manning, however, unmanned systems definitely require trained and specialized personnel to operate and maintain.

Gezer, Berat Levent. ***Multi-Beam Digital Antenna for Radar, Communications, and UAV Tracking Based on Off-the-Shelf Wireless Technologies***. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: David C. Jenn
Second Reader: Robert D. Broadston
http://hdl.handle.net/10945/2583
http://handle.dtic.mil/100.2/ADA456934

Abstract: The state-of-art technologies keep generating new ways of improving on the performance of the old systems. Array antennas, one of the continuously improving technologies,

brought many benefits to our life. The superiorities of array antennas remove the disadvantages of the old technology radars such as great sidelobes, vulnerability to the jammers, and degradation effect of the clutter. Array antennas find many applications on different areas. Today, unmanned aerial vehicles (UAVs) have begun to be seen in our life more often than before. UAVs prevent pilot loss of life. They carry out a variety of military and civilian missions such as surveillance and reconnaissance, target recognition, battle damage assessment, EW, search and rescue, and traffic monitoring. An important use of the UAVs is troop support, carrying out reconnaissance and surveillance missions, which requires maintaining a data-link with troops in order to send any data collected, such as video images, or audio. During operations it is necessary to continuously maintain a data and control link with the operator. This requires the ground station antenna to track the UAV so the antenna beam is pointed properly. The purpose of this research is to design and build an array to angle-track a UAV and, eventually, to accomplish the data transfer from the UAV to the ground station.

Hall, Jason S**. *Design and Integration of a Three Degrees-of Freedom Robotic Vehicle with Control Moment Gyro for the Autonomous Multiagent Physically Interacting Spacecraft (AMPHIS) Testbed*. M.S. in Astronautical Engineering. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: Marcello Romano
http://hdl.handle.net/10945/2354
http://handle.dtic.mil/100.2/ADA477754
Abstract: The use of fractionated spacecraft systems in on-orbit spacecraft assembly has the potential to provide benefits to both the defense and civil space community. To this end, much research must be conducted to develop and prove the requisite technologies to achieve these benefits. This thesis contributes to that effort by presenting the design and system integration, operating procedures and software development for a prototype three Degrees-Of-Freedom (DOF) Spacecraft Simulator. This simulator will be used in the Proximity Operations Simulator Facility, as part of the Naval Postgraduate School's Spacecraft Robotics Laboratory, to simulate autonomous guidance, navigation and control (GNC) for spacecraft proximity operations and assembly within the framework of the Autonomous Multi-Agent Physically Interacting Spacecraft project. The new spacecraft simulator includes several key enhancements over the previous Autonomous Docking and Spacecraft Servicing Simulator (AUDASS) developed in 2005 including a smaller and more agile structure, reduced air consumption and a Miniature Single-Gimbaled Control-Moment-Gyroscope (MSGCMG) to provide the necessary torque about the rotation axis. The MSGCMG in the simulator is a low-cost, low-mass, easily controlled momentum exchange device with a high torque to required power ratio. Furthermore, it provides the vehicle with high slew-rate capability, a key measure of performance in on orbit spacecraft assembly. Simulation and experimental results are presented for the prototype AMPHIS vehicle, demonstrating a potential slew-rate of 4.8 deg/s for a 30 degree rest-to-rest maneuver. The ultimate goal of this thesis is to provide the design specifications, combined with the necessary documentation and software development, for the prototype vehicle of the testbed for the AMPHIS project. The work conducted in fabricating the prototype vehicle will enable rapid fabrication of two additional vehicles which will provide an essential hardware-in-the-loop capability for experimentation with evolving control algorithms, sensors and mating mechanisms to be used for autonomous spacecraft assembly.

Hibbert, Kirk R. *A Need for Systems Architecture Approach for Next Generation Mine Warfare Capability*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2006.
Principal Advisor: John Osmundson
Associate Advisor: Martha Jallim Hall
http://hdl.handle.net/10945/2635
http://handle.dtic.mil/100.2/ADA457204
Abstract: When operating in a sea borne environment, sea mines can prevent U.S. Navy vessels from meeting operational objectives. Sea mines have the potential of damaging, or destroying

ships at sea. The U.S. Navy conducts mine warfare (MIW) operations to meet this threat. Although effective against mining, our countermining operations are currently employing 1960s technology in an attempt to keep pace with new Concepts of Operations (CONOPS). Todays legacy MIW processes currently employed by the warfighter, although capable of countering the mining threat, are a reactive process that is slow to engage and employ assets that are cumbersome to operate. With the advent of new technologies, a transformation of MIW capability is on the horizon and has the potential of influencing how the U.S. Navy maintains maritime dominance in the openoceans and littoral environments. The influence that technologies bring to MIW includes multi-spectral sensors, laser imagery, compact modular systems, unmanned and semi-autonomous weapons, as well as new communications architecture and tactics. Although these technical innovations present a level of capability superior to the existing legacy systems, developmental barriers and the lack of an overarching systems architecture will hinder or prevent these systems from being effectively integrated into tomorrows CONOPS.

Ho, Sze-Tek Terence. ***Investigating Ground Swarm Robotics using Agent Based Simulation***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, December 2006. Thesis Advisor: Susan M. Sanchez
Second Reader: Chwee Seng Choo
Outstanding Thesis Award
http://hdl.handle.net/10945/2449
http://handle.dtic.mil/100.2/ADA462523
Abstract: The concept of employing ground swarm robotics to accomplish tasks has been proposed for future use in humanitarian de-mining, plume monitoring, searching for survivors in a disaster site, and other hazardous activities. More importantly in the military context, with the development of advanced explosive detectors, swarm robotics with autonomous search and detection capability could potentially address the improvised explosive device (IED) problem faced by foot patrols, and aid in the search for hidden ammunition caches and weapons of mass destruction (WMDs). The intent of this research is to leverage on agent based simulation to model a ground robotic swarm on a search and detection mission in a semi-urban environment rigged with stationary IEDs. Efficient design of experiment (DOE) techniques and data farming are engaged to help identify controllable factors and capabilities that have the most impact on overall effectiveness. The focus of this thesis is to explore agent based simulation applied to swarm robotics; the technological and algorithmic aspects are not delved on. Results from the simulations provide several insights on the impact of both decision and noise factors on the performance of the swarm. Incorporation of virtual pheromones as a shared memory map is modeled as an additional capability that is found to enhance the robustness and reliability of the swarm.

Hoffman, Andrew J. ***Object Orientated Programmable Integrated Circuit (OOPIC) Upgrade and Evaluation for Autonomous Ground Vehicle (AGV)***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Co-Advisors: Richard Harkins and Nancy Haegel
http://hdl.handle.net/10945/2434
http://handle.dtic.mil/100.2/ADA462596
Abstract: A small, low-power Object-Oriented Programmable integrated circuit (OOPic) microcontroller was integrated and tested with the architecture for an autonomous ground vehicle (AGV). Sensors with the OOPic, and the XBee Wireless Suite were included in the integration. Tests were conducted, including range and time operation analysis for wireless communications for comparison with the legacy BL2000 microcontroller. Results demonstrated long battery life for the electronics of the robot, as well as communication ranges exceeding high power modems. The OOPic was limited by processing power and an ability to interpret some incoming form data. Consequently its use as a one for one replacement for the BL2000 is limited. However combined use with the BL2000 shows promise as a replacement for sensor monitoring and a hardware substitute for the legacy Pulse Width Modulator.

Kertmen, Aykut. ***Evaluation of the Littoral Combat Ship (LSC) Potential for the Turkish Navy***.
M.S. Systems Engineering. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: Edward Fisher
Second Reader: Orin Marvel
http://hdl.handle.net/10945/2625
http://handle.dtic.mil/100.2/ADA457219
Abstract: This thesis will examine the potential of the two competing designs for the Littoral Combat Ship (LCS), with regard to potential deployment of this vessel type by the Turkish Navy. The first design is by Lockheed Martin and has been designated the USS Freedom as the U.S. Navys first LCS. The second design is by General Dynamics. This thesis will focus on the LCS usage concepts in Naval Capability Pillars and Information Operations. As a transformation platform, the LCS will be critical in implementing new operational concepts and in providing a focused, littoral mission platform for joint forces. Its superior speed and maneuverability; low radar, infrared, and acoustic signatures; and ability to lay distributed sensor fields are all fundamental to mission success. It will also carry a squadron of unmanned vehicles (air, surface, and undersea) that will considerably extend its sensor and weapon coverage and provide substantial Anti-Submarine Warfare (ASW) capabilities. This thesis will also discuss present and future platforms and their concepts of operation in Turkish littoral waters (Aegean Sea, Black Sea, and Mediterranean Sea).

Khakimbayev, Jasur S. ***Development of Integrated 3D Terrain Maps for Unmanned Aerial Vehicle (UAV) Flight and Mission Control Support System (FMCSS)***. M.S. Modeling, Virtual Environments and Simulation (MOVES). Monterey, California: Naval Postgraduate School, March 2006.
Thesis Co-Advisors: Wolfgang Baer and Curtis L. Blais
http://hdl.handle.net/10945/2875
http://handle.dtic.mil/100.2/ADA445408
Abstract: The purpose of this thesis is to conduct the research necessary to develop integrated 3D terrain maps capable of supporting an Unmanned Aerial Vehicle Flight Mission Control Support System. In this work, the author has tried to explore the feasibility of exploiting digital topographic maps and further understanding of the digital terrain support available to UAV FMCSS developers. This thesis explores numerous digital terrain data representations and tools available to create digital environments. This work examines and gives a methodology how to find, process, and operate in these environments. To accomplish this, the author explores the more general problem of where to find the data, what tools are available, and how to put the pieces together to create a registered digital environment on a state-of-the-art computer. This work provides a logical construct and design methodology for an analyst to create high fidelity terrain data sets. It functions as a how to manual to help analysts understand which information and tools are available to use for different types of simulation projects.

Kriewaldt, Hannah A. ***Communications Performance of an Undersea Acoustic Wide-Area Network***. M.S. in Engineering Acoustics. Monterey, California: Naval Postgraduate School, March 2006.
Thesis Advisor: Joseph A. Rice
Second Reader: Frank E. Kragh
http://hdl.handle.net/10945/2926
http://handle.dtic.mil/100.2/ADA445438
Abstract: The U.S. Navy is developing through-water acoustic communications capability for undersea, distributed systems. These wireless communication links form a wide-area network of fixed nodes consistent with future autonomous sensors on the seafloor. Mobile nodes may operate in the domain of the grid using the fixed nodes as both navigation reference points and communication access points. This thesis evaluates the experimental performance of such networked communications between an undersea vehicle and a ship. Physical-layer considerations include refraction, wind-induced ambient noise, and vehicle aspect angle.

Kurcan, Remzi Serdar. ***Isolated Word Recognition from In-Ear Microphone Data Using Hidden Markov Models (HMM)***. M.S. in Electrical Engineering and M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, March 2006.
Thesis Co-Advisors: Monique P. Fargues and David Jenn
Second Reader: Ravi Vaidyanathan
http://hdl.handle.net/10945/2924
http://handle.dtic.mil/100.2/ADA445459

Abstract: This thesis is part of an ongoing larger scale research study started in 2004 at the Naval Postgraduate School (NPS) which aims to develop a speech-driven human-machine interface for the operation of semi-autonomous military robots in noisy operational environments. Earlier work included collecting a small database of isolated word utterances of seven words from 20 adult subjects using an in-ear microphone. The research conducted here develops a speaker-independent isolated word recognizer from these acoustic signals based on a discrete-observation Hidden Markov Model (HMM). The study implements the HMM-based isolated word recognizer in three steps. The first step performs the endpoint detection and speech segmentation by using short-term temporal analysis. The second step includes speech feature extraction using static and dynamic MFCC parameters and vector quantization of continuous-valued speech features. Finally, the last step involves the discrete-observation HMM-based classifier for isolated word recognition. Experimental results show the average classification performance around 92.77%. The most significant result of this study is that the acoustic signals originating from speech organs and collected within the external ear canal via the in-ear microphone can be used for isolated word recognition. The second dataset collected under low signal-to-noise ratio conditions with additive noise results in 79% recognition accuracy in the HMM-based classifier. We also compared the classification results of the data collected within the ear canal and outside the mouth via the same microphone. The second dataset collected under low signal-to-noise ratio conditions with additive noise results in 79% recognition accuracy in the HMM-based classifier. We also compared the classification results of the data collected within the ear canal and outside the mouth via the same microphone. Average classification rates obtained for the data collected outside the mouth shows significant performance degradation (down to 63%), over that observed with the data collected from within the ear canal (down to 86%). The ear canal dampens high frequencies. As a result, the HMM model derived for the data with dampened higher frequencies does not accurately fit the data collected outside the mouth, resulting in degraded recognition performances.

Lamb, Timothy G. ***Small Unmanned Aerial System (SUAS) Flight and Mission Control Support System (FMCSS) Design***. M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: Wolfgang Baer
Second Reader: Edward Fisher
http://hdl.handle.net/10945/2574
http://handle.dtic.mil/100.2/ADA457224

Abstract: Unmanned Aerial Systems (UAS) are playing a significant role in the Global War on Terrorism (GWOT). Until recently, small UAS (SUAS) were an insignificant part of these efforts. Now their numbers exceed those of their larger counterparts by an order of magnitude. Future projections anticipate a growing demand for SUAS making now the best time to examine the functions they perform in order to make better decisions concerning their future design and development. This thesis provides a brief history of UAS and discusses the current capabilities and mission areas in which they perform. Their relevance to modern warfare and assumptions concerning their future roles on the battlefield is presented. Predominant UAS missions are identified, as well as the technical requirements deemed necessary for their success. A generic UAS functional model is developed to illustrate where the challenges and technology gaps manifest in SUAS design. Possible technology solutions that could fill these gaps are presented and a field experiment is conducted to demonstrate the feasibility of several possible solutions. The goal of this thesis is to identify existing technology gaps and offer technology solutions that lead to better design of future SUAS flight and mission control support systems (FMCSS).

Landreth, Kent A. and John C. Glass. ***Extending the Tactical Horizon: Networking Aircraft to Enable Persistent Surveillance and Target Development for SOF***. M.S. in Defense Analysis. Technology Management. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: David W. Netzer
Second Reader: Robert O'Connell
Outstanding Thesis Award
http://hdl.handle.net/10945/2582
http://handle.dtic.mil/100.2/ADA457127

Abstract: The NPS Tactical Horizon Extension Project objective is to define and demonstrate a concept by which task force-level commanders and below can obtain a persistent, over-the-horizon surveillance capability for the purpose of target development and other missions without tasking national or theater-level assets. Our goal is to increase the ISR capacity of units who normally would not rate the priority to task a Predator, Global Hawk, or U-2. There are two guiding tenets in developing this concept. First, the equipment and its control should be organic to the SOF unit or task force. Second, utilizing this capability should not require the soldier to carry any additional equipment into the field. Initial research led us to the idea of using networked unmanned aerial systems (UAS's) to generate an over-the-horizon surveillance capability for SOF. We demonstrated the concept by forming a network comprised of a forward ground team, an inexpensive, test-bed UAS equipped with an off-the-shelf video camera, a manned aircraft, and a tactical operations center (TOC). We attained connectivity through an ITT Mesh structure at 2.4 GHz, amplified to 1W. Researchers were from the Defense Analysis, Mechanical and Astronautical Engineering, and Information Sciences Departments. We conducted successful experiments through the USSOCOM-NPS Cooperative Field Experimentation Program.

Lee, Anthony. ***Variable Resolution Direction Finding using the Robust Symmetrical Number System***. M.S. in Combat Systems Sciences and Technology. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisors: Phillip Pace, David Jenn and Donald Walters
http://hdl.handle.net/10945/2456
http://handle.dtic.mil/100.2/ADA462642

Abstract: A digital implementation of a phase sampling interferometer antenna system based on the Robust Symmetrical Number System (RSNS) is built using commercial-off-the-shelf (COTS) items. The RSNS-based direction finding (DF) system uses short baselines to achieve a high resolution DF capability in a physically compact system for use as stand-in sensors on unmanned aerial vehicles. The RSNS inherent integer Gray code property minimizes the possible encoding errors and adds a robustness to the accuracy of the estimated Angle of Arrival (AOA). A digital architecture using quadrature demodulators and real-time controllers provide grreater flexibility for signal processing and allows for the implementation of a new virtual spacing algorithm. The virtual spacing concept changes the RSNS moduli values to implement a virtual antenna spacing without having to physically change the antenna element spacing. This enables higher resolution DF in circumstances where the Signal-to-Noise Ratio is high enough to provide error free coding of the AOA. Two four element, digital 3-channel interferometer prototype systems were constructed and tested in the NPS anechoic chamber. The first antenna array is designed using pairwise relatively prime (PRP) moduli. When an extension of the virtual spacing concept for application to N-channel systems was successfully resolved, a second 3-channel array was built using non-PRP moduli for evaluating the performance of the virtual spacing concept. The simulated and experimental results, hardware implementation and testing procedures are presented in this thesis. Results for the first array show that the RSNS-based DF system is able to provide 0.7 degree RMS resolution with a baseline of 66 cm. For the second virtual spacing array, the short physical baseline of 14 cm was sensitive to noise and antenna spacing errors.

Lewis, Laird-Philip Ryan. ***Rapid Motion Planning and Autonomous Obstacle Avoidance for Unmanned Vehicles***. M.S. in Astronautical Engineering. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: I. Michael Ross
Second Reader: Wei Kang
http://hdl.handle.net/10945/2460
http://handle.dtic.mil/100.2/ADA462927

Abstract: This work introduces the use of optimal control methods for path planning and control of autonomous vehicles in an obstacle-rich environment. Traditional techniques harbor non-optimal, closed architectures primarily derived at a time when computational complexity could significantly hinder overall system performance. Advancements in computing power, miniaturization, and numerical methods permit the utilization of online, optimal path planning and control, thereby improving system flexibility and autonomy. The backbone of this concept is state-of-the-art optimal control techniques involving pseudospectral methods and sequential quadratic programming. Although this research focuses on a robotic car or Unmanned Ground Vehicle (UGV), several systems, including an Unmanned Aerial Vehicle (UAV) and a pendulum on a rotational base, are detailed for the purpose of illustrating the technique's modularity. With respect to the UGV, optimal control methods permit the optimization of maneuver parameters while accounting for complex vehicle kinematics and workspace obstacles, represented as dynamic and path constraints respectively. The path constraints are modeled such that an obstacle of any shape or size can be included. Maneuvering trajectories are first generated in an open-loop architecture, followed by an application of these same techniques in feedback form. Lastly, model fidelity is increased to improve control over vehicle behavior and closed-loop performance and a local knowledge scenario is evaluated.

Long, Eric J. ***Cost Valuation : A Model for Comparing Dissimilar Aircraft Platforms***. Master of Business Administration. MBA Professional Report. Monterey, California: Naval Postgraduate School, December 2006.
Advisors: Douglas A. Brook and William Gates
http://hdl.handle.net/10945/10086
http://handle.dtic.mil/100.2/ADA460310

Abstract: The purpose of this MBA Project was to investigate and provide an overview of current cost valuation methods used to compare aircraft and then determine if the current methods were satisfactory for comparing dissimilar aircraft platforms. The goal of the project was to develop a model using O&S and procurement cost inputs together with aircraft inventory and utilization data in order to produce a cost per unit hour for any given aircraft. A demonstration of the models validity using aircraft and cost data from the Predator UAV and the F-16 was then performed to illustrate how it can be used to aid comparisons of dissimilar aircraft platforms that perform similar missions.

Masson, Scott R. ***Unmanned Aerial Vehicle use in Army Brigade Combat Teams : Increasing Effectiveness Across the Spectrum of Conflict***. M.S. in Defense Analysis. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: David C. Tucker
Second Reader: Eugene P. Paulo
http://hdl.handle.net/10945/2465
http://handle.dtic.mil/100.2/ADA462656

Abstract: One of the major strengths of the U.S. Army conventional force, and its doctrinal methods, is the ability to conduct operational and tactical maneuver out of contact with an enemy force. This allows the U.S. to decide the time, place, and conditions of contact. Under this system national, strategic, and operational intelligence systems generate, analyze, and disseminate intelligence to maneuver units. When major conventional operations conclude, or in operations where they never take place, conventional forces transition to Stability Operations and Support Operations (SASO). Conducting SASO operations generally requires extensive interaction with, and conducting operations among, a local populace. The necessary physical interaction with a local populace causes two significant problems for conventional forces: traditional intelligence

assets (national, strategic, operational) are largely irrelevant to the operations U.S. forces conduct, and interacting with a local population whenever outside of a FOB affects the actions of the population. In military operations other than conventional combat, intelligence must be generated from the lowest possible tactical level, something conventional forces are not organized or equipped to do. Proliferating Shadow Tactical Unmanned Aerial Vehicle (TUAV) Platoons throughout Army Brigade Combat Team's (BCTs) subordinate battalions will enable commanders to gather the tactical intelligence necessary for success.

Matos, Antonio P. ***Characterization and Application of Four-Layer Semiconductor Structures in Pulse Mode Operation***. M.S. in Physics. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Co-Advisors; Gamani Karunasiri and James H. Luscombe
Outstanding Thesis Award
http://hdl.handle.net/10945/2569
http://handle.dtic.mil/100.2/ADA457352
Abstract: The characteristics and application of a thyristor (a four-layer semiconductor structure) in a pulse generating circuit are explored. A thyristor device was used to create a pulse generating circuit and the pulse interval duration of this circuit was experimentally measured. The pulse interval duration was determined to be characterized by a Poisson Point Process distribution that is dependent on both temperature and applied voltage bias. The adjustable aperiodicity of the pulse intervals was a key characteristic used to design a distributed processing system of micro-robots that are capable of swarming. A micro-robotic swarm platform was simulated using finite element analysis, a JAVA-based swarm model, and three fully operational macro-scale platforms.

Miller, Benjamin D. ***Improvised Explosive Devise [Device] Placement Detection from a Semi-Autonomous Ground Vehicle***. M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Richard Harkins
Second Reader: Nancy Haegel
http://hdl.handle.net/10945/2476
http://handle.dtic.mil/100.2/ADA462650
Abstract: Improvised Explosive Devices (IEDs) continue to kill and seriously injure military members throughout the Iraqi theatre. Autonomous Ground Vehicle (AGV) seeks to identify the human presence placing the IED and then report that contact to a unit of action. This research developed a semi-autonomous platform that can navigate to waypoints, avoid obstacles, investigate possible threats and then detect motion that triggers a visual camera. The information is then relayed back to the user and can trigger a variety of actions. AGV has been tested in a numerous environments with a wide range of success. It is limited by the communication range from its standard 802.11G router and the continuous availability of the global positioning system. Terrain with extensive peaks and valleys is not ideal for the current platform. However, for detecting the human presence that is consistent with IED placement, AGV is well suited.

Nannini, Christopher J. ***Analysis of the Assignment Scheduling Capability for Unmanned Aerial Vehicles (ASC-U) Simulation Tool***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2006.
Thesis Co-Advisors: Arnold H. Buss and Susan M. Sanchez
Second Reader: Darryl K. Ahner
Outstanding Thesis Award
http://hdl.handle.net/10945/2813
http://handle.dtic.mil/100.2/ADA457579
Abstract: The U.S. Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC) and the Modeling, Virtual Environments, and Simulations Institute (MOVES) at the Naval Postgraduate School, Monterey, California developed the Assignment Scheduling Capability for UAVs (ASC-U) simulation to assist in the analysis of unmanned aerial vehicle (UAV) requirements for the current and future force. ASC-U employs a discrete event simulation coupled with the optimization of a

linear objective function. At regular intervals, ASC-U obtains an optimal solution to a simplified problem that assigns available UAVs to missions that are available or will be available within a future time horizon. This thesis simultaneously explores the effects of 26 simulation and UAV factors on the mission value derived when allocating UAVs to mission areas. The analysis assists in defining the near term (2008) UAV force structure and the investment strategy for the mid term (2013), and far term (2018). We combine an efficient experimental design, exploratory modeling, and data analysis to examine 514 variations of a scenario involving five UAV classes and over 21,000 mission areas. The conclusions suggest the following: the optimization interval significantly influences the quality of the solution, percent mission coverage may depend on a few UAV performance factors, small time horizons increase percent mission coverage, and carefully planned designs assist in the exploration of the outer and interior regions of the response surface.

Ortiz, John E. ***Absolute Position Measurement for Automated Guided Vehicles Using the Greedy DeBruijn Sequence***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Co-Advisors: Harold M. Fredrickson and Jon T. Butler
http://hdl.handle.net/10945/2612
http://handle.dtic.mil/100.2/ADA457411
Abstract: Automated Guided Vehicles (AGVs) use different techniques to help locate their position with respect to a point of origin. This thesis compares two approaches that utilize a binary track laid on the floor for the AGV to follow. Both approaches use equally spaced n-tuples on the track that the AGV can use to compute its position. Both approaches also have the special feature that every n-tuple on the binary track is unique and can be used to designate the position of an AGV. The first approach, developed by E.M. Petriu, uses a Pseudo-Random Binary Sequence (PRBS) as a model for the binary track. In the second approach, we use a Greedy DeBruijn Sequence (GDBS) as a model for the binary track. Unlike the PRBS model, the GDBS model has a natural ordering which can be used to determine the position of the AGV more quickly and efficiently than the PRBS model.

Phang, Nyit Sin. ***Tethered Operation of Autonomous Aerial Vehicles to Provide Extended Field of View for Autonomous Ground Vehicles***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Co-Advisors: Douglas Horner and Vladimir Dobrokhodov
Second Reader: Anthony J. Healey
http://hdl.handle.net/10945/2491
http://handle.dtic.mil/100.2/ADA462612
Abstract: This thesis was part of the ongoing research conducted at the Naval Postgraduate School to achieve greater collaboration between heterogeneous autonomous vehicles. The research addresses optimal control issues in the collaboration between an Unmanned Aerial Vehicle (UAV) and Autonomous Ground Vehicles (AGV). The scenario revolves around using the camera onboard the UAV to extend the effective field of view of the AGV. For military operations, this could be helpful in improving security for convoys and riverine patrols. There were three main problems addressed in this thesis. The first problem dealt with the design of a UAV control law that takes into consideration the relative speed differences between the UAV and the AGV. The UAV was assumed to have a greater speed compared to the AGV in this thesis. The second was the keystone field of view projection effect of the UAVs onboard camera onto the earth. The image captured by the camera was distorted due to the view angle of the camera from a high elevation. The third problem addressed was control of the location of the UAV to ensure the reliability of the communication network between the UAV and the AGV. The communication was assumed to be a linear function of the relative positions of the UAV and the AGV.

Price, William D. ***Control System of a Three DOF Spacecraft Simulator by Vectorable Thrusters and Control Moment GYROS***. M.S. in Astronautical Engineering and Astronautical Engineer. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Marcello Romano
http://hdl.handle.net/10945/2350
http://handle.dtic.mil/100.2/ADA477316
Abstract: This thesis presents the continued design and system integration of a prototype three Degrees-Of-Freedom (DOF) Spacecraft Simulator used in the Proximity Operations Simulator Facility, as part of the Naval Postgraduate School's Spacecraft Robotics Laboratory, to simulate autonomous guidance, navigation and control (GNC) for spacecraft proximity operations and assembly as part of the Autonomous Multi-Agent Physically Interacting Spacecraft project. Several key enhancements of the spacecraft simulator were made including the integration of onboard sensors, improved electrical distribution system, improved command and data handling system, and the design and integration of vectorable thrusters. A pair of independently controlled 360 degree vectorable thrusters is now included in the spacecraft simulator. A control system and thruster mapping algorithm were developed to incorporate the translational and rotational control authority that the vectorable thrusters provide with the rotational control authority of the previously developed Miniature Single-Gimbaled Control-Moment-Gyroscope (MSGCMG). Simulation and experimental results are presented to demonstrate the functionality of the prototype AMPHIS vehicle. The work done in developing the prototype vehicle will enable rapid fabrication of additional vehicles to provide essential hardware-inthe- loop experimentation capabilities for evolving control algorithms, sensors and mating mechanisms to be used for autonomous spacecraft assembly.

Reed, Michael S. ***Use of an Acoustic Network as an Underwater Positioning System***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, June 2006.
Thesis Advisors: Joseph A. Rice and Roberto Cristi
http://hdl.handle.net/10945/2806
http://handle.dtic.mil/100.2/ADA457827
Abstract: Underwater acoustic networks provide an interface between UUVs and surface or land-based control systems. By exploiting range data measured incidental to communications on these networks it is possible to perform underwater positioning similar to that of the satellite-based GPS program. In this thesis, several algorithms for generating position fixes from these range data are implemented, tested, and evaluated with synthetic data. The algorithms are then applied to data obtained during operations at sea.

Richter, Matthew P. ***Analysis of Operational Manning Requirements and Deployment Procedures for Unmanned Surface Vehicles Aboard U.S. Navy Ships***. Master of Business Administration. Monterey, California: Naval Postgraduate School, September 2006.
Primary Advisor: Bill Hatch
Associate Advisor: Cary Simon
http://hdl.handle.net/10945/2616
http://handle.dtic.mil/100.2/ADA457242
Abstract: This research was conducted in association with Naval Warfare Development Command (NWDC) requests to update Unmanned Vehicle Tactical Memorandum TM-3-22- 5-SW. The research identified and discussed significant USV manning considerations such as source ratings and manpower qualities to pilot, operate sensors, support USV electronics, and the manpower implications associated with various weapons systems alternatives. In addition, this research described several existing and notional USV tactics, as well as a discussion about the existing N75 and N76 primary and secondary mission areas USV operations may support. The methodology consisted of a literature review of USV test reports; USV Advanced Concept Technology Demonstration briefs; USV Concept of Operations; fleet lessons learned; the USV tactical memorandum; Naval manpower instructions, and manuals; Weapons Tactical, Field, and Training Manuals; Military Utility Assessments; search of books, magazines, and manpower theses. The research found that determining manpower qualities and standard operating procedures will remain a dynamic process until USV equipment is standardized. The research also

showed USV launch and recovery is more manpower intensive than that of a standard RHIB. Gunners Mates (GM) and Aviation Ordnancemen (AO) are potential source ratings to support USV Hellfire and Javelin missile modules. The Navy should establish a GM Navy Enlisted Classification (NEC) to support Hellfire and Javelin or add these weapons to existing GM NECs. Electronics Technicians (ET), Fire Controlmen (FC), and Fire Control Technicians (FT) are potential source ratings for USV electrical/electronic support. FC and FT are potential source ratings to support the Remote Operated Small Arms Mount. This research found additional warfighting capabilities can be gained by equipping surface warfare vessels with USV's without any negative effects to primary or secondary warfare missions. Overall, USVs enhanced designed capabilities of Naval warships and directly support a capabilities based Navy.

Rodriguez Gallo, Luis E. **Department of Information Sciences.** *Propagation Modeling of Wireless Systems on Shipboard External Decks*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: David C. Jenn
Second Reader: Michael A. Morgan
http://hdl.handle.net/10945/2617
http://handle.dtic.mil/100.2/ADA457355
Abstract: Many onboard ship operations demand full radio coverage over the entire ship, not only indoor, but also from the interior spaces to the other decks. Onboard a ship, specifically in the upper decks, radio wave propagation is subjected to fading that would impede the quality and reliability of data links and communication. One example is the performance of unmanned aerial vehicle (UAV) data and communications links. The purpose of this thesis is to analyze, model, and simulate some communication scenarios that occur on naval ships using Urbana. Starting from known inputs (frequency, ship compartment geometry, material properties, propagation computation model, and antenna type), analytical results reflecting the propagation mechanisms and coverage area are presented. Variable inputs can then be optimized to achieve a desired signal distribution for a specific shipboard environment. The ship models were created by Rhino, a well-known Windows-based computer drawing software. The values of the signals received on the different points in the main deck are computed for different frequencies and powers. The results are used to draw conclusions of the deployment of antennas on the ship as well as operational aspects such as UAV flight paths.

Schall, Stephen A. *Path Calculation and Packet Translation for UAV Surveillance in Support of Wireless Sensor Networks*. M.S. in Computer Science. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Co-Advisors: Gurminder Singh and Ravi Vaidyanathan
http://hdl.handle.net/10945/2663
http://handle.dtic.mil/100.2/ADA457291
Abstract: Wireless Sensor Networks (WSNs) are a relatively new technology with many potential applications, including military and homeland security surveillance operations. Accurate classification of WSN contacts has been attempted using various sensor combinations over the past few years, yet video and photographic imagery remain the only choices for attaining context specific contact classification. While cameras have been successfully installed within some WSNs, there are serious limitations to this solution. Most stemming from the scarce power resources, immobility, and small form factor common among conventional WSN nodes. An efficient, low cost answer to this problem involves the use of unmanned aerial vehicles (UAVs) to acquire imagery of WSN contacts. For this system to scale to the wide expanses that WSNs deploy over, UAV contact surveillance operations must be controlled autonomously. The objective of this thesis is to research and implement an autonomous UAV WSN system, where an optimized two-dimensional flight plan is produced in response to WSN contact detection. Flight plans autonomously guide the UAV on a course to either an estimated interception point with the WSN contact or to the instigated WSN cluster, depending upon user input. The event driven application produced in this study functions in the periphery of the Kestrel Autopilot System, communicating flight plans to the UAV through properly crafted Kestrel packets.

Tay, Boon Chong. ***Development and Implementation of New Control Law for Vision Based Target Tracking System Onboard Small Unmanned Aerial Vehicles***. M.S. in Engineering Science (Mechanical Engineering). Monterey, California: Naval Postgraduate School, December 2006.
Thesis Co-Advisors: Issac I. Kaminer and Vladimir N. Dobrokhodov
http://hdl.handle.net/10945/2420
http://handle.dtic.mil/100.2/ADA462713
A new control law is being developed and implemented for the Vision Based Target Tracking (VBTT) system onboard a small unmanned aerial vehicle (SUAV). The new control law allows for coordinated SUAV guidance and vision-based target tracking of stationary and moving targets in the presence of atmospheric disturbances and measurements noise. The new control law is tested for its performance and stability in both the theoretical 6DOF simulation and the Hardware-in-the-Loop (HIL) simulation. Principal results show that realistic measures of performance of the control law are continuous and exhibit predictable degradation of performance with increase of target speed. The results are encouraging and comparable among theoretical predictions, actual hardware simulation results, and initial flight testing. The control law development, implementation, and trial processes and procedures are also examined and categorically documented in this thesis as future reference on the subject development, as well as for better knowledge retention, continuation and proliferation of the VBTT system.

Tsaprazis, Konstantinos. ***Design and Analysis of Side-Looking Sonar Experiments***. M.S. in Applied Physics and M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Co-Advisors: Lawrence J. Ziomek and Bruce Denardo
http://hdl.handle.net/10945/2411
http://handle.dtic.mil/100.2/ADA462697
Abstract: This research concerns the design and analysis of different Side-Looking Sonar experiments in order to satisfy different operational requirements. The different designs and analysis have been done via computer simulation. Side-Looking Sonar (also known as side-scan sonar) is known for very high quality, high resolution, ocean bottom imaging. Hence, it is used for bathymetric surveys, commonly called seafloor mapping. It is able to rapidly survey large ocean areas for bottom and suspended sea-mines or other kinds of threats. Another operational aspect of these systems is that they allow autonomous underwater vehicles (AUVs) to conduct operations, mostly in shallow water and near land. Thus Side-Looking Sonar can be a very useful device in littoral warfare operations. This research has defined the basic parameters that rule the operation of a Side-Looking Sonar and, furthermore, analyzed various aspects that affect the performance of these parameters. Special focus was given to the various operational requirements and conditions that a designer or a user may encounter in realistic situations. Toward that end, many numerical examples are presented. Moreover, the research has tried to indicate the various problems that may arise when a Side-Looking Sonar operates in its near-field region and suggests certain solutions. The active sonar equation and its factors were explained and were evaluated for a realistic example of mine detection as well.

Verett, Marianna J. ***Performance and Usage of Biometrics in a Testbed Environment for Tactical Purposes***. M.S. in Information Technology Management. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Alex Bordetsky
Second Reader: David N. Netzer
http://hdl.handle.net/10945/2414
http://handle.dtic.mil/100.2/ADA462718
Abstract: Naval Postgraduate School's (NPS) Tactical Network Topology (TNT) experiments seek to develop, implement and identify sensor-unmanned vehicle network, and network-centric operations to assist DoD warfighters in the Global War on Terrorism (GWOT). Using biometric data for rapid identification of High Value Targets (HVT) in ground and Maritiime Interdiction Operations (MIO) is critical to the emeging special operations concept. The goal is to explore solutions and operational constraints associated with biometric data analysis and rapid

identification by means of adhoc self forming sensor unmanned vehicle (UV) wireless networks. The objectives of this thesis are to look at how biometrics has performed in a testbed environment that is simulating a real special operations environment in theatre. This thesis is meant to explore and explain the biometrics process that was conducted on top of the tactical network and evaluate its performance. This thesis provided the process model for biometrics identification in the tactical networks environment. This thesis also evaluated the length of time that it took to transmit the fingerprint data from the field to the ABIS databvase, with an identification result then sent back to the field. The longest time that was observed was 70 minutes (using low bandwidth Satellite communications), while the shortest time was 4 minutes for reachback to ABIS and 2 minutes for a local database.

Vonheeder, Steven R. ***Analysis and Tuning of a Low Cost Inertial Navigation System in the ARIES AUV***. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Anthony J. Healey
http://hdl.handle.net/10945/2418
http://handle.dtic.mil/100.2/ADA462714

Abstract: Autonomous underwater vehicle navigation is a complex problem of state estimation. Accurate navigation is made difficult due to a lack of reference navigation aids or use of the Global Positioning System (GPS) that could establish the vehicles position. Accurate navigation is critical due to the level of autonomy and range of missions and environments into which an underwater vehicle may be deployed. Navigational accuracy depends not only on the initialization and drift errors of the low cost Inertial Motion Unit (IMU) gyros and the speed over ground sensor, but also on the performance of the sensor fusion filter used. This thesis will present the method by which an Extended Kalman Filter (EKF) was tuned after installation of an IMU in the ARIES Autonomous Underwater Vehicle. The goal of installing the IMU, analyzing the navigational results and tuning the EKF was to achieve navigational accuracy in the horizontal plane with a position error of less than one percent of distance traveled when compared to GPS. The research consisted of IMU installation and software modifications within the vehicle to fully realize the design goal. Data collection and analysis was conducted through field experiments and computer simulation. A significant result of this work was development of a pseudo-adaptive algorithm to vary the measurement noise values in selected channels to for a desired response in the filter and improve accuracy and precision in the state estimates.

Wahl, Douglas Timothy. ***Increasing Range and Lethality of Extended-Range Munitions (ERMS) using Numerical Weather Prediction (NWP) and the AUV Workbench to Compute a Ballistic Correction (BALCOR)***. M.S. in Meteorology and Physical Oceanography. Monterey, California: Naval Postgraduate School, December 2006.
Thesis Co-Advisors: Wendell Nuss and Don Brutzman
http://hdl.handle.net/10945/2417
http://handle.dtic.mil/100.2/ADA462735

Abstract: Extended Range Munitions (ERMs) are gun-launched rocket-boosted munitions having an effective range ocer 27 km. In accordance with Sea power 21 and the Marine Corps's requirements for sea-based fire support, three ERMs are being developed. The purpose of this work is to increase the range and lethality of these munitions by applying environmental effects when computing the projectiles' trajectory. A broad review of artillery and munitions literature reveals that historically 66% of ballistic error can be attributed to meteorological factors. The most important factors are wind (speed and direction), temperature, and pressure. It has also been shown that global atmospheric numerical weather presictions (NWP) data typically outperforms the traditional radiosonde data and is suitable for use in ballistic corrections. Forecasted NWP products provided by the Fleet Numerical Meteorology and Oceanographic Center (FNMOC) are integrated using the Joint Meteorology and Oceanographic (METOC) Broker Language (JMBL) into a Five Degree of Freedom (5DOF) aerodynamic model within the Autonomous Unmanned Vehicle (AUV) Workbench producing a ballistic correction (BALCOR) for the munition. This new capability can significantly enhance naval gunfire effectiveness since the

BALCOR increase the munitions' range and the ability apply kinetic energy onto the target rather than using it to maneuver to the target.

Yap, Kwee Chye. ***Incorporating Target Mensuration System for Target Motion Estimation Along a Road using Asynchronous Filter***. M.S. in Engineering Science (Mechanical Engineering) Monterey, California: Naval Postgraduate School, December 2006.
Thesis Advisor: Isaac I. Kaminer
Second Reader: Vladimir N. Dobrokhodov
http://hdl.handle.net/10945/2427
http://handle.dtic.mil/100.2/ADA462568
Abstract: In support of TNT experiments, the NPS UAV laboratory has developed a Vision-Based Target Tracking (VBTT) system for a Small Unmanned Aerial Vehicle (SUAV). This system provides an autonomous target tracking capability, while simultaneously estimating the target's velocity and position.The accuracy of the existing system can be improved by providing external corrections to the target position estimation from the georectification system (GIS). This thesis addresses the implementation of an asynchronous correction scheme into the target position estimation filter. The current autonomous position estimation algorithm provides 20-30 meters accuracy. The external correction system (Perspective View Nascent Technologies (PVNT)) is expected to provide target position accuracy of 1-2 m. However, a delay of up to 10 seconds is expected. Therefore, in order to improve the accuracy of current estimation of target motion, a new asynchronous correction technique that incorporates the more accurate PVNT data is proposed. To further improve the target motion estimation, it was also proposed to incoprate a known road model into the filter and compare its performance with the original filter.

Zacherl, Brian. ***Weapon-Target Pairing : Revising an Air Tasking Order in Real-Time***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2006.
Thesis Advisor: W. Matthew Carlyle
Second Readers: R. Kevin Wood and Sergio Posadas
http://hdl.handle.net/10945/2531
http://handle.dtic.mil/100.2/ADA457373
Abstract: Well-publicized lost opportunities for U.S. and coalition air forces to strike enemy leadership targets in Afghanistan and Iraq demonstrate the importance of Time Sensitive Targeting. How do we "pair" the weapon and weapons delivery platform with their target? The available platforms (aircraft, manned or unmanned) may be on the ground in an alert status, loitering airborne, or on their way to attack other targets. The problem is compounded by the facts that we actually wish to (a) create multiple strike packages simultaneously, (b) recompose existing strike packages that are disrupted by the new plans, (c) minimize such disruptions, (d) satisfy minimum kill probabilities, and (e) avoid the attrition of tasked assets. This thesis develops an automated, optimizing, heuristic decision aid, "RAPT-OR", that rapidly revises a current Air Taking Order (ATO) to meet the requirements above. Using a set-packing model, RAPT-OR, an ATO near optimally, on a desktop PC, in less than two seconds, for a typical scenario with 40 aircraft, four new targets and hundreds of potential strike packages. RAPT-OR allows decision makers the ability of adjusting risk acceptance in the formulation of possible courses of action by manipulating friendly attrition importance in formulating a solution.

2005

Ackerman, James S. ***Error Analysis of Sensor Measurements in a Small UAV***. M.S. in Engineering Science (Mechanical Engineering). Monterey, California: Naval Postgraduate School, September 2005.
Thesis Advisor: Isaac I. Kaminer
Second Reader: Vladimir Dobrokhodov
http://hdl.handle.net/10945/2021
http://handle.dtic.mil/100.2/ADA439651
Abstract: This thesis focuses on evaluating the measurement errors in the gimbal system of the SUAV autonomous aircraft developed at NPS. These measurements are used by the vision based target position estimation system developed at NPS. Analysis of the errors inherent in these measurements will help direct future investment in better sensors to improve the estimation system's performance.

Baggesen, Arne. ***Design and Operational Aspects of Autonomous Unmanned Combat Aerial Vehicles***. M.S. in Modeling, Virtual Environments and Simulation (MOVES). Monterey, California: Naval Postgraduate School, September 2005.
Thesis Advisor: Moshe Kress
Second Advisor: Thomas W. Lucas
http://hdl.handle.net/10945/2015
http://handle.dtic.mil/100.2/ADA439358
Abstract: A family of advanced weapon systems that deserves special attention comprises aerial autonomous weapons called Unmanned Combat Aerial Vehicles (UCAVs), which are characterized by the ability to loiter in the target area, sense the targets, acquire the targets, and then engage them. Modeling this combination of capabilities in a specific operational setting is necessary for addressing design and operational issues of this weapon. This work focuses on the development of an analytic probability model that capture   key aspects of the autonomous weapon systems' engagement process. Special attention is given to simultaneous attack occurrences, imperfect battle damage assessment, and attack coordination properties. The model is a continuous-time Markov Chain and for its implementation a state generator and an algorithm that computes the transition and limiting probabilities has been developed and programmed in Java based software. The Markovmodel derives values for several measures of effectiveness (MOEs), and the average engagement time. Different operational scenarios and design configurations are examined in a sample analysis to demonstrate the model's capabilities. Tradeoffs among sensing, data processing capabilities, vulnerability and lethality of UCAVs are explicitly represented with respect to selected MOEs.

Baskin, Clayton M. ***A Case Study of Insitu-Aircraft Observations in a Waterspout Producing Cloud***. M.S. in Meteorology. Monterey, California: Naval Postgraduate School, March 2005.
Thesis Co-Advisors: Haflidi Jonsson and Wendell Nuss
http://hdl.handle.net/10945/2320
http://handle.dtic.mil/100.2/ADA432302
Abstract: An analysis of in-situ aircraft observations collected in the parent cloud of a waterspout is presented. Previous waterspout studies were confined mainly to photometric and model simulated data, no in-situ observations were made internal to the parent cloud. On 27 June 2002 the Cooperative Institute for Remotely Piloted Aircraft Studies (CIRPAS) UV-18A Twin Otter aircraft collected observations in a cloud that had developed in a cloud line, located approximately 15km south of Key West, and that formed a waterspout. This study attempts to analyze the waterspout formation process using these data and through a series of scale interactions, from the synoptic scale down to the individual cloud scale. Based upon the analyzed data a hypothetical formation process is developed. The background synoptic scale flow is shown to establish the necessary ambient shear as a key factor in the waterspout formation. The orientation of mesoscale convergent boundaries and thermodynamic processes, internal to the

cloud, proved to be an essential factor in developing the vertical motion patterns necessary for formation of an organized circulation in the shear region and to provide the tipping and stretching of the resultant vortex necessary to account for the waterspout formation. This is consistent with conclusions derived from previous studies.

Brashear, Jr., Thomas James. *Analysis of Dead Time and Implementation of Smith Predictor Compensation in Tracking Servo Systems for Small Unmanned Aerial Vehicles*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, December 2005. Thesis Co-Advisors: Isaac I. Kaminer and Vladimir N. Dobrokhodov
http://hdl.handle.net/10945/1848
http://handle.dtic.mil/100.2/ADA443426
Abstract: Recent advances in technology have allowed for Small Unmanned Aerial Vehicles (SUAVs) to employ miniaturized smart payloads such as gimbaled cameras, deployable mechanisms, and network sensors. Gimbaled video camera systems, designed at NPS, use two servo actuators to command line of sight orientation via serial controller while tracking a target and is termed Visual Based Target Tracking (VBTT). Several Tactical Network Topology (TNT) experiments have shown high value of this new payload but also revealed inherent delays that exist between command and actuation of the pan-tilt servo actuators controlling the camera. Preliminary analysis shows that these delays are due to a communication lag between the ground control station and the onboard serial controller, a data processing delay within that controller, and the mechanical delays of the gimbal. This thesis applies system identification techniques to the servo controller system and considers the implementation of a Smith Predictor into the camera control algorithm in order to reduce the overall effect of the lag on the system performance.

Bromley, Joseph M. *Evaluation of the Littoral Combat Ship (LCS) and SPARTAN SCOUT as Information Operations (IO) Assets*. M.S. in Information Systems and Operations. Monterey, California: Naval Postgraduate School, March 2005.
Thesis Advisor: Michael T. McMaster
Second Reader: Steven J. Iatrou
http://hdl.handle.net/10945/2312
http://handle.dtic.mil/100.2/ADA432431
Abstract: This thesis will address the planned configuration of Lockheed Martin's Flight Zero, Module Spiral Alpha Littoral Combat Ship (LCS) and the ongoing development of the SPARTAN SCOUT, one of the Navy's Unmanned Surface Vessels (USV). Technology currently available as well as developmental technologies will be recommended for implementation in order to make the LCS and SCOUT assets to Information Operations (IO) objectives. Specific technology will include Outboard, TARBS, HPM, Loudspeakers, LRAD and Air Magnet. This thesis will include an evaluation of the current policy for authorizing Information Operations missions, specifically in the areas of Psychological Operations (PSYOP) and Electronic Warfare (EW).

Carter, Benjamin R. *Time-Optimization of High Performance Combat Maneuvers*. M.S. in Aeronautical Engineering. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Co-Advisors: R.M. Howard and I.M. Ross
http://hdl.handle.net/10945/2176
http://handle.dtic.mil/100.2/ADA435593
Abstract: Recent developments in post-stall maneuverability and thrust vectoring have opened up new possibilities in the field of air combat maneuvering. High angle of attack maneuvers like the Cobra, Herbst Reversal, and Chakra demonstrate that today's cutting edge fighters are capable of exploiting the post-stall flight regime for very dynamic and unconventional maneuvers. With the development and testing of Unmanned Combat Aerial Vehicles, even greater maneuvering ability is expected. However, little work has been done to make use of this increased ability by optimizing a wide range of combat maneuvers. The goal of this thesis was to begin that process by finding several time-optimal air combat maneuvers that could be employed by current and future high performance fighter aircraft.

Cesur, Fatih. ***Optimizing Formation Movement Over Heteregeneous Terrain***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Advisor: Gerald G. Brown
Second Reader: Ellen F. Roland
http://hdl.handle.net/10945/2174
http://handle.dtic.mil/100.2/ADA435595
Abstract: Formation movement is vital to preserve security among its units during military operations. We plan movement of a military formation over real, or simulated terrain, maximally preserving the relative positions of units in formation while it avoids barriers, and while its units avoid obstacles. Terrain is divided into homogeneous cells (say, squares), and a pair of neighboring cells is adjacent if the formation can transit between these cells while avoiding barriers with sufficient clearance. We induce a graph from these adjacencies, and determine the movement cost on each arc with a fine time-step simulation that finds local movement vectors to preserve relative formation position while avoiding approach too close to barriers or obstacles (this emulates solving differential equations with Euler's method). We then nominate an origin and a destination, select a shortest path, and repeat the time-step simulation over this path to determine the individual positions of each unit as the formation makes its transit. Game designers and robot controllers have published schemes to guide formation movement, but their movements can penetrate barriers, and myopically get caught in cul-de-sacs. By contrast, we guarantee that if a path exists that avoids these pitfalls, we will find it.

Cfir, Dolev. **A Model of Border Patrol to Support Optimal Operation of Border Surveillance Sensors.** M.S. in Operations Research, Naval Postgraduate School, December 2005.
Thesis Advisor: Roberto Szechman
Second Reader: Moshe Kress
Outstanding Thesis Award
http://hdl.handle.net/10945/1837
http://handle.dtic.mil/100.2/ADA443427
Abstract: Borders are monitored by a variety of moving and stationary sensors, e.g., patrol agents, video cameras, ground sensors, UAVs, etc. This paper introduces a model for a moving sensor that patrols a perimeter that is infiltrated by malevolent agents (targets). Targets arrive according to a Poisson process along the perimeter with a certain distribution of arrival location, and disappear (renege) a random amount of time after their arrival. The measures of effectiveness (MOEs) presented in this paper are the target detection rate and the time elapsed from target arrival to its detection (waiting time). We study two types of sensor trajectories that are periodic and with constant speed: 1. The sensor moves from a starting point to a certain location and then leaps instantaneously back to the starting point. 2. The sensor moves back and forth between two points. The controlled parameters (decision variables) are the beginning and end points of the patrolled sector. Properties of these trajectories are demonstrated in great generality. The results give decision makers a powerful tool for optimally deploying and operating a variety of sensors in an area of interest.

Crouch, Collier Craig. ***Integration of Mini-UAVs at the Tactical Operations Level: Implications of Operations, Implementation, and Information Sharing***. M.S. in Systems Technology. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Advisor: James Ehlert
Second Reader: Bill Kemple
Third Reader: Edward Fisher
http://hdl.handle.net/10945/2166
http://handle.dtic.mil/100.2/ADA435680
Abstract: Small units maneuvering on the battlefield have little time to establish data links and interface with the Global Information Grid (GIG) while trying to achieve an objective. The bandwidth and interface requirements necessary to receive live data from current strategic level systems limit the small unit operational user's ability to receive and act upon data and intelligence. Without the ability to interface with current strategic-level UAV assets, these small

units are left without a comprehensive operational picture. Mini-UAVs offer the capability for the tactical user, in a variety of missions, to have direct control over the aerial asset without intervention from higher authority. Organic UAV assets can be used to collect data relevant to small units without the need for connecting to intelligence systems. This offers increased mobility and a dedicated collection platform; however, there are still drawbacks to this capability. This thesis examines mini-UAVs, and their integration into the Coalition Operating Area Surveillance and Targeting System (COASTS) network.

Duhan, Daniel P. ***Tactical Decision Aid for Unmanned Vehicles in Maritime Missions***. M.S. in Systems Research. Monterey, California: Naval Postgraduate School, March 2005.
Thesis Co-Advisor: Russell Gottfried and Steven E. Pilnick
Second Reader: W. Matthew Carlyle
http://hdl.handle.net/10945/2274
http://handle.dtic.mil/100.2/ADA433030
Abstract: An increasing number of unmanned vehicles (UV) are being incorporated into maritime operations as organic elements of Expeditionary and Carrier Strike Groups for development of the recognized maritime picture. This thesis develops an analytically-based planning aid for allocating UVs to missions. Inputs include the inventory of UVs, sensors, their performance parameters, and operational scenarios. Operations are broken into mission critical functions: detection, identification, and collection. The model output assigns aggregated packages of UVs and sensors to one of the three functions within named areas of interest. A spreadsheet model uses conservative time-speed-distance calculations, and simplified mathematical models from search theory and queuing theory, to calculate measures of performance for possible assignments of UVs to missions. The spreadsheet model generates a matrix as input to a linear integer program assignment model which finds the best assignment of UVs to missions based on the user inputs and simplified models. The results provide the mission planner with quantitatively-based recommendations for unmanned vehicle mission tasking in challenging scenarios.

Elliott, Derek J. and Matthew G. Thompson. ***Comparison of "Functional Concept of Battlespace Awareness" Versus the Concept of "Power to the Edge," with a Focus on Integrating Shotspotter Sensors and Unmanned Aerial Vehicles***. Monterey, California: Naval Postgraduate School, September 2005.
Thesis Advisor: Shelley Gallup
Scond Reader: William Kemple
http://hdl.handle.net/10945/2120
http://handle.dtic.mil/100.2/ADA439286
Abstract: Current military doctrine is primarily hierarchical in nature with respect to power and authority. The "Functional Concept of Battlespace Awareness" (FCBA) is a military sensor methodology that employs a hierarchical command structure to test emerging technologies. Asymmetric warfare, however, demands a faster and more adaptive warfighting mentality that distributes power and responsibility across more of our forces; particularly those that are at the frontlines of the battlefield. "Power to the Edge" is a warfighting methodology that emphasizes a departure from traditional military hierarchies and a transition into a configuration that empowers "Edge" actors with information and authority. This thesis will prove that "Power to the Edge" doctrine is a more effective way to fight the enemies we will likely face in the Information Age. By analyzing and interpreting data collected at the Extended Awareness II and Extended Awareness IIB experiments, this thesis will show that transition in our current command and control methodology will be necessary to keep up with a changing enemy.

Frantz, Natalie R. ***Swarm Intelligence for Autonomous UAV Control***. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, March 2005.
Thesis Advisor: Phillip E. Pace
Second Reader: David C. Jenn
http://hdl.handle.net/10945/2152
http://handle.dtic.mil/100.2/ADA435664

Abstract: Unmanned Aerial Vehicles (UAVs) are becoming vital warfare platforms because they significantly reduce the risk of human life while accomplishing important missions. A UAV can be used for example, as stand-in sensor for the detection of mobile, low-probability-of-intercept battlefield surveillance and fire control emitters. With many UAVs acting together as a swarm, the location and frequency characteristics of each emitter can be accurately determined to continuously provide complete battlefield awareness. The swarm should be able to act autonomously while searching for targets and relaying the information to all swarm members. In this thesis, two methods of autonomous control of a UAV swarm were investigated. The first method investigated was the Particle Swarm Optimization (PSO) algorithm. This technique uses a non-linear approach to minimize the error between the location of each particle and the target by accelerating particles through the search space until the target is found. When applied to a swarm of UAVs, the PSO algorithm did not produce the desired performance results. The second method used a linear algorithm to determine the correct heading and maneuver the swarm toward the target at a constant velocity. This thesis shows that the second approach is more practical to a UAV swarm. New results are shown to demonstrate the application of the algorithm to the swarm movement.

Friedman, David A. **Laboratory Experimentation of Autonomous Spacecraft Docking using Cooperative Vision Navigation**. M.S. in Astronautical Engineering, Naval Postgraduate School, December 2005.
Thesis Advisor: Marcello Romano
Second Reader: Vladimir Dobrokhodov
http://hdl.handle.net/10945/1785
http://handle.dtic.mil/100.2/ADA443198.

Abstract On-orbit, autonomous docking and spacecraft servicing are key areas of research in the defense and civil space communities. This thesis contributes to that effort by developing portions of a testbed and an experimental docking vehicle at the Spacecraft Robotics Laboratory of the Naval Postgraduate School. The testbed was advanced by incorporating a large, flat epoxy surface and an indoor-GPS system into the laboratory framework. The epoxy floor allows a vehicle to emulate the space environment by floating on a nearfrictionless surface representing motion in two dimensions. Pseudo-GPS was integrated into the testbed to allow for independent verification and validation of a vehicle's performance. The docking simulator was developed by integrating computer hardware and attitude sensors into a newly-designed vehicle architecture to support its navigation and control needs. A position and attitude estimator was created to fuse the vehicle's sensor inputs. A control system was designed to allow for position control through eight thrusters and attitude control through the use of a reaction wheel. Finally, experiments of proximity navigation were conducted. One experiment established the versatility of the vehicle's control system by performing a closed loop maneuver. A second experiment successfully demonstrated a complete docking scenario.

Gow, Joel A. ***Testing the HG1700 Inertial Measurement Unit for Implementation into the AIRES Unmanned Underwater Vehicle***. M.S. in Applied Science. Monterey, California: Naval Postgraduate School, March 2005.
Thesis Co-Advisors: Anthony J. Healey and Edward B. Thornton
http://hdl.handle.net/10945/2149
http://handle.dtic.mil/100.2/ADA436083

Abstract: The ARIES Unmanned Underwater Vehicle (UUV) currently uses an Inertial Measurement Unit (IMU) with an inherent rotation rate error bias of 10 degrees/hour. Then need for a more accurate IMU for long term missions has led to the purchase of the Honeywell HG1700

IMU. The HG1700 is a ring laser gyroscope designed specifically as part of the navigation software in multiple U.S. missiles. The objective of this research is to perform numerous bench tests on the HG1700 to test its capabilities and to begin the process of implementing the IMU into the ARIES unmanned underwater vehicle. Specifically, the IMU is tested for correct setup configurations, angle of rotation accuracies, the rotation rate error bias, and positional accuracies. Also, guidelines for integrating the IMU with the current software in the ARIES vehicle are discussed.

Grabelle, Jason. *"Follow the Leader": Formation Control of Multiple Autonomous Underwater Vehicles using Forward Looking Sonar*. M.S. in Mechnical Engineering. Monterey, California: Naval Postgraduate School, March 2005.
Thesis Advisor: Anthony J. Healey
http://hdl.handle.net/10945/2150
http://handle.dtic.mil/100.2/ADA435568
Abstract: With the Global War on Terrorism (GWOT) taking place in full force, autonomous vehicles have become a major asset to government forces. Expansion of single vehicle technology to multiple vehicle technology is required in order for the United States to stay ahead of its adversaries in the GWOT and other technological fields (such as oceanography). Multiple vehicle technology has been explored by many different institutions in the recent past (Leonard, 2001 and Kucik, 2003). Expansion of this technology will lead to greater autonomy and robustness amongst the vehicles. This thesis presents a simulation of a "follow the leader" behavior for multiple Autonomous Underwater Vehicles (AUVs). The follower vehicle incorporates the use of forward-looking sonar to track the leader vehicle. This process will free up bandwidth between acoustic modems; allowing data transfer to occur with greater efficiency. Hydrodynamic coefficients are used to develop steering equations that model REMUS through a track of specified waypoints similar to a real-world mission track. A two-dimensional forward looking sonar model with a 120 [degree] horizontal scan and a 110 meter radial range is modeled to track the leader vehicle. Resulting bearing and range between the two vehicles is incorporated as control for positioning the follower vehicle.

Hahn, Matthew J. **Undersea Navigation Via a Distributed Acoustic Communications Network**. M.S. in Engineering Acoustics. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Co-Advisors: Joseph A. Rice and Clyde L. Scandrett
http://hdl.handle.net/10945/2141
http://handle.dtic.mil/100.2/ADA435873.
Abstract Acoustic modems are the basis for emerging undersea wireless communications networks. US Navy Seaweb technology offers an opportunity to perform undersea navigation and tracking by virtue of node-to-node ranging measurements acquired as a by-product of the acoustic communications protocol. A simple localization algorithm is developed and verified with synthetic data and is then tested with an Unmanned Undersea Vehicle (UUV) during an experiment at sea.

Hemminger, Daniel L. *Vertical Plane Obstacle Avoidance and Control of the REMUS Autonomous Underwater Vehicle using Forward Look Sonar*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Advisor: Anthony Healey
Second Reader: Doug Horner
http://hdl.handle.net/10945/2135
http://handle.dtic.mil/100.2/ADA435520
Abstract: Current rates of technological advancement continue to translate into changes on our battlefields. Aerial robots capable of gathering reconnaissance along with unmanned underwater vehicles capable of defusing enemy minefields provide evidence that machines are playing key roles once played by humans within our military. This thesis explores one of the major problems facing both commercial and military UUVs to date. Successfully navigating in unfamiliar environments and maneuvering autonomously to avoid obstacles is a problem that has yet to be

fully solved. Using a simulated 2-D ocean environment, the work of this thesis provides results of numerous REMUS simulations that model the vehicle's flight path over selected sea bottoms. Relying on a combination of sliding mode control and feedforward preview control, REMUS is able to locate obstacles such as seawalls using processed forward look sonar images. Once recognized, REMUS maneuvers to avoid the obstacle according to a Gaussian potential function. In summary, the integration of feedforward preview control and sliding mode control results in an obstacle avoidance controller that is not only robust, but also autonomous.

Henning, Wade A. and Daniel T. Walter. **Spiral Development in Action : A Case Study of Spiral Development in the Global Hawk Unmanned Aerial Vehicle Program**. Master of Business Administration. Monterey, California: Naval Postgraduate School, December 2005.
Advisors: Aruna U. Apte and Rene G. Rendon
http://hdl.handle.net/10945/9980
http://handle.dtic.mil/100.2/ADA443447.
Abstract: Evolutionary Acquisition (EA) is the established acquisition strategy of choice for the Department of Defense (DoD) and spiral development (SD) is the preferred process to execute this tactic. SD is used when the end-state of a weapon system is unknown, and its purpose is to get valuable capability into warfighters' hands much more quickly than before, even if the deliverable is only a partial solution. This approach is markedly different than the traditional DoD acquisition approach that too often fielded weapon systems late, over budget and with obsolete technology. As with any DoD initiative, SD is not a panacea. The purpose of this MBA Project is to identify some of the key characteristics necessary to implement SD in government acquisitions, and to present lessons learned from a program office currently using a spiral development approach. This is accomplished through a case study of the Global Hawk Unmanned Aerial Vehicle (UAV) Program. This paper examines the Global Hawk's spiral development strategies in several key program functional areas. It discusses SD challenges, and benefits with particular attention given to successful tactics and potential pitfalls of using this acquisition approach. Finally, it derives several lessons learned applicable to any DoD program manager.

Jenkins, Glenn E. and William J. Snodgrass, Jr. *The Raven Small Unmanned Aerial Vehicle (SUAV), Investigating Potential Dichotomies between Doctrine and Practice*. Master of Business Adminstration. NPS-PM-05-012. Monterey, California: Naval Postgraduate School, June 2005.
Advisors: David F. Matthews and Raymond Franck
http://hdl.handle.net/10945/834
Abstract: "The goal of this MBA Project is to investigate possible disconnects between doctrine and practice in the employment of the Raven Small Unmanned Aerial Vehicle (SUAV). The Army's current Small UAV requirements are based upon the Future Combat System's Operations Requirements Document and has not been validated at the platoon or company level. The Raven SUAV is a Commercial off the Shelf (COTS) item that swiftly became the Army's Small UAV of choice for operations in Afghanistan and Iraq. Doctrine and Techniques, Tactics, and Procedures (TTP) have been written for the Raven SUAV; however, it is not standard practice for all units operating the system abroad. The last review of the SUAV operational requirements was conducted in 2003 but did not specifically address its usage on the battlefield. In an attempt to fill that gap, this project focuses on real-world usage of the Raven SUAV system. We compare doctrine versus practice using the Department of Defense's (DOD) Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities (DOTML-PF) model as the primary logic construct. The report begins by providing a background of the Raven SUAV, to include its evolution from a COTS item to the Army's SUAV of choice, and how it has impacted the warfighter. Next, the authors provide an overview of DOTML-PF in order to provide a basis for comparing doctrine and practice. The study then looks in-depth at doctrine and practice using DOTML-PF as the model for revealing differences between the two. Finally, the authors analyze these differences and recommend solutions to mitigate shortfalls in actual Raven SUAV usage on the battlefield."--p. i.

Lear, Matthew R. *A Complex Adaptive System Approach to Forecasting Hurricane Tracks*. M.S. in Computer Science. Monterey, CA: Naval Postgraduate School, June 2005.
Thesis Advisor: John Hiles
Second Reader: Patrick Harr
http://hdl.handle.net/10945/1931
http://handle.dtic.mil/100.2/ADA435521.
Abstract Forecast hurricane tracks using a multi-model ensemble that is comprised by linearly combining the individual model forecasts have greatly reduced the average forecast errors when compared to individual dynamic model forecast errors. In this experiment, a complex adaptive system, the Tropical Agent Forecaster (TAF), is created to fashion a 'smart' ensemble forecast. The TAF uses autonomous agents to assess the historical performance of individual models and model combinations, called predictors, and weights them based on their average error compared to the best track information. Agents continually monitor themselves and determine which predictors, for the life of the storm, perform the best in terms of the distance between forecast and best-track positions. A TAF forecast is developed using a linear combination of the highest weighted predictors. When applied to the 2004 Atlantic hurricane season, the TAF system with a requirement to contain a minimum of three predictors, consistently outperformed, although not statistically significant, the CONU forecast at 72 and 96 hours for a homogeneous data set. At 120 hours, the TAF system significantly decreased the average forecast errors when compared to the CONU.

Lear, Matthew R. *Forecasting Hurricane Tracks Using a Complex Adaptive System*. M.S. in Meteorology. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Advisor: Patrick Harr
Second Reader: John Hiles
http://hdl.handle.net/10945/1930
http://handle.dtic.mil/100.2/ADA435522
Abstract: Forecast hurricane tracks using a multi-model ensemble that is comprised by linearly combining the individual model forecasts have greatly reduced the average forecast errors when compared to individual dynamic model forecast errors. In this experiment, a complex adaptive system, the Tropical Agent Forecaster (TAF), is created to fashion a 'smart' ensemble forecast. The TAF uses autonomous agents to assess the historical performance of individual models and model combinations, called predictors, and weights them based on their average error compared to the best track information. Agents continually monitor themselves and determine which predictors, for the life of the storm, perform the best in terms of the distance between forecast and best-track positions. A TAF forecast is developed using a linear combination of the highest weighted predictors. When applied to the 2004 Atlantic hurricane season, the TAF system with a requirement to contain a minimum of three predictors, consistently outperformed, although not statistically significant, the CONU forecast at 72 and 96 hours for a homogeneous data set. At 120 hours, the TAF system significantly decreased the average forecast errors when compared to the CONU.

Liang, Lawrence A. H. *The Use of Agent-Based Simulation for Cooperative Sensing of the Battlefield*. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, December 2005.
Thesis Advisor: Susan M. Sanchez
Second Reader: David W. Netzer
http://hdl.handle.net/10945/1740
http://handle.dtic.mil/100.2/ADA443319
Abstract: Many military Intelligence Surveillance and Reconnaissance (ISR) operations would benefit greatly from a fleet of disparate sensor-bearing UAVs that are tightly integrated via a communications network, work cooperatively for a common operational objective, enhance situation awareness of the areas of operation, and increase persistence of sensor dwell time on strategic targets. This would enable continuity in the entire target acquisition cycle, from detection to classification to identification and finally localization of targets, in a diverse and

dynamic environment. The integration of sensors and development of tactics in a cooperative sensing environment is one of the current focuses among the military intelligence community, and hence motivates this thesis effort. By building models with an existing agent-based simulation platform and using an extremely efficient experimental design methodology, numerous factors which could potentially affect the effectiveness of a cooperative sensing network against two arrays of targets are explored. The factors considered include UAV airspeed, reliability, detection/classification coverage and probability, network latency and degradation, UAV configurations and responsiveness, as well as air space separation. The two arrays of targets are mobile armor concentrations and time critical targets; these vary in their deployment profiles, vulnerability constraints and ease of detectability. Factors characterizing these targets, such as the shoot-and-scoot behavior of time critical targets, are also investigated. The study provides operational insights pertaining to the design and effective use of cooperative sensing for ISR purposes. These include the importance of having good UAV sensor capabilities, the need for a suite of sensors to aid in locating well-camouflaged time-critical targets, and the need for "intelligent" application of UAV cooperation tactics based on the characteristics of recently-classified targets.

McMindes, Kevin L. ***Unmanned Aerial Vehicle Survivability: The Impacts of Speed, Detectability, Altitude, and Enemy Capabilities***. M.S. in Operations Research. Monterey, California: Naval Postgraduate School, September 2005.
Thesis Advisor: Thomas W. Lucas
Second Reader: George E. Ehlers
http://hdl.handle.net/10945/1948
http://handle.dtic.mil/100.2/ADA439645
Abstract: Warfighters are increasingly relying on Unmanned Aerial Vehicle (UAV) systems at all levels of combat operations. As these systems weave further into the fabric of our tactics and doctrine, their loss will seriously diminish combat effectiveness. This makes the survivability of these systems of utmost importance. Using Agent-based modeling and a Nearly Orthogonal Latin Hypercube design of experiment, numerous factors and levels are explored to gain insight into their impact on, and relative importance to, survivability. Factors investigated include UAV speed, stealth, altitude, and sensor range, as well as enemy force sensor ranges, probability of kill, array of forces, and numerical strength. These factors are varied broadly to ensure robust survivability results regardless of the type of threat. The analysis suggests that a speed of at least 135 knts should be required and that increases in survivability remain appreciable up to about 225 knts. The exception to speed's dominance is in the face of extremely high capability enemy assets. In this case, stealth becomes more important than speed alone. However, the interactions indicate that as both speed and stealth increase, speed yields a faster return on overall survivability and that speed mitigates increased enemy capabilities.

Ouimet, Sean P. ***Undersea Navigation of a Glider UUV using an Acoustic Communications Network***. M.S. in Engineering Acoustics. Monterey, California: Naval Postgraduate School, September 2005.
Thesis Co-Advisors: Joseph A. Rice and Arlene A. Guest
http://hdl.handle.net/10945/2080
http://handle.dtic.mil/100.2/ADA439563
Abstract: The US Navy is developing Seaweb undersea acoustic networking technology to enable distributed autonomous ocean sensors. An Unmanned Undersea Vehicle (UUV) can operate as a mobile node among the grid in the conduct of its own mission, using the fixed nodes as navigation reference points. The fixed grid provides a cellular communications infrastructure for command & control and data telemetry. In turn, the UUV can support the fixed grid by physically redistributing large quantities of data throughout the network or for breaching the sea surface and acting as a mobile gateway node, communicating via satellite to a command center ashore. Assimilating UUVs as network nodes significantly enhances undersea network capability, expanding the available concepts of operations. This thesis concerns the use of the fixed undersea network as a means to track the UUV and anticipates routine operations of mobile

nodes in the context of fixed grids. This work is also a fundamental step toward advanced operations of fully mobile networks in the form of collaborative swarms.

Porter, Michael A. *Hyperspectral Imaging using Ultraviolet Light*. M.S. in Astronautical Engineering. Monterey, California: Naval Postgraduate School, December 2005.
Thesis Co-Advisors: Rcihard C. Olsen and Christopher Brody
http://hdl.handle.net/10945/1817
http://handle.dtic.mil/100.2/ADA443375
Abstract: The LINEATE IMAGING NEAR ULTRAVIOLET SPECTROMETER (LINUS) instrument has been used to remotely detect and measure sulfur dioxide (SO2). The sensor was calibrated in the lab, with curves of growth created for the 0.29 0.31 æ - spectral range of the LINUS sensor. Field observations were made of a coal burning plant in St. Johns, Arizona at a range of 537 m. The Salt River Coronado plant stacks were emitting on average about 100 ppm and 200 ppm from the left and right stacks respectively. Analysis of the LINUS data matched those values within a few percent. Possible uses for this technology include remote verification of industry emissions and detection of unreported SO2 sources.

Quek, Chin Khoon. *Vision Based Control and Target Range Estimation for Small Unmanned Aerial Vehicle*. M.S. in Engineering Science (Mechanical Engineering). Monterey, California: Naval Postgraduate School, December 2005.
Thesis Advisor: Isaac I. Kaminer
Second Reader: Vladimir N. Dobrokhodov
http://hdl.handle.net/10945/1815
http://handle.dtic.mil/100.2/ADA443306
Abstract: In the tracking of a moving ground target by small unmanned air vehicle (UAV) via camera vision, the target position and motion cannot be measured directly. Two different types of filters were assessed for their ability to estimate target motion, namely target velocity, directional heading on flat ground and distance from the UAV to target. The first filter is a nonlinear deterministic filter with stability guarantee. The second filter is based on nonlinear Kalman Filter technique. The application and performance of these two filters are presented, for simulated vision based target tracking.

Roberts, Scott D. *Stability Analysis of a Towed Body for Shipboard Unmanned Surface Vehicle Recovery*. M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, March 2005.
Thesis Advisor: Fotis Papoulias
Second Reader: William Solitario
http://hdl.handle.net/10945/2239
http://handle.dtic.mil/100.2/ADA432512A
Abstract: As the U.S. Navy develops new technologies which enhance automation and reduce crew size onboard naval vessels, unmanned vehicles will become increasingly valuable in conducting maritime operations. Effective launch and recovery systems (LARS) are necessary for unmanned vehicles to efficiently conduct operations at sea. The Towed Body system is a LARS with a wide range of applications for unmanned vehicle operations. The Towed Body can be evaluated as a small vessel with horizontal and vertical control surfaces. Since it is being towed, the directional stability of the Towed Body requires unique consideration due to the presence of the towing force. This thesis examines the effect of varying the longitudinal location of the vertical control surfaces, as well as the effective aspect ratio, size, and number of vertical control surfaces. The results identify critical stability values for the various fin configurations.

Schaeffer, Kevin M. and Thomas J. Gibbons, Jr. **Enhancing the Extended Awareness Capability of the ESG : Integrating Shotspotter and Cursor on Target Technologies with Unmanned Aerial Vehicles to Enhance the Mission Capability of the ESG.** M.S. in Systems Technology. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Advisor: Shelly Gallup
Second Reader: Bill Kemple
http://hdl.handle.net/10945/1858
http://handle.dtic.mil/100.2/ADA435746.
Abstract This thesis discusses two emerging technologies and how their integration with UAVs can improve the situational awareness capability of the Expeditionary Strike Group. Shotspotter is an acoustic gunshot detection system and Cursor on Target is an XML based schema to enhance information exchanges. When integrated with UAVs, these two technologies will drastically improve an ESG's efficiency and lethality in combat.

Shay, Tracy J. **Design and Fabrication of a Planar Autonomous Spacecraft Simulator with Docking and Fluid Transfer Capability.** M.S. in Astronautical Engineering, Naval Postgraduate School, December 2005.
Thesis Advisor: Marcello Romano
http://hdl.handle.net/10945/1823
http://handle.dtic.mil/100.2/ADA443398
Abstract The objective of this thesis is to describe the concept development, design, system integration, and operating procedures for the AUDASS II vehicle (Autonomous Docking and Spacecraft Servicing Simulator). The AUDASS II is an improved follow on design of AUDASS I, developed in September of 2002. The purpose of AUDASS II is to simulate a chaser spacecraft autonomously rendezvousing and docking with a target spacecraft for the purpose of conducting fluid transfer. This demonstration involves two vehicles elevated, via air pads, upon a smooth epoxy surface, thus allowing three near frictionless degrees of freedom. The ultimate goal of this thesis is to fabricate a vehicle and requisite documentation that will allow future students to conduct experiments using different control algorithms and/or sensors to conduct autonomous rendezvous and docking maneuvers.

St. Germain, Kenneth W. *Shipboard Radio Frequency and Free Space Optics Communications System using an Airborne Relay*. M.S. in Electrical Engineering. Monterey, California: Naval Postgraduate School, September 2005.
Thesis Advisor: Frank Kragh
Second Reader: Tri Ha
http://hdl.handle.net/10945/1991
http://handle.dtic.mil/100.2/ADA439542
Abstract: This thesis explores the possible gains and discusses the constraints of a communications system that uses a ship to unmanned aerial vehicle (UAV) radio frequency (RF) link paired with a UAV to satellite free space optic (FSO) link to accomplish satellite communications. Analysis shows that a data rate of 2 gigabits per second (Gbps) with a 1 . 10 probability of bit error can be attained by a shipboard system with a relatively small antenna and power supply if an FSO-enabled UAV is used. An experiment demonstrated that the addition of an FSO link and additional routing does not reduce the performance of a slower data rate RF link. The findings indicate that a composite RF and FSO ship-UAV-satellite system can be used within the Transformational Communications Architecture (TCA) and with the Navy's FORCEnet to enable network-centric operations (NCO).

Sulewski, Charles A. **An Exploration of Unmanned Aerial Vehicles in the Army's Future Combat Systems Family of Systems.** M.S. in Operations Research. Monterey, California: Naval Postgraduate School, December 2005.
Thesis Advisor: Thomas Lucas
Second Reader: Jeffrey B. Schamburg
http://hdl.handle.net/10945/1820
http://handle.dtic.mil/100.2/ADA443500.

Abstract Unmanned aerial vehicles (UAVs) will be a critical part of the U.S. Army's Future Force. The Future Force will be a highly mobile, network enabled family of systems with integrated sensors and precision munitions. The Future Force will rely heavily on UAVs to provide eyes on the battlefield. These eyes will trigger the deployment of precision munitions by other platforms, and possibly by UAVs themselves. To provide insight into how the numbers and capabilities of UAVs affect a Future Force Combined Arms Battalion*s (CAB*s) ability to secure a Northeast Asia urban objective, a simulation was built and analyzed. 46,440 computational experiments were conducted to assess how varying the opposing force and the numbers, tactics, and capabilities of UAVs affects the CAB*s ability to secure the objective with minimal losses. The primary findings, over the factors and ranges examined, are: UAVs significantly enhance the CAB*s performance; UAV capabilities and their tactics outweigh the number of UAVs flying; battalion level UAVs, especially when armed, are critical in the opening phases of the battle, as they facilitate the rapid attrition of enemy High Pay-off Targets; and, at least one company level and a platoon level UAV enhances dismounts survivability later in the battle.

Ulama, Tuncay. *Frequency and Polarization Diversity Jamming of Communications in Urban Environments*. M.S. in Systems Engineering. Monterey, California: Naval Postgraduate School, September 2005.
Thesis Advisor: David C. Jenn
Second Reader: Daniel C. Schleher
http://hdl.handle.net/10945/2095
http://handle.dtic.mil/100.2/ADA439586

Abstract: The purpose of this research is to investigate how to exploit frequency and polarization techniques in reducing the effects of jamming against UAV relay communication links in an urban warfare environment. There have been early studies investigating the diversity techniques against multipath and fading problems in urban environments. A medium without any jamming issues seems almost impossible to exist in today's warfare. Basically, noise jamming issues were taken into consideration. Urbana Wireless Toolset was used as the computer simulation. Even though it is a powerful tool to predict the radio wave propagation in urban environments, due to the problems about modeling the cities (lack of detail, like the shapes of the buildings, objects and vehicles that could be found in the streets, and other details that would contribute to the propagation mechanisms), it can only give us a trend with some guidelines instead of an exact mapping of propagation.

Valentine, Albert R. *Leveraging Emerging Technologies in Southern Thailand*. M.A. in National Security Studies. Monterey, California: Naval Postgraduate School, September 2005.
Thesis Advisor: Aurel Croissant
Second Reader: James F. Ehlert
http://hdl.handle.net/10945/2101
http://handle.dtic.mil/100.2/ADA439701

Abstract: Since 2001, the Kingdom of Thailand has seen a resurgence of ethno-religious (Malay-Muslim) violence that has killed approximately 800 people, causing obvious disruption within the nation and instability in the region. As one of the US' staunchest allies in Southeast Asia and with the potential for this violence to intensify further, it behooves the US government to offer solutions to help mitigate or reduce the violence in southern Thailand. This thesis examines the history of southern Thailand, analyzing the political factors behind the Malay-Muslim rebellions of the past, tracing the roots of their rebellion back to the era of Patani Raya and the "Siamization" of the south. It explores the various trends and actors and other antecedent conditions (external

influences) during the recent violence. Information on the various separatist groups operating in southern Thailand is provided along with an analysis of the porous Thai-Malay border and the role of PAS in southern Thailand. Lastly, this thesis examines an NPS field experimentation program entitled "Coalition Operation Area Surveillance and Targeting System" (COASTS). COASTS provides tactical, actionable information to remote and local decision-makers by integrating commercial-off-the-shelf (COTS) technologies such as unmanned aerial vehicles (UAVs), lighter than air vehicles (LTA), and unattended air and ground sensors, and wireless meshed networks technologies. If deployed to problematic areas, systems like COASTS can assist the Royal Thai government in reducing the violence in the south.

Van Reet, Alan Robert **Contour Tracking Control for the REMUS Autonomous Underwater Vehicle.** M.S. in Mechanical Engineering. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Advisor: Anthony Healey
http://hdl.handle.net/10945/1880
http://handle.dtic.mil/100.2/ADA435546
Abstract: In the interest of enhancing the capabilities of autonomous underwater vehicles US Naval Operations, controlling vehicle position to follow depth contours presents exciting potential for navigation. Use of a contour tracking control algorithm in lieu of preprogrammed waypoint navigation offers distinct advantages within new challenges. The difficult nature of this problem lies in the non-trivial connection between the necessary corrective action and the feedback error used in traditional control methods. Stated simply, modern vehicle control algorithms separate horizontal and vertical plane navigation. The autonomous vehicle senses heading error and applies rudder to steer the vehicle to a desired heading. Simultaneously, the vehicle might sense altitude and apply stern plane angles to maintain a safe height above ground. This thesis research examines the new problem of sensing depth and altitude in the vertical plane while steering the vehicle horizontally to find a specified bathymetry contour. While more remains to understand, this research proves the existence of a solution and suggests similar approaches may facilitate tying vehicle navigation to other indirect sensors. This thesis presents two contour tracking control algorithms and examines the performance of each by simulating the response of the REMUS underwater vehicle to ideal and real-world bathymetry models.

Ward, Jason L. **Design of a Prototype Autonomous Amphibious WHEGS^{TM} Robot for Surf-Zone Operations.** M.S. in Applied Physics. Monterey, California: Naval Postgraduate School, June 2005.
Thesis Co-Advisors: Richard Harkins and Vaidyanathan
http://hdl.handle.net/10945/1878
http://handle.dtic.mil/100.2/ADA435581.
Abstract The Small Robot Initiative at the Naval Postgraduate School (NPS) has spent several years in development based on the Foster Miller lemmings platform. This platform, in conjunction with a commercial off-the-shelf (COTS) control architecture, is capable of autonomous, land based waypoint navigation, self orientation, and rudimentary obstacle avoidance. It can receive waypoint information, manual control input, and transmit video and audio information back to a control station via 802.11 wireless communication. The introduction of the WHEGS design, developed at Case Western Reserve University, and a modified version of the COTS control system will provide a platform with greater speed, mobility and versatility. This thesis developed a prototype WHEGS vehicle and integrated the control system with improvements in the navigation routine through the addition of a dead reckoning sensor and calculation function. Although the mechanical design proved to be highly inefficient and unable to propel itself, the control system was successful, allowing integration with a more robust mechanical design from Case Western Reserve University. Follow on development and research will lighten the body through the use of carbon fiber and test the robots ability to maneuver effectively in the surf-zone.

Yang, Chuan-Hao. ***A Person-Tracking Mobile Robot using an Ultrasonic Positioning System***.
M.S. in Electrical and Computer Engineering. Monterey, California: Naval Postgraduate School, December 2005.
Thesis Advisor: Xiaoping Yun
Second Reader: Marcello Romano
http://hdl.handle.net/10945/1798
http://handle.dtic.mil/100.2/ADA443332

Abstract: It is desirable in many applications that a mobile robot is able to track and follow a person. There have been various efforts in literature to create person-tracking robots. However, current person-tracking robots are not capable of operating in unstructured environments. The problem of creating a person-tracking mobile robot has been studied by many researchers in literature. There are two main issues associated with this problem. The first issue is to equip a robot with proper sensory devices so that it is able to identify and locate the target person in a crowd in real time. Various approaches have been investigated, including vision, infrared sensors, ultrasonic sensors, and other approaches. The second issue is to control and navigate the robot so that it follows the target person within a certain distance. This seems to be simple, but in reality it is a fairly difficult task. For example, if the target person is in a busy corridor with many people standing and walking, the robot has to constantly avoid other people while following the target. There is still no reported evidence that a person-tracking robot has been implemented that is able to track a person in arbitrary environmental conditions. In this research, by using an innovative RF/ultrasonic sensor system, an intelligent person-tracking mobile robot is to be implemented that is able to follow the target person in unstructured, practical environments. The main focus of the thesis is development and implementation of control algorithms.

NPS Reports

2014

Oros, Carl L. *A Brief history of the NPS Field Experimentation Program: Spanning STAN, TNTand JIFX*. NPS-FX-14-003. Monterey, California: Naval Postgraduate School, 2014.
http://hdl.handle.net/10945/43732
Abstract: The NPS Field Experimentation Program was initiated in FY02 to provide an opportunity for NPS faculty and students to evaluate new technologies from their research in a field environment. These efforts were continued and integrated to create a formal decade long cooperative field experimental effort with USSOCOM (S&T /J9 and SORDAC) that began in FY03 as STAN (Surveillance and Targeting Acquisition Network) and culminated as TNT (Tactical Network Topology) in 2013. After TNT, sponsorship of NPS FX transitioned to OSD (AT&L) and the Department of Homeland Security (DHS). The NPS Joint Interagency Field Experimentation (JIFX) program exists today to support the S&T needs of all of the COCOMs, interagency, and first responders. This technical report serves to briefly document the history of the NPS FX program from STAN through current day JIFX. This document reflects the opinions of the author and does not represent the official policy or position of the Naval Postgraduate School, the United States Navy, or any other government organization.

2013

Beverly, Robert, Arthur Berger, Nicholas Weaver, and Larry Campbell. *Interring Internet Server IPv4 and IPv6 Address Relationships.* NPS-CS-13-002. Monterey, California: Naval Postgraduate School, 2013.
http://hdl.handle.net/10945/34089
Abstract: While IPv6 is finally experiencing non-trivial deployment, IPv4 and IPv6 are expected to co-exist for the foreseeable future, implying dual-stacked devices, and protocol interdependence. We develop and deploy a system for characterizing the association between IPv4 and IPv6 addresses ("siblings") within network server infrastructure, with specific forcus on Internet DNS and web servers. We develop two novel techniques for finding DNS resolver sibling groups, one passive and one active. For 674k observed (IPv4, IPv6) address pairs, we find that 34% of the addresses are one-to-one, i.e. appear in no other pair. Yet there are also complex cases, where distributed DNS resolution creates interconnected series of nameserver address pairs that can span continents and autonomous systems, compexity confirmed using active probing. We then describe a targeted method to actively interrogate candidate (IPv4, IPv6) pairs to determine if they are assigned to the same device. We find that the IPv4 and IPv6 addresses of Internet servers frequently belong to different interfaces, machines, and even autonomous systems Our results have important implications on network resilience, security, geolocation and performance measurement.

Buettner, Raymond R., Carl Oros, Ramsey Meyer and Nelly Turley. *NPS Field Experimentation Program for Special Operations (FEPSO) TNT 13-3 Final Report*. NPS-FX-14-002. Monterey, California: Naval Postgraduate School, 2013.
http://hdl.handle.net/10945/42544
Abstract: The NPS Field Experimentation Program was initiated in FY02 to Provide an opportunity for NPS faculty and students to evaluate New technologies from their research in a field environment. These efforts were continued and integrated to create a cooperative Effort with USSOCOM (S&T and J9) that began In FY03. TNT 13---3 Marked the this decade long USSOCOM--

-NPS field experimentation cooperative. This technical report serves to document this final event This report provides a consolidated analysis of event statistics and technological trends, to include unmanned autonomous system (UxS) activities from 2010 to 2013. The appendixes contain the Request for Information (RFI), list of experiments and schedule, experiment descriptions and after action reports. With the exception of the appendixes, this document reflects the opinions of the authors and does not represent the official policy or position of the Naval Postgraduate School, the United States Navy, or any other government organization. The data in the appendices were provided by the participants and have only been edited for clarity. Appendices C & D are Distribution B and will be published via a separate report.

2012

Brown, Thomas, Jonathan Damiano, Jhala Shivraj, Ryan Moore, Brett Morgan, Vincent Nguyen, Thomas Opheim, Timothy Ringwald, William Roman, John Turk, Christina Ushkevich, Kenneth Wampler, Paul Welsh, Paul and Heather Williams. *Next Generation Mine Countermeasures for the Very Shallow Water Zone in Support of Amphibious Operations*. NPS-SE-12-001. Monterey, California: Naval Postgraduate School, 2012.
http://hdl.handle.net/10945/6968
Abstract: This report describes system engineering efforts exploring next generation mine countermeasure (MCM) systems to satisfy high priority capability gaps in the Very Shallow Water (VSW) zone in support of amphibious operations. A thorough exploration of the problem space was conducted, including stakeholder analysis, MCM threat analysis, and current and future MCM capability research. Solution-neutral requirements and functions were developed for a bounded next generation system. Several alternative architecture solutions were developed that included a critical evaluation that compared performance and cost. The resulting MCM system effectively removes the man from the minefield through employment of autonomous capability, reduces operator burden with sensor data fusion and processing, and provides a real-time communication for command and control (C2) support to reduce or eliminate post mission analysis.

Dew, Nicholas. *Strategic Acquisition of Navy Unmanned Systems: Analysis and Options*. NPS-AM-12-179. Monterey, California: Naval Postgraduate School, 2012.
http://hdl.handle.net/10945/33850
Abstract: The U.S. Navy (USN) and U.S. Department of Defense (DoD) have many emerging robotics needs and potentialities. However, although the U.S. is strong in defense robotics in particular in Unmanned Aerial Systems (UAS) -- recent reports have identified fundamental weaknesses in the broader U.S. robotics innovation system in which defense robotics is embedded. Since the potential scale of commercial robotics is far greater than military robotics over the long run, the U.S. needs to develop a stronger national robotics innovation system to support the long-term development of defense robotics and help make the nation more secure. Traditionally, the policy response to such needs has involved stimulating the supply side. This report identifies robust local U.S. demand for robotics as a critical element in developing a thriving U.S. robotics innovation system. Therefore, while some DoD acquisition strategies attend to industry development via supply-side elements (such as research and development support for major suppliers, Small Business Innovation Research initiatives, etc.), I suggest that these initiatives must be complemented with a set of pro demand-side acquisition strategies. This report outlines the rationale for including a demand-side approach in DoD robotics acquisition policy, a set of appropriate strategies, and a framework for implementation.

Moltz, James Clay. ***Submarine and Autonomous Vessel Proliferation: Implications for Future Strategic Stability at Sea.*** PASCC Report Number 2012-021. Monterey, California: Naval Postgraduate School, 2012. http://hdl.handle.net/10945/34355

Abstract: "Conventional wisdom from the late Cold War onward suggests that the U.S. submarine force is virtually invulnerable to attack, particularly since the demise of the Soviet Union. U.S. nuclear force planning and a range of other Navy long-range procurement plans assume the safety of future SSBN [Ballistic Missile Submarine] and SSN [Nuclear Attack Submarine] operations and the relative absence of threats. This scoping study tests and challenges these assumptions by examining international trends in the proliferation of submarines and autonomous vessel technology. It begins by observing that undersea strategic stability during the Cold War relied on specific factors that may not be present in the future. The study then surveys the range of new countries and capabilities emerging in the 21st century undersea environment. It concludes by suggesting that undersea warfare is going to pose serious new challenges to the U.S. Navy, possibly putting its sea-based leg of the triad at risk as the number of operational boats declines, while also observing that overseas SSN operations will be complicated by changing conditions and ASW [Anti-Submarine Warfare] developments. Finally, Moltz offers several possible remedies: 1) revision of currently laissez-faire U.S. policies in the area of submarine export controls; 2) revised procurement and basing policies in regard to U.S. SSBNs to reduce emerging vulnerabilities; and 3) reconsideration of diesel/AIP [Air-Independent Propulsion] boats as a supplement to U.S. SSN forces for enhanced ASW and for conducting certain domestic and overseas missions better suited to smaller, less costly, less vulnerable, and more nimble vessels."

2011

Bechtel, Wayne, Nathaniel Hathaway, Trevor Jerdee, Eric Laskey, Jill McConaghy, Lisa Quade, Kariym Smith, Scott Sparrow, and James Tuey. ***Roving UAV IED Interdiction System***. NPS-SE-11-002. Monterey, California: Naval Postgraduate School, Department of Systems Engineering, 2011.
http://hdl.handle.net/10945/6957
http://handle.dtic.mil/100.2/ADA540926

Abstract: In support of the Naval Postgraduate School's Systems Engineering Capstone, a project team was formed from Cohort 311-093A to perform an analysis on the possibility of utilizing Unmanned Air Vehicles (UAVs) in campaign against improvised explosive devices (IEDs). The goal of the project was to determine if a weapon system is feasible to increase capabilities to the warfighter in the fight against the IED threat. The project scope was limited to the UAV classes with local (squad/battalion) control to provide an organic increase in capabilities; specifically Tier I (man-portable) and Tier II (tactical) families of UAVs. Modeling and simulation, warhead analysis, and a cost analysis were used to score the proposed alternatives on specific Key Performance Parameters. This information was analyzed and a recommendation was made to only arm the Tier II UAV using a small missile.

Calvert, Willard, Rachel Cohn, Gail Goodman, Brian Heidt, Joseph Lojek, Sarah Malecki, and Brian Powell. ***A System to Integrate Unmanned Undersea Vehicles with a Submarine Host Platform***. NPS-SE-11-006. Monterey, California: Naval Postgraduate School, Department of Systems Engineering, 2011.
http://hdl.handle.net/10945/6961

Abstract: Submarines offer a capability to deploy and retrieve unmanned undersea vehicles (UUV) in littoral and blue water Areas of Operation while avoiding detection. Integration of the submarine and UUV through a launch and recovery mechanism offers unique challenges with respect to host submarine safety, UUV recovery, UUV replenishment and life-cycle costs. The Capstone team elicited launch and recovery system requirements from stakeholders and conceived four (4) advanced alternatives and a baseline alternative considered to meet the requirements. Through functional, cost, risk, modeling and qualitative analysis, this study

assessed the value of each alternative to stakeholders. Of the concept alternatives explored, a high tech option featuring a carbon fiber structure, electromechanical pulse launch and recovery device and proximity vice contact battery charging and UUV stowage features provided the best value to the stakeholders for the investment. These results highlighted characteristics, including maintenance considerations, upgradeability, design for reliability and design for universal applications considered paramount for a successful system. Project lessons learned uncovered significant risk due to instability of UUV requirements as well as certification issues which adversely affect a submarine/UUV integration project. Early communications between key stakeholders must effectively address these short-comings.

Cox, Patrick, Christie Jordan, Kate Mangum, John Mitchell, Kevin O'Neill, and Kevin Seraile. ***Unmanned Surface Combatant Considerations for Concept Exploration***. NPS-SE-11-007. Monterey, California: Naval Postgraduate School, Department of Systems Engineering, 2011. http://hdl.handle.net/10945/6962
Abstract: This capstone project explored the operational and design considerations/constraints for an autonomous Unmanned Surface Combatant (USC). Using a USC in selected missions could lead to cost reductions and enhanced capabilities when compared with similar manned combatants by eliminating personnel and automating ship operations. Operations and Support (O&S) costs, which include personnel costs, are a large portion of the Navy's total ownership costs (TOC) for surface combatants, and can be as high as 38 percent of the TOC. Enhanced capabilities for a USC could be derived from performing operational activities manned ships cannot; and automated tasks could be performed more efficiently and effectively by a computer system than a human. A modified waterfall systems engineering process model was used to explore a USC concept. A needs analysis was performed, and mine warfare and anti-submarine warfare were identified as appropriate military missions for an initial USC concept. Top level constraints for a USC concept and support missions were developed. Design considerations, relevant technologies, and concept risks were investigated. This capstone project concluded that a lower cost, higher capability autonomous USC is possible based on the current state of relevant technologies. However there are significant technical challenges to overcome before full autonomy is possible. Further, more rigorous design studies are recommended.

Emmersen, Tracy; Chuan, Ng Kiang; Chiam, David; Xuan, Ong Zi; Daniel, Perh Hong Yih; Yung, Koh Wee; Wessner, Wes; Saburn, Jon; Wee, Lim Choon; Heng, Wong Chee; Silvestrini, Christian; Liang, Lu Zheng; Castaneda, Phil; Lun, Sor Wei; Kok, Pek Wee; Drennan, Jim; Kiong, Teo Yong; Fung, Tan Yick; Harvey, Scott; Walker, William; Chuan, Wee Hong; Malinowski, Matt; Zhu, Kelvin; Mills, Thomas; Wei, Chang Chung. ***Advanced Undersea Warfare Systems***. MSSEA in Systems Engineering. NPS-SE-11-004. Monterey, California: Naval Postgraduate School, Department of Systems Engineering, 2011. http://hdl.handle.net/10945/6959
Abstract: Over the next twenty years, the proliferation of threats in the undersea environment will likely challenge the platform-centric model that the United States Navy uses to maintain dominance in Undersea Warfare (USW). Meanwhile, rapidly maturing technologies offer greater capabilities to potential adversaries around the world. Such a paradigm creates an imperative for the Navy to harness emerging technologies to maintain USW dominance amid a dynamic threat environment, while balancing cost, risk, and required performance. This systems engineering analysis develops Advanced Undersea Warfare Systems (AUWS) that provide a technological and tactical advantage based on the needs of the war-fighter. Following critical analysis of the numerous possible alternatives for performing the necessary Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) and prosecution and an objective screening process, four system architectures, and associated operational concepts, are selected for detailed analysis. From cost, risk, and performance analyses, superior AUWS concepts are shown to be flexible, scalable, and tailorable systems that balance critical need areas. This analysis highlights the need for new warfare systems that can meet future challenges to the traditional platform-centric model for USW dominance. Using the

results and recommendations in this analysis will allow the Navy to deploy capabilities that effectively and efficiently meet future operational needs.

Franck, Raymond E., Ira Lewis, David Matthews and Bernard Udis. ***Emerging Patterns in the Global Defense Industry***. NPS-AM-11-001. Monterey, California: Naval Postgraduate School, 2011. http://hdl.handle.net/10945/33589

Abstract: We continue our ongoing research into the global defense industrial base with a view to better understanding its increasingly complex nature. Our aim has been to understand defense industrial developments, place those developments in context, and find explanatory paradigms suitable for better explanation of ongoing trends. In this report we consider the ongoing travails of the KC-X program, the C-27, and the rise of unmanned aerial combat systems (UAVs, UCAVs, UASs). The KC-X has been an excellent example of the complicated influences that shape the U.S. defense acquisition system ''bureaucratic, legalistic, and political. It has also illustrated (to this point) the capability of those influences to impose significant delays on even relatively simple projects. The C-27 is an excellent example of the increasingly globalized nature of aerospace industries'' and their complex relationships with defense customers. The rise of UAVs has been a significant event for military affairs, defense industrial firms, and military organizations. In this report, we discuss UAVs in the context of the ongoing competition between the U.S. and its allies against terrorist-insurgent opponents. We also discuss the organizational issues associated with UAVs through the Raven UAV and its integration with the U.S. Army's support structure.

Gordon, Brent and Gregg Lee, Brian Johnson, David Perko, Altonio Bullock, Kent Yen, Marcio Chinn, Benjamin Tan. ***Pirate Mother Ship Warning and Reporting System (PMSWRS).*** NPS-SE-11-011. Monterey, California: Naval Postgraduate School, 2011. http://hdl.handle.net/10945/6963

Abstract: The Pirate Mother Ship Warning and Reporting System (PMSW&RS) analysis identifies a suitable and effective combination of unmanned aerial systems land launched from regional main operating bases (MOB) or commercial airfields to provide persistent intelligence, surveillance, reconnaissance, and tracking of Pirate Mother Ships that are prowling the shipping lanes for commercial vessels transiting across the Horn of Africa (HOA). The team developed a systems concept, the context, and a requirements hierarchy to support mission objectives. Architectural baselines were developed to identify key design characteristics and to provide insight into the value system design, analysis, modeling, and research efforts. System modeling using IBM Rational Rhapsody toolset, OMOE analysis, and CAIV analysis confirm that the highest value solution uses the LEMV.

Payton, Leslie T. ***The Future of Unmanned Aircraft Systems in Support of the Marine Expeditionary Unit***. NPS-CE-11-183. Monterey, California: Naval Postgraduate School, 2011. http://hdl.handle.net/10945/33728

Abstract: The USMC Marine Expeditionary Unit (MEU) is commonly referred to as the nation''s 911 force. It must be capable of executing a full spectrum of missions from low-intensity humanitarian assistance and noncombat evacuations to high-intensity major combat operations. The MEU''s structure and equipment are designed around this multi-mission requirement. However, the USMC owns the fixed-winged Shadow unmanned aircraft system (UAS) and is in the process of acquiring a small fixed-wing UAS, the small tactical UAS to provide intelligence, surveillance, and reconnaissance. The USMC is also researching a cargo resupply UAS based on helicopter technology. The USMC focus on single-mission UAS does not fit with the MEUs mission requirements. This thesis will examine MEU mission requirements and recommend a UAS capability set that best supports MEU operations. From this recommended set of requirements, the thesis will use a cost analysis to determine a future UAS program of record.

Rice, Marshall and Rahul Petrie, Daniel Reese, Kurtis Hoots, Robert Taylor, Drew Nash, Jonathan Trdan-Schmidt, Thuan Huynh, Bunny Cooper. ***United States Navy Oceanic Armed Reconnaissance System***. MSSE & MSES in Systems Engineering. NPS-SE-11-017. Monterey, California: Naval Postgraduate School, 2011.
http://hdl.handle.net/10945/6967
Abstract: A student team at the Naval Postgraduate School studied the need for, and development of, a system that effectively and economically deters piracy in an area of interest. The system's proposed area of operation is the Gulf of Aden, but the system may be deployed to any operational theater where piracy threatens maritime commerce. Piracy and hijacking of ships off the Somali Coast have grown tenfold since 2006. In response to this growing problem, the U.S. Navy, along its with allies, formed Combined Task Force 151 (CTF-151) to protect approximately 33,000 merchant vessels transiting through this area daily. CTF-151 patrols the Internationally Recommended Transit Corridor (IRTC) in the Gulf of Aden and because of this, Somali pirates have begun to migrate away from the IRTC and CTF-151 patrols. For this reason, the team studied the use of UAV technology that allowed for broader area of piracy surveillance and detection. The system that was conceived and analyzed was the Oceanic Armed Reconnaissance System (OARS). The OARS Basic alternative, when analyzed against CTF-151, was found to be the most cost effective system. This OARS Basic system is comprised of a Littoral Combat Ship (LCS) as a host vessel, ScanEagle UAVs, an SH-60 Helicopter, and Zodiac Rigid Hulled Inflatable Boats (RHIB).

Roeting, Bill and Charles Menza. ***BRITEdge 11-1 Limited Objective Experiment***. NPS-IS-11-003. Monterey, California: Naval Postgraduate School, 2011.
http://hdl.handle.net/10945/684
Abstract: This report summarizes the results of a limited objective experiment to demonstrate the capability of ROVER technology to provide real-time full motion video surveillance of the US -- Mexican border in support of US Customs and Border Protection (CBP) agents.

2010

Albrant, Jeremiah, Raymond Buchholz, Brian Clulow, Raymond Held, Amrik Khatra, Todd Miller, Ira Minor, et al. ***An Analysis of Sensor Data Path as a "Game Changer" at the Operational Level of War***. NPS-SE-10-009. Monterey, California: Naval Postgraduate School, 2010.
http://hdl.handle.net/10945/6955
Abstract: This project describes a Systems Engineering approach to validate that variation of the sensor data path at the Operational Level of War (OLW) represents a "game changing" concept to improve Fleet Battle Management through the Naval Planning Process (NPP) in the Maritime Operations Center. The team used Vitech's CORE Model Based Systems Engineering tool to model and simulate the baseline and hypothesized data paths and information processes derived from two mission threads: Counter-Piracy and Humanitarian Assistance/Disaster Relief. Considerations for time-sensitive sensor data included key decisions on tasking, collection, processing, exploitation, fusion, analysis, and dissemination. Modeling and simulation results show that Unmanned Aerial Systems (UASs) at the OLW provides only a minor improvement to the overall performance of the NPP and a moderate improvement to the number of information requests the Maritime Intelligence Operations Center can fulfill. The results are significant in that they appear to validate an Operational Commander's decision not to directly use UAS to support the OLW. Future research should be directed towards the determination of the capacity of such "game changing" technology to effectively support mature operational environments or be the linkage for other sources of information for mission achievement.

Bartolomeo, Peter, William McCartney, Jack Plessinger, Shawn Woodson, Andrew Tebbano, Rebeca Nixon, and Kerry Westervelt. ***Investigation of the Potential Material Solution for Utilizing an Unmanned Aerial System to Protect Off-Shore Oil Platforms from Surface Threats***. NPS-SE-10-005. Monterey, California: Naval Postgraduate School, 2010. http://hdl.handle.net/10945/6951

Abstract: This paper describes a potential material solution for the utilization of an unmanned aerial system to identify, discriminate, and engage potential surface threats to off-shore oil platforms. The intent of the research effort was to identify how US maritime forces are presently deployed to protect off-shore oil platforms from sabotage, takeover, or destruction and to determine if an unmanned aerial system could be utilized to enhance that effort and perhaps reduce the manpower requirements. While numerous possible threats exist including aerial and sub-surface attack, the present study concentrated on surface threats. A disciplined systems engineering approach was utilized to determine the most cost-effective solution that meets key stakeholder requirements for identifying, engaging, and neutralizing potential threats in a time-critical manner through either lethal or non-lethal means. The initial capability requirements are decomposed into functions to be performed and the functions are evaluated through consideration of either fixedwing, rotary-wing, or lighter-than-air platforms using standard systems engineering tools and methods to determine the most cost-effective solution that meets stakeholders needs. Architectural views and functional block diagrams are provided which meet stakeholder requirements and a preferred solution is provided along with recommendations for further research.

Chanda, Michael, Julee DiPlacido, John Dougherty, Richard Egan, John Kelly, Trent Kingery, Daniel Liston, et al. ***Proposed Functional Architecture and Associated Benefits Analysis of a Common Ground Control Station for Unmanned Aircraft Systems***. NPS-SE-10-002. Monterey, California: Naval Postgraduate School, 2010. http://hdl.handle.net/10945/6949

Abstract: The proliferation of Unmanned Aerial Systems (UASs) and lack of mandated standards has led to unique Unmanned Aerial Vehicle (UAV) and Ground Control Station (GCS) designs. A former Under Secretary of Defense for Acquisition, Technology, and Logistics, stated in an Acquisition Decision Memorandum (ADM) that UAS GCS commonality could reduce manpower, procurement, sustainment and life cycle costs. While the ADM provided an impetus for commonality, it did not define a path. This project defines a common GCS functional architecture that provides the first steps on the path to UAS commonality. Stakeholder documentation was analyzed to identify areas of greatest concern and to examine previous efforts in this domain. Then, a tailored systems engineering process was employed to develop a new set of requirements which includes a common Air Vehicle Operator (AVO) Human-Machine Interface. These requirements enabled the creation of an innovative functional architecture for a common GCS concept. The utilization of this architecture has multiple operational, logistical, and financial benefits. This project quantified AVO training cost benefits and found that implementation of the common GCS architecture in accordance with the derived requirements will benefit the Department of Defense through reduced Operations and Support costs and increased operational capability.

Ford, David N., Thomas J. Housel, and John T. Dillard. ***System Dynamics Modeling for Improved Knowledge Value Assessment : A Proof-of-Concept Study***. NPS-GSPBB-10-015. Monterey, California: Naval Postgraduate School, 2010. http://hdl.handle.net/10945/651

Abstract: Effective and efficient DoD acquisition programs require the analysis of a wide range of materiel alternatives. Diversity among alternatives, difficulties in selecting metrics and measuring performance, and other factors make the Analysis of Alternatives (AoA) difficult. The benefits of alternatives should be included in the AoA, but cost estimates dominate most AoA processes. Incorporating benefits into AoA is particularly difficult because of the intangible nature of many important benefits. The current work addresses the need to improve the use of benefits in AoA by building a system dynamics model of a military operation and integrating it with the Knowledge

Value Added (KVA) methodology. The synergies may be able to significantly improve the accuracy of KVA estimates in the AoA process. A notional mobile weapon system was modeled and calibrated to reflect four weaponized Unmanned Aerial Vehicles (UAV). Modeling a hypothetical AoA for upgrading one of the UAV indicated that there were potentially significant synergies that could increase the number of alternatives that could be analyzed, establishing common units of benefit estimates for an AoA, improved reliability of an AoA, and improved justification of AoA results. These can improve alternative selection, thereby improving final materiel effectiveness, thereby improving the DoD acquisition processes.

Hernandez, Mark, Henry Jackson, Oscar Meza, Craig McKinney, Rebecca Morgan, Billy Palermo, Sommer Roach, Al Spaterna, and Diane Wathen. ***MH-60 Seahawk / MQ-8 Fire Scout Interoperability***. NPS-SE-10-006. Monterey, California: Naval Postgraduate School, 2010. http://hdl.handle.net/10945/6952
Abstract: As part of a Naval Postgraduate School's capstone project in Systems Engineering, a project team from Cohort 311-0911 performed a Systems Engineering analysis. This Project focused on defining alternatives for enhanced Anti-Surface Warfare (ASUW) mission effectiveness through increased interoperability and integration for the Fire Scout Unmanned Air Vehicle and Seahawk helicopter. Specifically, the Project explored the available trade space for enhancing communications back to the ship for analysis and decision-making. Modeling and Simulation (M&S) was used to assess the impact of enhanced communication on specific Key performance Parameters (KPPs) and Measures of Effectiveness (MOEs) associated with the ASUW mission. Once the trade space was defined, alternatives were analyzed and a recommendation provided that supports near-, mid-, and long-term mission enhancement.

Quincy, Keith E., Jamarr J. Johnson, Michael G. Moran, Drew J. Nilsson, and Bradley G. Thompson. ***An Integrated Command and Control Architecture Concept for Unmanned Systems in the Year of 2030***. NPS-SE-10-003. Monterey, California: Naval Postgraduate School, 2010. http://hdl.handle.net/10945/5244
http://handle.dtic.mil/100.2/ADA524154
Abstract: U.S. Forces require an integrated Command and Control Architecture that enables operations of a dynamic mix of manned and unmanned systems. The level of autonomous behavior correlates to: 1) the amount of trust with the reporting vehicles, and 2) the multi-spectral perspective of the observations. The intent to illuminate the architectural issues for force protection in 2030 was based on a multi-phased analytical model of High Value Unit (HVU) defense. The results showed that autonomous unmanned aerial vehicles are required to defeat high-speed incoming missiles. To evaluate the level of autonomous behavior required for an integrated combat architecture, geometric distributions were modeled to determine force positioning, based on a scenario driven Detect-to-Engage timeline. Discrete event simulation was used to schedule operations, and a datalink budget assessment of communications to determine the critical failure paths in the the integrated combat architecture. The command and control principles used in the integrated combat architecture were based on Boyd's OODA (Obseve, Orient, Decide, and Act) Loop. A conservative fleet size estimate, given the uncertainties of the coverage overlap and radar detection range, a fleet size of 35 should be anticipated given an UAV detection range of 20km and radar coverage overlap of 4 seconds.

2009

Bostwick, Shawn, Ben Buenviaje, Ali Fotouhi, Carlos Perez-Luna, Keri Pilling, and Jose C. Umeres. ***Augmenting Naval Capabilities in Remote Locations***. NPS-SE-10-001. Monterey, California: Naval Postgraduate School, December, 2009. http://hdl.handle.net/10945/6948
Abstract: The objective of this project was to apply a systems engineering approach to explore concepts for augmenting naval capabilities in remote sea locations using a standard Systems Engineering methodology coupled with Design for Lean Six Sigma tools. Because of increased

challenges related to complexity, cost, and timing, our engineering approach focused on finding failure modes early and implementing effective countermeasures. Following requirements analysis and identification of needed functions, the project team synthesized candidate solutions that introduced new concepts and also exploited known programs of record within the Navy, the Coast Guard, and the Marine Corps. These included Unmanned Air Vehicles (UAVs), Unmanned Surface Vehicles (USVs), the aerostat Multi-Function Phased Array Radar, automation, and a Remote Sea Station. Results from analysis and simulations showed that an Automated Super-Highway Concept (ASHC) addressed the immediate need. The proposed approach combines the capabilities of the systems above to control the battle space in an effort to divert or destroy all non-friendly entities in the areas of interest. This approach also allows for persistent presence and analysis of the enemy movement while reducing the naval task force already assigned to patrol these areas.

2008

Agpaoa, Roy, Matthew Cawley, Chad Cossey, Jose Galvan, Alan Giang, Joseph Hanchinamani, Jeffrey Ikeda, et al. *Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission Capability.* Keyport MSSE Cohort. NPS-SE-08-003. Monterey, California: Naval Postgraduate School, 2008.
http://hdl.handle.net/10945/6935
http://handle.dtic.mil/100.2/ADA483334
Abstract: The Hybrid Airship Multi-Role (HAMR) Anti-Submarine Warfare (ASW) Mission Module project applies established systems engineering principles and processes to the design of an ASW payload module that examines the capability of the HAMR to perform persistent ASW mission support. Critical system functions and objectives are identified and are assigned appropriate quantitative metrics. Additionally, three alternative architectures are generated and evaluated using the appropriate metrics based on results from modeling using Naval Systems Simulation (NSS). Manning is considered as a key stakeholder parameter and is included as an evaluation concern. The alternatives are also compared through the examination of life cycle costs. The recommendation to the stakeholders based on the research and results is an unmanned ASW sensor platform that uses other ASW assets for prosecution.

Tvaryanas, Anthony P., William Platte, Caleb Swigart, Jayson Colebank, Nita Lewis Miller, and 311th Performance Enhancement Directorate. *A Resurvey of Shift Work-Related Fatigue in MQ-1 Predator Unmanned Aircraft System Crewmembers*. Monterey, California: Naval Postgraduate School, 2008.
http://hdl.handle.net/10945/759
http://handle.dtic.mil/100.2/ADA477976
Abstract: A previous study showed shift working crewmembers in a MQ-1 Predator unmanned aircraft system (UAS) squadron had significantly increased fatigue, emotional exhaustion, and burnout relative to traditional aircrew from another "high-demand, low density" weapon system. This study presents the results of a follow-up survey of this population of UAS crewmembers who were supporting "reachback" teleoperations using a modified rotational shift work schedule. Specifically, shift work-related increases in fatigue, sleepiness, and risk for performance decrements were examined. Shift system features and individual and situational differences associated with fatigue were also explored. Finally, shift system features of several types of schedules were assessed through modeling and simulation. The study found no significant reduction in reported fatigue despite prior modifications to the shift work schedule. It also demonstrated the potential for inadequate staffing levels to magnify the adverse effects of shift work.

2007

Gassier, David, David Gassier, Jerome Rebollo, and Romain Dumonteil, and Association for the Development of Teaching and Research Area PACA. ***Implementing a Low-Cost Long-Range Unmanned Underwater Vehicle: The SeaDiver Glider***. NPS-MV-07-001. Monterey, California: Naval Postgraduate School, 2007.
http://hdl.handle.net/10945/819
http://handle.dtic.mil/100.2/ADA468591

Abstract: The SeaDiver Glider is an UUV (Unmanned Underwater Vehicle) used for underwater prospecting at a low cost with a long distances coverage (~1400 miles). It moves without propellers by changing its buoyancy with the help of ballast and its hydrodynamics profile reminiscent of a wing (model NACA0022). Ballast inflation makes it raise the surface, ballast deflated make it submerge the bottom. Ballast is positioned in front of its structure in an optimal position to use the lift of its shape. This up-and-down movement is converted into horizontal displacement by the wing-shape of the SeaDiver Glider. It mimics sinusoidal movements from the sea surface down to 300 feet underwater. This vehicle is able to traverse from one point to another without human intervention.

Hatch, William D. and Gregory Miller. **Graduate School of Business and Public Policy. *Unmanned Vehicles Systems; Unmanned Vehicle Tactical Memorandum (TM 3-22-5-SW) : Report of Findings and Recommendation***. NPS-AM-06-015. Monterey, California Graduate School of Business & Public Policy: Naval Postgraduate School, 2007.
http://hdl.handle.net/10945/381

Abstract: In response to a request by NWDC, the Naval Postgraduate School agreed to research and revise the current Maritime Tactical Memorandum (TACMEMO) TM 3-22-5-SW for unmanned vehicles systems (UVS). The CRUDES fleet would immediately benefit by the removal of Captain's gigs/second RHIB in favor of a unmanned surface vehicle (USV) in order to increase warfighting capabilities. An analysis of N86 CRUDES ROC/POEs revealed no impact to primary or secondary warfighting missions by removing the gig/second RHIB. In today's capabilities-based warfighting, this replacement better supports the global concept of operations. The research was limited to sparsely deployed platforms, developmental project results, and test procedures as delineated in various UV concepts of operations. It was found that the preponderance of UVs remain largely experimental and not integrated into organizational Navy (SMD/FMD) or Marine Corps (TO&E) manpower management documents. The research found that unmanned vehicles are actually part of larger UV systems (which require human operators) and that simply adding UVs does not result in manpower cost savings. Some advantages of UVs are persistent on station time and removal of the human operator from potentially harmful and fatiguing environments. Research indicates that, though still in their infancy, Navy UV's are being employed by naval personnel but closely supported by contractors while operating on Naval platforms and in Naval units. Additionally, the majority of existing UV tactics and training address ISR and undersea missions with no definitive operational doctrine for unmanned combat vehicles (UCV). The report includes an UV acronym list (Appendix B) extracted from publications (Appendix C), a notional launch-and-recovery procedure and a notional estimate of USV manpower requirements and watch organization. Significant consideration must be made in the design and acquisition process as to who will operate these systems. The responsibility and spatial acumen required to operate UVs must be delineated prior to the acquisition phase so as to include key performance parameters (KPP) in unmanned vehicle design. An UV's size, tier of operational employment and payload play a critical role in determining level of operator autonomy, responsibility (i.e., paygrade) and supervision.

Yakovac, Joseph. ***Early Lessons Learned from the Army's Future Combat Systems Program (FCS) : Developing an Appropriate Contractual Arrangement with Industry, Establishing an Enabling Program Management Structure and Test Organization***. NPS-GSBPP-08-003. Monterey, California: Naval Postgraduate School, 2007.
http://hdl.handle.net/10945/605
http://handle.dtic.mil/100.2/ADA476958

Abstract: The Future Combat System (FCS) program is, without a doubt, the most challenging modernization program ever attempted by the Army. The requirement defines the need to develop and field a fully integrated system-of-systems consisting of manned ground vehicles, unmanned ground systems, and unmanned aerial systems -- all connected by a complex network. The program is in its fifth year of System Development and Demonstration. Despite two restructures, due to reprioritizations of dollars within the Army and budget cuts imposed by Congress, the program remains on schedule to deliver capability to the current force in 2010 and, by 2017, to field a fully equipped FCS brigade combat team. To date, most articles, studies, and reports on FCS have focused on the complexities of the task of developing and fielding a system-of-systems and on the unique contractual arrangement between the Army and the program's lead system integrator. This paper provides early lessons learned from the FCS program that may be useful to acquisition professionals facing the challenges of managing the complexity inherent in 21st-century Department of Defense programs.

2006

Gaver, Donald P., Patricia A. Jacobs, and Hiroyuki Sato. ***Assessing Resource Requirements for Maritime Domain Awareness and Protection (Security)***. NPS-OR-06-010. Monterey, California: Naval Postgraduate School, 2006.
http://hdl.handle.net/10945/755

Abstract "A maritime domain or region contains a number w of nonhostile W (White) vessels of interest. Hostile R (Red) vessels enter the domain. The Rs are traveling through the domain toward targets. Overhead, friendly (Blue) sensors (S) patrol the domain and classify (perhaps incorrectly) detected vessels of interest as R or W. The misclassification of a W as an R is a false positive. An overhead sensor follows (or tracks) any vessel it classifies as R until it is relieved by another platform, perhaps a destroyer pair (DD). The overhead sensor is here assumed unable to detect and classify additional vessels while it is following a suspicious vessel; this may well be a somewhat pessimistic assumption, very possibly "richer possibilities" based on additional assets (such as unmanned aerial vehicles (UAVs)) are available, but loss of track may occur as well as misclassification. Deterministic and stochastic models are formulated and studied to evaluate the probability that Rs are successfully neutralized before reaching their destination. The model results quantify the effect of the resources and time needed to prosecute misclassified Ws (false positives) on the probability of successfully neutralizing R. The results indicate that the probability of neutralizing an R vessel is very sensitive to the false positive rate. Technologies, processes, and procedures that can decrease the false positive rate will increase the effectiveness of the Maritime Intercept Operation (MIO)."-- p. iii.

2005

Jenkins, Glenn E. and William J. Snodgrass. ***The Raven Small Unmanned Aerial Vehicle (SUAV), Investigating Potential Dichotomies between Doctrine and Practice***. NPS-PM-05-012. Monterey, California: Graduate School of Business & Public Policy, Naval Postgraduate School, 2005.
http://hdl.handle.net/10945/834

Abstract: "The goal of this MBA Project is to investigate possible disconnects between doctrine and practice in the employment of the Raven Small Unmanned Aerial Vehicle (SUAV). The Army's current Small UAV requirements are based upon the Future Combat System's Operations Requirements Document and has not been validated at the platoon or company level. The Raven SUAV is a Commercial off the Shelf (COTS) item that swiftly became the Army's Small UAV of choice for operations in Afghanistan and Iraq. Doctrine and Techniques, Tactics, and Procedures (TTP) have been written for the Raven SUAV; however, it is not standard practice for all units operating the system abroad. The last review of the SUAV operational requirements was conducted in 2003 but did not specifically address its usage on the battlefield. In an attempt to fill that gap, this project focuses on real-world usage of the Raven SUAV system. We compare doctrine versus practice using the Department of Defense's (DOD) Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities (DOTML-PF) model as the primary logic construct. The report begins by providing a background of the Raven SUAV, to include its evolution from a COTS item to the Army's SUAV of choice, and how it has impacted the warfighter. Next, the authors provide an overview of DOTML-PF in order to provide a basis for comparing doctrine and practice. The study then looks in-depth at doctrine and practice using DOTML-PF as the model for revealing differences between the two. Finally, the authors analyze these differences and recommend solutions to mitigate shortfalls in actual Raven SUAV usage on the battlefield."--p. i.

Journal Articles

2014

Chesi, Simone, Qi Gong, Veronica Pellegrini, **Roberto Cristi**, **Marcello Romano**. "Automatic Mass Balancing of a Spacecraft Three-Axis Simulator: Analysis and Experimentation." *Journal of Guidance, Control and Dynamics* 37, no. 1 (January-February 2014): 197-206.
Abstract: Spacecraft three-axis simulators provide frictionless and, ideally, torque-free hardware simulation platforms that are crucial for validating spacecraft attitude determination and control strategies. To reduce the gravitational torque, the distance between the simulator center of mass and the center of rotation needs to be minimized. This work proposes an automatic mass balancing system for spacecraft simulators, which uses only the three sliding masses during the balancing process, without need of further actuators. The proposed method is based on an adaptive nonlinear feedback control that aims to move, in real time, the center of mass toward the spacecraft simulator's centerof rotation. The stability of the feedback system and the convergence of the estimated unknown parameter (thedistance between the center of mass and the center of rotation) are analyzed through Lyapunov stability theory. The proposed method is experimentally validated using the CubeSat Three-Axis Simulator at the Spacecraft Robotics Laboratory of the Naval Postgraduate School.

Chung, Timothy H. and **Rachel T. Silvestrini**. " Modeling and Analysis of Exhaustive Probabilistic Search." *Naval Research Logistics* 61, no. 2 (March 2014): 164-178.
Abstract: This article explores a probabilistic formulation for exhaustive search of a bounded area by a single searcher for a single static target. The searcher maintains an aggregate belief of the target's presence or absence in the search area, concluding with a positive or negative search decision on crossing of decision thresholds. The measure of search performance is defined as the expected time until a search decision is made as well as the probability of the search decision being correct. The searcher gathers observations using an imperfect detector, that is, one with false positive and negative errors, and integrates them in an iterative Bayesian manner. Analytic expressions for the Bayesian update recursion of the aggregate belief are given, with theoretical results describing the role of positive and negative detections, as well as sensitivity results for the effect of the detection errors on the aggregate belief evolution. Statistical studies via design of simulation experiments provide insights into the significant search parameters, including imperfect sensor characteristics, initial belief value, search decision threshold values, and the available prior probability information. Regression analysis yields statistical models to provide prescriptive guidance on the search performance as a function of these search parameters.

Ciarcià, Marco, **Alession Grompone**, and **Marcello Romano**. "A Near-Optimal Guidance for Cooperative Docking Maneuver." *Acta Astronatica* 102 (September/October 2014): 367-377.
Abstract: In this work we study the problem of minimum energy docking maneuvers between two Floating Spacecraft Simulators. The maneuvers are planar and conducted autonomously in a cooperative mode. The proposed guidance strategy is based on the direct method known as Inverse Dynamics in the Virtual Domain, and the nonlinear programming solver known as Sequential Gradient-Restoration Algorithm. The combination of these methods allows for the quick prototyping of near-optimal trajectories, and results in an implementable tool for real-time closed-loop maneuvering. The experimental results included in this paper were obtained by exploiting the recently upgraded Floating Spacecraft-Simulator Testbed of the Spacecraft Robotics Laboratory at the Naval Postgraduate School. A direct performances comparison, in terms of maneuver energy and propellant mass, between the proposed guidance strategy and a LQR controller, demonstrates the effectiveness of the method.

Gaver, Donald P. and **Patricia A. Jacobs**. "Reliability Growth by Failure Mode Removal." ***Reliability Engineering & System Safety*** 130 (October 2014): 27-32.
Abstract: Modern systems, civilian (e.g. automotive), and military (manned and unmanned aircraft, surface vehicles, submerged vessels), suffer initial design faults or failure modes (FMs), including software bugs, which detrimentally affect the system's reliability and availability. FMs must be removed or mitigated in impact during initial testing, including accelerated testing, in order for the system to meet its reliability requirements and operate satisfactorily in the field. This paper concerns models for reliability growth in which the behaviors of FMs are assumed independent, but of different types. Test effort is guided by prior information, expressed probabilistically, on the random number and tenacities of such FMs that are of various origins in the designs. Estimation of the numbers of FMs that will ultimately activate while in the field is considered here.

Johnson. Thomas H. "The Thistle and the Drone: How America's War on Terror Became a Global War on Tribal Islam by Akbar Ahmed" ***The Middle East Journal*** 86, no. 1 (Winter 2014): 181-182.
Abstract: Book review.

Lucas, George R., Jr. "Automated Warfare." ***Stanford Law & Policy Review*** 25 (2014: 317-340.
http://hdl.handle.net/10945/43537
Abstract: In this Article, I review the military and security uses of robotics and "unmanned" or "uninhabited" (and sometimes "remotely piloted") vehicles in a number of relevant conflict environments that, in turn, raise issues of law and ethics that bear significantly on both foreign and domestic policy initiatives. My treatment applies to the use of autonomous unmanned platforms in combat and low-intensity international conflict, but also offers guidance for the increased domestic uses of both remotely controlled and fully autonomous unmanned aerial, maritime, and ground systems for immigration control, border surveillance, drug interdiction, and domestic law enforcement. I outline the emerging debate concerning "robot morality" and computational models of moral cognition and examine the implications of this debate for the future reliability, safety, and effectiveness of autonomous systems (whether weaponized or unarmed) that might come to be deployed in both domestic and international conflict situations. Likewise, I discuss attempts by the International Committee on Robot Arms Control (ICRAC) to outlaw or ban the use of autonomous systems that are lethally armed, as well an alternative proposal by the eminent Yale University ethicist, Wendell Wallach, to have lethally armed autonomous systems that might be capable of making targeting decisions independent of any human oversight specifically designated "mala in se" under international law. Following the approach of Marchant, et al., however, I summarize the lessons learned and the areas of provisional consensus reached thus far in this debate in the form of "soft-law" precepts that reflect emergent norms and a growing international consensus regarding the proper use and governance of such weapons.

Muratore, Mark, **Rachel T. Silvestri** and **Timothy H. Chung**. "Simulation Analysis of UAV and Ground Teams for Surveillance and Interdiction." ***Journal of Defense Modeling and Simulation*** 11, no. 2 (2014): 125-135.
Abstract: As unmanned aerial vehicles (UAVs) become more prevalent on the battlefield, ground forces will increasingly have to rely on them for intelligence, surveillance and reconnaissance, as well as target marking and overwatch operations. This paper presents the use of the Situational Awareness for Surveillance and Interdiction Operations simulation analysis tool in conjunction with the design and analysis of experiments to study aspects of UAVs' surveillance characteristics in conjunction with ground-based interdiction teams to aid in increasing the number of targets cleared from the area of interest. Different teaming strategies and coordination measures between searching and interdicting assets are studied in order to understand the effectiveness of the interdictor possessing an organic tracker UAV. The objective of this research is to quantify the benefit or penalty of an additional UAV asset that is organic to a quick reaction force in the context of the overall surveillance and interdiction operation.

Song, Kwang Sub and **Peter C. Chu**. " Conceptual Design of Future Undersea Unmanned Vehicle (UUV) System for Mine Disposal." *IEEE Systems Journal* 8, no. 1 (March 2014): 43-51.
Abstract: A conceptual design is proposed for an effective mine countermeasure (MCM) system, which consists of three unmanned underwater vehicles (UUVs) and 10-20 small charged deliverable vehicles. New underwater optical communication systems are introduced to improve onboard mine reconnaissance and decision making with the key technologies focused on system and communication efficiency, capability of data processing, and cost-effectiveness of MCM systems. The proposed UUV MCM system is cost-effective due to adapting disposable mine neutralization instruments, upgrading data process units, and configuring optical communication systems between heterogeneous underwater and surface vehicle units in operations. At the same time, efficient and reliable underwater optical and electromagnetic wave communication systems are also introduced and analyzed for future system applications.

Wang, Z. A. Sorooshian, G. Prabhakar, M.M. Coggon, and **H.H. Jonsson**. "Impact of Emissions from Shipping, Land, and the Ocean on Stratocumulus Cloud Water Elemental Composition during the 2011 E-PEACE Field Campaign." *Atmospheric Environment* 89 (June 2014): 570-580.
Abstract: This study reports on cloud water chemical and pH measurements off the California coast during the July August 2011 Eastern Pacific Emitted Aerosol Cloud Experiment (E-PEACE). Eighty two cloud water samples were collected by a slotted-rod cloud water collector protruding above the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) Twin Otter in boundary layer stratocumulus clouds impacted to varying degrees by ocean-derived emissions, ship exhaust, and land emissions. Cloud water pH ranged between 2.92 and 7.58, with an average of 4.46. Peak pH values were observed north of San Francisco, simultaneous with the highest concentrations of Si, B, and Cs, and air masses originating over land. The lowest pH values were observed south of San Francisco due to ship emissions resulting in the highest concentrations of sulfate, nitrate, V, Fe, Al, P, Cd, Ti, Sb, P, and Mn. Many of these species act as important agents in aqueous-phase reactions in cloud drops and are critical ocean micronutrients after subsequent wet deposition in an ocean system that can be nutrient-limited. E-PEACE measurements suggest that conditions in the California coastal zone region can promote the conversion of micronutrients to more soluble forms, if they are not already, due to acidic cloud water conditions, the ubiquity of important organic agents such as oxalic acid, and the persistence of stratocumulus clouds to allow for continuous cloud processing.

Wilde, Markus, Zarrin K. Chua and Andreas Fleischner. "Effects of Multivantage Point Systems on the Teleoperation of Spacecraft Docking," *IEEE Transactions on Human-Machine Systems* 44, no. 2 (April 2014): 200-210.
Abstract: Rendezvous and docking with uncooperative target objects are driving capabilities for future robotic on-orbit servicing and space debris removal systems. A teleoperation system augments a robotic system with the perception, cognition, and decision capabilities of a human operator, which can lead to a more capable and more flexible telerobotic system. The ThirdEye system was developed in order to support the human operator in the complex relative navigation task of final approach and docking. It provides the operator with a flexible camera vantage point which can be positioned freely in the relevant space around and between the chaser and target spacecraft. The primary and secondary camera views, an attitude head-up display, and a trajectory prediction display are integrated into an intuitive graphical user interface. A validation study was conducted to evaluate the effects of this ThirdEye system on the performance of the teleoperation system during final approach and docking with uncooperative, rotating targets. The results of this study show that the ThirdEye system increases the overall task success rate by 15% and improves operator situation awareness, without having negative impact on the usage of system resources. The partial failure rates are decreased by 20-30%. In high-difficulty scenarios, the operator task load is increased due to the dual task of teleoperating the camera arm and the spacecraft in tandem, which leads to a minor increase in failure rate in these scenarios.

2013

Carpin, Stefano, Derek Burch, Nicola Basilico, **Timothy H. Chung**, and **Mathias Kölsch**. "Variable Resolution Search with Quadrotors: Theory and Practice." *Journal of Field Robotics* 30, no. 5 (September 2013): 685-701.
Abstract: This paper presents a variable resolution framework for autonomously searching stationary targets in a bounded area. Theoretical formulations are also described for using a probabilistic quadtree data structure, which incorporates imperfect Bayesian (false positive and false negative) detections and informs the searcher's route based on optimizing information gain. Live-fly field experimentation results using a quadrotor unmanned aerial vehicle validate the proposed methodologies and demonstrate an integrated system with autonomous control and embedded object detection for probabilistic search in realistic operational settings. Lessons learned from these field trials include characterization of altitude-dependent detection performance, and we also present a benchmark data set of outdoor aerial imagery for search and detection applications.

Chandrasekhara, Muguru S. and Brian K. McLain. "Aerodynamic Studies over a Manoeuvring UCAV 1303 Configuration." *Aeronautical Journal* 117, no. 1190 (April 2013): 445-465.
Abstract:The flow past an unmanned combat air vehicle (UCAV) 1303 was investigated in a water tunnel in an effort to understand the complex flow field. The UCAV 1303 is characterised by a non slender, 47° swept-leading-edge delta wing, with a cranked trailing edge, a cropped wing tip and a fuselage. It also has no vertical tail. Dye visualisation pictures and five-axis strain gage load data were obtained on a 1:72 scale model in both steady flow and while the model executed preprogrammed manoeuvres. From the strain gage data, body axis force and moment data were derived. In addition to some similarities, comparison of the flow features observed with those of more well known slender delta wing flows showed some remarkable differences such as tip-stall, the presence of two like-sense vortices on the same side of the wing, their simultaneous spiral and bubble bursting. This paper predominantly discusses the flow visualisation results and attempts to correlate the load data to some of the observed flow features.

Giachetti, Ronald E., Veronica Marcelli, José Cifuentes, and José A. Rojas. "An Agent-based Simulation Model of Human-Robot Team Performance in Military Environments." *Systems Engineering* 16, no. 1 (Spring 2013): 15-28.
Abstract: Prior to deploying human-robot teams on military missions, system designers need to understand how design decisions affect team performance. This paper describes a multiagent simulation model that captures both team coordination and human-robot interaction. The purpose of the model is to evaluate proposed team designs in uncertain Military Operations in Urban Terrain (MOUT) scenarios and determine which design factors are most critical to team performance. The simulation model is intended to be a tool in the systems engineering iterations of proposing designs, testing them, and then evaluating them during the conceptual design phase. To illustrate the model's usefulness for this purpose, a fractional factorial design of experiments is conducted to evaluate team design factors and the two-factor interaction between controllable factors and noise factors that described the environment and robot reliability. The experimental results suggest that (1) larger teams have more robust performance over the noise factors, (2) robot reliability is critical to the formation of human-robot teams, and (3) high centralization of decision-making authority created communication bottlenecks at the commander in large teams. This work contributes to the agent-based modeling of teams, and to understanding how the U.S. Army can attain its goal of greater utilization of robots in future military operations.

Lee, Kyoungmin, Se-Jin Lee, **Mathias Kölsch**, Wan Kyun Chung. "Enhanced Maximum Likelihood Grid Map with Reprocessing Incorrect Sonar Measurements." *Autonomous Robots* 35, no. 2-3 (October 2013): 123-141.
Abstract: In this paper, we address the problem of building a grid map as accurately as possible

using inexpensive and error-prone sonar sensors. In this research area, incorrect sonar measurements, which fail to detect the nearest obstacle in their beamwidth, generally have been dealt with in the same manner as correct measurements or have been excluded from the mapping. In the former case, the map quality may be severely degraded. In the latter case, the resulting map may have insufficient information after the incorrect measurements are removed because only correct measurements are frequently insufficient to cover the whole environment. We propose an efficient grid-mapping approach that incorporates incorrect measurements in a specialized manner to build a better map; we call this the enhanced maximum likelihood (eML) approach. The eML approach fuses the correct and incorrect measurements into a map based on sub-maps generated from each set of measurements. We also propose the maximal sound pressure (mSP) method to detect incorrect sonar readings using the sound pressure of the waves from sonar sensors. In several indoor experiments, integrating the eML approach with the mSP method achieved the best results in terms of map quality among various mapping approaches. We call this the maximum likelihood based on sub-maps (MLS) approach. The MLS map created using only two sonar sensors exhibited similar accuracy to the reference map, which was an accurate representation of the environment. © 2013 Springer Science+Business Media New York.

McCamish, Shawn B., **Marco Ciarcià** and **Marcello Romano**. "Simulations of Multiple Spacecraft Maneuvering with MATLAB/Simulink and Satellite Tool Kit." ***Journal of Aerospace Information Systems*** 10, no. 7 (July 2013): 348-359.
Abstract: A software interface between the MATLAB/Simulink environment and the Satellite Tool Kit Environment is introduced. This research is based on the need for validating model performance and visualizing simultaneous multiple-spacecraft proximity maneuvers for emerging missions. It is common for spacecraft systems to be modeled with MATLAB and Simulink. Furthermore, the software package Satellite Tool Kit is often used for animating and evaluating spacecraft maneuvers. In this research, a MATLAB/Satellite Tool Kit interface was developed to propagate six-degree-of-freedom spacecraft models, compared against Satellite-Tool-Kit-generated ephemeris, and animated for analysis. MATLAB script with necessary formatting is used for Satellite Tool Kit initialization and animation. The MATLAB/Satellite Tool Kit simulation interface allows variations in number, shape, and dimensions of spacecraft. Additionally, numerous model and simulation parameters can be selected and synchronized between MATLAB and Satellite Tool Kit. Furthermore, either predetermined, or randomly distributed, initial spacecraft positions and orientations are permitted by the interface. The paper gives enough details to allow the interested readers to adapt to their needs and further develop the proposed software interface.

Xargay, Enric, **Isaac Kaminer**, Antonio M. Pascoal, Naira Hovakimyana, **Vladimir Dobrokhodov**, **Venanzio Cichella**, A. Pedro Aguiar and Reza Ghabcheloo. "Time-Critical Cooperative Path Following of Multiple Unmanned Aerial Vehicles over Time-Varying Networks." ***Journal of Guidance Control and Dynamics*** 36, no. 2 (March-April 2013): 499-516.
Abstract: This paper addresses the problem of steering a fleet of unmanned aerial vehicles along desired three-dimensional paths while meeting stringent spatial and temporal constraints. A representative example is the challenging mission scenario where the unmanned aerial vehicles are tasked to cooperatively execute collision-free maneuvers and arrive at their final destinations at the same time. In the proposed framework, the unmanned aerial vehicles are assigned nominal spatial paths and speed profiles along those, and then the vehicles are requested to execute cooperative path following, rather than open loop trajectory tracking maneuvers. This strategy yields robust behavior against external disturbances by allowing the unmanned aerial vehicles to negotiate their speeds along the paths in response to information exchanged over the supporting communications network. The paper considers the case where the graph that captures the underlying time-varying communications topology is disconnected during some interval of time or even fails to be connected at all times. Conditions are given under which the cooperative path-following closed-loop system is stable. Flight test results of a coordinated road-search

mission demonstrate the efficacy of the multi-vehicle cooperative control framework developed in the paper.

2012

Andersson, Klas, **Isaac Kaminer**, **Vladimir Dobrokhodov**, and **Venanzio Cichella**. "Thermal Centering Control for Autonomous Soaring: Stability Analysis and Flight Test Results." *Journal of Guidance Control and Dynamics* 35, no. 3 (May-June 2012): 963-975.
Abstract: This paper addresses the challenge of using autonomous soaring gliders to search for and exploit thermal lift to extend the gliders' endurance. For this purpose, a simple thermal centering controller is proposed. The paper includes theoretical analysis of stability and convergence properties of this controller. Using an exponential Gaussian function to represent the updraft field of a thermal, the Lyapunov type analysis shows the proposed controller to be asymptotically stable and determines its region of attraction. The size of the region of attraction is shown to be a function of the feedback gain that can be adjusted for any given strength and geometry of thermal. The paper additionally presents simulation and flight test results that verify the performance of the proposed controller. The results of the flight trials also confirm the feasibility and effectiveness of using autonomous thermal soaring to extend endurance for unmanned gliders.

Boxerbaum, Alexander S., Matthew A. Klein, **Jeffery E. Kline**, Stuart C. Burgess, Roger D. Quinn, Richard Harkins, **Ravi Vaidyanathan**. "Design, Simulation, Fabrication and Testing of a Bio-inspired Amphibious Robot with Multiple Modes of Mobility." *Journal of Robotics and Mechatronics* 24, no. 4 (2012): 629-641.
Abstract: Surf-zone environments represent an extreme challenges to robot operation. A robot that autonomously navigates rocky terrain, constantly changing underwater currents, hard-packed moist sand and loose dry sand characterizing this environment, would have significant utility in a range of defence and civilian missions. The study of animal locomotion mechanisms can elucidate specific movement principles that can be applied to address these demands. In this work, we report on the design and optimization of a biologically inspired amphibious robot for deployment and operation in an ocean beach environment. We specifically report a new design fusing a range of insectinspired passive mechanisms with active autonomous control architectures to seamlessly adapt to and traverse a range of challenging substrates both in and out of the water, and the design and construction of SeaDog, a proof-of-concept amphibious robot built for navigating rocky or sandy beaches and turbulent surf zones. The robot incorporates a layered hull and chassis design that is integrated into a waterproof Explorer Case in order to provide a large, protected payload in an easy-to-carry package. It employs a rugged drivetrain with four wheel-legs and a unique tail design and actuation strategy to aid in climbing, swimming and stabilization. Several modes of terrestrial and aquatic locomotion are suggested and tested versus range of mobility metrics, including data obtained in simulation and hardware testing. A waterproofing strategy is also tested and discussed, providing a foundation for future generations of amphibious mobile robots.

Chung, Timothy H. and Joel W. Burdick. "Analysis of Search Decision Making Using Probabilistic Search Strategies." *IEEE Transactions on Robotics* 28, no. 1 (February 2012): 132-144.
Abstract: In this paper, we propose a formulation of the spatial search problem, where a mobile searching agent seeks to locate a stationary target in a given search region or declare that the target is absent. The objective is to minimize the expected time until this search decision of targets presence (and location) or absence is made. Bayesian update expressions for the integration of observations, including false-positive and false-negative detections, are derived to

facilitate both theoretical and numerical analyses of various computationally efficient (semi-)adaptive search strategies. Closed-form expressions for the search decision evolution and analytic bounds on the expected time to decision are provided under assumptions on search environment and/or sensor characteristics. Simulation studies validate the probabilistic search formulation and comparatively demonstrate the effectiveness of the proposed search strategies.

MacMahan, Jamie, Ross Vennell, Rick Beatson, Jenna Brown and Ad Reniers. "Divergence-Free Spatial Velocity Flow Field Interpolator for Improving Measurements from ADCP-Equipped Small Unmanned Underwater Vehicles." *Journal of Atmospheric and Oceanic Technology* 29, no. 3 (March 2012): 478-484.
Abstract: Applying a two-dimensional (2D) divergence-free (DF) interpolation to a one-person deployable unmanned underwater vehicle's (UUV) noisymoving-vessel acousticDoppler current profiler (MV-ADCP)measurements improves the results and increases the utility of the UUV in tidal environments. For a 3.5-h MV-ACDP simulation that spatially and temporally varies with the M2 tide, the 2D DF-estimated velocity magnitude and orientation improves by approximately 85%. Next the 2D DF method was applied to velocity data obtained from two UUVs that repeatedly performed seven 1-h survey tracks in Bear Cut Inlet,Miami, Florida. The DFmethod provides a more realistic and consistent representation of the ADCP measured flow field, improving magnitude and orientation estimates by approximately 25%. The improvement increases for lower flow velocities, when the ADCP measurements have lowenvironmental signal-to-noise ratio.However, near slack tide when flow reversal occurs, the DF estimates are invalid because the flows are not steady state within the survey circuit.

Ross, I. Michael and **Mark Karpenko**. "A Review of Pseudospectral Optimal Control: From Theory to Flight." *Annual Reviews Control* 36, no. 2 (December 2012): 182-197.
Abstract: The home space for optimal control is a Sobolev space. The home space for pseudospectral theory is also a Sobolev space. It thus seems natural to combine pseudospectral theory with optimal control theory and construct "pseudospectral optimal control theory", a term coined by Ross. In this paper, we review key theoretical results in pseudospectral optimal control that have proven to be critical for a successful flight. Implementation details of flight demonstrations onboard NASA spacecraft are discussed along with emerging trends and techniques in both theory and practice. The 2011 launch of pseudospectral optimal control in embedded platforms is changing the way in which we see solutions to challenging control problems in aerospace and autonomous systems.

Vaidyanathan, Ravi, Chun-Ta Chen, Chan-Doo Jeong, Charles Williams, Yochiro Endo, Roy E. Ritzmann, and Roger D. Quinn. "A Reflexive Vehicle Control Architecture Based on a Neural Model of the Cockroach Escape Response." *Proceedings of the Institution of Mechanical Engineers. Part I: Journal of Systems and Control Engineering* 226, no. 5 (May 2012): 699-718. Abstract: This paper presents a biologically inspired architecture for rapid real-time control of autonomous or semi-autonomous vehicles based on a neural model of the escape response of the American cockroach, Periplaneta americana. The architecture fuses exteroceptive and proprioceptive inputs in a manner similar to the insect to produce commands for collision avoidance and, in some cases, orientation for target strike. It functions as a reflexive subsystem that integrates smoothly with higher-level planning and behavioral control systems. The performance of the reflex is demonstrated in simulation and in hardware experiments on both air and ground vehicles, even in the presence of noisy, false or disruptive sensor data.

Xargay, Enric, **Vladimir Dobrokhodov**, **Isaac Kaminer**, Antonio M. Pascoal, Naira Hovakimyana and Chengyu Cao. "Time-Critical Cooperative Control of Multiple Autonomous Vehicles." *IEEE Control Systems Magazine* 32, no. 5 (October 2012): 49-73.
Abstract: Worldwide, there has been growing interest in the use of autonomous vehicles to execute missions of increasing complexity without constant supervision of human operators. A key enabling element for the execution of such missions is the availability of advanced systems

for motion control of autonomous vehicles. Usually, the problems of motion control for a single autonomous vehicle are roughly classified into three groups.

Yang, Ji Hyun, Jesse Huston, Michael Day and **Imre Balogh**. "Modeling Peripheral Vision for Moving Target Search and Detection." *Aviation Space and Environmental Medicine* 83, no. 6 (June 2012): 585-593.

2011

Bandyopadhyay, Promode R., Henry A. Leinhos, J. Dana Hrubes, Norman Toplosky, and Joshua Hansen. "Turning of a Short-length Cable using Flapping Fin Propulsion*." IEEE Journal of Oceanic Engineering* 36, no. 4 (2011): 571-585.

Abstract: In this paper, the context of several self-propelled, short-length cables, embedded with passive sensors for environmental diagnostics and swimming efficiently in formation over long duration and in shallow water, is considered. The basic problem of this volumetric diagnostic-namely, the low-speed motion control of a short-length, neutrally buoyant cable-is examined. More specifically, the constant-rate, circular turning of a 7-m-long cable held taut in a shallow-water basin using a biorobotic propulsor that has multiple flapping fins at one end, the other end being tied to a mooring post, is examined via modeling and laboratory and basin experiments. A drag analysis is used to estimate the fastest steady turning rate achievable while holding the cable taut. An axial tension and position controller, as well as a depth controller, is developed and evaluated in a quiescent laboratory tank accounting for the cycle-averaged hydrodynamic characteristics of a rigid cylinder to which six flapping fins are attached, three at each end. A small test range of 100-m scale, containing seven floor-mounted hydrophones in a hexagonal layout, is built in a stillwater basin to track the motion of the propulsor, to which a pinger is attached. The estimated overall resolution of the acoustic tracking system is 5 cm; it is possible to detect the imprint of the environmental unsteadiness on the cable and propulsor assembly. In the basin experiment, a mean radius of turning of 8.91 m can be achieved within a standard of deviation of 0.27 m, and a uniform turn rate of 22 min for one full revolution can also be maintained, when the applied turning force is 10% of the cable tension. The basin experiment has verified the drag analysis. This paper explores the value of a flapping fin propulsor (which is inspired by large swimming animals) as an alternative to conventional rotational propulsors for the low-speed maneuvering of a short cable.

Bevilacqua, Riccardo, Tanya Lehmann, and **Marcello Romano**. "Development and Experimentation of LQR/APF Guidance and Control for Autonomous Proximity Maneuvers of Multiple Spacecraft." *Acta Astronautica* 68, no. 7-8 (2011): 1260-1275.
http://dx.doi.org/10.1016/j.actaastro.2010.08.012

This work introduces a novel control algorithm for close proximity multiple spacecraft autonomous maneuvers, based on hybrid linear quadratic regulator/artificial potential function (LQR/APF), for applications including autonomous docking, on-orbit assembly and spacecraft servicing. Both theoretical developments and experimental validation of the proposed approach are presented. Fuel consumption is sub-optimized in real-time through re-computation of the LQR at each sample time, while performing collision avoidance through the APF and a high level decisional logic. The underlying LQR/APF controller is integrated with a customized wall-following technique and a decisional logic, overcoming problems such as local minima. The algorithm is experimentally tested on a four spacecraft simulators test bed at the Spacecraft Robotics Laboratory of the Naval Postgraduate School. The metrics to evaluate the control algorithm are: autonomy of the system in making decisions, successful completion of the maneuver, required time, and propellant consumption. 2010 Published by Elsevier Ltd.

Brown, Jenna, **Chris Tuggle**, **Jamie MacMahan**, and Ad Reniers. "The Use of Autonomous Vehicles for Spatially Measuring Mean Velocity Profiles in Rivers and Estuaries." ***Intelligent Service Robotics*** 4, no. 4 (October 2011): 233-244.

Abstract: Autonomous vehicles (AVs) are commonly used in oceanic and more recently estuarine and riverine environments because they are small, versatile, efficient, moving platforms equipped with a suite of instruments for measuring environmental conditions. However, moving vessel observations, particularly those associated with Acoustic Doppler Current Profiler (ADCP) measurements, can be problematic owing to instrument noise, flow fluctuations, and spatial variability. A range of ADCPs manufactured by different companies were integrated on to an Unmanned Surface Vehicle (USV), an Unmanned Underwater Vehicle (UUV), and some additional stationary platforms and were deployed in a number of natural riverine and estuarine environments to evaluate the quality of the velocity profile over the depth, minimum averaging time interval requirements, and AV mission planning considerations. Measurements were obtained at fixed locations to eliminate any spatial variations in the mean flow characteristics. The USV has the unique capability to station-keep to within 1 m owing to its dual-propeller design, providing the best setup for spatially mapping velocity profiles. Single-propeller UUVs can perform a quasi-stationkeeping (<10 m) operation, but are designed for traveling underwater at speeds >1 m/s. An appropriate averaging window, T_*, was determined using the Kalman Algorithm with a Kalman gain equal to 1%. T_* was found to be independent of depth, flow velocity, and environment. There was no correlation ($R2 = 0.18$) for T_* between flow magnitude and direction. Results from all measurements had a similar T_* of approximately 3 min. Based on this, an averaging window of 4 min is conservatively suggested to obtain a statistically confident measure of the mean velocity profile.

Cazenave, Francois, Yanwu Zhang, Erika McPhee-Shaw, James G. Bellingham, and **Timothy P. Stanton**. "High-Resolution Surveys of Internal Tidal Waves in Monterey Bay, California, Using an Autonomous Underwater Vehicle." ***Limnology and Oceanography-Methods*** 9 (December 2011): 571-581.
http://www.mbari.org/staff/yzhang/Cazenave_etal_LOM.pdf

Chung, Hoam, Elijah Polak, **Johannes O. Royset**, and **Shankar Sastry**. "On the Optimal Detection of an Underwater Intruder in a Channel Using Unmanned Underwater Vehicles." ***Naval Research Logistics*** 58 no. 8 (December 2011): 804-820.

Abstract: Given a number of patrollers that are required to detect an intruder in a channel, the channel patrol problem consists of determining the periodic trajectories that the patrollers must trace out so as to maximized the probability of detection of the intruder. We formulate this problem as an optimal control problem. We assume that the patrollers' sensors are imperfect and that their motions are subject to turn-rate constraints, and that the intruder travels straight down a channel with constant speed. Using discretization of time and space, we approximate the optimal control problem with a large-scale nonlinear programming problem which we solve to obtain an approximately stationary solution and a corresponding optimized trajectory for each patroller. In numerical tests for one, two, and three underwater patrollers, an underwater intruder, different trajectory constraints, several intruder speeds and other specific parameter choices, we obtain new insight-not easily obtained using simply geometric calculations-into efficient patrol trajectory design under certain conditions for multiple patrollers in a narrow channel where interaction between the patrollers is unavoidable due to their limited turn rate.

Chung, Timothy H., Geoffrey A. Hollinger and Volkan Isler. "Search and Pursuit-Evasion in Mobile Robotics: A Survey." ***Autonomous Robots*** 31, no. 4-SI (November 2011): 299-316.

Abstract: This paper surveys recent results in pursuitevasion and autonomous search relevant to applications in mobile robotics. We provide a taxonomy of search problems that highlights the differences resulting from varying assumptions on the searchers, targets, and the environment. We then list a number of fundamental results in the areas of pursuit-evasion and probabilistic search, and we discuss field implementations on mobile robotic systems. In addition, we highlight current open problems in the area and explore avenues for future work.

Dobrokhodov, Vladimir, **Isaac Kaminer**, **Ioannis Kitsios**, Enric Xargay, Naira Hovakimyan, Chengyu Cao, Irene M. Gregory, and Lena Valavani. "Experimental Validation of L-1 Adaptive Control: The Rohrs Counterexample in Flight." ***Journal of Guidance Control and Dynamics*** 34, no. 5 (September-October 2011): 1311-1328.

Abstract: This paper presents flight-test results that examine the performance and robustness properties of an L-1 control augmentation loop implemented onboard a small unmanned aerial vehicle. The framework used for in-flight control evaluation is based on the Rohrs counterexample, a benchmark problem presented in the early 1980s, to show the limitations of adaptive controllers developed at that time. Hardware-in-the-loop simulations and flight-test results confirm the abilityofthe L-1 flight control systemtomaintain stability and predictable performance ofthe closed-loop adaptive system in the presence of general (artificially injected) unmodeled dynamics. The results demonstrate the advantages of L-1 control as a robust adaptive control architecture with the potential of facilitating the transition of adaptive control into advanced flight control systems.

Hollinger, Geoffrey A., **Timothy H. Chung** and Volkan Isler. "Special Issue on Search and Pursuit-Evasion with Mobile Robots." ***Autonomous Robots*** 31, no. 4-SI (November 2011): 297-298.

Lee, Deok-Jin and **Klas Andersson**. "Hybrid Control of Long-Endurance Aerial Robotic Vehicles for Wireless Sensor Networks." ***International Journal of Advanced Robotic Systems*** 8, no. 2 (June 2011): 101-113.
http://www.intechopen.com/download/get/type/pdfs/id/15965

Abstract: This paper presents an effective hybrid control approach for building stable wireless sensor networks between heterogeneous unmanned vehicles using longendurance aerial robotic vehicles. For optimal deployment of the aerial vehicles in communication networks, a gradient climbing based self-estimating control algorithm is utilized to locate the aerial platforms to maintain maximum communication throughputs between distributed multiple nodes. The autonomous aerial robots, which function as communication relay nodes, extract and harvest thermal energy from the atmospheric environment to improve their flight endurance within specified communication coverage areas. The rapidly-deployable sensor networks with the high-endurance aerial vehicles can be used for various application areas including environment monitoring, surveillance, tracking, and decision-making support. Flight test and simulation studies are conducted to evaluate the effectiveness of the proposed hybrid control technique for robust communication networks.

Ma, Jeremy, **Timothy H. Chung**, and Joel Burdick. "A Probabilistic Framework for Object Search with 6-DOF Pose Estimation." ***International Journal of Robotics Research*** 30, no. 10-SI (September 2011): 1209-1228.

Abstract: This article presents a systematic approach to the problem of autonomous 3D object search in indoor environments, using a two-wheeled non-holonomic robot equipped with an actuated stereo-camera head and processing done on a single laptop. A probabilistic grid-based map encodes the likelihood of object existence in each cell and is updated after each sensing action. The updating schema incorporates characteristic parameters modeled after the robot's sensing modalities and allows for sequential updating via Bayesian recursion methods. Two types of sensing modalities are used to update the map: a coarse search method (global search) based on a color histogram approach, and a more refined search method (local search) based on Scale-Invariant Feature Transform (SIFT) feature matching. If the local search correctly locates the desired object, its 6-DOF pose is estimated using stereo applied to each SIFT feature (i.e. 3D SIFT feature), which is then fed as measurements into an Extended Kalman Filter (EKF) for sustained tracking. If the local search fails to locate the desired object in a particular cell, the cell is updated in the probability map and the next peak probability cell is identified and planned to using a separate grid-based costmap populated via obstacle detection from stereo, with planning done using an A* planner. Experimental results obtained from the use of this method on a mobile

robot are presented to illustrate and validate the approach, confirming that the search strategy can be carried out with modest computation on a single laptop.

Slegers, Nathan and **Oleg A. Yakimenko**. "Terminal Guidance of Autonomous Parafoils in High Wind-to-Airspeed Ratios." ***Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*** 225, no. 3 (2011): 336-346. http://dx.doi.org/10.1243/09544100JAERO749
Abstract: Autonomous precision placement of parafoils is challenging because of their limited control authority and sensitivity to winds. In particular, when wind speed is near the airspeed, guidance is further complicated by the parafoils inability to penetrate the wind. This article specifically addresses the terminal phase and develops an approach for generating optimal trajectories in real-time based on the inverse dynamics in the virtual domain. The method results in efficient solution of a two-point boundary-value problem using only a single optimization parameter allowing the trajectory to be generated at a high rate, mitigating effects of the unknown winds. It is shown through simulation and experimental results that the proposed algorithm works well even in strong winds and is robust to sensor errors and wind uncertainty.

Sui, Jinxue and Li Yang. "Intelligent 3D Measurement Warehousing Service System Based on LMS Laser Scanning." ***Advances in Information Sciences and Service Sciences*** 3, no. 3 (April 2011): 154-162.
Abstract: The intelligent measurement warehousing service system has already applied in industry many aspects, realizes the unmanned operation through measuring shape, outline and position of the object and so on, this paper proposed one kind examination method in the intelligent warehousing service system, examines the goods position to park by using LMS laser measurement system in the intelligent warehousing service system, uses many algorithms to gain the configuration information and the positional information about goods, then carries on the data fusion to the goods shape, adjusts the posture to the goods, enables the goods put in the warehouse storage spot smoothly, the experiment prove that using LMS to examine can obtain much more information, high reliability, convenient data, the nimble second exploitive, LMS is be suitable for the 3D measurement of the intelligent warehousing service system, it is able to meet the need well.

Xiao, Yang, Yanping Zhang, John H. Gibson, Geoffrey G. Xie, and Hui Chen. "Performance Analysis of ALOHA and p-Persistent ALOHA for Multi-hop Underwater Acoustic Sensor Networks." ***Cluster Computing*** 14, no. 1 (January 2011): 65-80.
Abstract: The extreme conditions under which multi-hop underwater acoustic sensor networks (UASNs) operate constrain the performance of medium access control (MAC) protocols. The MAC protocol employed significantly impacts the operation of the network supported, and such impacts must be carefully considered when developing protocols for networks constrained by both bandwidth and propagation delay. Time-based coordination, such as TDMA, have limited applicability due to the dynamic nature of the water channel used to propagate the sound signals, as well as the significant effect of relatively small changes in propagation distance on the propagation time. These effects cause inaccurate time synchronization and therefore make time-based access protocols less viable. The large propagation delays also diminish the effectiveness of carrier sense protocols as they do not predict with any certainty the status of the intended recipients at the point when the traffic would arrive. Thus, CSMA protocols do not perform well in UASNs, either. Reservation-based protocols have seldom been successful in commercial products over the past 50 years due to many drawbacks, such as limited scalability, relatively low robustness, etc. In particular, the impact of propagation delays in UASNs and other such constrained networks obfuscate the operation of the reservation protocols and diminish, if not completely negate, the benefit of reservations. The efficacy of the well-known RTS-CTS scheme, as a reservation-based enhancement to the CSMA protocol, is also adversely impacted by long propagation delays. An alternative to these MAC protocols is the much less complex ALOHA protocol, or one of its variants. However, the performance of such protocols within the context of multi-hop networks is not well studied. In this paper we identify the challenges of modeling

contention-based MAC protocols and present models for analyzing ALOHA and p-persistent ALOHA variants for a simple string topology. As expected, an application of the model suggests that ALOHA variants are very sensitive to traffic loads. Indeed, when the traffic load is small, utilization becomes insensible to p values. A key finding, though, is the significance of the network size on the protocols' performance, in terms of successful delivery of traffic from outlying nodes, indicating that such protocols are only appropriate for very small networks, as measured by hop count.

2010

Basset, Gareth, Yunjun Xu, and **Oleg A. Yakimenko**. "Computing Short-Time Aircraft Maneuvers using Direct Methods." ***Journal of Computer and Systems Sciences International*** 49, no. 3 (June 2010): 481-513. doi:10.1134/S1064230710030159
This paper analyzes the applicability of direct methods to design optimal short-term spatial maneuvers for an unmanned vehicle in a faster than real-time scale. It starts by introducing different basic control schemes, which employ online trajectory generation. Next, it presents and analyzes the results obtained through two recently developed direct transcription (collocation) methods: the Gauss pseudospec-tral method and the Legendre-Gauss-Lobatto pseudosp ectral method. The achieved results are further compared with those found through the Pontryagin's Maximum (Minimum) Principle, and the paper continues by providing another set of direct method simulations incorporating more realistic boundary conditions. Finally, the results obtained using the third direct method, based on inverse dynamics in the virtual domain, are presented and discussed.

Bluestein, Howard B., Michael M. French, Ivan PopStefanija, Robert T. Bluth, and Jeffrey B. Knorr. "A Mobile, Phased-Array Doppler Radar for the Study of Severe Convective Storms the Mwr-05xp." ***Bulletin of the American Meteorological Society*** 91, no. 5 (May 2010): 579-+. doi:10.1175/2009BAMS2914.1
A mobile X-band, phased-array Doppler radar was acquired from the U.S. Army by the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) at the Naval Postgraduate School and adapted for meteorological use by ProSensing, Inc. The radar was used during field experiments conducted in the Southern Plains by faculty and students from the School of Meteorology at the University of Oklahoma during the spring storm seasons of 2007 and 2008. During these field experiments, storm-scale, rapid-scan, volumetric, Doppler-radar observations were obtained in tornadic and nontornadic supercells, quasilinear mesoscale convective systems, and in both boundary layer-based and elevated ordinary convective cells. A case is made for the use of the radar for studies of convective weather systems and other weather phenomena that evolve on time scales as short as tens of seconds.

Cowling, Ian D., **Oleg A. Yakimenko**, James F. Whidborne, and Alastair K. Cooke. "Direct Method Based Control System for an Autonomous Quadrotor." ***Journal of Intelligent & Robotic Systems*** 60, no. 2 (November 2010): 285-316. doi:10.1007/s10846-010-9416-9
This paper proposes a real time control algorithm for autonomous operation of a quadrotor unmanned air vehicle. The quadrotor is a small agile vehicle, which as well as being a excellent test bed for advanced control techniques could also be suitable for internal surveillance, search and rescue and remote inspection. The proposed control scheme incorporates two key aspects of autonomy; trajectory planning and trajectory following. Using the differentially-flat dynamics property of the system, the trajectory optimization is posed as a non-linear constrained optimization within the output space in the virtual domain, not explicitly related to the time domain. A suitable parameterization using a virtual argument as opposed to time is applied, which ensures initial and terminal constraint satisfaction. The speed profile is optimized independently, followed by the mapping to the time domain achieved using a speed factor. Trajectory following is achieved with a standard multi-variable control technique and a digital switch is used to re-optimize the reference trajectory in the event of infeasibility or mission

change. The paper includes simulations using a full dynamic model of the quadrotor demonstrating the suitability of the proposed control scheme.

Hurni, Michael A., **Pooya Sekhavat**, and **I. Michael Ross**. "Autonomous Multi-Rover Trajectory Planning using Optimal Control Techniques." *Astrodynamics 2009 135, Pts 1-3* 135, (2010): 2113-2132.
Future manned and robotic space missions call for autonomous coordination and control of planetary rovers. This paper presents the implementation of a pseudospectral (PS) optimal control-based algorithm for autonomous trajectory planning and control of several unmanned ground vehicles (UGV) with real-time information updates. The mission of the UGVs is to traverse from their initial start points and reach their targets in minimum time, with maximum robustness, while avoiding obstacles (static and dynamic) and each other. Control solutions are repeatedly recomputed and updated throughout the vehicles' missions. Simulation results illustrate the performance of the planner in various multi-rover scenarios.

Kaminer, Isaac, Antonio Pascoal, Enric Xargay, Naira Hovakimyan, Chengyu Cao, and **Vladimir Dobrokhodov**. "Path Following for Unmanned Aerial Vehicles using L(1) Adaptive Augmentation of Commercial Autopilots." *Journal of Guidance Control and Dynamics* 33, no. 2 (March-April 2010): 550-564. doi:10.2514/1.42056
The paper presents a three-dimensional path-following control algorithm that expands the capabilities of conventional autopilots, which are normally designed to provide only guidance loops for waypoint navigation. Implementation of this algorithm broadens the range of possible applications of small unmanned aerial vehicles. The solution proposed takes explicit advantage of the fact that normally these vehicles are equipped with autopilots stabilizing the vehicles and providing angular-rate tracking capabilities. Therefore, the overall closed-loop system exhibits naturally an inner-outer (dynamics-kinematics) control loop structure. The outer-loop path-following control law developed relies on a nonlinear control strategy derived at the kinematic level, while the inner-loop consisting of the autopilot together with an L(1) adaptive augmentation loop is designed to meet strict performance requirements in the presence of unmanned aerial vehicle modeling uncertainty and environmental disturbances. A rigorous proof of stability and performance of the path-following closed-loop system, including the dynamics of the unmanned aerial vehicle with its autopilot, is given. The paper bridges the gap between theory and practice and includes results of extensive flight tests performed in Camp Roberts, California, which demonstrate the benefits of the framework adopted for the control system design.

Kim, Dae-Young, Hyung-Sub Bae, Myeong-Kwan Park, Son-Cheol Yu, Young-Sool Yun, C. P. Cho, and Ryuichiro Yamane. "A Study of Magnetic Fluid Seals for Underwater Robotic Vehicles." *International Journal of Applies Electromagnetics and Mechanics* 33, no. 1-2 (2010): 857-863
http://dx.doi.org/10.3233/JAE-2010-1195
Underwater robotic vehicles (URVs) normally use mechanical seals with o-rings, rubber boots, PTFE or Grafoil wedges, or V-rings. Because mechanical seals can cause an unexpected malfunction, we try to adapt magnetic fluid seal (MFS) for underwater robotic vehicles. For reliable design of the MFS, we use numerical simulation of the flow in the MFS using finite element method. The results obtained from experimental investigations of the operation of the MFS contacting with pressurized water will be compared to numerical simulation results. 2010 - IOS Press and the authors. All rights reserved.

Lee, Deok-Jin, **Isaac Kaminer**, **Vladimir Dobrokhodov**, and **Kevin Jones**. "Autonomous Feature Following for Visual Surveillance using a Small Unmanned Aerial Vehicle with Gimbaled Camera System." *International Journal of Control Automation and Systems* 8, no. 5 (October 2010): 957-966. doi:10.1007/s12555-010-0504-1
This paper represents the development of feature following control and distributed navigation algorithms for visual surveillance using a small unmanned aerial vehicle equipped with a low-cost

imaging sensor unit. An efficient map-based feature generation and following control algorithm is developed to make an onboard imaging sensor to track a target. An efficient navigation system is also designed for real-time position and velocity estimates of the unmanned aircraft, which is used as inputs for the path following controller. The performance of the proposed autonomous path following capability with a stabilized gimbaled camera onboard a small unmanned aerial robot is demonstrated through flight tests with application to target tracking for real-time visual surveillance.

Lee, Deok-Jin and Richard Mark. "Decentralized Control of Unmanned Aerial Robots for Wireless Airborne Communication Networks." *International Journal of Advanced Robotic Systems* 7, no. 3 (September 2010): 191-200.
This paper presents a cooperative control strategy for a team of aerial robotic vehicles to establish wireless airborne communication networks between distributed heterogeneous vehicles. Each aerial robot serves as a flying mobile sensor performing a reconfigurable communication relay node which enabls communication networks with static or slow-moving nodes on gorund or ocean. For distributed optimal deployment of the aerial vehicles for communication networks, an adaptive hill-climbing type decentralized control algorithm is developed to seek out local extremum for optimal localization of the vehicles. The sensor networks estabilished by the decentralized cooperative control approach can adopt its configuraiton in response to signal strength as the function of the relative distance between the autonomous aerial robots and distributed sensor nodes in the sensed environment. Simulation studies are conducted to evaluate the effectiveness of the proposed decentralized cooperative control technique for robust communication networks.

Lock, Richard J., **Ravi Vaidyanathan**, Stuart C. Burgess, and John Loveless. "Development of a Biologically Inspired Multi-Modal Wing Model for Aerial-Aquatic Robotic Vehicles through Empirical and Numerical Modelling of the Common Guillemot, Uria Aalge." *Bioinspiration & Biomimetics* 5, no. 4 (December 2010): 046001. doi:10.1088/1748-3182/5/4/046001
The common guillemot, Uria aalge, a member of the auk family of seabirds exhibits locomotive capabilities in both aerial and aquatic substrates. Simplistic forms of this ability have yet to be achieved by robotic vehicle designs and offer significant potential as inspiration for future concept designs. In this investigation, we initially investigate the power requirements of the guillemot associated with different modes of locomotion, empirically determining the saving associated with the retraction of the wing during aquatic operations. A numerical model of a morphing wing is then created to allow power requirements to be determined for different wing orientations, taking into account the complex kinematic and inertial dynamics associated with the motion. Validation of the numerical model is achieved by comparisons with the actual behaviour of the guillemot, which is done by considering specific mission tasks, where by the optimal solutions are found utilizing an evolutionary algorithm, which are found to be in close agreement with the biological case.

Ma, Lili, Chengyu Cao, Naira Hovakimyan, **Vladimir Dobrokhodov**, and **Isaac Kaminer**. "Adaptive Vision-Based Guidance Law with Guaranteed Performance Bounds." *Journal of Guidance Control and Dynamics* 33, no. 3 (May-June 2010): 834-852. doi:10.2514/1.46287
This work discusses vision-based tracking of a ground vehicle moving with unknown time-varying velocity. The follower unmanned aerial vehicle is equipped with a single camera. The control objective is to regulate the two-dimensional horizontal range between the unmanned aerial vehicle and the target to a constant. The contribution of this paper has two distinct features. The developed guidance law uses the estimates of the target's velocity obtained from a fast-estimation scheme. It is shown that the fast-estimation scheme has guaranteed performance bounds and the tracking performance bound can be explicitly derived as a function of the estimation error. The performance bounds imply that the signals of the closed-loop adaptive system remain close to the corresponding signals of a bounded closed-loop reference system, both in transient and steady-state responses. The reference system is introduced solely for the purpose of analysis. This paper also analyzes the stability and the performance degradation of

the closed-loop adaptive system in the presence of out-of-frame events, when continuous extraction of the target's information is not feasible due to failures in the image-processing module. The feedback loop is then closed using the frozen estimates. The out-of-frame events are modeled as brief instabilities. A sufficient condition for the switching signal is derived that guarantees graceful degradation of performance during target loss. The results build upon the earlier-developed fast-estimation scheme of the target's velocity, the inverse-kinematics-based guidance law, and insights from switching systems theory.

McCamish, Shawn Baxter, **Marcello Romano**, and **Xiaoping Yun**. "Autonomous Distributed Control of Simultaneous Multiple Spacecraft Proximity Maneuvers." ***IEEE Transactions on Automation Science and Engineering*** 7, no. 3 (2010): 630-644. http://dx.doi.org/10.1109/TASE.2009.2039010
An autonomous distributed control algorithm for multiple spacecraft performing simultaneous close proximity maneuvers has been developed. Examples of these maneuvers include automated on-orbit inspection, assembly, or servicing. The proposed control algorithm combines the control effort efficiency of the Linear Quadratic Regulator (LQR) and the robust collision avoidance capability of the Artificial Potential Function (APF) method. The LQR control effort serves as the attractive force toward goal positions, while APF-based repulsive functions provide collision avoidance for both fixed and moving obstacles. Comprehensive validation and performance evaluation of the control algorithm is conducted by numerical simulations. The simulation results show the developed LQR/APF algorithm to be both robust and efficient for controlling multiple spacecraft during simultaneous docking maneuvers. 2010 IEEE.

Ryan, John P., Shannon B. Johnson, A. Sherman, Kanna Rajan, Frederic Py, H. Thomas, Julio B. J. Harvey, L. Bird, **Jeffrey D. Paduan**, and Robert C. Vrijenhoek. "Mobile Autonomous Process Sampling within Coastal Ocean Observing Systems**."** ***Limnology and Oceanography-Methods*** 8, (August 2010): 394-402. http://aslo.org/lomethods/free/2010/0394.html
Predicting when and where key oceanic processes will be encountered is problematic in dynamic coastal waters where diverse physical, chemical, and biological factors interact in varied and rapidly changing combinations. Defining key processes often requires efficient sampling of specific water masses and prompt sample return for subsequent analyses. This compound challenge motivated our efforts to develop mobile autonomous process sampling (MAPS) for use with autonomous underwater vehicles (AUVs). With this system, features are recognized by artificial intelligence that integrates AUV sensor data to estimate probabilistic states for adaptive control of survey navigation and triggering of targeted water samplers. To demonstrate the utility of the MAPS/AUV system, we focused on intermediate nepheloid layers (INLs), episodic transport events that may play a role in zooplankton ecology. During multiple field tests in Monterey Bay, California, the MAPS/AUV system recognized, mapped, and sampled INLs. Invertebrate larvae contained in the water samples were subsequently characterized with molecular probes developed for high-throughput screening. Preliminary results support the hypothesis that INLs function as vehicles for episodic larval transport. Applying MAPS within a greater coastal ocean observing system permitted description of regional oceanographic dynamics that influenced the patterns and scales of INL and larval transport.

2009

Bachmann, Richard J., Frank J. Boria, **Ravi Vaidyanathan**, Peter G. Ifju, and Roger D. Quinn. "A Biologically Inspired Micro-Vehicle Capable of Aerial and Terrestrial Locomotion." ***Mechanism and Machine Theory*** 44, no. 3 (March 2009): 513-526.
This paper reports the design, fabrication, and field testing of a small (30.5 cm wingspan) robot capable of aerial and terrestrial locomotion. The micro air-land vehicle (MALV)flies using a chord-wise, undercambered, bat-like compliant wing and walks over rough terrain using passively

compliant wheel-leg running gear. MALV successfully performs transitions from flight to walking and in some situations, from walking to flight. The lightweight (similar to 100 g) carbon fiber vehicle can fly, land, and crawl with a sensor payload exceeding 20% its own mass. (c) 2008 Elsevier Ltd. All rights reserved.

Bevilacqua, Riccardo, Jason S. Hall, James Homing, and **Marcello Romano**. "Ad Hoc Wireless Networking and Shared Computation for Autonomous Multirobot Systems." *Journal of Aerospace Computing, Information and Communication* 6, no. 5 (2009): 328-353.
http://dx.doi.org/10.2514/1.40734
A wireless ad hoc network is introduced that enables inter-robot communication and shared computation among multiple robots with PC/104-based single board computers running the real-time application interface patched Linux operating system. Through the use of IEEE 802.11 ad hoc technology and User Datagram Protocol, each robot is able to exchange data without the need of a centralized router or wireless access point. The paper presents three key aspects of this novel architecture to include: 1) procedures to install the real-time application interface patched operating system and wireless ad hoc communication protocol on a multiple robot system; 2) development of a Simulink&reglibrary to enable intercommunication among robots and provide the requisite software-hardware interfaces for the onboard sensor suite and actuator packages; 3) methods to rapidly generate and deploy real-time executables using Mathwork's Real-Time Workshop to enable an autonomous robotic system. Experimental test results from the Spacecraft Robotics Laboratory at the Naval Postgraduate School are presented which demonstrate negligible network latencies and real-time distributed computing capability on the Autonomous Spacecraft Assembly Test Bed. A complete manual is also included to replicate the network and software infrastructures described in this work. Also, the developed Simulink&reglibrary can be requested from the authors.

Boxerbaum, Alexander S., Richard J. Bachmann, Roger D. Quinn, Richard M. Harkins, Thomas Dunbar, Stuart C. Burgess, and **Ravi Vaidyanathan**. "Design and Testing of a Highly Mobile Insect-Inspired Autonomous Robot in a Beach Environment." *International Journal of Design and Nature and Ecodynamics* 4, no. 4 (2009): 319-336.
http://dx.doi.org/10.2495/DNE-V4-N4-319-336
The capability of autonomous platforms to function on beaches and in the ocean surf-zone is critical for a wide range of military and civilian operations. Of particular importance is the ability to navigate autonomously through the rocky terrain, hard-packed moist sand, and loose dry sand characterizing this environment. The study of animal locomotion mechanisms can elucidate specific movement principles that can be applied to address these demands. In this work, we report the design, fabrication, control system development, simulation, and field testing of a biologically inspired autonomous robot for deployment and operation in an ocean beach environment. The robot successfully fuses a range of insect-inspired passive mechanisms with active autonomous control architectures to seamlessly adapt to and traverse through a range of challenging substrates.Field testing establishes the performance of the robot to navigate semi-rugged terrain in the surf-zone environment including soft to hard-packed sand, mild to medium inclines, and rocky terrain. Platform autonomy is shown to be effective for navigation and communication. The fusion of passive mechanisms and active control algorithms results in a robot with mobility comparable to a legged vehicle with a control system of comparable simplicity to a wheeled robot. Based on the success of this platform, we further introduce the design of a fully amphibious robot designed to extend its performance to completely undersea surroundings. 2009 WIT Press.

Chao, Yi, Zhijin Li, John Farrara, James C. McWilliams, James Bellingham, Xavier Capet, Francisco Chavez, et al. "Development, Implementation and Evaluation of a Data-Assimilative Ocean Forecasting System Off the Central California Coast." *Deep-Sea Research Part II: Topical Studies in Oceanography* 56, no. 3-5 (2009): 100-126.
http://dx.doi.org/10.1016/j.dsr2.2008.08.011
The development and implementation of a real-time ocean forecast system based on the Regional

Ocean Modeling System (ROMS) off the coast of central California are described. The ROMS configuration consists of three nested modeling domains with increasing spatial resolutions: the US West coastal ocean at 15-km resolution, the central California coastal ocean at 5 km, and the Monterey Bay region at 1.5 km. All three nested models have 32 vertical sigma (or terrain-following) layers and were integrated in conjunction with a three-dimensional variational data assimilation algorithm (3DVAR) to produce snapshots of the ocean state every 6 h (the reanalysis) and 48-h forecasts once a day. This ROMS forecast system was operated in real time during the field experiment known as the Autonomous Ocean Sampling Network (AOSN-II) in August 2003. After the field experiment, a number of improvements were made to the ROMS forecast system: more data were added in the reanalysis with more careful quality control procedures, improvements were made in the data assimilation scheme, as well as model surface and side boundary conditions. The results from the ROMS reanalysis are presented here. The ROMS reanalysis is first compared with the assimilated data as a consistency check. An evaluation of the ROMS reanalysis against the independent measurements that are not assimilated into the model is then presented. This evaluation shows the mean differences in temperature and salinity between reanalysis and observations to be less than 1 C and 0.2 psu (practical salinity unit), respectively, with root-mean-square (RMS) differences of less than 1.5 C and 0.25 psu. Qualitative agreement is found between independent current measurements and the ROMS reanalysis. The agreement is particularly good for the vertically integrated current along the offshore glider tracks: the ROMS reanalysis can realistically reproduce the poleward California Undercurrent. Reasonably good agreement is found in the spatial patterns of the surface current as measured by high-frequency (HF) radars. Preliminary results concerning the ROMS forecast skill and predictability are also presented. Future plans to improve the ROMS forecast system with a particular focus on assimilation of HF radar current measurements are discussed. 2008 Elsevier Ltd.

Ghabcheloo, Reza, A. Pedro Aguiar, Antonio Pascoal, Carlos Silvestre, **Isaac Kaminer**, and Joao Hespanha. "Coordinated Path-Following in the Presence of Communication Losses and Time Delays." ***SIAM Journal on Control and Optimization*** 48, no. 1 (2009): 234-265. http://dx.doi.org/10.1137/060677884
This paper addresses the problem of steering a group of vehicles along given spatial paths while holding a desired time-varying geometrical formation pattern. The solution to this problem, henceforth referred to as the coordinated path-following (CPF) problem, unfolds in two basic steps. First, a path-following (PF) control law is designed to drive each vehicle to its assigned path, with a nominal speed profile that may be path dependent. This is done by making each vehicle approach a virtual target that moves along the path according to a conveniently defined dynamic law. In the second step, the speeds of the virtual targets (also called coordination states) are adjusted about their nominal values so as to synchronize their positions and achieve, indirectly, vehicle coordination. In the problem formulation, it is explicitly considered that each vehicle transmits its coordination state to a subset of the other vehicles only, as determined by the communications topology adopted. It is shown that the system that is obtained by putting together the PF and coordination subsystems can be naturally viewed as either the feedback or the cascade connection of the latter two. Using this fact and recent results from nonlinear systems and graph theory, conditions are derived under which the PF and the coordination errors are driven to a neighborhood of zero in the presence of communication losses and time delays. Two different situations are considered. The first captures the case where the communication graph is alternately connected and disconnected (brief connectivity losses). The second reflects an operational scenario where the union of the communication graphs over uniform intervals of time remains connected (uniformly connected in mean). To better root the paper in a nontrivial design example, a CPF algorithm is derived for multiple underactuated autonomous underwater vehicles (AUVs). Simulation results are presented and discussed. 2009 Society for Industrial and Applied Mathematics.

Gong, Qi, **L. Ryan Lewis**, and **I. Michael Ross**. "Pseudospectral Motion Planning for Autonomous Vehicles." ***Journal of Guidance, Control, and Dynamics*** 32, no. 3 (2009): 1039-1045. http://dx.doi.org/10.2514/1.39697
A unified optimal motion planning algorithm for heterogeneous vehicles navigating through an obstacle-cluttered environment has been demonstrated. Discipline-based design of motion planning algorithms have led to the development and evolution of different techniques to solve specific problems. These methods use probabilistic means of connecting the initial configuration to the final configuration thereby enabling an improved capacity to achieve the goal and a capability to generate initial feasible paths. The optimal control theory is the most natural framework for solving motion planning problems. The motion planning algorithms that purport to mimic human rules do not provide the best solutions and also create unintended problems such as conflicts between rules. Solutions can be obtained quite seamlessly and even more intelligently than with a human driver as demonstrated in the case of an unmanned car in optimal control approach.

Jones, Kevin D. and **Max F. Platzer.** "Design and Development Considerations for Biologically Inspired Flapping-Wing Micro Air Vehicles." ***Experiments in Fluids*** 46, no. 5 (2009): 799-810. http://dx.doi.org/10.1007/s00348-009-0654-1
In this paper, the decade of numerical and experimental investigations leading to the development of the authors' unique flapping-wing micro air vehicle is summarized. Early investigations included the study of boundary layer energization by means of a small flapping foil embedded in a flat-plate boundary layer, the reduction of the recirculatory flow region behind a backward-facing step by means of a small flapping foil, and the reduction or suppression of flow separation behind blunt or cusped airfoil trailing edges by flapping a small foil located in the wake flow region. These studies were followed by systematic investigations of the aerodynamic characteristics of single flapping airfoils and airfoil combinations. These unsteady flows were described using flow visualization, laser-Doppler velocimetry in addition to panel and Navier-Stokes computations. It is then shown how this flapping-wing database was used to conceive, design and develop a micro air vehicle which has a fixed wing for lift and two flapping wings for thrust generation. While animal flight is characterized by a coupled force generation, the present design appears to separate lift and thrust. However, in fact, the performance of one surface is closely coupled to the other surfaces. 2009 US Government.

Kang, Wei, I. Michael Ross, Khanh Pham, and Qi Gong. "Autonomous Observability of Networked Multisatellite Systems." ***Journal of Guidance, Control, and Dynamics*** 32, no. 3 (2009): 869-877.
http://dx.doi.org/10.2514/1.38826
The focus of this paper is on the development of observability theory and estimation algorithms for multisatellite systems. The results could have applications in space missions that require minimum support from ground control centers and other systems such as the Global Positioning System. The main results consist of 1) the observability of two satellites, either cooperative or noncooperative, using relative measurements only, 2) a computational method for networked multiagent systems to check the observability using their topologies of communication and sensor network, 3) an unscented Kalman filter for the estimation of orbits, positions, and velocities using relative measurements, and 4) simulations on the observability of satellite systems, including a scenario of two satellites and, in another simulation, a networked multisatellite constellation with random communication interruptions.

Lee, Deok-Jin and Kyle T. Alfriend. "Additive Divided Difference Filtering for Real-Time Spacecraft Attitude Estimation using Modified Rodrigues Parameters." ***Journal of the Astronautical Sciences*** 57, no. 1-2 (2009): 93-111.
In this paper, a real-time attitude estimation algorithm is derived by using an additive divided difference filter as an efficient alternative to the extended Kalman filter. To make the attitude filtering algorithm suitable for real-time applications and to minimize the computational load, a square-root sigma point attitude filter is designed by integrating the divided difference filter with

the additive noise concept using the modified Rodrigues attitude parameters. The new attitude filter provides numerically stable and accurate estimates of the state and covariance, but the computational workload of the new estimator is almost identical to the computational complexity of the extended Kalman attitude filter. For performance evaluation the new sigma point attitude filter is compared with the unscented attitude filter and the extended Kalman filter. The sensor measurements include a three-axis magnetometer and rate-gyros. Simulation results indicate that the proposed additive divided difference attitude filter shows faster convergence with accurate and reliable estimation.

Pizzi, Rita M. R., Danilo Rossetti, Giovanni Cino, D. Marino, Angelo L. Vescovi, and **Wolfgang Baer**. "A Cultured Human Neural Network Operates a Robotic Actuator." ***Biosystems*** 95, no. 2 (February 2009): 137-144.
The development of bio-electronic prostheses, hybrid human-electronics devices and bionic robots has been the aim of many researchers. Although neurophysiologic processes have been widely investigated and bio-electronics has developed rapidly, the dynamics of a biological neuronal network that receive sensory inputs, store and control information is not yet understood. Toward this end, we have taken an interdisciplinary approach to study the learning and response of biological neural networks to complex stimulation patterns. This paper describes the design, execution, and results of several experiments performed in order to investigate the behavior of complex interconnected structures found in biological neural networks. The experimental design consisted of biological human neurons stimulated by parallel signal patterns intended to simulate complex perceptions. The response patterns were analyzed with an innovative artificial neural network (ANN), called ITSOM (Inductive Tracing Self Organizing Map). This system allowed us to decode the complex neural responses from a mixture of different stimulations and learned memory patterns inherent in the cell colonies. In the experiment described in this work, neurons derived from human neural stem cells were connected to a robotic actuator through the ANN analyzer to demonstrate our ability to produce useful control from simulated perceptions stimulating the cells. Preliminary results showed that in vitro human neuron colonies can learn to reply selectively to different stimulation patterns and that response signals can effectively be decoded to operate a minirobot. Lastly the fascinating performance of the hybrid system is evaluated quantitatively and potential future work is discussed. (C) 2008 Elsevier Ireland Ltd. All rights reserved.

Ramp, Steven R., Russ E. Davis, Naomi E. Leonard, Igor Shulman, Yi Chao, Allan R. Robinson, J. Marsden, et al. "Preparing to Predict: The Second Autonomous Ocean Sampling Network (AOSN-II) Experiment in the Monterey Bay." ***Deep-Sea Research Part II: Topical Studies in Oceanography*** 56, no. 3-5 (2009): 68-86.
http://dx.doi.org/10.1016/j.dsr2.2008.08.013
http://mseas.mit.edu/publications/PDF/ramp_etal_AOSNII_DSRII_2009.pdf
The Autonomous Ocean Sampling Network Phase Two (AOSN-II) experiment was conducted in and offshore from the Monterey Bay on the central California coast during July 23-September 6, 2003. The objective of the experiment was to learn how to apply new tools, technologies, and analysis techniques to adaptively sample the coastal ocean in a manner demonstrably superior to traditional methodologies, and to use the information gathered to improve predictive skill for quantities of interest to end-users. The scientific goal was to study the upwelling/relaxation cycle near an open coastal bay in an eastern boundary current region, particularly as it developed and spread from a coastal headland. The suite of observational tools used included a low-flying aircraft, a fleet of underwater gliders, including several under adaptive autonomous control, and propeller-driven AUVs in addition to moorings, ships, and other more traditional hardware. The data were delivered in real time and assimilated into the Harvard Ocean Prediction System (HOPS), the Navy Coastal Ocean Model (NCOM), and the Jet Propulsion Laboratory implementation of the Regional Ocean Modeling System (JPL/ROMS). Two upwelling events and one relaxation event were sampled during the experiment. The upwelling in both cases began when a pool of cold water less than 13 C appeared near Cape Ano Nuevo and subsequently spread offshore and southward across the bay as the equatorward wind stress continued. The

primary difference between the events was that the first event spread offshore and southward, while the second event spread only southward and not offshore. The difference is attributed to the position and strength of meanders and eddies of the California Current System offshore, which blocked or steered the cold upwelled water. The space and time scales of the mesoscale variability were much shorter than have been previously observed in deep-water eddies offshore. Additional process studies are needed to elucidate the dynamics of the flow. 2008 Elsevier Ltd.

Royset, Johannes O., **W. Matthew Carlyle**, and **R. Kevin Wood**. "Routing Military Aircraft with A Constrained Shortest-Path Algorithm." ***Military Operations Research*** 14, no. 3 (2009): 31-52. We formulate and solve aircraft-routing problems that arise when planning missions for military aircraft that are Subject to ground-based threats such as surface-to-air missiles. We use a constrained shortest-path (CSP) model that discretizes the relevant airspace into a grid of vertices representing potential waypoints, and connects those vertices with directed edges to represent potential flight segments. The model is flexible: It can route any type of manned or unmanned aircraft; it can incorporate any number of threats; and it can incorporate, in the objective function or as side constraints, numerous mission-specific metrics such as risk, fuel consumption, and flight time. We apply a new algorithm for solving the CSP problem and present computational results for the routing of a high-altitude F/A-18 strike group, and the routing of a medium-altitude unmanned aerial vehicle. The objectives minimize risk from ground-based threats while constraints limit fuel consumption and/or flight time. Run times to achieve a near-optimal solution range from fractions of a second to 80 seconds on a personal computer. We also demonstrate that our methods easily extend to handle turn-radius constraints and round-trip routing. Composite Group: Advances in Military OR.

Royset, Johannes O. and Daniel N. Reber. "Optimized Routing of Unmanned Aerial Systems for the Interdiction of Improvised Explosive Devices." ***Military Operations Research*** 14, no. 4 (2009): 5-19.
The paper describes an optimization-based tool for selecting routes that will best employ unmanned aerial systems (UASs) for the purpose of detecting improvised explosive devices (IEDs) or related activity. The routing tool uses preprocessing procedures, an integer linear program, and an IED prediction model to direct UASs to sectors of the area of operations with high IED activity, while accounting for factors such as winds, aircraft de-confliction, and blue force activity. Initial evaluation of the routing tool through field experiments with actual UASs suggests that the tool produces realistic routes, which can be flown in the allocated amount of time, even under windy conditions.

Shulman, Igor, Clark Rowley, Stephanie Anderson, Sergio DeRada, John Kindle, Paul Martin, James Doyle, et al. "Impact of Glider Data Assimilation on the Monterey Bay Model." ***Deep-Sea Research Part II: Topical Studies in Oceanography*** 56, no. 3-5 (2009): 188-198. http://dx.doi.org/10.1016/j.dsr2.2008.08.003
Glider observations were essential components of the observational program in the Autonomous Ocean Sampling Network (AOSN-II) experiment in the Monterey Bay area during summer of 2003. This paper is focused on the impact of the assimilation of glider temperature and salinity observations on the Navy Coastal Ocean Model (NCOM) predictions of surface and subsurface properties. The modeling system consists of an implementation of the NCOM model using a curvilinear, orthogonal grid with 1-4 km resolution, with finest resolution around the bay. The model receives open boundary conditions from a regional (9 km resolution) NCOM implementation for the California Current System, and surface fluxes from the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) atmospheric model at 3 km resolution. The data assimilation component of the system is a version of the Navy Coupled Ocean Data Assimilation (NCODA) system, which is used for assimilation of the glider data into the NCOM model of the Monterey Bay area. The NCODA is a fully 3D multivariate optimum interpolation system that produces simultaneous analyses of temperature, salinity, geopotential, and vector velocity. Assimilation of glider data improves the surface temperature at the mooring locations for the NCOM model hindcast and nowcasts, and for the short-range (1-1.5 days) forecasts. It is

shown that it is critical to have accurate atmospheric forcing for more extended forecasts. Assimilation of glider data provided better agreement with independent observations (for example, with aircraft measured SSTs) of the model-predicted and observed spatial distributions of surface temperature and salinity. Mooring observations of subsurface temperature and salinity show sharp changes in the thermocline and halocline depths during transitions from upwelling to relaxation and vice versa. The non-assimilative run also shows these transitions in subsurface temperature; but they are not as well defined. For salinity, the non-assimilative run significantly differs from the observations. However, the glider data assimilating run is able to show comparable results with observations of thermocline as well as halocline depths during upwelling and relaxation events in the Monterey Bay area. It is also shown that during the relaxation of wind, the data assimilative run has higher value of subsurface velocity complex correlation with observations than the non-assimilative run. 2008 Elsevier Ltd.

Tvaryanas, Anthony P. and Glen D. MacPherson. "Fatigue in Pilots of Remotely Piloted Aircraft before and After Shift Work Adjustment." *Aviation Space and Environmental Medicine* 80, no. 5 (May 2009): 454-461.
Background: Remotely piloted aircraft (RPA) with long endurance allow near-continuous operations, necessitating the implementation of shift work for crewmembers to provide the necessary manning of ground control stations. Shift work has a well-known association with fatigue, degraded work performance, and an increased risk for errors and accidents. This study presents the results of a follow-up survey of a particular population of shift-working RPA crewmembers 1 yr after modification of their shift work schedule. Methods: A cross-sectional survey of 66 RPA crewmembers was conducted using a collection of validated fatigue scales. This data was compared to survey data collected a year prior from the same population and from a reference group of non-shift-working aircrew. Shift system features and individual and situational differences associated with fatigue were explored. Additionally, several alternative types of shift schedules were assessed through modeling and simulation. Results: The study found no significant reduction in reported fatigue despite prior modifications to the shift work schedule to increase opportunities for recovery. Months shift working, sleep quality, and disturbances in family and social activities were associated with overall fatigue scores. Approximately half of those surveyed met criteria for occupationally Significant fatigue. Months shift working, use of on-duty napping, and fatigue scores were predictive of those with occupationally significant fatigue. Modeling of feasible variants of the Current shift work schedule failed to reveal a significantly improved alternative schedule. Conclusions: Collectively, the results demonstrate a persistent problem with chronic fatigue in this study population, likely reflective of continued inadequate opportunities for recover), and restorative sleep.

2008

Bevilacqua, Riccardo and Marcello Romano. "Rendezvous Maneuvers of Multiple Spacecraft using Differential Drag Under J2 Perturbation." *Journal of Guidance, Control, and Dynamics* 31, no. 6 (2008): 1595-1607.
http://dx.doi.org/10.2514/1.36362
In this work, the residual atmospheric drag is exploited to perform rendezvous maneuvers among multiple spacecraft in low Earth orbits. These maneuvers are required, for instance, for autonomous on-orbit assembly. By varying the level of aerodynamic drag of each spacecraft, relative differential accelerations are generated among the spacecraft of the group and therefore their relative orbits are controlled. Each of the spacecraft is assumed to include a drag plate, which can be actively opened or closed, to vary the atmospheric drag. The recently developed Schweighart-Sedwick model is used to describe the relative dynamics of different spacecraft with respect to a circular orbit with the inclusion of J2effects. Furthermore, the natural relative dynamics of each chaser with respect to the target is decoupled into a secular motion and a periodic oscillation. In particular, the following two-phase control method is proposed. First, the secular motion of each chaser is controlled via differential drag in order for the spacecraft to

sequentially move from an arbitrary initial condition to a closed stable relative orbit around the target spacecraft. After the relative orbit stabilization, a relative eccentricity control is applied to each spacecraft to zero-out the semi-axis of the relative orbit around the target and to achieve the rendezvous condition. The control algorithm considers mutual constraints among the values of differential drag that the different spacecraft can experience. Potential collisions are avoided by changing the maneuvering initial time. The main advantage of the proposed technique is that it enables a fleet of spacecraft to rendezvous without propellant expenditure. Furthermore, no numerical optimization is needed, because the control policy is based on closed-form analytical solutions. The proposed technique was validated via numerical simulations.

Blanding, Wayne R., Peter K. Willett, Yaakov Bar-Shalom, and Robert S. Lynch. "Directed Subspace Search ML-PDA with Application to Active Sonar Tracking." *IEEE Transactions on Aerospace and Electronic Systems* 44, no. 1 (2008): 201-216.
http://dx.doi.org/10.1109/TAES.2008.4516999
The maximum likelihood probabilistic data association (ML-PDA) tracking algorithm is effective in tracking Very Low Observable targets (i.e., very low signal-to-noise ratio (SNR) targets in a high false alarm environment). However, the computational complexity associated with obtaining the track estimate in many cases has precluded its use in real-time scenarios. Previous ML-PDA implementations used a multi-pass grid (MPG) search to find the track estimate. Two alternate methods for finding the track estimate are presented - a genetic search and a newly developed directed subspace (DSS) search algorithm. Each algorithm is tested using active sonar scenarios in which an autonomous underwater vehicle searches for and tracks a target. Within each scenario, the problem parameters are varied to illustrate the relative performance of each search technique. Both the DSS search and the genetic algorithm are shown to be an order of magnitude more computationally efficient than the MPG search, making possible real-time mplementation. In addition, the DSS search is shown to be the most effective technique at tracking a target at the lowest SNR levels-reliable tracking down to 5 dB (postprocessing SNR in a resolution cell) using a 5-frame sliding window is demonstrated, this being 6 dB better than the MPG search. 2008 IEEE.

Dobrokhodov, Vladimir N., **Isaac I. Kaminer**, **Kevin D. Jones**, and Reza Ghabcheloo. "Vision-Based Tracking and Motion Estimation for Moving Targets using Unmanned Air Vehicles." *Journal of Guidance, Control, and Dynamics* 31, no. 4 (2008): 907-917.
http://dx.doi.org/10.2514/1.33206
The algorithm performs autonomous tracking of a moving target, while simultaneously estimating geographic coordinates, speed, and heading of the target. Tight real-time integration of unmanned air vehicle's video and telemetry data streams with georeferenced database allows for reliable target identification, increased precision, and shortened time of target motion estimation. A low-cost off-the-shelf system is used, with a modified radiocontrolled aircraft airframe, gas engine, and servos. Tracking is enabled using a low-cost, miniature pan-tilt gimbal. The control algorithm provides rapid target acquisition and tracking capability. A target motion estimator was designed and shown in multiple flight tests to provide reasonable targeting accuracy. The impact of tracking loss events on the control and estimation algorithms is analyzed in detail.

Gezer, Levent, Robert Broadston, David Jenn, and Gert Burgstaller. "Digital Tracking Array using Off-the-Shelf Hardware." *IEEE Antennas and Propagation Magazine* 50, no. 1 (2008): 108-114.
http://dx.doi.org/10.1109/MAP.2008.4494509
The design, development, and testing of a digital tracking array is described. The array operates at 2.4 GHz for tracking video and data from UAVs and other mobile transmitters. A monopulse tracking technique is used to keep the beam scanned to the direction of the incoming signal. The array is built entirely of commercial off-the-shelf (COTS) components. Calibration, measurement of patterns, and verification of the tracking function are also discussed. 2008 IEEE.

Lee, Deok-Jin. "Nonlinear Estimation and Multiple Sensor Fusion using Unscented Information Filtering." *IEEE Signal Processing Letters* 15, (2008): 861-864.
http://dx.doi.org/10.1109/LSP.2008.2005447
This letter represents a new unscented information filtering algorithm for nonlinear estimation and multiple sensor information fusion. The proposed information fusion algorithm is derived by embedding the unscented transformation method used in the sigma point filter into the extended information filtering architecture. The new information filter achieves not only the accuracy and robustness of the sigma point filter but also the flexibility of the information filter for multiple sensor estimation. Performance comparison of the proposed filter with the extended information filter is demonstrated through a target-tracking simulation study. 2008 IEEE.

Moreira, Lucia and C. Guedes Soares. "H2 and Hinfin; Designs for Diving and Course Control of an Autonomous Underwater Vehicle in Presence of Waves." *IEEE Journal of Oceanic Engineering* 33, no. 2 (2008): 69-88.
http://dx.doi.org/10.1109/JOE.2008.918689
H2 and H designs applied to the diving and course control of an autonomous underwater vehicle (AUV) considering the presence of wave disturbances are described. The six-degrees-of-freedom equations of motion of the vehicle are described as a linear model and divided into three noninteracting (or lightly interacting) subsystems for speed control, steering, and diving. This work is based on the slender form of the Naval Postgraduate School (NPS, Monterey, CA) AUV, considering that the subsystems can be controlled by means of two single-screw propellers, a rudder, port and starboard bow planes, and a stern plane. A model of the AUV dynamics is presented with the first- and the second-order wave force disturbances, i.e., the Froude-Kriloff and diffraction forces. An algorithm of nonlinear regression for the rationalization of the subsurface sea spectrum is provided in this case study. The obtained results are analyzed and evaluated in the frequency domain comparing the controllers performance considering or not the inclusion of the model of waves. 2008 IEEE.

Nicholson, John W. and **Anthony J. Healey**. "The Present State of Autonomous Underwater Vehicle (AUV) Applications and Technologies." *Marine Technology Society Journal* 42, no. 1 (2008): 44-51.
http://dx.doi.org/10.4031/002533208786861272
AUVs have proved their usefulness in recent years and continue to do so. This paper is a review of the current state of the art of AUVs. Present AUV capabilities are reviewed through a discussion of feasible present-day AUV missions. The state of key AUV design features and sensor technologies is also addressed, identifying those areas most critical to continued future progress in AUV development.

Platzer, Max F., **Kevin D. Jones**, John Young, and Joseph C. S. Lai. "Flapping-Wing Aerodynamics: Progress and Challenges." *AIAA Journal* 46, no. 9 (2008): 2136-2149.
http://dx.doi.org/10.2514/1.29263
It is the objective of this paper to review recent developments in the understanding and prediction of flapping-wing aerodynamics. To this end, several flapping-wing configurations are considered. First, the problem of single flapping wings is treated with special emphasis on the dependence of thrust, lift, and propulsive efficiency on flapping mode, amplitude, frequency, and wing shape. Second, the problem of hovering flight is studied for single flapping wings. Third, the aerodynamic phenomena and benefits produced by the flapping-wing interactions on tandem wings or biplane configurations are discussed. Such interactions occur on dragonflies or on a recently developed micro air vehicle. The currently available two- and three-dimensional inviscid and viscous flapping-wing flow solutions are presented. It is shown that the results are strongly dependent on flapping frequency, amplitude, and Reynolds number. These findings are substantiated by comparison with the available experimental data.

Vaidyanathan, Ravi, Troy S. Prince, Mohammad Modarreszadeh, Lalit Gupta, and Fredrick J. Lisy**. "Computationally Efficient Predictive Adaptive Control for Robotic Operation in Dynamic Environments and Task Domains." *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture* 222, no. 12 (December 2008): 1695-1713. This paper presents a new adaptive predictive control algorithm and its refinement for robotic utility. The controller addresses the need for practical, computationally efficient, robust real-time adaptive control for multivariable robotic systems working in challenging industrial environments. It exploits a special matrix representation to obtain Substantial reductions in the computational expense relative to standard methods. Controller performance is established for a simple robotic manipulator directing motion through sharply changing loading conditions and on an industrial robot loading heavy shells within the weapons magazine of a naval vessel. The new controller demonstrates the ability to adapt to varying actuator performance and rapidly changing sea states for which a classic proportional-integral-derivative controller cannot adjust. Control commands and parameter adjustments are executed in time frames Suitable for real-time use, even on platforms and in environments with limited computational resources. Future work involves the implementation and testing of the controller on a prototype robot during facsimile naval operations. This work may serve as a foundation to address control issues for robots working in uncertain dynamic environments with varying task domains through the implementation of computationally efficient predictive adaptive control.

Vincent, Patrick, **Murali Tummala**, and **John McEachen**. "A New Method for Distributing Power Usage Across a Sensor Network." *Ad Hoc Networks* 6, no. 8 (November 2008): 1258-1280. We present a method for more uniformly distributing the energy burden across a wireless ground-based sensor network communicating with ail overhead unmanned aerial vehicle (UAV). A subset of sensor nodes, termed a transmit cluster, receives and aggregates data gathered by the entire network, and forms a distributed antenna array, concentrating the radiated transmission into a narrow beam aimed towards the UAV. Because these duties are power-intensive, the role of transmit cluster must be shifted to different nodes as time progresses. We present ail algorithm to reassign the transmit cluster, specifying the time that should elapse between reassignments and the number of hops that should be placed between successive transmit clusters in order to achieve three competing goals: first, we wish to better and more broadly spread the energy load across the sensor network while, second, minimizing the energy expended in moving the transmit cluster, all the while, third, reducing to the extent practicable the time to bring the UAV and the sensor network's beam into alignment. Additionally, we present a method for reconfiguring the communication burden between the ground-based sensor network and the UAV. We describe and analyze two alternative strategies to bring the UAV and the sensor network's beam into alignment, while minimizing the energy expended by the sensor network. The performance of the two strategies is compared in terms of probability of beam-UAV alignment as a function of time, and the expected time to alignment. We examine the performance tradeoff between the choice of strategy and parameters of the sensor network that affect power conservation. Published by Elsevier B.V.

2007

Ahner, Darryl K. "Real-Time Planning and Control of Army UAVs Under Uncertainty." *Journal of Aerospace Computing, Information and Communication* 4, no. 5 (May 2007): 798-815. http://dx.doi.org/10.2514/1.25587
With advances in sensor technology and data fusion used in military operations, more information is available for decision making. A key question is how to make effective use of this information. Higher level sensors cue lower level sensors, in this case unmanned aerial vehicles (UAVs), to indicate potential target arrivals. Given probability distributions of these target arrivals, simulation and mathematical programming are used within a dynamic programming framework

to determine control strategies for UAVs. An adaptive dynamic programming methodology is presented for the a uniform travel time UAV planning and control problem. Special structure of a network assignment problem is exploited to recursively update functional approximations representing future rewards through the network assignment problem's subgradient information. We develop an approximate dynamic approach to real-time planning and control of unmanned aerial vehicles with a focus on accounting for stochastic arrivals of new tasks. Experimentation demonstrates the use of this method and its potential for providing quick real-time controls for UAVs. Approaching the UAV routing problem using Adaptive Dynamic Programming offers a tractable framework in which to solve these difficult problems. Copyright 2007 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

Bachmann, Eric R., **Xiaoping Yun**, and Anne Brumfield. "Limitations of Attitude Estimnation Algorithms for Inertial/Magnetic Sensor Modules - Investigating the Effects of Magnetic Variations on Inertial/Magnetic Orientation Sensors." *IEEE Robotics and Automation Magazine* 14, no. 3 (September 2007): 76-87.
http://dx.doi.org/10.1109/MRA.2007.901320
Inertial/magnetic sensor modules and their associated data filtering algorithms are designed to be capable of estimating three degrees of orientation over a wide area in a variety of unprepared tracking environments. The modules commonly contain three linear accelerometer and three magnetometers. In an indoor environment, sources of magnetic interference are constantly present that may affect the direction and magnitude of the field measured by the sensor. This kind of interference from objects with fixed position and orientation can be calibrated by removing any soft iron materials and dealing with the hard iron effects directly. Also, if with only one or known source is present, maintaining a distance of approximately 1m from the source of interference can avoid distortions. However, in a tracking application, sources of magnetic distortions vary considerably. In series of experiments, sensor modules are subjected to controlled changes in the direction and strength of the sensed magnetic field in order to characterize the resulting orientation estimation errors. A second set of experiments involve exposing a triad of magnetometers to magnetic fields generated by various electrical appliances and ferrous objects in order to examine the magnitude of the errors and the range at which they occur. In the last set, a robot arm is tracked using inertial/magnetic sensor modules and an optical tracking system. Despite drawbacks, tracking experiments indicate that inertial/magnetic sensor modules can be used to track posture with an accuracy that is comparable to optical tracking. However, given the current state of the art of orientation estimation algorithms designed to process inertial/magnetic sensor module data, it should not be used without studying first the nature of magnetic field in the environment in which it will be used.

Ghabcheloo, Reza, Antonio Pascoal, Carlos Silvestre, and **Isaac Kaminer**. "Non-Linear Co-Ordinated Path Following Control of Multiple Wheeled Robots with Bidirectional Communication Constraints." *International Journal of Adaptive Control and Signal Processing* 21, no. 2-3 (March-April 2007):133-137
http://dx.doi.org/10.1002/acs.923
The paper presents a solution to the problem of steering a group of wheeled robots along given spatial paths, while holding a desired inter-vehicle formation pattern. This problem arises for example when multiple robots are required to search a given area in cooperation. The solution proposed addresses explicitly the dynamics of the cooperating robots and the constraints imposed by the topology of the intervehicle communications network. Lyapunov-based techniques and graph theory are brought together to yield a decentralized control structure where the information exchanged among the robots is kept at a minimum. With the set-up proposed, path following (in space) and inter-vehicle co-ordination (in time) are essentially decoupled. Path following for each vehicle amounts to reducing a conveniently defined error variable to zero. Vehicle co-ordination is achieved by adjusting the speed of each of the vehicles along its path according to information on the positions and speeds of a subset of the other vehicles, as determined by the communications topology adopted. Simulations illustrate the efficacy of the solution proposed. Copyright 2006 John Wiley Sons, Ltd.

Romano, Marcello, David A. Friedman, and Tracy J. Shay. "Laboratory Experimentation of Autonomous Spacecraft Approach and Docking to a Collaborative Target." *Journal of Spacecraft and Rockets* 44, no. 1 (2007): 164-173.
http://dx.doi.org/10.2514/1.22092
A new laboratory test bed is introduced that enables the hardware-in-the-loop simulation of the autonomous approach and docking of a chaser spacecraft to a target spacecraft of similar mass. The test bed consists of a chaser spacecraft and a target spacecraft simulator floating via air pads on a flat floor. The prototype docking interface mechanism of the Defense Advanced Research Projects Agency's Orbital Express mission is integrated on the spacecraft simulators. Relative navigation of the chaser spacecraft is obtained by fusing the measurements from a single-camera vision sensor and an inertial measurement unit, through Kalman filters. The target is collaborative in the sense that a pattern of three infrared light emitting diodes is mounted on it as reference for the relative navigation. Eight cold-gas on-off thrusters are used for the translation of the chaser vehicle. They are commanded using a nonlinear control algorithm based on Schmitt triggers. Furthermore, a reaction wheel is used for the vehicle rotation with a proportional derivative linear control. Experimental results are presented of both an autonomous proximity maneuver and an autonomous docking of the chaser simulator to the nonfloating target. The presented results validate the proposed estimation and control methods and demonstrate the capability of the test bed.

Squire, Kevin M. and Stephen E. Levinson. "HMM-Based Concept Learning for a Mobile Robot." *IEEE Transactions on Evolutionary Computation* 11, no. 2 (April 2007): 199-212.
http://dx.doi.org/10.1109/TEVC.2006.890263
We are developing an intelligent robot and attempting to teach it language. While there are many aspects of this research, for the purposes here the most important are the following ideas. Language is primarily based on semantics, not syntax, which is still the focus in speech recognition research these days. To truly learn meaning, a language engine cannot simply be a computer program running on a desktop computer analyzing speech. It must be part of a more general, embodied intelligent system, one capable of using associative learning to form concepts from the perception of experiences in the world, and further capable of manipulating those concepts symbolically. In this paper, we present a general cascade model for learning concepts, and explore the use of hidden Markov models (HMMs) as part of the cascade model. HMMs are capable of automatically learning and extracting the underlying structure of continuous-valued inputs and representing that structure in the states of the model. These states can then be treated as symbolic representations of the inputs. We show how a cascade of HMMs can be embedded in a small mobile robot and used to find correlations among sensory inputs to learn a set of symbolic concepts, which are used for decision making and could eventually be manipulated linguistically.

Tao, Weimin, Mingjun Zhang, Ou Ma, and **Xiaoping Yun**. "Industrial Robot Track Modeling and Vibration Suppression." *Industrial Robot* 34, no. 4 (2007): 317-325.
http://dx.doi.org/10.1108/01439910710749645
Purpose - The purpose of this paper is to investigate the vibration suppression of industrial track robot and propose a practical solution. Design/methodology/approach - Root-cause analysis through dynamic modeling, and vibration suppression using the acceleration smoother. Findings - The vibration is due to insufficient damping based on the model analysis. The solution achieved significant performance improvement without redesign of robot hardware and controller. Research limitations/implications - The design of the proposed acceleration smoother is still empirical based, which is unable to achieve optimal design. Practical implications - This solution is very easy to implement. It is robust, reliable and is able to generate consistent results. Originality/value - A very practical industrial solution, especially useful for upgrading the existing systems in the field without redesign the hardware and controller. Emerald Group Publishing Limited.

Vaidyanathan, Ravi, **Monique P. Fargues**, Remzi S. Kurcan, Lalit Gupta, Srinivas Kota, Roger D. Quinn, and Lin Dong. "A Dual Mode Human-Robot Teleoperation Interface Based on Airflow in the Aural Cavity." *International Journal of Robotics Research* 26, no. 11-12 (2007): 1205-1223. http://dx.doi.org/10.1177/0278364907082612
Robot teleoperation systems have been limited in their utility due to the need for operator motion, lack of portability and limitation to singular input modalities. In this article, the design and construction of a dual-mode human-machine interface system for robot teleoperation addressing all these issues is presented. The interface is capable of directing robotic devices in response to tongue movement and/or speech without insertion of any device in the vicinity of the oral cavity. The interface is centered on the unique properties of the human ear as an acoustic output device. Specifically, we present: (1) an analysis of the sensitivity of human ear canals as acoustic output device; (2) the design of a new sensor for monitoring airflow in the aural canal; (3) pattern recognition procedures for recognition of both speech and tongue movement by monitoring aural flow across several human test subjects; and (4) a conceptual design and simulation of the machine interface system. We believe this work will lay the foundation for a new generation of human machine interface systems for all manner of robotic applications.

2006

Ghabcheloo, Reza, Antonio Pascoal, Carlos Silvestre, and **Isaac Kaminer**. "Coordinated Path Following Control of Multiple Vehicles Subject to Bidirectional Communication Constraints RID F-9189-2010." *Group Coordination and Cooperative Control* 336, (2006): 93-111.
The paper addresses the problem of making a set of vehicles follow a a set of given spatial paths at required speeds, while ensuring that they reach and maintain a desired formation pattern. Problems of this kind arise in a number of practical applications involving ground and underwater robots. The paper summarizes and brings together in a unified framework previous results obtained by the authors for wheeled robots and fully actuated underwater vehicles. The decentralized solution proposed does not require the concept of a leader and applies to a very general class of paths. Furthermore, it addresses explicitly the dynamics of the vehicles and the constraints imposed by the inter-vehicle bi-directional communications network. The theoretical machinery used brings together Lyapunov-based techniques and graph theory. With the set-up proposed, path following (in space) and inter-vehicle coordination (in time) can be viewed as essentially decoupled. Path following for each vehicle is formulated in terms of driving a conveniently defined generalized error vector to zero; vehicle coordination is achieved by adjusting the speed of each vehicle along its particular path, based on information on the position and speed of a number of neighboring vehicles, as determined by the communications topology adopted. The paper presents the problem formulation and summarizes its solution. Simulations with dynamics models of a wheeled robot and an underwater vehicle illustrate the efficacy of the solution proposed.

———. "Coordinated Path Following Control of Multiple Wheeled Robots using Linearization Techniques RID F-9189-2010." *International Journal of Systems Science* 37, no. 6 (MAY 15, 2006): 399-414.
The paper addresses the problem of steering a fleet of wheeled robots along a set of given spatial paths, while keeping a desired inter-vehicle formation pattern. This problem arises for example when multiple vehicles are required to scan a given area in cooperation. In a possible mission scenario, one of the vehicles acts a leader and follows a path accurately, while the other vehicles follow paths that are naturally determined by the formation pattern imposed. The paper solves this and other related problems using a simple algorithm that builds on linearization techniques and gain scheduling control theory. Using this set-up, path following (in space) and inter-vehicle coordination (in time) are almost decoupled. Path following for each vehicle amounts to reducing a conveniently defined generalized error vector to zero. Vehicle coordination is achieved by

adjusting the speed of each of the vehicles along its path, according to information on the position of all or some of the other vehicles. No other information is exchanged among the robots. The set-up adopted allows for a simple analysis of the resulting coordinated path following control system. The paper describes the structure of the coordination system proposed and addresses challenging problems of robustness with respect to certain types of vehicle failures.

Kress, Moshe, **Arne Baggesen** and Eylam Gofer. "Probability Modeling of Autonomous Unmanned Combat Aerial Vehicles (UCAVs)." ***Military Operations Research***, 11, no. 4 (May 2006): 5-24. http://hdl.handle.net/10945/41144

Lu, Fei, Mu-Min Song, Guo-Hui Tian, Ning Xi, and Wei Kang. "Event-Based Planning and Control Technology and the Application in Robotic System." ***Kongzhi Lilun Yu Yingyong/Control Theory and Applications*** 23, no. 5 (2006): 756-762.
There is a growing interest in the technology of event-based planning and control. The basic idea is to introduce a new action reference variable related to the output of the system, by which the desired input and the plant are parameterized. The designer can adjust and modify the original plant in real time to generate the desired system input according to the system output and sensory information. Therefore the planning becomes a decision component and has the ability to deal with unexpected or uncertain events. The input can be adjusted automatically by the output for the realization of the control on real time. Robotic system is an intelligent system, its main character is the coordination among multiple robots. In the paper, the event-based control theory and its development are reviewed. Its application in formation of moving robots, in manufacturing system and the coordination of multi-robot are introduced. The experiment shows that the event-based planning and control technology can improve the performance of these systems. Finally, the future research directions are discussed.

Ross, I. Michael and Fariba Fahroo. "Issues in the Real-Time Computation of Optimal Control." ***Mathematical and Computer Modelling*** 43, no. 9-10 (May 2006): 1172-1188.
doi: http://dx.doi.org/10.1016/j.mcm.2005.05.021
Under appropriate conditions, the dynamics of a control system governed by ordinary differential equations can be formulated in several ways: differential inclusion, control parametrization, flatness parametrization, higher-order inclusions and so on. A plethora of techniques have been proposed for each of these formulations but they are typically not portable across equivalent mathematical formulations. Further complications arise as a result of configuration and control constraints such as those imposed by obstacle avoidance or control saturation. In this paper, we present a unified framework for. handling the computation of optimal controls where the description of the governing equations or that of the path constraint is not a limitation. In fact, our method exploits the advantages offered by coordinate transformations and harnesses any inherent smoothness present in the optimal system trajectories. We demonstrate how our computational framework can easily and efficiently handle different cost formulations, control sets and path constraints. We illustrate our ideas by formulating a robotics problem in eight different ways, including a differentially flat formulation subject to control saturation. This example establishes the loss of convexity in the flat formulation as well as its ramifications for computation and optimality. In addition, a numerical comparison of our unified approach to a recent technique tailored for control-affine systems reveals that we get about 30% improvement in the performance index. (c) 2005 Elsevier Ltd. All rights reserved.

Smuda, William J., Grant Gerhart, Man-Tak Shing, and Mikhail Auguston. "A Software Design Approach for Heterogeneous Systems of Unattended Sensors, Unmanned Vehicles and Monitoring Stations." ***Proceedings of SPIE - The International Society for Optical Engineering*** 6394, (2006):
http://dx.doi.org/10.1117/12.693035
The design and implementation of software for network systems of diverse physical assets is a continuing challenge to sensor network developers. The problems are often multiplied when

adding new elements, and when reconfiguring existing systems. For software systems, like physical systems, explicit architectural descriptions increase system level comprehension. Coupled with well defined object oriented design practices, system extensibility is defined and software reuse and code composition are enabled. Our research is based on model driven design architecture. High level system models are defined in the Unified Modeling Language (UML), the language of the software engineer. However, since most experimental work is done by non-software specialists, (electronics Engineers, Mechanical Engineers and technicians) the model is translated into a graphical, domain specific model. Components are presented as domain specific icons, and constraints from the UML model are propagated into the domain model. Domain specialists manipulate the domain model, which then composes software elements needed at each node to create an aggregate system.

Yun, Xiaoping and Eric R. Bachmann. "Design, Implementation, and Experimental Results of a Quaternion-Based Kalman Filter for Human Body Motion Tracking." *IEEE Transactions on Robotics* 22, no. 6 (December 2006): 1216-1227.
http://dx.doi.org/10.1109/TRO.2006.886270
Real-time tracking of human body motion is an important technology in synthetic environments, robotics, and other human-computer interaction applications. This paper presents an extended Kalman filter designed for real-time estimation of the orientation of human limb segments. The filter processes data from small inertial/magnetic sensor modules containing triaxial angular rate sensors, accelerometers, and magnetometers. The filter represents rotation using quaternions rather than Enter angles or axis/angle pairs. Preprocessing of the acceleration and magnetometer measurements using the Quest algorithm produces a computed quaternion input for the filter. This preprocessing reduces the dimension of the state vector and makes the measurement equations linear. Real-time implementation and testing results of the quaternion-based Kalman filter are presented. Experimental results validate the filter design, and show the feasibility of using inertial/magnetic sensor modules for real-time human body motion tracking.

2005

Ball, Robert E. and Dale B. Atkinson. "Designing for Survivability." *Aerospace America* 43, no. 11 (2005): 32-36.
The steps taken for survivability for both military and civilian aircraft systems in the US are discussed. The Joint Aircraft Survivability Program Office (JASPO) service office of the US DoD was formed in January 2003 by combining the Joint Technical Coordinating Group on Aircraft Survivability with several related activities to increase overall effectiveness. The combined group has a long and dedicated history of developing survivability technology and getting it applied to aircraft through the Vulnerability Reduction and Susceptibility Reduction Subgroups. The enhanced powder panels for fire protection in dry bays and ionomer self-sealing technologies have shown promise and are lightweight enough for unmanned air vehicles.

Curtin, Thomas B., Denise M. Crimmins, Joseph Curcio, Michael Benjamin, and Christopher Roper. "Autonomous Underwater Vehicles: Trends and Transformations." *Marine Technology Society Journal* 39, no. 3 (2005): 65-75.
http://dx.doi.org/10.4031/002533205787442521
Three examples of inter-agency cooperation utilizing current generation, individual Autonomous Underwater Vehicles (AUVs) are described consistent with recent recommendations of the U.S. Commission on Ocean Policy. The first steps in transforming individual AUVs into adaptive, networked systems are underway. To realize an affordable and deployable system, a network-class AUV must be designed with cost-size constraints not necessarily applied in developing solo AUVs. Vehicle types are suggested based on function and ocean operating regime: surface layer, interior and bottom layer. Implications for platform, navigation and control subsystems are

explored and practical formulations for autonomy and intelligence are postulated for comparing performance and judging behavior. Laws and conventions governing intelligent maritime navigation are reviewed and an autonomous controller with conventional collision avoidance behavior is described. Network-class cost constraints can be achieved through economies of scale. Productivity and efficiency in AUV manufacturing will increase if constructive competition is maintained. Constructive strategies include interface and operating standards. Professional societies and industry trade groups have a leadership role to play in establishing public, open standards.

Jones, Kevin D., Chris J. Bradshaw, Jason Papadopoulos, and Max F. Platzer. "Bio-Inspired Design of Flapping-Wing Micro Air Vehicles." **Aeronautical Journal** 109, no. 1098 (2005): 385-393.
In this paper the development and flight testing of flapping-wing propelled, radio-controlled micro air vehicles are described. The unconventional vehicles consist of a low aspect ratio fixed-wing with a trailing pair of higher aspect ratio flapping wings which flap in counterphase. The symmetric flapping-wing pair provides a mechanically and aerodynamically balanced platform, increases efficiency by emulating flight in ground effect, and suppresses stall over the main wing by entraining flow. The models weigh as little as 11g with a 23cm span and 18cm length and will fly for about 20 minutes on a rechargeable battery. Stable flight at speeds between 2 and 5ms -1 has been demonstrated, and the models are essentially stall-proof while under power. The static-thrust figure of merit for the device is 60% higher than propellers with a similar scale and disk loading.

Wood, E. R. "Vertical Highlights 2004." **Vertiflite** 51, no. 1 (2005): 64-68.
In vertical flight, 2004 is a year of preparation and transition. For the Bell Boeing V-22 Osprey tiltrotor, 2004 saw completion of 2900 hours of flight-testing by 14 aircraft in preparation for the four month Marine Operational Evaluation scheduled to begin in mid-February 2005. For the Bell/Agusta 609 tiltrotor, final modifications near completion in readiness for flight envelope expansion that is about to get underway. For Bell Helicopter Textron, Low Rate Initial Production (LRIP) started in January 2005 for the Bell H-1 Upgrade Program with the first Cobra down the line at the Bell assembly plant in Amarillo, Texas. For the Lockheed Martin F-35B, the STOVL version of Joint Strike Fighter, a "STOVL Weight Attack Team" (SWAT) of technical experts identified and executed weight savings strategies. For Sikorsky Aircraft, the Canadian government selected the Sikorsky H-92 Superhawk medium lift helicopter to replace Sikorsky Sea King helicopters currently in service with Canadian forces. The past year also saw termination of the Unmanned Combat Armed Rotorcraft (UCAR).

Conference Papers

2014

Cichella, Venanzio, Ronald Choe, S. Bilal Mehdi, Enric Xargay, Naira Hovakimyan, **Vladimir Dobrokhodov**, **Isaac Kaminer**. Trajectory Generation and Collision Avoidance for Safe Operation of Cooperating UAVs. *AIAA Guidance, Navigation, and Control Conference 2014 - SciTech Forum and Exposition 2014.* National Harbor, MD: January 13-17, 2014.
Abstract: This paper presents an integrated approach for trajectory generation and time coordination for multiple vehicles, combined with collision avoidance. Pythagorean Hodograph B'ezier curves are used to generate desired feasible trajectories that satisfy the dynamic constraints of the vehicles, and guarantee spatial separation between the paths for safe operation. Time coordination ensures that the temporal requirements of the mission are met. Collision avoidance with dynamic obstacles is achieved by properly adjusting the speed profiles of the vehicles along the corresponding paths. A simulation scenario is presented where three quadrotors are coordinating their positions along pre-computed paths, while at the same time avoiding moving objects. The results show that the integrated approach achieves time coordination along feasible paths, and that the collision avoidance algorithm allows for safe operation in the presence of moving obstacles.

Hewgley, Charles W., **Roberto Cristi**, and **Oleg A. Yakimenko**. "Visual Pose Estimation for Shipboard Landing of Autonomous Parafoils." *Proceedings of the 2014 IEEE/ION Position, Location and Navigation Symposium, PLANS 2014. Monterey, CA, United States May 5-8, 2014, p. 1301-1308.*
Abstract: This paper outlines an investigation into the use of a simple, focal-plane imaging sensor for guidance of an autonomous parafoil system for approach and landing on a moving platform such as a ship underway. The perspective-projective transformation between an object in a three-dimensional world and an image on a twodimensional plane is analyzed and then formulated using a homogeneous coordinate system. The estimation problem is addressed; specifically, the challenge of dealing with the out-of-frame condition due to parafoil oscillation as it approaches the target. A dual-mode Kalman estimation-scheme is proposed that suspends measurement when the target is out-of-frame, and incorporates a two-view measurement when the target reenters the frame.

Keller, James, Dinesh Thakur, Vladimir Dobrokhodov, Kevin Jones, **Maxim Likhachev**, Jean Gallier, Isaac Kaminer, and Vijay Kumar. "Coordinated commencement of Pre-Planned Routes for Fixed-Wing UAS Starting from Arbitrary Locations-A Near Real-Time Solution." *2014 International Conference on Unmanned Aircraft Systems, ICUAS 2014 - Conference Proceedings*. Orlando, FL: May 27-30. 2014. p. 552-561.
Abstract: Coordinated time optimal path planning and trajectory management algorithms for air vehicles depend on precise simultaneous mission commencement by all agents. Ground-based and rotary-wing aerial vehicles can be staged at their mission initial conditions until a mission is commenced but fixed-wing aerial vehicles, which must maintain a minimum forward airspeed at all times, can only be positioned approximately. A computationally simple algorithm for these vehicles that determines simultaneous arrival paths from arbitrary starting points is presented. The algorithm is based on planar B-spline curves so that fully defined feasible trajectories can be quickly determined, compactly encoded, and precisely executed.

Nissen, Mark E. and **W. David Price**. "Toward Computational Modeling of C2 for Teams of Autonomous Systems and People." ***19th International Command & Control Research & Technology Symposium (ICCRTS)***, Alexandria, VA. (June 2014).
http://hdl.handle.net/10945/43381

Abstract: The technological capabilities of autonomous systems (AS) continue to accelerate. Although AS are replacing people in many skilled mission domains and demanding environmental circumstances, people and machines have complementary capabilities, and integrated performance by AS and people working together can be superior to that of either AS or people working alone. We refer to this increasingly important phenomenon as Teams of Autonomous Systems and People (TASP), and we identify a plethora of open, command and control (C2) research, policy and decision making questions. Computational modeling and simulation offer unmatched yet largely unexplored potential to address C2 questions along these lines. The central problem is, this kind of C2 organization modeling and simulation capability has yet to be developed and demonstrated in the TASP domain. This is where our ongoing research project begins to make an important contribution. In this article, we motivate and introduce such TASP research, and we provide an overview of the computational environment used to model and simulate TASP C2 organizations and phenomena. We follow in turn with an approach to characterizing a matrix of diverse TASP C2 contexts, as well as a strategy for specifying, tailoring and using this computational environment to conduct experiments to examine such contexts. We conclude then by summarizing our agenda for continued research along these lines.

Thulasiraman, Preetha, Grace A. Clark, and **Timothy M. Beach**. "Mobility Estimation Using an Extended Kalman Filter for Unmanned Ground Vehicle Networks." ***2014 IEEE International Inter-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support, CogSIMA 2014***. San Antonio, TX, March 3-6, 2014, p. 223-229.

Abstract: An ad hoc unmanned ground vehicle (UGV) network operates as an intermittently connected mobile delay tolerant network (DTN). In this paper, we develop a mobility estimation algorithm that can be coupled with a cooperative communication routing algorithm to provide a basis for real time path planning in UGV-DTNs. A Gauss-Markov state space model is used for the node dynamics. The nonlinear measurement signals are constant-power RSSI (Received Signal Strength Indicator) signals transmitted from fixed-position base stations. An extended Kalman filter (EKF) is derived for estimating the position, velocity and acceleration of aUGV node in a two-dimensional spatial grid environment. We use Matlab to simulate a single mobile node traveling along a trajectory that includes abrupt maneuvers. Estimation performance is measured using zero-mean whiteness tests on the innovations sequences, root mean square error (RSME) of the state estimates, weighted sum squared residuals (WSSRs), and the posterior Cramer-Rao lower bound (PCRLB). Under these performance indices, we demonstrate that the mobility estimation algorithm performs effectively.

Thulasiraman, Preetha, and **Yavuz Sagir**. "Dydnamic Bandwidth Provisioning using Markov Chain Base RSVP for Unmanned Ground Networks." ***2014 IEEE International Inter-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support, CogSIMA 2014***. San Antonio, TX, March 3-6, 2014, p. 130-136.

Abstract: An unmanned ground vehicle (UGV) network operates as an intermittently connected system, distributed over large geographic areas. The cooperative nature of a UGV network requires that bandwidth be allocated depending on necessity between individual UGV nodes. In this paper, we study the problem of dynamic bandwidth provisioning in a UGV network. Specifically, we integrate the use of a basic statistical model, known as the Markov chain with a widely known network reservation protocol known as the Resource Reservation Protocol (RSVP). The Markov chain is used to estimate future traffic demand along a path based on channel conditions. The Markov chain results are used as input to the RSVP which then allocates the required bandwidth along the path. Using a wireless network simulation platform called Qualnet, we show that the integrated Markov chain and RSVP algorithm provides higher bandwidth guarantees and better overall quality of service (QoS) when compared solely with using RSVP in wireless communication networks.

2013

Benton, Joshua E. and **Oleg A. Yakimenko**. "On Development of Autonomous HAHO Parafoil System for Targeted Payload Return." *22nd AIAA Aerodynamic Decelerator Systems (ADS) Conference 2013*.
Abstract: An autonomous HAHO (high altitude, high-opening) parafoil system design is presented as a solution to the final descent phase of an on-demand International Space Station (ISS) sample return concept. The system design is tailored to meet specific constraints defined by a larger study at NASA Ames Research Center, called SPQR (Small Payload Quick-Return). Building on previous work in small, autonomous parafoil systems development, a SPQR-compatible evolution of an existing advanced parafoil delivery system is designed, built, and test-flown deployed from unmanned air vehicles and high-altitude balloons. Results of the preliminary tests of the original and SPQR-compatible systems are presented, and applicability of the test article to actual spaceflight conditions is discussed.

Brewer, Scott S. "The Use of Unmanned Systems in Law Enforcement." **AUVSI Unmanned Systems 2013**. Vol. 2. Washington, DC. August 12-15, 2013. p. 1353-1356.

Carpin, Stefano, **Timothy H. Chung**, and Brian M. Sadler. "Theoretical Foundations of High-Speed Robot Team Depolment." *2013 IEEE International Conference on Robotics and Automation, ICRA 2013*. Karlsruhe, Germany: May 6-10, 2013.
Abstract: n this paper we study the multi-robot deployment problem under hard temporal constraints. After proposing a model for this task, we consider the simplest deployment algorithm and we analyze the relationship between three fundamental parameters, the temporal deadline, the probability of success, and the number of robots. Because an exact analysis of even the simplest algorithm is computationally intractable, we derive an approximate bound leading to performance curves useful to answer design questions (how many robots are needed to get a certain performance guarantee?) or analysis questions (what is the probability of success given a certain deadline and number of robots?) Simulations show that the bounds are sharp and provide a useful tool to predict team deployment performance and tradeoffs.

Casey, Robert T., **Mark Karpenko**, Renwick Curry, and Gabriel H. Elkaim. "Attitude Representation and Kinematic Propagation for Low-cost UAVs." *2013 AIAA Guidance, Navigation, and Control (GNC) Conference*. August 19, 2013 - August 22, 2013.
Abstract: Complementary filter-based algorithms for attitude estimation seek to minimize the short-comings associated with the low-cost MEMS sensors and low-power embedded processors that are frequently used in unmanned aerial vehicles. This paper explores the performance impact of three different ingredients for attitude estimation within the complementary filter framework: 1) kinematic propagation, 2) attitude representation, and 3) the assumptions on the behavior of the angular rate vector between samples. Forward Euler integration and matrix exponential propagation methods are compared within several attitude representations, namely the direction cosine matrix (DCM), quaternion, Euler angle, and the angle-axis schemes. Assumptions of constant, linear, and quadratic angular velocities between samples are also examined. The resulting algorithms are evaluated from the points of view of accuracy, computational load, and noise response. Tests using analytic inputs as well as real data within the framework of the SLUGS autopilot are performed to evaluate algorithm performance. The results of the experiments indicate that by combining matrix exponential propagation with a quaternion representation of attitude high accuracy can be obtained with a standard processor.

Choe, Ronald, Venazio Cichella, Enric Xargay, Naira Hovakimyan, Anna C. Trujillo, and **Isaac Kaminer**. "A Trajectory-generation Framework for Time-critical Cooperative Missions." *AIAA Infotech at Aerospace (I at A) Conference 2013* August 19, 2013 - August 22, 2013
Abstract: This paper introduces a heuristic planar trajectory-generation framework for multiple vehicles. Desired feasible trajectories are generated using Pythagorean Hodograph Bezier curves that satisfy the dynamic constraints of the vehicles, and guarantee spatial separation between the paths for safe operation. It is shown that the trajectory generation framework can be cast into a constrained optimization problem where a set of (sub)optimal desired trajectories are obtained by minimizing a cost function. To show the efficiency of the algorithm, a simulation example is given, where three fixed-wing Unmanned Aerial Vehicles are following and coordinating along feasible trajectories that are generated by the algorithm.

Chung, Timothy H., **Kevin D. Jones**, **Michael A. Day**, **Marianna Jones**, and **Michael Clement**. "50 vs. 50 by 2015: Swarm vs. Swarm UAV Live-fly Competition at the Naval Postgraduate School." Volume 2. *AUVSI Unmanned Systems 2013*. Washington, DC: August 12-15, 2013. p. 1792-1811.
Abstract: Aerial Combat Swarms is a swarm vs. swarm UAV live-fly competition, designed to inspire new concepts of operations and illuminate new tactics in unmanned systems employment, specifically in the swarm and counter-swarm robotics arenas. The competition scenario involves a tournament of "battles" where in each such battle two teams comprising many autonomous aerial robots vie for air superiority while simultaneously defending a high value unit on the ground and/or attacking that of the opponent's. The vision for the inaugural grand challenge event is for 50 vs. 50 UAVs by the year 2015. The Aerial Combat Swarms competition further serves as an innovation testbed, providing the infrastructure and open architecture interface definitions for hardware/software/network connections between UAVs, ground command stations, observers, and the "Arbiter," which serves as an "autonomous referee." An additional element includes specifications for operating in a virtual battle arena for modeling and simulation experiments and hardware-in-the-loop flight validation. The overarching open design enables participants to leverage existing technologies available from the Aerial Combat Swarms open source community. The ambitious grand challenge competition effort described in this paper presents a novel and unique opportunity to explore advanced tactics for robotic swarms. Perhaps more increasingly and operationally relevant, this competition actively accelerates future concepts for also engaging and defeating adversarial unmanned systems.

Cichella, Venanzio, Ronald Choe, S. Bilal Mehdi, Enric Xargay, Naira Hovakimyan, **Isaac Kaminer**, and **Vladimir Dobrokhodov**. "A 3D Path-following Approach for a Multirotor UAV on SO(3). *2nd IFAC Workshop on Research, Education and Development of Unmanned Aerial Systems, REDUAS 2013 – Proceedings*. Compiegne, France, November 20-23, 2013. P. 13-18.
Abstract: This paper presents a path-following control law that enables a multirotor, equipped with an autopilot tracking angular rates and thrust reference commands, to converge to and follow a three-dimensional path. The approach is based on the Special Orthogonal group SO(3) and allows for independent adjustment of the vehicle's speed profile in order to satisfy desired temporal specifications. Simulation results illustrate the efficacy of the proposed path-following control law.

Cichella, Venanzio, **Isaac Kaminer**, **Vladimir Dobrokhodov** and Naira Hovakimyan. "Cooperative Vision Based Tracking of Multiple UAVs." *AIAA Guidance, Navigation, and Control (GNC) Conference, 2013*. August 19-22, 2013.
Abstract: This paper considers the problem of Cooperative Vision Based Tracking of a ground target by a fleet of multiple UAVs. The objective of this work is to present a decentralized control algorithm that enables multiple cooperative vehicles to maintain a horizontal orbital path around the target, while coordinating their space separation. A typical scenario involves multiple aerial surveillance UAVs which are required to monitor a ground object by orbiting around it (target tracking), while maintaining a desired phase shift (coordination). To solve the tracking problem, the angular velocity of each vehicle is used as control input, while the ground speeds are

adjusted to ensure coordination. The paper provides a Lyapunov-based solution that guarantees exponential convergence properties of the tracking and distributed time-coordination algorithms. A rigorous proof based on Lyapunov analysis, as well as flight test results demonstrate the effectiveness of the proposed approach.

Cosby, J Alan, Yuri B. Shtessel, and **Alex Bordetsky**. "Retaining Connectivity in Multi-task Communications Network with Multiple Agents: Connectability Theory Approach." ***2013 American Control Conference, ACC 2013***. June 17-19, 2013, Washington, DC. Institute of Electrical and Electronics Engineers Inc., Piscataway, NJ, p. 2745-2750.
Abstract: Practical retention of mobile ad hoc network communications via connectability theory is presented and compared to predictive modeling techniques. Network communication disruptions is prevented by driving relay agents to computed waypoints using sliding mode and LQ control, or using predictive modeling to optimally control relay agents. The connectability matrix is used to determine where future node isolation will occur. This paper expands the connectability matrix concept into connectability theory to not only predict node isolation, but to directly compute the waypoints for relay agents. The existing methods of computing waypoints, of controlling robotic routers to form so called network bridges, and the outcome of predictive modeling are shown to be special cases of the proposed connectability theory. Also, case studies and simulations are presented to show this connectability theory's utility in various network configurations.

Dobrokhodov, Vladimir, **Kevin Jones**, and **Isaac Kaminer**. "Rapid Flight Control Prototyping-Steps Toward Cooperative Mission-oriented Capabilities." ***Proceedings of the American Control Conference 2013 American Control Conference, ACC 2013***. Washington, DC June 17-19, 2013, Institute of Electrical and Electronics Engineers Inc., Piscataway, NJ, p. 680-685.
Abstract: The paper describes the latest advancements in the development of the Rapid Flight Control Prototyping system that were motivated primarily by the need to enable cooperative missions of multiple unmanned aerial vehicles and to enhance the capabilities of human operators to design and oversee the collaborative behaviors of multiple heterogeneous UAVs. The evolution of the system is driven by the mission level objectives and supported on one hand by the progress in miniature sensors, computational power, communication and portable energy technologies and on the other hand by the advanced capabilities of embedded control and communication-oriented software. As a result the developed system enables rapid design, onboard integration and in-flight verification of multiple UAV collaborative concepts that seemed impossible just a couple of years ago. Advantages of the designed system are illustrated by a couple of scenarios that were recently developed and verified in flight by multiple cooperating UAVs. The paper concentrates on presenting the motivation and the conceptual design ideas which drive the evolution of the flight prototyping platform.

Dono, Thomas F. and **Timothy H. Chung**. "Optimzed Transit Planning and Landing of Aerial Robotic Swarms." ***2013 IEEE International Conference on Robotics and Automation, ICRA 2013***. Karlsruhe, Germany. May 6-10, 2013. p. 1843-1850.
Abstract: This research explores the efficient and safe landing and recovery of a swarm of unmanned aerial vehicles (UAVs). The presented work involves the use of an overarching (centralized) airspace optimization model, formulated analytically as a network-based model with side constraints describing a time-expanded network model of the terminal airspace in which the UAVs navigate to one or more (possibly moving) landing zones. This model generates optimal paths in a centralized manner such that the UAVs are properly sequenced into the landing areas. The network-based model is 'grown' using agent-based simulation with simple flocking rules. Relevant measures of performance include, e.g., the total time necessary to land the swarm. Extensive simulation studies and sensitivity analyses are conducted to demonstrate the relative effectiveness of the proposed approaches.

Edwards, Christopher, Prathyush P. Memon, Yuri Shtessel, and **Alexander Bordetsky**. "On Connectivity Preservation in Mobile Wireless Multi-agent/node Mesh Networks." ***2013 1st American Control Conference, ACC 2013***. June 17-19, 2013 Washington, DC. Institute of Electrical and Electronics Engineers Inc., Piscataway, NJ p. 5881-5886.

Abstract: The paper considers the development of a mission planning system for a so-called 'non-cooperative' multi-agent network. The network comprises two classes of agent: primary mission agents and relay agents. The primary mission agents have predefined tasks to execute and operate autonomously within the field of operation. Although these agents operate independently, from a mission planning perspective the base station is required to maintain contact. In order to ensure this, relay agents are employed under the direct command of the base station with the objective of maintaining connectivity. This paper proposes an architecture to control the relay agents in such a way that connectivity, as measured in terms of the Fiedler eigenvalue, is maximized subject to the cost of moving the relay agents. A model predictive control-like layer is used to generate a set of way-points to position the relay agents at specific places at specific instances of time to maximize connectivity. These way-points are then converted into continuous time paths for the relay agents to follow. A low level sliding mode controller implemented on each relay agent ensures that the proposed path is followed in a robust fashion.

Fahroo, Fariba and **I. Michael Ross**. "Enhancing the Practical Agility of UAVs via Pseudospectral Optimal Control." ***Lecture Notes in Control and Information Sciences***, v. 444. Berlin: Springer, 2013, p. 1-30.

Abstract: UAVs have the capability to perform maneuvers that would otherwise be unrealistic to do in an inhabited craft due to human limitations of both response time as well as comfort or black-out limits. Given this expansion of its operational envelope, a natural question to ask is on the design of new maneuvers for UAVs that serve the needs of the mission. One of these needs is a rapid response time. In this context, we explore the design of a minimum-time velocity reversal maneuver for a fixed-wing UAV. Pseudospectral optimal control theory is used to address this problem. We discuss a wide-range of issues from theory to flight implementation. We show that these issues are interdependent and explore key convergence results that are critical for a successful flight. Results for a MONARC UAV are used to illustrate the close connection between theory and practice.

Feng, Lin Ping, Yu Qiang Wu, Shuang Pan and Xibin Wang. "FastSLAM Algorithm for Uninhabited Flying Vehicle." ***2013 International Conference on Precision Mechanical Instruments and Measurement Technology, ICPMIMT 2013*** May 25-26, 2013 Shenyang, Liaoning, China, p. 3596-3599.

Abstract: For uninhabited flying vehicle, it is a key prerequisite of truly autonomous mobile vehicles to simultaneously localize and accurately map its surroundings. Kalman filter-based algorithms require time quadratic in the number of landmarks to incorporate each sensor observation. This paper presents an algorithm so called FastSLAM that recursively estimates the full posterior distribution over robot pose and landmark locations, but scales logarithmically with the number of landmarks in the map. FastSLAM factors the posterior into a product of conditional landmark distributions and a distribution over UAV paths. The algorithm has been tested in UAV environments. Experimental results demonstrate the advantages and disadvantages of the FastSLAM algorithm for UAV.

Harada, Masanori, Hideyuki Nagata, and **Kevin Bollino**. "Tracking Control of a Single Coaxial Rotor UAV using Dynamic Inversion." ***AIAA Guidance, Navigation, and Control (GNC) Conference***. August 19-22, 2013.

Abstract: This paper investigates the application of nonlinear dynamic inversion (DI) control to the experimental flight of a Single Coaxial Rotor (SCR) Unmanned Aerial Vehicle (UAV) conducted in the indoor flight facility of the National Defense Academy (NDA) of Japan. The DI controller is constructed from a nonlinear dynamical model of the SCR UAV including a stabilizer bar effect. Feasibility of the approach is verified by numerical simulation before the actual flight experiment.

Additionally, the DI controller is used for hovering flight, Figure-L maneuvers, and obstacle avoidance maneuvers. Experimental results validate the numerical simulations of the DI controller indicating accurate results within an expected tolerance.

Harada, Masanori, Hideyuki Nagata, Johan Simond, and **Kevin Bollino**. "Optimal Trajectory Generation and Tracking Control of a Single Coaxial Rotor UAV." ***AIAA Guidance, Navigation, and Control (GNC) Conference 2013*** August 19-22, 2013.
Abstract: This paper investigates the application of optimal control to the experimental flight of a Single Coaxial Rotor (SCR) Unmanned Aerial Vehicle (UAV) conducted in the indoor flight facility of the National Defense Academy (NDA) of Japan. The optimal control problem is prescribed as a minimum-length obstacle avoidance maneuver of the SCR UAV and it is solved using pseudospectral (PS) optimal control theory. The optimal trajectory is computed offline as a kinematic path-planning problem and then provided to the real UAV system as reference input commands. While only preliminary studies have been conducted at NDA, the results provide nominal tracking performance and validate the feasibility of the approach.

Horner, Douglas and **Geoffrey Xie**. "Data-Driven Acoustic Communication Modeling for Undersea Collaboration Navigation." ***OCEANS 2013 MTS/IEEE - San Diego: An Ocean in Common***. San Diego, CA: September 23-26, 2013.
Abstract: Feedback control of collaborative mobile systems requires assumptions with regards to wireless networking to bound system performance. Traditional assumptions include a physics-based signal propagation model which can be especially inaccurate in dynamic and cluttered communication environments. This paper addresses a data-driven approach for modeling signal strength. It presents local and global connectivity maps for providing greater resolution with respect to received signal strength over a bounded area. The approach may be particularly useful for enabling more flexible and robust multi-vehicle navigation.

Kragelund, Sean, **Vladimir Dobrokhodov**, **Aurelio Monarrez**, Michael Hurban, Curtis Kho. "Adaptive Speed Control for Autonomous Surface Vessels." ***OCEANS 2013 MTS/IEEE – San Diego Conference: An Ocean in Common***. September 23-26, 2013.
Abstract: The paper addresses the problem of speed control for the SeaFox unmanned surface vessel (USV). This small, versatile robotic platform can operate over a wide range of speeds, making it attractive for a number of scientific, commercial, and naval applications. This versatility, however, comes at a price. The vessel operates in displacement mode at low speeds and operates in planing mode at high speeds. These two regimes are connected via a highly unstable transition mode, where steady state operation is not possible, making autonomous operations challenging. Speed following is one of the key challenges in automating this class of vessel, as this capability is adversely affected by (i) the inherently slow dynamic response of the propulsion system, (ii) significant variation of the vessel's hydrodynamics in three distinct operating modes, and (iii) significant coupling between these hydrodynamics and the propulsion force. This paper presents a comparative study of three adaptive control algorithms developed for speed-holding capability on the SeaFox USV: (i) classical PID control with gain scheduling, (ii) model reference adaptive control, and (iii) L1 adaptive control. Beginning with a description of the system identification experiments that informed our understanding of the open-loop plant dynamics, this paper proceeds through controller design and simulation, and presents results from open ocean sea trials. The experimental results provide a basis for an objective comparison of each algorithm's speed following performance and explicitly highlight the benefits of adaptive controllers.

McLauchlan, Lifford, Mehrube Mehrubeoglu, and Jayson Durham. "Problem Based Learning Through Modeling and Simulation of Unmanned Vehicles." ***120th ASEE Annual Conference and Exposition, 2013*** June 23, 2013 - June 26, 2013.
Abstract: Problem based learning has been shown to increase student excitement and attention which will increase student understanding of course material and concepts. With the high cost of large scale underwater, land and air vehicles, the use of modeling and simulation capabilities

becomes more important for university programs. Autonomous Unmanned Vehicle (AUV) Workbench was developed at the Naval Postgraduate School as a modeling and simulation environment to enable physics based real time simulation of autonomous vehicles, such as unmanned surface vehicles (USV), unmanned underwater vehicles (UUV) and unmanned aerial vehicles (UAV). Vehicle missions can also be replayed for further study. 1-5 At Texas A&M University-Kingsville and Texas A&M University-Corpus Christi, a lab exercise for multiple vehicles has been created for the students to illustrate waypoint navigation and control for unmanned surface and air vehicles. Two versions were developed, an abbreviated version for the freshman students in introductory courses at the two universities, and a more extensive one for the senior students at Texas A&M University-Kingsville. By enabling a visual representation of the effects of the control algorithm in the simulated actions, freshman students gain a larger scale understanding of more advanced theoretical concepts that they will learn during their junior and senior years, thereby allowing the students to gain insights into how the theory in various undergraduate classes may be used in applications. The seniors in the undergraduate linear controls course at Texas A&M University-Kingsville can investigate different controllers such as Proportional Integral Derivative (PID) in the AUV Workbench environment, thus enabling students to see how the control of the vehicle is affected as the controller is varied. System-of-Systems Engineering (SOSE) necessitates an increased sharing and interoperability of information. In support of mission-driven SOSE, a critical need exists to support science and technology research and education that provide increased coordination of activities supporting mission driven SOSE. The AUV Workbench simulation environment enhances the student's understanding of modeling systems which in turn helps to continue addressing this need at the university educational level. American Society of Engineering Education, 2013.

McMullen, Eric L., B. Shane Grass, **Quinn Kennedy**, **Joseph Sullivan**, and Ji Hyun Yang. "Effects of UAV Supervisory Control on F-18 Formation Flight Performance in a Simulator Environment." ***AIAA Modeling and Simulation Technologies (MST) Conference***, August 19-22, 2013. Abstract: No known studies have been conducted to assess the impact of distractions in a military aviation environment. Constant advances in technology and increasing cockpit workload, particularly the shift from two-seat to single-seat fighters to save money and reduce the risk to life, push the limits of human mental capacity. With the rapid increase in the use of unmanned aerial vehicles (UAVs) over the past decade, there is an interest within the military aviation community in integrating this capability into the cockpit to expand the firepower, range, or options. This study compared the effects of two different secondary tasks on the formation flight performance. The two secondary tasks corresponded to the traditional secondary task of target prosecution using an electro-optical forward looking infrared (FLIR) pod and a futuristic secondary task involving unmanned aerial vehicle (UAV) supervisory command and control. A total of 34 military aviators, all U.S. naval aviators with the exception of one U.S. Marine Corps pilot, with varying levels of flight experience volunteered to fly three 5-min F-18 simulator sessions in close formation while presented with two secondary tasks; the effects of these distractions on the following distance performance were evaluated. The simulators used for this experiment were high fidelity F- 18C/D/E/F tactical operational flight trainers (TOFT), which are currently used to conduct training and maintain the proficiency of active duty Navy and Marine Corps pilots. The results provided clear indications that a futuristic task such as a UAV supervisory interface is significantly more challenging than a traditional task and that both secondary tasks increased the average mean following distance and variance compared to the undistracted flying baseline scenario. Additionally, we found no evidence that increased flight experience (total flight hours) significantly improved the performance of the primary task of formation flight when the participants were presented with a distraction. The integration of a futuristic secondary task (UAV supervisory interface) into the simulator cockpit was successful and well received by the participants, but requires further development to be a viable combat multiplier. The knowledge gained from the analysis of the performance differences could contribute to not only improved crew resource management and pilot workload balancing, but also better flight safety through the modification of flight procedures based on the known effects of distractions in the cockpit.

Ohleger, Mike, **Geoffrey G. Xie** and **John H. Gibson**. "Extending UAV Video Dissemination Via Seamless Handover: A Proof of Concept Evaluation of the IEEE 802.21 Standard." ***Proceedings of the 46th Annual Hawaii International Conference on System Sciences, HICSS 2013***, p. 5106-5114.
Abstract: With an increase in the amount of daily UAV flights and the number of Digital Video Broadcast Return Channel Satellite (DVBRCS) suites in theater, the demand for a constant access to the operational picture has also increased. Until recently, there have been limited solutions for enlarging the access to DVBRCS video feeds. With the advent of wireless technologies, such as WiFi, WiMAX, 3G, and LTE, the opportunity to extend the access should be considered. In particular, the IEEE 802.21 standard, known as Media Independent Handover services, could be the solution to not only extending the network beyond the reaches of the forward operating bases, but allowing for no loss in connectivity, due to its ability to conduct seamless handovers, while on the move. In this paper, we present a proof of concept evaluation of the compatibility of the IEEE 802.21 standard and the DVBRCS system, using an open source implementation. We find the standard to be a viable solution for extending the services of DVBRCS to forward deployed units via wireless networks.

Severinghaus, Robert, **Murali Tummala**, and **John McEachen**. "Availability of Ad Hoc Wireless Networks of Unmanned Ground Vehicles with Group Mobility." ***Proceedings of the 46th Annual Hawaii International Conference on System Sciences, HICSS 2013***, p. 5097-5105.
Abstract: Maintaining network availability is critical to teams of mobile unmanned ground vehicles (UGV) and requires a realistic mobility model for accurate calculation. Mobile ad-hoc networks (MANET) have been extensively studied using the random waypoint mobility model. But to more exactly model teams of unmanned systems and their relative positions, we provide a model of communication states using the reference point group mobility (RPGM) model. We consider the unique requirements of unmanned systems as having two data rate thresholds. The analysis includes log-normal shadowing and determines the probability that each team member has received power above a threshold while moving. The analysis results allow computation of network availability in different topologies. We conclude with a discussion of various methods for overcoming shadowing and small-scale fading effects in order to maintain high network availability of MANETs.

Shakarian, Paulo, Gerardo I. Simari, and **Robert Schroeder**. "MANCaLog: A Logic for Multi-Attribute Network Cascades." Volume 2. *12th International Conference on Autonomous Agents and Multiagent Systems 2013, AAMAS 2013*. Saint Paul, MN, May 6-10, 2013. P. 1175-1176.

Stevens, Timothy and **Timonthy H. Chung**. "Autonomous Search and Counter-Targeting Using Levy Search Models." **2013 IEEE International Conference on Robotics and Automation, ICRA 2013**. Karlsruhe, Germany, May 6-10. 2013. p. 3953-3960.
Abstract: In this study, we explore the use of nondeterministic search trajectories to accomplish a two-fold mission of mobile robot search for a stationary target while avoiding counter-targeting by the adversary throughout the operation. We analyze the characteristics associated with a Levy distribution of search leg lengths to generate appropriate randomized search trajectories. We discuss the alteration of the probability distribution of the Levy search as a result of the method utilized to best address the presence of the bounded search area and confine the searcher within its boundaries. Through regression analysis of simulation results, we determine expressions for the coverage ratio evolution of the modified Levy search strategy and the distribution on time to target detection TD, from which we are able to calculate the expected time, E[TD], to detect the target uniformly distributed within the search area. We assert assumptions regarding the adversary's detection and tracking abilities to estimate the expected time, E[TC], required for it to counter target the searcher. From these two expected times, we construct a novel probabilistic mission performance metric that measures the likelihood that the searcher will detect the target before it is counter targeted itself.

Streenan, Andrew and **Noel E. Du Toit**. "Diver Relative AUV Navigation for Joint Human-Robot Operations." *OCEANS 2013 MTS/IEEE - San Diego: An Ocean in Common*. San Diego, CA, September 23-26, 2013.
Abstract: A novel application for Autonomous Underwater Vehicles (AUVs) is considered here: a robotic diver assistant that enables close-quarters robotic operations with human divers. A robotic diver assistant has the potential to improve the efficiency, effectiveness and safety of diver operations. The robot diver assistant must share the operating environment with human divers: the robot must navigate relative to the environment to reach a specified site location (along with moving divers), then maneuver among the mostly static divers as they perform their tasks on location. Strategies for navigating among divers while ensuring diver safety are presented in this paper. A reactive strategy, based on potential fields, is investigated with a deliberative approach that accounts for process and environmental disturbances, as well as measurement noise. The deliberative approach is based on the Partially Closed-Loop Receding Horizon Control method. Accounting for such uncertainties is required for close-quarter operations due to the challenges associated with underwater navigation and sensing.

Thakur, Dinesh, Maxim Likhachev, James Keller, Vijay Kumar, **Vladimir Dobrokhodov**, **Kevin Jones**, **Jeff Wurz**, and **Isaac Kaminer**. "Planning for Opportunistic Surveillance with Multiple Robots." *IROS 2013: New Horizon, Conference Digest - 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems*. Tokyo, Japan: November 3-8, 2013.
Abstract: We are interested in the multiple robot surveillance problem where robots must allocate waypoints to be visited among themselves and plan paths through different waypoints while avoiding obstacles. Furthermore, the robots are allocated specific times to reach their respective goal locations and as a result they have to decide which robots have to visit which waypoints. Such a problem has the challenge of computing the allocation of waypoints across robots, ordering for these waypoints and dynamical feasibility of the paths between waypoints. We present an algorithm that runs a series of graph searches to solve the problem and provide theoretical analysis that our approach yields an optimal solution. We present simulated results as well as experiments on two UAVs that validate the capability of our algorithm. For a single robot, we can solve instances having 10-15 waypoints and for multiple robots, instances having five robots and 10 waypoints can be solved.

Trassare, Samuel T., **Robert Beverly**, and **David Alderson**. "A Technique for Network Topology Deception." *Proceedings - 2013 IEEE Military Communications Conference, MILCOM 2013*. San Diego, CA: November 18-20, 2013. p. 1795-1800.
Abstract: Civilian and military networks are continually probed for vulnerabilities. Cyber criminals, and autonomous botnets under their control, regularly scan networks in search of vulnerable systems to co-opt. Military and more sophisticated adversaries may also scan and map networks as part of reconnaissance and intelligence gathering. This paper focuses on adversaries attempting to map a network's infrastructure, i.e., the critical routers and links supporting a network. We develop a novel methodology, rooted in principles of military deception, for deceiving a malicious traceroute probe and influencing the structure of the network as inferred by a mapping adversary. Our Linux-based implementation runs as a kernel module at a border router to present a deceptive external topology. We construct a proof-of-concept test network to show that a remote adversary using traceroute to map a defended network can be presented with a false topology of the defender's choice.

Weiss, Joshua D. and **Noel E. Du Noit**. "Real-time Dynamic Model Learning and Adaptation for Underwater Vehicles." *OCEANS MTS/IEEE - San Diego: Ocean Common*. San Diego, CA: September 23-26, 2013.
Abstract: Precision control of Unmanned Underwater Vehicles (UUVs) requires accurate knowledge of the dynamic characteristics of the vehicles. However, developing such models are time and resource intensive. The problem is further exacerbated by the sensitivity of the dynamic model to vehicle configuration. This is particularly true for hovering-class UUVs since sensor payloads are often mounted outside the vehicle body. This paper presents a method to learn a

dynamic model for such a hovering-class UUV in real time from motion and position measurements. System identification techniques are employed to estimate equations of motion coefficients. Initial results on the approach are presented.

Yang, Ji Hyun , Marek Kapolka, and **Timothy H. Chung**. "Autonomy Balancing in a Manned-unmanned Teaming (MUT) Swarm Attack." ***Advances in Intelligent Systems and Computing***, v. 208. Berlin: Springer, 2013. Presented Papers from the 1st International Conference on Robot Intelligence Technology and Applications, RiTA 2012, p. 561-569.

Abstract: In this paper, we describe a framework for developing an interactive feedback model of manned-unmanned teaming (MUT) operational mode selections for a broad spectrum of unmanned vehicle (UV) autonomy levels. Though the highest autonomy levels are within reach as technology continues to advance, lower level autonomy or human manual control will still be needed depending on mission scenarios and dynamic situations. Understanding when and how we change the autonomy level of MUT is critical to ensure system safety and to maximize system performance. Thus, we propose to integrate feedback from various human state variables (i.e., physiological and behavioral signals such as heart rate, skin conductance level, and postures) for estimating human workload and interest level and key task performance measures (accuracy and speed for assigned missions, task interaction) into MUT systems so that the MUT adapts its mode automatically as needed. We developed RESCHU-SA (Research Environment for Supervisory Control of Heterogeneous Unmanned Vehicles Swarm Attacks), a modified version of the RESCHU simulator originally developed at MIT. We designed a human-in-the-loop experiment to collect baseline data for varying levels of autonomy using the RESCHU-SA along with a physiological sensor BioHarness. Different levels of autonomy include 1) high level autonomy using an auction algorithm or nearest-neighbor assignment algorithm, 2) low level autonomy using manual assignment, and 3) interactive autonomy which allows operators to change between high and low autonomy level. The purpose of the research is to investigate the level of autonomy that should be given to unmanned vehicles (UVs) to successfully complete a mission using a MUT in a swarm attack scenario.

2012

Andersson, Klas, **Kevin Jones**, **Vladimir Dobrokhodov**, **Isaac Kaminer**. "Thermal Highs and Pitfall Lows - Notes on the Journey to the First Cooperative Autonomous Soaring Flight." ***51st IEEE Conference on Decision and Control, CDC 2012***, p. 3392-3397.

Abstract: This paper discusses the development and flight testing of an algorithm for cooperative soaring by multiple autonomous gliders. Flight test results confirmed that the algorithm functioned as expected and that the gliders worked cooperatively to find and utilize the same updrafts during the test. However, the flight also indicated that the effectiveness of the strategy depends largely on the existing thermal conditions in combination with how restrictively the limits of separation between the cooperating gliders are set. To the best of the authors' knowledge this was the world's first cooperative autonomous thermal soaring flight.

Bachmann, Eric, **James Calusdian**, Eric Hodgson, and **Xiaoping Yun**. "In situ Heading Drift Correction for Human Position Tracking using Foot-mounted Inertial/magnetic Sensors." ***2012 IEEE International Conference on Robotics and Automation, ICRA 2012***, p. 5425-5430.

Abstract: This paper presents a heading drift correction method and experimental results for position tracking of human movement based on the use of foot-mounted inertial/magnetic sensor modules. A position tracking algorithm was previously developed, which incorporated a zero velocity update technique for correcting accelerometer drift. Previous experiments indicated the presence of a persistent heading drift in the estimated position. In this paper, a simple method

for correcting this drift is presented. The method requires the user to walk over a closed loop path with the foot-mounted sensor module. Assuming a constant sensor bias for this initial walk, the resulting position error is then used to accomplish an in situ correction for position estimates during future walks. Experimental results validate the effectiveness of the drift correction method and show a significant improvement in position tracking accuracy. Accuracy is determined based on the final position estimates following walks of 100 and 400 meters. Estimated distance traveled averages within 0.2% of actual distance traveled and distance from the actual position averages within 0.28% of actual distance traveled.

Braga, José, Anthony J. Healey, João Sousa. "Navigation Scheme for the LSTS SEACON Vehicles: Theory and Application." *3rd IFAC Workshop on Navigation, Guidance and Control of Underwater Vehicles, NGCUV 2012*, p. 69-75.
Abstract: Underwater Systems and Technology Laboratory (LSTS) vehicles used an Extended Kalman Filter (EKF) navigation scheme that considered global positioning system (GPS), longbaseline (LBL) and the propeller's angular velocity sensor readings information. Although an attitude, heading and reference system (AHRS) and a doppler velocity logger (DVL) sensors were available in the latest generation of vehicles, that information was not used in the original EKF algorithm. A new filter was designed that considers GPS, LBL, inertial measurement unit (IMU), AHRS and DVL data. This Navigation scheme, although supporting LBL data information, aims at a fully autonomous dead reckoning operation, relying only on "proprioceptive" sensors, since the next generation of LSTS LAUV Seacon vehicles will carry a high precision, low drift error rate IMU. This paper presents the theory involved in this EKF, as well as other preconditioning functions applied to extract good data from noisy sensor readings. Simulation and real mission results are presented to validate the approach.

Brutzman, Don, Robert McGhee, Duane Davis. "An Implemented Universal Mission Controller with Run Time Ethics Checking for Autonomous Unmanned Vehicles-A UUV Example." *2012 IEEE/OES Autonomous Underwater Vehicles, AUV 2012*.
Abstract: The authors have been involved for several decades in the development and testing of both remotely controlled and autonomous subsea and ground vehicles. This experience has led us to view autonomous mobile robot control problems from both a bottom up and a top down perspective. Specifically, in our work, we have developed and tested a three-level software architecture called Rational Behavior Model (RBM), in which a top (strategic) level mission control finite state machine (FSM) orders the rational execution, at an intermediate (tactical) level, of vehicle behaviors in such a way as to carry out a specified mission. This implementation experience and these principles have led us to believe that human-like intelligence and judgment are not required to achieve a useful operational capability in autonomous mobile robots. Furthermore, we are convinced that a primitive but useful type of robot ethical behavior can also be attained, even in hazardous or military environments, without invoking concepts of artificial intelligence. To support our views, we present a software invention called a mission execution engine (MEE), implemented in the Prolog logic programming language. This MEE can be shown to represent an extension of the idea of a universal Turing machine and is therefore well grounded in existing mathematical automata theory. We further show how human readable mission orders, also written in Prolog, can specialize an MEE to any desired mission control FSM. An important aspect of our work is that mission orders can be tested exhaustively in human executable form before being translated into robot executable form. This provides the kind of transparency and accountability needed for after action review of missions, and possible legal proceedings in case of loss of life or property resulting from errors in mission orders.

Buettner Jr., Raymond R. "The Impact of Multi-institutional Semi-structured Learning Environments (MISSLE)." *Proceedings - 2012 7th International Conference on System of Systems Engineering, SoSE 2012*, p. 309-313.
Abstract: A specific instance of the multi-institutional semi-structured learning environment (MISSLE) informing system construct is introduced and described. The description places an emphasis on aspects that have proven successful in accelerating new systems to the customer

and in the enhancement of systems for those participating in these collaborative learning events. Examples are provided that include unmanned/robotic systems, command and control systems, and surveillance/reconnaissance systems.

Chesi, Simone, Veronica Pellegrini, Qi Gong, **Roberto Cristi**, and **Marcello Romano**. "Automatic Mass Balancing for Small Three-axis Spacecraft Simulator Using Sliding Masses Only." ***ASTRODYNAMICS 2011 - Advances in the Astronautical Sciences: Proceedings of the AAS/AIAA Astrodynamics Specialist Conference***, p. 2547-2562.
Abstract: Small satellite spacecraft simulator is a very useful tool for developing, improving and verifying spacecraft attitude control algorithms. Accurate ground testing of spacecraft attitude dynamics and control requires a frictionless and space-like environment that can be simulated using spherical air bearing. The major issue using spherical air bearing is the minimization of the gravitational torque due to misalignment between the spacecraft center of mass and center of rotation. This paper introduces a novel automatic mass balancing technique that allows to drastically reduce the gravitational torque by a precise alignment of the center of mass and the center of rotation using sliding masses only. The automatic mass balancing method, is based on an adaptive dynamical nonlinear feedback control law that relocates, in real-time, the center of mass into the spacecraft simulator center of rotation. The control law derivation and simulation are performed, based on real parameters of CubeSat three-axis simulator of the Spacecraft Robotic and NanoSatellite Laboratory at the Naval Postgraduate School.

Clau, Sebastian, Stefan Brüggenwirth, Pierre Aurich, Axel Schulte, **Vladimir Dobrokhodov**, and **Isaac Kaminer**. "Design and Evaluation of a UAS Combining Cognitive Automation and Optimal Control." ***AIAA Infotech at Aerospace Conference and Exhibit 2012***.
Abstract: The University of the Bundeswehr Munich (UBM) and the Naval Postgraduate School (NPS) conduct cooperative research in the field of single operator UAV guidance and ISR payload control. For the first time cognitive automation and Optimal Control elements are combined to join high-level mission guidance with path planning and real-time path following. In this scope, the CoCAMPUS (Cooperative Cognitive Automation through Mathematically optimized Path-Following of UAVs) project is conducted to explore how to properly support a single operator in mission-guidance and flight-control to enhance the overall system performance, based on a simplified Air-Attack mission including static threats. The Cognitive System Architecture COSA[2] is used to implement cognitive automation behavior on the basis of explicit knowledge models, dynamically deriving implicit cost-functions, serving the purpose of path optimization.

Gulum, Taylan O., Ahmet Y. Erdogan, Tulay Yildirim, and **Phillip E. Pace**. "A Parameter Extraction Technique for FMCW Radar Signals using Wigner-Hough-Radon Transform." ***2012 IEEE Radar Conference: Ubiquitous Radar, RADARCON 2012*** - Conference Program, p. 0847-0852.
Abstract: An autonomous parameter extraction algorithm for frequency modulated continuous wave (FMCW) radar signals using Wigner-Ville Distribution (WVD)-Hough transform was investigated in [1] and extraction of polyphase radar modulation parameters using a Wigner-Ville distribution-Radon transform was investigated in [2]. The algorithm in [1] produced very dependable results with as low as -6 dB SNR levels, however some degradation has been observed below -6 dB SNR. The proposed approach in this study uses the WVD as a time-frequency (T-F) detection technique and combined Hough-Radon transform (HRT) to identify the parameters of the modulation. We showed that our algorithm can extract FMCW radar modulation parameters at low SNR levels, such as -9 dB, efficiently.

Harada, Masanori, Masataka Ito, Hideyuki Nagata, and **Kevin Bollino**. "Minimum-time Hover-to-hover Maneuver of a Single Coaxial Rotor UAV: Example and Experimental Results." ***AIAA Guidance, Navigation, and Control Conference 2012***.
Abstract: This paper investigates the application of optimal control results to the experimental flight of a Single Coaxial Rotor (SCR) Unmanned Aerial Vehicle (UAV) conducted in the indoor flight facility of the National Defense Academy of Japan (NDA). The optimal control problem is

prescribed as a minimum-time hover-to-hover maneuver of the SCR UAV and it is solved using pseudospectral (PS) optimal control theory. The computed optimal results are applied as open-loop commands to the real UAV system. Additionally, a PID control is used for hovering flight before and after the minimum-time maneuver. Preliminary experimental results demonstrate the feasibility of commanding the UAV with open-loop optimal solutions generated offline.

Horner, Douglas and Geoffrey Xie. "Undersea Acoustic Communication Maps for Collaborative Navigation." *2012 IEEE/OES Autonomous Underwater Vehicles, AUV 2012.*
Abstract: Communications play a key role in collaborative navigation algorithms. A better understanding of the ability to send and receive messages permits greater navigational flexibility and system robustness. This paper focuses on the building of an underwater acoustic communications map for collaborative navigation. The emphasis is in two areas- A local and global communications map. The local communications is defined with respect to a single destination reference point. Using a sample set of a priori signal to noise ratio acoustic modem data, Kriging techniques are used to create mean and variance map estimates. The global communications map is a compendium of local maps and is defined within a bounded survey space. Bayesian Inferencing is used for building the global map. It is based on REML parameter estimation of an anisotropic covariance function. The paper analyzes acoustic communication signal to noise datasets recently collected in Monterey Harbor, Monterey, CA and is used to demonstrate the above-described techniques.

Klein, Matthew A., Alexander S. Boxerbaum, Roger D. Quinn, Richard Harkins, and **Ravi Vaidyanathan**. "SeaDog: A Rugged Mobile Robot for Surf-zone Applications." *2012 4th IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechatronics, BioRob 2012*, p. 1335-1340. Abstract: Water and land mine detection performed on beaches and in turbulent surf-zone areas pose specific challenges to robot operation. A robot which is useful in the effort to disarm mined waterways must be capable of navigating rocky terrain, hard-packed wet sand and loose dry sand, and constantly changing underwater currents common to these environments. It is also preferable for them to be man-packable and have a large payload capacity for sensors. Studies of insect locomotion mechanisms, and their abstraction to specific movement principles, provides a framework for designing robots that can quickly adapt to varied terrain types. Based on recent success with beach environment autonomy and a new rugged waterproof robotic platform, we propose a new design that will fuse a range of insect-inspired passive mechanisms with active control strategies to seamlessly adapt to and traverse through a range of challenging environments both in and out of the water.

Lee, K., S. Lee, D. Lee, and Mathias Kölsch. "Odometry-Prefered Scan Matching Method." *9th International Conference on Ubiquitous Robots and Ambient Intelligence, URAI 2012*, p. 563-564,
Abstract: In this paper, we address the problem of estimating rigid body transformations in two-dimensional space. A new probabilistic weight function is proposed to find a solution closes to odometry information more preferably. The weight function is motivated by hypothesis that a solution of a scan matching problem which prefers odometry information may show better performance in terms of accuracy and convergence. Through the test with three real data sets, our hypothesis was confirmed.

Oleg, Yakimenko and **Timothy, Chung**. "Extending Autonomy Capabilities for Unmanned Systems with CRUSER." *28th Congress of the International Council of the Aeronautical Sciences 2012, ICAS 2012,* p. 3365-3370.
Abstract: The paper introduces a field experimentation program developed and maintained at NPS for almost a decade and its latest expansion, Consortium for Robotics and Unmanned Systems Education and Research. It also presents some of the successful developments accomplished within aforementioned initiatives, including indoor and outdoor platforms.

Schwamm, Riqui and Neil C. Rowe. "The Android Smartphone as an Inexpensive Sentry Ground Sensor." ***Unattended Ground, Sea, and Air Sensor Technologies and Applications XIV***, April 25, 2012 - April 26, 2012. Proceedings of SPIE - The International Society for Optical Engineering.

Abstract: A key challenge of sentry and monitoring duties is detection of approaching people in areas of little human traffic. We are exploring smartphones as easily available, easily portable, and less expensive alternatives to traditional military sensors for this task, where the sensors are already integrated into the package. We developed an application program for the Android smartphone that uses its sensors to detect people passing nearby; it takes their pictures for subsequent transmission to a central monitoring station. We experimented with the microphone, light sensor, vibration sensor, proximity sensor, orientation sensor, and magnetic sensor of the Android. We got best results with the microphone (looking for footsteps) and light sensor (looking for abrupt changes in light), and sometimes good results with the vibration sensor. We ran a variety of tests with subjects walking at various distances from the phone under different environmental conditions to measure limits on acceptable detection. We got best results by combining average loudness over a 200 millisecond period with a brightness threshold adjusted to the background brightness, and we set our phones to trigger pictures no more than twice a second. Subjects needed to be within ten feet of the phone for reliable triggering, and some surfaces gave poorer results. We primarily tested using the Motorola Atrix 4G (Android 2.3.4) and HTC Evo 4G (Android 2.3.3) and found only a few differences in performance running the same program, which we attribute to differences in the hardware. We also tested two older Android phones that had problems with crashing when running our program. Our results provide good guidance for when and where to use this approach to inexpensive sensing.

Xu, Nathan, Wei Kang, Guowei Cai, and Chen, Ben M. Chen. "Minimum-time Trajectory Planning for Helicopter UAVs Using Computational Dynamic Optimization." ***Proceedings 2012 IEEE International Conference on Systems, Man, and Cybernetics, SMC 2012***, p. 2732-2737.

Abstract: In this paper, we apply pseudospectral optimal control, a computational algorithm of dynamic optimization, to the problem of helicopter UAV for minimum-time trajectory planning in the presence of obstacles. The problem is formulated as a nonlinear optimal control subject to the dynamics and limitations of helicopter UAVs, in which the obstacles are formulated as inequality constraints by using p-norms. The dynamical system is defined by a set of fifteen states nonlinear differential equations developed for HeLion, a helicopter UAV constructed in National University of Singapore (NUS). The problem does not have an analytic solution. We numerically solve the problem using a pseudospectral method. Various terrain scenarios were tested, from a single obstacle to multiple obstacles. We found bifurcation points of minimum-time trajectories near obstacles. The bifurcation points and their relationship with the distance to the obstacle are analyzed.

Yau, Joses and **Timothy H. Chung**. "Search-theoretic and Ocean Models for Localizing Drifting Objects." ***25th IEEE/RSJ International Conference on Robotics and Intelligent Systems, IROS 2012***, p. 4749-4755.

Abstract: This paper investigates the combined use of ocean models, such as idealized surface current flows, and search models, including expanding area and discrete myopic search methods, to improve the probability of detecting a near-surface, drifting object over time. Enhanced search effectiveness is facilitated by the use of robotic search agents, such as a tactical unmanned aerial vehicle (UAV), leveraging simulation methods to inform the search process. The presented work investigates the impact of using naive vs. optimized search patterns on localizing a drifting object, including a surrogate ocean model using idealized flow with Weibull-distributed perturbations. Numerical studies and extensive analysis using different permutations of model parameters (including the relative speed of the drifting object, time late in the searcher's arrival to the search area, sensor sweep width, and duration of the search mission) identify the

significant factors affecting the overall probability of detection. Such insights enable further explorations using empirical datasets for specific oceanographic regions of interest.

2011

Blais, Curtis L. and Anders Alstad. "Coalition Battle Management Language (C-BML) Phase i Standard: Trial Use Findings and Next Steps." ***Fall Simulation Interoperability Workshop 2011, 2011 Fall SIW***, p. 7-14.
Abstract: The Coalition Battle Management Language (C-BML) is a common language for expressing and exchanging plans, orders, requests, and reports across command and control systems, modeling and simulation systems, and robotic systems. The Simulation Interoperability Standards Organization (SISO) has approved a Product Development Group (PDG) to generate a specification and guidelines document for the C-BML standard through a three-phase effort. Phase 1 specifies the underlying data model for the standard and provides preliminary building blocks for generation of C-BML expressions together with numerous examples of application of the standard. Phase 2 will specify a formal grammar governing generation of valid C-BML expressions. Phase 3 will specify a formal semantic model for C-BML. This paper identifies several of the organizations participating in a trial use of draft Phase 1 products, describes their intentions for trial use of the draft products, and provides some initial findings from trial use of the products. Findings from the trial use will inform finalization of the draft Phase 1 specifications in preparation for the start of a comment round on the product.

Calusdian, James, **Xiaoping Yun** and Eric Bachmann. "Adaptive-gain Complementary Filter of Inertial and Magnetic Data for Orientation Estimation." ***2011 IEEE International Conference on Robotics and Automation, ICRA 2011***, p. 1916-1922.
Abstract: Accurate estimation of orientation based on data from small low-cost strapdown inertial and magnetic sensors is often inaccurate during highly dynamic motion or when trying to track movements that include two or more periods characterized by significantly different frequencies. This paper presents a complementary filtering algorithm for estimating orientation based on inertial/magnetic sensor measurements. The algorithm takes advantage of the complementary nature of the information offered by high-frequency angular rate sensor data and low-frequency accelerometers and magnetometers. The filtering algorithm utilizes a single gain that can be adaptively adjusted to achieve satisfactory performance while tracking two or more different types of motion. An additional feature of our approach involves the simple estimation of the gyro bias during periods exhibiting low dynamics and its subsequent use to correct the instantaneous gyro measurements. Simulation and experimental results are presented that demonstrate the performance of the algorithm during slow or nearly static movements, as well as, those which are highly dynamic. Experimental results indicate that the algorithm is able to track pitch and roll during dynamic motion with an RMS error of less than two degrees This is believed to be superior to current proprietary commercial algorithms.

Carpin, Stefano, Derek Burch, and **Timothy H. Chung**. "Searching for Multiple Targets using Probabilistic Quadtrees." ***2011 IEEE/RSJ International Conference on Intelligent Robots and Systems: Celebrating 50 Years of Robotics, IROS'11***, p. 4536-4543.
Abstract: We consider the problem of searching for an unknown number of static targets inside an assigned area. The search problem is tackled using Probabilisitic Quadtrees (PQ), a data structure we recently introduced. Probabilistic quadtrees allow for a variable resolution representation and naturally induce a search problem where the searcher needs to choose not only where to sense, but also the sensing resolution. Through a Bayesian approach accommodating faulty sensors returning both false positives and missed detections, a posterior distribution about the location of the targets is propagated during the search effort. In this paper we extend our previous findings by considering the problem of searching for an unknown number of targets. Moreover, we substitute our formerly used heuristic with an approach based on information gain and expected costs. Finally, we provide some convergence results showing that

in the worst case our model provides the same results as uniform grids, thus guaranteeing that the representation we propose gracefully degrades towards a known model. Extensive simulation results substantiate the properties of the method we propose, and we also show that our variable resolution method outperforms traditional methods based on uniform resolution grids.

Castaneda, Phil, Chan Chung Wei, David Chiam, Jim Drennan, Tracy Emmersen, Scott Harvey, Koh Wee Yung, Lim Choon Wee, Lu Zheng Liang, Matt Malinowski, Thomas Mills, Ng Kiang Chuan, Ong Zi Xuan, Pek Wee Kok, Perh Hong Yih, Jon Saburn, Christian Silvestrini, Sor Wei Lun, Tan Yick Fung, Teo Yong Kiong, William Walker, Wee Hong Chuan, Wes Wessner, Wong Chee Heng, Kelvin Zhu. "Advanced Undersea Warfare Systems." ***AUVSI Unmanned Systems North America Conference 2011***, p. 691-693.
Abstract: Over the next twenty years, the proliferation of threats in the undersea environment will likely challenge the platform-centric model that the United States Navy uses to maintain dominance in Undersea Warfare (USW). Meanwhile, rapidly maturing technologies offer greater capabilities to potential adversaries around the world. Such a paradigm creates an imperative for the Navy to harness emerging technologies to maintain USW dominance amid a dynamic threat environment, while balancing cost, risk, and required performance. This systems engineering analysis develops Advanced Undersea Warfare Systems (AUWS) that provide a technological and tactical advantage based on the needs of the warfighter. Following critical analysis of the numerous possible alternatives for performing the necessary Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) and prosecution and an objective screening process, four system architectures, and associated operational concepts, are selected for detailed analysis. From cost, risk, and performance analyses, superior AUWS concepts are shown to be flexible, scalable, and tailorable systems that balance critical need areas. This analysis highlights the need for new warfare systems that can meet future challenges to the traditional platform-centric model for USW dominance. Using the results and recommendations in this analysis will allow the Navy to deploy capabilities that effectively and efficiently meet future operational needs.

Cichella, Venanzio, Enric Xargay, **Vladimir Dobrokhodov**, **Isaac Kaminer**, Antonio M. Pascoal, and Naira Hovakimyan. "Geometric 3D Path-following Control for a Fixed-wing UAV on SO(3)." ***AIAA Guidance, Navigation, and Control Conference 2011***.
Abstract: This paper addresses the problem of steering an Unmanned Aerial Vehicle along a given path. In the setup adopted, the vehicle is assigned a nominal path and a speed profile along it. The vehicle is then tasked to follow this nominal path independently of the temporal assignments of the mission, which is in contrast to "open-loop" trajectory tracking maneuvers. The paper builds on previous work by the authors on path-following control and derives a new control algorithm that uses the Special Orthogonal group SO(3) in the formulation of the attitude control problem. This formulation avoids the geometric singularities and complexities that appear when dealing with local parameterizations of the vehicle's attitude, and leads thus to a singularity-free path-following control law. Flight test results performed in Camp Roberts, CA, demonstrate the efficacy of the path-following control algorithm developed in this paper.

Cichella, Venanzio, Roberto Naldi, **Vladimir Dobrokhodov**, **Isaac Kaminer**, Lorenzo Marconi. "On 3D Path Following Control of a Ducted-fan UAV on SO(3)." ***2011 50th IEEE Conference on Decision and Control and European Control Conference, CDC-ECC 2011***, p. 3578-3583.
Abstract: This article focuses on the problem of computing a control law for a particular class of tail-sitter aircraft able to switch their flight configuration from hover to level flight and vice-versa. We address the problem of steering a ducted-fan UAV along a given path (path following problem) so as to meet spatial constraints. One possible scenario is the situation where a vehicle is required to execute collision-free maneuvers under strict spatial limitations and arrive at his final destination while pointing with a camera to a moving target. Path following control in 3D builds on a nonlinear control strategy that is first derived at the kinematic level using the Special Orthogonal Group (SO(3)) theory.

Chung, Hoam, Elijah Polak, **Johannes O. Royset**, and S.Shankar Sastry. "Optimal Periodic Patrolling Trajectories of UUVs Guarding a Channel." ***Proceedings of the 2011 American Control Conference, ACC 2011***, p. 888-893. Abstract: Given a number of patrollers, the channel patrol problem consists of determining the periodic trajectories that the patrollers must trace out so as to maximize the probability of detection of the intruder. We formulate this problem as an optimal control problem. We assume that the patrollers' sensors are imperfect and that their motions are subject to turnrate constraints, and that the intruder travels straight down a channel with constant speed. Using discretization of time and space, we approximate the optimal control problem with a large-scale nonlinear programming problem which we solve to obtain an approximately stationary solution and a corresponding optimized trajectory for each patroller. In numerical tests, we obtain new insight - not easily obtained using geometric calculations - into efficient patrol trajectory design for up to two patrollers in a narrow channel where interaction between the patrollers is unavoidable due to their limited turn rate.

Chung, Timothy H. and Stefano Carpin. "Multiscale Search Using Probabilistic Quadtrees." ***2011 IEEE International Conference on Robotics and Automation, ICRA 2011***, p. 2546-2553. Abstract: We propose a novel framework to search for a static target using a multiscale representation. The algorithm we present is appropriate when the target detection sensor trades off accuracy versus covered area, e.g., when a UAV can fly and sense at different elevations. A structure based on quadtrees is used to propagate a posterior about the target location using a variable resolution representation that is dynamically refined in regions associated with higher probability of target presence. Probabilities are updated using a Bayesian approach accounting for erroneous sensor readings in the form of false positives and missed detections. The model we propose is coupled with a search and decision algorithm that determines where to sense next and with which accuracy. The search algorithm is based on an objective function accounting for both probability of detection and motion costs, thus aiming to minimize traveled distances while trying to localize the target. The paper is concluded with simulation results showing our approach outperforms commonly used methods based on uniform resolution grids.

Harada, Masanori and **Kevin Bollino**. "Minimum-time Circling Flight of a Triarm Coaxial Rotor UAV." ***AIAA Guidance, Navigation, and Control Conference 2011***.
Abstract: This paper investigates characteristics of minimum-time trajectories for circling flight of a Triarm Coaxial Rotor (TCR) Unmanned Aerial Vehicle (UAV). Optimal open-loop solutions for a circling TCR UAV are presented including scenarios with failed rotors. The optimal control problem is solved using pseudospectral (PS) optimal control theory. With dual rotors on each of the three arms, even if one of the rotors stops working, the TCR UAV can maintain stable flight using the remaining five rotors. Furthermore, depending on the motor power, if two counter-rotating rotors mounted on different arms are stopped, the UAV can fly using the remaining four rotors. Numerical results demonstrate that this PS-control approach has the ability to obtain optimal circling flight trajectories consisting of three phases. With the majority of the flight being steady-state circling, the other phases consist of transient flight between circling and hovering at the boundary points. It is shown that although the optimal controls vary with each failed rotor scenario, the state response remains the same. This preliminary assessment is indicative of a simplified approach to adaptive flight control for improved mission robustness.

Hewgley, Charles W. and **Oleg A. Yakimenko**. "Improved Surface Layer Wind Modeling for Autonomous Parafoils in a Maritime Environment." ***21st AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar 2011***.
Abstract: This paper investigates the use of atmospheric boundary layer theory to produce more accurate wind estimates for guiding an autonomous parafoil during the last portion of its flight before touchdown. The problem of wind estimation for a prototype autonomous parafoil aerial delivery system is first explained, followed by the simple assumptions for wind estimation that its guidance algorithm makes. A logarithmic wind profile model in the atmospheric surface layer is

then introduced. The parameters and limitations of this model are discussed, along with the characteristics of this model that make it especially useful over the surface of the ocean. Finally, the incorporation of this model into the guidance algorithm of the prototype aerial delivery system is discussed, and subsequently evaluated in flight tests against the original algorithm that did not include the logarithmic surface layer wind model.

Hewgley, Charles W., **Oleg A. Yakimenko**, and Nathan J. Slegers. "Shipboard Landing Challenges for Autonomous Parafoils." *21st AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar 2011*.
Abstract: This paper examines some of the challenges that must be overcome if future aerial delivery systems are to have the capability to land on the flight deck of a ship underway. The unique aspects of trajectory planning for landing on a ship's flight deck are first examined, followed by formulation of the position estimation problem for a moving target. Some preliminary investigations into characterizing the wind over a moving landing platform at sea are then described. Finally, experimental results are presented for testing of a small prototype autonomous parafoil with a simple moving target on land.

Lock, Richard J., B.H. Peiris, M. Pasindu, Simon Bates, Stuart C. Burgess, and **Ravi Vaidyanathan**. "Quantification of the Benefits of a Compliant Foil for Underwater Flapping Wing Propulsion." *2011 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2011*, p. 898-903.
Abstract: This paper presents results detailing the performance of a flexible wing for use on a vehicle capable of both aerial and aquatic modes of locomotion, with primary focus on the aquatic substrate. The motivation for the research stems from the ability of avian species within the natural world demonstrating this multi-modal capability, utilsing a flapping mechanism as a means of propulsive generation. The fundamental aim is to capture the beneficial traits of a flexible wing and quantify any potential improvements in performance. We present a simplified numerical model which acts as an initial design tool prior to the fabrication of a flexible wing. This model aids in wing geometry selection so that under key kinematic parameters the wing passively deforms during aquatic operations in a beneficial manner, in an attempt to increase the maximum lift coefficient of the foil. Using the model we have fabricated a flexible wing and experimentally evaluated its performance in a range of tests, varying kinematic parameters relating to the flapping motion and forward velocities and compared this with a rigid wing model to investigate if the passive chord-wise flexibility leads to an increase in propulsive efficiency. We present the initial data set making this comparison, showing that the flexible wing was found to exhibit higher propulsive efficiencies at specific kinematic parameter sets. This modeling and experimental study will provide a foundation for the design of future vehicles capable of swimming and aerial locomotion, and help quantify the benefits of passively compliant structures in flapping wing propulsion.

Ma, Zhanshan, Axel W. Krings, **Richard Millar**, Feng Wang, and Jun Chao. "Insect Navigation and Communication in Flight and Migration: A Potential Model for Joining and Collision Avoidance in MAVs and Mobile Robots Fleet Control." *2011 IEEE Aerospace Conference*, **AERO 2011**, March 5, 2011 - March 12 IEEE Computer Society, 2011.
http://dx.doi.org/10.1109/AERO.2011.5747513
Abstract: The human being should be awarded the championship of navigation on the planet, on the virtues that they not only have invented and manufactured the compass, GPS, aircraft, vessel, spacecraft, but also have demonstrated exceptional non-instrumental navigation skills. The Austronesian expansion from the Asian mainland into the Pacific performed by the Pacific navigators, who eventually populated the most remote islands of the Pacific about 4000 years ago, is a vivid example (Wehner 1998). However, animals, especially flying birds and insects are strong contenders. Monarch butterflies can migrate up to 2000 miles from their reproductive sites in the eastern US and Canada to their over-wintering sites in the forests of Mexico, and it is postulated that they may possess a biological equivalent of a low-resolution GPS system that is based on the magnetic field of the earth. In fact, even the long-legged ants (Cataglyphis fortis) in

the Saharan desert use the dead-reckoning navigation strategy, which is attributed to the Polynesians, but the ants apparently have acquired the capability much earlier, given the relative short evolutionary history of humans. In this article, we briefly review the state-of-the-art research on insect navigation and communication used in flight and communication, with the objective to inspire cross-disciplinary studies in aerospace engineering, biology and computer science. After a brief review, we overview and identify seven cross-disciplinary research topics that may draw on inspirations from insect navigation and communication in flight and migration. These topics include: ants colony inspired swarm intelligence, honeybee inspired group decision-making, insect sociobiology, MAV/mobile robot flight control and remote control of insect flights, optimal migration strategy, Quorum sensing, and joining and collision avoidance for MAV fleet control. An interesting question one may pose is: given the rich and advanced navigation and communication technologies humans have already invented, such as satellite-based GPS, the Internet, and cellular wireless communication, why do we still expect to possibly learn from insects? A simple answer is that the distributed and self-organized nature of insect navigation and communication systems makes it simple but very robust due to their highly adaptive nature. For example, without satellites, the GPS system will break down, but the biological GPS of monarch butterfly can operate in natural conditions without even using a battery. 2011 IEEE.

Madgwick, Sebastian O.H., Andrew J.L. Harrison, and **Ravi Vaidyanathan**. "Estimation of IMU and MARG Orientation using a Gradient Descent Algorithm." ***2011 IEEE International Conference on Rehabilitation Robotics, ICORR 2011 - Rehab Week Zurich 2011***.
Abstract: This paper presents a novel orientation algorithm designed to support a computationally efficient, wearable inertial human motion tracking system for rehabilitation applications. It is applicable to inertial measurement units (IMUs) consisting of tri-axis gyroscopes and accelerometers, and magnetic angular rate and gravity (MARG) sensor arrays that also include tri-axis magnetometers. The MARG implementation incorporates magnetic distortion compensation. The algorithm uses a quaternion representation, allowing accelerometer and magnetometer data to be used in an analytically derived and optimised gradient descent algorithm to compute the direction of the gyroscope measurement error as a quaternion derivative. Performance has been evaluated empirically using a commercially available orientation sensor and reference measurements of orientation obtained using an optical measurement system. Performance was also benchmarked against the propriety Kalman-based algorithm of orientation sensor. Results indicate the algorithm achieves levels of accuracy matching that of the Kalman based algorithm; < 0.8° static RMS error, < 1.7° dynamic RMS error. The implications of the low computational load and ability to operate at small sampling rates significantly reduces the hardware and power necessary for wearable inertial movement tracking, enabling the creation of lightweight, inexpensive systems capable of functioning for extended periods of time.

Sadagic, Amela. "Validation of Virtual Humanoid Intelligent Agents in Virtual Reality Systems." ***IEEE Virtual Reality Conference 2012, VR 2012 – Proceedings***, p. 91-92.
Abstract: One of the great benefits VR systems offer is their ability to simulate a number of virtual humans when their presence is needed in the context of some learning or training experience. Being that the real humans may not be available to play different roles and support virtual sessions, the ability of a system to generate highly believable representations of autonomous virtual humans - virtual intelligent agents - is vital in achieving specific learning and training objectives. Eliminating the elements of the system that can cause a negative learning and training transfer is a paramount in those systems. We illustrate the results of two user studies focused on validation of non-deterministic domain-specific behaviors generated by our system (example: behaviors typical for a well coordinated group of paramedics or military unit). The results and observations confirmed that when it comes to VR systems with stringent requirements and high expectations for positive learning/training transfer, we still need humans to evaluate and validate synthesized human-like agent behaviors.

Sujit, P.B., **Anthony J. Healey**, and João B. Sousa. "AUV Docking on a Moving Submarine Using a K-R Navigation Function." ***IROS'11 - 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems: Celebrating 50 Years of Robotics***, p. 3154-3159
Abstract: Inapproach for docking onto a moving submarine. Docking of a AUV is a difficult problem due to currents and the presence of no fly zones around the submarine. The navigation function approach provides an integration of no-fly zones into the controller and determines the desired heading taking the kinematic constraints of the AUV into account. Simulations are presented to validate the navigation functions ba this paper, we present a navigation function based sed docking solution.

Tang, K., Ben Wang, **Wei Kang**, and Ben Chen. "Minimum Time Control of Helicopter UAVs using Computational Dynamic Optimization." ***9th IEEE International Conference on Control and Automation, ICCA 2011***, p. 848-852.
Abstract: This paper focuses on the problem of minimum time trajectory planning for helicopter UAVs. It is formulated as a nonlinear optimal control subject to the dynamics and limitations of helicopter UAVs. The dynamical system is defined by a set of fifteen states nonlinear differential equations developed for HeLion, a UAV helicopter constructed in National University of Singapore (NUS). The problem is then solved numerically using pseudospectral method for dynamic optimization. The results show that minimum time trajectories are highly nonlinear that require complicated maneuvering.

Yakimenko, Oleg A. "Recent Advances and New Horizons in Aerial Payload Delivery." ***9th IEEE International Conference on Control and Automation, ICCA 2011***, p. 148-152.
Abstract: This paper discusses a progress in improving a touchdown accuracy of an aerial payload delivery over the course of the last decade and overviews new applications brought by the smallest and most accurate systems. Specifically, the paper reviews the key features of a Blizzard aerial delivery system and introduces several research projects on delivery of small payload/sensors/ground robots and establishing short-range short-term mesh networks.

Yakimenko, Oleg A., **Eugene A. Bourakov**, **Charles W. Hewgley**, Nathan J. Slegers, Red P. Jensen, Andrew B. Robinson, Josh R. Malone, Phil E. Heidt. "Autonomous Aerial Payload Delivery System 'Blizzard'." ***21st AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar 2011***.
Abstract: This paper presents a self-contained aerial payload/sensor delivery system Blizzard and discusses its potential applications.

Yingling, Adam J., **Charles W. Hewgley**, Thomas A. Seigenthaler, and **Oleg A. Yakimenko**. "Miniature Autonomous Rocket Recovery System (MARRS)." ***21st AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar 2011***.
Abstract: This paper discusses the development and testing of the new-generation recovery system in highpowered rockets. It starts from the overall description of the rocket system, the requirements of the Miniature Autonomous Rocket Recovery System (MARRS) and is followed by a description of a flight tested MARRS. Next, simulation and results from the flight tests are given. This paper ends with conclusions and recommendations for follow-on testing

2010

Baer, Wolfgang. "Multi-Eye Input Experiments for UAV Image Navigation and Control." ***Signal Processing, Sensor Fusion, and Target Recognition XIX***, April 5, 2010 - April 7 SPIE, 2010:The Society of Photo-Optical Instrumentation Engineers (SPIE).
http://dx.doi.org/10.1117/12.850555
Abstract: Real time Unmanned Arial Vehicle (UAV) image registration is achieved by stimulating one eye with a live video image from a flying UAV while stimulating the other eye with calculated images. The calculated image is initialized by telemetry signals from the UAV and corrected using

the Perspective View Nascent Technology (PVNT) software package model-image feedback algorithm. Live and registered calculated images are superimposed allowing command functions including target geo-location, UAV sensor slewing, tracking, and way point flight control. When the same equipment is used with the naked eye the forward observer function can be implemented to produce accurate target coordinates. The paper will then discuss UAV mission control and forward observer target tracking experiments conducted at Camp Roberts, California. 2010 SPIE.

Bazo, Daniel, **Ravi Vaidyanathan**, Alexander Lentz, and Chris Melhuish. "Design and Testing of a Hybrid Expressive Face for a Humanoid Robot." ***23rd IEEE/RSJ 2010 International Conference on Intelligent Robots and Systems, IROS 2010***, October 18, 2010 - October 22 IEEE Computer Society, 2010:5317-5322.
http://dx.doi.org/10.1109/IROS.2010.5651469
Abstract: The BERT2 social robot, a platform for the exploration of human-robot interaction, is currently being built at the Bristol Robotics Laboratory. This paper describes work on the robot's face, a hybrid face composed of a plastic faceplate and an LCD display, and our implementation of facial expressions on this versatile platform. We report the implementation of two representations of affect space, each of which map the space of potential emotions to specific facial feature parameters and the results of a series of human-robot interaction experiments to characterize the recognizability of the robot's archetypal facial expressions. The tested subjects' recognition of the implemented facial expressions for happy, surprised, and sad was robust (with nearly 100% recognition). Subjects, however, tended to confuse the expressions for disgusted and afraid with other expressions, with correct recognition rates of 21.1% and 52.6% respectively. Future work involves the addition of more realistic eye movements for stronger recognition of certain responses. These results demonstrate that a hybrid face with affect space facial expression implementations can provide emotive conveyance readily recognized by human beings. 2010 IEEE.

Byers, Kenneth L., **Timothy H. Chung**, and Rachel T. Johnson. "Modeling and Analysis of Tactical Installation Protection Missions." ***2010 43rd Winter Simulation Conference, WSC'10***, December 5, 2010 - December 8 Institute of Electrical and Electronics Engineers Inc, 2010:1347-1355.
http://dx.doi.org/10.1109/WSC.2010.5679058
Abstract: Security of U.S. military installations is of high interest and operational importance to the U.S. military and allied forces. The Situational Awareness for Surveillance and Interdiction Operations (SASIO) model was developed to simulate the operational tasking of a single Unmanned Aerial Vehicle (UAV) and a ground-based interceptor used for searching, identifying, and intercepting potential hostile targets prior to reaching a military base. This research explores insights for the tactical employment of a UAV and an interceptor to combat potential hostile actions against a predefined area of interest. The design and analysis of experiments are used to create surrogate models that quantify the success rates of interception based on the employment strategies for both the UAV and ground-based interceptor and also characteristics of the mission. The results provide guidance for tactical employment of Blue Force assets, as well as provide alternative means to influence Red force behavior in a beneficial manner. 2010 IEEE.

Calusdian, James, **Xiaoping Yun**, and **Leonidas Drakopoulos**. "Testing and Evaluation of an Inertial/Magnetic Sensor-Based Pen Input Device." ***23rd IEEE/RSJ 2010 International Conference on Intelligent Robots and Systems, IROS 2010***, October 18, 2010 - October 22 IEEE Computer Society, 2010:5232-5237.
http://dx.doi.org/10.1109/IROS.2010.5653798
Abstract: Testing and evaluation of a novel pen input device are presented in this paper. The pen input device could be used to write on any type of surface including desktops, blackboards, or in the air. It is constructed by attaching an inertial/magnetic sensor module to a writing instrument such as a pencil, a marker, or a piece of chalk. The inertial/magnetic sensor module has three accelerometers, three angular rate sensors, and three magnetometers. A tracking algorithm and

a calibration algorithm are described. The tracking algorithm is for estimating the pen tip trajectories based on the sensor measurements, and the calibration algorithm is for estimating the relative position of the sensor module on the writing instrument. Experimental results for writing alphanumeric characters are presented. The relationship between tracking accuracy and writing speed is also discussed. 2010 IEEE.

Chung, Timothy H. "On Probabilistic Search Decisions Under Searcher Motion Constraints." ***8th International Workshop on the Algorithmic Foundations of Robotics, WAFR***, December 7, 2008 - December 9 Springer Verlag, 2008:501-516.
http://dx.doi.org/10.1007/978-3-642-00312-7_31
Abstract: This article presents a sequential decision-theoretic formulation for conducting probabilistic search for a stationary target in a search region. A general recursion expression describing the evolution of the search decision (i.e., presence or absence of the target) is derived, which relates the temporal sequence of imperfect detections, both false positives and false negatives, to the spatial search conducted by a search agent. This relationship enables quantification of the decision performance - time till decision - for a given search strategy. Also, the role of searcher motion constraints, represented by a search graph, on the time till decision is characterized by the second smallest eigenvalue of the Laplacian of this graph. Numerical studies demonstrate this relationship.

Craig, Richard, **Ravi Vaidyanathan**, Christopher James, and Chris Melhuish. "Assessment of Human Response to Robot Facial Expressions through Visual Evoked Potentials." ***10th IEEE-RAS International Conference on Humanoid Robots, Humanoids 2010***, December 6, 2010 - December 8 IEEE Computer Society, 2010:647-652.
http://dx.doi.org/10.1109/ICHR.2010.5686272
Abstract: The focus of this work is to investigate and quantify the ability of a humanoid 'hybrid face' robot to effectively convey emotion to a human observer by mapping their physiological (EEG) response to perceived emotional information. Specifically, we examine the event related response during two implicit emotion recognition experiments to determine the modulation of the face-specific N170 brain response component to robot facial expressions. EEG recordings were taken from a range of test subjects observing the BERT2 robot cycle through a range of facial emotions in each emotion recognition experiment. Results from both experiments demonstrate that the stimuli evoke the N170 component and that digital facial expressions with high correlations can be discriminated. Emotional expressions evoke a larger response relative to neutral stimuli, with negative evoking an increased amplitude and latency to positive emotions, and demonstrate that the response to robot facial expressions evoke similar brain activity to that of a human emotions. This study is the first of its nature to investigate and quantify the human physiological response to digital facial expressions as conveyed in real-time by a humanoid robot. 2010 IEEE.

Hurni, Michael A., **Pooya Sekhavat**, **Mark Karpenko**, and **I. Michael Ross**. "Autonomous Multi-Vehicle Formations using a Pseuodspectral Optimal Control Framework." ***2010 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2010***, July 6, 2010 - July 9 Institute of Electrical and Electronics Engineers Inc, 2010:980-986.
http://dx.doi.org/10.1109/AIM.2010.5695884
Abstract: Future civilian and military missions call for the autonomous coordination and control of unmanned vehicles. This paper presents the implementation of a pseudospectral (PS) optimal control-based algorithm for autonomous trajectory planning and control of multiple UGVs with real-time information updates. The mission of the UGVs is to maintain formation with respect to a lead vehicle traversing from a start point to a target point. Each vehicle must avoid static and dynamic obstacles including other vehicles. Real-time PScontrols accommodate unforseen events and changes in the environment that may take place over the course of the mission. Simulation results illustrate the performance of the algorithm for various multi-vehicle scenarios. 2010 IEEE.

———. "A Pseudospectral Optimal Motion Planner for Autonomous Unmanned Vehicles." *2010 American Control Conference, ACC 2010*, June 30, 2010 - July 2 IEEE Computer Society, 2010:1591-1598.
Abstract: This paper presents a pseudospectral (PS) optimal control algorithm for the autonomous motion planning of a fleet of unmanned ground vehicles (UGVs). The UGVs must traverse an obstacle-cluttered environment while maintaining robustness against possible collisions. The generality of the algorithm comes from a binary logic that modifies the cost function for various motion planning modes. Typical scenarios including path following and multi-vehicle pursuit are demonstrated. The proposed framework enables the availability of real-time information to be exploited by real-time reformulation of the optimal control problem combined with real-time computation. This allows the each vehicle to accommodate potential changes in the mission/environment and uncertain conditions. Experimental results are presented to substantiate the utility of the approach on a typical planning scenario. 2010 AACC.

Li, Zhiyuan, Naira Hovakimyan, **Vladimir Dobrokhodov**, and **Isaac Kaminer**. "Vision-Based Target Tracking and Motion Estimation using a Small UAV." *49th IEEE Conference on Decision and Control, CDC 2010*, December 15, 2010 - December 17 Institute of Electrical and Electronics Engineers Inc, 2010:2505-2510.
http://dx.doi.org/10.1109/CDC.2010.5718149
Abstract: This work extends the earlier results on passive vision-based tracking and motion estimation of a ground vehicle. The follower small unmanned air vehicle (UAV) is equipped with a single gimbaled pan/tilt camera and a high bandwidth wireless link for video and command transmitting. The objective is for the UAV to maintain a horizontal circular orbit about the target with a predefined radius and to concurrently provide real-time estimation of the target's position, speed and heading. The target velocity estimation problem is formulated such that the recently developed L1 fast adaptive estimator can be applied. We give a rigorous proof of asymptotic stability for the guidance law for the static target case, and provide a reformulation of the control objective for the moving target case so that the existing controller can be applied naturally. 2010 IEEE.

Lizarraga, Mariano I., Gabriel H. Elkaim, G. M. Horn, Renwick Curry, **Vladimir Dobrokhodov**, and **Isaac Kaminer**. "Low Cost Rapidly Reconfigurable UAV Autopilot for Research and Development of Guidance, Navigation and Control Algorithms." *2009 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC2009*, August 30, 2009 - September 2 American Society of Mechanical Engineers, 2009:585-594.
Abstract: This paper presents the development and preliminary results of a rapidly reconfigurable autopilot for small Unmanned Aerial Vehicles. The autopilot presented differs from current commercial and open source autopilots mainly as it has been designed to: (i) be easily reprogrammable via Simulink (models are directly transferred to the autopilot through the Real-Time Workshop's code-generation capability); (ii) decouple the traditional tasks of attitude estimation/navigation and flight control by using two Digital Signal Controllers (one for each task) interconnected via a Serial Peripheral Interface; and, (iii) being able to interact directly with Simulink as a Hardware-in-the-Loop simulator. This work details each of the main components of the autopilot and its ground control station software. Preliminary results for sensor calibration, Hardware-in-the-loop, ground and flight tests are presented. Copyright 2009 by ASME.

Lock, Richard J., **Ravi Vaidyanathan**, and Stuart C. Burgess. "Development of a Biologically Inspired Multi-Modal Wing Model for Aerial-Aquatic Robotic Vehicles." *23rd IEEE/RSJ 2010 International Conference on Intelligent Robots and Systems, IROS 2010*, October 18, 2010 - October 22 IEEE Computer Society, 2010:3404-3409
http://dx.doi.org/10.1109/IROS.2010.5650943
Abstract: This paper presents a numerical model of a morphing wing supporting the development of a biologically inspired vehicle capable of aerial and aquatic of locomotion. The model draws inspiration from the seabird Uria aalge, the common guillemot. It is implemented within a

parametric study associated with aerial and aquatic performance, specifically aiming at minimizing energy of locomotion. The implications of varying wing geometry and kinematic parameters are investigated and presented in the form of nested performance charts. Trends within both the aquatic and aerial model are discussed highlighting the implications of parameter variation on the power requirements associated with both mediums. Conflicts of geometric parameter selection are contrasted between the aerial and aquatic model, as well as other trends that impact the design of concept vehicles with this capability. The model has been validated by implementing a heuristic optimization of its key parameters under conditions akin to those of the actual bird; optimal parameters output by the model correlate to the actual behaviour of the guillemot. 2010 IEEE.

Ma, Zhanshan, **Richard Millar**, Robert Hiromoto, and Axel Krings. "Logics in Animal Cognition: Are they Important to Brain Computer Interfaces (BCI) and Aerospace Missions?" *2010 IEEE Aerospace Conference,* March 6, 2010 - March 13 IEEE Computer Society, 2010:Aerospace and Electronics Systems Society
http://dx.doi.org/10.1109/AERO.2010.5446798
Abstract: Conventional wisdom is that logic and language are tightly connected to logics in human cognition. However, recent studies have revealed that, in animal cognition, there exist logics that do not depend on languages. In other words, logical behavior is not human brain specific. At least four logics: perceptual logic, technical logic, social logic, and inference logic have been studied in animal cognition. Despite the obvious differences between animals and humans in using languages, recent studies confirm that both humans and animals utilize the so-called sensor brain maps for most sensory modalities: populations of neurons are selectively tuned to different stimulus features or feature combinations (Ewert 2005, Ma and Krings 2009). This commonality suggests that the studies of animal logics should also be insightful for understanding human logics. After briefly reviewing some of the recent advances in animal logics research, we turn to a more practical research field - the Brain Computer Interface (BCI) [also known as Brain Machine Interface (BMI)] in biomedicine. BCI promises to provide non-muscular communication and control for people with severe motor disabilities. A fundamental goal of BCI is to translate thought or intent into action with brain activity only (Birbaumer 2006). If we recognize that logic is about the way of thinking and it is probably the most reliable and possibly most efficient way to understand thoughts, an interesting question could be: will the understanding of animal logics be very helpful for BCI research? The current BCI research is primarily targeted for rehabilitation applications. In this article, we also discuss the potential of using BCI techniques in aerospace systems and space explorations. One can imagine the potential that an astronaut operates a robot device by only thinking. Perhaps a revolutionary breakthrough from BCI technology can be the 'copiloting' of aerial vehicles by multiple pilots including some who stations at the ground. This copiloting not only reduces the stress (brain fatigue) of pilots, but also enhances the reliability and fault tolerance of aerial vehicles. 2010 IEEE.

Mace, Michael, Khondaker Abdullah-Al-Mamun, **Ravi Vaidyanathan**, Shouyan Wang, and Lalit Gupta. "Real-Time Implementation of a Non-Invasive Tongue-Based Human-Robot Interface." *23rd IEEE/RSJ 2010 International Conference on Intelligent Robots and Systems, IROS 2010*, October 18, 2010 - October 22 IEEE Computer Society, 2010:5486-5491.
http://dx.doi.org/10.1109/IROS.2010.5648834
Abstract: Real-time implementation of an assistive humanmachine interface system based around tongue-movement ear pressure (TMEP) signals is presented, alongside results from a series of simulated control tasks. The implementation of this system into an online setting involves short-term energy calculation, detection, segmentation and subsequent signal classification, all of which had to be reformulated based on previous off-line testing. This has included the formulation of a new classification and feature extraction method. This scheme utilises the discrete cosine transform to extract the frequency features from the time domain information, a univariate Gaussian maximum likelihood classifier and a two phase cross-validation procedure for feature selection and extraction. The performance of this classifier is presented alongside a real-

time implementation of the decision fusion classification algorithm, with each achieving 96.28% and 93.12% respectively. The system testing takes into consideration potential segmentation of false positive signals. A simulation mapping commands to a planar wheelchair demonstrates the capacity of the system for assistive robotic control. These are the first real-time results published for a tongue-based human-machine interface that does not require a transducer to be placed within the vicinity of the oral cavity. 2010 IEEE.

McEachen, John. "Cyber and Unmanned Systems Operations." ***AUVSI Unmanned Systems North America Conference 2010***, August 24, 2010 - August 27 Association for Unmanned Vehicle Systems International, 2010:1186-1203.

Abstract: The world's growing reliance on information technology has introduced a level of real-time connectivity that while making US operations much more effective and efficient across numerous missions areas, has also introduced increased vulnerabilities that continuously require mitigation and preparedness in order to protect against and deter threats from both state and non-state actors. History shows that government regulations and protections, despite arguments that they are anathema to the Internet's openness, are required to protect our operations and forces. Furthermore, balance is needed to achieve transparency and information sharing within a secure trusted cyber environment. Now, more than ever, mission success depends on the ability to continually achieve network readiness and situational awareness while assuring trust and security. The key questions before us are: What do I need to do to secure my network from attack? How will new technologies affect our current security strategies? How do we protect all technology components given the globalized, complex nature of the supply chain? Are we ready to promote broad and collaborative engagement among stakeholders from all sectors, geographic regions, and levels of government? Can we articulate the goal we are striving for, align our efforts, measure success and chart the path for getting there?

Ross, Mike, **Isaac Kaminer**, **Dave Netzer**, **Xiaoping Yun**, **Tony Healey**, and Wei Kang. "Autonomous Systems Curriculum - A Proposal for an Interdisciplinary Education Program." ***AUVSI Unmanned Systems North America Conference 2010***, August 24, 2010 - August 27 Association for Unmanned Vehicle Systems International, 2010:1204-1246.

Sonnenburg, C., Aditya Gadre, **Douglas Horner**, **Sean Kragelund**, A. Marcus, Daniel J. Stilwell, and Craig A. Woolsey. "Control-Oriented Planar Motion Modeling of Unmanned Surface Vehicles." ***MTS/IEEE Seattle, OCEANS 2010***, September 20, 2010 - September 23 IEEE Computer Society, 2010
http://dx.doi.org/10.1109/OCEANS.2010.5664297

Abstract: This paper describes a comparison of experimentally identified dynamic models for the planar motion of an unmanned surface vehicle (USV). The objective is to determine a model which is rich enough to enable effective motion planning and control, simple enough to allow straight forward parameter identification, and general enough to describe a variety of hullforms and actuator configurations. Starting from a three degree-of-freedom nonlinear model obtained from physical principles, we consider four simplified variants: (1) a linear model obtained by linearizing about straight, constant-speed motion, (2) a first order steering model (for turn rate) coupled with a first order speed model, (3) a second order steering model (for turn rate and sideslip angle), coupled with a first order speed model, and (4) a nonlinear model for low speed operation. The paper provides analysis of system identification data collected from field trials of three USV platforms in Summer 2010. The platforms represent three distinct control system implementations: a servo-actuated outboard engine, a servo-actuated jet-drive thruster, and differential thrusters. 2010 IEEE.

Xargay, Enric, Naira Hovakimyan, **Vladimir Dobrokhodov**, **Isaac Kaminer**, Irene M. Gregory, and Chengyu Cao. "L1 Adaptive Flight Control System: Flight Evaluation and Technology Transition." ***AIAA Infotech at Aerospace 2010***, April 20, 2010 - April 22 American Institute of Aeronautics and Astronautics Inc, 2010

Abstract: Certification of adaptive control technologies for both manned and unmanned aircraft represent a major challenge for current Verification and Validation techniques. A (missing) key step towards flight certification of adaptive flight control systems is the definition and development of analysis tools and methods to support Verification and Validation for nonlinear systems, similar to the procedures currently used for linear systems. In this paper, we describe and demonstrate the advantages of L1 adaptive control architectures for closing some of the gaps in certification of adaptive flight control systems, which may facilitate the transition of adaptive control into military and commercial aerospace applications. As illustrative examples, we present the results of a piloted-simulation evaluation on the NASA AirSTAR flight test vehicle, and results of an extensive flight test program conducted by the Naval Postgraduate School to demonstrate the advantages of L1 adaptive control as a verifiable robust adaptive flight control system. Copyright 2010 by Xargay, Hovakimyan, Dobrokhodov, Kaminer, Cao, Gregory.

Yakimenko, Oleg. "Optimization of Holonomic Attitude Dynamics using IDVD Method." ***3rd International Symposium on Systems and Control in Aeronautics and Astronautics, ISSCAA2010**, June 8, 2010 - June 10* IEEE Computer Society, 2010:1496-1499
http://dx.doi.org/10.1109/ISSCAA.2010.5632357

Abstract: This paper exploits advantages of the differential flatness of rotational dynamics of a three-dimensional holonomic robot, and presents two alternative approaches to invert it. Specifically, it utilizes the inverse dynamics in the virtual domain method, widely used for the translational motion, to develop a simple and yet effective numerical procedure for optimization of attitude dynamics based on the Euler angles or quaternion. 2010 IEEE.

2009

Andersson, Klas. "Extending Endurance for Small UAVS by Predicting and Searching for Thermal Updrafts." ***AUVSI Unmanned Systems North America Conference 2009**, August 10, 2009 - August 13* Association for Unmanned Vehicle Systems International, 2009:33-41

Abstract: This paper discusses the topic of exploiting atmospheric energy in the form of thermal updrafts to extend endurance for small unmanned aerial vehicles. It introduces a way to increase efficiency in the search for thermal lift by developing a dynamic thermal prediction map. This prediction mapping concept evaluates the underlying ground topography in conjunction with sun angle. Areas which are likely to produce lift are predicted and marked as waypoints. A search pattern emerges that focuses on minimizing the time between when the UAV visits each of the predicted thermal locations. As a form of learning behavior, the prediction map is dynamically updated with additional waypoints if unexpected thermal activity is encountered during flight.

Andersson, Klas and **Isaac Kaminer**. "On Stability of a Thermal Centering Controller." ***AIAA Guidance, Navigation, and Control Conference and Exhibit**, August 10, 2009 - August 13* American Institute of Aeronautics and Astronautics Inc, 2009.

Abstract: In previous work1 the concept of using cooperating unmanned aerial vehicles (UAVs) to search for thermal lift in order to extend endurance was investigated. This paper elaborates upon this work by including a theoretical analysis of the stability and convergence of the heuristic controller used for centering on thermals. Using an exponential Gaussian function to represent the updraft field in a thermal, the analysis proves the controller to be asymptotically stable at the equilibrium state given. It further provides the region of stability for varying feedback gains of the controller and for different strength and sizes of the thermal. Copyright 2009 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

Andersson, Klas, **Isaac Kaminer**, **Kevin D. Jones**, **Vladimir Dobrokhodov**, and **Deok-Jin Lee**. "Cooperating UAVs using Thermal Lift to Extend Endurance." ***Unlimited Conference***, *April 6, 2009 - April 9* American Institute of Aeronautics and Astronautics Inc, 2009.
Abstract: One method of improving flight endurance for UAVs is to take advantage of thermal lift occurring in convective boundary layers of the atmosphere. This paper investigates the possible benefits of using a cooperating team of small UAVs to increase the probability of finding thermal lift. An algorithm that employs a team of two autonomous gliders was developed, simulated and initially flight tested. Probability studies suggest that a cooperative approach increases the chance of finding lift to a significant extent. Due to the unpredictable nature of thermals, simulation results need to be complemented with further flight testing to determine the effectiveness of this approach. Copyright 2009 by the American Institute of Aeronautics and Astronautics, Inc.

Baer, Wolfgang and **Mathias Kölsch**. "Shadow and Feature Recognition Aids for Rapid Image Geo-Registration in UAV Vision System Architectures." ***Signal Processing, Sensor Fusion, and Target Recognition XVIII***, *April 13, 2009 - April 15* SPIE, 2009:The International Society for Optical Engineering (SPIE)
http://dx.doi.org/10.1117/12.818225
Abstract: The problem of real-time image geo-referencing is encountered in all vision based cognitive systems. In this paper we present a model-image feedback approach to this problem and show how it can be applied to image exploitation from Unmanned Arial Vehicle (UAV) vision systems. By calculating reference images from a known terrain database, using a novel ray trace algorithm, we are able to eliminate foreshortening, elevation, and lighting distortions, introduce registration aids and reduce the geo-referencing problem to a linear transformation search over the two dimensional image space. A method for shadow calculation that maintains real-time performance is also presented. The paper then discusses the implementation of our model-image feedback approach in the Perspective View Nascent Technology (PVNT) software package and provides sample results from UAV mission control and target mensuration experiments conducted at China Lake and Camp Roberts, California. 2009 SPIE.

Barisic, Matko, Zoran Vukic, Nikola Miskovic, and **Sean P. Kragelund**. "A MOOS-Based Online Trajectory Re-Planning System for AUVs." ***OCEANS '09 IEEE Bremen: Balancing Technology with Future Needs***, *May 11, 2009 - May 14* IEEE Computer Society, 2009
http://dx.doi.org/10.1109/OCEANSE.2009.5278131
Abstract: His paper describes an open source navigation system architecture for use in autonomous underwater vehicles. It is based on the Mission Oriented Operating System proposed, published and programmed by ([1], [2]). It is uniquely applicable for work-in-progress type and development-stage software and capability installation onto an AUV system. This applicability is achieved by its completely modular nature, which is obtained by the operating system kernel running separate processes for each advanced navigation or control feature. Robustness is also achieved in this respect since failures and errors will cause only the individual modules that incurs them to fail. Such critical errors, bugs and failures will thereby be contained and their propagation halted from completely freezing even the low-level control loops and decision-making processes needed to successfully retrieve the malfunctioning AUV. 2009 IEEE.

Bevilacqua, Riccardo, Andrew P. Caprari, Jason Hall, and **Marcello Romano**. "Laboratory Experimentation of Multiple Spacecraft Autonomous Assembly." ***AIAA Guidance, Navigation, and Control Conference and Exhibit, August 10, 2009 - August 13*** American Institute of Aeronautics and Astronautics Inc, 2009
Abstract: This work introduces a novel approach and its experimental verification for propellant sub-optimal multiple spacecraft assembly via a Linear Quadratic Regulator (LQR). The attitude dynamics of the spacecraft are linearized at each time step, about the current state vector, and the relative dynamics between two spacecraft are assumed as a double integrator. This allows for implementation in real-time of a LQR that computes the optimal gain matrix depending on the current phase of the spacecraft's mission. As a result, both the attitude and position are sub-

optimally controlled. The presented logic compensates for the structural evolution related to an incremental assembly by updating the system's dynamics matrices. The actuators' reallocation and command of the assembled structure is dealt with through inter-robot wireless ad-hoc communication. Each spacecraft runs symmetric algorithms, differing only in the number of docking ports that each possesses for the mission, which are related to the number of assembling spacecraft and the final structure's desired shape. Once the spacecraft are assembled, one acts as master by performing the required navigation and control of the new structure through real-time wireless commanding of the other spacecraft's actuators. The improved third generation (3G-i) of spacecraft simulators developed at the Spacecraft Robotics Laboratory SRL of the Naval Postgraduate School (NPS) is presented to demonstrate experimental verification of the proposed methodology. Features of the (3G-i) robots include an unique customized construction of rapid prototyped thermoplastic (polycarbonate) that incorporates a lightweight modular design with a small footprint, thus maximizing the entire surface of the SRL robotic testbed.

Boxerbaum, Alexander S., Matthew A. Klein, Richard Bachmann, Roger D. Quinn, Richard Harkins, and **Ravi Vaidyanathan**. "Design of a Semi-Autonomous Hybrid Mobility Surf-Zone Robot." *2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2009*, *July 14, 2009 - July 17* Institute of Electrical and Electronics Engineers Inc, 2009:974-979 http://dx.doi.org/10.1109/AIM.2009.5229713
Abstract: Surf-zone environments pose extreme challenges to robot operation. A robot that could autonomously navigate through the rocky terrain, constantly changing underwater currents, hard-packed moist sand, and loose dry sand characterizing this environment, would have very significant utility for a range of defence and civilian missions. The study of animal locomotion mechanisms can elucidate specific movement principles that can be applied to address these demands. In this work, we report on the design and optimization of a biologically inspired autonomous robot for deployment and operation in an ocean beach environment. Based on recent success with beach environment autonomy and a new rugged waterproof robotic platform, we propose a new design that will fuse a range of insect-inspired passive mechanisms with active autonomous control architectures to seamlessly adapt to and traverse through a range of challenging substrates both in and out of the water. 2009 IEEE.

Boyarko, George A. "System Level Simulation of Artificial Potential Function Guidance for a Neutrally Buoyant Autonomous Vehicle Equipped with Non-Ideal Actuators." *47th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*, *January 5, 2009 - January 8* American Institute of Aeronautics and Astronautics Inc, 2009
Abstract: Path planning and trajectory generation in the presence of obstacles is of utmost importance in vehicle autonomy. While optimal trajectories are able to minimize an objective function for such an operation, they cannot be evaluated in "real time", require global knowledge of the environment, are open loop in nature and are not resistant to vehicle and environmental disturbances. For this reason, Artificial Potential Functions (APF) will be explored for use as a guidance strategy on board an autonomous vehicle that does not have global knowledge of the environment or limited actuator capability and is subject to many forms of disturbance. System level simulations are necessary to analyze the interactions of a given control system in the presence of nonlinear dynamics of the vehicle, its actuator/sensor properties and the non deterministic interaction with the environment. A SIMULINK&reg system level model of the Phoenix Autonomous Underwater Vehicle (AUV) is constructed to evaluate the control system within the current scenario. A novel strategy to mitigate local minima in the APF is also explored. While the simulation is specific to the AUV, the architecture and guidance methodology is easily transferable to other autonomous vehicles used in air, space and terrestrial applications.

Cascio, Joseph, Mark Karpenko, Qi Gong, **Pooya Sekhavat**, and **I. Michael Ross**. "Smooth Proximity Computation for Collision-Free Optimal Control of Multiple Robotic Manipulators." ***2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2009***, *October 11, 2009 - October 15* IEEE Computer Society, 2009:2452-2457
http://dx.doi.org/10.1109/IROS.2009.5354382
Abstract: This paper presents a novel approach for trajectory planning of multiple robot manipulators operating amongst obstacles. Karush-Kuhn-Tucker (KKT) conditions are exploited to compute the proximity between line-swept sphere (LSS) bounding volumes used to model potentially colliding objects. The KKT multipliers and the parameters giving the minimum distance between LSS volumes are augmented into the manipulator trajectory planning problem as dummy control variables. These extra variables allow the planning problem to be cast as a standard nonlinear optimal control problem with smooth path constraints, which is then solved using the pseudospectral method. The utility of the approach is demonstrated by a trajectory planning example involving stationary workspace obstacles and for a centralized multi-robot system in which each robot acts as a dynamic obstacle that the other should avoid. The optimal control formulation incorporates practical constraints on the manipulator joint angles, velocities and accelerations as well as limits on the control torque. The computed collision-free optimal trajectories are executed on a pair of experimental robots to verify the feasibility of the numerical results. 2009 IEEE.

Chung, Timothy H., **Moshe Kress**, and **Johannes O. Royset**. "Probabilistic Search Optimization and Mission Assignment for Heterogeneous Autonomous Agents." ***2009 IEEE International Conference on Robotics and Automation, ICRA '09***, *May 12, 2009 - May 17* Institute of Electrical and Electronics Engineers Inc, 2009:939-945
http://dx.doi.org/10.1109/ROBOT.2009.5152215
Abstract: This paper presents an algorithmic framework for conducting search and identification missions using multiple heterogeneous agents. Dynamic objects of type "neutral" or "target" move through a discretized environment. Probabilistic representation of the current level of situational awareness - knowledge or belief of object locations and identities - is updated with imperfect observations. Optimization of search is formulated as a mixed-integer program to maximize the expected number of targets found and solved efficiently in a receding horizon approach. The search effort is conducted in tandem with object identification and target interception tasks, and a method for assignment of these missions among agents is developed. The proposed framework is demonstrated in simulation studies, and an implementation of its decision support capabilities in a recent field experiment is reported.

Clement, Michael R., **Eugene Bourakov**, **Kevin D. Jones**, and **Vladimir Dobrokhodov**. "Exploring Network-Centric Information Architectures for Unmanned Systems Control and Data Dissemination." ***Unlimited Conference, April 6, 2009 - April 9*** American Institute of Aeronautics and Astronautics Inc, 2009
Abstract: The exploration and development of an information architecture for networked unmanned systems is described. The unmanned systems discussed utilize standard components for guidance and navigation, coupled with additional computing devices for interfacing with a network. These platforms in turn communicate with a broader network of devices, applications, and users via a variety of wireless network links. Networking a platform that is traditionally operated via serial control links and analog sensor downlinks provides two distinct advantages: (i) high-level control, or "tasking," of the platform is easily extended from the single operator to any authorized user on the network; and (ii) sensor data and status information may be disseminated rapidly across the network to all interested recipients. The architecture developed through this exploration is applied in a prototype UAV which is utilized as both a high-resolution imaging platform and a wireless network relay. Testing and evaluation of the architecture occurs on an ongoing, quarterly basis through a cooperative field experiment program run by U.S. Special Operations Command and the Naval Postgraduate School.

Dobrokhodov, Vladimir, **Ioannis Kitsios**, **Isaac Kaminer**, **Kevin D. Jones**, Enric Xargay, Naira Hovakimyank, Chengyu Cao, Mariano I. Lizarraga, and Irene M. Gregory. "Preliminary Results of Development, System Integration and Flight Validation of a Metrics Driven L1 Adaptive Control." ***Unlimited Conference, April 6, 2009 - April 9*** American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: This paper addresses initial steps in the development and flight implementation of a new metrics driven L1 adaptive flight control system. The work primarily focuses on (i) definition of appropriate control driven metrics that account for the control surface failures; (ii) tailoring a recently developed L1 adaptive controller to the design of adaptive flight control systems that explicitly address these metrics in the presence of control surface failures and dynamic changes under adverse flight conditions; (iii) development of a flight control system for implementation of the resulting algorithms onboard of a small UAV; and (iv) conducting a comprehensive flight test program that demonstrates performance of the developed adaptive control algorithms in the presence of failures. As an initial milestone, the paper focuses on the adaptive flight system setup and initial efforts addressing the ability of a commercial off-the-shelf autopilot with and without adaptive augmentation to recover from abrupt control surface failures.

Gadre, Aditya, **Sean Kragelund**, Theodore Masek, Daniel Stilwell, Craig Woolsey, and **Douglas Horner**. "Subsurface and Surface Sensing for Autonomous Navigation in a Riverine Environment." ***AUVSI Unmanned Systems North America Conference 2009***, *August 10, 2009 - August 13* Association for Unmanned Vehicle Systems International, 2009:1192-1208.

Abstract: Autonomous and robust navigation in a riverine system requires sensing of the surface and subsurface environment. We report on experiments and development activities conducted by Virginia Tech and the Naval Post-graduate School to evaluate the effectiveness of optical surface sensing and acoustic subsurface sensing on an unmanned surface vehicle for autonomous navigation in a riverine environment. Subsurface sensing utilizes a small forward-looking sonar with both vertical and horizontal beam patterns. The sonar head is mechanically steered in pan and tilt. Surface sensing utilizes a laser line-scanner along with optical cameras. The laser line-scanner is gimbaled in tilt and roll in order to decouple boat motion. A stochastic map of the environment, generated from both surface and subsurface sensors, is used for real-time path planning. Successful experiments have been conducted that demonstrate navigation in a riverine system where the a priori map is inaccurate and both surface and subsurface obstacles are present.

Ghabcheloo, Reza, **Isaac Kaminer**, A. Pedro Aguiar, and Antonio Pascoal. "A General Framework for Multiple Vehicle Time-Coordinated Path Following Control." ***2009 American Control Conference, ACC 2009, June 10, 2009 - June 12*** Institute of Electrical and Electronics Engineers Inc, 2009:3071-3076.
http://dx.doi.org/10.1109/ACC.2009.5160564

Abstract: This paper describes a general framework for the study of multiple vehicle, time-coordinated path following (TCPF) control problems. An example is the situation where a group of vehicles is tasked to maneuver and arrive at preassigned final positions at the same time in a collision-free manner, while reducing some optimality criterion. The time of arrival is not fixed a priori, and the vehicles must negotiate their speeds along the spatial paths that they follow in order to arrive simultaneously and avoid collision. The general framework adopted leads to integrated solutions to TC-PF problems that unfold in three steps: 1) Generation of Deconflicted Trajectories for a group of vehicles, 2) Path Following for each vehicle along its assigned path, and 3) Coordination of the relative motion of the vehicles along their paths, so as to guarantee deconfliction and meet desired temporal constraints such as equal times of arrival. The last step is accomplished by varying the speed of each vehicle about the nominal speed profile computed in step 1, based on the exchange of information with its neighbors. The paper formulates the problem mathematically, offers a general framework for its solution, and illustrates the efficacy of the proposed methodology in simulation with dynamic models of Autonomous Underwater Vehicles (AUVs). 2009 AACC.

Harada, Masanori and **Kevin Bollino**. "Fuel Optimization of Figure-8 Flight for Unmanned Aerial Vehicles." ***AIAA Guidance, Navigation, and Control Conference and Exhibit, August 10, 2009 - August 13*** American Institute of Aeronautics and Astronautics Inc, 2009.
Abstract: This paper investigates characteristics of minimum-fuel figure-8 trajectories for an Unmanned Aerial Vehicle (UAV) at high altitude. Given that loitering over an area of interest (i.e., ground target) falls within the purview of UAV missions, previous research has shown that periodic circling flight, consisting of a boost arc (maximum thrust) and a coast arc (minimum thrust), improves the fuel consumption when compared to steady-state circling. Through numerical simulations, this work investigates the effectiveness of figure-8 flight for optimizing fuel consumption while loitering. The results show that the periodic flight improves the fuel consumption up to 5% when compared to steady-state-flight. In addition, the optimal figure-8 trajectory shape is elongated compared to that of the steady-state flight. As demonstrated, this optimal control approach can improve the fuel consumption even while fuel is used during the coast arc. Copyright 2009 by the American Institute of Aeronautics and Astronautics, Inc. All right reserved.

Hausler, Andreas J., Reza Ghabcheloo, **Isaac Kaminer**, Antonio M. Pascoal, and A. Pedro Aguiar. "Path Planning for Multiple Marine Vehicles." ***OCEANS '09 IEEE Bremen: Balancing Technology with Future Needs, May 11, 2009 - May 14*** IEEE Computer Society, 2009.
http://dx.doi.org/10.1109/OCEANSE.2009.5278209
Abstract: Motivated by increasingly complex and challenging missions at sea, there is widespread interest in the development of advanced systems for cooperative control of multiple autonomous marine vehicles. Central to the implementation of these systems is the availability of efficient algorithms for multiple vehicle path planning that can take explicitly into account the capabilities of each vehicle and existing environmental conditions. Examples include path planning to steer a group of marine vehicles and enable them to reach a specific target site simultaneously with a desired formation pattern, while avoiding inter-vehicle collisions, and online path replanning for a vehicle fleet upon detection of episodic events or obstacles. Multiple vehicle path planning methods build necessarily on key concepts and algorithms for single vehicle path following. However, they go one step further in that they must explicitly address such issues as inter-vehicle collision avoidance and simultaneous times of arrival. As such, they pose considerable challenges both from a theoretical and practical implementation standpoint. This paper is a brief survey of multiple vehicle path planning techniques. The exposition is focused on specific algorithms for path planning developed in the scope of research work in which the authors have participated. The algorithms make ample use of direct optimization methods that lead to efficient and fast techniques for path generation. The paper affords the reader a fast paced presentation of key algorithms that had their genesis in the aircraft field, discusses them critically, and suggests problems that warrant further consideration. 2009 IEEE.

Hausler, Andreas J., Reza Ghabcheloo, Antonio M. Pascoal, A. Pedro Aguiar, **Isaac I. Kaminer**, and **Vladimir N. Dobrokhodov**. "Temporally and Spatially Deconflicted Path Planning for Multiple Autonomous Marine Vehicles." ***8th International IFAC Conference on Manoeuvring and Control of Marine Craft, MCMC 2009, September 16, 2009 - September 18*** IFAC **Secretariat**, 2009:376-381.
http://dx.doi.org/10.3182/20090916-3-BR-3001.0069
Abstract: There is currently a surge of interest in the development of advanced systems for cooperative control of multiple autonomous marine vehicles. Central to the implementation of these systems is the availability of efficient algorithms for multiple vehicle path planning that can take explicitly into account the capabilities of each vehicle and existing environmental conditions. Multiple vehicle path planning methods build necessarily on key concepts and algorithms for single vehicle path following. However, they go one step further in that they must explicitly address intervehicle collision avoidance, together with a number of criteria that may include simultaneous times of arrival at the assigned target points and energy minimization, to name but a few. As such, they pose considerable challenges both from a theoretical and practical implementation standpoint. This paper is a short overview of multiple vehicle path planning

techniques. The exposition is focused on specific algorithms developed in the scope of research work in which the authors have participated. Namely, algorithms that ensure that at no time will two vehicles get closer in space than a desired safety distance, that is, achieve trajectory deconfliction. The algorithms make ample use of direct optimization methods that lead to efficient and fast techniques for path generation using a polynomial-based approach. The paper affords the reader a fast paced presentation of key algorithms that had their genesis in the aircraft field, discusses the results of simulations, and suggests problems that warrant further consideration. 2009 IFAC.

Hewgley, Charles W. and **Oleg A. Yakimenko**. "Precision Guided Airdrop for Vertical Replenishment of Naval Vessels." *20th AIAA Aerodynamic Decelerator Systems Technology Conference, May 4, 2009 - May 7* American Institute of Aeronautics and Astronautics Inc, 2009
Abstract: This paper addresses the investigation into the feasibility of the use of precision guided airdrop as a means to deliver cargo to naval vessels at sea. In this context, precision guided airdrop means delivering unmanned cargo packages that, once dropped from an aircraft at high altitude, have the capability to guide themselves to a precise landing point by controlling an aerodynamic decelerator (parafoil or parachute) to which the cargo package is attached. The paper describes the problem of replenishment of naval vessels at sea and describes the benefits that the application of precision airdrop might provide. Improved accuracy of aerial delivery systems is the major focus of analysis, and how the application of model predictive control has potential to achieve the necessary improvements in accuracy that would make shipboard landings possible. A simple example is developed of a model predictive control algorithm adapted to track a target landing area that is moving with constant velocity. Additional techniques are also surveyed, as well as other potential applications of precision airdrop to maritime operations.

Hurni, Michael A., **Pooya Sekhavat**, and **I. Michael Ross.** "Issues on UGV Optimal Motion Planning and Obstacle Avoidance." *Unlimited Conference, April 6, 2009 - April 9* American Institute of Aeronautics and Astronautics Inc, 2009
Abstract: We present two different optimal control problem formulations that can be used to solve various trajectory planning scenarios of an Unmanned Ground Vehicle (UGV). It is less a study of trajectory planning than it is an analysis of the optimal control planning method itself. Numerous issues regarding vehicle modeling, obstacle modeling and computational complexity are discussed. The results and recommendations presented in this work are quite simple concepts, but have not been covered in the literature of trajectory planning to the knowledge of the co-authors. Simulation results illustrate successful implementation in various scenarios.

Jones, Kevin D., Vladimir Dobrokhodov, **Isaac Kaminer**, **Deok Jin Lee**, **Eugene Bourakov**, and Michael R. Clement. "Development, System Integration and Flight Testing of a High-Resolution Imaging System for Small UAS." *47th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, January 5, 2009 - January 8* American Institute of Aeronautics and Astronautics Inc, 2009
Abstract: The development and flight testing of a high-resolution imaging system for small unmanned aircraft systems is described. The system utilizes an off-the-shelf camera coupled to an onboard computer and a wireless network to provide very high quality imagery from a very low cost platform with a simple web-based tasking and data retrieval interface. The project incorporates three primary developments: (i) control over a tactical wireless ad-hoc network, (ii) an advanced path-following flight control algorithm that couples the flight and camera control, and (iii) a remote control capability for the sensor. The camera is a dual use sensor, providing full frame/rate video as well as 12MP digital still images, and a gimbal provides a limited pointing capability. The path-following flight control system allows an untrained operator to scribble a path on a digital map, which becomes the ground-track for the sensor. The aircraft autonomously determines the optimal flight trajectory to keep the sensor footprint on this track. A robust wireless mesh network integrates the aircraft with the tactical network, offering control of autopilot and sensor functions from any other node on the network. The complete system is evaluated in the joint Cooperative Field Experiments conducted quarterly by U.S. Special

Operations Command and the Naval Postgraduate School, where operators put the system to use in realistic scenarios.

Kitsios, Ioannis, **Vladimir Dobrokhodov**, **Isaac Kaminer**, **Kevin D. Jones**, Enric Xargay, Naira Hovakimyan, Chengyu Cao, et al. "Experimental Validation of a Metrics Driven L1 Adaptive Control in the Presence of General Unmodeled Dynamics." *AIAA Guidance, Navigation, and Control Conference and Exhibit, August 10, 2009 - August 13* American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: The paper summarizes the results of an ongoing effort in the development and flight validation and verification of the metrics driven L1 adaptive flight control system. In particular, the paper develops a unified framework for design, implementation, validation and verification of flight critical control systems including: (i) definition of experimental control validation technique that accounts for control surface failures and generalized plant uncertainties or unmodeled dynamics; (ii) tuning the developed L1 adaptive controller to explicitly address performance metrics in the presence of control actuator/surface failures and modeling uncertainties under adverse flight conditions; (iii) development of a flight control system testing environment that includes both hardware and software setup for implementation of the resulting algorithms onboard of a small unmanned aerial vehicle; and (iv) designing and conducting of a comprehensive flight test validation and verification program that demonstrates performance of the proposed adaptive control algorithms in the presence of failures. Copyright 2009 by Kitsios, Dobrokhodov, Kaminer, Jones, Xargay, Hovakimyan, Cao, Lizarraga.

Kota, Srinivas, Michael Mace, Lalit Gupta, and **Ravi Vaidyanathan**. "A DCT-Gaussian Classification Scheme for Human-Robot Interface." *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2009, October 11, 2009 - October 15* IEEE Computer Society, 2009:5503-5508.
http://dx.doi.org/10.1109/IROS.2009.5354008

Abstract: The ultimate success of a human-robot-interface system depends on how accurately user control signals are classified. This paper is aimed at developing and testing a strategy to accurately classify human-robot control signals. The primary focus is on overcoming the dimensionality problem frequently encountered in the design of Gaussian multivariate signal classifiers. The dimensionality problem is overcome by selecting, using two different ranking criteria, a small set of linear combinations of the input signal space generated by the discrete cosine transform (DCT). The application of the resulting DCT-Gaussian signal classification strategy is demonstrated by classifying tongue-movement ear-pressure (TMEP) bioacoustic signals that have been proposed for control of an assistive robotic arm. Classification results show that the DCT-Gaussian classifiers outperform classifiers described in a previous study. Most noteworthy is the fact that the Gaussian multivariate control signal classifiers developed in this paper can be designed without having to collect a prohibitively large number of training signals in order to satisfy the dimensionality conditions. Consequently, the classification strategies will be especially beneficial for designing personalized assistive interfaces for individuals from whom only a limited number of training signals can reliably be collected due to severe disabilities. 2009 IEEE.

Lackey, Stephanie, Denise Nicholson, and William Becker. "What Can VR Do for U? Virtual Reality for Training Uninhabited Aircraft Systems." *53rd Human Factors and Ergonomics Society Annual Meeting 2009, HFES 2009, October 19, 2009 - October 23* Human Factors an Abstract: Ergonomics Society Inc, 2009:1986-1988.

The proliferation of Uninhabited Aircraft Systems (UAS) during forward deployed military operations presents compelling challenges to the training community. This presentation will examine how Virtual Reality (VR) technologies may be employed to instantiate novel training approaches targeted at UAS team coordination and tactics. The RQ-11 Raven-B, and its associated training issues will be used to illustrate challenges facing the U.S. Marine Corps. VR solutions currently applied to this domain and emerging research efforts will also be discussed.

Lee, Deok-Jin, **Klas Andersson**, and **Kevin D. Jones**. "Hybrid Control of Long Endurance Unmanned Aerial Vehicles for Robust Wireless Communication Networking**." AIAA Guidance, Navigation, and Control Conference and Exhibit, August 10, 2009 - August 13** American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: This paper presents an effective hybrid control approach for building stable wireless sensor networks between heterogeneous unmanned vehicles using high endurance aerial vehicles. For optimal deployment of the aerial vehicles in communication networks, a gradient descent based self-estimating control algorithm is utilized to locate the aerial platforms to maintain maximum communication throughputs between distributed multiple nodes. The autonomous aerial robots, which function as communication relay nodes, harness thermal energy from the atmosphere to improve their flight endurance within specified communication coverage areas. The rapidly-deployable communication networks with the high-endurance aerial vehicles can be used for various application areas including environment monitoring, surveillance, tracking, and decision-making support. Flight test and simulation studies are conducted to evaluate the effectiveness of the proposed hybrid control technique for robust communication networks. Copyright 2009 by Deok Jin Lee.

Lee, Deok-Jin, Khim Kam, **Isaac Kaminer, Douglas Horner**, **Anthony Healey**, **Sean Kragelund**, **Klas Andersson**, and **Kevin Jones**. "Wireless Communication Networks between Distributed *Autonomous Systems using Self-Tuning Extremum Control." Unlimited Conference, April 6, 2009 - April 9* American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: This paper represents an effective optimization approach for building high bandwidth wireless communication networks between distributed autonomous systems using unmanned aerial vehicles as airborne relay nodes. A self-tuning extremum control technique is developed to find an optimal location of the aerial vehicles to provide maximum communication throughputs. The idea behind the self-tuning control is to use an on-line gradient estimator to identify the derivative of a cost function and to use this as an input to a gradient-based hill-climbing algorithm. The on-line estimation of the gradient of a performance function is achieved by utilizing a perturbation-based peek-seeking approach which provides a quantitative gradient value of the cost function in a numerical way. Flight experiments are conducted to evaluate the performance of the proposed airborne wireless sensor networking control algorithm. Copyright 2009 by the authors.

Leve, Frederick A., George A. Boyarko, and Norman Fitz-Coy. "Optimization in Choosing Gimbal Axis Orientations of a CMG Attitude Control System." *Unlimited Conference, April 6, 2009 - April 9* American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: Control momentum gyros (CMGs) are often chosen for satellites where high attitude precision and torque are needed while using minimal input power. Control of these types of systems is complicated and is directly dependent on the number of actuators and their gimbal axis orientations with respect to the satellite body frame. This paper discusses the potential benefits of optimizing these gimbal axis configurations and compares these results to existing configurations such as the box, rooftop, and pyramid. A static optimization is performed to find the correct gimbal axis configuration in terms of Euler angles for an attitude control system (ACS) consisting of four CMGs. A four CMG configuration is chosen for minimal redundancy in avoiding singularities. The paper also proposed a method of reconfiguring the CMG gimbal axis orientations online. Reconfiguring the CMGs online can be beneficial to larger systems with deployables and/or systems with on-orbit assembly which can afford the mass and volume of extra mechanisms for onboard reconfiguration. Copyright 2009 by the American Institute of Aeronautics and Astronautics, Inc.

Li, Zhiyuan, **Vladimir Dobrokhodov**, Enric Xargay, Naira Hovakimyan, and **Isaac Kaminer.** "Development and Implementation of L1 Gimbal Tracking Loop Onboard of Small UAV." ***AIAA Guidance, Navigation, and Control Conference and Exhibit, August 10, 2009 - August 13*** American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: This work extends the earlier results of authors on passive vision-based tracking and motion estimation of a non-cooperating ground vehicle. The follower small unmanned air vehicle (UAV) is equipped with a single gimbaled pan/tilt camera and a high bandwidth wireless link for video and command transmitting. The objective is to control the UAV turn rate and gimbaled camera cooperatively to maintain a horizontal circular orbit about the target with a predefined radius, and to keep the target image in the center of the image frame, concurrently providing real-time estimation of the target's position, speed and heading. In this paper, a new L1 adaptive controller is designed for the gimbal pan control, which provides guaranteed transient performance in the presence of disturbances and model uncertainty. The target velocity estimation problem is formulated such that the recently developed L1 fast adaptive estimator can be applied. We give a rigorous proof of asymptotic stability for the guidance law for the static target case, and provide a reformulation of the control objective for the moving target case so that the existing controller can be applied naturally. The impact of target loss events on the control and estimation algorithms is also analyzed. Copyright 2009 by Zhiyuan Li.

Lizarraga, Mariano I., **Vladimir Dobrokhodov,** Gabriel H. Elkaim, Renwick Curry, and **Isaac Kaminer**. "Simulink Based Hardware-in-the-Loop Simulator for Rapid Prototyping of UAV Control Algorithms." ***Unlimited Conference, April 6, 2009 - April 9*** American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: This paper describes a recently developed architecture for a Hardware-in-the-Loop simulator for Unmanned Aerial Vehicles. The principal idea is to use the advanced modeling capabilities of Simulink rather than hard-coded software as the flight dynamics simulating engine. By harnessing Simulink's ability to precisely model virtually any dynamical sys- tem or phenomena this newly developed simulator facilitates the development, validation and verification steps of flight control algorithms. Although the presented architecture is used in conjunction with a particular commercial autopilot, the same approach can be easily implemented on a flight platform with a different autopilot. The paper shows the implementation of the flight modeling simulation component in Simulink supported with an interfacing software to a commercial autopilot. This offers the academic community numerous advantages for hardware-in-the-loop simulation of flight dynamics and control tasks. The developed setup has been rigorously tested under a wide variety of conditions. Results from hardware-in-the-loop and real flight tests are presented and compared to validate its adequacy and assess its usefulness as a rapid prototyping tool. Copyright 2009 by the American Institute of Aeronautics and Astronautics, Inc.

Lock, Richard J., **Ravi Vaidyanathan**, Stuart C. Burgess, and Roger D. Quinn. "Impact of Passive Stiffness Variation on Stability and Mobility of a Hexapod Robot." ***2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2009, July 14, 2009 - July 17*** Institute of Electrical and Electronics Engineers Inc, 2009:980-986
http://dx.doi.org/10.1109/AIM.2009.5229714

Abstract: This paper presents a biologically inspired approach to simulation design for a walking hexapod robot with focus on the parameter selection of critical values (e.g. joint stiffness) for robot performance. The fundamental aim is to mimic key aspects within a dynamic simulation environment to develop a clearer picture of the tradeoffs that biological systems naturally regulate. Although the importance of compliance in locomotion and disturbance rejection is well established in robotics, the actual design selection of system parameters involving tradeoffs between active movement, passive disturbance rejection, and energy minimization remain a challenging design task for mobile robots. We present initial work aimed at resolving this issue for the design optimization of a 20:1 scale Blaberus discoidalis cockroach robot through a simulation environment where complex interactions between passive stabilization and active

walking may be examined in detail with respect to energy consumption and robotic performance. 2009 IEEE.

Slegers, Nathan J. and **Oleg A. Yakimenko.** "Optimal Control for Terminal Guidance of Autonomous Parafoils." *20th AIAA Aerodynamic Decelerator Systems Technology Conference, May 4, 2009 - May 7* American Institute of Aeronautics and Astronautics Inc, 2009

Abstract: This paper deals with the development of guidance, navigation and control algorithms for a prototype of a miniature aerial delivery system capable of high-precision maneuvering and high touchdown accuracy. High accuracy enables use in precision troop resupply, sensor placement, urban warfare reconnaissance, and other similar operations. Specifically, this paper addresses the terminal phase, where uncertainties in winds cause most of the problems. The paper develops a six degree-of-freedom model to adequately address dynamics and kinematics of the prototype delivery system and then reduces it to a two degrees-of-freedom model to develop a model predictive control algorithm for reference trajectory tracking during all stages. Reference trajectories are developed in the inertial coordinate frame associated with the target. The reference trajectory during terminal guidance, just prior to impact, is especially important to the final accuracy of the system. This paper explores an approach for generating reference trajectories based on the inverse dynamics in the virtual domain. The method results in efficient solution of a two-point boundary-value problem onboard the aerial delivery system allowing the trajectory to be generated at a high rate, mitigating effects of the unknown winds. This paper provides derivation of the guidance and control algorithms and present analysis through simulation. Copyright 2009 by N. Slegers and O. Yakimenko.

Wolfgang, Baer. "Live/virtual Cognitive Systems Simulation." *9th WSEAS International Conference on Applied Computer Science, ACS '09, October 17, 2009 - October 19* World Scientific and Engineering Academy and Society, 2009:56-61

Abstract: Evidence from neuroscience, physics, and cognitive sciences suggest that conscious experience involves a feedback loop between the sensor plane and the memories that hold the explanation of those sensory experiences. If modeled as a loop in time the resulting event provides a basis for a Whitheadean interpretation of Quantum Theory that eliminates the vonNeuman division between the classic and quantum worlds. I will show that live cognitive systems, serving as operators in a control room, when replaced by such cognitive loops can be treated on the same footing as the quantum systems they observe. This implies our personal every day cognitive experiences must be recognized as quantum phenomena in a new integrated world view that provides a theoretical basis for quantum computation in biological systems at room temperature. I will then discuss the applications for the simulation of the sensor-memory feedback loop in conventional computer machinery. Though such an implementations only mimics cognitive operations they can provide a new class of image recognition and real world knowledge generation algorithms that are useful in cases where simple real world models are adequate. One such applications is encountered on top down earth models describing the explanation for sensor measurements from Unmanned Aerial Vehicles (UAV). Experiments conducted in support of the development of UAV vision systems will then be reviewed and the future for cognitive vision systems discussed.

Xargay, Enric, **Vladimir Dobrokhodov**, **Ioannis Kitsios**, **Isaac Kaminer**, **Kevin D. Jones**, Naira Hovakimyan, Chengyu Cao, Mariano I. Lizarraga, and Irene M. Gregory. "Flight Validation of a Metrics Driven L1 Adaptive Control in the Presence of General Unmodeled Dynamics." *2009 IEEE International Conference on Control and Automation, ICCA 2009, December 9, 2009 - December 11* IEEE Computer Society, 2009:2243-2248
http://dx.doi.org/10.1109/ICCA.2009.5410355

Abstract: The paper summarizes the results of an ongoing effort in the development and flight validation and verification of the metrics driven L1 adaptive flight control system. In particular, the paper develops a unified framework for design, implementation, validation and verification of flight critical control systems including: (i) definition of experimental control validation technique that accounts for generalized plant uncertainties or unmodeled dynamics; (ii) tuning the

developed L1 adaptive controller to explicitly address performance metrics in the presence of modeling uncertainties under adverse flight conditions; (iii) development of a flight control system testing environment for implementation of the resulting algorithms onboard of a small unmanned aerial vehicle; and (iv) designing and conducting of a comprehensive flight test validation and verification program that demonstrates performance of the proposed adaptive control algorithm. 2009 IEEE.

Yakimenko, Oleg A., Nathan J. Slegers, **Eugene A. Bourakov**, **Charles W. Hewgley**, **Alex B. Bordetsky**, Red P. Jensen, Andrew B. Robinson, Josh R. Malone, and Phil E. Heidt. "Mobile System for Precise Aero Delivery with Global Reach Network Capability." ***2009 IEEE International Conference on Control and Automation***, ICCA 2009, December 9, 2009 - **December 11** IEEE Computer Society, 2009:1394-1398
http://dx.doi.org/10.1109/ICCA.2009.5410590
Abstract: This paper discusses the current status of the development of the mobile aerial delivery system to be further employed in a variety of different applications. High accuracy of the developed system enables its use in precision troop resupply, precise sensors placement, urban warfare reconnaissance and other similar operations. This paper overviews the overall system architecture and components of the developed aero delivery system itself and then proceeds with describing the current status of integrating it with an advanced deployment platform, unmanned aerial system, to achieve mobility and autonomy of operations. The paper also discusses some other systems in development pursuing similar goals and reviews some novel applications that become possible with the developed aerial delivery system. 2009 IEEE.

2008

Aguiar, A. Pedro, Antonio M. Pascoal, **Isaac Kaminer**, **Vladimir Dobrokhodov,** Enric Xargay, Naira Hovakimyan, Chengyu Cao**,** and Reza Ghabcheloo. "Time-Coordinated Path Following of Multiple UAVs Over Time-Varying Networks using L1 Adaptation." ***AIAA Guidance, Navigation and Control Conference and Exhibit, August 18, 2008 - August 21*** American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: Motivated by challenging mission scenarios, this paper tackles the problem of multi-Unmanned Aerial Vehicle (UAV) cooperative control in the presence of time-varying communication networks. Specifically, we address the problem of steering a fleet of UAVs along given paths (path following) so as to meet spatial and/or temporal constraints. One possible scenario is the situation where a fleet of vehicles is tasked to execute collision-free maneuvers under strict spatial constraints and arrive at their final destinations at exactly the same time. The paper builds on previous work by the authors on coordinated path following and extends it to allow for time-varying communication topologies. Path following control in 3D builds on a nonlinear control strategy that is first derived at the kinematic level (outer-loop control). This is followed by the design of an L1 adaptive output feedback control law that effectively augments an existing autopilot and yields an inner-outer loop control structure with guaranteed performance. Multiple vehicle time-critical coordination is achieved by enforcing temporal constraints on the speed profiles of the vehicles along their paths in response to information exchanged over a dynamic communication network. We address explicitly the situation where each vehicle transmits its coordination state to only a subset of the other vehicles, as determined by the communications topology adopted. Further, we consider the case where the communication graph that captures the underlying communication network topology may be disconnected during some interval of time (or may even fail to be connected at any instant of time) and provide conditions under which the complete coordinated path following closed-loop system is stable. Hardware-in-the-Loop (HITL) simulation results demonstrate the benefits of the

developed algorithms. ; 2008 by A. P. Aguiar, I. Kaminer, R. Ghabcheloo, A. M. Pascoal, E. Xargay, N. Hovakimyan, C. Cao, V. Dobrokhodov.

Ball, Gregory P., **Kevin Squire**, **Craig Martell**, and **Man-Tak Shing**. "MAJIC: A Java Application for Controlling Multiple, Heterogeneous Robotic Agents." ***19th IEEE/IFIP International Symposium on Rapid System Prototyping, RSP 2008, June 2, 2008 - June 5*** Inst. of Elec. and Elec. Eng. Computer Society, 2008:189-195
http://dx.doi.org/10.1109/RSP.2008.30
Abstract: When teaching robotics, we have a number of constraints and desires to satisfy. We are limited by the time available to teach a class, so we need a robotic system that our students can get up to speed on quickly and easily. We are limited by robot availability, in the robots that are on hand, but also because manufacturers of inexpensive teaching robots tend to go bankrupt or change focus quickly, making it difficult to purchase new robots with the same interface as previous models. Thus, we desire an interface easily adaptable to new robots. Finally, we have recently become interested in teaching techniques for dealing with teams of possibly heterogeneous robots. All existing systems that we examined fall short in one or more of these areas, prompting our development of the The Multi-Agent Java Interface Controller (MAJIC). MAJIC was designed from the bottom up with modern software engineering principles. The interface is easy to use and learn, can be quickly adapted to new robots, and allows control of multiple robots simultaneously. This paper presents the design of this system, highlighting rapid development and clarity compared with other systems. DOI 10.1109/RSP.2008.30.

Bollino, Kevin P. and **L. Ryan Lewis**. "Collision-Free Multi-UAV Optimal Path Planning and Cooperative Control for Tactical Applications." ***AIAA Guidance, Navigation and Control Conference and Exhibit, August 18, 2008 - August 21*** American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: Stemming from previous work that addressed the optimal path planning of an unmanned aerial vehicle (UAV) in obstacle-rich environments, this paper demonstrates the approach's scalability to that of a multi-UAV application. The proposed concept, based on optimal control techniques and pseudospectral methods, offers the improved system flexibility and autonomy demanded by UAV tactical missions in urban areas. As demonstrated, employing optimal control methods for path planning problems provides a simplistic yet powerful capability of flight trajectory optimization that includes simultaneous collision avoidance between vehicles and terrain obstacles. Departing from traditional techniques that harbor non-optimal architectures, the employed method facilitates real-time, onboard computations that may potentially improve overall system performance. Recent developments in the field of optimal control theory point at an emerging paradigm shift that may involve less dependency on the typical inner-loop control. Extending these developments, this paper provides not only a fresh perspective, but also illustrates a viable technique for efficiently generating maneuvering flight trajectories for single vehicles or multiple vehicle sorties.

Cheney, Margaret and **Brett Borden**. "Imaging that Exploits Spatial, Temporal, and Spectral Aspects of Far-Field Radar Data." ***Algorithms for Synthetic Aperture Radar Imagery XV, March 17, 2008 - March 18*** SPIE, 2008:The International Society for Optical Engineering (SPIE)
http://dx.doi.org/10.1117/12.777416
Abstract: We develop a linearized imaging theory that combines the spatial, temporal, and spectral aspects of scattered waves. We consider the case of fixed sensors and a general distribution of objects, each undergoing linear motion; thus the theory deals with imaging distributions in phase space. We derive a model for the data that is appropriate for any waveform, and show how it specializes to familiar results when the targets are far from the antennas and narrowband waveforms are used. We develop a phase-space imaging formula that can be interpreted in terms of filtered backprojection or matched filtering. For this imaging approach, we derive the corresponding point-spread function. We show that special cases of the theory reduce to: a) Range-Doppler imaging, b) Inverse Synthetic Aperture Radar (ISAR), c) Spotlight Synthetic Aperture Radar (SAR), d) Diffraction Tomography, and e) Tomography of

Moving Targets. We also show that the theory gives a new SAR imaging algorithm for waveforms with arbitrary ridge-like ambiguity functions.

Chung, Timothy H. and Joel W. Burdick. "Multi-Agent Probabilistic Search in a Sequential Decision-Theoretic Framework." *2008 IEEE International Conference on Robotics and Automation, ICRA 2008, May 19, 2008 - May 23* Institute of Electrical and Electronics Engineers Inc, 2008:146-151
http://dx.doi.org/10.1109/ROBOT.2008.4543200
Abstract: Consider the task of searching a region for the presence or absence of a target using a team of multiple searchers. This paper formulates this search problem as a sequential probabilistic decision, which enables analysis and design of efficient and robust search control strategies. Imperfect detections of the target's possible locations are made by each search agent and shared with teammates. This information is used to update the evolving decision variable which represents the belief that the target is present in the region. The sequential decision-theoretic formulation presented in this paper provides an analytic framework to evaluate team search systems, as it includes a performance metric (time until decision), a measure of uncertainty (decision confidence thresholds) and imperfect information gathering (detection error). Strategies for cooperative search are evaluated in this context, and comparisons between homogeneous and hybrid search strategies are investigated in numerical studies. 2008 IEEE.

Dobrokhodov, Vladimir, **Ioannis Kitsios**, **Isaac Kaminer**, **Kevin D. Jones**, Enric Xargay, Naira Hovakimyan, Chengyu Cao, Mariano I. Lizarraga, and Irene M. Gregory. "Flight Validation of a Metrics Driven L1 Adaptive Control." *AIAA Guidance, Navigation and Control Conference and Exhibit, August 18, 2008 - August 21* American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: The paper addresses initial steps involved in the development and flight implementation of new metrics driven L1 adaptive flight control system. The work concentrates on (i) definition of appropriate control driven metrics that account for the control surface failures; (ii) tailoring recently developed L1 adaptive controller to the design of adaptive flight control systems that explicitly address these metrics in the presence of control surface failures and dynamic changes under adverse flight conditions; (iii) development of a flight control system for implementation of the resulting algorithms onboard of small UAV; and (iv) conducting a comprehensive flight test program that demonstrates performance of the developed adaptive control algorithms in the presence of failures. As the initial milestone the paper concentrates on the adaptive flight system setup and initial efforts addressing the ability of a commercial off-the-shelf autopilot with and without adaptive augmentation to recover from control surface failures.

Hall, Janson S. and **Marcello Romano**. "Control of Satellites with Minimum Number of Control Actuators." *31st Annual AAS Rocky Mountain Guidance and Control Conference*, **February 1, 2008 - February 6** Univelt Inc, 2008:61-80
Abstract: Within the framework of a growing need for rapid and continuous space situational awareness, autonomous on-orbit assembly of small spacecraft is being investigated as a possible alternative method to the use of monolithic large spacecraft. In this paper, a novel six degrees of freedom (6-DoF) State Control System (SCS) is presented which uses a minimal set of actuators composed of two thrusters with hemispherical vectoring capability and one paired thruster combination. This control system and actuator architecture is proposed as a possible alternative to conventional fixed thruster architecture for rapidly de-ployable, lower-cost, lower-mass spacecraft. The potential advantages include simplifying the spacecraft design and reducing the required fuel and size of the propulsion system while providing the requisite 6-DoF controllability for proximity spacecraft maneuvers. This paper presents the dynamics model of the proposed unconventional spacecraft architecture and the demonstration of small-time-local controllability through Lie Algebra methods. Additionally, the input-output linearizability of the nonlinear Multi-Input Multi-Output system is developed through nonlinear control theory. Furthermore, a feedback linearized control law is designed in order to control the feedback linearized system with a standard Linear Quadratic Regulator. The analytical results are validated on a reduced model

(3-DoF) by exploiting the Autonomous Multi-Agent Physically Interacting Spacecraft Simulator (AMPHIS) test bed of the Spacecraft Robotics Laboratory. This testbed consists of a spacecraft robotic simulator floating via planar air bearing on a flat horizontal floor. The robotic simulator is provided with a mini-control moment gyroscope and two semi-circular rotating thrusters. Both the analytical and experimental results are presented to demonstrate the promising nature of a minimally control architecture for small spacecraft during autonomous proximity operations.

Harada, Masanori and **Kevin Bollino**. "Minimum Fuel Circling Flight for Unmanned Aerial Vehicles in a Constant Wind." ***AIAA Guidance, Navigation and Control Conference and Exhibit***, **August 18, 2008 - August 21** American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: This paper investigates characteristics of minimum-fuel trajectories for an Unmanned Aerial Vehicle (UAV) in high altitude, circling flight under a constant wind. Previous research has shown that periodic circling flight, consisting of a boost arc (maximum thrust) and a coast arc (minimum thrust), improves the fuel consumption when compared to steady-state circling. Since the periodic flight includes ascending flight at the boost arc and descending flight at the coast arc, it is naturally expected that the wind energy influences the trajectories. In this work, numerical simulations are used to investigate the effects of both wind speed and direction on a UAV flying around one loop enclosed in a cylindrical boundary area. The results show that the optimal wind direction manifests as a tail wind just at the coast arc. In addition, the results demonstrate that the optimal wind direction changes with the wind speed and, in some cases, the trajectory under high winds results in smaller fuel consumption than the zero wind case. Thus, the importance of these results is two fold. First, that the periodic flight reveals the existence of an optimal wind direction for the minimum fuel circling. Second, and probably more importantly, generating optimal trajectories without rejecting wind disturbances provides an autonomous capability of using wind to its advantage and therefore improving fuel consumption or perhaps other mission performance metrics. 2008 by the American Institute of Aeronautics and Astronautics, Inc.

Harkins, Richard H., Thomas Dunbar, Alexander S. Boxerbaum, Richard J. Bachmann, Roger D. Quinn, **Ravi Vaidyanathan**, and Stuart C. Burgess. "Confluence of Active and Passive Control Mechanisms Enabling Autonomy and Terrain Adaptability for Robots in Variable Environments." ***Advances in Electrical and Electronics Engineering - IAENG Special Edition of the World Congress on Engineering and Computer Science 2008, WCECS 2008***, October 22, 2008 - October 24 IEEE Computer Society, 2008:138-149
http://dx.doi.org/10.1109/WCECS.2008.25
Abstract: We report the successful design and fabrication of an autonomous robot, dubbed the CASE/NPS Beach Whegs robot, capable of navigating the challenging terrain of the non-submersed surf-zone region based on abstracted biological inspiration. Abstracted biological inspiration attempts to distill salient biological principles and implement them using presently available technologies; its efficacy lies in the successful fusion of organic and inorganic architectures such that the proper level of influence of biology is established for optimum performance. The CASE/NPS Beach Whegs" robot benefits from insect inspired mechanisms of locomotion for movement over challenging and different terrains. The robot's mechanics are an integrated and essential part of its control system. It does not have, or need, sensors and control circuits to actively change its gait. Instead, its mechanics cause it to passively adapt its gait appropriately to very different terrains. Therefore, its motor control circuits are reduced to controlling broad directives of the robot. Its navigational system is a higher-level circuit that communicates desired speed and heading to the local control system. The confluence of active and passive control mechanisms in the robot have resulted in a system with the simplicity of a wheeled vehicle that nevertheless facilitates the mobility of a legged vehicle. 2008 IEEE.

Hurni, Michael A., **Pooya Sekhavat**, and **I. Michael Ross**. "Autonomous Trajectory Planning using Real-Time Information Updates." *AIAA Guidance, Navigation and Control Conference and Exhibit*, **August 18, 2008 - August 21** American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: We present a dynamic optimal control method for autonomous trajectory planning and control of an Unmanned Ground Vehicle (UGV) using real-time information updates. The objective of the UGV is to traverse from an initial start point and reach its goal in minimum time, with maximum robustness, while avoiding both static and dynamic obstacles. This is achieved by deriving the control solution that carries out the initial planning problem while minimizing a cost and satisfying constraints based on the initial global knowledge of the area. To combat the problem of inaccurate global knowledge and a dynamic invironment, the UGV uses its sensors to map the locally detected change in the environment and continuously updates its global map to re-compute a control solution that can achieve an optimal trajectory to the goal. Simulation results illustrate successful implementation of the method in various scenarios.

Lee, **Deok-Jin**. "Unscented Information Filtering for Distributed Estimation and Multiple Sensor Fusion." *AIAA Guidance, Navigation and Control Conference and Exhibit*, August 18, 2008 - August 21 American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: This paper represents distributed estimation and multiple sensor information fusion using an unscented information filtering algorithm. The proposed information fusion algorithm is developed by embedding the unscented transformation method used in the sigma point filter into the extended information filtering architecture, and its algorithm is further extended for distributed estimation in hierarchical sensor networks. The new information fusion filter achieves not only the accuracy and robustness of the sigma point filter, but also the flexibility of the information filter for multiple sensor estimation in distributed sensing networks. Performance comparison of the proposed sensor fusion filter with the extended information filter is demonstrated through a simple target-tracking simulation study. 2008 by the American Institute of Aeronautics and Astronautics, Inc.

Lee, **Deok-Jin** and Kyle T. Alfriend. "Additive Divided Difference Filtering for Attitude Estimation using Modified Rodrigues Parameters." *Landis Markley Astronautics Symposium*, June 29, 2008 - July 2 Univelt Inc, 2008:401-421
Abstract: In this paper, a real-time attitude estimation algorithm is derived by using an additive divided difference filter as an efficient alternative to the extended Kalman filter. To make the attitude filtering algorithm suitable for real-time applications and to minimize the computational load, a square-root sigma point attitude filter is designed by integrating the divided difference filter with the additive noise concept using the modified Rodrigues attitude parameters. The new attitude filter provides numerically stable and accurate estimates of the state and covariance, but the computational workload of the new attitude estimator is almost identical to the computational complexity of the extended Kalman attitude filter. For performance evaluation the new sigma point attitude filter is compared with the unscented attitude filter and the extended Kalman filter. The sensor measurements include a three-axis magnetometer and rate-gyros. Simulation results indicate that the proposed additive divided difference attitude filter shows faster convergence with accurate and reliable estimation.

Lee, **Deok-Jin**, **Isaac Kaminer**, **Vladimir Dobrokhodov**, and **Kevin D. Jones**. "Feature Following and Distributed Navigation Systems Development for a Small Unmanned Aerial Vehicle with Low-Cost Sensors." *AIAA Guidance, Navigation and Control Conference and Exhibit*, August 18, 2008 - August 21 American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: This paper represents the development of feature following control and distributed navigation algorithms for a small unmanned aerial vehicle equipped with a low-cost sensor unit. An efficient map-based feature generation and following control algorithm is developed. A distributed navigation system is designed for real-time attitude, position, and velocity estimation of the unmanned aircraft with a cascade filtering architecture, resulting in a fault-tolerant navigation system. The performance of the proposed feature following control and the cascaded

navigation algorithm is demonstrated in both hardware-in-the-loop simulation and real flight test with application to feature tracking with a stabilized gimbaled camera onboard a small unmanned aerial vehicle. 2008 by the American Institute of Aeronautics and Astronautics, Inc.

Luqi and Douglas S. Lange. "Schema Changes and Historical Information in Conceptual Models in Support of Adaptive Systems." ***1st International Active Conceptual Modeling of Learning Workshop***, November 8, 2006 - November 8 Springer Verlag, 2006:112-121
http://dx.doi.org/10.1007/978-3-540-77503-4_9
Abstract: Conceptual changes and historical information have not been emphasized in traditional approaches to conceptual modeling such as the entity-relationship approach. Effective representations for such changes are needed to support robust machine learning and computer-aided organizational learning. However, these aspects have been modeled and studied in other contexts, such as software maintenance, version control, software transformations, etc. This paper reviews some relevant previous results, shows how they have been used to simplify conceptual models to help people make sense out of complex changing situations, and suggests some connections to conceptual models of machine learning. Areas where research is required to support conceptual models for adaptive systems are also explored. These are suggested by studies of the issues surrounding deployment of adaptive systems in mission critical environments. 2008 Springer-Verlag Berlin Heidelberg.

Ma, Lili, Chengyu Cao, Naira Hovakimyan, **Vladimir Dobrokhodov**, and **Isaac Kaminer**. "Adaptive Vision-Based Guidance Law with Guaranteed Performance Bounds for Tracking a Ground Target with Time-Varying Velocity." ***AIAA Guidance, Navigation and Control Conference and Exhibit***, August 18, 2008 - August 21 American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: This work extends the earlier results of authors on vision-based tracking of a ground vehicle moving with unknown time-varying velocity. The follower UAV is equipped with a single camera. The control objective is to regulate the 2D horizontal range between the UAV and the target to a constant. The extension in this paper has two distinct features. The earlier developed guidance law used the estimates of the target's velocity obtained from a fast estimation scheme. In this paper, we prove guaranteed performance bounds for the fast estimation scheme and explicitly derive the tracking performance bound as a function of the estimation error. The performance bounds imply that the signals of the closed-loop adaptive system remain close to the corresponding signals of a bounded closed-loop reference system both in transient and steady-state. The reference system is introduced solely for the purpose of analysis. This paper also analyzes the stability and the performance degradation of the closed-loop adaptive system in the presence of out-of-frame events, when continuous extraction of the target's information is not feasible due to failures in the image processing module. The feedback loop is then closed using the frozen estimates. The out-of-frame events are modelled as brief instabilities. A sufficient condition for the switching signal is derived that guarantees graceful degradation of performance during target loss. The results build upon the earlier developed fast estimation scheme of the target's velocity, the inverse-kinematics-based guidance law and insights from switching systems theory.

McCamish, Shawn B., **Marcello Romano**, Simon Nolet, Christine M. Edwards, and David W. Miller. "Ground and Space Testing of Multiple Spacecraft Control during Close-Proximity Operations." ***AIAA Guidance, Navigation and Control Conference and Exhibit***, August 18, 2008 - August 21 American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: A multiple spacecraft close-proximity control algorithm was implemented and tested with the Synchronized Position Hold Engage and Reorient Experimental Satellites (SPHERES) facility onboard the International Space Station (ISS). During flight testing, a chaser satellite successfully approached a virtual target satellite, while avoiding collision with a virtual obstacle satellite. This research contributes to the control of multiple spacecraft for emerging missions, which may require simultaneous gathering, rendezvous, and docking. The unique control algorithm was developed at NPS and integrated onto the MIT SPHERES facility. The control

algorithm implemented combines the efficiency of the Linear Quadratic Regulator (LQR), and the robust collision avoidance capability of the Artificial Potential Function method (APF). The LQR control effort serves as the attractive force toward goal positions, while the APF-based repulsive functions provide collision avoidance for both fixed and moving obstacles. The amalgamation of these two control methods into a multiple spacecraft close-proximity control algorithm yielded promising results as demonstrated by simulations performed at NPS. Comprehensive simulation evaluation enabled implementation and testing of the spacecraft control algorithm on the SPHERES facility at MIT. Finally, successful ground testing enabled execution of flight testing onboard the ISS. The NPS's Spacecraft Robotics Laboratory (SRL) and MIT's Space Systems Laboratory (SSL) simulations, the MIT's SSL SPHERES ground testing, and the SPHERES flight testing results are all presented in this paper. 2008 by Shawn B. McCamish and Simon Nolet.

Thunberg, Carl and Anthony P. Tvaryanas. "Human-Centered Ground Control Station Design: The Predator/Reaper Approach." ***AUVSI Unmanned Systems North America Conference 2008***, June 10, 2008 - June 12 Association for Unmanned Vehicle Systems International, 2008:395-409 Abstract: There is an emerging understanding of unmanned aircraft as complex, distributed systems rather than simply aircraft, a perspective formally captured in the preferred term of reference of unmanned aircraft system. Implicit in this systems view should be the comprehension that the Ground Control Station (GCS) plays a significant role in defining the overall attributes of a UAS. In the case of the U.S. Air Force's MQ-1 Predator and MQ-9 Reaper UAS programs, acknowledgement of this fact has led to a comprehensive initiative led by - the Advanced Cockpit program - to overhaul the underlying GCS architecture and core human-machine interface. A significant challenge in addressing GCS design and crewmember performance, however, is the relatively immaturity of the state of the art in human factors engineering for this specific application. This paper details the Predator/Reaper program office's strategy for meeting this challenge - a coordinated systems engineering approach built around a proven human-centered design process and focused on making usability the primary attribute of the system. In so doing, the Advanced Cockpit program will allow the Air Force to make maximal use of its most expensive resource, namely its human capital, while providing enhanced and new capabilities to the joint force.

Vaidyanathan, Ravi, Troy S. Prince, Mohammad Modarreszadeh, and Frederick J. Lisy. "Computationally Efficient Predictive Adaptive Control for Robot Control in Dynamic Environments and Task Domains." ***2008 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS***, September 22, 2008 - September 26 Inst. of Elec. and Elec. Eng. Computer Society, 2008:3306-3311
http://dx.doi.org/10.1109/IROS.2008.4650926
Abstract: This paper presents the tuning and implementation of a computationally efficient adaptive predictive control algorithm for robotic utility. The controller addresses the need for practical, computationally efficient, robust real-time adaptive control for multivariable robotic systems. It exploits a special matrix representation to obtain substantial reductions in the computational expense relative to standard methods. We report the design, modeling, and implementation of the controller on a simple pick-and-place manipulator and on an industrial robot loading heavy shells within the magazine of a naval vessel. The proposed controller demonstrates the ability to adapt to varying actuator performance and rapidly changing sea states. Future work involves the implementation and testing of the controller during actual naval operations. We believe this work may serve as a foundation to address control issues for robots working in uncertain dynamic environments and provide a basis for design and control of shipboard robotic devices. 2008 IEEE.

Yakimenko Jr., Oleg A., Douglas P. Horner, and Douglas G. Pratt. "AUV Rendezvous Trajectories Generation for Underwater Recovery." ***2008 Mediterranean Conference on Control and Automation, MED'08***, June 25, 2008 - June 27 Inst. of Elec. and Elec. Eng. Computer Society, 2008:1192-1197
http://dx.doi.org/10.1109/MED.2008.4601975

Abstract: For many years, autonomous underwater vehicles (AUVs) have been developed and employed for a myriad of tasks. Their ability to accurately collect and monitor oceanic conditions makes them a valuable asset for a variety of naval missions. Deploying and recovering AUVs, however, is currently largely limited to surface vessels or swimmers. The purpose of this paper is to demonstrate that by using a mathematical technique called a direct method of calculus of variations, it is possible for an AUV to autonomously compute and execute a trajectory that will allow for recovery by a submerged mobile recovery system (another AUV, submarine, etc.). The algorithm ensures that a smooth trajectory is produced that, while not traditionally optimal, is realistic and still close to the optimal solution. Also, using this technique allows the trajectory to be computed very rapidly allowing it to be recomputed every couple of seconds to accommodate sudden changes, possible adjustments and different disturbances, and therefore to be used in the real life. 2008 IEEE.

Yakimenko, Oleg A., Yunjun Xu, and Gareth Basset. "Computing Short-Time Aircraft Maneuvers using Direct Methods." ***AIAA Guidance, Navigation and Control Conference and Exhibit***, August 18, 2008 - August 21 American Institute of Aeronautics and Astronautics Inc, 2008
Abstract: This paper analyzes applicability of direct methods to optimize short-term spatial maneuvers of the general aircraft (unmanned vehicle) in a faster than real-time scale. It starts by introducing different basic control schemes employing online trajectory generation. Then, it deals with developing a simplified three-degree-of-freedom vehicle model based upon an analytically presented drag polar, and proceeds with the formulation of a minimum-time optimization problem. Next, it presents and analyzes the results obtained through two most recently developed direct transcript (collocation) methods: the Gauss pseudospectral method (GPOCS) and the Legendre-Gauss-Lobatto pseudospectral method (DIDO). The paper further proceeds with the analysis and synthesis of the optimal control for the same two-point boundary-value problem using the Pontryagin's Maximum (Minimum) Principle, followed by another set of direct method simulations incorporating more realistic boundary conditions. Finally, the results achieved using the third direct method, based on inverse dynamics in the virtual domain, are presented and discussed. The paper ends with conclusions. 2008 by the American Institute of Aeronautics and Astronautics, Inc.

Zhao, Hongchao, Ruchuan Zhang, and Hongyun Yu. "Extended Proportional Navigation Guidance Law for Anti-Warship Missile Based on Lyapunov Stability." ***7th World Congress on Intelligent Control and Automation, WCICA'08***, June 25, 2008 - June 27 Institute of Electrical and Electronics Engineers Inc, 2008:8245-8249.
http://dx.doi.org/10.1109/WCICA.2008.4594219

Abstract: An extended proportional navigation guidance (EPNG) law based on Lyapunov stability is proposed applying the concept of virtual target and 3-dimensional pursuit-evasion model. This guidance law can satisfy the requirements of miss distance and terminal angle, thus it guarantees that different parts of the large-airspace varying trajectory link smoothly. Guided by this guidance law an anti-warship missile realizes various forms of large-airspace varying trajectory. Adopting the large-airspace variable trajectory, an anti-warship missile can improve its maneuverability and penetration ability. The simulation results show the effectiveness of the proposed extended proportional navigation guidance law based on Lyapunov stability. 2008 IEEE.

Ahner, Darryl K. and Arnold Buss. "Scheduling of Army UAVs Accounting for the Uncertainty of Attrition." ***2007 AIAA InfoTech at Aerospace Conference***, May 7, 2007 - May 10 American Institute of Aeronautics and Astronautics Inc, 2007:809-820.
Abstract: The Assignment Scheduling Capability for Unmanned Aerial Systems (ASC-U) is a scheduling model whose objective is to maximize the combat value through the assignment of payloads and air vehicles (AVs) while considering location of units, Unmanned Aerial System (UAS) components, control devices and location and duration of payload demands. The model assigns available UAS capabilities (AV, control means, mission payloads, etc.) using an approximate dynamic programming approach while considering the constraints of the demand (mission type, location, duration, etc.) and the attributes and performance characteristics of the UAS capabilities. To account for attrition, we further develop ASC-U using an adaptive dynamic programming approach to scheduling air vehicles with a focus on accounting for the uncertainty of attrition.

Bollino, Kevin P. and L. Ryan Lewis. "Optimal Path Planning and Control of Tactical Unmanned Aerial Vehicles in Urban Environments." ***Unmanned Systems North America Conference 2007***, August 6, 2007 - August 9 Association for Unmanned Vehicle Systems International, 2007:96-109
Abstract: This paper introduces a new approach to the onboard command and control of unmanned aerial vehicles (UAV) with particular focus on optimal path planning in obstacle-rich environments. The proposed concept, based on optimal control techniques and pseudospectral methods, offers the improved system flexibility and autonomy demanded by UAV tactical missions in urban areas. As demonstrated, optimal control methods permit the optimization of maneuver parameters while accounting for vehicle kinematics and workspace obstacles, represented as dynamic and path constraints respectively. Departing from traditional techniques that harbor non-optimal architectures, the employed method facilitates real-time, onboard computations that consequently improve overall system performance.

Bollino, Kevin P., L. Ryan Lewis, Pooya Sekhavat, and I. Michael Ross. "Pseudospectral Optimal Control: A Clear Road for Autonomous Intelligent Path Planning." ***2007 AIAA InfoTech at Aerospace Conference***, May 7, 2007 - May 10 American Institute of Aeronautics and Astronautics Inc, 2007:1228-1241.
Abstract: This paper captures the essence of intelligent path planning by posing the problem in a framework based on optimal control theory. Design requirements for autonomous vehicles call for on-board intelligence capable of making timely decisions, performing tasks in a "smarter" fashion, and ultimately accomplishing missions with extreme accuracy. This is the definition of an optimal control problem! Indeed, most, if not all, motion planning problems can be formulated and solved using optimal control techniques. Motivated by the significant advancements in optimal control techniques over the last decade, we demonstrate the broad range of unmanned systems that can operate both optimally and autonomously by solving path-planning problems using pseudospectral methods.

Dobrokhodov, Vladimir N., Isaac I. Kaminer, Kevin D. Jones, Ioannis Kitsios, Chengyu Cao, Lili Ma, Naira Hovakimyan, and Craig Woolsey. "Rapid Motion Estimation of a Target Moving with Time-Varying Velocity." ***AIAA Guidance, Navigation, and Control Conference 2007***, August 20, 2007 - August 23 American Institute of Aeronautics and Astronautics Inc, 2007:3774-3787.
Abstract: This paper describes the development of a vision-based motion estimation and target tracking system for a small unmanned air vehicle (SUAV) equipped with an inertially stabilized gimballed camera. The work concentrates on the design of a new rapid motion estimation algorithm for a ground target moving with time-varying velocity. The capability to estimate target motion for tracking significantly improves operational utility of an inexpensive tactical SUAV. This

work extends previous results in which a SUAV simultaneously tracked a ground target moving at constant speed and estimated its motion (position and velocity). In this paper, we allow for time-varying unknown target velocity. The target velocity estimation problem is formulated such that the recently developed 1 rapid estimator can be applied. The estimator uses two real-time measurements: the target position in the camera frame, provided by image processing software, and the relative altitude above the target, provided by an external geo-referenced database. Simulations show that the proposed algorithm is effective at tracking a non-cooperating target moving with unknown velocity, despite repeated out-of-frame events. The paper also describes the development of a Hardware-in-the-Loop simulation, reflecting a realistic tactical scenario, that is intended to provide further validation in advance of flight tests.

Dobrokhodov, Vladimir N., **Oleg A. Yakimenko**, **Kevin D. Jones**, **Isaac I. Kaminer**, **Eugene Bourakov**, **Ioannis Kitsios**, and Mariano Lizarraga. "New Generation of Rapid Flight Test Prototyping System for Small Unmanned Air Vehicles." *2007 AIAA Modeling and Simulation Technologies Conference*, August 20, 2007 - August 23 American Institute of Aeronautics and Astronautics Inc, 2007:495-519.
Abstract: This paper describes the development and application of a rapid prototyping system for flight testing of novel autonomous flight algorithms for unmanned air vehicles (UAVs) at the Naval Postgraduate School. The system provides a small team with the ability to rapidly prototype new theoretical concepts and flight-test their performance in realistic mission scenarios. The original development was done using MATRIXX Xmath/SystemBuild environment almost a decade ago. Currently, the system has been converted to the Mathworks MATLAB/Simulink development environment. This paper describes the hardware and software tools developed for the system and briefly discusses the variety of projects including vision-based target tracking, 3D path following, SUAV control over the network and high-resolution imagery on the fly.

Hall, Jason S. and **Marcello Romano**. "A Novel Robotic Spacecraft Simulator with Mini-Control Moment Gyroscopes and Rotating Thrusters." *2007 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM*, September 4, 2007 - September 7 Institute of Electrical and Electronics Engineers Inc, 2007:IEEE Robotics and Automation Society; IEEE Industrial Electronics Society; ASME Dynamic Systems and Control Division; ETH Zurich http://dx.doi.org/10.1109/AIM.2007.4412475
Abstract: A novel hardware-in-the-loop spacecraft simulator is introduced for the laboratory validation of guidance, navigation and control algorithms. This three-degrees-of-freedom robotic vehicle uses the principle of airfloating along a flat floor in order to reproduce in two dimensions the frictionless and weightlessness conditions of the orbital flight. For the first time in its class, to the authors' knowledge, the new spacecraft simulator uses Miniature Control Moment Gyroscopes for the attitude control and rotating thrusters for both attitude and translational control. A pseudo-GPS, a LIDAR and a fiber optic gyroscope are used as navigation sensors. The paper presents in details the design of the robotic vehicle and the results of preliminary experiments. 2007 IEEE.

Healey, Anthony J., **Douglas P. Horner**, **Sean P. Kragelund**, Benjamin Wring, and Aurelio Monarrez. "Collaborative Unmanned Systems for Maritime and Port Security Operations." *7th IFAC Conference on Control Applications in Marine Systems, CAMS 2007*, September 19, 2007 - September 21 IFAC Secretariat, 2007:1-6.

Horner, Douglas and **Oleg Yakimenko**. "Recent Developments for an Obstacle Avoidance System for a Small AUV." *7th IFAC Conference on Control Applications in Marine Systems, CAMS 2007*, September 19, 2007 - September 21 IFAC Secretariat, 2007:19-25
Abstract: Improvements in high resolution small forward looking sonar (FLS) and computer processing have made it possible to develop an obstacle avoidance system (OAS) for small diameter Autonomous Underwater Vehicles (AUV). An AUV with such a system can maneuver around unanticipated obstacles that may be proud of the ocean floor. This ability can prevent

serious damage to the vehicle or the environment. This paper discusses developments in control and computer vision techniques of an OAS designed to vertically avoid obstacles found on the ocean floor. Results are presented from recent in-water testing. Copyright 2007 IFAC.

Kaminer, Isaac, **Oleg Yakimenko**, **Vladimir Dobrokhodov**, Antonio Pascoal, Naira Hovakimyan, Chengyu Cao, Amanda Young, and Vijay Patel. "Coordinated Path Following for Time-Critical Missions of Multiple UAVs Via L1 Adaptive Output Feedback Controllers." ***AIAA Guidance, Navigation, and Control Conference 2007***, August 20, 2007 - August 23 American Institute of Aeronautics and Astronautics Inc, 2007:915-948
http://arc.aiaa.org/doi/abs/10.2514/6.2007-6409
Abstract: This paper develops a complete framework for coordinated control of multiple unmanned air vehicles (UAVs) that are tasked to execute collision-free maneuvers under strict spatial and temporal constraints in restricted airspace. The framework proposed includes strategies for deconflicted real-time path generation, nonlinear path following, and multiple vehicle coordination. Path following relies on the augmentation of existing autopilots with L1 adaptive output feedback control laws to obtain inner-outer loop control structures with guaranteed performance. Multiple vehicle coordination is achieved by enforcing temporal constraints on the speed profiles of the vehicles along their paths in response to information exchanged over a communication network. Again, L1 adaptive control is used to yield an inner-outer loop structure for vehicle coordination. A rigorous proof of stability and performance bounds of the combined path following and coordination strategies is given. Flight test results obtained at Camp Roberts, CA in 2007 demonstrate the benefits of using L1 adaptive control for path following of a single vehicle. Hardware-in-the-loop simulations for two vehicles are discussed and provide a proof of concept for time-critical coordination of multiple vehicles over communication networks with fixed topologies.

Lewis, L. Ryan, I. Michael Ross, and Qi Gong. "Pseudospectral Motion Planning Techniques for Autonomous Obstacle Avoidance." ***46th IEEE Conference on Decision and Control 2007, CDC***, December 12, 2007 - December 14 Institute of Electrical and Electronics Engineers Inc, 2007:5997-6002
http://dx.doi.org/10.1109/CDC.2007.4434545
Abstract: We consider the problem of generating minimum-time trajectories for autonomous vehicles. Shapes of arbitrary number, size and configuration are modeled in the form of path constraints in the resulting constrained nonlinear optimal control problem. Pseudospectral techniques are used to solve the problem. Solutions are obtained within a few seconds even under a MATLAB environment running on legacy computer hardware. The method is tested under various obstacle environments, and the optimality of the computed trajectories is verified by way of the necessary conditions. 2007 IEEE.

Ma, Lili, Chengyu Cao, Naira Hovakimyan, Craig Woolsey, **Vladimir N. Dobrokhodov**, and **Issac I. Kaminer**. "Development of a Vision-Based Guidance Law for Tracking a Moving Target." ***AIAA Guidance, Navigation, and Control Conference 2007***, August 20, 2007 - August 23 American Institute of Aeronautics and Astronautics Inc, 2007:3760-3773
Abstract: This paper develops a guidance law for a small unmanned aerial vehicle (UAV) performing vision-based tracking of a target moving on the ground. The target's velocity is unknown, but constant; the relative altitude between the target and the UAV is also assumed to be unknown and constant. This work extends earlier results for which the relative altitude between the target and the UAV was known, for example, by comparing captured images with a geo-referenced database. The problem of estimating the unknown parameters is addressed using an adaptive estimator that uses real-time measurements of the target position in the camera frame, as provided by an image processing algorithm. The parameter estimates are used in the UAV guidance law, with turn rate as the input, where the objective is to maintain a desired horizontal distance between the UAV and the target. Simulations show that the proposed algorithm is effective at tracking a target moving with unknown constant velocity, even with repeated out-of-frame events. A stability proof for the combined estimation and guidance

algorithm is provided. The paper also describes the development of a Hardware-in-the-Loop simulation, reflecting a realistic tactical scenario, that is intended to provide further validation in advance of flight tests.

Marques, Eduardo R. B., Jose Pinto, **Sean Kragelund**, Paulo S. Dias, Luis Madureira, Alexandre Sousa, Marcio Correia, et al. "AUV Control and Communication using Underwater Acoustic Networks." *OCEANS 2007* - Europe, June 18, 2007 - June 21 Inst. of Elec. and Elec. Eng. Computer Society, 2007
Abstract: Underwater acoustic networks can be quite effective to establish communication links between autonomous underwater vehicles (AUVs) and other vehicles or control units, enabling complex vehicle applications and control scenarios. A communications and control framework to support the use of underwater acoustic networks and sample application scenarios are described for single and multi-AUV operation. 2007 IEEE.

Rice, Joseph A. "US Navy Seaweb Development." *2007 International Conference on Mobile Computing and Networking, MobiCom'07 - Second Workshop on Underwater Networks, WUWNet'07*, September 14, 2007 - September 14 Association for Computing Machinery, 2007:3-4
http://dx.doi.org/10.1145/1287812.1287814
Abstract: This talk traces the development of Seaweb through-water networking from 1995 to the present day. Encompassing the physical, link, network, transport, and session layers of the open-systems interconnect (ISO/OSI) stack, Seaweb technology enables undersea sensor networks, autonomous/unmanned underwater vehicle (AUV/UUV) communication navigation, and submarine communications at speed depth (CSD). Given the severely constrained physical layer, we examine the benefits of hierarchical network topologies and the need for adaptation to prevailing environmental conditions and mission requirements. With results derived from an aggressive experimental program, we consider the quality of service (QoS) trade-offs of underwater networks in terms of reliability, availability, throughput, area coverage, security, and latency.

Sjoberg, Eric, **Kevin Squire**, and **Craig Martell**. "Online Parameter Estimation of a Robot's Motion Model." *2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2007*, October 29, 2007 - November 2 Institute of Electrical and Electronics Engineers Inc, 2007:735-740.
http://dx.doi.org/10.1109/IROS.2007.4399501
Abstract: Simultaneous Localization and Mapping (SLAM) algorithms rely heavily on a good motion model to provide critical information about the robot's current pose. Most of these algorithms assume that the distribution defining a robot's motion will remain stationary over the period of operation, and as such use a fixed model for the duration of a trial. This does not easily allow for changes in the robot's motion model due to surface changes, wear and tear, and battery life. Also, if new robots of a similar class are to be used, a new motion model may need to be constructed from scratch. In this paper, we introduce a method that allows the robot to automatically learn its motion model, given a rough estimate of its model or the model from a robot of similar class. We validate our method by demonstrating that it learns a new motion model when a robot crosses a threshold onto a different surface. We also demonstrate our method can estimate the motion model for a new robot given the motion model of a robot of similar class. 2007 IEEE.

Vincent, Patrick J., **Murali Tummala**, and **John McEachen**. "A Beamforming Approach for Distributed Wireless Sensor Networks." *2007 IEEE International Conference on System of Systems Engineering, SOSE*, April 16, 2007 - April 18 Inst. of Elec. and Elec. Eng. Computer Society, 2007
http://dx.doi.org/10.1109/SYSOSE.2007.4304326

Abstract: We present an energy-aware approach for enabling communication between a wireless ground-based sensor network, and an overhead unmanned aerial vehicle (UAV). Specifically, we present a technique for assembling a subset of sensor nodes into a distributed antenna array useful for beamforming. A small subset of sensor nodes receives and aggregates information gathered by the network, and forms a distributed antenna array, concentrating the radiated transmission into a narrow beam aimed towards the UAV. Although, in general, the relative orientations of the elements in a distributed antenna array have an effect on antenna performance, our proposed approach can be employed in scenarios where the individual sensor nodes do not have knowledge of their location within an absolute coordinate system.

———. "A New Method for Distributing Power Usage Across a Sensor Network." *2006 3rd Annual IEEE Communications Society on Sensor and Ad hoc Communications and Networks, Secon 2006*, September 25, 2006 - September 28 Institute of Electrical and Electronics Engineers Inc, 2006:518-526.
http://dx.doi.org/10.1109/SAHCN.2006.288508

Abstract: We present a method for more uniformly distributing the energy burden across a wireless ground-based sensor network communicating with an overhead unmanned aerial vehicle (UAV). A subset of sensor nodes, termed a transmit cluster, receives and aggregates data gathered by the entire network, and forms a distributed antenna array, concentrating the radiated transmission into a narrow beam aimed towards the UAV. Because these duties are power-intensive, the role of transmit cluster must be shifted to different nodes as time progresses. We present an algorithm to reassign the transmit cluster, specifying the time that should elapse between reassignments and the number of hops that should be placed between successive transmit clusters in order to achieve three competing goals: First, we wish to better and more broadly spread the energy load across the sensor network while, second, minimizing the energy expended in moving the transmit cluster, all the while, third, reducing to the extent practicable the time to bring the UAV and the sensor network's beam into alignment. The algorithm thus extends the lifetime of the sensor network while meeting system-level performance objectives. 2006 IEEE.

Yun, Xiaoping, Eric R. Bachmann, **Hyatt Moore IV**, and **James Calusdian**. "Self-Contained Position Tracking of Human Movement using Small inertial/magnetic Sensor Modules." *2007 IEEE International Conference on Robotics and Automation, ICRA'07*, April 10, 2007 - April 14 Institute of Electrical and Electronics Engineers Inc, 2007:2526-2533.
http://dx.doi.org/10.1109/ROBOT.2007.363845

Abstract: Numerous applications require a self-contained personal navigation system that works in indoor and outdoor environments, does not require any infrastructure support, and is not susceptible to jamming. Posture tracking with an array of inertial/magnetic sensors attached to individual human limb segments has been successfully demonstrated. The "sourceless" nature of this technique makes possible full body posture tracking in an area of unlimited size with no supporting infrastructure. Such sensor modules contain three orthogonally mounted angular rate sensors, three orthogonal linear accelerometers and three orthogonal magnetometers. This paper describes a method for using aeeelerometer data combined with orientation estimates from the same modules to calculate position during walking and running. The periodic nature of these motions includes short periods of zero foot velocity when the foot is in contact with the ground. This pattern allows for precise drift error correction. Relative position is calculated through double integration of drift corrected aeeelerometer data. Preliminary experimental results for various types of motion including walking, side stepping, and running document accuracy of distance and position estimates. 2007 IEEE.

2006

Ahner, Darryl K., **Arnold H. Buss**, and John Ruck. "Assignment Scheduling Capability for Unmanned Aerial Vehicles - a Discrete Event Simulation with Optimization in the Loop Approach to Solving a Scheduling Problem." *2006 Winter Simulation Conference, WSC*, December 3, 2006 - December 6 Institute of Electrical and Electronics Engineers Inc, 2006:1349-1356. http://dx.doi.org/10.1109/WSC.2006.323234
Many military planning problems are difficult to solve using pure mathematical programming techniques. One such problem is scheduling unmanned aerial vehicles (UAVs) in military operations subject to dynamic movement and control constraints. This problem is instead formulated as a dynamic programming problem whose approximate solution is obtained via the Assignment Scheduling Capability for UAVs (ASC-U) model using concepts from both simulation and optimization. Optimization is very effective at identifying the best decision for static problems, but is weaker in identifying the best decision in dynamic systems. Simulation is very effective in modeling and capturing dynamic effects, but is weak in optimizing from alternatives. ASC-U exploits the relative strengths of both methodologies by periodically re-optimizing UAV assignments and then having the simulation transition the states according to state dynamics. ASC-U thus exploits the strengths of simulation and optimization to construct good, timely solutions that neither optimization nor simulation could achieve alone. 2006 IEEE.

Bollino, Kevin P., Michael W. Oppenheimer, and David D. Doman. "Optimal Guidance Command Generation and Tracking for Reusable Launch Vehicle Reentry." *AIAA Guidance, Navigation, and Control Conference 2006*, August 21, 2006 - August 24 American Institute of Aeronautics and Astronautics Inc, 2006:4614-4636.
The objective of this work is to develop a robust guidance and control architecture for autonomous reusable launch vehicles that incorporates elements of recent advances in the areas of optimal trajectory generation and reconfigurable control This work integrates three separately developed methods to form a coherent architecture with the potential to manage control effector failures, vehicle structural/aerodynamic degradation, uncertainty, and external disturbances. Outer-loop guidance commands in the form of body-frame angular rates (roll, pitch, and yaw) are generated from an optimal reference trajectory that is computed off-line with a direct pseudospectral method and then tracked by a reconfigurable inner-loop control law. The appropriate open-loop state histories from the psuedo-four-degree-of-freedom reference trajectory are converted using a modified backstepping approach that complements the inner-loop control law in a six-degree-of-freedom simulation. The inner-loop control law is capable of reacting and compensating for off-nominal conditions by employing nonlinear reconfigurable control allocation, dynamic inversion, and model-following/anti-windup prefilters. The results show that the inner-loop control can adequately track the desired optimal guidance commands; thus, confirming the applicability of this control architecture for future development involving on-line, optimal trajectory generation and high-fidelity guidance and control for reentry vehicles.

Davighi, Andrea, **Marcello Romano**, and Franco Bernelli-Zazzera. "Vibration Suppression of Flexible-Link Manipulator by PZT Actuators and Sensors." *Earth and Space 2006 - 10th Biennial International Conference on Engineering, Construction, and Operations in Challenging Environments*, March 5, 2006 - March 8 American Society of Civil Engineers, 2006:172 http://dx.doi.org/10.1061/40830(188)172
Abstract: In this paper a vibration suppression control system by piezoelectric actuators and sensors is presented for a one flexible link manipulators for space activities. This research is innovative because of the very high flexibility, stringent pointing requirements and a low first vibration frequency. In the last years there has been a large number of studies on the possible use of distributed actuators and sensors, in the framework of 'smart' materials technology. Among the various available materials for smart structures actuators and sensors, lead zirconate titanate piezoceramics (PZT) patches are very attractive: they undergo mechanical stresses and

strain when subjected to an applied electric field and, vice-versa, generate an electric field in response to mechanical stresses and strains. They are easy to bond to a structure, and their high stiffness makes it possible to induce high strain energy in the system. In fact it is possible to bond or even embed these materials into a passive traditional structure to perform both sensing and actuation functions, provided that appropriate placement and size is chosen for them. In this paper, a Linear Quadratic Regulator controller (LQR) for vibration suppression is used on both an aluminum link with bonded PZT patches and a carbon fiber link with embedded PZT patches. One test with aluminum link is conducted also with the link mounted on an Harmonic Drive motor. Some experimental tests of vibration suppression, to validate the proposed method, are presented. This experiment has been performed at the Spacecraft Robotics Laboratory of Naval Postgraduate School at Monterey, while the carbon fiber link were manufactured at Politecnico di Milano. Copyright ASCE 2006.

Dobrokhodov, Vladimir N., **Isaac I. Kaminer**, **Kevin D. Jones**, and Reza Ghabcheloo. "Vision-Based Tracking and Motion Estimation for Moving Targets using Small UAVs." ***2006 American Control Conference***, June 14, 2006 - June 16 Institute of Electrical and Electronics Engineers Inc, 2006:1428-1433.
Abstract: This paper addresses the development of a vision-based target tracking system for a small unmanned air vehicle. The algorithm performs autonomous tracking of a moving target, while simultaneously estimating GPS coordinates of the target. A low cost off the shelf system is utilized, with a modified radio controlled aircraft airframe, gas engine and servos. Tracking is enabled using a low-cost, miniature pan-tilt gimbal. The control algorithm provides rapid and sustained target acquisition and tracking capability. A target position estimator was designed and shown to provide reasonable targeting accuracy. The impact of target loss events on the control and estimation algorithms is analyzed in detail. 2006 IEEE.

———. "Vision-Based Tracking and Motion Estimation for Moving Targets using Small UAVs." ***AIAA Guidance, Navigation, and Control Conference 2006***, August 21, 2006 - August 24 American Institute of Aeronautics and Astronautics Inc, 2006:4389-4400.
Abstract: This paper addresses the development of a vision-based target tracking system for a small unmanned air vehicle. The algorithm performs autonomous tracking of a moving target, while simultaneously estimating GPS coordinates, speed and heading of the target. Tight real-time integration of UAV's video and telemetry data-streams with geo-refereaced database allows for reliable target identification, increased precision and shortened time of target motion estimation. A low cost off the shelf system is utilized, with a modified radio controlled aircraft airframe, gas engine and servos. Tracking is enabled using a low-cost, miniature pan-tilt gimbal. The control algorithm provides rapid and persistent target acquisition and tracking capability. A target position estimator was designed and shown in multiple flight tests to provide reasonable targeting accuracy. The impact of target loss events on the control and estimation algorithms is analyzed in detail.

Eikenberry, Blake, **Oleg Yakimenko**, and **Marcello Romano**. "A Vision Based Navigation among Multiple Flocking Robots: Modeling and Simulation." ***AIAA Modeling and Simulation Technologies Conference, 2006***, August 21, 2006 - August 24 American Institute of Aeronautics and Astronautics Inc, 2006:695-705.
Abstract: This paper presents modeling and simulation developments related to the navigation and guidance of a group of robots floating without friction along a planar floor. Each robot has three degrees-of-freedom, uses a rotating thruster as an actuator, and has both artificial vision and pseudo-GPS sensors. Each robot is prescribed a desired final relative position: each of the other robots have an associated desired range, bearing and orientation angle on that bearing. Each robot will initially locate the others by scanning the floor. Once each robot is found and identified, they will compute a trajectory and control profile to arrive at the final desired relative position. Simulated photographs are taken by the camera which alternates between the robots on the floor. These simulated photos are analyzed to determine the position and pose of each robot. Tables are constructed to track the positions of each robot and represent the system state. The

guidance system on board each robot will update their independent system state and re-compute trajectories as needed. Collision avoidance with other robots and with the floor boundary must be employed. The paper includes simulations and modeling within MATLAB/Simulink environment involving enhanced animation.

Esposito, Joel M. and **Thomas W. Dunbar**. "Maintaining Wireless Connectivity Constraints for Swarms in the Presence of Obstacles." ***2006 IEEE International Conference on Robotics and Automation, ICRA 2006***, May 15, 2006 - May 19 Institute of Electrical and Electronics Engineers Inc, 2006:946-951.
http://dx.doi.org/10.1109/ROBOT.2006.1641831
Abstract: The low power requirements of many small radio modems suggest that robust operation is best attained when the transmitter/receiever pair is: (1) separated by less than some maximum distance (Range); and (2) not obstructed by large dense objects (Line-of-Sight). Therefore to maintain a wireless link between two robots, it is desirable to comply with these two spatial constraints. Given a swarm of point robots with specified initial and final configurations and a set of desired communication links consistent with the above criteria, we explore the problem of designing inputs to achieve the final configuration while preserving the desired links for the duration of the motion. Some interesting conclusions about the feasibility of the problem are offered. An algorithm is provided and its operation is demonstrated through both simulation and experimentation on Koala Robots.

Ghabcheloo, Reza, A. Pedro Aguiar, Antonio Pascoal, Carlos Silvestre, **Isaac Kaminer**, and Joao Hespanha. "Coordinated Path-Following Control of Multiple Underactuated Autonomous Vehicles in the Presence of Communication Failures." ***45th IEEE Conference on Decision and Control 2006, CDC***, December 13, 2006 - December 15 Institute of Electrical and Electronics Engineers Inc, 2006:4345-4350.
Abstract: This paper addresses the problem of steering a group of underactuated autonomous vehicles along given spatial paths, while holding a desired inter-vehicle formation pattern. For a general class of vehicles moving in either two or threedimensional space, we show how Lyapunov-based techniques and graph theory can be brought together to yield a decentralized control structure where the dynamics of the cooperating vehicles and the constraints imposed by the topology of the inter-vehicle communications network are explicitly taken into account. Path-following for each vehicle amounts to reducing an appropriately defined geometric error to a small neighborhood of the origin. Vehicle coordination is achieved by adjusting the speed of each vehicle along its path according to information on the positions of a subset of the other vehicles, as determined by the communications topology adopted. The system obtained by putting together the path-following and vehicle coordination strategies adopted takes a cascade form, where the former subsystem is input-to-state stable (ISS) with the error variables of the latter as inputs. Convergence and stability of the overall system are proved formally. The results are also extended to solve the problem of temporary communication failures. Using the concept of "brief instabilities" we show that for a given maximum failure rate, the coordinated path following system is stable and the errors converge to a small neighborhood of the origin. We illustrate our design procedure for underwater vehicles moving in three-dimensional space. Simulations results are presented and discussed..

Jones, Kevin D. and **Max F. Platzer**. "Bio-Inspired Design of Flapping Wing Micro Air Vehicles - an Engineer's Perspective." ***44th AIAA Aerospace Sciences Meeting 2006***, January 9, 2006 - January 12 American Institute of Aeronautics and Astronautics Inc, 2006:463-476.
Abstract: In this paper the decade of numerical and experimental investigations leading up to the development of the authors' unique flapping-wing micro air vehicle is summarized. Early investigations included the study of boundary layer energization by means of a small flapping foil embedded in a flat-plate boundary layer, the reduction of the recirculatory flow region behind a backward-facing step by means of a small flapping foil, and the reduction or suppression of flow separation behind blunt or cusped airfoil trailing edges by flapping a small foil located in the wake flow region. These studies were followed by systematic investigations of the aerodynamic

characteristics of single flapping airfoils and airfoil combinations. These unsteady flows were described using flow visualization, laser-Doppler velocimetry and panel and Navier-Stokes computations. It is then shown how this flapping-wing database was used to conceive, design and develop a micro air vehicle which has a fixed wing for lift and two flapping wings for thrust generation. While the design appears to separate lift and thrust, in fact, the performance of one surface is closely coupled to the other surfaces.

Kaminer, Isaac, **Oleg Yakimenko,** Antonio Pascoal, and Reza Ghabcheloo. "Path Generation, Path Following and Coordinated Control for Time-Critical Missions of Multiple UAVs." ***2006 American Control Conference***, June 14, 2006 - June 16 Institute of Electrical and Electronics Engineers Inc, 2006:4906-4913.
http://dx.doi.org/10.1109/AERO.2006.1656026
Abstract: The paper proposes a solution to the problem of coordinated control of multiple unmanned air vehicle (UAV) to ensure collision-free maneuvers under strict spatial and temporal constraints. First, a set of feasible trajectories are generated for all UAVs using a new direct method of optimal control that takes into account rules for collision avoidance. A by-product of this step yields, for each vehicle, a spatial path to be followed together with a nominal desired speed profile. Each vehicle is then made to execute a pure path following maneuver in three-dimensional space by resorting to a novel 3D algorithm. Finally, the speed profile for each vehicle is adjusted to enforce the temporal constraints that must be met in order to coordinate the fleet of vehicles. Simulations illustrate the potential of the methodology developed. 2006 IEEE.

Kaminer, Isaac I., **Oleg A. Yakimenko**, and Antonio M. Pascoal. "Coordinated Control of Multiple UAVs for Time-Critical Applications." ***2006 IEEE Aerospace Conference***, March 4, 2006 - March 11 Inst. of Elec. and Elec. Eng. Computer Society, 2006
http://dx.doi.org/10.1109/AERO.2006.1656026
Abstract: The paper12 proposes a solution to the problem of coordinated control of multiple unmanned air vehicles (UAVs) to ensure collision-free maneuvers under strict spatial and temporal constraints. The solution proposed relies on the decoupling of space and time in the problem formulation. First, a set of feasible trajectories are generated for all UAVs using a new direct method of optimal control that takes into account rules for collision avoidance. A by-product of this step yields for each vehicle a spatial path to be followed, together with a desired nominal speed profile along that path. Each vehicle is then asked to execute a pure path following maneuver in three-dimensional space by resorting to a novel 3-D algorithm that enforces temporal constraints aimed at coordinating the fleet of vehicles. Simulations illustrate the potential of the methodology developed.

Platzer, Max F. and **Kevin D. Jones**. "Flapping Wing Aerodynamics - Progress and Challenges." ***44th AIAA Aerospace Sciences Meeting 2006***, January 9, 2006 - January 12 American Institute of Aeronautics and Astronautics Inc, 2006:6051-6069.
Abstract: It is the objective of this paper to review recent developments in the understanding and prediction of flapping-wing aerodynamics. To this end, several flapping-wing configurations are considered. First, the problem of single flapping wings is treated with special emphasis on the question of which flapping modes, amplitudes, frequencies, and wing shapes produce optimum cruise flight efficiencies. Second, the problem of hovering flight is studied for single flapping wings. Third, aerodynamic phenomena produced by flapping wing interactions are discussed, such as tandem wing configurations, as used by dragonflies, or biplane configurations, as used on the authors' micro air vehicle. Potential flow and viscous flow solutions are presented and the role of vortex shedding, especially from wing leading edges, is discussed. Comparisons with available experimental results are provided.

Puranik, Anand, Gordon Parker, Chris Passerelle, J. Dexter Bird III, **Oleg Yakimenko**, and **Isaac Kaminer**. "Modeling and Simulation of a Ship Launched Glider Cargo Delivery System." *AIAA Guidance, Navigation, and Control Conference 2006*, August 21, 2006 - August 24 American Institute of Aeronautics and Astronautics Inc, 2006:5332-5341.
Abstract: The paper deals with the high-fidelity modeling and simulation of a powered parafoil-payload system with respect to its application in autonomous precision airborne cargo delivery. In the proposed concept the cargo transfer is accomplished in two phases: Initial towing phase when the glider follows the towing vessel in a passive lift mode and the autonomous gliding phase when the system is guided to the desired point. During the towing phase, the system gains as much altitude as possible by taking the angle-of-attauk that will provide the best lift. Once sufficient altitude is attained, the gliding phase starts. The system is steered to the desired location by controlling the lengths of the rear suspension lines using two control inputs. The paper presents the concept of the system, its 6DoF model, the control algorithm at the stage of passive glide and the simulation results. Copyright 2006 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

Romano, Marcello, David A. Friedman, and Tracy J. Shay. "Laboratory Experimentation of Autonomous Spacecraft Approach and Docking to a Collaborative Target." *AIAA Guidance, Navigation, and Control Conference 2006*, August 21, 2006 - August 24 American Institute of Aeronautics and Astronautics Inc, 2006:5434-5460.
Abstract: A new laboratory lest bed is introduced, which enables the hardware-in-the-loop simulation of the autonomous approach and docking of a chaser spacecraft to a target spacecraft of similar mass. The test bed consists of a chaser spacecraft and a target spacecraft simulators floating via air pads on a flat floor. The prototype docking interface mechanism of Defense Advanced Research Projects Agency's (DARPA's) Orbital Express mission is integrated on the spacecraft simulators. Relative navigation of the chaser spacecraft is obtained by fusing the measurements from a single-camera vision sensor and an inertial measurement unit, through Kalman filters. The target is collaborative in the sense that a pattern of three infrared Light Emitting Diodes is mounted on it as reference for the relative navigation. Eight cold-gas on-off thrusters are used for the translation of the chaser vehicle. They are commanded using a non-linear control algorithm based on Schmitt triggers. Furthermore, a reaction wheel is used for the vehicle rotation with a proportional derivative linear control. Experimental results are presented of both autonomous proximity maneuver and autonomous docking of the chaser simulator to the non-floating target. The presented results validate the proposed estimation and control methods and demonstrate the capability of the test bed.

Romano, Marcello and Jason Hall. "A Test Bed for Proximity Navigation and Control of Spacecraft for on-Orbit Assembly and Reconfiguration." *Space 2006 Conference*, September 19, 2006 - September 21 American Institute of Aeronautics and Astronautics Inc, 2006:3002-3012.
Abstract: This paper introduces the preliminary development of a test-bed related to the research project named Autonomous Multi-agent Physically Interacting Spacecraft System (AMPHIS) which is ongoing at the Spacecraft Robotics Laboratory. A new laboratory test bed is under development which will enable hardware-in-the-loop simulation of autonomous proximity operations of a cluster of small spacecraft. The test-bed, which is an evolution of a previously developed Autonomous Docking test-bed, consists of three degrees-of-freedom spacecraft simulators floating via air pads on a flat floor. In particular, this paper introduces a new spacecraft simulator which is being currently integrated, using on-off thrusters for the translation and a small control-moment-gyro for the rotation.

Ross, I. Michael, Qi Gong, **Fariba Fahroo**, and Wei Kang. "Practical Stabilization through Real-Time Optimal Control." *2006 American Control Conference*, June 14, 2006 - June 16 Institute of Electrical and Electronics Engineers Inc, 2006:304-309.
http://dx.doi.org/10.1109/ACC.2006.1655372
Abstract: Infinite-horizon, nonlinear, optimal, feedback control is one of the fundamental problems in control theory. In this paper we propose a solution for this problem based on recent

progress in real-time optimal control. The basic idea is to perform feedback implementations through a domain transformation technique and a Radau based pseudospectral method. Two algorithms are considered: free sampling frequency and fixed sampling frequency. For both algorithms, a theoretical analysis for the stability of the closed-loop system is provided. Numerical simulations with random initial conditions demonstrate the techniques for a flexible robot arm and a benchmark inverted pendulum problem. 2006 IEEE.

Tao, WeiMin, MingJun Zhang, Michael Liu, and **XiaoPing Yun**. "Residual Vibration Analysis and Suppression for SCARA Robot Arm in Semiconductor Manufacturing." ***2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2006***, October 9, 2006 - October 15 Institute of Electrical and Electronics Engineers Inc, 2006:5153-5158. http://dx.doi.org/10.1109/IROS.2006.282610
Abstract: This paper investigates residual vibrations of industrial SCARA robots in wafer handling applications. Due to rapid point-to-point movements, SCARA robot arms exhibit large vibrations after reaching the destination position. A mathematical model particularly suitable for residual vibration analysis is developed. The root cause of residual vibrations is analyzed using the model. Based on the root cause analysis, a practical solution to suppress vibrations is proposed. The solution utilizes an acceleration smoother to smooth the commanded trajectory, and it can be easily implemented in practice without redesign the robot hardware or control system. Experimental results show over 40% reduction in both vibration amplitude and settling time. 2006 IEEE.

Vaidyanathan, Ravi, **Monique Fargues**, Lalit Gupta, Srinivas Kota, Dong Lin, and James West. "A Dual-Mode Human-Machine Interface for Robotic Control Based on Acoustic Sensitivity of the Aural Cavity." ***1st IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics, 2006, BioRob 2006***, Febrary 20, 2006 - Febrary 22 Institute of Electrical and Electronics Engineers Computer Society, 2006:927-932. http://dx.doi.org/10.1109/BIOROB.2006.1639210
Abstract: We introduce an unobtrusive sensor-based control system for human-machine interface to control robotic and rehabilitative devices. The interface is capable of directing assistive robotic devices in response to tongue movement and/or speech without insertion of any device in the vicinity of the oral cavity. The interface is centered on the unique properties of the human ear as an acoustic output device. Our work has shown that various movements within the oral cavity create unique, traceable pressure changes in the human ear, which can be measured with a simple sensor (such as a microphone) and analysed to produce commands signals, which can in turn be used to control robotic devices. In this work, we present: 1) an analysis of the sensitivity of human ear canals as acoustic output device, 2) the design of a new sensor for monitoring airflow in the aural canal, 3) pattern recognition procedures for recognition of both speech and tongue movement by monitoring aural flow across several human test subjects, and 4) a conceptual design and simulation of the machine interface system.

Vaidyanathan, Ravi, Lalit Gupta, Hyunseok Kook, and James West. "A Decision Fusion Classification Architecture for Mapping of Tongue Movements Based on Aural Flow Monitoring." ***2006 IEEE International Conference on Robotics and Automation, ICRA 2006***, May 15, 2006 - May 19 Institute of Electrical and Electronics Engineers Inc, 2006:3610-3617. http://dx.doi.org/10.1109/ROBOT.2006.1642253
Abstract: A complete signal processing strategy is presented to detect and precisely recognize tongue movement by monitoring changes in airflow that occur in the ear canal. Tongue movements within the human oral cavity create unique, subtle pressure signals in the ear that can be processed to produce command signals in response to that movement. The strategy developed for the human machine interface architecture includes energy-based signal detection and segmentation to extract ear pressure signals due to tongue movements, signal normalization to decrease the trial-to-trial variations in the signals, and pairwise cross-correlation signal averaging to obtain accurate estimates from ensembles of pressure signals. A new decision fusion classification algorithm is formulated to assign the pressure signals to their respective tongue-

movement classes. The complete strategy of signal detection and segmentation, estimation, and classification is tested on 4 tongue movements of 4 subjects. Through extensive experiments, it is demonstrated that the ear pressure signals due to the tongue movements are distinct and that the 4 pressure signals can be classified with over 96% classification accuracies across the 4 subjects using the decision fusion classification algorithm. 2006 IEEE.

Vincent, Patrick J., **Murali Tummala**, and **John McEachen**. "An Energy-Efficient Approach for Information Transfer from Distributed Wireless Sensor Systems." ***2006 IEEE/SMC International Conference on System of Systems Engineering***, April 24, 2006 - April 26 Inst. of Elec. and Elec. Eng. Computer Society, 2006:100-105. http://dx.doi.org/10.1109/SYSOSE.2006.1652281
Abstract: We present a method for reconfiguring the communication and computational burden between a system consisting of two subsystems: a wireless ground-based sensor network, and an overhead unmanned aerial vehicle (UAV). A small subset of sensor nodes receives and aggregates information gathered by the network, and forms a distributed antenna array, concentrating the radiated transmission into a narrow beam aimed towards the UAV. We describe and analyze two alternative strategies to bring the UAV and the sensor network's beam into alignment, while minimizing the energy expended by the sensor network. The performance of the two strategies is compared in terms of probability of beam-UAV alignment as a function of time, and the expected time to alignment. We examine the performance tradeoff between the choice of strategy and parameters of the sensor network that affect power conservation. 2006 IEEE.

2005

Ahner, Darryl K. "Real-Time Planning and Control of Army UAVs Under Uncertainty." ***InfoTech at Aerospace: Advancing Contemporary Aerospace Technologies and Their Integration***, September 26, 2005 - September 29 American Institute of Aeronautics and Astronautics Inc, 2005:1077-1092.
Abstract: With advances in sensor technology and data fusion used in military operations, more information is available for decision making. A key question is how to make effective use of this information. One specific area the Army has funded is the development of Unmanned Aerial Vehicles (UAVs) as part of its Future Combat Systems (PCS). These UAVs use information from higher level sensors as cues and perform part of the reconnaissance, surveillance, and target acquisition (RSTA) mission. We develop a neuro-dynamic approach to real-time planning and control of unmanned aerial vehicles with a focus on accounting for vehicle risk and stochastic arrivals of new tasks. Copyright 2005 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

Bachmann, Richard J., Frank J. Boria, Peter G. Ifju, Roger D. Quinn, **Jeffrey E. Kline**, and **Ravi Vaidyanathan**. "Utility of a Sensor Platform Capable of Aerial and Terrestrial Locomotion." ***Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2005***, July 24, 2005 - July 28 Institute of Electrical and Electronics Engineers Inc, 2005:1581-1586.
http://dx.doi.org/10.1109/AIM.2005.1511237
Abstract: Homeland security and national defense include many missions that would be served by a multisensor platform capable of flying, landing, perching, and walking. Soldiers in an urban environment could obtain near- and medium-field intelligence by deploying the vehicle and landing it on the top of a building. Maritime domain protection would be significantly enhanced by a small aerial vehicle that could 'perch on' (hang from) the high point of a cargo ship during onboard inspection. The surveillance capability of unmanned aerial vehicles (UAVs), which are

beginning to enjoy widespread use in military and reconnaissance situations, could be significantly enhanced by a vehicle with sufficient stealth to gain closer approach to the surveillance target without being detected. Finally, long term surveillance could be performed by a vehicle capable of flying, walking, and taking off from the ground. The Morphing Micro Air-Land Vehicle (MMALV) has been developed in response to these opportunities in surveillance and intelligence gathering. MMALV integrates the University of Florida's micro air vehicle (MAV) technology with the terrestrial mobility of Mini-Whegs, MMALV is capable of flying and walking, and successfully performs the transition from flight to walking. Furthermore, MMALV is currently able to transition from terrestrial to aerial locomotion by walking off the roof of a two story building. A wing retraction mechanism improves the portability of the vehicle, as well as its terrestrial stealth and ability to enter small openings. A tail hook is currently in the design process, to allow for the 'perching' behavior. 2005 IEEE.

Boria, Frank J., Richard J. Bachmann, Peter G. Ifju, Roger D. Quinn, **Ravi Vaidyanathan**, Chris Perry, and Jeffrey Wagener. "A Sensor Platform Capable of Aerial and Terrestrial Locomotion**." *IEEE IRS/RSJ International Conference on Intelligent Robots and Systems, IROS 2005*, August 2, 2005 - August 6 IEEE Computer Society, 2005:4024-4029. http://dx.doi.org/10.1109/IROS.2005.1545597
Abstract: A sensor platform has been developed that is capable of both aerial and terrestrial locomotion, as well as transitioning between the two. The Morphing Micro Air-Land Vehicle (MMALV) implements biological inspiration in both flying and walking. MMALV integrates the University of Florida's Micro Air Vehicle (MAV) technology with the terrain mobility of Mini-Whegs. Fabricated of lightweight carbon fiber, the UFMAV employs a flexible wing design to achieve improved stability over other MAVs of similar size. Mini-Whegs employs the patented (pending) wheel-leg running gear that makes the Whegs and Mini-Whegs line of robots fast, agile, and efficient. MMALV has a 30.5cm wingspan, and is 25.4cm long. Terrestrial locomotion is achieved using two independently controlled wheel-legs, which are differentially actuated to perform turning. The vehicle successfully performs the transition from flight to walking. Furthermore, MMALV is capable of transitioning from terrestrial to aerial locomotion by walking off a structure of only 20 feet. A wing retraction mechanism improves the portability of the vehicle, as well as its terrestrial stealth and ability to enter small openings. 2005 IEEE.

Boxerbaum, Alexander S., Philip Werk, Roger D. Quinn, and **Ravi Vaidyanathan.** "Design of an Autonomous Amphibious Robot for Surf Zone Operation: Part I Mechanical Design for Multi-Mode Mobility." *Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2005*, July 24, 2005 - July 28 Institute of Electrical and Electronics Engineers Inc, 2005:1459-1465. http://dx.doi.org/10.1109/AIM.2005.1511216
Abstract: The capability of autonomous and semiautonomous platforms to fraction in the shallow water surf zone is critical for a wide range of military and civilian operations. Of particular importance is die ability to transition between locomotion modes in aquatic and terrestrial settings. The study of animal locomotion mechanisms can provide specific inspiration to address these demands. In this work, we summarize on-going efforts to create an autonomous, highly mobile amphibious robot A water-resistant amphibious prototype design, based on the biologically-inspired Whegs platform, has been completed. Through, extensive field-testing, mechanisms have been Isolated to improve the implementation of die Whegs concept and make it more suited for amphibious operation. Specific design improvements include wheel-leg propellers enabling swimming locomotion, an active, compliant, water resistant, non-backdrtvable body joint, and improved feet for advanced mobility. These design innovations will allow Whegs IV to navigate on rough terrain and underwater, and accomplish tasks with little or no low-level control, thus greatly simplifying autonomous control system implementation. Complementary work is presently underway for autonomous control. We believe these results will lay the foundation for the development of a generation of amphibious robots with an unprecedented versatility and mobility.

Dobrokhodov, Vladimir and Mariano Lizarraga. "Developing Serial Communication Interfaces for Rapid Prototyping of Navigation and Control Tasks." ***AIAA Modeling and Simulation Technologies Conference 2005***, August 15, 2005 - August 18 American Institute of Aeronautics and Astronautics Inc, 2005:430-442.

Abstract: This work is intended to be a simple guide in developing RS232 Interfaces for the Mathwork's RTW/xPC target. The work discusses the details of system level programming of serial interfaces and provides a simple means of developing data decoding routines. The technique presented herein alows one to easily work with an RS232 device daring a system development without detailed knowledge about either the hardware or the low-level hardware programming. This valuable technique has been developed and successfully tested at the Naval Postgraduate School during several long-term projects primarily targeting design and implementation of GNC algorithms for various UAV applications.

Ekaterinaris, John A., **Muguru S. Chandrasekhara**, and **Max F. Platzer**. "Recent Developments in Dynamic Stall Measurements, Computations and Control." ***43rd AIAA Aerospace Sciences Meeting and Exhibit***, January 10, 2005 - January 13 American Institute of Aeronautics and Astronautics Inc, 2005:10923-10939.

Abstract: Issues related to the development of facilities and testing for unsteady aerodynamics, in particular dynamic stall and its control are addressed. The presence of a deterministic time scale requires the test facility to faithfully reproduce the degree of unsteadiness in order to simulate its effects properly. Similarly, control of unsteady flow separation demands an approach that can overcome underlying cause without sacrificing the performance. Unsteady flow computations can add significant value and reduce the iterations in this process. Furthermore, with today's increasing emphasis on unmanned air vehicles, the problem of dynamic stall should be understood in an entirely different Reynolds number and Mach number range. Some of these aspects are also reviewed in this paper. Copyright 2005 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

Ghabcheloo, Reza, Antonio Pascoal, Carlos Silvestre, and **Isaac Kaminer**. "Coordinated Path Following Control of Multiple Wheeled Robots with Directed Communication Links." ***44th IEEE Conference on Decision and Control, and the European Control Conference, CDC-ECC '05***, December 12, 2005 - December 15 Inst. of Elec. and Elec. Eng. Computer Society, 2005:7084-7089.
http://dx.doi.org/10.1109/CDC.2005.1583303

Abstract: The paper addresses the problem of steering a fleet of wheeled robots along a set of given spatial paths, while keeping a desired inter-vehicle formation pattern. This problem arises for example when multiple vehicles are required to scan a given area in cooperation. In a possible mission scenario, one of the vehicles acts as a leader and follows a path accurately, while the other vehicles follow paths that are naturally determined by the formation pattern imposed. The solution adopted for coordinated path following builds on Lyapunov-based techniques and addresses explicitly the constraints imposed by the topology of the inter-vehicle communications network, which is captured in the framework of directed graph theory. With this set-up, path following (in space) and inter-vehicle coordination (in time) are essentially decoupled. Path following for each vehicle amounts to reducing a conveniently defined error variable to zero. Vehicle coordination is achieved by adjusting the speed of each of the vehicles along its path, according to information on the position of the other vehicles, as determined by the communications topology adopted. Simulations illustrate the efficacy of the solution proposed. 2005 IEEE.

Harkins, Richard, Jason Ward, **Ravi Vaidyanathan**, Alexander S. Boxerbaum, and Roger D. Quinn. "Design of an Autonomous Amphibious Robot for Surf Zone Operations: Part II - Hardware, Control Implementation and Simulation." ***Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2005***, July 24, 2005 - July 28 Institute of Electrical and Electronics Engineers Inc, 2005:1465-1470. http://dx.doi.org/10.1109/AIM.2005.1511217
Abstract: This paper describes on-going work at The Naval Postgraduate School (NFS) and Case Western Reserve University (CWRU) to create an autonomous highly mobile amphibious robot A first generation land-based prototype has been constructed and field tested. This robot design, based on a tracked element, is capable of autonomous waypoint navigation, self-orientation, obstacle avoidance, and has the capacity to transmit sensor (visual) feedback. A water-resistant second generation amphibious prototype design, based around the biologically inspired Wbegs platform, has been completed. This design marries the unprecedented mobility of Whegs with the autonomous hardware and control architectures implemented in the first generation prototype. Furthermore, we have also implemented a dynamic simulation capturing salient features of Whegs for testing of robotic locomotion capabilities. The integration of these elements will lay the foundation for the development of a new generation of highly mobile autonomous amphibious robots.

Horner, Douglas P., **Anthony J. Healey**, and **Sean P. Kragelund**. "AUV Experiments in Obstacle Avoidance." ***MTS/IEEE OCEANS, 2005***, September 18, 2005 - September 23 Inst. of Elec. and Elec. Eng. Computer Society, 2005 http://dx.doi.org/10.1109/OCEANS.2005.1639962
Abstract: Reactive Obstacle Avoidance (OA) is an important step in attaining greater autonomy in Autonomous Underwater Vehicles (AUV). For AUVs that conduct underwater surveys, avoidance of uncharted obstacles can improve vehicle survivability. This paper discusses initial experiments at the Center for AUV Research in obstacle detection and avoidance using the Naval Postgraduate School ARIES AUV with the Blueview Blazed Array forward looking sonar. It includes a discussion on evaluating OA optimality, autopilot control design and sonar image processing. It concludes with a description of successful results from a recent demonstration.

Ouimet, Sean P., Matthew J. Hahn, and **Joseph Rice**. "Undersea Communication Network as a UUV Navigation Aid." ***MTS/IEEE OCEANS, 2005***, September 18, 2005 - September 23 Inst. of Elec. and Elec. Eng. Computer Society, 2005 http://dx.doi.org/10.1109/OCEANS.2005.1640141
Abstract: Acoustic modems are the basis for emerging undersea wireless communications networks. US Navy Seaweb technology offers an opportunity to perform undersea navigation and tracking by virtue of node-to-node ranging measurements acquired as a by-product of the acoustic communications protocol. A simple localization algorithm is developed and verified with synthetic data and is then tested with an Unmanned Undersea Vehicle (UUV) during an experiment at sea. This work will look at improvements to an existing algorithm that was tested with data from the Seaweb UUV Test that was conducted in May 2005 in Monterey Bay. The main improvement that will be tested involves incorporating the third dimension (depth) into the equations.

Romano, Marcello. "Laboratory Experimentation of Autonomous Spacecraft Proximity-Navigation using Vision and Inertia Sensors." ***AIAA Guidance, Navigation, and Control Conference 2005***, August 15, 2005 - August 18 American Institute of Aeronautics and Astronautics Inc, 2005:6172-6182
Abstract: This paper presents the current status of the research effort on spacecraft autonomous proximity-navigation and docking which is on-going at the Spacecraft Robotics Laboratory. An experimental test-bed has been designed and is in the advance integration phase. The test-bed consists of two spacecraft models floating via air-pads on a flat surface to simulate in two dimensions the reduced-gravity environment. A Kalman filter is used for the navigation. The Kalman filter estimates the relative orientation and position of the target spacecraft with respect

to the chaser using measurements given by a custom-developed Vision Sensor System and a MEMS-based Inertial Measurement Unit. This paper presents an overall description of the test-bed and the navigation algorithms.

———. "On-the-Ground Experiments of Autonomous Spacecraft Proximity-Navigation using Computer Vision and Jet Actuators." ***Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2005***, July 24, 2005 - July 28 Institute of Electrical and Electronics Engineers Inc, 2005:1011-1016.
http://dx.doi.org/10.1109/AIM.2005.1511142
This paper presents the current status of the research effort on autonomous proximity-navigation and space-craft docking, which is on-going at the Spacecraft Servicing and Robotics Laboratory of the Naval Postgraduate School. An experimental test-bed has been designed and is in the advance integration phase, which can be used for validating analytical and numerical results regarding dynamic models and control laws. The test-bed consists of two spacecraft models floating via air-pads on a flat surface to simulate in two dimensions the weightlessness of the orbital flight. A custom-developed Vision Navigation Sensor is used to determine the relative position and orientation of the two spacecraft. This paper presents an overall description of the test-bed and reports the preliminary experimental results of autonomous navigation of the chaser-spacecraft model in the proximity of the target spacecraft. 2005 IEEE.

Sekhavat, Pooya, Andrew Fleming, and **I. Michael Ross**. "Time-Optimal Nonlinear Feedback Control for the NPSAT1 Spacecraft." ***Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM 2005***, July 24, 2005 - July 28 Institute of Electrical and Electronics Engineers Inc, 2005:843-850.
http://dx.doi.org/10.1109/AIM.2005.1511114
NPSAT1 is a small satellite being built at the Naval Postgraduate School, and due to launch in January 2006. It uses magnetic actuators and a pitch momentum wheel for attitude control. In this paper, a novel time-optimal sampled-data feedback control algorithm is introduced for closed-loop control of NPSAT1 in the presence of disturbances. The feedback law is not analytically explicit; rather, it is obtained by a rapid re-computation of the open-loop time-optimal control at each update instant. The implementation of the proposed controller is based on a shrinking horizon approach and does not require any advance knowledge of the computation time. Preground-test simulations show that the proposed control scheme performs well in the presence of parameter uncertainties and external disturbance torques. 2005 IEEE.

Shaffer, Patrick J., **I. Michael Ross**, Michael W. Oppenheimer, and David B. Doman. "Optimal Trajectory Reconfiguration and Retargeting for a Reusable Launch Vehicle." ***AIAA Guidance, Navigation, and Control Conference 2005***, August 15, 2005 - August 18 American Institute of Aeronautics and Astronautics Inc, 2005:2985-2998.
Autonomous reusable launch vehicles (RLV) are being pursued as low-cost alternatives to expendable launch vehicles and the Shuttle. The employment of autonomous, reusable launch vehicles requires additional guidance and control robustness to fulfill the role of an adaptive human pilot, in the event of failures or unanticipated conditions. The guidance and control of these vehicles mandate new guidance strategies that are able to identify and adapt to vehicle failures during the flight and still return to earth safely. This work utilizes an online trim algorithm that provides the outer loop with the feasible range of Mach number and angle of attack, for which the vehicle can be rotationally trimmed. The algorithm allows one to include 6-degree-of-freedom (DOF) trim effects and constraints in a reduced order dynamical model which is used in the solution of an optimal control problem. A direct pseudospectral method is used to solve a two-point-boundary-value problem which determines the optimal entry trajectory subject to appropriate constraints such as normal load, dynamic pressure limits, heat load limits, and state dependent constraints.

Tummala, Murali, Chee Wai Chan, and Patrick Vincent. "Distributed Beamforming in Wireless Sensor Networks." ***39th Asilomar Conference on Signals, Systems and Computers***, October 28, 2005 - November 1 Inst. of Elec. and Elec. Eng. Computer Society, 2005:793-797.
Abstract: We present an adaptive distributed beamforming approach for sensor networks, wherein sensor nodes coordinate their transmissions to form a distributed antenna array that directs a beam toward an airborne relay (an Unamanned Aerial Vehicle). Distributed beamforming using sensors is challenging since the number of nodes and their exact positions are unknown. A simulation model was implemented to study adaptive beamforming, and results are compared to theoretical results for random arrays. We show that the antenna main lobe remains stable in the presence of position errors and sensor failures, and thus can be steered in an adaptive manner as a UAV flies past. 2005 IEEE.

Wang, Ick H., **Vladimir N. Dobrokhodov**, **Isaac I. Kaminer**, and Kevin D. Jones. "On Vision-Based Target Tracking and Range Estimation for Small UAVs." ***AIAA Guidance, Navigation, and Control Conference 2005***, August 15, 2005 - August 18 American Institute of Aeronautics and Astronautics Inc, 2005:5507-5517.
Abstract: Development of a vision-based target tracking algorithm for an unmanned air vehicle is described. The algorithm provides an autonomous target tracking capability, while simultaneously estimating GPS coordinates of the target. A low cost, primarily COTS system is utilized, with a modified RC aircraft airframe, gas engine and servos. Tracking is enabled using a low-cost, miniature pan-tilt gimbal, driven by COTS servos and electronics. The control algorithm provides rapid and sustained target acquisition and tracking capability. A target position estimator was designed and shown to provide reasonable targeting accuracy. Impact of target loss events on the control and estimation algorithms is analyzed in detail.

Xiaoping, Yun, Conrado Aparicio, Eric R. Bachmann, and Robert B. McGhee. "Implementation and Experimental Results of a Quaternion-Based Kalman Filter for Human Body Motion Tracking." ***2005 IEEE International Conference on Robotics and Automation***, April 18, 2005 - April 22 Institute of Electrical and Electronics Engineers Inc, 2005:317-322.
http://dx.doi.org/10.1109/ROBOT.2005.1570138
Abstract: A human body motion tracking system based on use of the MARG (Magnetic, Angular Rate, and Gravity) sensors has been under development at the Naval Postgraduate School and Miami University. The design of a quaternion-based Kalman filter for processing the MARG sensor data was described in [1]. This paper presents the real-time implementation and testing results of the quaternion-based Kalman filter. Experimental results validate the Kalman filter design, and show the feasibility of the MARG sensors for real-time human body motion tracking.

Yakimenko, Oleg A. and Roman B. Statnikov. "Multicriteria Parametrical Identification of the Parafoil-Load Delivery System." ***18th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar***, May 23, 2005 - May 26 American Institute of Aeronautics and Astronautics Inc, 2005:630-641.
Abstract: This paper addresses the problem of multicriteria (versus single-criterion) parametrical identification of the autonomously controlled cargo parafoil. Based on the structural identification as an initial step toward creation of an adequate model of the parafoil, a high-fidelity model including several dozens of optimization parameters has been developed. The present paper proposes the correct statement of the multicriteria parametrical identification problem including the necessity to investigate the feasible set of variable parameters. The paper advocates the use of the Parameter Space Investigation method and Multicriteria Optimization / Vector Identification software package to solve the problem.

Yildiz, Kursad, **Phillip E. Pace**, and **Murali Tummala**. "Electronic Attack Against Boost-Phase ICBM Defense System." *IEEE Systems, Man and Cybernetics Society, Proceedings - 2005 International Conference on Systems, Man and Cybernetics*, October 10, 2005 - October 12 Institute of Electrical and Electronics Engineers Inc, 2005:1889-1895
http://dx.doi.org/10.1109/ICSMC.2005.1571422

Abstract: In this paper, the different electronic attack (EA) techniques that can be deployed to reduce the effectiveness of boost-phase target sensing, tracking, and intercepting are examined. The purpose is to investigate the effects of the EA on the performance of the radio frequency (RF) sensors used within a boost-phase ballistic missile defense sensor system. The EA types investigated include barrage noise, chaff tactics, and the use of expendable decoys. The reduction of the radar cross-section is also addressed and predicted using a physical optics approach. The desired effect of the EA against the RF sensors is degradation of the target track quality, thereby forcing the sensors to use other methods to estimate the target position (e.g., triangulation). An inadequately designed sensor fusion scheme can lead to loss of target track, which is undesirable in a boost-phase ballistic missile intercept system. 2005 IEEE.

PATENTS

Bourakov, Eugene, Oleg Yakimenko, and Alex Bordetsky. "Aerial Delivery System with High Accuracy Touchdown." August 12, 2014. Patent no: 8,800,930 B1
http://hdl.handle.net/10945/43059

Abstract: Embodiments described herein provide a system and method for persistent high-accuracy payload delivery utilizing a twophase procedure during the terminal descent phase of aerial payload delivery. In the first phase a small parafoil provides aerial delivery of a payload to within a close proximity of an intended touchdown point, e.g., a target. In the second phase a target designator acquires the target and a trajectory to the target is determined. A harpoon launcher deploys a harpoon connected to the payload by an attachment line, such as a rope. A reel mechanism reels up the attachment line causing the payload to be moved to the target thus providing high accuracy touchdown payload delivery.

Kanayama, Yutaka John. "Method of Controlling a Vehicle to Make a Combination of Arbitrary Translaitonal and Rotational Motions." February 17, 1998. 5,719,762
http://www.google.com/patents/US5719762

Abstract: A method of controlling a rotary vehicle to navigate a heading using a combination of translational and rotational motions by a plurality of driving-steering wheels controlling the motion in three degrees of freedom for a manned or unmanned vehicle having at least two drive-steering wheels, wherein a drive-steering wheel is a wheel with its heading orientation and driving velocity positively controlled, wherein a global motion is a vehicle trajectory with vehicle orientation from the initial position (with orientation) to a final destination (with orientation), which comprises comparing a global motion selected to the vehicle's body position and orientation to compute a motion instruction in three degrees of freedom. the acceleration, path of curvature, and rotation rate, collectively known as the motion command then converting the motion command into a translational speed, a translational direction, and a rotational rate and converting the translational speed, the translational direction and the rotational rate into the direction and driving speed for each independent drive-steering wheel.

APPENDIX

Former and Current NPS Faculty Members Advising on UxS Topics

The following list is a compilation of faculty members who have served as advisors on at least two theses found in the previous pages. The list is not inclusive of all NPS members who are doing research in these topics. It is provided to give researchers a starting place for finding additional works of interest.

DEPARTMENT OF COMPUTER SCIENCE

Kölsch, Mathias N.
Martell, Craig
Singh, Gurminder
Xie, Geoffrey

DEPARTMENT OF DEFENSE ANALYSIS

Arquilla, John
O'Connell, Robert

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING / DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING & SPACE SYSTEMS ACADEMIC GROUP

Cristi, Roberto
Fargues, Monique P.
Goshorn, Rachel
Hernandez, Alejandro
Jenn, David C.
Loomis, Herschel H.
McEachen, John C.
Michael, Sherif
Pace, Phillip E.
Staples, Zac
Tummala, Murali
Wilson, Lonnie A.
Yun, Xiaoping

DEPARTMENT OF INFORMATION SCIENCE

Abdel-Hamid, Tarek
Baer, Wolfgang
Bergin, Richard
Bordetsky, Alex
Buettner, Raymond G.
Ehlert, James F.
Fisher, Edward L.
Gallup, Shelley P.
Gibson, John
Gordis, Joshua
Goshorn, Deborah
MacKenzie, Cameron
Osmundson, John S.
Papoulias, Fotis
Steckler, Brian

Welch, William J.

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING / DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING & SPACE SYSTEMS ACADEMIC GROUP

Bevilacqua, Riccardo
Chandrasekhara, Muguru S.
Du Toit, Noel
Healey, Anthony J.
Horner, Douglas P.
Jones, Kevin D.
Kaminer, Isaac (Center for Autonomous Vehicle Research)
Lee, Deok Jin (Center for Autonomous Vehicle Research)
Papoulias, Fotis
Romano, Marcello
Ross, I. Michael
Yakimenko, Oleg A.

DEPARTMENT OF METEOROLOGY / DEPARTMENT OF METEOROLOGY & SPACE SYSTEMS ACADEMIC GROUP

Nuss, Wendell
Durkee, Philip A.

DEPARTMENT OF NATIONAL SECURITY AFFAIRS

Bruneau, Thomas C.
Croissant, Aurel S.
Dahl, Erik
Moltz, Clay
Moran, Daniel
Rollins, John
Simeral, Robert
Wirtz, James J

DEPARTMENT OF OCEANOGRAPHY

Stanton, Timothy P.

DEPARTMENT OF OPERATIONS RESEARCH

Brown, Gerald G.
Carlyle, W. Matthew
Craparo, Emily
Horne, Gary E.
Kress, Moshe
Lin, Kyle Y.
Lucas, Thomas W.
McCauley, Michael E.
Nussbaum, Daniel.
Royset, Johannes O.

DEPARTMENT OF PHYSICS

Haegel, Nancy
Harkins, Richard M.
Kapolka, Daphne
Rice, Joseph A.
Squire, Kevin M.

DEPARTMENT OF SYSTEMS ENGINEERING

Chung, Timothy H.
Langford, Gary O.
Paulo, Eugene P.
Rhoades, Mark M.
Vaidyanathan, Ravi
Whitcomb, Clifford
Williams, Richard
Yakimenko, Oleg A.

GRADUATE SCHOOL OF BUSINESS AND PUBLIC POLICY

Dew, Nicholas
Doyle, Richard
Fast, William
Hatch, William D., II
Mutty, John
Sanchez, Susan M.
Simon, Cary

MODELING, VIRTUAL ENVIRONMENTS, AND SIMULATION INSTITUTE

Alt, Jonathan
Blais, Curtis L.
Buss, Arnold H.
Kennedy, Quinn

UNDERSEA WARFARE ACADEMIC GROUP

Brutzman, Donald P. (Modeling, Virtual Environments, and Simulation Institute)