With easy access to the Gulf of Mexico and a wealth of technical expertise, the Naval Support Activity Panama City (NSA PC) on St. Andrew Bay is the US Navy's home of advanced Unmanned Maritime Vehicles, experimental technology for Navy diving, advanced mine-hunting systems, and expeditionary Landing Craft Air Cushion (LCAC), or as they are more commonly known, hovercrafts. All of these technologies support the US Navy's littoral (near-shore) warfare operations, and as threats to our national interests shift, these technologies are becoming more important to our war-fighting capabilities. This is especially true of unmanned underwater vehicle (UUV) autonomy being developed by the Unmanned Systems Technology and Automation, Dynamics, & Special Programs branches of the Naval Surface Warfare Center Panama City Division (NSWC PCD).

Today, the NSWC PCD is a significant developer of autonomy for mine countermeasures (MCM) and littoral warfare for the US Navy, using unmanned vehicles as a force multiplier to defeat littoral threats and reducing the risk to the warfighter. Researchers focus on both conceptual problems and responding to needs identified by partners such as the Explosive Ordnance Disposal (EOD) program office, Naval Expeditionary Combat Command (NECC), Office of Naval Research (ONR), and the Naval Oceanography Mine Warfare Center (NOMWC).

The application of unmanned systems to the underwater regime is particularly challenging due to the many restrictions that the environment places on sensing and communication. Turbidity and low light levels greatly diminish the utility of cameras, laser line scanners, and other common visual sensors used for land and air-based applications. Additionally, operator-to-vehicle RF communications can only be practically used when vehicles are on the surface and acoustic communications typically has a limited usable range of a few kilometers. These restrictions eliminate the possibility of effective remote control operation, and demand more decisions to be made by the vehicle with minimal information from the operator (i.e. more autonomy).

NSWC PCD autonomy researchers have recently been focused on payload autonomy, which utilizes an independent on-board computer that acts as a “backseat driver,” thereby enabling researchers to develop, integrate, and test behaviors using proprietary UUVs through documented interfaces. Researchers started by leveraging an existing autonomy architecture, namely the Mission-Oriented Operating Suite (MOOS), to develop vehicle behaviors and algorithms relevant to the MCM mission area. Using these

Please see NSWC-PCD on page 5
Unmanned Maritime Systems for A2/AD
by Dr. Charles Y. Chen, Northrop Grumman Electronic Systems

A key part of naval operations has always been sea control—safe and unrestricted use of the sea to support military objectives and ensure safety of commerce. Also within the range of sea based operations is sea denial, the ability to prevent an adversary from using their sea lines of communication for military or commercial purposes.

Adversaries from rogue states to peer competitors are attempting to use a concept known as anti-access/area denial (A2/AD) to asymmetrically counter the US Navy’s sea control and force projection capability. The concept behind A2/AD is to use lower cost weapons and systems to keep the US Navy from operating in their littorals for some operationally meaningful period of time. This approach could significantly reduce the freedom of movement and power projection of U.S. ground and air forces.

A significant element of A2/AD measures involves undersea operations in the form of high performance, diesel-electric submarines armed with advanced anti-ship cruise missiles (ASCMs) and a mix of both sophisticated and vintage sea mines. Other components of a fully developed A2/AD system include a variety of land-based ASCMs, and theater ballistic missiles (TBMs).

The key to “taking down” this A2/AD complex is an “access-insensitive” platform with the mobility to get to and into the littoral area of interest quickly, the endurance to maintain a persistent presence there, the stealth to do so undetected, and the sensors to locate, classify, report on demand a broad range of threats and obstructions. Unmanned systems (UxS), both unmanned surface vessels (USV) and unmanned undersea vessels (UUV), are perhaps most ideally suited for such applications.

Northrop Grumman has been a global leader in unmanned systems for over 60 years. This includes the recent effort that developed a network of UUV’s, which achieved over 10,000 at-sea hours and two weeks of fully autonomous operation without human intervention.

Recently, we have been looking at both the technologies as well as the capabilities that USVs and UUVs need to support A2/AD missions, such as the USV, shown in Figure 1 which has performed mine hunting operations. We believe that key technologies already exist and have been demonstrated in a variety of missions and systems. The next key steps are to identify the appropriate missions and demonstrations where USV and UUV can provide the greatest efficiency and effectiveness. We look forward to continuing to work with the government, academia, and industry partners to make unmanned surface and undersea systems an integral part of our war fighting capability.

Robots in the Roses 2012
by Lyla Englehorn

Building on the success of last year’s inaugural research fair highlighting UxS activity on the NPS campus, the primary mission of this 2nd Annual Robots in the Roses Research Fair is to offer the CRUSER community of interest (CoI) an opportunity to share research and educational opportunities in the areas of unmanned and robotic systems. We hope to reach a greater audience with this year’s event, expand the CRUSER COI, provide NPS students the opportunity to explore potential thesis topics involving emergent technology, and inspire younger students to approach their formal education in science, technology, engineering and math with zeal.

- Display current research on UxS
- Showcase new technologies for UxS
- Recruit NPS students to complete thesis research in support of DoD projects

http://www.nps.edu/Research/CRUSER/RobotsInRoses.html
Filling the holes in Wireless Sensor Networks
by Bob Severinghaus, ECE PhD Candidate

Wireless Sensor Networks (WSN) are a logical extension for the capabilities of unmanned systems. These groups of individual sensors can be small, cheap, low energy, and placed in large fields to detect targets, and then pass information to a responding unmanned system(s). However, one problem with the wireless sensors is determining their connectivity. This connectivity is influenced by the communications environment which can cause signal fading, and requires measures such as error correction coding or repeated transmissions. This increased energy use from the environmental effects can lead to battery exhaustion of the sensors in difficult environments. The result is a sensor network with “holes” that need to be patched.

Recent research conducted here at NPS examined the statistical nature of the wireless environment, and established a relationship between the signal strength and the probability of availability of the individual communications link. This computed availability for a single communications link can then be extended to a network of communications links by the use of graph theory. The results of graph theory analysis show an increasing (exponentially) difficult problem to solve to compute the overall network’s availability as the number of sensors increases.

To solve this large problem, the large network can be broken down into smaller “formations” of nodes for the network analysis. Theoretically, these “formations” could be deployed according to the environment, in a linear structure, therefore stitching together a large formation with known overall network availability. Networks constructed in this way also have balanced energy use, and are less likely to cause “holes” in the sensor network.

In summary, this research points to the possibility that an unmanned system is well suited for the dull mission of monitoring the communications environment and deploying wireless sensors in locations that are both good for target sensing and overall energy conservation of the WSN.

For more details, see our research paper, “Network Formations to Bridge or Extend Wireless Sensor Networks”, available on the IEEE Xplore digital library at the NPS library website.

CRUSER Monthly Meetings

CRUSER holds monthly meetings in which the whole community is invited to participate in. They are available in-person on NPS or via VTC or dial-in. The meetings are at 1200 PST and last for 50 minutes. Please e-mail cruser@nps.edu for additional information on how to join in on our next meeting on 22 Feb.

Librarian’s Corner

Welcome to the inaugural edition of the Librarians’ Corner! As the Naval Postgraduate School’s academic library, Dudley Knox Library (DKL) is dedicated to providing information resources and services to NPS personnel and those involved with NPS-related research. This is the first in a series of regular columns; we are excited to engage readers in this newsletter. Please let us know how we are doing and feel free to make suggestions to us at libcruser@nps.edu.

Here are some links of key interest to the CRUSER/UxS community:

- [DoD] Unmanned Systems Integrated Roadmap FY2011-2036
- NPS-authored Unmanned Systems Bibliography
- DKL “Ask a Librarian!” Service

For more information on Unmanned Systems at Dudley Knox Library, visit our Subject Guide: http://libguides.nps.edu/unmanned

We look forward to hearing from you and sharing some more helpful tips in the next newsletter!

Jeff Rothal & Andrea Davis, Librarians at NPS Dudley Knox Library
What’s in an Acronym? – “The first step is admitting you have a problem” 
by Lyla Englehorn, MPP

Acronyms are useful when a series of words to describe an idea or object are reused many times within the same written or spoken piece. The acronym is noted with first use and then replaces the series of words in the rest of the piece. Within an established community of interest (COI), an acronym often takes the place of the series of words to the point that the idea or object becomes recognizable only by its acronym – the expansion of the acronym quickly falling out of common usage.

Some common acronyms used in our rapidly growing and evolving unmanned systems (UxS) COI are used inconsistently. One idea, asset or system may be referred to using a different series of words by stakeholders from disparate perspectives, resulting in several different acronyms for the same thing. As Mark Ballinger so aptly articulated in the fourth issue of CRUSER News (June 2011) some of this inconsistency has to do with evolving technology, regulatory challenges, and cultural acceptance – or rejection. As an UxS COI, we have the opportunity to recognize these acronym issues early and often. The first step is admitting you have a problem. This will be the first in an ongoing series on acronym issues.

Within the UxS COI we have already coined quite a list of useful acronyms. I will start my ongoing analysis with these four acronyms for unmanned assets by domain:

- **UAV** - unmanned aerial vehicle (see Mr. Ballinger’s article for more on the use of UAV)
- **UGV** - unmanned ground vehicle (the terrestrial surface of the Earth)
- **USV** - unmanned surface vehicle (the surface of the water)
- **UUV** - unmanned undersea vehicle (or “unmanned underwater vehicle” from the industry perspective…and the subject of a future article)

Within our COI, even these four acronyms are used inconsistently – commonly interchanged with RPV (remotely piloted vehicle) over all four common domains (air, ground, surface, undersea), or as an autonomous vehicle as an *A*V where the asterisk denotes the domain. I note here that many members of the UxS COI validly state as an operationally autonomous vehicle does not yet exist the A*V acronym should not yet be used. Autonomy will also be the subject of a future article.

This usage convention of U*V is scalable, as it should be. We have no idea what the future holds. When a quad rotor with landing gear has the ability to approach a structure by air as a UAV, and then land and roam through the unknown structure as a UGV it will need a name to denote this double-domain capability. What if this same vehicle also has the capability like a water bird to land on the surface as a USV, or like a common mure submerges as a UUV for short or long periods of time? When we reach the technology level where one vehicle spans several domains, a new acronym – or several acronyms – will need to be coined from a unique series of words describing the capabilities and accessible domains of these unique new vehicles. Until then, we have these four. I recommend we embrace and use them.

When these vehicles are combined in any way, or referred to as a whole, the acronyms change – as well they should. A current effort we should all support is to use the U*V convention for the individual vehicles, and then shift to the systems level where U*S applies to the vehicles in combination with the man-in-the-loop (MITL), communication system, sensor packages, and other payloads. In his piece “U.S. Unmanned Aerial Systems” released in early January 2012 by the Congressional Research Service specialist in military aviation Jeremiah Gertler states that, “Unmanned aircraft are commonly called unmanned aerial vehicles (UAVs), and when combined with ground control stations and data links, form UAS, or unmanned aerial systems.” Currently this convention is most commonly applied within the air domain, as the UAVs are the most mature vehicles of the four standard domains. This will change over time, and when it does I anticipate the more frequent use of UGS, USS and UUS. At that time we will need to preemptively differentiate between the USS Nicholas and an ancillary system of unmanned surface vehicles (USS) operating off the USS Nicholas!

When domain systems are combined, we reach the full UxS level – and then you join CRUSER! I welcome your comments and suggestions for future columns. Please submit your ideas to crusere@nps.edu.

**SOURCES:**
Consortium for Robotics and Unmanned Systems Education and Research

NPS Acquires Two USVs, Opens Sea Web Lab for Expanded Undersea Warfare Research
By Amanda D. Stein

Naval Postgraduate School leaders, students and guests gathered on the roof of Spanagel Hall, Jan. 11, to welcome two new unmanned surface vehicles (USVs) to the university’s research community, and to celebrate the establishment of the new Sea Web and Wave Glider Laboratory.

David Jackson, Chief Emerging Technology Officer for the Office of Naval Intelligence (ONI), attended the ceremony on behalf of the ONI, officially presenting one of the Wave Gliders to the Undersea Warfare Research Center. The two vehicles, referred to by the Navy as Sensor Hosting Autonomous Remote Crafts (SHARCs), were appropriately named Tiburon and Mako, and christened with a stream of champagne carefully poured on the crafts.

During the christening ceremony, retired Rear Adm. Jerry Ellis, Director of the Undersea Warfare Research Center, offered confident predictions that the crafts would be invaluable additions to the institution. “I christen you Mako and Tiburon, may you always provide good research for the Naval Postgraduate School and may you always return to your home base.”

NPS has long invested time and research into a wide range of unmanned systems, and the addition of the USVs will only help broaden the scope of the university’s research. Ellis noted that Navy leadership had vowed, only days before, to make unmanned systems a main objective for fiscal year 2012.

“The Chief of Naval Operations, the Secretary of the Navy and the Commandant of the Marine Corps signed a document which outlined the objectives for the Department of the Navy for fiscal year 12,” explained Ellis. “One of those six objectives was the following: ‘Dominate in unmanned systems by integrating unmanned systems into the Department of the Navy culture, by developing unmanned systems in the air, by deploying and establishing unmanned systems on and underneath the sea and by fielding unmanned systems for ground use.’

“With the acquisition of these wave gliders today and with the opening of the Sea Web and Wave Glider Laboratory in front of me, NPS will be working toward meeting the objective of the Navy and adding to the great work that is already being done here at NPS with unmanned systems,” Ellis continued. “We are clearly doing what the Navy wants us to do in this area, and I think we are doing it very well.”

Jackson followed Ellis’ remarks with a prediction that the Wave Gliders marked the beginning of a long, fruitful relationship between ONI and NPS.

Joe Rice, Research Professor of Physics, joined Dr. Phil Durkee, Dean of the Graduate School of Engineering and Applied Sciences, in cutting the ribbon to the new Sea Web and Wave Glider Laboratory, noting how long the program has been without lab space, and the excitement of having a place for research.

“Previously, Sea Web has developed experiments of opportunity around the world. We have done over 50 trials at sea, and that has been our laboratory,” said Rice. “We’re very pleased to finally have a home base here on campus.”

From NSWC PCD on page 1
behaviors, they were able to experiment with in-stride re-tasking of individual vehicles, automated generation of search and inspection plans, and task prioritization. However, the most compelling work has been the multi-vehicle arbitration scenario, which uses multiple vehicles to collaboratively complete search and identification phases of the MCM mission in parallel.

NSWC PCD is committed to the creation of robust solutions that practically serve the needs of the warfighter. Under ONR sponsorship, a modular open architecture is being designed and built that will not only support the behaviors discussed above, but will also support rapid incorporation of new capabilities from Government and third-party sources. Additionally, NSWC PCD engineers are leading several working groups that are chartered to identify near-term solutions and develop a transition plan for the integration of autonomous behaviors and tools into existing programs of record. As the demand for autonomy increases, these steps lay the foundation for robust and intelligent autonomy solutions that will transform the littoral battlespace using unmanned systems, and are already being considered as candidates for transition to the fleet within the next few years.

NSWC PCD researchers prepare to launch a 12 inch diameter UUV with experimental sensor payload in St. Andrew Bay for testing. The launch and recovery device in use was also invented and manufactured in Panama City.
STUDENT RESEARCH


STUDENTS: Capt Troy Peterson, USMC & LT Jason Staley, USN

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 of 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 and fixed and rotary wing assets.

CRUSER Brings Robo-Ethics Symposium to the Pentagon

by CAPT Carol O’Neal

The Office of Naval Research (ONR), Naval Intelligence (N2) and Communications (N6) directorate, along with the Naval Postgraduate School’s Consortium for Robotics and Unmanned Systems Education and Research (CRUSER), sponsored a two-day Robo-Ethics Symposium, Jan. 25-26, in the Pentagon in Washington, D.C.

The symposium featured multiple two-hour panel sessions focused on cultural, legal and ethical issues surrounding the policy, design and utilization of robotic defense technologies. More than 100 participants from the National Capitol Region attended the symposium representing several defense and academic institutions including ONR, the U.S. Naval Academy and Naval War College, Office of the Secretary of Defense (OSD), the Joint Staff and many others.

Symposium Director Mark Dankel noted, “The symposium captured the intellectual depth and horizon of our warfighters. Fluent in their disciplinary expertise, they are equally concerned for the connection between their missions and the legal, cultural and ethical values which form and shape their ethos.”

CRUSER Director and NPS Operations Research Senior Lecturer Jeff Kline commented, “This is our first major outreach effort to support CRUSER’s mission of continuing education in support of robotics and unmanned systems. This symposium provided an effective venue to bring together lawyers, ethicists, engineers and warfighters to openly debate the myriad ethical issues we will face in the future.”

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The CRUSER Wave was at AUVSI’s Unmanned Systems Program Review 2012