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CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH (CRUSER):

FY12 Annual Report

The Transition Year

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NAVAL POSTGRADUATE SCHOOL

November 2012

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The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems in military and naval operations. CRUSER seeks to align efforts, both internal and external to NPS, by facilitating active means of collaboration, providing a portal for information exchange among researchers and educators with collaborative interests, and supporting innovation through directed programs of operational experimentation.

Chartered to capture a broad array of issues related to emerging unmanned systems (UxS) technologies, CRUSER intends to encompass the successful research, education, and experimentation efforts in unmanned systems currently ongoing at NPS and across the naval enterprise. Controls, sensors, design, architectures, human capital resource requirements, concept generation, risk analysis and field experimentation are just a few interest points.

Major aligned events starting in FY11 through FY14 are plotted along major program Innovation Threads (*see Figure 1*) starting with concept generation workshops, developed in technical symposia, and demonstrated in field experimentation to test selected technologies. These activities each have separate reports, and are available upon request. However, research and education will continue to include a broader landscape than just mission areas. As of 30 September 2012 the CRUSER community of interest included just over 800 members from government, academia and industry. This FY12 Annual Report provides a summary of activities during CRUSER's second year of operation – or transition year – and highlights future plans.

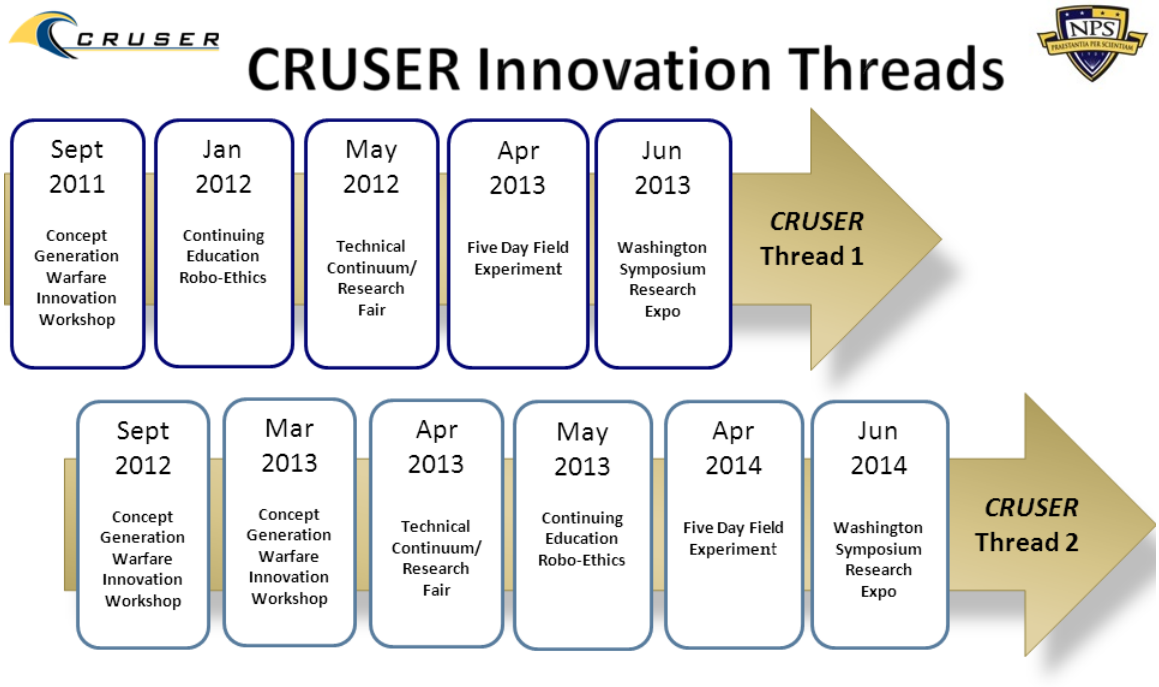

Figure 1. CRUSER program Innovation Thread overview

Highlights from this year include a continuing education seminar held in the Pentagon addressing the cultural, ethical and legal issues related to employing unmanned systems; a technical continuum held at NPS to advance the concepts generated during the September 2011 Warfare Innovation Workshop; the annual NPS Robots in the Roses research fair attended by Undersecretary of the Navy Bob Work; and the September 2012 Warfare Innovation Workshop to kick off the second CRUSER Innovation Thread.

In FY12, CRUSER's transition year, the nationwide community of interest grew from 375 to just over 800 participants representing government, academia, industry and allied interests in unmanned systems. CRUSER also supported or executed a variety of STEM and research events associated with unmanned systems.

ACKNOWLEDGMENTS

CRUSER thanks the entire community of interest who joined us since the program inception in March 2011 – we look forward to many successful years to come.

CRUSER also thanks the Under Secretary of the Navy, the Honorable Robert O. Work for his forward-thinking leadership and support of CRUSER program efforts.

CRUSER gives thanks to the advisory board for their guidance and foresight essential to program success.

CRUSER thanks the dedicated staff of the NPS Dudley Knox Library for their support, in particular librarians Andrea Davis and Jeff Rothal.

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I. BACKGROUND

From Technical to Ethical…
From Concept Generation to Experimentation…

The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems in military and naval operations

CRUSER intends to encompass the successful research, education, and experimentation efforts in unmanned systems (UxS) currently ongoing at NPS and across the naval enterprise. Controls, sensors, design, architectures, human capital resource requirements, concept generation, risk analysis and field experimentation are just a few interest points.

Major aligned events starting in FY11 through FY13 include concept generation workshops, technical symposia, and field experimentation to test selected technologies. However, research and education will include a broader landscape than just mission areas.

A. VISION

At the direction of SECNAV, NPS leverages its long-standing experience and expertise in the research and education of robotics and unmanned systems to support the Navy's mission. The CRUSER program grew out of the SECNAV's unmanned systems prioritization, and concurrent alignment of unmanned systems research and experimentation at NPS. CRUSER serves as a vehicle by which to align currently disparate research efforts and integrate academic courses across discipline boundaries.

CRUSER is a facilitator for the Navy's common research interests in current and future unmanned systems and robotics. The Consortium, working in partnership with other organizations, will continue to inject a focus on robotics and unmanned systems into existing joint and naval field experiments, exercises, and war games; as well as host specific events, both experimental and educational. The Consortium will host classified and unclassified websites and has established networking and collaborative environments for the community of interest.

Furthermore, with the operational needs of the Navy and the Marine Corps at its core, CRUSER will continue to be an inclusive, active partner for the effective education of future military leaders and decision makers. Refining existing courses of education and designing new academic programs will be an important benefit of CRUSER, making the Consortium a unique and indispensable resource for the Navy and highlighting the educational mission of NPS.

Specific CRUSER goals are to:

- Provide a source for unmanned systems employment concepts for operations and technical research;
- Provide an experimentation program to evaluate unmanned system employment concepts;
- Provide a venue for Navy-wide education in unmanned systems;
- Provide a DoD-wide forum for collaborative education, research, and experimentation in unmanned systems.

CRUSER will take a broad systems and holistic approach to address issues related to naval unmanned systems research and employment, from technical to ethical, and concept generation to experimentation. Manning requirements, human systems integration, information processing, information display, training, logistics, acquisition, development, command and control (C2) architectures, legal constraints, and levels of autonomy versus mission risk are just a sample of topics for investigation in addition to technical research areas for these systems. These research areas will inform and

augment traditional technical research in unmanned systems and aid in their integration into fleet operations.

B. MANAGEMENT

CRUSER is organized as a regular NPS research project except with a more extensive charter than most reimbursable projects. It has both an oversight organization and coordination team. The Director, with the support of a lean research and administrative staff, leads CRUSER and executes the collaborative vision for the Consortium. The Director encourages, engages, and enhances on-campus efforts among all four graduate schools and existing Centers and Institutes. Faculty and students from all curricula with an interest in the development of unmanned systems are welcome to contribute and participate.

CRUSER continues to build upon existing infrastructure involving research in robotics and unmanned systems, including the Center for Autonomous Vehicles Research (CAVR), the Center for Network Innovation and Experimentation (CENETIX), and the Seaweb acoustic network. These and other programs will continue to be major partners in CRUSER research endeavors. The strong interdisciplinary approach of the Consortium is supported by active interest in the Operations Research, Mechanical and Aerospace Engineering, Information and Computer Sciences, Systems Engineering, Electrical and Computer Engineering, Space Systems, Physics, Applied Mathematics, Oceanography, Meteorology, and Business Administration Departments at the Naval Postgraduate School. Externally, CRUSER leverages NPS's substantial experience in building collaborative communities to create a dynamic learning environment that engages fleet operators, government experts, industry leaders and academic researchers around the naval unmanned systems challenges.

Courses and educational resources contribute to an integrated academic program. CRUSER augments this holistic academic approach by providing diverse topics and aligned projects for courses not traditionally associated with CRUSER focus areas such as: cost estimation of future systems; data mining large sensor data sets; and manpower and personnel implications of unmanned systems.

The Director guides the activities of CRUSER such that they continually align with the unmanned systems priorities of the Navy and Marine Corps. The Director reports to the NPS Dean of Research, and will further serve as a conduit between associated faculty and students at the Naval Postgraduate School and partnering institutions and agencies.

The Director is supported by an NPS Advisory Board consisting of the Undersea Warfare Chair, the Intelligence Chair, the Expeditionary and Mine Warfare Chair and the Director, Field Experimentation. The Board ensures that the fleet and its operations remain a primary consideration in CRUSER activities.

II. PRIORITIES

Concept generation, education, research, experimentation, and outreach are all basic tenets for CRUSER. To support the four CRUSER goals, various activities and research initiatives will occur, ranging from unmanned systems innovation symposia and technical symposia to experimentation and research projects. The six year funding expectation for CRUSER is:

FY11	FY12	FY13	FY14	FY15	FY16
$200K	$1.4M	$3M	$5M	$5M	$5M

Activities for each year will be briefed to the Advisory Board and will receive approval from the sponsor.

FY11 was considered a CRUSER stand up year. With the program's initial funding, CRUSER was established with a Director, Director for Research and Education, Director of Concept Generation and Innovation, and Operations Manager. A CRUSER Community of Interest was created with over 250 members joining from across DoD, academia, and industry within thirty days of the launch of the website (http://CRUSER.nps.edu), an information exchange portal – a "wiki" – was created, and monthly newsletter started. CRUSER aided execution of events like the Future Unmanned Naval Systems (FUNS) Wargame, Robots in the Roses Research Fair, STEM outreach events, exploration of UxS as operational decoys, and the Advanced Undersea Weapons Systems (AUWS) Systems Engineering Analysis Capstone Project. A final FY11 Annual Report was released in December 2011 summarizing these activities.

FY12 is CRUSER's first full year in operation and as a transition year, continued many items started in FY11 such as the Community of Interest database – which is over 800 members near the close of FY12, a monthly newsletter, monthly VTC meetings, and online presence to include a SIPR site. Community-wide monthly meetings are held on the Naval Postgraduate School campus in Monterey, and CoI members are encouraged to attend by phone or via VTC to allow for collaboration with those are not located at NPS. CRUSER sponsored a Warfare Innovation Workshop (WIW) at the close of FY11

focusing on revolutionary concept generation using evolving Naval Unmanned Systems technologies with three teams of NPS students and young engineers from Navy labs and industry, along with a team with more experienced NPS faculty and engineers from Navy labs and industry. Five selected focus areas from the concepts generated during the September 2011 WIW provided the basis for presentations that refined those concepts at the CRUSER Technical Continuum held May 2012 in coordination with the Tenth International Mine Warfare Technical Symposium in Monterey, California. Three of the presentations will lead to field experimentation in FY13: **1) *MISSION***, an underwater network sensor grid; **2) *Digital Semaphore***, a passive communication concept using QR codes and E/O sensors; and **3) *Aerial Combat Swarms***, a swarm versus swarm concept.

Seed funding was provided to eight NPS faculty members to start research across many aspects of unmanned systems, to include the joint ONR/NPS Seaweb at-sea experimentation program with Singapore (*see report section II:D:1*). CRUSER also funds NPS student travel to participate in research, experimentation, and war games dealing with all aspects of unmanned systems to help develop the next generation of military officers.

CRUSER is continuing to provide a discussion venue for new Navy unmanned and robotic initiatives. For example, hosting initial discussions for the Navy's Robotics Education Continuum in conjunction with the CRUSER Technical Continuum provided an opportunity to align unmanned systems education at USNA, NPS and NWC. Additionally CRUSER hosted a legal, social, cultural, and ethical continuing education symposium for operators, acquisition professionals, and engineers in the Washington D.C. area in coordination with OPNAV N2/6 and ONR. Building on the success of this educational symposium, a similar event is being planned for FY13 in San Diego.

Specific FY12 objectives are to provide:

- a source of concept generation,
- an education venue,
- DoD-wide experimentation programs,

- and a DoD-wide forum for collaboration

The remaining sections of this report will address each of these objectives.

A. CONCEPT GENERATION

1. Warfare Innovation Workshops (WIW)

The first NPS Innovation Seminar supported the CNO sponsored *Leveraging the Undersea Environment* Wargame in February 2009. Since that time, warfare innovation workshops have been requested by various sponsors to address self-propelled semi-submersibles, maritime irregular challenges, undersea weapons concepts and unmanned concept generation. Participants in these workshops involved junior officers from NPS and the fleet, young engineers from Navy laboratories, and NWC Strategic Studies Group (SSG) Director Fellows.

a. Revolutionary Concept Generation from Evolutionary UxS Technology Changes, September 2011

The NWDC and CRUSER sponsored WIW was held at NPS in September 2011 in direct support of the SECNAV directive that CRUSER foster the development of UxS concepts to be applied in naval operations. Although the workshop took place during FY11, the results of the CRUSER WIW 2011 were used to inform CRUSER research, symposia, and experimentation throughout FY12 and planning for the future through FY14. The results also serve as an "idea" bank for the entire CRUSER community of interest. Subtitled "*Revolutionary Concept Generation from Evolutionary UxS Technology Changes*," this WIW leveraged the innovation lessons learned in previous workshops and was designed specifically to support concept development for UxS. Participants included NPS students, practicing engineers from Navy labs and industry, and visiting command representatives. They were asked to generate revolutionary concepts using rapidly evolving unmanned naval systems technologies.

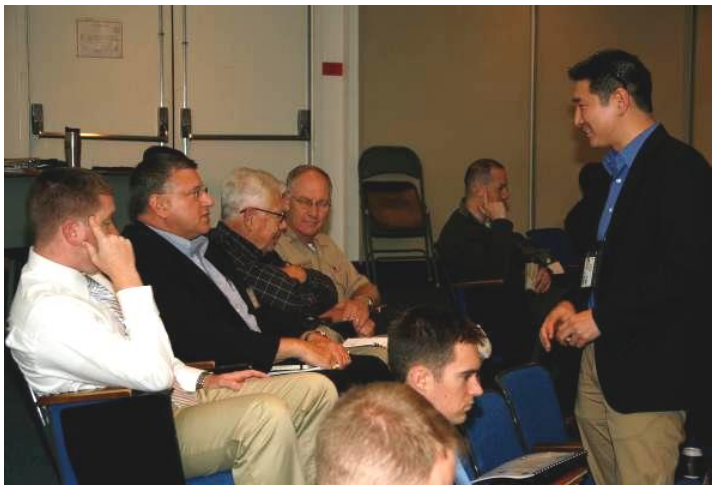

Figure 2. CRUSER Director of Research and Education Dr. Timothy Chung (standing at right), with CAPT T. Doorey (USN, ret.), CAPT W. Hughes (USN, ret.), and ADM N. Carr before the CRUSER WIW 2011 final briefs on 22 September 2011

A final report released in October 2011 details the concepts generated by all four teams and presented in their final briefs (*see Figure 2*). From these innovative concepts, the CRUSER leadership team chose five concept areas that warranted further investigation: 1) counter UAV, 2) information assurance, 3) ISR, 4) knowledge management/data management, and 5) non-kinetic strike. CRUSER then invited industry, Navy labs, and academic researchers to demonstrate related technologies at a three day CRUSER Technology Continuum in May 2012.

Two emergent outcomes of the CRUSER WIW 2011 that are not necessarily related to concept generation, but are in line with CRUSER's mandate, were 1) the advancement of general UxS knowledge among the participants; and 2) a greater appreciation for the technical viewpoints for officers, and an operational viewpoint for engineers. The information interchange and relationship building that occurred during this event are characteristic of the WIW venue, and also support CRUSER's overall intent.

b. Advancing the Design of Undersea Warfare, September 2012

Figure 3. September 2012 warfare innovation workshop, "Advancing the Design of Undersea Warfare"

This 2012 WIW was sponsored by NWDC and CRUSER, and was held during the NPS Enrichment Week 17-20 September 2012 to advance the design of undersea warfare and explore unmanned systems contribution to the concept (*see Figure 3*). In direct support of the NWDC Line of Operation in developing the DUSW, CRUSER developed and executed a WIW focused on employment of the undersea warfare operating concept in the War at Sea Strategy. This WIW focused on innovative concept generation for leveraging U.S. strengths in the undersea domain to counter anti-access/area denial (A2/AD) in Phase 0/1.

The Navy Warfare Development Command (NWDC) and Consortium for Robotics and Unmanned Systems (CRUSER) sponsored warfare innovation workshop (WIW) was held during the NPS Enrichment Week 17-20 September 2012 to advance the design of undersea warfare and explore the contribution of unmanned systems to the concept. In direct support of the NWDC Line of Operation in developing the *Design for Undersea Warfare* (July 2011), CRUSER developed and executed this WIW focused on employment of the undersea warfare operating concept in

the War at Sea Strategy. This WIW focused on innovative concept generation for leveraging U.S. strengths in the undersea domain to counter anti-access/area denial (A2/AD) in Phase 0/1.

Figure 4. September 2012 Warfare Innovation Workshop participants

Nearly fifty participants (*see Figure 4*) including NPS students from across campus, academia and industry attended. After a morning of orientation to the workshop, the scenario, and approaches to innovation; six teams spent the next two and a half days generating concepts to counter an anti-access/area denial (A2/AD) threat. Each team concluded the workshop presenting a twenty-five minute brief summarizing their work and sharing their best ideas. From these innovative concepts, several ideas were identified for further research and development. Selected concepts fell into seven distinct categories (*full concepts are detailed in the NWDC/CRUSER September 2012 Warfare Innovation Workshop final report available upon request*):

1) **Decoys and military deception (MILDEC):** *Designs to obfuscate targeting or cloud the enemy's operational picture – such as a USV swarm fleet or acoustic deception by unmanned systems.*
2) **Vessel tagging:** *For domain awareness and tracking – such as remora tag with hydro-fan generator.*
3) **Non-lethal kinetic effects:** *Generation of non-lethal stopping tactics and mechanisms – such as condenser fouling agents.*

4) **Undersea positioning, navigation and timing:** *For navigation accuracy and domain awareness as an alternative to GPS and surrogate for underwater use.*

5) **Undersea "garage":** *Autonomous docking, power generation and transfer, deployment and to extend time on station.*

6) **Hybrid unmanned vehicles:** *Multi-domain vehicles that transition between domains.*

7) **Crowd-sourcing:** *Leveraging white shipping, regional fishing fleet and other entities to meet mission data collection needs.*

CRUSER leadership will evaluate feasibility based on the technical maturity of each component, the integration potential of the proposed component, scalability, demonstrability, and derivations. Members of the CRUSER community of interest will be invited to further develop these concepts at a three day CRUSER UxS Technical Continuum in April 2013 on the NPS campus. This is the next step in CRUSER's second Innovation Thread.

This workshop targeted participants from the NPS undersea warfare (USW) students and volunteer students from a variety of curriculum tracks across campus; newly selected SSG Director Fellows from the NPS student body; active duty military from commands focusing on undersea warfare; and early career engineers from DoD labs, academia and industry.

A final report detailing process and outcomes was distributed to NWDC, NUWC, the NPS Chair of Undersea Warfare, and the CRUSER community of interest. This report is controlled release, and is available upon request (laengleh@nps.edu).

2. Class projects

Select NPS courses contribute to CRUSER's mission by conduction class projects in various aspects of unmanned systems employment. For example, the capstone Joint C4I course examined C2 in a South China Sea scenario involving unmanned systems in the maritime domain, while the Joint Campaign Analysis class evaluated technologies like the impact of advanced underwater weapon systems on South China Sea scenarios.

Beyond advancing research and concept development, these projects enhance education in unmanned systems.

a. C2 for the New Navy Fighting Machine in a South China Sea Scenario: CC4913 Class Project, June 2012

The specific problem posed to this class was what command and control structure is required for an alternative naval force structure, instantiated by Missile and Patrol Craft vessels, to be integrated in distributed operations within the South China Sea naval environment? The scenario developed to address the stated problem was based upon "The War at Sea Summary," J. Kline and W. Hughes, 14 March 2012 revision. However, for the class project, the assumed was adjusted to 2020 to 2024.

Two smaller vessels are introduced into this South China Sea scenario: Missile Boats and Patrol Craft. The Missile Boat (MB), larger of the two craft, will challenge Red's targeting capabilities and will have primary missions of anti-surface warfare, offensive maritime interdiction operations, and battle force screening. Secondary missions include maritime domain awareness as well as functioning as an integrated communications network node and a limited ISR node. The Patrol Craft (PC) will conduct blue and green water operations and will have primary missions of maritime interdiction operations; visit, board, search, and seizure operations; green water warfare; ISR; and insertion/extraction of Marines/Special Forces ground teams. Secondary missions include maritime domain awareness and an integrated communications network node.

Two operational phases are envisioned for this scenario: the Deterrence Phase and the Hostilities Phase. This class defined separate C2 structures for each phase. In the Deterrence Phase, a Patrol Craft Green-water Surface Action Group (GSAG) will consist of one Missile Boat and five Patrol Craft. The GSAG will report directly to the GSAG Squadron Commander (GSAGRON), who, along with the staff, will reside as a cell in the South China Sea Maritime Operations Center (SCS MOC) located either ashore in Singapore or onboard a C2 ship such as USS Blue Ridge. Both vessel types (MB and

PC), along with other U.S. forces, will engage in non-offensive missions during the Deterrence Phase.

In the Hostilities Phase, all Missile Boats from the PC GSAGs will be withdrawn to create Missile Boat SAGs, which will report to the Surface Warfare Commander (Commanding Officer onboard CVN/LHA/LHD) to conduct, primarily, battle force screening and anti-surface warfare for the CSG/ESGs. During this phase, the PC GSAG will consist of five PCs, the senior of which will be the primary in the group. The PC GSAGs will continue to report directly to the GSAGRON at the SCS MOC, and they will be tasked with all of the missions noted above.

Command and control network structures are provided for both the Deterrence and Hostilities Phases. A combination of legacy and new technology communication assets will be utilized in this scenario as the assumed timeframe indicates. The primary communications platform will be airships positioned over the operating area to provide a footprint for naval assets for an air-gapped theater area network. The primary means of communication between air, ground, and surface assets will be point-to-point FALCON laser communications. Secondary communications will consist of HF, VHF, UHF Line of Sight, UHF Satellite, VLF, and SHF/EHF. Coalition partners (formal or informal) will engage in communications with U.S. assets depending upon their own capabilities, to include CENTRIXS.

POC: Professor Dan Boger (dboger@nps.edu)

b. Joint Campaign Analysis class - 2012

The Joint Campaign Analysis class is a capstone seminar composed of operations research, operations logistics, systems engineering analysis, and modeling and simulation students applying their technical and analytical skills to a major campaign scenario. The Summer 2012 Joint Campaign Analysis class addressed the contributions of UUVs in a major War at Sea scenario. UUVs were used as extended ISR sensors for their submarine hosts, and as delivery platforms for undersea weapons. Quantitative results are restricted (distribution limited), but may be requested from the course instructor

POC: Professor Jeff Kline (jekline@nps.edu)

B. EDUCATION

CRUSER education programs consist primarily of science, technology, engineering, and math (STEM) outreach events; support for NPS student thesis work; and a variety of education initiatives. These initiatives include sponsored symposia, catalog degree programs, short courses, and certificate programs. CRUSER's education work also involves surveying and aligning curricula for interdisciplinary unmanned systems education.

1. Education Initiatives

a. Robo-Ethics Symposium, January 2012

January 25-26, 2012, ONR, DCNO for Information Dominance (N2/N6), and the Naval Postgraduate School Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) sponsored *Robo-Ethics: Rhetoric vs. Reality*, a 2-day symposium comprised of four panels addressing social, cultural, legal and ethical aspects of unmanned system employment. To minimize costs and maximize participant convenience the venue was the Pentagon Conference Center.

Designed as a continuing education opportunity for war fighters and policy makers assigned to the Pentagon and Washington, D.C. area commands, the symposium's interdisciplinary syllabus had four independent but related foci:

- Robot Rhetoric: Revolution or Evolution?
- Rules of War: The Law of Armed Conflict
- Reciprocity: Worth Killing For vs. Worth Dying For
- Praise and Blame: Moral Agency and the Ambiguity of Accountability in Robotics.

Figure 5. Robo-Ethics panelists and organizers, January 2012 (Washington DC)

Panelists included faculty from the U.S. Navy's three educational institutions, SECDEF staff, Navy JAGC, and one retired general officer (*see Figure 5*). Their professional and academic disciplines included weapons and systems engineering, military and naval history, joint campaign analysis, operations research, international law, and applied ethics. Active and retired Naval officers represented the surface warfare, submariner, aviator, nuclear engineering and JAGC communities – most post-command.

Over the course of the two days, over 100 participants from the DC area attended the Symposium. Organizations represented included USNA, NWC, ONR, OSD, Joint Staff, DOS, Virginia Tech, and the Navy Staff. CRUSER Director 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 of ethical issues we will face in future."

Based upon discussions between panelists and participants, most attending were professionally knowledgeable, possessing mature insight into the complex relationships between panel foci, policy-making and operational risks and opportunities. As expected, they were particularly concerned about (1) how issues discussed may/should affect development of policy governing fully autonomous systems; (2) the significance of fiscal

drivers in the equation and (3) the challenge of integrating semi and fully autonomous weapons platforms more fully into tactical commander's arsenal of choices s/he is willing to employ.

A quick, web-based survey instrument was used to capture participant opinions regarding the quality and professional value of the symposium. The overwhelming majority of those responding believed the event was professionally worthwhile and they would participate again; indeed, most who addressed the question recommended the program be offered again. For a follow-on iteration, several suggested the audience be expanded to include contractors and the non-DoD academic community. They also recommended future panelists and operational examples be less Navy-centric. While this iteration was deliberately restricted in order to capture candid, frank professional discussion, symposium organizers are in agreement a less restricted (venue and audience) iteration of the symposium possesses a high potential for attracting broad meaningful interest and participation. Based on this feedback and requests for reprisal, this continuing education opportunity will be offered again in May 2013 in San Diego.

b. CRUSER Technology Continuum, May 2012

Scheduled in conjunction with Tenth International Mine Warfare Symposium in Monterey, the CRUSER Technology Continuum *"Unmanned Systems – The Way Ahead"* was designed to be a follow-on to the CRUSER WIW in September 2011. The combined event was sponsored by NPS, ONR, the Program Executive Office, Littoral Combat Ships, OPNAV (N85), and CRUSER. CRUSER invited industry and Navy labs to demonstrate the technical capabilities related to the selected concepts in this three day CRUSER Technology Continuum. Presenters will then be invited to participate in a field experimentation of selected UxS technologies planned for FY13. This full process fulfills the second tenet of CRUSER – *from concept generation to experimentation*.

Table 1. CRUSER Technical Continuum presentations, May 2012

TOPIC	SPEAKER
Project MISSION: Maritime In Situ Sensing Inter-Operable Networks	Professor Joe Rice, NPS

Wave Powered Unmanned Surface Vehicle Operation in the Open Ocean: a station keeping asset for distributed netted systems	LT Timothy Rochholz, USN
Mine Burial Expert System for Changing MIW Doctrine	Dr. Peter Chu, NPS
Channel Modeling and Time Delay Estimation for Clock Synchronization Among Seaweb Nodes	LCDR Pascal Gagnon, RCN
NILUS – An Underwater Acoustic Sensor Network Demonstrator System	Dr. Roald Otnes, FFI
Underwater Acoustic Network as a Deployable Range	ENS Rebecca King, USN
Tailorable Remote Unmanned Combat Craft (TRUCC)	LCDR Loren Jacobi, USN and LT Adam Bush, USN
Countering Inundation with Innovation: Defeating Swarm UAV Threats with Aerial Battle Bots	Dr. Timothy Chung, NPS
Autonomous System Support for Maritime Visit, Board, Search and Seizure Operations	Dr. Noel du Toit, NPS
Emerging Applications of 4K Ultra-high Resolution Full Motion Video for Unmanned Systems and Remote Sensing	Jeff Weekley, NPS
Digital Semaphore	Dr. Don Brutzman, NPS

The CRUSER Technical Continuum was unclassified with foreign participation expected and welcome. DoD and industry plenary speakers addressed a broad range of topics including the current status and future requirements of mine warfare technology (*see Table 1*). Break-out sessions showcased scientific and emerging technology research with applications to the undersea environment and specialized sessions focused on five specific areas of interest: 1) counter UAV, 2) information assurance, 3) ISR, 4) knowledge management/data management, and 5) non-kinetic strike.

c. 2nd Annual Robots in the Roses Research Fair, May 2012

Building on the success of the FY11 inaugural research fair highlighting UxS activity on the NPS campus, the primary mission of the *2nd Annual Robots in the Roses Research Fair* was to offer the CRUSER community of interest an opportunity to share research and educational opportunities in the areas of unmanned and robotic systems. The invitation to this event was distributed to a greater audience in hopes of expanding the CRUSER community of interest, 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.

To help non-local community of interest members maximize their travel resources, the 2nd Annual Robots in the Roses Research Fair was scheduled to complete a series of concurrent UxS related events in Monterey. The International Mine Warfare Symposium was held from 7-10 May 2012 at the Embassy Suites in Monterey – in close proximity to the NPS campus. Integrated into the Mine Warfare Symposium schedule was the inaugural CRUSER UxS Technology Continuum.

Figure 6. Under Secretary of the Navy, the Honorable Robert O. Work, visiting the exhibits at the *2nd Annual Robots in the Roses Research Fair*, May 2012

Several hundred NPS staff, faculty, and students were joined by local community members and families on the NPS campus in Monterey. The Honorable

Robert O. Work, Under Secretary of the Navy, gave the welcome address from the balcony of Herman Hall then visited all the exhibits (*see Figure 6*). Local press coverage captured the event well – view the Monterey County Weekly video piece at http://www.youtube.com/watch?v=bLjCCQzz_h4.

c. Continuing Education

Figure 7. Jeff Weekley interpreting 4K imagery results, October 2011

In an effort to bring varying perspectives and keep the NPS campus community of interest up to date on current UxS topics and thinking, CRUSER was instrumental in bringing several prominent speakers to Monterey to present on a variety of topics, as well as giving resident faculty a platform to share their work (*see Figure 7*). Table 2 includes a representative listing of these presentations.

Table 2. Representative listing of CRUSER supported presentations on the NPS campus, FY12

MONTH/YEAR	DETAILS
October 2011:	**4K Aloft Ultra-high Resolution Video Screening:** NPS Professor Jeff Weekley
	Persistent Ocean Monitoring with Underwater Gliders: Path Plans and Adapting Sampling Resolution: Prof. Ryan Smith of the Queensland University of Technology (QUT)
	MENNEKEN LECTURE – Mr. John Quigley, Vice President and a Director at Systems Planning and Analysis, Inc.

	MENNEKEN LECTURE – Dr. Kevin Mahoney, NAVO Gliders
	ECE PhD Seminar - Precision Guided Parafoils - Rocket and UAV deployed payloads: CDR Chas Hewgley
	OceanGate: Mr. Guillermo Sohnlein, Co-Founder and CEO
	ECE PhD Seminar - Sun Tzu, Clausewitz, and the art of advanced ISR (Intelligence Surveillance reconnaissance): USAF Maj Matt Nussbaum and Maj Ken Hall from Beale AFB, and Mr. Kenny Warren from Goodrich ISR
November 2011:	**CRUSER SPONSORED LECTURE -** Vice Admiral Joseph W. Dyer (U.S. Navy, Ret.) - Chief Operating Officer, iRobot Corp.
December 2011:	**MENNEKEN LECTURE - Supervision of Unmanned vehicles Mission Management by Interactive Teams:** Dr. Meghann Lomas, Lockheed Martin Advanced Technology Laboratories (Cherry Hill NJ)
January 2012	**LECTURE: Remote Sensing & Digital Exploitation for Advanced ISR using the Optical Bar Camera (OBC):** Paul Avery of Goodrich ISR Systems
	OR SEMINAR - Autonomy, Planning, and Control of JPL Robotics: Yoshiaki Kuwata, Michael Wolf, and Adrian Stoica of Jet Propulsion Laboratory (JPL)
	LECTURE - Control and Modeling in Tightly Integrated Human/Cyber-physical Systems: Haomiao Huang, Stanford University
	CRUSER/SE LECTURE – UCAS, UCLAS, and other UAVs: RADM Bill Shannon, PEO UAV and Strike
February 2012	**Cohort SEA-18B's Interim Progress Report - Unmanned Surface Vehicle Future Concept "Tailorable Remote/Unmanned Combat Craft (TRUCC)**
	Control and Modeling in Tightly Integrated Enhanced Operational Capabilities of UAVs: Dr. David Shim, KAIST Aerospace Engineering (South Korea)
	MENNEKEN LECTURE – BAMS: CAPT Jim Hoke, LCDR
	MENNEKEN LECTURE - Mr. Chris Von Alt, President and Co-Founder of HYDROID, INC
	CRUSER SPONSORED LECTURE - Future Trends in ASW and Unmanned Systems: Mr. Scott Littlefield, Program Manager, DARPA TTO

March 2012	**Autonomous Systems in Militarily Relevant Environments:** Mr. Stuart Young, Dr. Jonathan Fink and Dr. Ethan Stump from the Army Research Lab
	CRUSER SPONSORED LECTURE - Collaborative Robot Tracking of Geophysical Flows: Dr. Ani Hsieh, Drexel University
May 2012	**CRUSER Technical Continuum:** *a variety of presenters gave talks related to UxS research and experimentation over three days*
	MENNEKEN LECTURE – CAPT (ret.) Karl Hasslinger, Washington Office Director, General Dynamics/Electric Boat
	MENNEKEN LECTURE – Potential Advances in Ocean Acoustics Enabled by Time-Reversal Signal Processing: Dr. Dave Chambers and Dr. Jim Candy, LLNL

d. UxS Curriculum Alignment

FY12 marked the start of an envisioned long-term effort to align the UxS curriculum offerings, not only across the NPS campus but among the Navy's institutions of higher education – the U.S. Naval Academy (USNA) in Annapolis, Maryland, and the Naval War College (NWC) in Newport, Rhode Island. To that end, CRUSER hosted the initial meeting of the Navy Robotics Education Continuum concurrent with the 2nd Annual Robots in the Roses Research Fair in early May 2012. This promising work seeks to align curriculum offerings, ultimately benefiting UxS students at all military institutions.

A catalog of unmanned systems related courses at all three institutions is being populated using the CRUSER wiki tool at: https://wiki.nps.edu/display/CRUSER/Navy+Robotics+Education+Continuum.

2. NPS Student Theses

CRUSER community of interest members guided several NPS students as they developed and completed their thesis work in the initial program year in FY11 (*included in iterative listing in Appendix C*). In FY12, CRUSER members continued to mentor many students as they completed unmanned systems related thesis work. Although not an inclusive list, students mentored in FY12 include:

Table 3. FY12 CRUSER mentored NPS student theses (*alphabetical by author*)

Thesis project title/subject:	NPS Student (s)	
Tailorable Remote Unmanned Combat Craft (TRUCC)	Systems Engineering Analysis Cross-Campus Study (SEA 18B)	FY12
Autonomous Dirigible Airships: a Comparative Analysis and Operational Efficiency Evaluation for Logistical Use in Complex Environments	LT Brian Acton, USN LT David Taylor, USN	FY12
An Interpolation Approach to Optimal Trajectory Planning for Helicopter Unmanned Aerial Vehicles	Maj Jerrod Adams, US Army	FY12
Implementation of Autonomous Navigation And Mapping Using a Laser Line Scanner on a Tactical Unmanned Vehicle	Maj Mejdi Ben Ardhaoui, Tunisian Army	FY12
An Analysis of Undersea Glider Architectures and an Assessment of Undersea Glider Integration into Undersea Applications	Mr William P. Barker	FY12
Integration of an Acoustic Modem onto a Wave Glider Unmanned Surface Vehicle	ENS Joseph Beach, USN	FY12
Investigation of Propagation in Foliage Using Simulation Techniques	LCDR Chung Wei Chan, Republic of Singaporean Navy	FY12
Joint Sensing/Sampling Optimization for Surface Drifting Mine Detection with High-Resolution Drift Model	LT Kristie M. Colpo, USN	FY12
Does China Need A "String Of Pearls"?	Capt Martin Conrad, USAF	FY12
Unmanned Aircraft Systems: A Logical Choice For	Maj Bart Darnell, USAF	FY12

Homeland Security Support		
Multi-Agent Task Negotiation Among UAVs	Mr. Michael Day	FY12
Optimized Landing of Autonomous Unmanned Aerial Vehicle Swarms	Maj Thomas F. Dono, USMC	FY12
An Analysis of the Manpower Impact of Unmanned Aerial Vehicles (UAV's) on Subsurface Platforms	LT Thomas Futch, USN	FY12
Clock Synchronization through Time-Variant Underwater Acoustic Channels	LCdr Pascal Gagnon, Canada	FY12
UAV to UAV Target Detection And Pose Estimation	Capt Riadh Hajri, Tunisian Air Force	FY12
A Cost-Benefit Analysis Of Fire Scout Vertical Takeoff And Landing Tactical, Unmanned, Aerial Vehicle (VTUAV) Operator Alternatives	CDR Kevin L. Heiss, USN	FY12
Autonomous Parafoils: Toward a Moving Target Capability	CDR Chas Hewgley, USN	FY12
Design and Development of Wireless Power Transmission for Unmanned Air Vehicles	Captain Chung-Huan Huang, Taiwan (Republic of China) Army	FY12
Adaptive Speed Controller for the Seafox Autonomous Surface Vessel	LT Michael A. Hurban, USN	FY12
Coordination and Control for Multi-Quadrotor UAV Missions	LT Levi C. Jones, USN	FY12
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	LT Serkan Kilitci, Turkish Navy LT Muzaffer Buyruk, Turkish Army	FY12
Underwater Acoustic Network As A Deployable Positioning System	ENS Rebecca King, USN	FY12
Business Case Analysis of Medium Altitude Global ISR Communications (MAGIC) UAV System	Ramesh Kolar	FY12
The EP-3E vs. the BAMS UAS An Operating and Support Cost Comparison	LT Colin G. Larkins, USN	FY12
Global Versus Reactive Navigation for Joint UAV-UGV Missions in a Cluttered Environment	ENS Michael Martin, USN	FY12
Bridging Operational and Strategic Communication Architectures Integrating Small Unmanned Aircraft Systems as Airborne Tactical Communication	Maj Jose D. Menjivar, USMC	FY12

Vertical Nodes		
The Aerodynamics of a Maneuvering UCAV 1303 Aircraft Model and its Control through Leading Edge Curvature Change	ENS Christopher Medford, USN	FY12
Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)	Maj Les Payton, USMC	FY12
Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks	LT Timothy Rochholz	FY12
GSM Network Employment on a Man-Portable UAS	LT Darren J. Rogers, USN	FY12
New Navy Fighting Machine in the South China Sea	LT Dylan Ross, USN LT Jimmy Harmon, USN	FY12
Business Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF)	LT Jason Staley, USN Capt Troy Peterson, USMC	FY12
Application Of An Entropic Approach To Assessing Systems Integration	Mr Hui Fang Evelyn Tan, Republic of Singapore	FY12
Analysis of the Sustainment Organization And Process for the Marine Corps' Rq-11b Raven Small, Unmanned Aircraft System (SUAS)	Capt Jeffery Van Bourgondien, USMC	FY12
The Study of Upper Ocean Stratification that controls the Propagation of Internal Tidal Bores in Coastal Areas	Kathryn A. Yanez	FY12
Localization of Surface or Near-Surface Drifting Mines for Unmanned Systems in the Persian Gulf	LCDR Meng Wee Joses Yau, Republic of Singapore Navy	FY12

To aid new NPS students in their search for viable thesis topics, CRUSER maintains an iterative listing of potential thesis topics related to UxS using the wiki tool at https://wiki.nps.edu/display/CRUSER/Potential+Thesis+Topics.

3. STEM Outreach Events

Several CRUSER efforts were directly in support of the nationwide initiative to increase student exposure to fields of study and subsequent careers in science, technology, engineering and math. CRUSER leverages the simple fact that robots are

cool as a catalyst to engage students at a visceral level. Once engaged, student interest in STEM pursuits is more easily nurtured.

a. CRUSER Summer Internships

In an effort to foster future technologists and innovators, CRUSER also supports various high school and undergraduate internships for students to get hands-on experience working in a robotics laboratory environment. Intern applications were reviewed, applicants interviewed, and successful candidates were engaged. Those selected were each given a specially prepared "CRUSER Intern Notebook" prepared by the CRUSER Operations Manager to aid navigation of the NPS campus environment. The eleven CRUSER interns this summer represent the following schools (*listed alphabetically*):

- Cal Poly San Luis Obispo
- Carmel High School
- Chico State
- Drexel University
- Monterey Peninsula College
- UC Los Angeles
- UC Santa Barbara

In addition to the multi-disciplinary skills each intern experiences, ranging from mechanical to electrical to computer and software engineering, CRUSER interns are challenged to accomplish their given tasks by seeking out cross-campus faculty, researchers, and even each other, in addition to their internship mentor, to learn first-hand the benefits of an interdisciplinary approach to robotics. Further, each intern is encouraged to develop professional and research skills, including résumé building, research documentation in lab notebooks, and application of textbook knowledge to real research problems. As these CRUSER interns represent the next generation thinkers, the vision for their internships is to highlight a holistic, collaborative learning and research environment, which they can continue to foster throughout their academic career.

b. STEM Activities, K-8

In April 2012, CRUSER supported two innovative STEM activities of note. On Friday, 27 April, fifty fifth graders from the elementary school in the NPS student housing community came to campus on a "Science Day" field trip.

Figure 8. La Mesa "Science Day" robotics lab activity, April 2012

Their day included a series of lab tours, one of which was Dr. Timothy Chung's robotics lab. Dr. Chung and his lab staff designed an engineering challenge for the students using LEGO MindStorm robots. Students were introduced to robotics, and then tasked as teams to program their robot to complete a predefined course (*see Figure 8*).

The following morning, Dr. Chung conducted a "Robotics Exploration" with a local cub scout den (*see Figure 9*), tasking them with the same programming challenge for the LEGO MindStorm robots. The activity was well received, and the students gained an appreciation for the study of robotics.

Figure 9. Dr. Timothy Chung guiding Cub Scout "Robotics Exploration" activity, April 2012

Additionally, a STEM element was included in the *Robots in the Roses Research Fair*. Taking advantage of the available power sources (i.e. wind, solar, current, waves) is a rich research field for unmanned systems. To introduce that engineering element, the 2012 STEM activity – the "USV Design Challenge" – tasked youngsters to redesign rubber duckies by adding balloons and rubber bands to increase the buoyancy and endurance of their duck (*see Figure 10*).

Figure 10. USV Design Challenge test pool, May 2012

These creations were then "field tested" in a rubber duck race in the newly renovated Roman Plunge reflecting pool. The designer of the winning duck was awarded a duck whistle – in lieu of a research grant!

C. RESEARCH

At the direction of the SECNAV, NPS continues to leverage long-standing experience and expertise in the research and education of robotics and UxS to support the Navy's mission. The establishment of CRUSER served as a vehicle by which to align currently disparate research efforts across the NPS campus as well as among our academic partners and greater community of interest.

1. FY12 CRUSER Funded Research

In March 2011, CRUSER made its first call for proposals to seed research topics. The stated funding period was 31 October 2011 through September 2012, and the funding levels were set at $75,000 to $125,000. Researchers were asked to submit proposals in one of the following five general subject areas:

1) Technical
2) Concept Generation
3) Experimentation
4) Human Capital Requirements
5) Social, Cultural, Political, Ethical and Legal

Due at the beginning of August 2011, nineteen proposals, totaling more than $1.9m in requests were submitted. The CRUSER on-campus advisory board selected eight projects to receive a total of $400k to support their work in FY12 (*see Table 3*).

Table 4. FY12 CRUSER funded research projects

PRINCIPAL INVESTIGATOR(S)	PROJECT TITLE
Professor Joe Rice	Maritime In Situ Sensing Inter-Operable Networks (MISSION)
Dr. Roberto Cristi & Dr. Oleg Yakimenko	Passive UxV Navigation using Visual Sensors
Dr. Patrick Harr	Tropical Cyclone Reconnaissance with the Global Hawk: Operational Requirements, Benefits, and Feasibility

Dr. Peter Chu	Joint Optimization of Sensing and Sampling with Unmanned Undersea Vehicles
Dr. Dan Nussbaum	Roadmap for Reduction of Total Ownership Cost (TOC) to Support Acquisition Decisions of Unmanned Autonomous Vehicle - Phase I
Dr. Don Brutzman	Establishing Ethical Constraints on Mission Planning for Autonomous Systems: AVCL Declarations and AUV Workbench Implementation
Dr. Noel du Toit & Professor Doug Horner	Extended Autonomy Capability for the ScanEagle UAV
Dr. Don Brutzman & Mr. Jeff Weekley	Developing Novel Approaches to Quick Response Code (QR Code) Image Acquisition using Live-streaming 4K Ultra-high Resolution 60p Camera Systems

a. Maritime In Situ Sensing Inter-Operable Networks (MISSION)

Project MISSION is advancing acoustic communications (acomms) and underwater networking technology. Project MISSION is emphasizing operations in noisy littoral environments and is fostering cross-nation interoperability (*see Figure 11*).

MISSION is a bilateral project formally established by Navy International Programs Office (NIPO) and Office of Naval Research (ONR) involving collaborative research by the NPS CRUSER Program and National University of Singapore (NUS) Acoustic Research Laboratory. ONR 32 and CRUSER each provide matching funds for the U.S. MISSION activities, and Singapore Ministry of Defence supports the Singapore national participation in like kind. Moreover, Singapore is hosting the annual MISSION experiments and is providing ship support, logistical support, and environmental compliance support.

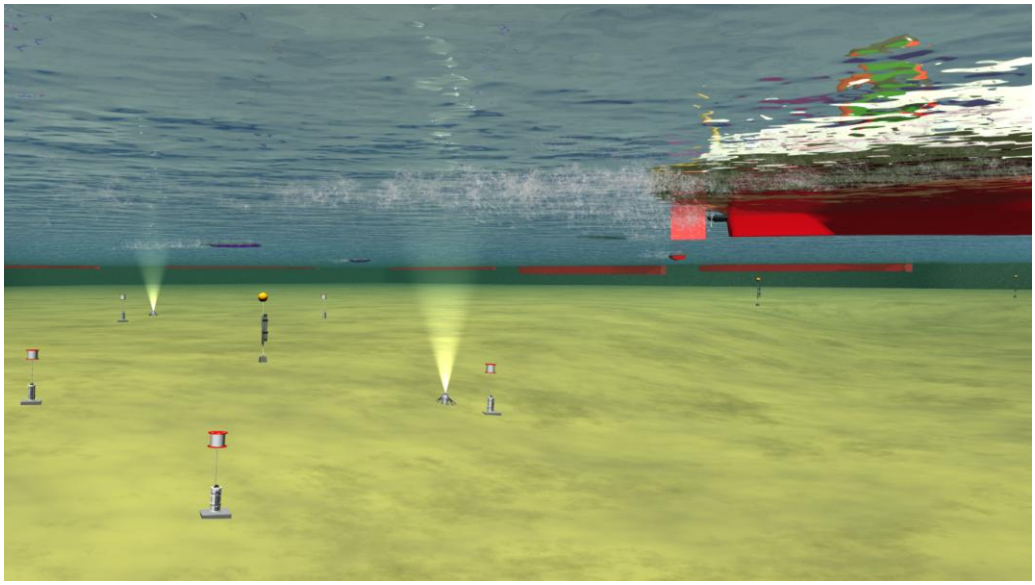

Figure 11. Project MISSION experimentation involves the collaborative testing of NPS Seaweb and NUS UNet underwater acoustic networks in the shallow (15-40 meter), noisy waters of Singapore Strait. MISSION experiments are scheduled for October 2012 and October 2013.

In FY12, the NPS Physics Department and the NPS Undersea Warfare (USW) Research Center established the Seaweb Lab on the rooftop floor of Spanagel Hall in support of Project MISSION. The rooftop may seem an unusual location for an underwater technology lab, but the sky access to solar energy and satellite communications is essential to the development of autonomous maritime Seaweb nodes. In FY12 the NPS Seaweb Lab acquired two Wave Glider Unmanned Surface Vehicles (USVs) as experimental platforms in the advancement of a station-keeping, unmoored gateway node to provide an interface between the Seaweb underwater domain and the above-water Iridium satellite domain. In FY12 a series of MISSION experiments performed on the Monterey campus in Del Monte Lake supported student thesis research. In addition, a May 2012 engineering experiment in Singapore Strait established baseline metrics for planned MISSION experimentation in that challenging environment.

The Seaweb Lab, Wave Glider USVs, Del Monte Lake, and the pre-existing inventory of Seaweb acoustic modems and underwater sensors are providing the basis for a series of MISSION experiments in FY13 and FY14. In the first quarter of FY13, NPS will perform a 3-week trial in Singapore Strait with NUS, and a 2-week trial in Oslo Fjord with NATO partners Defence R&D Canada (DRDC Atlantic), Germany

Federal Armed Forces Underwater Acoustic and Marine Geophysics Research Institute (FWG), Norway Defence Research Establishment (FFI), and U.S. Space & Naval Warfare Systems Center (SSC Pacific). These international experiments will exercise Seaweb technology in diverse undersea environmental conditions and will foster U.S. interoperability with the NUS UNet underwater acoustic network and with undersea ASW sensors being developed by NATO collaborators Canada, Germany, Norway, and U.S. Naval laboratories.

For more on the MISSION project please refer to the Experimentation section of this report, II:D:1.

b. Passive UxV Navigation using Visual Sensors

The overall goal of this research is to design a novel capability enabling unmanned vehicles to navigate with respect to a stationary or moving target with unknown position using passive inertial sensors (IMU and GPS) and mono vision (EO or IR). That includes estimating a relative position of an aerial platform intended to land autonomously onto a moving platform with no help provided by/from this platform. The research includes both theoretical study and practical implementation where the developed algorithms are to be implemented on an aerial payload delivery platform, ultra-light weight unpowered guided parafoil system, deployed from an unmanned aerial vehicle to land onto a ship's deck.

Such a system, Blizzard, consisting of a high-performance / long-endurance Arcturus T-20 UAV and Snowflake payload delivery unit, has been developed and demonstrated on multiple occasions already featuring delivering small payloads within 10 meters from a stationary target. The guidance algorithms to guide parafoil to a moving target were also developed and successfully tested. In these tests the moving target broadcasted its position to the descending platform, so that the latter could constantly recomputed the location of an intended impact point. However, a fully autonomous landing assumes no help from the target and there is where algorithms for passive navigation using visual sensor data are urgently needed. The algorithm

development within this research effort is based on both simulated and actual video data collected during the aforementioned drops onto a moving platform.

While integrating vision with IMU/GPS data in order to estimate the position and velocity of a moving target several assumptions have to be made. The main assumption on the target is that it moves in a horizontal plane, which of course is the case for a moving ship or a ground platform, and it moves at an almost constant velocity (speed and direction). The latter assumption is crucial since successful landing of an aerial vehicle relies on a prediction of the target's position based on passive observations (you cannot safely land onto a maneuvering ship anyway). Nevertheless, robustness of developed algorithms allows a mild violation of this assumption.

The challenge of the problem of integrating vision with IMU/GPS data, especially for an uppowered parafoil system is that the trajectory of the payload, propelled by the winds only, loiters over the target to best take advantage of the wind profile during landing maneuvers. As a consequence the camera, which is fixed with the payload and has a limited field of view, sees the target only at certain time intervals while facing the target. This causes extensive "out-of-frame" events which, in standard implementations, cause the estimates of the target position and velocity to diverge and become unreliable.

In the proposed approach, using standard concepts from 3D vision we reformulated the problem as a linear estimation with two distinct dynamic models, one for in-frame events (when the target is in the camera's field of view) and one for out of frame events (when the target is not in the camera's field of view). While the in frame model is fairly standard, the out-of-frame model is based on epipolar geometry by which the last observation (before losing the target) and the first observation (right after we acquire it again) can be viewed as a pair of stereo observations of the same target with unknown displacement. Camera observations together with its position and orientation can then be related to the unknown target out of frame displacement to yield the necessary observation for the dynamic model. Standard recursive optimal filtering (like Kalman filtering) can then be used to recursively track the target.

The particular feature of the developed approach is that the nonlinearities are "memoryless". In this way, the dynamic model is linear, thus guaranteeing the convergence of the estimator. However the drawback is that the nonlinear processing of the observations causes the measurement errors to be nongaussian, biased and also sensitive to the geometry of the system. More recent techniques based on the Unscented Kalman Filter were also investigated to provide the more reliable estimates in the presence of sensor errors.

The project involved extensive theoretical and trade-off studies based on both simulated and experimental data and included participation of several master students and one PhD student.

Actual implementation and integration with onboard guidance algorithm is expected to involve students and instructors of the U.S. Naval Academy who built their version of Snowflake and have seamanship training craft of the "YP 676" class equipped with and aft deck for autonomous landing trials.

POCs: Dr. Roberto Cristi (rcristi@nps.edu) and Dr. Oleg Yakimenko (oayakime@nps.edu)

c. Tropical Cyclone Reconnaissance

Tropical cyclones (TCs) form and initially track over data sparse, oceanic regions. Forecasts of tropical cyclone structure and wind radii, as well as formation, intensification, and motion are based upon guidance from numerical weather prediction models. These models integrate the basic equations that govern atmosphere-ocean dynamic and thermodynamic properties as an initial-value problem. Therefore, the accuracy of the simulation (i.e., numerically-generated forecast) is dependent upon the quality of the initial conditions used to initialize the time integration. Because of the lack of in situ data in the region of a tropical cyclone, the initial conditions are often based upon a blend of a previously-generated, short-term (i.e., 6 h) model forecast and synthetic observations that are based on an assumed storm structure for a given intensity. Other sources of information for wind radii estimation and model initialization are data derived from remotely-sensed, satellite-based observations. However, crucial satellite

observations of surface wind radii such as from a satellite-based scatterometer are no longer available due to satellite failure and lack of a replacement. Further, the uncertainty in satellite-based observations can be large, which lowers the influence of these observations in the definition of initial wind radii as well as initial environmental and tropical cyclone inner core conditions for numerical model integrations.

Over the North Atlantic Ocean, an operational manned aircraft-based 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 occur. 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.

POC: Dr. Patrick Harr (paharr@nps.edu)

d. Joint Optimization of UUV Sensing and Sampling

This project is jointly funded by the CRUSER and the Naval Oceanographic Office (NAVO) in FY12. Five NPS METOC/USW students have been working on the project for their MS degrees with the participation of scientists as co-advisors with inter-disciplinary backgrounds from multi-institutions: Peter Chu (Oceanography, NPS), Timothy Chung (Systems Engineering, NPS), Thomas Wettergren (Applied Mathematics, NUWC-NP), Ronald Bestch (Mine Warfare, NAVO), Frank Bub

(Ocean Modeling and Prediction, NAVO), and Peter Fleischer (Sedimentology, NAVO). Five theses have been completed. Most of them will be published in scientific journals and presented in national and international conferences. Five NPS theses have been produced from this project:

1) LT Kristie Colpo, *Joint Sensing/Sampling Optimization for Surface Drifting Mine Detection with High-resolution Drift Model*, MS, METOC, September 2012.

2) LCDR Timothy Knapp, *Ocean Resurvey-Tactical Decision Aid With Joint Optimization of Sampling and Sensing, MS*, METOC, September 2012.

3) LCDR Joses Yau, *Localization of Surface or Near-surface Drifting Mines for Unmanned Systems in the Persian Gulf*, MS, Physical Oceanography, March 2012

4) LCDR Jason Gipson, *Application of Mine Burial Expert System to Mine Warfare Doctrine*, MS METOC, June 2012

5) LT Patrick Earls, *New Bottom Roughness Calculation from Multibeam Echo Sounders for Mine Warfare*, MS, Physical Oceanography, September 2012

The Navy's ocean models were taken as an important component into optimal UUV sensing and sampling with application to mine warfare (MIW) and anti-submarine warfare (ASW). Two high-resolution NAVO operational ocean models, the Navy Coastal Ocean Model (NCOM) and Delft3D, are used for the study. Frank Bub at NAVO conducted thorough quality control on these models and provided near real-time ocean environmental data for the Persian Gulf (*see Figure 12a*) and Hampton Roads Inlet (*see Figure 12b*) with the horizontal resolution up to 60 m and time increment of 10 min.

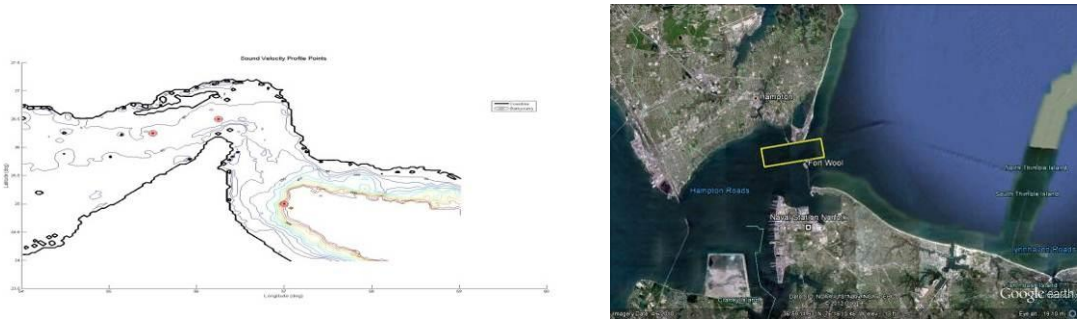

Figure 12: Navy's ocean models for (a) Persian Gulf, and (b) Hampton Roads inlet

This project improves time-varying search areas, tactical sensor network, ocean resurvey tactical decision aid, and mine warfare doctrine with ocean models and data. The search and detection problem formulation with near real-time environment, extensive simulation studies, and subsequent statistical analysis provide insights into how to incorporate real-time and/or historical oceanographic data to maximize the probability of detection.

Navy tactical ocean environmental models and data are very important and useful for the CRUSER program. Tasks accomplished in FY12 to effectively incorporate the ocean models in the UUV operations within this project are included in five individually titled subprojects, each the subject of an NPS student thesis. The first, *Joint Sensing/Sampling Optimization Algorithm for Mine Detection Using UUV* included work by Peter Chu, Kristie Colpo, Thomas Wettergren, Frank Bub (NAVO), and Ronald Betsch. By incorporating tactical oceanographic models into optimal sensing/sampling network, an algorithm has been developed to determine the location and time with minimal number of UUV deployments to have high detection probability (*see Figure 13*) for moving targets (such as drifting mines and maritime IEDs). Besides, a mine drift model was also developed on the base of ocean circulation model. It offers an estimation of surrounding environmental effects and therefore provides time critical estimations of target movement. These approximations can be used to further optimize sensor network components and locations through a defined methodology using estimated detection probabilities.

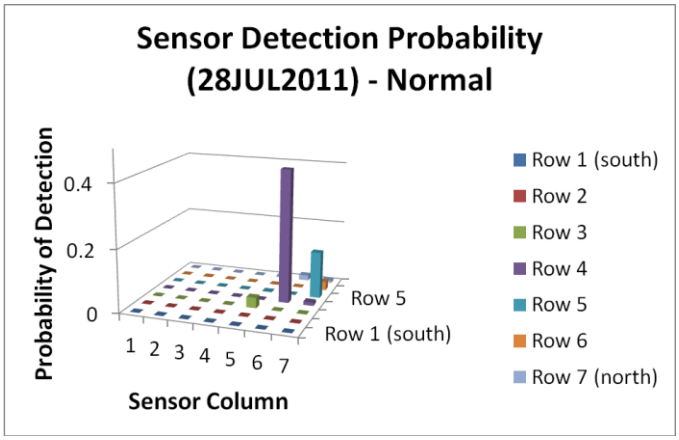

Figure 13. Calculated sensor detection probability by the joint optimization algorithm with the Navy ocean model for the Hampton Roads inlet on 28 July 2011

The second set of work, *Ocean Resurvey-Tactical Decision Aid with Joint Optimization of Sampling and Sensing*, was conducted by Peter Chu, Timothy Knapp, and Ronald Betsch. The combination of temperature and salinity variation has a significant effect on the sound velocity profile of the ocean. Many militarily significant ocean areas exhibit rapid change in ocean temperature and salinity, making operational monitoring critical to maintain our military advantage and presenting an operational challenge for military planners on how to efficiently schedule ocean survey assets so as to optimize the survey area. The Ocean Resurvey-Tactical Decision Aid (OR-TDA) was developed as a supplemental tool to the Navy Coastal Ocean Model (NCOM) that will aid military planners in scheduling limited survey assets in areas of the world that are of military significance. The OR-TDA is intended to be a decision aid to help optimize the time and location to deploy ocean sensors in order to get realistic sound speed profiles for accurate estimation of the acoustic transmission for naval operations. Using NCOM output data, the OR-TDA will help planners by identifying areas of the ocean that are changing more rapidly than others (*see Figure 14*). Planners can then use that information to help prioritize ocean locations to be re-surveyed and then schedule survey assets appropriately.

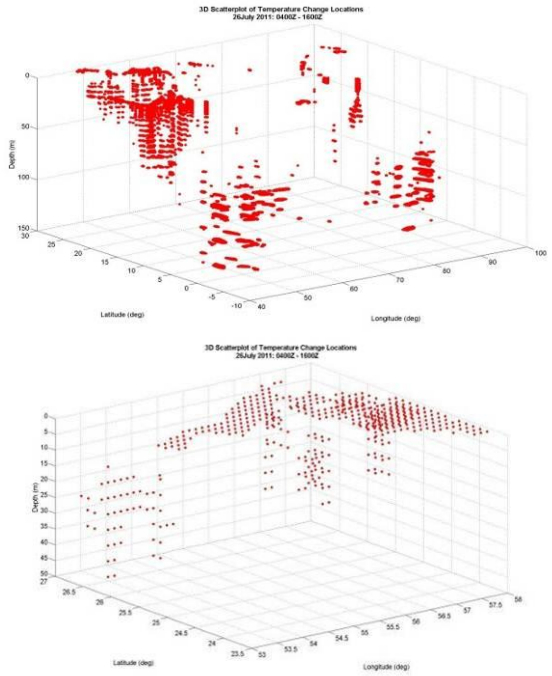

Figure 14. OR-TDA sample output plots in the Persian Gulf: (a) temperature, and (b) salinity

Development of Integrated Search and Ocean Model for Detecting Drifting Mines with Unmanned Systems in the Persian Gulf, a thesis by Joses Yau, involved the work of Dr. Timothy Chung, Peter Chu, and Ronald Betsch. 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 naive 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 (*see Figure 15*). Such insights enable further explorations using empirical datasets for specific oceanographic regions of interest.

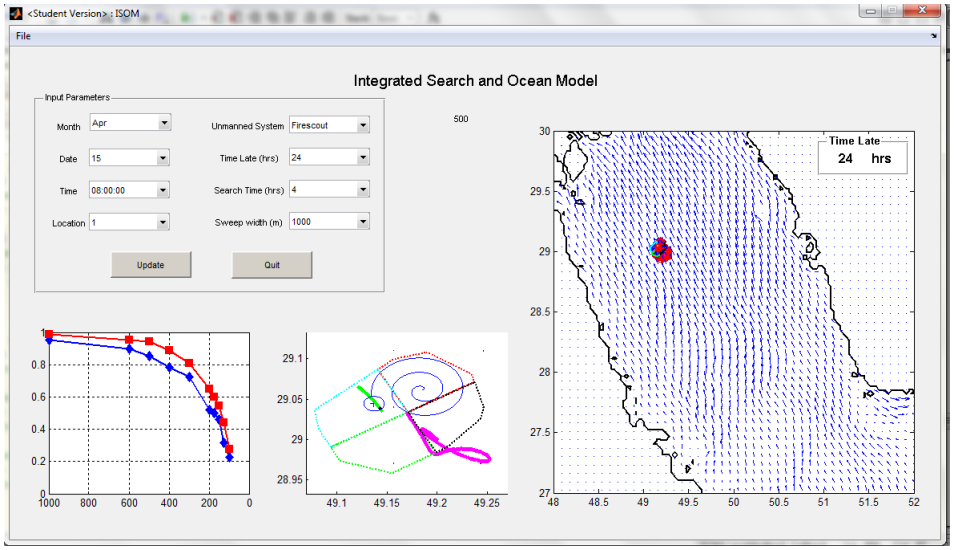

Figure 15. Integrated search and ocean model for detecting surface drift mines

New Bottom Roughness Calculation from Multibeam Echo Sounders for Mine Warfare was a project conducted by Peter Chu, Patrick Earls, and Ronald Betsch. Bottom roughness has a significant effect on acoustic backscattering on the ocean bottom. Sonar systems rely on backscattering and shadows for detecting objects lying on the seafloor. The seafloor is rather complex including craters, gullies, seaweed, rocks, sand ridges, tall obstructions, deep holes and sloping regions. Underwater mines can be hidden around these objects to make it more difficult to be detected. High resolution (1 m × 1 m) seafloor data collected by the Navy using multibeam echo sounder (EM710) off the western coast of Saipan was processed by the MB Systems. The advanced least-square method is used to establish new bottom reference level from the EM710 data. After removing the reference level, the high-resolution bathymetry data converts into bottom roughness percentage using a threshold. The calculated bottom roughness percentage is ready to be incorporated into the current Navy doctrine. Two new (gradient and mathematical morphology) methods have been developed in this thesis to calculate the bottom roughness without the reference level (*see Figure 16*). Statistical analysis was conducted to illustrate the added value of the new bottom roughness calculation.

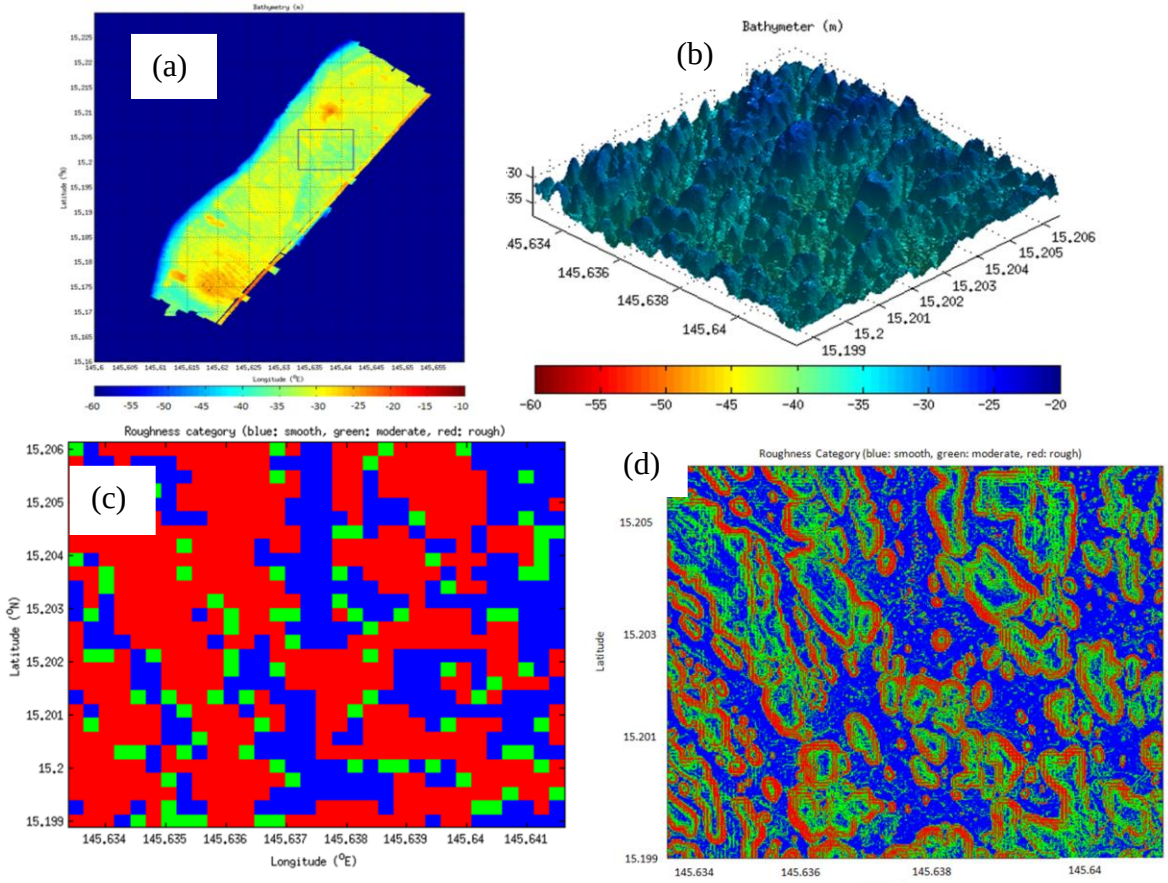

Figure 16. Bottom roughness from multibeam echo sounders (EM710): (a) experimental area, (b) bottom bathymetry from EM710, (c) bottom roughness with the conversion of bathymetry into roughness percentage, and (d) new gradient method for bottom roughness

Finally, *Application of Mine Burial Expert System to Mine Warfare with UUV* resulted in a thesis by Jason Gipson with supporting work by Peter Chu, and Peter Fleischer. An assumption central to this project work is that sea mines are the quintessential asymmetric threat to the Navy's ability to conduct operations in the maritime domain. Presently, the U.S. Navy has a limited ability to find buried mines. This capability gap is compounded by the apparent phase lag between emergent technology and the existent outdated mine warfare (MW) doctrine used to for planning and measuring clearance success; where such elements like the use of the doctrinal bottoms types can skew a commander's decision–making process for how to properly apply technology to defeat the threat.

Understanding the extent of sea mine burial is pivotal for executing MCM clearance operations effectively. The Mine Burial Expert System (MBES) was developed

to determine the dynamic physical behavior for and magnitude of sea mine burial while communicating the inherent uncertainty in the specified degree of burial. This thesis showed the utility of the MBES to make accurate burial predictions utilizing Bayesian networks, deterministic models for burial, mine threat and environmental uncertainty (e.g. sediments) and expert opinion in comparison to traditional "limited" doctrinal methods; especially in terms of resolution. It further expounds on the current operational state of the MBES—highlighting the need to leverage emergent technologies and relationships between the scientific, acquisition and warfighter communities especially use of UUVs.

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e. Roadmap for Reduction of Total Ownership Cost (TOC)

According to the methodology section of our proposal, we planned to research 4D/RCS and Technomics to accomplish our objectives. We analyzed the implications of using 4D/RCS as a common architecture for all UAVs, and drafted a white paper on this topic. We have also researched a paradigm shift in UAV cost estimation, which will take the form of a student thesis by LT K. Beth Jasper. LT Jasper will finish her write up by the end of September. Instead of focusing on Technomics, however, we decided to look at whether the use of an Open Architecture model for unmanned systems resulted in cost savings. LCDR Paula Firenze completed a thesis on this subject in June.

This project was addressed in three parts, the first being the 4D/Real-time Control System (4D/RCS). The trend of increasing drone missions, with respect to missions for manned aircraft, shows that drone missions may be the way of the future. As such, the O&S costs of UAVs must be optimized. The 4D/RCS architecture is a hierarchical control structure that addresses the problems faced by an intelligent vehicle system, such as a UAV, to accomplish mission goals. In 4D/RCS, the lowest cost plan is always implemented. There are a number of cost functions at each level within the architecture to determine the planned action at that particular level.

For example, the 4D/RCS architecture should use the fewest number of UAVs to accomplish a particular mission. This saves on fuel costs because fewer UAVs would be travelling to the target location. By optimizing UAVs with regards to the missions performed, there will also be an increase in life cycle for the UAVs in the squadron and fewer wasted man-hours because the UAVs will need fewer repairs within a given time period.

The next section of this three part project in FY12 took a closer look at A paradigm shift in UAV cost estimation. The purpose in this part of the project is to provide a TOC that reflects the end-to-end costs associated with ISR platforms. We do this by developing an amended, and expanded, Work Breakdown Structure (WBS) within the standard cost estimating methodology. Additional WBS elements include:

- C2 Function
- Data uplink
- Bandwidth
- Intelligence manning
- Data storage
- Software licensing
- Exploitation hardware
- Processing hardware
- Ground support elements

Research questions that addressed through this approach were:

— *What are the total costs associated with manned and unmanned aerial vehicles from exploitation to the dissemination of intelligence?*

— *What are the costs associated with measuring bandwidth as UAV's become operational?*

— *What are the Measures of Effectiveness (MOEs) to construct the balance between manned and unmanned aircraft from an Intelligence, Surveillance, and Reconnaissance perspective?*

— *How should the Navy balance UAV cost with capability?*

— *How should the Navy best characterize UAV costs to ensure the total cost is fully recognized?*

— *Is there value in analyzing other manned aircraft within the DOD that could provide a manned capability equivalent to unmanned at a cheaper cost?*

Results are available in LT Jasper's thesis, available at the end of September 2012.

The Open Architecture (OA) portion of this project was based on the primary assumption that while there are savings that could potentially be achieved by using OA, especially in conjunction with a Common Architecture, the Navy must be careful when and how it chooses to use the OA. There are risks that could potentially cost more than any savings OA might be able to achieve. There are three potential areas in which using OA might result in cost savings: reuse, open source, and interoperability.

In order to quantify the effects of reuse, SLOC and equivalent SLOC (ESLOC) data from the BAMS program were analyzed. The data showed a savings of $1.4 Billion, but all of this savings was attributed to opportunistic reuse as opposed to OA.

The open source part of the thesis drew data again from the BAMS program. By using Linux OS instead of VxWorks OS, the program was able to save $2.9 Million over the assumed 20-year life cycle of the program (assuming 25 licenses). The problem with open source code is security. More money may need to be spent on developing tighter and more layers of security, so some of the savings achieved by reusing the code may be offset by the need to write multiple types of security for the same code.

The interoperability section was focused on ground control station and the Navy's attempt at developing a Common Control System in which it owns all data rights. It is unclear whether this would in fact save money, as the BCA did not include any data rights costs, and the projected number of UAVs that would participate was reduced from six to three. The Army has developed a similar system, however it is proprietary.

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f. Establishing Ethical Constraints on Mission Planning for Autonomous Systems: AVCL Declarations and AUV Workbench Implementation

Recent years have shown that the concept of robot ethics is important for establishing norms on allowed behaviors for unmanned systems. However, approaches considered to date are either based on highly abstract artificial intelligence schemes or else uniquely "hard wired" into a given robotic architecture in an unrepeatable fashion. A more-general approach is needed for defining and deploying ethical constraints on robotic systems that are expected to operate autonomously with only occasional human control.

Approximately 2 years of current design effort have been applied towards applying ethical considerations to a long-stable and well-recognized 3-layer robot architecture developed at NPS: the Rational Behavior Model (RBM). Excellent conceptual progress has been made which builds upon a critical insight: establishing ethical reasoning to govern robot behaviors consists of applying ethical constraints to existing patterns of robot planning, rather than creating some new paradigm for philosophical contemplation. This approach is intentionally patterned after similar patterns used by military forces, which often must operate in a loosely coordinated fashion while observing highly consistent rules of engagement (ROEs).

A recent paper and presentation by Brutzman, McGhee and Davis provides a detailed description of this approach. Feedback at the IEEE Oceanic Engineering Society (OES) Autonomous Underwater Vehicles (AUV) 2012 Conference in Southampton UK was uniformly positive and enthusiastic. This work outlines specific next steps for testing and demonstrating such ethical constraints. This work further builds on two decades of successful effort establishing an open-source codebase, the Autonomous Unmanned Vehicle (AUV) Workbench.

The figure below (*see Figure 17*) provides a simple illustration about how ethical constraints might be inserted into mission conduct. Technical review with available staff indicates that this approach is directly feasible in the existing codebase. Implementation efforts will consist of two primary activities:

1. Autonomous Vehicle Command Language (AVCL) additions and refactoring for inclusion of constraint descriptions in mission agenda declarations
2. User interface additions to allow setting, observing, simulating and reporting on strategic agenda missions that include ethical constraints.

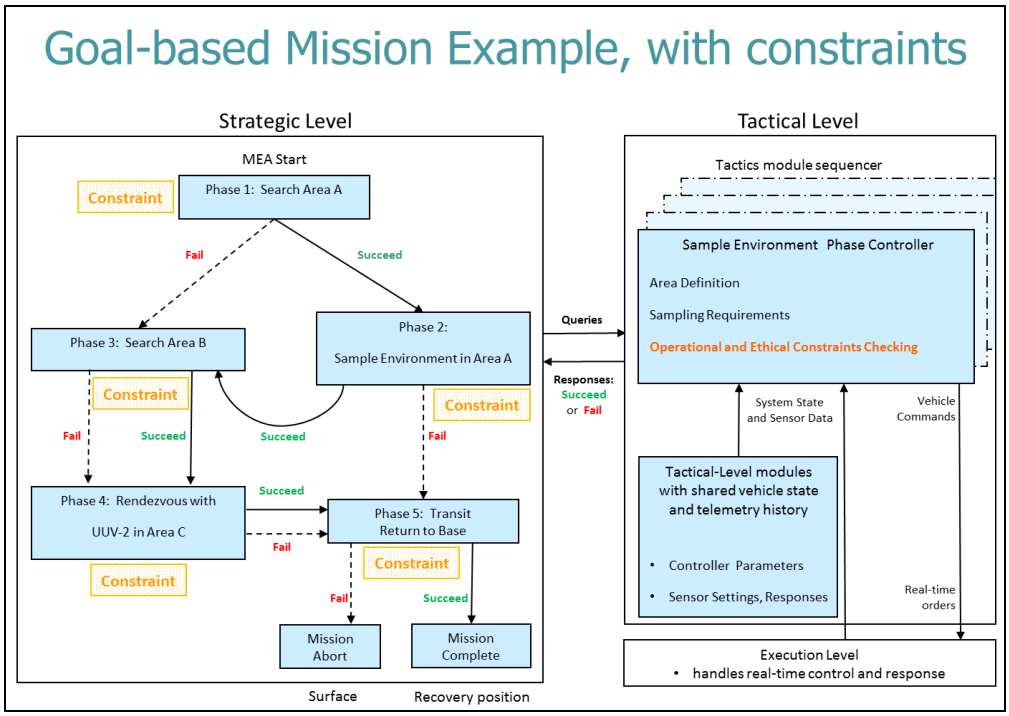

Figure 17. Goal-based mission example, with task-oriented constraints being investigated and integrated for potential general applicability of ethical bounds on robot operations

This research team will perform the following tasks.

1. Improve agenda-mission planning and execution phase of AUV Workbench
2. Refactor Autonomous Vehicle Command Language (AVCL) as needed, design appropriate declarations and integrate constraints into AVCL 2.2
3. Simulate, test, and create annotated mission reports. Demonstrate differences in sequencing of mission phases by autonomous controller with and without ethical constraints.

4. Write a short report on results with 2-3 exemplar missions that illustrate the different outcomes that occur when robot tasking is (or is not) constrained by ethical considerations.

A further result of this rapid-response effort will be to write a longer, more extensive proposal for external sponsor in the autonomous ethics arena that advances CRUSER progress further. Our current thinking regarding that proposal objective will be to compare our capabilities with other emerging concepts. Field testing will be an important aspect of demonstrating such capabilities.

Inability to show ethical behavior means that unmanned systems will always require direct human supervision, in effect tethering them as simple remote tools. We are optimistic that our work can show the applicability of applying ethical constraints to autonomous systems that follow ROEs by working in concert with human-led afloat task groups.

Participants include:

- Don Brutzman is project PI with overall responsibility for design, conduct and execution.
- Dr. Duane Davis is co-PI conducting development and oversight of AVCL extensions.
- Dr. George Lucas is co-PI with oversight and review of ethical considerations.
- Dr. Bob McGhee (Emeritus Professor) is providing technical oversight and review on a voluntary basis.
- Research Associates Terry Norbraten Mike Bailey and Don McGregor are performing programming tasks.

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g. Extended Autonomy Capability for the ScanEagle UAV

Figure 18. Boeing/Insitu ScanEagle UAV

The Boeing/Insitu ScanEagle UAV platform (*see Figure 18*) is extensively used in theater, having logged more than 500,000 combat flight hours. NPS CAVR maintains and operates seven of these vehicles, which are often employed during USSOCOM-NPS TNT experimentation. However, the utility of this platform for autonomy research is limited due to semi-autonomous operation: a dedicated pilot operates the vehicle remotely, with the option of a few basic autonomous behaviors (such as loitering). For this platform to be utilized in advanced autonomy applications (e.g., autonomous multi-vehicle, multi-tier wide-area surveillance support for tactical forces engaged in maritime Visit, Board, Search, and Seizure or Close Quarters Combat for Military Operations in Urban Terrain), the platform must be able to adapt its behavior as the mission evolves. This adaptation is accomplished through onboard sensing and decision-making. The focus of this project is extending the autonomy capability of the ScanEagle UAV platform by developing and implementing a secondary autopilot architecture (i.e., backseat driver). The backseat driver architecture allows the existing stock autopilot to be tasked from an onboard computer, leveraging the proven capabilities of the stock autopilot for execution. The secondary autopilot consists of software and hardware components. An onboard computer was integrated as a payload on the ScanEagle and connected to the stock autopilot. For the software, the MATLAB Simulink and Stateflow environments were used for algorithm development. These algorithms must be executed either in a real-time (RT) or non-real time (NRT) environment, for which OROCOS and ROS were used, respectively. Two interfaces with

the stock autopilot were implemented: waypoint (high-level) and angular-rate (low-level) commands. A mission management module was developed (NRT) and implemented (see Figure 2a) and waypoint-following (high-level) mission execution has been demonstrated in simulation, and will be demonstrated in field experiments in November 2012. Additionally, a real-time path-generation capability and a path-following controller were integrated in the secondary autopilot architecture (*see Figure 19*).

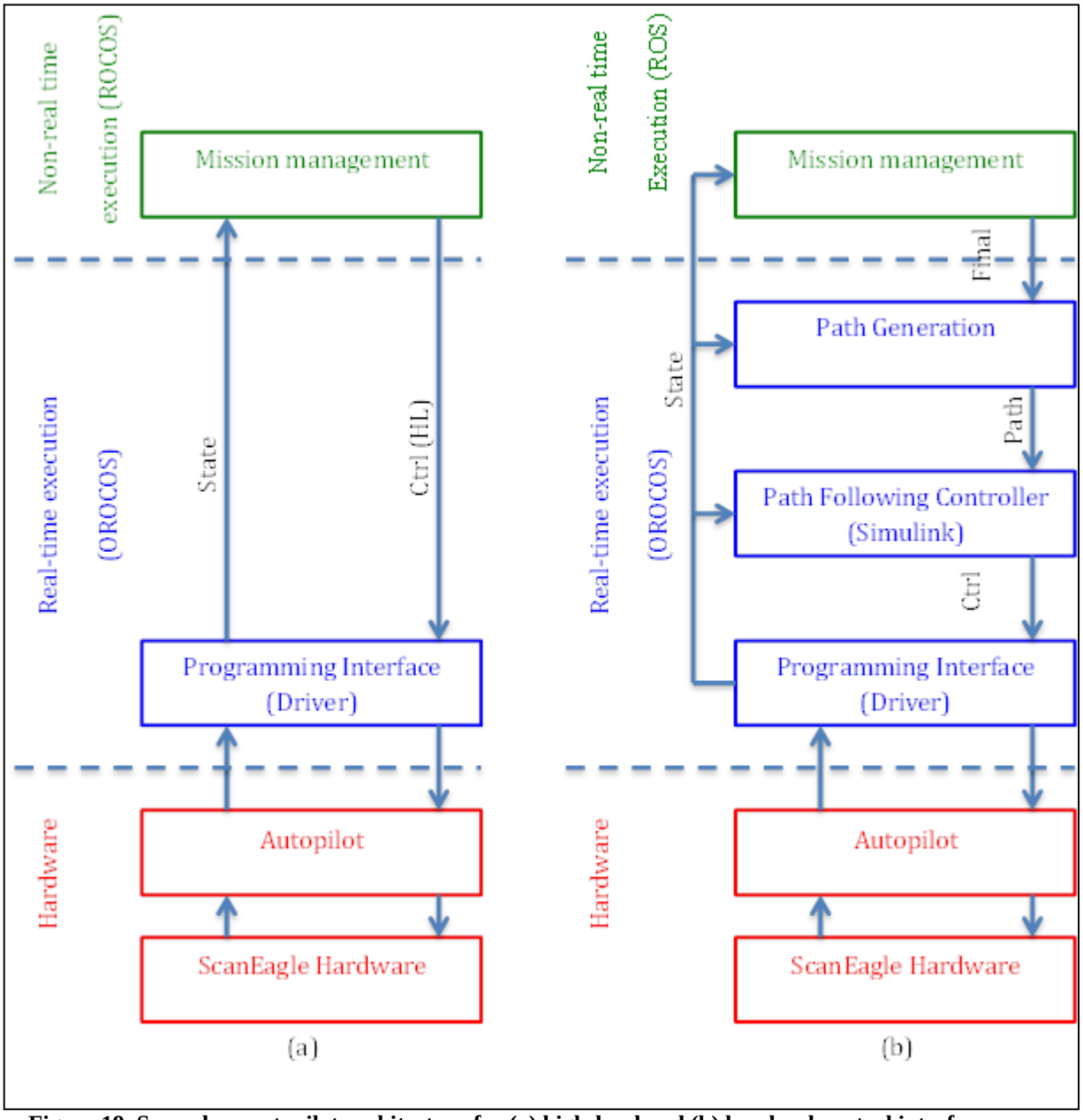

Figure 19. Secondary autopilot architecture for (a) high-level and (b) low-level control interfaces

The low-level interface will be demonstrated in simulation in November 2012. Limitations associated with the stock autopilot have been identified, most notably limited control over data access and update rates from the autopilot (e.g., UAV state data) and limited simulation capabilities. Switching to a commercial-of-the-shelf (COTS) autopilot is recommended as it will overcome these limitations and further facilitate cross-platform compatibility, while leveraging the secondary autopilot architecture developed in this project.

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h. Developing Novel Approaches to Quick Response Code (QR Code) Image Acquisition using Live-streaming 4K Ultra-high Resolution 60p Camera Systems

Figure 20. Video demonstration shows a series of QR codes streaming at 30 Hz and being captured frame-by-frame with a handheld commercial QR code reader

The ability to create and display Quick Response (QR) codes can be achieved easily. The proliferation of online and offline QR code creation applications and the ubiquity of digital signage allows users to find, encode and decode these 2D barcodes with few barriers to success (*see Figure 20*). However, initial research findings indicate their use as tactical, digital semaphores for line-of-sight communications will require equipment (e.g. best-in-class optics, ultra-high resolution image sensors), digital signal

processing and special tactics in order to exploit the technology fully – for instance QR codes decoded from distances with tactical significance. We found significant improvements from commercial-of-the-shelf (COTS) high-definition (HD) cameras, both 1280X720 and 1920X1080, when using 4K at 2160X3840 (ultra-high definition, or 4K). Trends indicate that the larger 4K CMOS sensor increases decode performance over long distances for general purpose imaging systems. Specialized systems, such as a "Black-and-White" industrial camera which gathers only luminance (brightness and contrast) and reconstructs an image without a Bayer pattern decoding process might do even better, but the principle that a larger sensor is better would still hold.

This project proposes a novel approach to acquiring QR code images using emerging ultra-high resolution, high-frame rate, live-streaming 4K digital video camera systems from static and time-varying QR codes at various distances and presentation formats as preliminary tests for future applications in field exercises and relevant operations. The goal is to perform a series of QR code image acquisition tests using emerging 4K live-streaming camera systems. The tests include both laboratory bench tests for initial system configuration (*see Figure 21*) and in-field tests to determine performance characteristics of the camera system and various QR code schemes. Preliminary results were presented at the TENTH International Mine Warfare Technology Symposium in May 2012 in Monterey CA.

Figure 21. Research Associate Jeff Malnick tosses a QR code spinning in the air to demonstrate the ability of the 4K Camera System to freeze highly dynamic imagery suitable for the capture of QR codes on fast-moving objects.

Initial tasks:

- Establish initial system configuration, tests and results
- Procure appropriate loaner camera systems under existing or new LPCRADA
- Establish initial bench tests to include QR code image acquisition, image processing and associated workflows
- Conduct limited field experiments to establish likely operational parameters of QR code reader 4K camera system

Follow-on Tasks:

- Field deploy, test and evaluate
- Evaluate suitability of system for purchase and integration into NPS and Navy-owned unmanned systems and surrogates (e.g. MZ-3A Airship)
- Operational experience guides ongoing development and deployment

Other contributing factors to QR code decode performance include lowering the QR code version type. QR codes at higher versions (e.g. Version 10 versus

two sequential Version 4 QR codes), have smaller "QR Bits" which take up less pixels per frame of motion video. Our testing shows that you need at least a 6x6 pixel block per QR bit to successfully decode. One area where tactical decision aids can help would be the automatic encoding of QR codes based on the known parameters, such as current environmental optical backscatter, transmission distance, physical dimensions of the QR Code display medium, message, etc. Our initial research indicates that any optimization scheme should not allow the derived approximate minimum pixel block on the reconstructed image for a CMOS-based sensor per QR bit to fall below 6X6 pixels. Based on this finding, it should be possible to predict readability of any given QR code with any given imaging system.

QR codes that are moving in space or streaming are herein called "Dynamic QR Codes" and they require very high electronic shutter speeds to "freeze frame" the QR code for decoding. It is analogous to an ISO rating on analog film and is reflected in the 'wagon-wheel' effect of analog film moving picture cameras. Cameras without the ability to control the electronic shutter speed typically have the electronic shutter speed adjusted based on sensed lighting conditions or have fixed electronic shutter speeds. Dynamic QR codes are captured as blurred images in these typical cameras. Furthermore, typical compression schemes (codecs) employed on COTS camera systems are incapable of extracting individual QR codes from dynamic QR codes because they only record changes between frames (inter frame compression) over a series of groups of frames, known as LongGOP (groups of pictures) compression. If the image is out of range for these codecs, it will appear blocky and unreadable.

It is unlikely that both the QR code and the capturing camera will be on stationary or motion-controlled platforms. Only cameras for industrial applications or cameras used in visual effects for Hollywood films can have such predictability for both camera and target. So, any QR code in a tactical situation will likely be dynamic and will benefit from both a tunable electronic shutter and uncompressed frame-by-frame reconstruction from the sensor.

Thus, consumer and even professional-consumer (Pro-Sumer) cameras which are highly appropriate for capturing typical scenes of everyday life are not suitable

for capturing Dynamic QR codes. This would allow for Dynamic QR codes to be hidden in plain sight, with little or no risk that commercially available cameras could incidentally detect the code. This is perhaps significant tactically.

Over long distances even with the 4K cinema resolution we tested it may not be possible to decode larger data-volume QR codes. This may be due to the environment such as lighting and air quality or it could be due to the sheer distances involved in the capture. In some cases, it may be necessary to use a QR code that has very large QR Bits, also known as a lower version QR code. The character limit of such a QR code may not be enough to hold all the data that needs to be transmitted; yet two or more QR codes can be 'strung together in a moving image (a movie) to form a 'Streaming QR code'. To facilitate the transfer of enough data we propose streaming lower version QR codes, optimizing for current and known conditions. While the exact format for encoding a Streaming QR code is not yet determined by us, the advantages of having metadata about the message streamed with the message are obvious. We believe the concept of a streaming QR code is significant and bears further investigation.

Flashed on a screen at 1/30th of a second, our streaming QR codes were above the perceptual ability of humans (certainly), and most any machine in current, common use. Multiple samples over a long period of time would be required to detect and decode a Streaming QR code, an impossible task if the Streaming QR code is sent in a 1-second burst (but still allowing 30 QR codes to be transmitted!). However, our 60 frame per second 4K camera can capture them, and capture them in a manner that they are able to be decoded as individual frames. This indicates that the tested camera or a custom-built camera system could be employed across a variety of tactical situations, with a variety of message types, message lengths and QR encodings in a way that is both more secure and more robust than current methods that may be employed.

For optimal decode performance a marriage of proper lensing and sensor must be established. A lens with a focal length that can achieve a 6x6 pixels per QR bit for the given sensor is necessary. With a smaller sensor that has less pixels in general you need to use a larger lens to pull the QR code "closer" to the sensor, focusing more photons of light and rendering a larger QR code. With 4K, we found you could achieve

the 6x6 pixel decode threshold sooner and from further distances than with HD. The optics have perhaps a larger impact on best performance than perhaps sensor size and frame rate, but it is equally important across each of these formats, so should be considered regardless. We propose a software-based decode process for this advanced QR code signaling technique.

While NPS still does not own its own 4K camera system, researchers are hoping to return the camera to NPS for further testing. Proposed plans include deploying the 4K camera system on the CAVR Sea-fox to test image acquisition from an Unmanned System, ship-to-shore, ship-to-ship and underwater. Extreme long-distance image acquisition with extreme telephoto lenses or with telescopic lenses and large format QR codes, as well as development of a predictive model of QR Code successful transmission based on atmospheric conditions (mainly optical backscatter vs. transmissibility through the atmosphere) are other proposals. Access to a 4K camera would ultimately allow for rigorous testing of dynamic QR codes with tunable RPM mounts for QR code displays (wagon wheel effect in frame compressed and uncompressed cameras).

Initial testing of streaming QR codes on moving objects shows promise, however in order to fully realize the benefits of streaming QR codes the development and implementation of an automated QR code image decoder is paramount. Streaming QR codes would be flashed faster than any current image-based QR code reader could digest. To decode a stream of QR codes today one needs to decode the single frames of the QR code stream with handheld scanners. Such a QR code decoder would be software-based, as opposed to image-based. It would ingest either a live stream coming off the Ethernet or firewire port. Most likely the latter is where the stream will be coming from as current video-based streams tend to use firewire or the more current Apple-created thunderbolt standard.

The data stream would be image frames, and once rendered on the local machine would be digested as individual files, "scanned" as a binary entity and decoded for the QR code located within the image file itself. A system such as this would have a lot of obstacles to overcome, mainly with 4k video frames being 25 megabytes each and being ingested at 60 frames per second. Such a system would be running faster than the

I/O speed of it's hard drives, and would have to be read and written into RAM only - purely a decoding machine and not a recording machine, as is the case with current 4K JPEG 2000 CODECS.

The system would most likely decode the image and dump the image frame, saving only the decoded message as its output to save not only space but enhance speed and performance. This system would have to be capable of ingesting 1.5 gigabytes of data per second, decoding and dumping the unnecessary decoded frames while simultaneously displaying the decoded messages. Those messages could be text, network links or any assortment of data. This machine would have to be able to keep up with whatever the stream is asking it to display, which may be media intensive.

Also recommended for future work is the concept of auto generation of streaming QR code sequences. Software would take the data to encode into a QR sequence and auto-generate the QR code sequence. Currently, QR code frames are generated one by one with open source QR code generators. An additional and related proposal for future work is auto generation of situation appropriate QR codes for streaming. This software system would take the distance from the capture camera, the capture camera's focal length and senor format as well as environmental data as input and generate a readable QR code as an output, or potentially (as a plugin to the above stated streaming QR code generator) a stream of QR codes for said capture camera.

Auto generation of QR codes based on distance, focal length and sensor format of capture camera also needs further investigation. In a real-world tactical signaling scenario the ability to quickly take into account the environmental factors, transmit display and decode camera is necessary to quickly transmit information. To do so would require software that takes a string of text and automatically creates the QR code stream for transmission. The QR codes within this stream will have to be of low-enough data density that the decoding camera can read and decode individual frames on the receiving end. This would be a seamless process where the user enters in only the data for the stream, the display type, distance between the transmitter and receiver and capture camera qualities such as sensor, and lensing.

Currently, two Naval Officers in the NPS Information Sciences Department are actively exploring this new capability as the subject of complementary theses examining both from technical and tactical perspectives in detail.

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2. ONR/NRL S&T 113 Relationship

Also in FY12, CRUSER has strengthened and formalized a relationship with ONR/NRL S&T 113 within the Reserve S&T Program. CAPT David Harach, who serves as Commanding Officer of the unit and Program Lead for CRUSER activities, spent two weeks in July 2012 in residence at NPS to support CRUSER. In August 2012, CDR Chris Wolfgeher conducted his active-duty tour in residence at NPS. CRUSER will continue to enhance and leverage this relationship further in FY13. A couple of members of this unit also attended our annual research fair as well as our September 2012 WIW.

3. Advanced Robotic Systems Engineering Laboratory (ARSENL)

The newly established Advanced Robotic Systems Engineering Laboratory (ARSENL) represents a diverse academic and research group at NPS, emphasizing that robotic and unmanned systems merit a holistic, multi-disciplinary approach for their design, their employment, and their future concepts. Led by Assistant Professor Timothy Chung in the NPS Systems Engineering Department, ARSENL comprises students representing all naval unmanned systems domains (sea, subsurface, aerial, amphibious, and ground robotics), five countries in addition to U.S. Navy and Marine Corps students, and from over six different academic departments across the NPS campus. Associated research projects range from algorithms for improved autonomy of UAV swarms to design and modeling of surf-zone crawling robots to assessment of unmanned capabilities for subsurface operations. ARSENL facilitates innovation and camaraderie through opportunities for information exchange at weekly group meetings, where interactions can lead to ideas and better mutual understanding. In October 2012, ARSENL will

commemorate its new laboratory space, co-located with other collaborative unmanned systems research and education facilities at NPS.

POC: Dr. Timothy Chung, thchung@nps.edu

D. EXPERIMENTATION

CRUSER-affiliated NPS faculty and students continue to engage in their own UxS experimentation, and participate in outside experiments and tests. Aligning parallel efforts and sharing research updates among a greater COI through CRUSER has magnified the benefits of these formerly disparate experimentation efforts. Current NPS field experimentation efforts take place regularly at Camp Roberts, an hour drive south of the NPS campus in Monterey. Two projects conducting CRUSER sponsored experimentation in FY12 are Project MISSION and QR Code.

1. Maritime In Situ Sensing Inter-Operable Networks (MISSION) Field Experimentation

Maritime surveillance is a Naval and Homeland Security imperative that can be met with the deployment of autonomous underwater sensor networks. In FY12 Project MISSION has advanced through-water acoustic communications and networking capability (*see Figure 22*) with emphasis on cross-nation interoperability in noisy littoral environments.

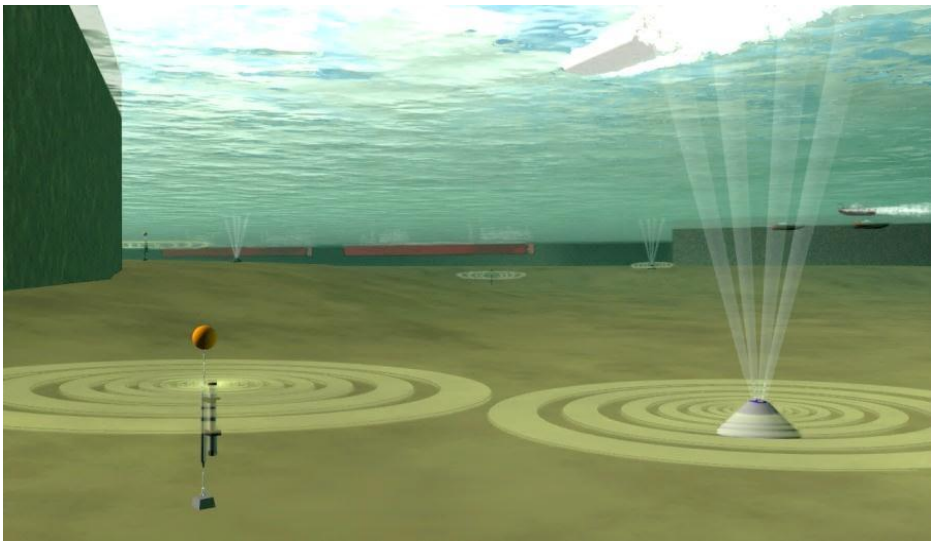

Figure 22. Maritime In Situ Sensing Inter-Operable Networks (MISSION) deliver near-real-time data from distributed underwater sensor stations.

Project MISSION is a bilateral R&D project involving collaboration by NPS and National University of Singapore (NUS) in advancing state-of-the-art, through-water, acoustic communications (acomms) and networking technology. Project goals include:

- Study noisy underwater environments.
- Achieve acomms through adverse channels.
- Obtain datasets for acomms channel studies and transmission security (TRANSEC) studies.
- Integrate U.S. Seaweb and Singapore UNet networks.
- Demonstrate acoustic networks in Singapore Strait.
- Enable distributed wireless architectures for maritime domain awareness (MDA) and undersea warfare (USW).

Project MISSION permits researchers to study noisy and variable acoustic communication channels, perform collaborative studies, and conduct long-duration in situ measurements. This project provides opportunities to test channel-tolerant and channel-adaptive acoustic communications, and enables the project team to conduct controlled signaling experiments (i.e., utilizing Signalex scientific method with parametric analysis

of signals and careful measurement of environmental factors) in acoustically challenging and operationally relevant littoral environments.

Figure 23. Site for MISSION 2012 and 2013 sea trials: waiting basin for container ships adjacent to the port of Singapore (*background waters*), and the Singapore Strait (*foreground*), a vital sea lane connecting the Indian and Pacific Oceans.

NPS and NUS will perform multi-week MISSION trials in Singapore Strait (*see Figure 23*) in October 2012 and October 2013. Singapore is a challenging environment for underwater communications because of strong tidal currents, shipping noise, and biological noise (snapping shrimp). NUS has developed underwater modems that have been optimized for performance in Singapore waters. These modems can provide short-range links (for local-area networks) to complement the Seaweb medium-range modems (for wide-area networks). MISSION researchers anticipate this work will produce technology that can be deployed on demand in Singapore and elsewhere.

The sponsored portions of the U.S. contributions are derived in approximately equal measure from two sources, CRUSER and ONR 32. In keeping with the CRUSER charter, the CRUSER funds are directed toward research on the NPS campus, including procurement of equipment, operation of facilities, and work performed by NPS faculty and students. Specific CRUSER expenditures include acquisition of Seaweb modems and hardware, establishment of on-campus Seaweb laboratories, preparation and operation of an on-campus test site at Del Monte Lake (*see Figure 24*), engineering testing on the bench, project-relevant labor and travel for the Principal Investigator, funding for student

research, and expenses associated with conference presentations and publications. The ONR funds will be issued to NPS and will largely cover the contributions by U.S. contractor Teledyne Benthos, Inc. and SPAWAR Systems Center Pacific.

Figure 24. MISSION researchers and students perform engineering experiments in Del Monte Lake on the NPS campus in Monterey.

In FY12, Project MISSION conducted several preliminary field experiments, including work in the Singapore Strait and in Del Monte Lake.

A six-node Seaweb network was established in Del Monte Lake. This infrastructure supported the development of methods to use an underwater network as a positioning system for mobile nodes operating in its domain. Ensign Rebecca King published an NPS thesis based on her research during this experiment.

LCdr Pascal Gagnon considered the problem of synchronizing underwater clocks using acoustic signaling. The experimental portions of his research were also performed in Del Monte Lake.

NPS and SSC Pacific performed preliminary experiments in Singapore Strait to establish baseline performance metrics. Communication ranges of 1000 meters were achieved between a pair of acoustic modems. This result informs the design of the 10-node Seaweb network planned for the MISSION 2012 sea trial in October.

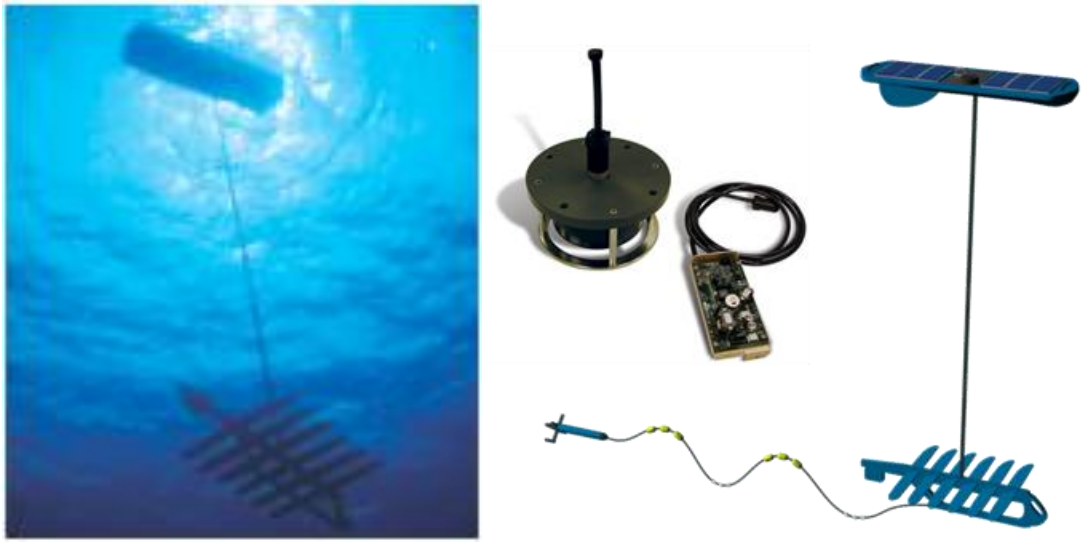

Figure 25. The Wave Glider USV (left) converts vertical sea surface motion to forward thrust. It captures solar energy to power on-board navigation, sensors and communications. Project MISSION has begun work to integrate a Seaweb acoustic modem (electroacoustic transducer and electronics board shown) with a tow body compliantly attached to the lower body of the Wave Glider (right). The resulting "gatekeeper" station-keeping gateway node will provide a communications interface between the underwater Seaweb network domain and the space-borne Iridium satellite communications domain.

One of the problems with underwater networks is the vulnerability of gateway nodes at the sea surface. The gateway node has traditionally been implemented as a moored buoy. Project MISSION is exploring the feasibility of using an unmoored, station-keeping USV as the gateway node (*see Figure 25.*) Toward this goal, Ensign Joe Beach studied the engineering tradeoffs arising from the addition of an acoustic modem to a Wave Glider USV. He considered the impact of hydrodynamic drag and the acoustic performance of the modem for candidate locations on the Wave Glider USV. LT Tim Rochholz considered the practicality of persistent station keeping by the Wave Glider. To gain insight, he followed the progress of 4 Wave Gliders during the first leg (California to Hawaii) of a trans-oceanic crossing of the Pacific.

NPS Project MISSION investigators are contributing knowledge to various U.S. Naval programs, including the Deep Seaweb JCTD, the PMW770 Undersea Connectivity Roadmap, and the N2N6 Undersea Distributed Network.

NPS has been selected to provide Seaweb acoustic networking capability to the Next-Generation Autonomous System (NGAS), a NATO Joint Research Project (JRP)

involving ASW sensors from Canada, Germany, Norway and United States. NGAS experimentation will occur in Oslo Fjord early in FY13.

With the MISSION 2012 sea trial occurring in October 2012, the experiment objectives are as follows:

- Install Seaweb and UNet communication nodes at stations designated by the Singapore Coast Guard.
- Form a Seaweb wide-area network consisting of 10 nodes; test long-range network-layer routes with up to 8 hops.
- Test deployment of Singapore PANDA-based underwater networks; test Singapore UNetStack and UNet II modem software.
- Deploy a telesonar testbed as a surrogate acoustic intercept node to record extended time series capturing up to 24 hours of Seaweb network activity.
- Exercise Seaweb network discovery process whereby ad hoc node deployments are autonomously configured with optimized network-layer routes.
- Evaluate ranging performance, and test range-based geometry inversion techniques.
- Understand and model variability of non-coherent communication performance; understand and model variability of coherent communication performance.
- Understand and model communication bit errors for communication links.
- Understand variability of channel spreading function.
- Understand variability of in-band ambient noise and relationship to external factors (diurnal cycle, rain, wind, shipping, etc).
- Evaluate interference between UNet and Seaweb networks.

- Determine joint error performance (or outage probability) across network links.
- Test Multi-Access, Collison-Avoidance (MACA) implementation.

NPS participation in Project MISSION is co-sponsored by the NPS CRUSER Program and ONR 32. NUS participation in Project MISSION is sponsored by the Singapore Ministry of Defence (MINDEF). Project MISSION is sanctioned by the U.S. Navy International Programs Office.

POC: Professor Joseph Rice, jarice@nps.edu

2. Digital Semaphore and 4K Camera Field Experimentation

Figure 26. USN Airship MZ-3A over Pax River Naval Air Station performing aerial survey after *Hurricane Irene* using a Live-streaming 4K Camera System, August 2011

In cooperation with the Naval Research Lab's Scientific Development Squadron ONE (VXS-1) and CineGrid, NPS demonstrated the capture and streaming of 4K full motion video (3840X2160 at 60 frames per second) from the USN Airship MZ-3A during the week of 22- 28 August 2011 (*see Figure 26*). In early FY12 NPS Research Associate Jeff Weekley and two volunteers from the newly formed Remote Sensing Center's candidates in Intelligence, Surveillance, and Reconnaissance program, captured imagery using a 4K camera from a U.S. Navy dirigible. At 3840 x 2160 pixels, 4K doubles the 1080p high-definition television standard in both the vertical and horizontal dimensions; has 2.5 times the frame rate of conventional digital cinema and supports full 12-bit color sampling. The imagery was compressed using NTT Advanced Technology

JPEG2000 Real-time Codec and streamed via the Global Lambda Integrated Facility (GLIF) 10gbps network through NPS' CENIC connection. The imagery will be made available to NPS researchers upon request to assess its value in Intelligence, Surveillance, and Reconnaissance (ISR) programs; stereoscopic 3D reconstruction; inclusion in hyper-spectral imagery; and for various computer vision techniques.

Imagery from the 4K camera is also being used to evaluate the operational capacity of the Digital Semaphore concept generated by CRUSER WIW participants in September 2011. This concept employs QR codes to transmit data visually and reduce the risk of interception. Laboratory and field experimentation of this concept continued throughout FY12, and results will be reported.

POC: Jeff Weekley, jdweekle@nps.edu

3. Aerial Combat Swarm: a Swarm vs. Swarm Grand Challenge Competition

Figure 27. Experimentation team led by Dr. Timothy Chung (at front left) with aerial battle bots

CRUSER also supports the active development of live-fly experimentation capabilities for many-robot unmanned aerial vehicle (UAV) systems research ongoing at NPS (*see Figure 27*). Leveraging access to unique resources, such as facilities at Camp Roberts, California and frequent experimentation events, the Many vs. Many (MvM) Autonomous Systems Testbed provides the infrastructure to holistically explore many-

robot systems research in operationally realistic settings, and challenges engaged researchers to more actively and expediently translate theory to practice. The MvM Testbed is designed to integrate technological advances in hardware (inexpensive, expendable); software (open source, open architecture); networking (dynamic information management); and operational concepts (tactics, command and control); and leverage many corollary efforts. Development of this testbed also highlights NPS' focus area of generating new concepts of operations, especially in the context where they may face non-cooperative or even adversarial systems. Enabling technologies that provide the autonomous abilities to perceive, recognize, and respond to these players will further enhance their operational relevance. In this context, the NPS Aerial Drone Swarm project is designed to leverage the MvM Autonomous Systems Testbed to explore practical and operationally relevant avenues to counter these "swarm" opponents, and to pursue validation of advanced theoretical approaches concurrently. The vision for the Aerial Drone Swarm project is to push the boundaries of many-robot systems research with an ambitious initiative culminating in live-fly field experiments involving 50 vs. 50 UAVs by 2015. This project leverages existing infrastructure through the NPS Field Experimentation Cooperative and CRUSER programs, and offers a venue for concept generators, researchers, and operators to holistically address many technologically and operationally challenging problems in a field experimentation context.

FY13 activities will include laying the foundation for a national competition in coordination with ONR, AFRL, and DARPA.

POC: Dr. Timothy Chung, thchung@nps.edu

E. OUTREACH

1. Community of Interest

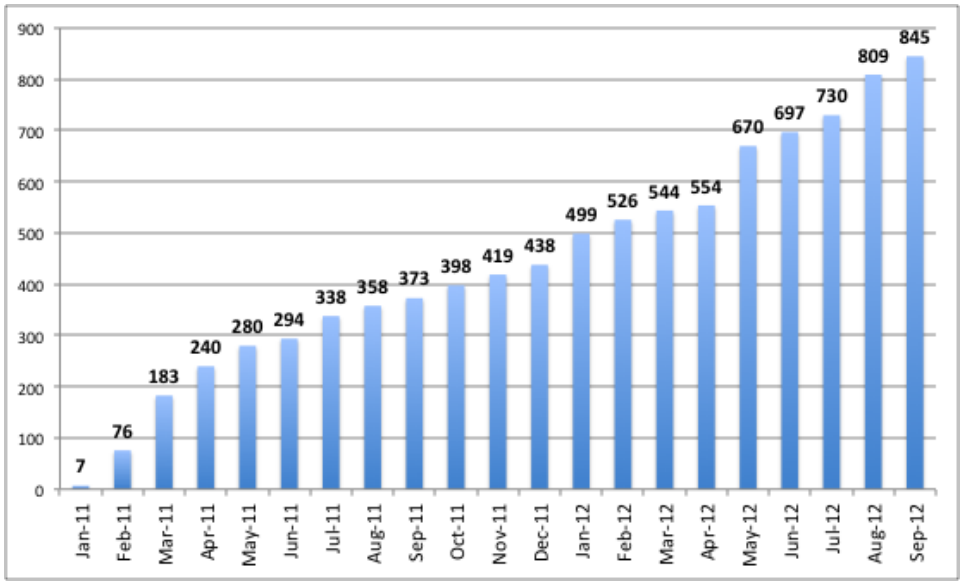

Figure 28. CRUSER COI growth, January 2011 through September 2012

At the end of FY11, CRUSER's first program year, the CRUSER COI had grown to include almost 400 members. As of 1 September 2012 this fledgling COI has doubled in size and now stands at just over 800 members (*see Figure 28*). Beyond NPS community members, the CRUSER COI includes major stakeholders from across the DoD, as well as significant representation from industry and academia (*see Figure 29*).

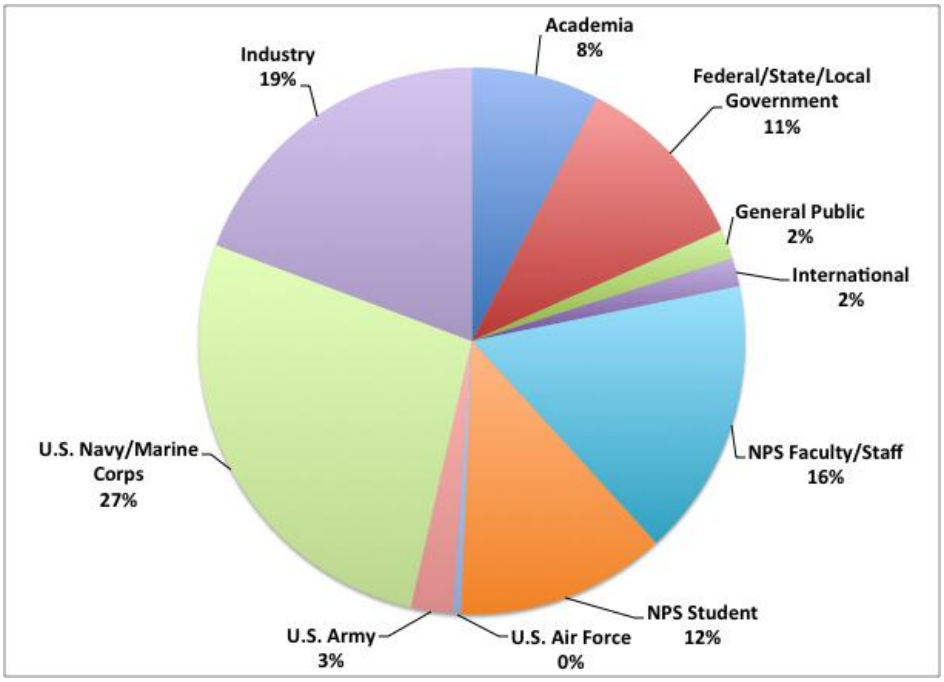

Figure 29. CRUSER COI breadth of membership, September 2012

Thanks to the outreach efforts involved with the 2nd Annual Robots in the Roses Research Fair in May 2012, the COI now includes a number of secondary school students and faculty who are integral in bringing the next generation of thinkers into the emergent field of robotics and UxS research and experimentation.

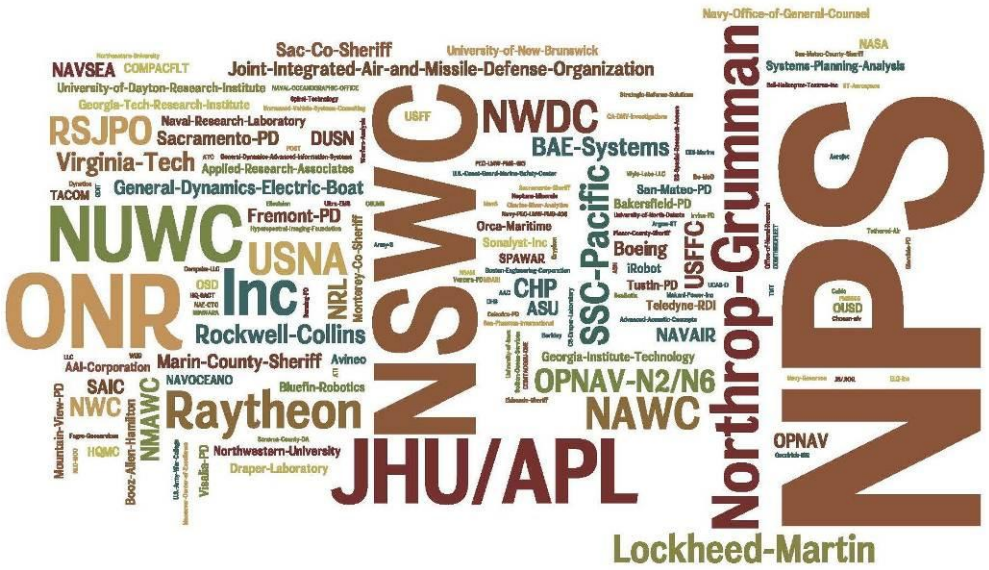

Figure 30. CRUSER community of interest (COI) membership roster word cloud, September 2012

2. Briefings

As in the start-up year, the CRUSER leadership team continued to meet a steady request for briefings on the program by visiting representatives of industry, academia, other DoD commands, as well as international military visitors. A representative listing of CRUSER briefings is included in Appendix B of this report. Most briefings were delivered on the NPS campus in the CRUSER Coordination Center, although CRUSER briefings were given in other campus locations as well as offsite.

3. Conferences

CRUSER supported student travel to several conferences in FY12. In December 2011 Major Christian Klaus presented his paper at the 50th IEEE Conference on Decision and Control. In March 2012, Major Thomas Dono attended the Black Dart 2012 Mid-Planning Conference. Also in March 2012, LT Beth Jasper attended the 2012 Ground Robotics Capabilities Conference & Exhibition. To start the summer, Major Peter Nesbitt (USA) and LT Tim Stevens (USN) presented at the MORSS Symposium. CRUSER also supported conference attendance for Dr. Fotis A. Papoulias, an Associate Professor from the Department of Mechanical and Aerospace Engineering in the NPS Graduate School of Engineering and Applied Sciences.

CRUSER will continue to support student and faculty participation in unmanned systems related conferences on an ongoing basis.

III. CONCLUSION

The overarching CRUSER program Innovation Threads (*see Figure 31*) give a broad overview of programming themes through FY13, starting in September 2011 with the CRUSER WIW concept generation event – the start of program Innovation Thread 1. Program Innovation Thread 2 began with the CRUSER September 2012 WIW and continues concurrently as Innovation Thread 1 moves through field experimentation in early FY13. Both threads will end with unmanned systems exposition events in Washington DC, in June 2013 and June 2014 respectively.

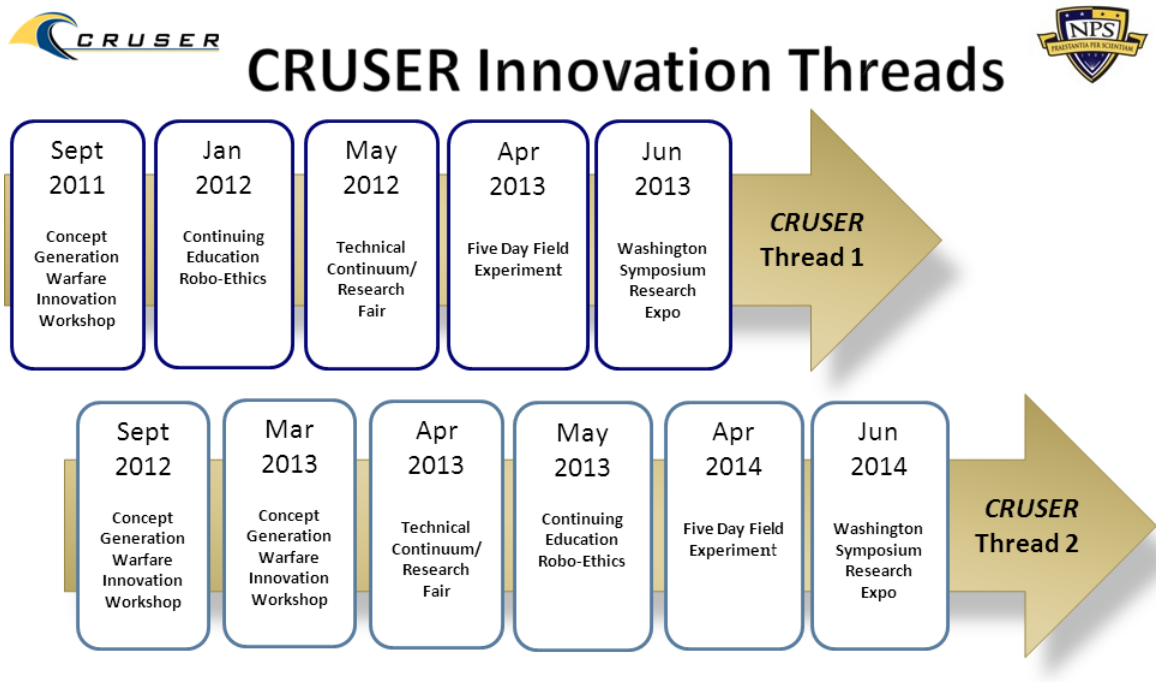

Figure 31. CRUSER innovation thread overview

A. PROPOSED FY13 ACTIVITIES

As described above FY13 will allow the completion of the Thread 1 and the beginning of Thread 2 (*see Figure 30*). The following deliverables are planned:

- CRUSER will host the *Robo-Ethics Continuing Education Program* - a second continuing education seminar about legal, social, cultural, and ethical issues for

operators, acquisition professionals, and engineers in San Diego, California scheduled for May 2013

- CRUSER will sponsor experimentation in FY13 of the most promising technologies from the May 2012 CRUSER Technical Continuum
- CRUSER will host a technical symposium for Thread 2 in April 2013 in conjunction with the annual UxS research fair at NPS to demonstrate technologies to aid in the concepts generated the September 2012 WIW
- CRUSER will sponsor a Technical Fair to be held at ONR in June 2013 to demonstrate the results of the first CRUSER Thread: From Concept Generation to Experimentation.
- CRUSER will sponsor NPS faculty research and experiments across the holistic topic areas not traditionally sponsored by ONR technical funds such as human resources, human systems integration, concept exploration, and others. The call for proposals is in Appendix E of this report.
- CRUSER will fund the joint ONR/NPS Seaweb at-sea experimentation program with Singapore.
- CRUSER will provide a discussion venue for new Navy initiatives. For example, ongoing dialogue between the Naval Postgraduate School, the Naval Academy, and the Naval War College constituting the Navy Robotics Education Continuum will provide an opportunity for all three Navy schools to share their UxS curricula to provide better alignment. Additionally an inter-disciplinary UxS degree at NPS will be studied and proposed to OPNAV N2/N6. Finally, the concept of a CRUSER Scholar will be raised allowing a USNA or NROTC midshipman to be offered travel funds to attend a technical symposium or warfare innovation workshop to present their research.
- CRUSER will sponsor a WIW in September 2013 to complete FY13, and begin CRUSER Innovation Thread 3.

- CRUSER will continue to fund NPS student travel to participate in research, experimentation, and wargames dealing with all aspects of unmanned systems
- CRUSER will continue community of interest database generation, monthly newsletter production and distribution, and monthly community-wide meetings.
- CRUSER will continue to sponsor and participate in STEM outreach events relevant to robotics education

B. LONG TERM PLANS

Projected to continue into FY14, CRUSER plans to catalog degree programs, short courses, and certificate programs nationwide. Other long term plans include the creation of short course programs as identified by community of interest, and a continued effort to align curricula for interdisciplinary autonomous systems education on the NPS campus.

Begun with the CRUSER WIW 2011 in FY11, and then continued in FY12 with the UxS Technology Continuum and the FY13 CRUSER field experimentation, FY13 will close the first full cycle of concept generation to experimentation with the CRUSER Research Expo in Washington DC.

1. UxS Experimentation

By early 2013 the concepts developed for the UxS Technology Continuum, generated in the CRUSER WIW 2011, will be demonstrated and refined in five days of field experimentation at Camp Roberts in Paso Robles, California.

2. UxS Research Expo

The fully developed and demonstrated concepts that were initially generated during the CRUSER WIW 2011 will be introduced to the federal level community of interest at the Washington DC Symposium Research Expo in June 2013.

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APPENDIX A: SELECTED PUBLICATIONS AND TECHNICAL REPORTS

Andersson, K., I. Kaminer, V. Dobrokhodov, and V. Cichella (2012). "Thermal Centering Control for Autonomous Soaring; Stability Analysis and Flight Test Results," *Journal of Guidance, Control, and Dynamics*, Vol. 35, No. 3 (2012), pp. 963-975. doi: 10.2514/1.51691

Auguston, M. and C. Whitcomb (2012). "Behavior Models and Composition for Software and Systems Architecture", *ICSSEA 2012, 24th International Conference on SOFTWARE & SYSTEMS ENGINEERING and their APPLICATIONS*, Telecom ParisTech, Paris, 23-25 October 2012. http://icssea.enst.fr/icssea12/

Boxerbaum, A., M. Klein, J. Kline, S. Burgess, R. Quinn, R. Harkins, R. Vaidyanatham (2012). "Design, Simulation, Fabrication and Testing of Bio-Inspired Amphibious Robot with Multiple Modes of Mobility," *Journal of Robotics and Mechatronics*, Vol. 24, No.4 August 2012.

Brutzman, D., with T. Chung, C. O'Neal, J. Ellis and L. Englehorn (2011). *Future Unmanned Naval Systems (FUNS) Wargame Competition Final Report* (NPS-USW-2011-001) released July 2011.

Green, D. (2012). "ACOMMS Based Sensing, Tracking, and Telemetry," *Proc. 3rd WaterSide Security Conference*, Singapore, 28-30 May 2012

Gagnon, P. and J, Rice, G. Clark (2012). "Channel Modeling and Time Delay Estimation for Clock Synchronization Among Seaweb Nodes," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Gagnon, P. and J. Rice, G. A. Clark, "Clock Synchronization through Time-Variant Underwater Acoustic Channels," *Proc. NATO Underwater Communications Conference (UComms)*, Sestri Levante, Italy, 12-14 September 2012

King, R. E. (2012). "Localization of a Mobile Node in an Underwater Acoustic Network," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Kline J. and L. Englehorn (2011). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Warfare Innovation Workshop (WIW) 2011 After Action Report*, released October 2011.

Kline J. and L. Englehorn (2011). *Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) Annual Report 201: The Startup Year*, released December 2011.

Otnes, R. and V. Forsmo, H. Buen (2012). *NGAS Sea Trials*, Gulf of Taranto, Italy, September 2011, January 2012

Otnes, R. (2012). "NILUS – An Underwater Acoustic Sensor Network Demonstrator System," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rice, J. (2011). "Maritime Surveillance in the Intracoastal Waterway using Networked Underwater Acoustic Sensors integrated with a Regional Command Center," invited presentation to *Small Vessel Security Threat Conference*, San Francisco CA, 29 September 2011

Rice, J. (2011). "Seaweb ASW Sensor Network," FY11 year-end project report for publication in *ONR Ocean Battlespace Sensing*, December 2011

Rice, J. and G. Wilson, M. Barlett (2012). "Deep Seaweb 1.0 Maritime Surveillance Sensor Network," *NDIA 2012 Joint Undersea Warfare Technology Spring Conference*, Undersea Sensors technical track, San Diego CA, 26-29 March 2012

Rice, J. (2012). "Node Ranging, Localization and Tracking as Functions of Underwater Acoustic Networks," *Proc. Acoustics 2012* Hong Kong, p. 91, 13-18 May 2012

Rice, J. and C. Fletcher, B. Creber, B. Marn, S. Ramp, F. Bahr (2012). "Implementation of an Underwater Wireless Sensor Network in San Francisco Bay," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rice, J. (2012). "Project MISSION – Maritime In Situ Sensing Inter-Operable Networks," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rice, J. (2012). "Weaponized Underwater Surveillance Network," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rice, J. and C. Fletcher, B. Creber, B. Marn, S. Ramp, F. Bahr (2012). "Implementation of an Underwater Wireless Sensor Network in San Francisco Bay," *Proc. 3rd WaterSide Security Conference*, Singapore, 28-30 May 2012

Rice, J. (2012). "Seaweb Subsurface Sensor Network for Port Surveillance and Maritime Domain Awareness," *NMIO Technical Bulletin*, National Maritime Intelligence-Integration Office, Summer 2012 issue, Vol. 3, pp. 10-14, August 2012

Rochholz, T. (2012). "Wave-Powered Unmanned Surface Vehicle Operation in the Open Ocean: A Station Keeping Asset for Distributed Netted Systems; PAC X: Transpacific Crossing of Wave Glider USVs," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey CA, 7-10 May 2012

Rochholz, T. (2012). "Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks," presented at *NDIA Undersea Warfare Technology Conference*, Groton, CT, 24-27 September 2012

Rothal, J. and A. Davis (2011). *A Sampling of NPS Theses and Reports on UxS*, produced by the Dudley Knox Library, released August 2011.

Xargay E., V. Dobrokhodov, I. Kaminer, A. Pascoal, N. Hovakimyan, and C. Cao (2011). "Time–Coordinated Path Following of Multiple Heterogeneous Vehicles over Time–Varying Networks," invited paper for *IEEE Control Systems Magazine, Special Issue on UAVs and Controls*, 2011.

Xargay, E., N.Hovakimyan, V.N. Dobrokhodov, I.I. Kaminer, C. Cao, I.M. Gregory (2012). "L1 Adaptive Control in Flight", chapter in a *book "Progress in Aeronautics and Astronautics Series", AIAA*, 2012.

Xu, N., G. Cai, W. Kang, and B.M. Chen (2012). "Minimum-time trajectory planning for helicopter UAVs using dynamic optimization." *IEEE International Conference on Systems, Man, and Cybernetics*, Seoul, South Korea, October 2012.

Yakimenko, O.A., and Chung, T.H., "Extending Autonomy Capabilities for Unmanned Systems with CRUSER," *Proceedings of the 28th Congress of the International Council of the Aeronautical Sciences (ICAS 2012)*, Brisbane, Australia, 23-28 September 2012.

Zhang, Jiexin, Yang Liu, Mikhail Auguston, Jun Sun and Jin Song Dong (2012). "Using Monterey Phoenix to Formalize and Verify System Architectures", *19th Asia-Pacific Software Engineering Conference APSEC 2012*, Hong Kong 4 – 7 December 2012. http://www.comp.polyu.edu.hk/conference/APSEC2012/

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APPENDIX B: SELECTED PRESENTATIONS FY12

This list of briefings is representative of those given by CRUSER leadership in the second program year up to the release date of this FY12 Interim Report. It is not meant to be inclusive, only give a sense of the depth and breadth of interest in CRUSER.

DATE (mo/yr)	AUDIENCE (affiliation: name/s)
October 2011	**Georgia Tech Research Initiative** representatives
	Joint Ground Robotics Enterprise (JGRE): Rob Maline and Chris Dew
	Defense Advanced Research Projects Agency (DARPA): Craig Powell
	Systems Planning and Analysis, Inc.: John Quigley, Vice President
	Advanced Technology International: Rick Self, President
	PEO LCS: Megan Cramer
	Surface Warfare N86B: RDML Mercado, Deputy Director
	South Korean Visitors
	Naval Submarine League: RADM John Padgett (ret.), President
	Office of Naval Intelligence: CDR John Mohn, Director of SWORD
November 2011	**N87: RADM Barry Bruner**
	Lockheed Martin Advance Technologies Laboratory: Dr. Meghann Lomas
	Georgia Tech Research Institute: Dr. Lora Weiss, Lab Chief Scientist
January 2012	**Office of Naval Intelligence:** David Jackson, Chief Emerging Technology Officer
	JHU/APL: Jack Keane, Glenn Mitzel, John Schuster, Vic McCrary
	Defense Intelligence Agency (DIA) Joint Reserve Intelligence Program (JRIP): Michelle Lee, Regional Operations Officer (Camp Parks CA)
	Rockwell Collins: Ms. Nan Mattai, Mr. Kelly Ortberg and Mr. John Borghese

	OPNAV N2/N6F: RADM William Leigher, Director of Warfare Integration for Information Dominance
	PEO: RADM Bill Shannon, Unmanned Aviation and Strike Weapons
	N2/N6: Mr. Brett Vaughan
February 2012	**AUVSI Program Review:** an audience of approximately 75
	Georgia Tech Research Institute: Directors and key personnel
	ESG2: RDML Ann Phillips
	NUWC: RDML Wears, Capt. Nils Sjostrom, USN (ret), Mr. Robert Manke, and CDR Paul Vebber USN (ret)
	Avineon, Inc.: Dr. R. Scott Starsman and CDR (Ret) Neil Bourassa
	DARPA's Tactical Technology Office: Mr. Scott Littlefield
March 2012	**San Diego DPO/Outreach:** CAPT Craig Turley, USN (ret)
	National Intelligence Officer for Cyber Issues: Mr. Sean Kanuck and Ms. Jessica Vielhuber (deputy)
	Northrop Grumman Shipbuilding-Newport News: Andrew Poole, Manager Submarine Technology and Marine Integrated Power Technology
	Commander 4th Fleet: RDML Sinclair Harris
	Marine Corps Warfighting Lab: MGEN Spiese, BGEN Wise
	Northrop Grumman group
	ONR: Chris Marchefsky, SEA18B POC
	ONR Reserve Unit - San Jose
	EUCOM J-2: RDML Norman Hayes
	COMSUBFOR: VADM Richardson
April 2012	**Naval Mine and Anti-submarine Warfare Command (NMAWC):** RADM Hebner, Commander and Heidi Boose, ONR Science Advisor
	PACFLT: ADM Haney, Commander
May 2012	**Electric Boat:** Karl Hasslinger, Director, Washington Operations and John Biederka, Program Manager

	Tenth International Mine Warfare Technical Symposium: plenary address to 160 participants
	Office of Naval Intelligence: Mr. David Jackson, LT Wagner, LTJG Robinson
	OASD(R&E): Dr. Robert Neches, Advanced Engineering Initiatives
	U.S. Air Force Research Lab (AFRL): Dr. Ricklin, Chief Technologist
	Strategic Studies Group: Bill Glenny
	10th Security Workshop: address to participants
	NATO SACT C4I: CDR Howard Wanamaker (USN) and LTC Alexander Schulz (GE)
	California Peace Officer Association: address to 100 police officers
	SEA Curriculum sponsor: Mr. Mike Novak
June 2012	**CATU:** address to participants
	Saudi Arabia: MAJGEN Nayef
	Hyperspectral Imaging Foundation: Janek Kaliczak and Dr. Rama Inguva
July 2012	**Associate Director Of The Applied Physics Laboratory (APL) At The University Of Washington (UW):** CAPT(ret) Dr. David Martin
August 2012	**Rensselaer Polytechnic Institute (RPI):** Selmer Bringsjord, PhD
	Monitor National Security: RADM Wachendorf and Mr. Patel
	VP for Navy Systems for Boeing: RADM(ret) Matt Moffit
	NDU's Center for Technology and National Security Policy (CTNSP)
	CYBERCOM J2: RADM Sam Cox
September 2012	**Korean ADD (Agency for Defense Development)**
	Channel Technologies Group: Richard Franklin, Ender Kuntsal

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APPENDIX C: SELECTED THESES AND PROJECTS SUPPORTED

This list includes thesis and projects from program start in FY11 forward. Unclassified NPS theses are available through the NPS Dudley Knox Library and DTIC.

Thesis project title/subject:	NPS Student (s)	
Tailorable Remote Unmanned Combat Craft (TRUCC)	Systems Engineering Analysis Cross-Campus Study (SEA 18B)	FY12
Autonomous Dirigible Airships: a Comparative Analysis and Operational Efficiency Evaluation for Logistical Use in Complex Environments	LT Brian Acton, USN LT David Taylor, USN	FY12
An Interpolation Approach to Optimal Trajectory Planning for Helicopter Unmanned Aerial Vehicles	Maj Jerrod Adams, US Army	FY12
Implementation of Autonomous Navigation And Mapping Using a Laser Line Scanner on a Tactical Unmanned Vehicle	Maj Mejdi Ben Ardhaoui, Tunisian Army	FY12
An Analysis of Undersea Glider Architectures and an Assessment of Undersea Glider Integration into Undersea Applications	Mr William P. Barker	FY12
Integration of an Acoustic Modem onto a Wave Glider Unmanned Surface Vehicle	ENS Joseph Beach, USN	FY12
Investigation of Propagation in Foliage Using Simulation Techniques	LCDR Chung Wei Chan, Republic of Singaporean Navy	FY12
Joint Sensing/Sampling Optimization for Surface Drifting Mine Detection with High-Resolution Drift Model	LT Kristie M. Colpo, USN	FY12
Does China Need A "String Of Pearls"?	Capt Martin Conrad, USAF	FY12
Unmanned Aircraft Systems: A Logical Choice For Homeland Security Support	Maj Bart Darnell, USAF	FY12
Multi-Agent Task Negotiation Among UAVs	Mr. Michael Day	FY12
Optimized Landing of Autonomous Unmanned Aerial Vehicle Swarms	Maj Thomas F. Dono, USMC	FY12
An Analysis of the Manpower Impact of Unmanned Aerial Vehicles (UAV's) on Subsurface Platforms	LT Thomas Futch, USN	FY12

Clock Synchronization through Time-Variant Underwater Acoustic Channels	LCdr Pascal Gagnon, Canada	FY12
UAV to UAV Target Detection And Pose Estimation	Capt Riadh Hajri, Tunisian Air Force	FY12
A Cost-Benefit Analysis Of Fire Scout Vertical Takeoff And Landing Tactical, Unmanned, Aerial Vehicle (VTUAV) Operator Alternatives	CDR Kevin L. Heiss, USN	FY12
Autonomous Parafoils: Toward a Moving Target Capability	CDR Chas Hewgley, USN	FY12
Design and Development of Wireless Power Transmission for Unmanned Air Vehicles	Captain Chung-Huan Huang, Taiwan (Republic of China) Army	FY12
Adaptive Speed Controller for the Seafox Autonomous Surface Vessel	LT Michael A. Hurban, USN	FY12
Coordination and Control for Multi-Quadrotor UAV Missions	LT Levi C. Jones, USN	FY12
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	LT Serkan Kilitci, Turkish Navy LT Muzaffer Buyruk, Turkish Army	FY12
Underwater Acoustic Network As A Deployable Positioning System	ENS Rebecca King, USN	FY12
Business Case Analysis of Medium Altitude Global ISR Communications (MAGIC) UAV System	Ramesh Kolar	FY12
The EP-3E vs. the BAMS UAS An Operating and Support Cost Comparison	LT Colin G. Larkins, USN	FY12
Global Versus Reactive Navigation for Joint UAV-UGV Missions in a Cluttered Environment	ENS Michael Martin, USN	FY12
Bridging Operational and Strategic Communication Architectures Integrating Small Unmanned Aircraft Systems as Airborne Tactical Communication Vertical Nodes	Maj Jose D. Menjivar, USMC	FY12
The Aerodynamics of a Maneuvering UCAV 1303 Aircraft Model and its Control through Leading Edge Curvature Change	ENS Christopher Medford, USN	FY12
Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)	Maj Les Payton, USMC	FY12
Wave-Powered Unmanned Surface Vehicle as a	LT Timothy Rochholz	FY12

Station-Keeping Gateway Node for Undersea Distributed Networks		
GSM Network Employment on a Man-Portable UAS	LT Darren J. Rogers, USN	FY12
New Navy Fighting Machine in the South China Sea	LT Dylan Ross, USN LT Jimmy Harmon, USN	FY12
Business Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF)	LT Jason Staley, USN Capt Troy Peterson, USMC	FY12
Application Of An Entropic Approach To Assessing Systems Integration	Mr Hui Fang Evelyn Tan, Republic of Singapore	FY12
Advanced Undersea Warfare Systems	Systems Engineering Analysis Cross-Campus Study (SEA 17B)	FY11
The Dispersal Of Taggant Agents With Unmanned Aircraft Systems (UAS) In Support Of Tagging, Tracking, Locating, And Identification (TTLI) Operations	Capt Dino Cooper, USMC	FY11
Adaptive Reception for Underwater Communications	LTJG Spyridon Dessalermos, Hellenic Navy (Greece)	FY11
The Design and Implementation of a Semi-Autonomous Surf-Zone Robot Using Advanced Sensors and a Common Robot Operating System	LT Steve Halle, USN LT Jason Hickle, USN	FY11
Probabilistic Search on Optimized Graph Topologies	Major Christian Klaus, German Army	FY11
Brave New Warfare Autonomy in Lethal UAVS	LT Matthew Larkin, USN	FY11
Agent-based simulation and analysis of a defensive UAV swarm against an enemy UAV swarm	Lieutenant Mauricio M. Munoz, Chilean Navy	FY11
Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV)	LT Matthew Pawlenko, USN	FY11
Design Requirements For Weaponizing Man-portable UAS In Support Of Counter-sniper Operations	Maj Derek Snyder, USMC	FY11
Self-propelled semi-submersibles the next great threat to regional security and stability	LT Lance J Watkins, USN	FY11

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APPENDIX D: PARTNERSHIPS

This is a representative listing of the CRUSER community of interest in the second program year. It is not meant to be inclusive, but is included to demonstrate depth and breadth of interest.

USN and USMC Organizations:	COMPACFLT
	Marine Corps Combat Development Command, Operations Analysis Division (MCCDC)
	NAVAIR
	Naval Research Laboratory (NRL)
	NAVSEA
	Naval Special Warfare Command (NSW)
	Naval Surface Warfare Center (NSWC) Carderock
	Naval Surface Warfare Center (NSWC) Crane
	Naval War College (NWC)
	Naval Undersea Warfare Command (NUWC) Newport
	Navy Office of General Counsel
	Navy PEO Littoral and Mine Warfare (LMW), PMS 408
	Navy Reserves
	Navy Warfare Development Command (NWDC)
	Office of Naval Intelligence (ONI)
	Office of Naval Research (ONR)
	Office of Naval Research - Global (ONR-G)
	Space Systems Center, Pacific (SSC Pacific)
	U.S. Naval Academy (USNA)

Other Government Organizations & Institutes:	Joint Ground Robotics Enterprise (JGRE OUSD)
	Joint Unmanned Aerial Systems - Center of Excellence
	Lawrence Livermore National Laboratory (LLNL)
	Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD(AT&L))
	Robotic Systems Joint Project Office
	U.S. Army Robotics Center of Excellence
	U.S. Army Unmanned Aerial Systems - Center of Excellence
	U.S. Army Tank-automotive and Armaments Command (TACOM)
	U.S. Military Academy (USMA)
	U.S. Army War College
Non DoD Organizations:	Autonomous Undersea Vehicle Applications Center (AUVAC)
	Institute for Religion and Peace
	Monterey Bay Aquarium Research Institute (MBARI)
International Military	French Air Force Academy
	Netherlands Defence Academy (NLDA), Eindhoven University of Technology (TU/e), School of Innovation Sciences: Philosophy & Ethics, TNO and Delft University of Technology
Academia:	American University
	Arizona State University
	California State University at Monterey Bay (CSUMB)
	Georgia Institute of Technology
	Georgia Tech Research Institute (GTRI)
	The Johns Hopkins University Applied Physics Laboratory (JHU/APL)

	Macquarie University
	Massachusetts Institute of Technology (MIT)
	MIT Lincoln Laboratory
	Northeastern University
	Northwestern University
	University of Iowa
	University of New Brunswick
	University of North Dakota
	University of Notre Dame
	Virginia Tech
Industry:	AAI Corporation
	Aerojet
	Alpha Research & Technology, Inc.
	Applied Research Associates, Inc.
	Aurora Flight Sciences
	Bell Helicopter Textron, Inc.
	Bluefin Robotics Corporation
	Boeing
	Booz Allen Hamilton
	Boston Engineering Corporation
	Charles River Analytics
	Charles Stark Draper Laboratory
	Computer Systems Center, Inc. (CSCI)
	Compsim LLC

	Daniel H. Wagner Associates
	Dynetics
	ELG, Inc.
	EQC, Inc.
	General Dynamics Information Technology (GDIT)
	General Dynamics, Electric Boat
	Innovative Vessel Design
	iRobot
	Lockheed Martin
	Makani Power, Inc.
	NAVPRO Consulting LLC
	Neptune Minerals
	Northrop Grumman
	Orca Maritime, Inc.
	Odyssey Marine Exploration
	Raytheon
	Rockwell Collins, Inc.
	SAGE Solutions Group, Inc.
	SAIC, Inc.
	Soliton Ocean Services, Inc.
	Spatial and Spectral Research
	Spiral Technology, Inc.
	ST Aerospace
	Strategic Defense Solutions, LLC

	Systems Planning & Analysis, Inc.
	Tactical Air Support, Inc.
	Tech Associates, LLC
	Teledyne RDI
	Tethered Air, Inc.
	Unmanned Vehicle Systems Consulting, LLC
	Vehicle Control Technologies, Inc.
	Wyle Labs LLC

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APPENDIX E: CRUSER FY13 CALL FOR PROPOSALS

From Technical to Ethical…..From Concept Generation to Experimentation…
http://CRUSER.nps.edu

CRUSER Call for Proposals FY13

PROPOSALS DUE DATE:	**1 Aug 12**
Selection Date:	**1 Sept 12**
Funding Period:	**31 Oct 12 – 30 Sept 13**
Funding Levels:	**$75,000 - $125,000**
	(no indirect)

Research Goal: The Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) at the Naval Postgraduate School provides a collaborative environment for the advancement of educational and research endeavors across the Navy and Marine Corps. The establishment of CRUSER seeks to align efforts, both internal and external to NPS, by facilitating active means of collaboration, providing a portal for information exchange among researchers and educators with collaborative interests, and supporting innovation through directed programs of operational experimentation.

At the direction of the Secretary of the Navy, the Naval Postgraduate School leverages its long-standing experience and expertise in the research and education of robotics and unmanned systems to support the Navy's mission. The establishment of CRUSER serves as a vehicle by which to align currently disparate research efforts and integrate academic courses across discipline boundaries.

CRUSER will be a facilitator for the Navy's common research interests in current and future unmanned systems and robotics. The Consortium, working in partnership with other organizations, will inject a focus on robotics and unmanned systems into existing joint and naval field experiments, exercises, and war games, as well as host specific events, both experimental and educational. The Consortium will host classified and unclassified websites and establish networking and collaborative environments for the community.

Furthermore, with the operational needs of the Navy and the Marine Corps at its core, CRUSER will be an inclusive, active partner for the effective education of future military leaders and decision makers. Refining existing courses of education and designing new academic programs will be an important benefit of CRUSER, making the Consortium a unique and indispensable resource for the Navy and highlighting the educational mission of the Naval Postgraduate School.

Specific CRUSER goals are to:

- Provide a source for unmanned systems employment concepts for operations and technical research;
- Provide an experimentation program to evaluate unmanned system employment concepts;
- Provide a venue for Navy-wide education in unmanned systems;
- Provide a DoD-wide forum for collaborative education, research, and experimentation in unmanned systems.

CRUSER will take a broad systems and holistic approach to address issues related to naval unmanned systems research and employment, from technical to ethical, and concept generation to experimentation. Manning requirements, human systems integration, information processing, information display, training, logistics, acquisition, development, C2 architectures, legal constraints, levels of autonomy versus mission risk are just a sample of topics for research in addition to technical research areas for these systems.

Funding: Funding is not yet received for FY13; however the purpose of this call for proposals is to prepare researchers on campus to begin work as soon as possible in the fall of the new fiscal year. The anticipated funding level is $3M dollars in FY13 with a proposed budget break down as follows:

Labor and Travel for Coordination Group:	$270K
Travel (Student research support and faculty):	$100K
Field Experimentation	$420K
Technical Symposium	$75K
Technical Fair at ONR for research travel	$40K
Education Advancement and Development	$130K
Faculty Research and Development	$560K
Social, Cultural, and Ethical Continued Education Symposium	$62K
ONR/NPS Seaweb Experiment in Singapore:	$200K
Equipment	$75K
STEM Events	$25K
Contracts and Conference Fees	$20K
Indirect (30.6% - FY12 amount)	$918K
Total	**$3000K**

Therefore, <u>at a minimum</u>, $700,000 dollars are anticipated to be available in FY13 for open research proposals, including participation in the CRUSER field experimentation. In addition, student travel and support is also budgeted, so proposals should include anticipated student travel funding requirements, but not include that amount in the total requested.

Faculty members who receive CRUSER Research and Experimentation funds are expected to be fully active in supporting CRUSER's goals to include: monthly meeting attendance, presentations, CRUSER News articles, displays at Robots in the Roses, and participation at other CRUSER sponsored events, including presentations to ONR during the ONR CRUSER visit.

<u>Proposal Criteria</u>: Proposals will be evaluated on the following criteria:

1.) Student involvment
2.) Interdisciplinary, interagency, and partnerships with naval labs
3.) Partnerships with other sponsors' funding
4.) Research related to unmanned systems' catagories:
    a. Technical: Power, Sensors, Controls, Communications, Architectures, Human Factors, Information Processing and Dissemination
    b. Organization and Employment: Human Capital Requirements, Risk Analysis, Force Transition, Acquistion, Policy, Concept Generation evaluation and Authorities
    c. Social, Cultural, Political, Ethical and Legal
    d. Experimentation
    e. Defense against threat UxS capabilities
5.) New research area (Seed money to attract other contributors)
6.) Related to CRUSER mission thread: UxS support to naval operations
7.) Alignment with SECNAV's DoN Unmanned Systems Goals (see *CRUSER Charter* memo)
8.) Researchers are members of the CRUSER Community of Interest
9.) Proposals should aim to make an immediate impact on the community. Hence proposals are expected to range from $75K - $125K

<u>Review and Selection Board</u>: Proposals will be evaluated by a panel of reviewers chaired by the Dean of Research and composed of the NPS CRUSER Advisory Board and CRUSER Director. Any member of the CRUSER coordination group or Advisory Board submitting a funding proposal will not serve on the panel.

<u>Proposed Format</u>: Short (3-8 page) proposals are solicited using the NPS research proposal format. The proposal should use NPS' research proposal front page and be clearly marked as "CRUSER Proposal FY12". Address and send to Director, CRUSER Jeff Kline at jekline@nps.edu and Lisa Trawick at cruser@nps.edu.

The following sections are nominally required:

1. Name of PIs, NPS Address, e-mail address, ID any security holders clearance
2. Period of Performance, Total Funding required, Student funding required (with names if available)
3. Description of the Project
4. Potential FY14 follow on efforts and potential or anticipated external funding
5. FY13 Budget Details
6. Self evaluation of proposal criteria above

APPENDIX F: CRUSER MANAGEMENT TEAM

Mr. Jeffrey Kline, CAPT, USN (ret.), is a Professor of Practice in the Operations Research Department at the Navy Postgraduate School and Navy Warfare Development Command Chair of Warfare Innovation. He also is the National Security Institute's Director for Maritime Defense and Security Research Programs. He has over 26 years of extensive naval operational experience including commanding two U.S. Navy ships and serving as Deputy Operations for Commander, Sixth Fleet. In addition to his sea service, Kline spent three years as a Naval Analyst in the Office of the Secretary of Defense. He is a 1992 graduate of the Naval Postgraduate School's Operations Research Program where he earned the Chief of Naval Operations Award for Excellence in Operations Research, and a 1997 distinguished graduate of the National War College. Jeff received his BS in Industrial Engineering from the University of Missouri in 1979. His teaching and research interests are joint campaign analysis and applied analysis in operational planning. His NPS faculty awards include the 2009 American Institute of Aeronautics and Astronautics Homeland Security Award, 2007 Hamming Award for interdisciplinary research, 2007 Wayne E. Meyers Award for Excellence in Systems Engineering Research, and the 2005 Northrop Grumman Award for Excellence in Systems Engineering. He is a member of the Military Operations Research Society and the Institute for Operations Research and Management Science. Kline holds a TS/SCI clearance. http://faculty.nps.edu/jekline/

Dr. Timothy H. Chung is an Assistant Professor of Systems Engineering at the Naval Postgraduate School. His research interests include probabilistic search optimization, degrees of autonomy for robotic systems, and multi-agent coordination for information gathering applications. His efforts lie at the interface between operations and robotics research. Professor Chung received his doctorate (2007) and M.S. (2002) at the California Institute of Technology in mechanical engineering, specializing in algorithms for distributed sensing and decision-making methods for multi-robot systems. He joined the NPS OR department in 2008 and currently holds a SECRET security clearance. http://faculty.nps.edu/thchung/

Ms. Carol O'Neal, CAPT, USN (Ret.), is a Research Associate in the Operations Research Department at the Naval Postgraduate School, where she is supporting applied analytical research in optimization-based decision support tools for use in mission planning in the Globally Networked Maritime Headquarters with Maritime Operations Centers, and Warfare Concept Generation workshops. She has 30 years of extensive naval experience including command and major command tours in Navy recruiting and as a USNA Battalion Officer and NPS Dean of Students in Navy education. She graduated as the President's Honor Graduate from the Naval War College with a Masters in National Security and Strategic Studies and a Masters in International Relations from Salve Regina College. She was also selected for a Federal Executive Fellowship at RAND and a SEMINAR XXI fellow at MIT. O'Neal holds a SECRET clearance.

Ms. Lisa Trawick is the CRUSER Operations Manager. She has been in the Air Force Reserves for 21 years and is currently serving as a Logistical Readiness Officer for the Surface Deployment and Distribution Command (SDDC). Her previous assignment was a full-time tour for 3.5 years at DFAS Internal Review (IR) as a Financial Data Analyst, where she won the DFAS IR Innovation Award in 2008. In her civilian life she spent 12 years at Frito Lay with various roles in manufacturing/warehouse operations and as a Demand Planner. She received a Bachelors in Statistical Computing from the University of Utah (1998) and a Masters in Information Technology from the Naval Postgraduate School (2008). Trawick holds a SECRET Clearance.

Ms. Lyla Englehorn is the CRUSER Program Manager. Ms. Englehorn earned a Master of Public Policy degree from the Panetta Institute at CSU Monterey Bay. She looks at issues related to policy in the maritime domain and is involved in a number of projects at the Naval Postgraduate School. She currently provides research assistance and support for the Consortium for Robotics and Unmanned System Education and Research (CRUSER), the Multimodal Information Sharing Team (MIST), and the Operations Research Department. Other work at NPS has included curriculum development for an International Maritime Security course sequence, technical writing, and creating a presentation skills seminar for NPS Systems Engineering students. Ms. Englehorn holds a SECRET clearance.

ABSTRACT

The Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) provides a collaborative environment and community of interest for the advancement of unmanned systems education and research endeavors across the Navy (USN), Marine Corps (USMC) and Department of Defense (DoD). CRUSER is a Secretary of the Navy (SECNAV) initiative to build an inclusive community of interest on the application of unmanned systems (UxS) in military and naval operations. CRUSER seeks to align efforts, both internal and external to NPS, by facilitating active means of collaboration, providing a portal for information exchange among researchers and educators with collaborative interests, and supporting innovation through directed programs of operational experimentation. This FY12 annual report summarizes CRUSER activities in its second year of operation – or transition year, and highlights future plans.

KEYWORDS: robotics, unmanned systems, UxS, UAV, USV, UGV, UUV

POC: Jeff Kline, CRUSER Director
http://cruser.nps.edu
cruser@nps.edu

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access area denial
AFRL	U.S. Air Force Research Lab
ARSENL	Advanced Robotic Systems Engineering Laboratory
C2	Command and control
C4I	Command, control, computers, communications and intelligence
CAVR	NPS Center for Autonomous Vehicle Research
CNO	Chief of Naval Operations
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
DoD	Department of Defense
DoN	Department of the Navy
ISR	Intelligence, surveillance, and reconnaissance
JCA	Joint campaign analysis
MDA	Maritime domain awareness
MINDEF	Singapore Ministry of Defense
MISSION	Maritime In Situ Sensing Inter-Operable Network
MvM	Many versus Many
NPS	Naval Postgraduate School
NSWC	Naval Surface Warfare Command
NUS	National University of Singapore
NUWC	Naval Undersea Warfare Command
NWDC	Navy Warfare Development Command
ONR	Office of Naval Research
OR	Operations Research Department, NPS

QR	Quick Response (*in QR code*)
SECDEF	Secretary of Defense
SECNAV	Secretary of the Navy
SME	Subject matter expert
SSG	Strategic Studies Group
STEM	Science, technology, engineering, and mathematics
TNT	Tactical Network Testbed
TRANSEC	transmission security
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
UGV	Unmanned ground vehicle
USMC	U.S. Marine Corps
USN	U.S. Navy
USV	Unmanned surface vehicle
USW	Undersea warfare
UUV	Unmanned undersea vehicle
UxS	Unmanned system
WIW	Warfare Innovation Workshop

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