The Challenges of Field Experimentation
By LT Ryan Hilger, USN, NPS Student

In September 2013, CRUSER sponsored me to travel with the Center for Autonomous Vehicles Research (CAVR) at NPS to Key Largo, Florida, to conduct collaborative research with NASA at an underwater habitat facility, the Aquarius Reef Base. The missions would be part of the NASA Extreme Environment Mission Operations (NEEMO) program and would focus on the use of unmanned systems, both autonomous and remotely operated, to aid the aquanauts in their research and testing program. As with all field research, nothing went exactly as we had planned. However, the experience yielded several valuable lessons for future engineers and scientists conducting field experimentation with unmanned vehicles.

The NPS crew, consisting of two professors and several students, brought three unmanned vehicles to Florida: two modified REMUS 100 autonomous unmanned vehicles (AUV) and one SeaBotix ROV. The challenges began months before leaving for the trip. The SeaBotix had only really been tested in the CAVR lab at NPS and needed to have several new systems integrated to enable it to do open water testing, including the installation of several new systems and an ultra-short baseline (USBL) navigation system. Integration of these new systems continued well into the first week of research in Key Largo, with small issues popping up periodically for the remainder of the trip. USBL can be a finicky system to work with on the water. Stabilizing the transponder to the ROV required relearning some lessons of naval architecture in stability, and stabilizing the transmitter to the support boat required several trips to a nearby hardware store for a jury-rigged mounting system to reduce the oscillations.

For the REMUS vehicles, we had an ambitious testing plan to conduct extensive underwater mapping using a new microbathymetry suite to support the NASA program. Much to our dismay, one of the AUVs was rendered dead on arrival. We believe that a power surge from the shore power connection damaged a number of components. We spent most of the second week working closely with Hydroid attempting to repair the vehicle with no success. At least with the second UUV we were able to conduct a limited research program, though the vehicle had a peculiar habit of rebooting at random times during a mission, which forced the AUV to the surface and us to strain our eyes to find it. Since we were at the whim of NASA’s schedule much of the time, we took to exploiting on-water dead time to conduct much smaller mapping missions that we had originally planned. Despite these frustrations, we were able to collect partial mission data for those missions.

Overall, we considered the field experimentation a success—we left with three vehicles and came back with three vehicles! The challenges were numerous, but left us with a few key takeaways for field research: preparation for field research requires significantly more time than you think, always have 2-3 backup plans that will still further your research objectives, be flexible and creative in your problem solving, and remember to have fun while doing it!
**Director’s Corner**

Dr Timothy H Chung, CRUSER Deputy Director

Summer for many in the CRUSER Community means time for robotics “fun in the sun,” including educational activities such as summer robotics internships across universities, research labs, and industry. With students across the country wrapping up their internships across the Naval research enterprise, we are happy to see continued enthusiasm and excitement in robotics and unmanned systems. To that end, CRUSER congratulates and applauds both the interns, who’ve broadened their perspectives and knowledge in robotics and unmanned systems, and also their mentors, who have helped shaped this next generation of future engineers, innovators, and leaders.

**Certified Autonomous Vehicle**

by Nick Tudor, Business Director, D-RisQ Ltd, www.drisq.com, njt@drisq.com

D-RisQ Ltd is a company based in the UK which undertook a project which sought to outline an approach to the production of a certified autonomous vehicle under a project funded by the UK Technology Strategy Board. The aim of the project was to show that it is possible to automate the system design validation as well as the verification of the implementation in software. The study was predicated upon the use of formal methods, a technique which allows credit to be claimed for verification against DO-333, a technology specific Supplement to DO-178C. D-RisQ has expertise in the development of automated formal methods based techniques which underpin commonly used software tools such as Simulink®, Stateflow® and SysML/UML, as well as autocoders. The project took about 9 months and, in collaboration with a partner, we attempted to show that there was potential to rapidly develop unmanned systems such that they could be certified.

The focus of the work was on the certifiable implementation of a collision avoidance decision-making function in response to perceptual stimuli of a given confidence level. There were two aspects to this: the first was showing that the decision to ‘avoid’ could be legitimately taken, and the second that the avoidance function was sound. Conventional approaches to systems and software validation and verification involve a considerable amount of process. These processes have grown over many years of experience, but as software systems grow ever larger and more complex they push project cost and time to untenable levels, undermining the business case for product development. This is currently the case for many autonomous systems. We needed to show that there was a route to certification for decision making systems, i.e. the replacement of the human in the loop for crucial decisions and then to show that they and the avoid function could be quickly and assuredly implemented.

For any system, safety requirements ultimately boil down to three things: i) what it must do; ii) what it must NEVER do; and iii) what the behaviour must be under failure. For all systems and software, showing that the system does what is required under nominal conditions is relatively straightforward. The second is almost impossible to show through the use of conventional techniques (i.e. test based), and the third is expensive, if indeed possible, using conventional techniques. The project was therefore as much about cost and time as about demonstrating integrity.

The project started in August 2013 and finished at the end of April 2014. Although the stringent software development standards employed were from the air domain, a maritime case study was selected due to considerable recent interest in safety critical Maritime Autonomous Systems, and a desire to demonstrate true cross-domain applicability of the methods.

The project successfully showed that the techniques could be used to develop decision making systems such that they could be verified. Another result was that we could automatically produce control system functionality in software that was automatically verified. The final result was that we could support the evidence requirements for DO-333. Although no measurement was specifically undertaken, because of the automation and the tool qualification, we now know that it is possible to produce such certifiable software systems very quickly and very cheaply.
In August, 2014, Maritime Applied Physics Corporation (MAPC) will retrieve a hydrothermal vent energy harvesting system from a hydrothermal vent in the caldera of the Axial Volcano at 1530m depth, 250 miles off the coast of Oregon. Operating from the R/V Thomas G. Thompson, the Woods Hole Oceanographic Institute's Jason ROV was used to install the test system on top of the volcano in October 2013. The project, code named “Mercury,” was funded by the ONR to determine the feasibility of direct thermal to electric power conversion using the temperature difference between vent fluids as hot as 340°C, and icy seawater at 3°C. MAPC's laboratory testing and data retrieved to date show that thermal to electric energy conversion on the seafloor is possible from hydrothermal vent fluids and other thermal resources. This finding opens the door to use of the conversion technology with other seafloor thermal energy sources including drilled geothermal wells, abandoned oil and gas wells, and hot and cold seeps. The deep-ocean conversion technology under development by MAPC may also be used in the construction of radioisotope thermoelectric generators (RTGs) similar to those used by NASA to power equipment in deep space, to provide power on the seafloor.

As novel as it is, the energy technology MAPC is developing may not be as interesting as its applications and the likely changes in how marine operations are performed. The availability of kilowatt-scale hydrothermal and geothermal electric power on the seafloor is likely to bring transformative changes in military operations, commercial resource development, ocean exploration, and scientific research. To date, virtually all seafloor power infrastructure employs seabed cabling from land-based or surface platforms that are very expensive to operate. There may soon be an alternative to deploying and operating AUVs from manned surface support vessels. In perhaps five years, seafloor electric generators could be providing energy for AUV docking stations, enabling AUV operations without manned “mother ships” constantly present to recharge the AUV, in applications as diverse as mine hunting, pipeline inspection, surveillance, ocean exploration, and environmental monitoring. Large displacement underwater vehicles may be acting as “fuel trucks” to deliver electric power from seafloor generators at seafloor hotspots to sensors and instruments on the seafloor hundreds of miles away. Unmanned underwater vehicles may soon be deployed to remote seafloor locations using unmanned surface vehicles. This technology already exists, but looking further into the future, AUVs may be traveling to their work sites along routes where seafloor power stations are available to provide for recharge, much the same as automobiles visit filling stations along interstate highways. For many commercial applications, the savings from seafloor power generation can be thought of in terms of the reduced length of seafloor cables delivering power from a land-based resource, or the elimination of surface vessels and platforms burning carbon fuels.

Utilities, commercial oil and gas, and mineral mining operations typically require hundreds of kilowatts to megawatts of power for their primary operations. This means seafloor power will have to follow an evolutionary path from the 70 watts demonstrated by MAPC in short term testing, to reach the power levels needed to support resource development. This new technology is an essential first step toward the future development of the ocean's enormous clean energy resources, resources that are currently beyond our reach.
STUDENT CORNER

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TITLE: Da Vinci’s Children Take Flight: Unmanned Aircraft Systems in the Homeland

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LINK TO COMPLETED THESIS: HTTP://hdl.handle.net/10945/41420

ABSTRACT:

In 2015, the Federal Aviation Administration will open national airspace to unmanned aircraft systems (UAS). Nonmilitary uses for UAS range from agriculture services to entertainment purposes, and include tasks as mundane as inspecting gutters and as consequential as fighting fires.

Outside of the safety issues that accompany many breakthrough technologies, the effort to integrate UAS into national airspace is enmeshed in political, legal and economic policies that require careful navigation. Factors like cybersecurity and technological advancements will continue to influence the way UAS can be used.

This thesis provides an orientation to the key considerations in UAS integration. Policy recommendations include early stakeholder engagement; a national data protection law; no-fly zones around private residences; clearly identifying UAS operators and owners; nonlethal payloads in national airspace; adapting current surveillance laws to UAS; a single, national privacy law to facilitate the free flow of commerce and coordination across state lines; a federal office in charge of monitoring data privacy; accountability of data collectors; limited exemptions for activities conducted in the interest of national security or to protect life and property; and managing cybersecurity risks.

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Pew Research Global Attitudes Project
Global Opposition to U.S. Surveillance and Drones, but Limited Harm to America’s Image http://www.pewglobal.org/2014/07/14/global-opposition-to-u-s-surveillance-and-drones-but-limited-harm-to-americas-image/

Building Toward an Unmanned Aircraft System Training Strategy
http://www.rand.org/pubs/research_reports/RR440.html

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