RECENT FIELD EXPERIENCE WITH MULTIPLE COOPERATING SOLAR-POWERED AUVS

Steven G. Chappell[1] chappell@ausi.org,
Rick J. Komerska[1] komerska@ausi.org,
D. Richard Blidberg[1] blidberg@ausi.org,
Christiane N. Duarte[2] duartecn@npt.nuwc.navy.mil,
Gerald R. Martel[2] martelgr@npt.nuwc.navy.mil,
Denise M. Crimmins[2] crimminsdm@npt.nuwc.navy.mil,
Michel A. Beliard[3] beliardma@npt.nuwc.navy.mil,
Robert Nitzel[4] rnitzel@technologysystemsinc.com,
James C. Jalbert[5] falmouthinc@bellsouth.net
Radim Bartoš[6] rbartos@cs.unh.edu

1) Autonomous Undersea Systems Institute (AUSI) – USA
2) Naval Undersea Warfare Center (NUWC) – USA
3) Science Applications International Corp. (SAIC) – USA
4) Technology Systems, Inc. (TSI) – USA
5) Falmouth Scientific, Inc. (FSI) – USA
6) University of New Hampshire (UNH) – USA

Abstract

This paper presents the details of three field efforts involving multiple Solar-powered Autonomous Undersea Vehicles (SAUVs). All three efforts were designed to test and demonstrate a growing capability for cooperative behavior among multiple SAUVs. The tools and technologies used by our team in conducting research and evaluation of AUV cooperation are also outlined in this paper.

1 Introduction

Since its inception, the design, construction, deployment, and further development of the Solar AUV II (hereafter SAUV) has been a team effort. Initially consisting of the Autonomous Undersea Systems Institute (AUSI), Falmouth Scientific, Inc (FSI) and Technology Systems, Inc (TSI), the team has grown to include researchers from the Naval Undersea Warfare Center/Newport (NUWC), University of New Hampshire (UNH) and Rensselaer Polytechnic Institute (RPI). The Multiple Cooperating AUV (MCAUV) initiative has provided the umbrella program for focusing this team on the R&D issues associated with multiple cooperating AUVs, using the SAUV platforms as a testbed system.

Built on the original work with the initial generation of the SAUV [Ageev et al., 2001], the first example of the current generation (SAUV01) saw water testing in the summer of 2003. Subsequently, four more SAUVs have been built: SAUV02 in 2004 and SAUV03, SAUV04 and SAUV05 in 2005. SAUV03 is owned by NUWC, the rest are owned by AUSI.

By the time of AUVFest in June 2005, these vehicles were sufficiently developed to the point where multiple vehicle operations could be attempted, as long as a human was in direct control of the cooperation aspect of the mission at hand. For example, given a set of SAUVs station-keeping in the water and some mission to perform, the operator would typically observe which SAUV had the most energy reserve based on its acoustic status packets and decide to employ the one with the most energy reserve. The operator would then go through a manual exercise to command that specific SAUV to perform the mission. With this capability in hand, the MCAUV team set out to explore automating this operation through cooperative behaviors.

Section 2 of this paper introduces the tools and technologies being brought to bear on the cooperative behavior problem. Section 3 describes modifications and additions to the SAUV run time environment, which directly support our cooperative behavior work. Section 4 relates the efforts of our first wet test of cooperative behavior at Lake George, NY in June, 2006. Section 5 describes our participation in the Monterey Bay, CA data gathering experiment in July of that year. Section 6 discusses our most recent wet test of cooperative behavior at AUVFest in June of 2007. Section 7 finishes with conclusions and some ideas concerning future work.

2 Tools & Technologies to Support Cooperating AUVs

As a team, we have been developing a set of enabling tools and technologies which allow us to test and evaluate multiple cooperating AUVs. Many of these technologies listed below are described in a document entitled “Multiple Cooperating AUV (MCAUV) Digest” [Blidberg and Crimmins, 2005]. This is a compendium of technical papers published by personnel from AUSI, RPI, TSI, FSI and NUWC/Newport.

2.1 CADCON simulation

AUSI researchers have recently augmented their Cooperative AUV Development Concept (CADCON) environment to provide “system in the loop” capability for testing and evaluating SAUV system components and multiple cooperative vehicle mission profiles before going in the water [Komerska and Chappell, 2006]. This simulation facility allows for complete testing of SAUV onboard high-level software, including underwater networking protocol logic. The facility also has a training functionality in that top level mission planning and vehicle monitoring applications used by SAUV operators can also be tested as if they were in a field setting. Hardware components, such as radio frequency (RF) and acoustic modems can also be tested within the systems context. In this harness, the SAUV PC-104 system, running a Linux OS and the high-level software, can be tested as a networked bench-level component. In addition, significant portions of the standalone SAUV can be put into simulation mode, thereby allowing the testing of other on-board vehicle electronics and subsystems. This simulation facility was extensively used to support vehicle behavior development and mission planning prior to the wet tests described in this paper. Figure 1 shows a CADCON Visualizer client screen depicting a typical multiple vehicle scenario underway.

2.2 Common Control Language (CCL)

High-level multiple vehicle cooperation relies upon the ability of vehicles to communicate and understand each other. AUSI and NUWC are developing a CCL to provide (1) a common messaging interface to different AUVs, (2) an operator to vehicle group mission specification interface, (3) a sufficiently rich vocabulary and grammar to permit development of high level behaviors from lower level behaviors, and (4) support for optimization strategies for multiple AUV cooperation [Duarte et al., 2007]. The message specification in particular draws heavily upon past work in “generic behaviors” [Blidberg, 1994] and other AUV command languages, as well as work done in intelligent agent communications. It is explicitly designed to support a wide range of vehicle types in its command and informational structure. In addition, this protocol allows for arbitrary execution of behaviors (parallel, sequential, adversary, general choice, cost choice) and, when combined with \$-calculus, allows vehicles to accept a goal, jointly plan how to achieve that goal and carry out the plan. The AUSI/NUWC CCL has been field tested in the past on both a NUWC REMUS and a Mid-size Autonomous Research Vehicle (MARV). The newest revision is currently implemented on the SAUV and the TSI modular mission planning toolkit (MMPT) application for glider platform mission planning, monitoring and control. It will also soon be tested on the new FSI Gatekeeper buoy [Jalbert et al., 2007].

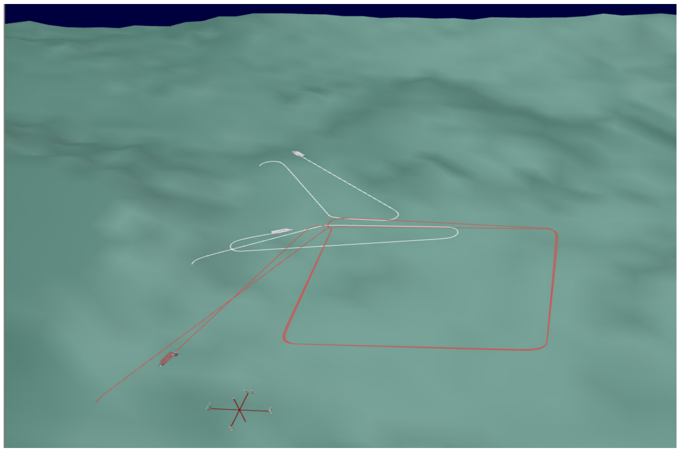


Figure 1: CADCON simulation of cooperative role-swapping behaviors with 3 SAUVs.

2.3 Distributed Control Environment (DICE)

NUWC has developed the Distributed Control Environment (DICE) as a tool for developing behavior-based distributed control systems [Duarte et al., 2005]. It enables communication between distributed system components as well as communication between different systems. DICE has many features specialized for behavior-based systems, thus, it can be useful for development of a wide range of architectures from reactive to deliberative. It supports coordination of processor-intensive tasks, such as high-level planning interacting with responsive low-level control. DICE designers developed this framework to facilitate implementation of multiple autonomous systems that operate with noisy and range-limited communication, rapidly-changing real-world situations, and variations in resource availability. DICE extends subsumption-style tasking with message passing to the multi-agent domain and provides for a wide variety of behavior-arbitration techniques. It allows a great deal of run-time system flexibility including dynamic reconfiguration of behavior structure. DICE is well suited for fast data-driven control strategies. It provides for rapid code development and effective code re-use. Behaviors can be multiply-instantiated and interact through abstract “ports”, which can be dynamically connected to other ports at run-time.

Behaviors can be distributed across hosts without code changes.

2.4 *Cooperative behaviors*

Over the past few years, the MCAUV team has been building up the ability of the SAUVs to participate in cooperative role swapping missions. The most recent and complex arrangement of our evolving "reference mission" is depicted in Figure 2. In general, this mission involves an area which is to be constantly surveyed by a group of SAUVs. In the reference mission, a single SAUV having the highest initial energy takes on the survey role. Those SAUVs not performing the survey maintain a watch circle on the surface recharging their batteries, or as shown in this figure, take on new roles (e.g. mobile communications gateway).

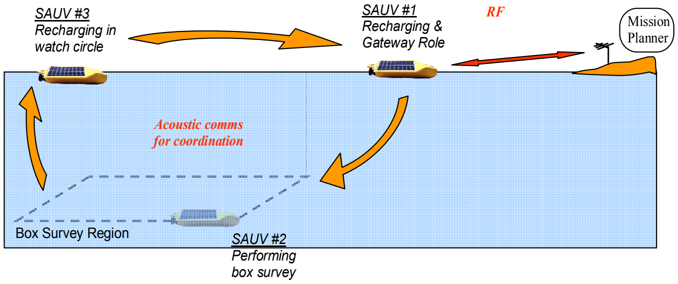


Figure 2: Energy-based role swapping.

Our reference mission builds on the set of behaviors required to implement the mission defined in our DEPSCoR project entitled "Highly Accurate Temporal and Spatial Mapping of Coastal Regions Using Long Endurance AUVs" [ONR Grant #N000140510666]. These include behaviors to support gateway functionality, the survey task, background navigation (including inter-vehicle ranging), networked communications and energy management. These will augment a set of cooperative behaviors already developed, including watch circle, box and lawnmower survey behaviors. These behaviors leverage our CCL and DICE efforts, providing us the ability to implement and test using AUVs in the water.

2.5 *Networking/Media Access Control*

We are currently designing a MAC layer collision handling mechanism which supports ranging as well as communication, while in parallel exploring ad hoc network protocol designs which extend or replace AUSNET [Mupparapu et al., 2005] or COFSNET [Bartoš et al., 2007] designs. Testing of this MAC layer with a ranging component will occur in simulation (using CADCON) to be followed by field testing using the SAUVs. Based upon these results, we will design, implement and test a merged MAC-layer/network-layer protocol with ability to support system level inputs (e.g. energy, navigation, and mission) and support non-trivial gateway functionality such as packet type queuing and store-and-forward [Haag et al., 2006]. This evolved protocol will provide the communications infrastructure necessary to allow platforms to communicate in an ad-hoc, peer-to-peer manner, while supporting the underlying navigation (ranging) requirement and permit platform system inputs to optimize efficiency.

We have recently completed a task to compare FreeWave RF modems with MaxStream and NovaRoam RF modems to assess their performance and understand the current state of the practice in RF networking [Bartoš et al., 2006]. We plan to examine how these capabilities impact requirements for autonomous mobile and fixed node networking in the ocean.

2.6 *Navigation*

As part of our DEPSCoR project, we are investigating the use of inter-vehicle ranging to improve underwater dead reckoning (DR) navigation. To enable vehicle acoustic ranging, we have augmented a Time Division Media Access (TDMA) scheme with special "ranging intervals" for each node in the acoustic network. In this scheme, a node's time slot for transmissions is divided into a communicate interval for normal transmissions and a ranging interval for ranging on all other modems in the network. During its communication interval the source node sends its normal transmissions. During its ranging interval, the source node ranges on all other nodes in the network, collects and stores the results. The resulting information is used by the source node to maintain an understanding of where the other nodes are in relation to it. Preliminary testing of this scheme took place at Lake George, NY in June, 2006. As part of this effort, we are also working with Dale Green's group at Teledyne-Benthos to support their development of an underwater GPS system [Jalbert et al., 2007].

2.7 *Advanced operator planning/monitoring tools*

TSI, in cooperation with AUSI, is currently developing a modular mission planning toolkit (MMPT) to support AUV mission planning for the Navy (SPAWAR Phase II SBIR). This application provides for planning, monitoring, command and control of multiple heterogeneous AUVs, particularly long endurance glider platforms, with a particular emphasis on incorporating environment data (e.g. currents) into the planning process. Prototype versions of MMPT were used during the 2006 Lake George, NY and Monterey Bay, CA experiments. During the recent AUVFest'07 testing, MMPT was used exclusively to monitor and control a fleet of 3 SAUVs, as well as demonstrate mission planning aspects based on water current METOC data supplied by NRL/Stennis.

2.8 *Collaboration environment*

We have performed work with Dave Bellino's group at NUWC/Newport to help them evaluate tools for collaborative mission planning and monitoring. During the 2006 testing at Lake George, we utilized the Macromedia Breeze room environment to share the desktop view of the vehicle operator's computer, allowing remote users to observe the live mission.

We are also working with Don Brutzman's group at Naval Postgraduate School investigating the utility of using the NPS AUV Workbench tools for post-mission analysis. During the AUVFest'07 event, we were able to demonstrate plotting of SAUV log file data for all three participating vehicles.

2.9 Physical SAUV infrastructure

We continue to develop ways to work more efficiently with the SAUV platform. For example, during spring of 2006, NUWC personnel designed a simple lifting beam that mates with an engine lift to allow for single operator lifting for access to the pressure tube and for transfer of a SAUV from trailer to transport dolly.

3 Preparation for Multiple AUV Missions

Extensive modifications to the SAUV software architecture were undertaken in the winter of 2005/2006 in order to prepare the foundation for the multiple cooperative vehicle work in 2006 and 2007. This work [Komerska and Chappell, 2006] involved the design and implementation of onboard simulation software along with linkages to a pre-existing off board simulation harness: CADCON.

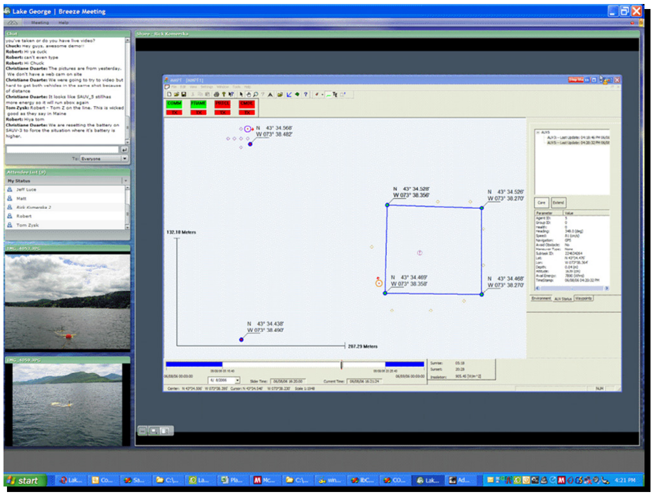
The first addition provided for easy SAUV standalone simulation functionality that enabled localized testing of a single vehicle's higher level functions. This was accomplished via the addition of a program (called *sauvSim*), which simulates inputs needed by and responds to output generated by the upper level software. When activated, this onboard simulator substitutes itself in for the SAUV's lower level subsystems, accepting commands from the upper level while feeding the appropriate response data back to it. In this manner, the SAUV's upper level can be made to believe it is in the water while on the bench connected to the laboratory network. This provides for the development of a great deal of high level single vehicle functionality prior to committing to wet testing.

The second addition provided a means for routing those inputs and outputs off the vehicle to the CADCON multiple vehicle simulation and testing harness. Thus equipped, multiple SAUVs networked together in the lab can be made to cohabit a CADCON simulated block of water and interact with each other "physically" as well as via simulated acoustic and RF communications. This arrangement enabled the development and testing of cooperative behaviors in those SAUVs.

A third addition to our simulation harness is in the form of utilizing *virtual machines* [Rosenblum and Garfinkel, 2005]. These virtual SAUVs run the full complement of high level SAUV software just as if it was running on the real PC-104 board set. The above two additions required actual SAUVs or physical PC-104 stacks running SAUV high level software in order to participate in multiple SAUV scenarios. Now, using virtual SAUVs, we have the capability to do the bulk of our high level SAUV software using only development systems; no specialized hardware is needed. This allows for very powerful multiple vehicle mission rehearsals using only a few networked computers.

4 First Wet Test – June 2006, Lake George, NY

In June of 2006, cooperative behaviors were wet tested in Lake George off Bolton Landing, NY at RPI's Darrin Fresh Water Institute. The cooperative mission given to a pair of SAUVs was for one of them to run a box shaped survey while its partner maintained position in a charging mode. The cooperative mission statement specified only that the vehicle with the most energy was to run the survey and the other was to charge. The vehicles were to decide which one would take on the survey role at runtime. The successful experiment demonstrated several autonomous role switches based on the vehicles' relative energy levels. This indicated that our initial design of the high level behavior logic as proven under simulation conditions transitioned well into the real world. It also showed the value and utility of our growing simulation harness capabilities.



you've taken or do you have live video?
Chuck: Hey guys, awesome demo!!
Robert: Hi ya cuck
Robert: can't even type
Robert: Hi Chuck
Christiane Duarte: The pictures are from yesterday. We don't have a web cam on site
Christiane Duarte: We were going to try to video but hard to get both vehicles in the same shot because of distance
Christiane Duarte: It looks like SAUV_5 stillhas more energy so it will run sbox again
Tom Zysk: Robert - Tom Z on the line. This is wicked good as they say in Maine
Robert: Hiya tom
Christiane Duarte: We are resetting the battery on SAUV-3 to force the situation where it's battery is higher.

Figure 3: Breeze room screen showing collaborative mission planning and monitoring.

Figure 3 shows a screen shot taken during that experiment. The entire image shows the Breeze system in use, where the output of various applications appears in Breeze subwindows. On the right is TSI's early prototype MMPT plotting the vehicle positions along with data pulled out of the vehicles' status messages. The column of subwindows on the left shows an ongoing live chat-like interaction between MCAUV team members at Bolton Landing, NY, Wiscasset, Me (TSI), and Newport, RI (NUWC) as well as photos taken on the lake. In order to use the Breeze system, it was not necessary to alter any pre-existing applications; they simply functioned normally within the Breeze context.

5 Second Wet Test – July 2006, Monterey Bay, CA

In July of 2006, the cooperative behaviors were further wet tested, this time in the context of a data gathering exercise as part of the Monterey Bay, CA AOSN experiments. Here, two SAUVs were to loiter on station in the immediate neighborhood of a set of fixed vertical profilers operated by researchers with the Layered Organization in the Coastal Ocean (LOCO) group. In this experiment, LOCO personnel operated their profiler systems normally, uploaded collected data to shore, and then analyzed that data to determine if any so called "thin layers" of biological activity had been detected in the water column. Upon finding such a layer, the approach was to have LOCO personnel contact SAUV mission control and provide the coordinates and depth they wanted the SAUVs to investigate. SAUV planners would then craft the proper cooperative mission and issue it to the SAUV group with the intention that the SAUV with the most energy available would undertake the mission, while the other would continue to charge. Again, the vehicles were to make the role decision at runtime. Although damage to SAUV05 early in the test forced operations to continue with a single vehicle, the MCAUV and LOCO teams were able to carry out the basic test paradigm demonstrating a human-in-the-loop adaptive sampling strategy.

The most important lesson learned from this experiment was that the SAUV can be successfully integrated into a mixed sensor network (fixed and mobile nodes) and carry out the role of a responsive sensor platform. Over the course of two days, the SAUV was able to Fgather science data within the LOCO region. The positive results from this test have led to team discussions with Dr. Percy Donaghay (University of Rhode Island) exploring the idea of combining autonomous profiler arrays with the SAUVs to create a distributed network system for adaptively sampling coastal systems. This concept would build upon the initial capabilities demonstrated during this field test.

6 Third Wet Test – June 2007, Panama City, FL

As a result of various issues exposed in the SAUVs' CCL interface layer during the previous wet tests, an effort was made during the winter of 2006/2007 to rework that layer of software. This resulted in the implementation of a far more generic input/output scheme for the basic vehicle behaviors that make up that layer. This work also went hand-in-hand with the formalization of the CCL development into five distinct levels of document-able and implement-able effort [Komerska and Chappell, 2007; Duarte et al., 2007].

In June of 2007, the MCAUV team attended the ONR sponsored AUVFest'07 in Panama City, FL. The objectives (relative to cooperative behavior) of this exercise were to:

1. Demonstrate a 3 vehicle cooperative survey.
2. Demonstrate an "on the fly update mission behavior" capability.
3. Add a third role to the cooperative mission.
4. Test COFSNET in a three acoustic node situation.
5. Exercise the improved onboard CCL interface software.
6. Exercise a prototype MMPT operator interface.

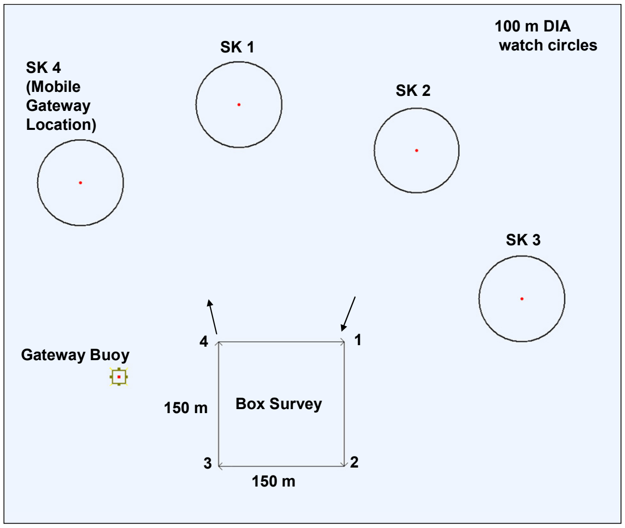


Figure 4: 3 SAUV energy role swapping mission.

At AUVFest, we fielded three SAUVs running a more complex version of the cooperative survey mission; this time involving three roles: *survey*, *recharge*, and a new one we called *networker* (for gateway services). As in previous versions of this sort of mission, the vehicles were to decide among themselves at runtime which one was to run the survey, which one was to simply recharge, and which one was to become a communication gateway node for the other two. Since the actual gateway software was not completed, this new gateway role was defined only to be positioning a vehicle to a place advantageous for becoming a networking gateway between the RF and acoustic communication realms. The geometry of the experiment is shown in Figure 4.

As in the previous scenarios, the vehicle group's primary role was to provide continual coverage of the survey area. That role was filled by the vehicle with the highest available energy. The previous experiments' secondary role of just charging was now split out into a selection between charging and the new gateway duty, also based on available energy: the vehicle with the most energy would take on the gateway duties. In order to simplify the overall experiment, this gateway role was specified as a station-keeping behavior centered at a fixed location relative to the survey.

Throughout the development work leading up to AUVFest'07, as well as running scenario rehearsals immediately prior to the actual missions, the CADCON infrastructure proved invaluable for immersing the vehicle behavior software in realistic contexts. As a result, we were able to achieve objective 2 in the water. An acoustic networking issue (see below), however, prevented us from moving completion of objective 1 out of the simulation realm and into the water. Implementation of the new (simplified) gateway role under objective 3 was accomplished by revising the previous wet test logic of various behaviors in the highest level of the vehicles. The new CCL command for changing the parameter of a previously defined and currently executing mission was also successfully implemented and demonstrated.

Cooperative behavior is certainly dependent on the vehicles' ability to communicate important data and information to one other. When three or more nodes are involved, some form of networking protocol is necessary. At AUVFest'07, we continued testing our Controlled Flooding for Small Networks (COFSNET) protocol (objective 4), in this case stress testing the protocol by placing three active nodes within a relatively small area. Since neither the acoustic modems nor the protocol have provisions for media access control (MAC), a time division media access (TDMA) scheme of sorts was implemented manually by setting each to broadcast its status acoustically every three minutes, staggered at 1 minute intervals between vehicles. Note that this sets up what amounts to only "half" of a true TDMA scheme. While the initiation of each node's broadcast was time division controlled, the COFSNET retransmission of packets was not.

We found that this mission kick off strategy worked well operationally, but apparently fell victim to the lack of TDMA control on those COFSNET retransmissions. We observed that at some variable time (roughly 10 minutes or so) after the third vehicle joined the group, one of the three would then become "deaf and dumb" relative to the other two. On repeated experiments, we found all three vehicles to separately exhibit this behavior, thus eliminating outright modem failure on any single vehicle. We also observed several instances where the affected vehicle would somehow "heal" itself and rejoin the network. Certainly, the leading suspect in this problem is multiple packets being simultaneously received at the affected node's modem. On line *in situ* debugging along with detailed post mission data file analysis also supports that determination. What we are not yet clear on is precisely how this is affecting the receiving modem, and how that situation is propagating up through the various layers of software of the COFSNET protocol stack.

We were forced to modify our planned operations given this newly discovered communication anomaly. For three vehicle testing (objective 1), we decided to work around communication dropouts by re-setting the effected vehicle so that it could then be made to re-join the group. Using this operational scheme, we continued the cooperative three vehicle survey, where one vehicle maintained the co-survey mission and the other two were allowed to stop and start the mission as needed. Given the communication issues, this was the best way to get them to generate at least sporadic status messages, which are necessary in order that each vehicle be able to make the proper role decision. In this manner, we were able to show a semblance of the full three vehicle role swapping, although not precisely as we had desired.

Despite not being able to fully realize objective 1, our operational fix did demonstrate an important feature of ad hoc networking: the capability for agents to enter and leave a functioning network without damaging that network. COFSNET was able to automatically deal with the deaf/dumb node being momentarily taken offline and then put back online as it was reset by human intervention. This operational adjustment also illustrated the importance for agents being able to reason about the "freshness" of the data, on which they are making their decisions. In several instances, due to missed status packets while one vehicle was being reset, we observed the other SAUVs utilizing outdated status information from that reset vehicle.

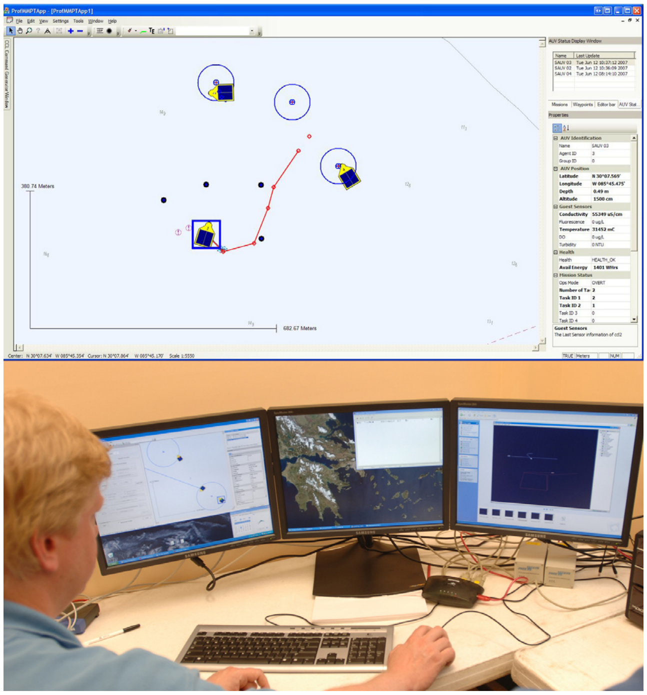


Figure 5: Modular Mission Planning Toolkit (MMPT) operator console for mission planning, monitoring and control.

Throughout the exercise, TSI's prototype MMPT was utilized for vehicle group monitoring and control (objective 6). In addition to plotting the SAUVs' positions and status on the screen, water current predictions obtained from NRL/Stennis were incorporated into the display. During the testing of objective 2, the "on the fly" update of the station-keep behavior was based on the water current pattern that was predicted by NRL models. SAUV03 was sent an update command changing the location of its station-keep circle such that the vehicle would be traveling with the current when returning to its "parking place".

Also, throughout the exercise, normal vehicle group control and monitoring was accomplished exclusively via CCL command and status packets passing between the AUV team and MMPT via an acoustic/RF gateway buoy. This was greatly facilitated by the successful work on the CCL interface layer in each vehicle (objective 5). The upper half of Figure 5 shows the MMPT screen during operations, while the lower half of the figure shows the three monitor system used at AUVFest'07. MMPT is shown on the left hand screen of that setup while a CADCON simulation visualization client is on the right hand screen.

7 Conclusions and Future Efforts

The overall design of our logic for implementing cooperative behavior in these vehicles has shown improvement over the various wet tests. We've been able to add complexity to the original design in terms of adding agents and giving them additional roles to take on and reason about. The simulation harness does a good job at embedding that logic in dynamic and realistic contexts, thus enabling a great deal of bench testing before the entire system hits the water.

Obviously, the acoustic networking issue must be corrected. Analysis of the data files is currently underway. We are also designing experiments for re-generating the problem in more controlled situations which will provide for better measurement of what is actually occurring when the situation manifests itself. We have a partially completed TDMA scheme in the wings that we hope to further test this fall; it was not operational enough for use during AUVFest'07.

While we have most of the maneuvering portion of the gateway role well in hand, the networking portion of that role must be designed and implemented. When performing this role, the vehicle will be actively routing communications between the acoustic and RF realms.

The specific points in the vehicles' cooperative behavior logic where decisions are made as to whether or not the vehicle will take on a specific role have been necessarily simplistic. Now that the overall logic is functional, we want to explore more complex decision making logic. This would enable the vehicles to move beyond threshold-based reasoning and into more complex (and hopefully) more robust decision-making. Additionally, the age of the communicated data should be taken into account when the vehicle performs its reasoning.

Acknowledgments

This research was partially supported by the following Office of Naval Research grants: N0001407WX20178 N00014-04-1-0264, N00014-05-1-0666, and N00014-06-1-0447. We wish to thank Dr. Arthur Sanderson, Dr. Sandra Nierzwicki-Bauer, and David Diehl at RPI's Darrin Fresh Water Institute for making available their wonderful test facility.

References

M. D. Ageev, V. E. Gornak, D. B. Khmelkov, A. Ph. Scherbatyuk, Ju. V. Vaulin, and D. Richard Blidberg (2001). "Mission Control System for Solar AUV and Results of the Vehicle Long Time Operation Trials". In *Proceedings of the Twelfth International Symposium on Unmanned Untethered Submersible Technology*, August 2001.

Radim Bartoš, Rick Komerska, Steven G. Chappell and Matthew Haag (2007). "COFSNET+: A Routing Protocol for Communication among Autonomous Underwater Vehicles", In *Proceedings of the Fifteenth Annual International Symposium on Unmanned Untethered Submersible Technology (UUST07)*, Durham, NH, August 2007.

R. Bartoš, V. Gorla, L. Cyril, R. Komerska, S. G. Chappell, and R. Sharma (2006). "Experimental Evaluation and Modeling of RF Modems for Use in Fleets of Multiple Cooperating Autonomous Undersea Vehicles". In *Proceedings of Oceans'06 MTS/IEEE-Boston*, Boston, MA, September 2006.

D. R. Blidberg and D. M. Crimmins (2005). "Multiple Cooperating AUV (MCAUV) Digest", Naval Undersea Warfare Center Division Newport, Newport, RI, Dec. 2005.

D. R. Blidberg (1994). "Generic Behaviors: Definition and Structure, an Approach to Modularity". In *Intelligent System Control Architectures – Volume 1: Technical Proposal*, Proposal for SOL BAA #94-19, July 21, 1994.

Steven G. Chappell, Sai S. Mupparapu, Rick J. Komerska, and D. Richard Blidberg (2005). "SAUV II High Level Software Architecture", In the *Proceedings of the Fourteenth International Symposium on Unmanned Untethered Submersible Technology*, August, 2005.

Christiane N. Duarte, Rick Komerska, Gerald R. Martel, Steven G. Chappell, D. Richard Blidberg, Robert Nitzel, Denise Crimmins (2007) "An Update on a Common Control Language to Support Multiple Cooperating AUVs". In the *Proceedings of the Fifteenth Annual International Symposium on Unmanned Untethered Submersible Technology (UUST07)*, Durham, NH, August 19-22, 2007.

Christiane N. Duarte, Gerald R. Martel, Christine Buzzell, Denise Crimmins, Rick J. Komerska, Sai S. Mupparapu, Steven G. Chappell, D. Richard Blidberg and Robert Nitzel (2005). "A Common Control Language to support Multiple

Cooperating AUVs". In the *Proceedings of the Fourteenth Annual International Symposium on Unmanned Untethered Submersible Technology (UUST05)*, Durham, N.H., August 21-24, 2005.

M. Haag, E. Agu, R. Komerska, S. G. Chappell and R. Bartoš (2006). "Status Packet Deprecation and Store-Forward Routing in AUSNet". In the *Proceedings of the First ACM International Workshop on UnderWater Networks (WUWNet),* September 25, 2006, Los Angeles, CA, September 2006.

James C. Jalbert, John Baker, D. R. Blidberg, Steven G. Chappell, Rick Komerska, Robert Nitzel, Matt Haag, Christiane Duarte, Gerry Martel and Michel Beliard (2007). "SAUV II Operations and Technology Transfer into Autonomous Station-Keeping Gateway Buoys". In *Proceedings of the Fifteenth International Symposium on Unmanned Untethered Submersible Technology*, August, 2007.

Rick J. Komerska and Steven G. Chappell (2007). "AUV Common Control Language (CCL) – A Proposed Standard Language and Framework for AUV Monitoring & Control, Layer 1 – CCL Vocabulary and Message Set Specification". AUSI Working Draft CCL Version 2.13, AUSI Internal Report, 9 July 2007.

Rick J. Komerska and Steven G. Chappell (2006). "A Simulation Environment for Testing and Evaluating Multiple Cooperating Solar power AUVs". In *Proceedings of the MTS/IEEE Oceans 2006 Conference*, September 2006.

Sai Mupparapu, Radim Bartoš and Matthew Haag (2005). "Performance Evaluation of Ad Hoc Protocols for Underwater Networks". In *Proceedings of the Fourteenth International Symposium on Unmanned Untethered Submersible Technology*, Durham, NH, August 2005.

M. Rosenblum and T. Garfinkel (2005). "Virtual Machine Monitors: Current Technology and Future Trends," *Computer*, vol. 38, no. 5, pp. 39-47, May 2005.