

NOAA's AUV Vision: Status and Opportunities

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Abstract - The National Oceanic and Atmospheric Agency (NOAA) is charged with a diverse set of missions. Many of which can be served by the appropriate application of new technologies, such as autonomous underwater vehicles (AUVs). To capitalize on the rapidly evolving AUV technology base, NOAA chartered a cross-agency working group to coordinate AUV activities in the agency. This team has compiled results from pilot programs and analyzed operational results to understand the value of AUVs in NOAA missions. A report entitled *Applying AUVs to NOAA Goals: Current Status and Future Opportunities* was submitted to NOAA senior leadership on June 1, 2006. This paper provides an overview of the NOAA AUV opportunities report. It discusses the role of AUVs in major NOAA strategic goal areas such as ecosystem research and management, commerce and transportation and climate. Significant pilot programs discussed include coast survey, fisheries science and ecosystem research applications. Technical and operational challenges are discussed and recommended steps for further integration of AUVs in NOAA are described.

supportive and advisory role in the management of living marine resources in coastal areas under state jurisdiction, provides scientific and policy leadership in the international arena and implements international conservation and management measures. A variety of programs support this mission including regional fisheries science centers and the NMFS Advanced Technology Working Group (ATWG). These programs actively examine science and technology for fisheries research and management.

Between 2004 and 2005 NMFS specified and acquired a prototype AUV optimized for their specific research needs. A vehicle from Sias-Patterson (acquired by Prizm Inc. in late 2005) was ordered and delivered in the Fall of 2005. Prior to that, NMFS partnered with Sias-Patterson and the Virginia Institute of Marine Science to conduct pilot field studies on the value of an AUV in fisheries research in Antarctica. [1] NMFS has also partnered with the SeaBed AUV from the Woods Hole Oceanographic Institution to conduct preliminary groundfish habitat studies.

I. AUV PILOT PROGRAMS IN NOAA

NOAA has engaged in several AUV pilot programs designed to inform managers and scientists in the agency. These programs are exploring the role of AUVs in specific niche missions. While NOAA has supported more fundamental AUV research and development it is these recent pilot programs that best set the stage for the broader NOAA AUV planning efforts.

A. National Marine Fisheries Service

The National Marine Fisheries Service (NMFS) is responsible for the management, conservation and protection of living marine resources within the United States Exclusive Economic Zone. NMFS also plays a



Fig 1. Fetch^{3.5} the NOAA Fisheries AUV

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B. Office of Coast Survey

The Office of Coast Survey (OCS) manages the NOAA nautical charting and nautical data collection and information programs. The Office manages an integrated suite of programs in hydrography and cartography. It operates interactively to help protect both life and property, support economic growth and development, and protect the environment in support of the overall mission to promote safe navigation.

In support of this mission OCS employs many assets, including survey vessels operated by NOAA Marine and Aviation Operations (NMAO). OCS and NMAO recognized the potential of small, lightweight AUVs as platforms for sonar systems and ancillary sensors, but also realized that the horizontal positioning and depth sounding accuracy requirements of shallow water hydrography challenged the capabilities of the current generation of vehicles. OCS and NMAO chose to initiate an experimental AUV program, with the goal of rigorously testing the capabilities of a small, commercially available vehicle against the requirements of the International Hydrographic Organization's (IHO) S-44 standard for hydrographic surveys. This program has been ongoing since 2004 using a modified REMUS AUV. [1]



Fig. 2. The Office of Coast Survey REMUS AUV

C. NOAA Ecosystem Research Program

The NOAA Ecosystem Research Program (ERP) is a cross-agency matrix of offices and programs relevant to the understanding of ocean ecosystems. Within ERP the Office of Ocean Exploration (OE) and the National

Undersea Research Program (NURP) engage in AUV projects. OE primarily sponsors innovative research and development of AUVs or their deployment in voyages of discovery to unknown ocean regions. Ocean exploration offers a wealth of applications for AUVs. [2]

NURP is a network of six centers in partnership with Universities and a private foundation, which provides scientists with the tools and expertise for undersea research. In 2001, NURP partnered with The University of Mississippi and the University of Southern Mississippi to form the National Institute for Undersea Science and Technology (NIUST). Among other programs, NIUST includes the Undersea Vehicles Technology Center focused on the research and development of viable technologies for the operation and deployment of ROVs and AUVs. Through a NURP funded program NIUST has acquired, and in August 2006 will deploy, an AUV developed by International Submarine Engineering. [1]

After qualification dives, this AUV will support habitat characterization and similar missions using its multibeam sonar. A large volume of this vehicle is available to support new payloads and it is anticipated that this will support experimental sensors for investigation of methane hydrates in the Gulf of Mexico.

II. LOOKING FORWARD

A. A Vision for the Future of AUVs at NOAA

The current pilot projects are relatively small scale efforts but they are complemented by a more powerful vision of the role of AUVs in NOAA. In 1989 Henry Stommel portrayed a vision of the future that made wide use of AUVs to study the ocean. [3] Dr. Richard Spinrad, Assistant Administrator for NOAA Research, echoed that concept in a 2004 comment on his vision for the ocean in 2020. [4] These visionary concepts have influenced NOAA.

The NOAA AUV Working Group has developed an AUV vision:

Our vision begins in the ocean depths. Autonomous underwater vehicles (AUVs) will roam the ocean reliably "mowing the lawn" to establish baseline data sets and adaptively sampling and studying the sea. Emerging tropical storms will be detected by networked systems that will then adjust to follow the storm and provide superior modeling and warning to coastal communities. Other systems will detect pollution in fragile ecosystems and follow it back to the source, calling in appropriate enforcement and cleanup nearly instantaneously. Fisheries will be monitored by robotic underwater herders guiding fisherman to the most efficient catches and resource managers to truly sustainable use of these natural resources. New energy and biopharmaceutical resources will be discovered and evaluated by autonomous underwater agents circling the globe, and making new maps and charts as they go. Robots, becoming ubiquitous as the

“Roomba” vacuum cleaners in our homes in 2006, will provide truly synaptic views of our ocean in NOAA’s future. [5]

Clearly such an ambitious vision is more valuable for inspiration than actual implementation. Thus some more immediate technology needs and early application areas for AUVs at NOAA should be considered.

B. Anticipated AUV Technology Needs at NOAA

The U.S. Navy UUV Master Plan identifies four main classes of vehicles; Man Portable (<100 lbs), Light Weight (~500lbs), Heavy Weight (~3000 lbs), and Large (~20,000 lbs). It also describes missions for, and desired capabilities of, these vehicles. The military market is likely to be significantly larger than that of the NOAA community. Therefore, it is likely that NOAA will simply work with the products developed by industry to meet the Navy requirements.

Within the four classes of vehicles those likely to be of greatest interest to NOAA are the Man Portable and Light Weight systems. The vast majority of NOAA pilot projects have worked with vehicles in these classes. The NURP/NIUST AUV does fall under the Heavy Weight class but it is likely to be one of only a few such vehicles in use by NOAA in the near future. The factors that will drive NOAA to the smaller vehicles include cost and operational requirements. Many of the envisioned AUV missions in NOAA do not demand larger vehicles.

As with all AUV users, NOAA will welcome increased endurance and further miniaturization of electronics. New communications and telemetry systems and improved “autonomy” will also be of benefit to NOAA. Beyond these desires common to most AUV users NOAA will also require some more specialized technology. Advanced *in situ* biological and chemical sensors are likely to be one significant need within the NOAA AUV arena. Devices to collect and/or process samples of water, organisms and geologic materials would also be beneficial to NOAA missions.

Another technology area where NOAA will look for further development is in cooperative and “swarm” behavior of AUVs. Many NOAA missions, such as monitoring red tides or marine mammals could benefit from cooperating autonomous vehicles. One could envision several vehicles mapping the surface and depth profiles of a harmful algae bloom (HAB) and then following its borders to provide advance warning to resource managers impacted by the HAB. Similarly one vehicle tracking a critical organism, such as an endangered right whale, could hand off the tracking duties to a replacement vehicle with fresh batteries, thus ensuring continual monitoring of the subject. Advances in artificial intelligence and robotic behavior would facilitate such activities.

An important area requiring technical, and policy, development is the subject of interaction between autonomous, or simply unmanned, vehicles and other vessels. As the demand for such vehicle grows so will their numbers. Most NOAA missions are in coastal waters, frequently heavily trafficked. A single AUV caught in a fishing net can be passed off as an inconvenience. Repeated incidents could become a significant problem. Small recreational vessels such as jet skis also pose potential challenges to the wide use of AUVs in coastal waters. There is some ongoing research into developing technologies to “teach” robotic vehicles to follow the “rules of the road.”[6] Such efforts will need to be complemented by policies designed to reduce risks and increase the benefits to all users of the marine environment.

C. Likely Missions for NOAA AUVs

Several pilot projects were described above. These give some sense of individual mission areas where NOAA might apply AUVs. Beyond fisheries research, coastal survey, ocean exploration and research there are other missions that could include:

Marine sanctuary monitoring – NOAA administers several marine sanctuaries to protect natural and cultural heritage resources. In June 2006 the Northwestern Hawaiian Islands were named a national monument, creating the largest marine protected area in the world. NOAA must also manage this expanse of pristine ocean. AUVs, especially long endurance vehicles like gliders and solar powered vehicles, offer an excellent method to maintain a regular monitoring presence in these regions. AUVs therefore can support scientific and enforcement missions in sanctuaries.

Physical oceanography – NOAA regularly collects physical oceanographic data for a variety of uses. Climate studies, in particular, can benefit from the use of AUVs to improve temporal and spatial distribution and resolution of oceanographic data. AUVs can perform this task well in both coastal and open ocean environments.



Fig. 3. AUV Gliders, like these from Webb Research, might support NOAA’s sanctuaries and climate studies

Homeland security – as the agency with responsibility for mapping U.S. coastal waters NOAA is cooperating with the Department of Homeland Security. Monitoring the seafloor for hazardous devices is clearly an AUV mission area. AUVs are a likely tool to support this additional step, target identification, in the coastal survey mission already undertaken by NOAA.

Marine fisheries enforcement – observation of fishing vessels and ensuring compliance with international and domestic regulations can be quite challenging. AUVs loitering in major fishing grounds might serve as early warning of incursion into no fish zones by unauthorized vessels.

These various missions, and expansion of the pilots described above into operations, have a common theme. Most NOAA AUV missions involve ocean observing. As NOAA, together with a variety of other entities, moves to establish an Integrated Ocean Observing System (IOOS) AUVs will play an important role. Much like the envisioned autonomous ocean sampling network (AOSN) of the last decade, [7] IOOS will make extensive use of unmanned vehicles on and below the surface. As a leader in the development and deployment of IOOS NOAA looks toward using AUVs in regular observing of the ocean to increase understanding and improve management of our ocean realm.

III. COORDINATING AUVs ACROSS NOAA

A. The NOAA AUV Working Group

The ongoing pilot projects at NOAA have demonstrated the potential value of AUVs in a variety of NOAA missions. To capitalize on the benefits of AUVs these program level activities required coordination and future activities needed to be planned cooperatively to reduce costs and leverage multiple investments. So, to coordinate AUV efforts a cross-agency working group has been created. This team includes technical representatives from all the NOAA programs described above. It also includes members of NOAA Marine and Aviation Operations the NOAA “fleet.” A steering committee of senior managers from across the agency oversees the efforts of the working group.

During 2005 the NOAA AUV Working Group (AUVWG) engaged in two primary activities, internal and external communication and outreach and future planning. To address the communication task the AUVWG developed an AUV situation report provided to NOAA leadership. In addition to internal briefings, the AUVWG hosted a workshop in Silver Spring, MD. At this event NOAA AUV users and potential users gave presentations on their needs and results from their ongoing pilot projects. AUV vendors were also given an opportunity to give briefings on their capabilities. The

presentations from this workshop are available upon request to the author.

While raising awareness of NOAA AUV programs the AUVWG was also working to develop a planning document entitled “Applying AUVs to NOAA Goals, Current Status and Future Opportunities.”² For those familiar with the U.S. Navy’s UUV Master Plan it is important to note that this NOAA document is not comparable in its detailed definition of missions and technical specifications. Rather, it examines how AUVs can be used to address NOAA’s missions and goals. This document is of greatest value to NOAA program managers unfamiliar with AUV technology. It provides a more detailed overview of the background material in the preceding sections of this paper. It also outlines a vision for the future of AUVs in NOAA, discussed above, and recommendations to achieve that vision.

B. Beyond the Working Group

Moving from small pilot programs to the broad deployment of AUVs envisioned by the AUV Working Group and NOAA colleagues will require a phased approach. Government budget planning and execution processes must be followed. Careful analysis and effective planning is required to avoid redundancy and capitalize on the economic and technical benefits of AUVs. The NOAA AUV Working Group envisions a series of steps including further workshops to educate the NOAA user community and solicit feedback from the AUV community. Pilot programs will require cost benefit analyses feeding in to the development of transition to operation plans. The eventual development of a NOAA AUV “Master Plan” is conceivable. At this time the NOAA AUV Working Group is awaiting feedback on its opportunities report. That feedback will guide the future course of AUVs in NOAA.

IV. CONCLUSIONS

AUVs appear to hold great promise for reducing the costs and increasing the benefits of NOAA’s ocean research and management activities. In missions ranging from habitat characterization and fisheries research to coastal survey, pilot projects are underway and demonstrating results. NOAA has organized a working group to coordinate current pilot programs and advise leadership on the opportunities AUVs offer. Major NOAA leadership bodies have been informed about the technology, and potential benefit, of AUVs and guidance from these bodies is expected soon. Further progress in the development and deployment of AUVs for NOAA missions can be anticipated.

² This draft document is currently restricted to internal NOAA readers. This paper aims to summarize it and future versions and documents will be available to help the AUV community interact with NOAA.

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REFERENCES

- [1] J. Manley, "Autonomous Underwater Vehicles in Ocean Science: Case Studies from, and applications within, the National Oceanic and Atmospheric Administration," *Proceedings of the World Marine Technology Conference*, IMAREST, London, U.K., March 2006.
- [2] J. Manley, "Autonomous Underwater Vehicles for Ocean Exploration," *Proceedings of Oceans 2003*, MTS/IEEE, San Diego, CA, September 2003.
- [3] H. Stommel, "The Slocum Mission" *Oceanography*, 2:22 -25, 1989
- [4] R. Spinrad, "A Vision for the Ocean Planet in 2020," *Proceedings of Oceans/Techno-Oceans 2004*, MTS/IEEE, Kobe, Japan, November, 2004
- [5] Unpublished, NOAA AUV Working Group, "Applying AUVs to NOAA Goals: Current Status and Future Opportunities. NOAA Internal Report, Silver Spring, MD, June, 2006.
- [6] Benjamin, M. and Curcio, J. "COLREGS-Based Navigation of Autonomous Marine Vehicles," *Proceedings of Autonomous Underwater Vehicles 2004*, IEEE, Sebasco, ME, June 2004.
- [7] Curtin T., Bellingham, J. G., Catipovic, J., and Webb, D., "Autonomous Ocean Sampling Networks," *Oceanography*, Vol. 6, No. 3, pp 86-94, 1993.