Autonomous Underwater Vehicles for Ocean Exploration

Justin E. Manley

NOAA Office of Ocean Exploration[1], Silver Spring, MD
http://oceanexplorer.noaa.gov, justin.manley@noaa.gov

Mitretek Systems[1], Falls Church, VA
http://www.mitretek.org, justin.manley@mitretek.org

***Abstract* - Autonomous Underwater Vehicles (AUVs) have evolved rapidly and now serve many applications in commercial, military, and scientific sectors. The NOAA Office of Ocean Exploration (OE) recognizes AUVs as an important component of its research and operational programs. From large survey vehicles to small hand deployed systems, the entire spectrum of AUVs has a role to play in OE programs. This paper discusses aspects of AUV research and development supported by, and of interest to, OE. Current and envisioned operational use of AUVs in exploration will be described and examples of exploration missions that would benefit from both current and near-future AUV capabilities are presented.**

I. NOAA OCEAN EXPLORATION

A. Program Background

The oceans and great inland seas are widely recognized as among the few remaining frontiers of human discovery on our planet. History demonstrates that exploration results in discoveries of great value. Every ocean expedition has the potential to discover important information about the origins of life on earth, or new living or non-living resources that may have potential to benefit humanity. Recent progress in technology is enabling new initiatives. Ocean exploration assets and capabilities may one day rival those of space exploration, with potential for enormous economic, archeological, health, and quality of life benefits.

The national need to explore the ocean and large inland lakes was an important rationale stated by the Stratton Commission in 1969 for establishing the National Oceanic and Atmospheric Administration (NOAA) as an organization. [1] The importance of this mission was reinforced in October 2000 by a national panel of ocean experts appointed by the President of the United States in its report: *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration* (hereafter referred to as the *Frontier Report).* [2] The panel noted that the same reasons that motivated early explorers to accept great risks in their search for new discoveries—survival, inspiration, wealth, and national pride—provide fundamental justification for embarking on a new era of ocean exploration:

"Exploration is fundamental to the human spirit. Since the dawn of our species we have been explorers, with the motivation for these journeys ranging from survival to spiritual inspiration."

The *Frontier Report* provides a comprehensive vision for exploring the oceans that continues our national legacy of seeking new knowledge at the great frontiers of human discovery. NOAA has recognized the important role of the Federal government in achieving this vision throughout the history of our Nation and has assumed a leadership role in implementing a program for systematically exploring the ocean through its Office of Ocean Exploration (OE).

As a principal component of the national strategy contained in the *Frontier Report,* OE seeks to bring the best of the nation's scientists to the leading edges of ocean science and technology to (1) discover more about life and processes within the oceans, (2) learn more about maritime cultural resources and heritage, (3) reap the benefits of the ocean's biological and mineral resources and (4) share new knowledge across a broad, multi-disciplinary user community. In the ongoing efforts to meet these goals OE is working across NOAA, other federal agencies, academia and the private sector to foster the development and deployment of state-of-the-art ocean technologies.

B. OE Technology Program

The *Frontier Report* highlighted "developing new sensors and systems for ocean exploration" as a key focus of the nation's ocean exploration program. Areas of interest included "1) Underwater navigation and communication technologies; 2) State-of-the-art sensors; and 3) Deployment strategies for multidisciplinary, in-situ and remote sensing [ocean exploration]."

[1] This paper has been prepared by Mitretek Systems, a nonprofit corporation chartered to work in the public interest. Mitretek performs under a directed award contract with NOAA to provide objective, conflict-free advice, especially regarding technology investment, program management, and budget and strategy formulation.

0-933957-31-9

With this guidance OE is working to leverage its limited budget for greatest impact. The primary focus of the technology program thus far has been pilot projects with limited budgets and developing ties to other agencies, both within and outside NOAA, interested in advanced technology. Through such partnerships OE aims to find the areas with the greatest potential return for the ocean community as a whole.

Some examples of OE's technology program include the use of laser line scan imaging for habitat assessment, [3] supporting the development of the *Global Explorer* ROV for arctic deployment from an ice-breaker [4] and the use of Autonomous Underwater Vehicles, the focus of this paper.

II. AUVs IN OCEAN EXPLORATION

A. Deep Ocean Access

A primary region of interest to OE, which also distinguishes it from most oceanographic programs, is the very deep ocean. While conventional oceanography accepts 6,000 meters as "full ocean depth" the OE program is charged to explore even the deepest trenches, beyond 10,000 meters. This is a particularly challenging place to explore.

The high costs of an 11,000 meter rated manned submersible rule out a human occupied vehicle (HOV) approach to the trenches. Remotely Operated Vehicles (ROVs) are an alternative to HOVs. Experience with *Kaiko* has proven that ROVs can be deployed to the deepest parts of the ocean floor. [5] Unfortunately, these efforts have also shown that the "footprint" of a conventional ROV at these depths is small and difficult to move. Thorough exploration requires more mobility and flexibility than an ROV can provide at 11,000 meters.

Fig. 1. ABE deployed in the Galapagos

An answer to OE's need for access to the ocean floor beyond 10,000 meters is likely to be found in AUVs. OE funded investigators have had excellent results using the Autonomous Benthic Explorer (ABE). During the 2002 field season an OE expedition used ABE to explore the seafloor off the Galapagos Islands at depths over 2400 m. [6]

Given these positive results, OE is looking forward to further use of AUVs in deep ocean exploration. The development of an 11,000 meter AUV to support basic "reconnaissance" to the ocean trenches would be of interest to OE. An alternative might be a hybrid vehicle, using a data tether but independent battery power. Such an approach would provide more real-time data to explorers but preserve the mobility and cost-effectiveness of an AUV.

B. Operational Efficiency

Another feature of AUVs, of particular interest to OE, is the increased operational efficiencies they offer in all water depths. Missions such as oceanographic sampling, habitat surveys, and even tracking of marine life are all well suited to AUVs. Replacing, or augmenting, conventional research vessels in these missions could provide significant reductions in the cost of exploration.

With vast regions of the ocean unexplored an exciting AUV class is "gliders." Platforms such as the Slocum gliders from Webb Research have very long endurance. [7] This allows them to support exploration across ocean basins. A fleet of gliders could complete a wide ranging survey of physical oceanography across the globe. This type of mission would provide valuable baseline data that could be used to plan further, more detailed, research cruises. While gliders have a limited ability to reach defined waypoints, another long range concept, solar powered AUVs, [8] could improve the fidelity of autonomous wide ocean exploration.


Fig. 2. Webb Research autonomous gliders

In focused blue water research, OE envisions one vessel supporting multiple platforms for increased effectiveness. The 2002 Galapagos cruise used the proven approach of daytime *Alvin* dives and ABE deployments during the night. The results of ABE missions were quickly evaluated and used to guide the next day's *Alvin* dives. [6] Alternative, but similar, approaches might include a swarm of AUVs covering large spatial regions or deploying multiple sensor types. Investigators planning to use multiple AUVs as "force multipliers" are welcome to submit proposals to OE.

AUVs also offer the possibility of eliminating the need for, and high costs associated with, a large research vessel. Moderately sized AUVs, operated from small boats can be used to conduct significant oceanographic research. For example, the Odyssey class AUVs developed at MIT have demonstrated this many times. In 1997 an Odyssey II was deployed from a small vessel to search for giant squid in Kaikoura Canyon off New Zealand. In a 1999 oceanographic experiment, an Odyssey II was deployed from the R/V *Shana Rae* a 52 foot vessel. [9]

Fig. 3. An Odyssey II AUV on the R/V *Shana Rae*

In both cases, and others since, smaller vessels combined with AUVs have provided access to the deep ocean that otherwise would have required full scale research cruises. This approach is limited by the endurance, and sea state limitations, of smaller vessels. However, given that OE's budget supports a limited number of ship-days; the use of AUVs from smaller vessels is likely to expand the scope of exploration in regions where such platforms are practical.

C. Mapping

Mapping the ocean floor is an important aspect of ocean exploration. Such maps provide a baseline from which to prioritize further exploratory or research missions. While the use of multibeam bathymetry is expanding and more hydrographic data is collected each year there is still a significant need for expanded mapping of the seafloor.

The commercial sector, notably offshore oil, has led the way in developing and deploying AUVs for seafloor survey. The improved data quality and faster survey rates of systems like the Hugin operated by C&C Technologies have proven that AUVs are a viable tool for this application. Currently OE does not require a large enough volume of mapping information in any one region to justify the mobilization costs of a commercial AUV survey. As more vehicles enter the market and costs come down OE anticipates meeting some of its deep water mapping needs through the use of AUVs.

In shallower waters, small AUVs provide a capable mapping tool. Currently the positioning accuracy of smaller AUVs does not match that of their larger brethren. However, in some cases this is not a critical issue. There are missions where the ease of deployment and high quality side-scan images from a vehicle like REMUS far outweighs the lower level of position accuracy in the resulting "maps." As the capability of these smaller AUVs develops their mapping potential increases. NOAA's Office of Coast Survey, responsible for production of nautical charts, has recently begun investigating the potential of a REMUS to support their missions. OE sees small AUVs as a likely tool to replace towed side-scan sonars in coastal search and survey.

D. Unique Science

There are certain areas of oceanographic research where OE is especially interested in expanding baseline knowledge. Two of these, under ice exploration and marine archaeology, are well suited for AUVs.

Due to the extreme logistical challenges of operating in the arctic and Antarctic few expeditions conduct oceanography in these regions. OE supported an arctic exploration cruise during 2002 but this utilized an ROV. AUVs have been strongly considered for under-ice operations for over 10 years. [10] As AUV power systems continue to evolve and multi-week deployments become common under-ice exploration will be a significant target area for OE use of AUVs.

OE is also interested in marine archaeology. As ocean engineers and archaeologists collaborate to explore this field, AUVs have been recognized as well suited to certain archaeological applications. [11] Broad area survey for locating shipwrecks and submerged cultural heritage sites is one, somewhat obvious AUV application. In deep water, beyond diver depth, there are likely to be many undiscovered sites of interest. Given the high cost of deep towed search systems, and frequently limited budgets for archaeology projects, AUVS become more advantageous search platforms as target depths increase.

Recent technical advances have led to the concept of "inspection" AUVs. [12] These vehicles are intended to maneuver similar to ROVs and offer a significantly improved range of motion when compared to traditional AUVs designed as autonomous towfish. This will allow these vehicles to slowly, and precisely, traverse shipwreck sites and create detailed maps and photo mosaics, key data for archaeologists. The WHOI Seabed vehicle has demonstrated field results in habitat characterization surveys that indicate it will be able to carefully survey and inspect shipwrecks as well. [13] Archaeologists have already used AUVs to answer important historical questions such as the fate of the WWII submarine U-166 in the Gulf of Mexico. [14] OE expects AUVs to play a growing role in deep sea archaeology.

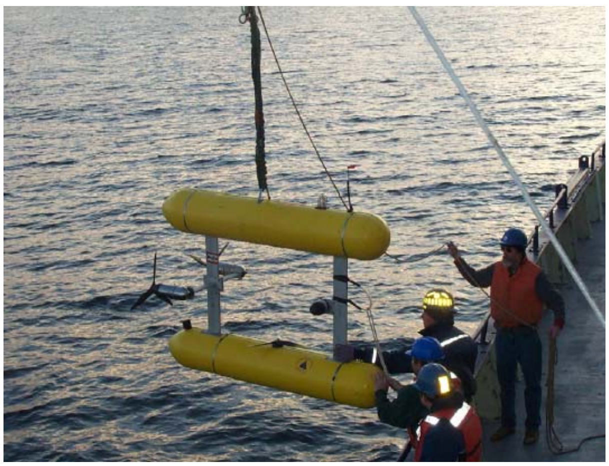

Fig. 4. Seabed, a highly maneuverable AUV

III. LOOKING FORWARD

The pace of AUV development has allowed tremendous increases in the number, and capability, of vehicles available to the oceanographic community. As a sponsor of high risk ocean research OE welcomes this development. There are many missions of interest to OE where AUVs are the best, or only viable, tool. Over the next few years OE aims to continue supporting the deployment of AUVs in ocean exploration. Investigators with plans to use AUVs in exploration missions are welcome, and encouraged, to submit proposals through OE's annual Announcement of Opportunity.

The Frontier Report recommended an ocean exploration budget of $75 Million. OE's current budget, approximately $14 Million, does not allow it to make significant investments in the development of technology. As additional funds become available to support the technology needs of exploration AUVs, particularly those with significant depth capabilities, will be of significant interest to OE.

Currently OE is leveraging its limited technology investments by collaborating with other federal agencies. In cooperation with NASA and the Office of Naval Research, OE has been studying the possibility of providing AUV capacity to the ocean community through a proposal driven process. This effort is ongoing and it is hoped that by 2004 AUVs will be available to support new exploration and oceanography missions.

Another area of collaboration is with the Naval Undersea Warfare Center (NUWC). OE is working with NUWC to direct some of its existing AUVs, and its technology development capacity, towards scientific applications. As this program progresses OE anticipates multidisciplinary collaborative expeditions built around naval AUVs and associated technology.

As deployment costs decrease, and capabilities increase, OE anticipates additional use of AUVs in ocean exploration missions. If OE's budget moves closer to the Frontier Report recommended $75 Million significant investments in AUV development and related technologies such as sensors can be expected. Until that time limited, but strategic, investments in AUVs should continue.

References

[1] *Our Nation and the Sea - A Plan for National Action.* Report of the Commission on Marine Science, Engineering and Resources. United States Government Printing Office, Washington, D.C., January 1969

[2] *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration,* Report of the President's Panel on Ocean Exploration, University Corporation for Atmospheric Research, October 2000.

[3] M. Yoklavich, C. Grimes, and W. Wakefield, "Using Laser Line Scan Imaging Technology to Assess Deepwater Seafloor Habitats in the Monterey Bay National Marine Sanctuary," *Marine Technology Society Journal,* Vol. 37, No. 1, pp 18-26, 2003.

[4] R. White, "First Eyes in the Hidden Abyss," *Sea Technology*, Vol. 43 No. 12, pp 14 – 18, 2002.

[5] R. Wernli ed., "Operational Effectiveness of Unmanned Underwater Systems," Marine Technology Society, Washington D.C., 1999.

[6] T. Shank, S. Hammond, "Galapagos Rift Exploration, 25 Years of Hydrothermal Vent Discovery," Cruise Report, NOAA/NSF/WHOI, September 20, 2002.

[7] D. C. Webb and P. J. Simonetti, "The slocum AUV: An environmentally propelled underwater glider," *Proceedings of the 11th International Symposium on*

Unmanned Untethered Submersible Technology, vol. 11, pp. 75 - 85, August 1999.

[8] M. D. Ageev, D. R. Blidberg, J. Jalbert, C. J. Melchin, and D. P. Troop, "Results of the evaluation and testing of the solar powered AUV and its subsystems," *Proceedings of the 11th International Symposium on Unmanned Untethered Submersible Technology,* vol. 11, pp. 280 - 288, August 1999.

[9] MIT AUV Lab, "Expeditions" [Online] Available: http://auvlab.mit.edu/expeditions/ [June 12, 2003)

[10] J. G. Bellingham, M. Deffenbaugh, J. J. Leonard, J. Catipovic, and H. Schmidt, "Arctic under-ice survey operations," *Proceedings of the Eighth International Symposium on Unmanned Untethered Submersible Technology,* vol. 8, pp. 50 - 59, September 1993.

[11] D. Mindell and B. Bingham, "New archaeological uses of autonomous undersea vehicles," *MTS/IEEE Conference Proceedings Oceans 2001,* Honolulu, HI, November 2001.

[12] R. Damus, J. Manley, S. Desset, J. Morash, C. Chryssostomidis, "Design of an Inspection Class Autonomous Underwater Vehicle," *MTS/IEEE Conference Proceedings Oceans 2002*, Biloxi, MS, October 2002.

[13] H. Singh, "SeaBed AUV" [Online]. Available: http://www.dsl.whoi.edu/DSL/hanu/seabed/index.html [June 12, 2003]

[14] R. Church, D. Warren, A. Hill, and J. Smith, "The Discovery of U-*166*: Rewriting History with New Technology," *Proceedings of the Offshore Technology Conference,* Houston, TX, 2002