

Autonomous Underwater Vehicles

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Introduction

An Autonomous Underwater Vehicle (AUV) is a robotic device that is driven through the water by a propulsion system, controlled and piloted by an onboard computer, and maneuverable in three dimensions. This level of control, under most environmental conditions, permits the vehicle to follow precise preprogrammed trajectories wherever and whenever required. Sensors on board the AUV sample the ocean as the AUV moves through it, providing the ability to make both spatial and time series measurements. Sensor data collected by an AUV is automatically geospatially and temporally referenced and normally of superior quality. Multiple vehicle surveys increase productivity, can insure adequate temporal and spatial sampling, and provide a means of investigating the coherence of the ocean in time and space.

The fact that an AUV is normally moving does not prevent it from also serving as a Lagrangian, or quasi Eulerian, platform. This mode of operation may be achieved by programming the vehicle to stop thrusting and float passively at a specific depth or density layer in the sea, or to actively loiter near a desired location. AUV's may also be programmed to swim at a constant pressure or altitude or to vary their depth and/or heading as they move through the water, so that undulating sea saw survey patterns covering both vertical and/or horizontal swaths may be formed. AUV's are also well suited to perform long linear transects, sea sawing through the water as they go, or traveling at a constant pressure. They also provide a highly productive means of performing seafloor surveys using acoustic or optical imaging systems.

When compared to other Lagrangian platforms, AUV's become the tools of choice as the need for control and sensor power increases. The AUV's advantage in this area is achieved at the expense of endurance, which for an AUV is typically on the order of 8- 50 hours. Most vehicles can vary their velocity between 0.5 and 2.5 m/s. The optimum speed and the corresponding greatest range of the vehicle occur when its hotel load (all required power except propulsion) is twice the propulsive load. For most vehicles, this occurs at a velocity near 1.5 m/s.

The degree of autonomy of the robot presents an interesting dichotomy. Total autonomy does not provide the user with any feedback on the vehicle's progress or health, nor does it provide a means of controlling or redirecting the vehicle during a mission. It does, however, free the user to perform other tasks, thereby greatly reducing operational costs, as long as the vehicle and the operator meet at their duly appointed times at the end of the mission. For some missions, total autonomy may be the only choice; in other cases when the vehicle is performing a routine mission, it may be the preferable mode of operation.

Bidirectional acoustic, radio frequency, and satellite based communications systems offer the capability to monitor and redirect AUV missions worldwide from a ship or from land. For this reason, semi-autonomous operations offer distinct advantages over fully autonomous operations.

History

The following presents highlights of some notable achievements in the history of AUV's. In the short space and time available, it is unfortunately not possible to provide information on all systems.

The origin of AUV's should probably be linked to the Whitehead Automobile "Fish" Torpedo. Robert Whitehead is credited with designing, building, and demonstrating the first Torpedo in Austria in 1866. Torpedoes are named after the Torpedo fish, which is an electric ray capable of delivering a stunning shock to its prey. Whitehead's first torpedo achieved a speed of over 3.0 m/s and ran for 700 m. The vehicle was driven by compressed air and carried an explosive charge. If one ignores the fact that it carried an explosive charge, it might be considered the first AUV.

The need to obtain oceanographic data along precise trajectories and under ice motivated Stan Murphy, Bob Francois, and later Terry Ewart of the Applied Physics Laboratory of the University of Washington to begin development of what may have been first "true" AUV in the late 1950's. Their work led to the development and operation of The Self Propelled Underwater Research Vehicle(s) (SPURV). SPURV I, became operational in the early 60's and supported research efforts through the mid 70's. SPURV I displaced 480 kg, and could operate at 2.2 m/s for 5.5 hours at depths to 3 km. The vehicle was acoustically controlled from the surface and could autonomously run at a constant pressure, sea saw between two depths, or climb and dive at up to 50 degrees. Researchers used the vehicle to make CT measurements along isobaric lines in support of internal wave modeling [1]. The vehicle was used later in the 70's to support observations of Horizontal and Vertical Diffusion using a dye tracer at depths to 1 km. The vehicle was able to track the dye plume 66 hours after the dye was released [2]. SPURV II was more capable than SPURV I, and was used to study the dispersion of submarine wakes using a dye tracer during the 70's and 80's. There were over 400 SPURV deployments.

The Naval Ocean System Center, now SPAWAR, began development of the Advanced Unmanned Search System (AUSS) in 1973 in response to the sinking of the USS Thresher, the USS Scorpion, and the H bomb loss of Palomares. The vehicle was launched in 1983, and reports and publications on the system were still in press in the 90's. AUSS displaced 907 kg, carried 20 kw-hours of energy in silver zinc batteries, and was rated to 6 km. It had an acoustic communication system that transmitted video images through the water. AUSS completed over 114 dives, some to 6 km. The concept of using multiple free swimming vehicles to improve system performance can be traced to the development of this system. This work was completed some time in the early 80's. [5]

IFREMER's Epulard was designed in 1976, assembled by 1978, and was fully operational by 1980. Epulard was the first 6 km rated acoustically controlled AUV that supported deep ocean photography and bathymetric surveys. The vehicle maintained a constant altitude above the bottom by dragging a cable. Epulard completed 300 dives, some to 6 km, between 1970 and 1990 [3].

According to Busby's 1987 Undersea Vehicle Directory, there were six operational AUV's and an additional 15 other vehicles that were considered to be prototypes or under construction by 1987. During this period, AUV's were called un-tethered (autonomous) ROV's, and the acronym AUV stood for Advanced Underwater Vehicle, a vehicle under development by the U.S. Defense Advanced Research Projects, which was completed in 1984. The origin of the

Hugin vehicle, which is currently manufactured by Kongsberg Simard, can also be traced back to the late 80's [4].

During the 90's, there was a rekindling of interest in AUV's in academic research.

The Massachusetts Institute of Technology's Sea Grant AUV lab developed six Odyssey vehicles during the early 90's. These vehicles displaced 160 kg, could operate at 1.5 m/s for up to six hours, and were rated to 6 km. Odyssey vehicles were operated under ice in 1994, and to a depth of 1.4 km for 3 hours in the open ocean in 1995 [6]. Odyssey vehicles were also used in support of experiments demonstrating the Autonomous Ocean Sampling Network during this period [7].

WHOI's Autonomous Benthic Explorer (ABE) was also developed during the early 90's and completed its first scientific mission in 1994. ABE displaces 680 kg and can operate for up to 34 hours to depths of 5 km, and typically travels at about 0.75 m/s. ABE carries six thrusters, making it a highly maneuverable vehicle in all three dimensions. These capabilities make ABE an excellent platform to perform near bottom surveys in rough terrain. ABE has completed over 80 dives in support of science; one dive lasted for 30 hours at 2.2 km. Its deepest dive to date was to 4 km [7].

International Submarines Engineering, Ltd's Theseus was developed during the early 90's for the U.S. and Canadian defense establishments. Theseus displaces 8,600 kg, and could operate at 2 m/s for 100 hours to depths of 1 km. The vehicle successfully laid 190 km of fiber optic cable under ice in 500 m of water in 1996; total mission length was 365 km and was completed in 50 hours [9].

WHOI's REMUS vehicle was developed in the late 90's to support scientific objectives at the LEO-15 observatory in Tuckerton, NJ, with funding from NSF and NOAA. REMUS completed its first scientific mission in 1967. The vehicle displaces 36 kg and can operate for up to 20 hours at 1.5 m/s and to a depth of 100 m. There are currently over 50 REMUS vehicles in 20 different configurations that are being independently operated by nine universities, three US Navy laboratories, one British defense laboratory, and three branches of the US Navy. Hundreds of people have been successfully trained in the use of REMUS vehicles. It is not possible to determine how many missions have been performed by REMUS. The longest REMUS mission lasted 17 hours. The vehicle traveled 60 km at 1.75 m/s at a maximum depth of 20 m off the coast of NJ at the LEO-15 observatory [10].

South Hampton Oceanography Center's Autosub was developed during the early 90's to provide scientists with the capability to monitor the oceans in new ways. Autosub completed its first scientific mission in 1998. The vehicle displaces 1700 kg, and can travel for up 6 days at 3 knots at depths up to 1.6 km. Autosub has completed 271 missions, totaling 750 hours and covering 3,596 km. Its deepest dive was to 1 km.; its longest mission lasted 50 hours [11]. In 1998, the UK National Environmental Research Council provided 2.6m pounds in grants and training awards for use with the Autosub. These grants stimulated a great deal of interest in the scientific community.

The turn of the century ushered in the first commercial enterprise to offer deep water (3 km) AUV survey services. C&C Technologies of Lafayette, Louisiana offers a Hugin 3000 AUV for charter. The vehicle was manufactured by Kongsberg Simrad of Norway. The vehicle displaces 1400 kg, and can operate at 4 knots for 40 hours utilizing an aluminum/oxygen fuel cell. C&C Technologies has completed over 17,702 km of (paid for) geophysical mapping, some to 3 km, since the vehicle was first offered in 2000. C&C Technologies also offers its clients interactive software on their web site that permits them to monitor and direct the progress of the generation of charts that are being made aboard the survey ship that is supporting the AUV survey. [12].

State of the Art

The following provides a discussion of emerging capabilities that will directly benefit scientists who are interested in using AUV's.

By far the most important considerations by which to assess a vehicle's state of the art are:

- Does the system inspire confidence? Is it easy to use and reliable?
- Does it provide a complete solution, i.e., mission planning, execution, data analysis, and report generation?
- Does the vehicle provide access to a wide variety of sensors?
- Is there a safe and reliable means of launching and recovering the system?
- Can it be operated from ships of opportunity?

Historically, AUV's navigate through the ocean under the assumption that the ocean is large and contains few obstacles that will impede the completion of their mission. They execute scripts that take them from objective to objective. They may react differently to a rising or falling seafloor based on the need to maintain a constant altitude above the bottom and not collide with the bottom, but in general they do use sensor data obtained during a mission to make them more successful and/or reliable. Sensor information is recorded. It is not processed and used to provide the vehicle with the ability to adapt, and change its current objective; it is simply recorded for future analysis.

The ability to imbed software into a vehicle system that can alter the vehicle's current mission, based on measurements from the sensor(s) it carries, and direct it toward a source or phenomena of interest will greatly reduce the time it takes to locate and study such phenomenon of interest. Following a plume of "whatever" to its source, detecting an obstacle ahead and maneuvering around it, and following a "layer in the sea" are all examples of how AUV's can be made more intelligent and useful. These capabilities are available in some systems today.

The capability for one vehicle to pass information that it acquires from a sensor to another vehicle via an acoustic link, so that the second vehicle may then redirect its own mission based on the information, can be extended to multiple vehicles. These cooperative relationships exemplify the emerging potential of multiple vehicle operations; extension of this concept beyond two or three systems invokes the need for water space management- an underwater air traffic control system.

Future Possibilities

The trouble with our times is that the future is not what it used to be. –Paul Valery

Finding better ways of observing and reporting on the interior of the ocean, its seafloors and coastal boundaries remain principal objectives of the oceanographic community. Utilizing productive and affordable technologies that offer a new perspective of the ocean by providing sampling methodologies that merge the high spatial resolution of ship-based surveys with the endurance and temporal resolution of moorings may be one “better way” The broad use of this technology by the ocean science community is hopefully in our future.

C&C Technologies, Inc.’s AUV Hugin has proven that the cost of deep water survey operations can be reduced by 40% to 60% by using AUV’s rather than conventional methods, while improving the quality of the data that is collected [12]. Given the budgetary constraints that face the oceanographic community and the need for high quality data, it is unwise to ignore this potential.

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