Sensors and Platforms for Autonomous Undersea Systems

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Abstract

The Applied Physics Laboratory (APL) is developing a variety of sensors and sensing systems for autonomous underwater systems, including high resolution imaging sonars and unique oceanographic probes. In addition, we are developing several new autonomous platforms such as freely drifting floats with vertical profiling capability and controlled vehicles propelled by buoyancy changes.

Introduction

Autonomous underwater vehicles and sensing systems have been under development for nearly fifty years. The first AUV (other than a torpedo) made in the U.S. was APL’s SPURV (Self-Propelled Undersea Research Vehicle), first tested in 1959 and subsequently used for a number of years to measure the dispersion properties of turbulent wakes. Since then, progress has been rapid. In the last two decades the advent of low-power solid state electronics, high energy density batteries, closed cycle diesels, fuel cells, small inertial navigation systems, and ring laser gyros have resulted in highly developed vehicles, but appropriate sensors and imaging systems have lagged behind. The technology for the design of propelled vehicles is far more advanced than the sensors they carry.

At the same time, there is increasing interest in using autonomous systems for a wide variety of tasks, such as search and survey, monitoring, measuring, observing and surveillance, exploration, and executing routine work functions remotely. These systems take the form of self-propelled vehicles, freely drifting floats, buoyancy driven gliders, platforms attached to moorings and structures as well as those fixed to the ocean, river or lake bottom. Ocean scientists speak of long-term ocean observations made with autonomous devices with the goal of sampling the ocean in space and time autonomously and remotely, to provide the data needed for accurate forecasts of ocean and terrestrial weather and climate. A goal of the oil, gas and minerals industries is to conduct surveys autonomously, and deploy and operate extraction equipment remotely. Militaries want to be able to locate and identify underwater objects such as mines, autonomously and remotely. Each of these demanding applications requires sophisticated sensors that are
smaller, lighter, more capable, higher resolution, lower power and ‘smarter’ than those presently available.

The Applied Physics Laboratory is developing a number of sensors, imaging systems and autonomous devices aimed at achieving these goals.

**Imaging Sonars**

APL has developed a number of miniature, high frequency imaging sonars for a variety of applications including mine hunting, hull inspection, and search and rescue. These sonars are based on acoustic lens technology which has several advantages over mechanically or electronically steered sonars. Lens sonars are compact, lightweight, robust, and consume relatively less power.

An acoustic lens is analogous to an optical lens in that sound rays (instead of light rays) are refracted by lenses made of plastic (instead of glass) or other materials whose index of refraction differs from that of water (Figure 1). Lenses do not require beamforming hardware or software. They have the desirable feature of retaining full beam resolution in all remaining beams if one or more become inoperative, whereas the loss of a single element in a phased array destroys to some extent all remaining beams. This is an example of the type of robustness desired in autonomous systems that must operate for long periods without the possibility of repair.

![Diagram of an acoustic lens sonar](image)

Figure 1. Block diagram of a simple acoustic lens sonar
An example of a diver hand-held sonar based on acoustic lens technology is shown in Figure 2. It’s design characteristics were chosen to provide enough resolution to detect limpet mines on ship hulls.

![Figure 2](image)

**Figure 2**  LIMIS-Limpet Mine Imaging Sonar (Courtesy E. Belcher)

This sonar operates at 2 Mhz, has 64 beams, each with beamwidth of 0.35° horizontal by 13.0° vertical, and a total field of view of 19.2°. It has adjustable range increments of 15, 7.5, 3.8 and 1.9m with downrange resolution of 24, 12, 6 and 3 mm respectively. It weighs 7.7 kg in air, 0 kg in water, and consumes 25 watts.

The remarkable feature of APL’s lens-based sonars is the near-video quality of the images they produce, and their rapid refresh rates of up to 12 frames/sec. The video-like images open they way for the application of a wide variety of automatic target and feature recognition algorithms and methods that have been developed for processing optical images. The rapid refresh produces images that follow movement in real-time.

![Figure 3](image)

**Figure 3.** LIMIS images. (a) limpet mine; (b) diver’s hands; (c) cooling water inlet. (Courtesy E. Belcher)
Another example of an imaging sonar is MIRIS (Mine Relocation and Identification Sonar), shown in Figure 4. It produces NTSC video images at a refresh rate of between 5 and 11 frames/sec.

Figure 4. MIRIS (Courtesy E. Belcher)

MIRIS has similar specifications to LIMIS, but in addition is designed for AUV applications (Figure 5). Examples of MIRIS images are shown in Figure 6.

Figure 5. MIRIS mounted in an AUV (Courtesy E. Belcher)
A final example of a lens based imaging sonar combines a lower frequency, longer range sonar for wide area imaging with a higher frequency, shorter range, but higher resolution sonar for detailed inspection. The 1 MHz portion has 48, 0.6° beams, and a range of 40m. The identification portion operates at 1.8 MHz and has 96 beams with 0.3° resolution. Total field of view is 29°, the frame rate is between 4 and 12 frames/sec, and the video output is either Ethernet or NTSC. The sonar is shown in Figure 7, and an image of a swimmer in Figure 8.

Figure 7. Dual frequency imaging sonar. The compound acoustic lens is shown in the cutaway view on the left. (Courtesy E. Belcher)
Oceanographic Sensors

APL has developed a number of oceanographic sensors for use on autonomous systems. Miniature shear probes—air foils—are built into the microstructure profiler in Figure 9, and miniature version of the commercially available SeaBird conductivity, temperature and depth sensor has been integrated into several AUV’s such as the Autonomous Micro conductivity Vehicle (AMTV) shown in Figure 10. This AUV is used to collect heat flux data in Arctic leads, and is deployed under the ice.
A third example of an autonomous system with oceanographic sensors is APL’s Deep Langrangian Float (DLF). The DLF accurately follow water motions through a combination of a density which matches that of seawater and a high drag. The density is matched to that of the ambient water by actively changing the float's volume and will stay
matched, despite changes in pressure and temperature, though a combination of active control and a hull compressibility which is close to that of seawater. High drag is achieved through a large circular cloth drogue attached to the float. These autonomous floats, which can be submerged to 2000 m, carry temperature and pressure sensors, as well as satellite data transmitters.

**Buoyancy Propelled Platform and Sensors**

APL is developing a new type of autonomous system, a vehicle-like device that uses ambient water currents and changes in buoyancy for propulsion (Figure 12.) Buoyancy

![Figure 12. Schematic diagram of buoyancy driven autonomous system. (Courtesy R. Light.)](image)

is controlled by pumping oil from an internal reservoir to an external bladder. Pumping oil into the bladder increases displacement, thereby increasing buoyancy causing the system to rise; pumping from the bladder to the internal reservoir decreases buoyancy and the device sinks. Vehicle attitude, pitch and roll, is controlled by shifting an internal mass, the battery pack. The vehicle is made to steer from one location to another—or remain in the same place—by estimating prevailing current speed and direction based on successive position measurements, and then self-adjusting its trim to glide in the desired direction while descending or ascending. The present position sensor is GPS, which requires the vehicle to come to the surface to expose an antenna. The development of a small, low power inertial navigation system, for example, would allow the vehicle to stay submerged which would greatly lower its power requirements and increase its life. (The present design is rated for 500 depth cycles to 2000 m, and 10,000 km range.)

For communications, the vehicle anticipated the deployment of a worldwide cellular telephone system such as Iridium, that has failed to materialize. It currently has a cellular telephone link useful near shore, and could be equipped with an ARGOS link for open ocean use.

This autonomous system combines the best features of freely drifting and propelled devices. The former generally require less power, but their position cannot be controlled, while the latter can be maneuvered, but their power demand is high. The buoyancy driven
system uses very little power and its position can be controlled. It can be programmed to follow a specific course and schedule, or it can be directed to remain in one place, either on the bottom, or continuously taking vertical profiles.

Figure 13. Buoyancy driven autonomous system. (Courtesy R. Light)

In the photograph in Figure 13, the GPS antenna is shown beneath the hull, but it is normally attached at the rear. The external bladder is on the left. The pressure hull is isopycnal, i.e., it mimics the compressibility of seawater to conserve power by greatly reducing the need for continuous buoyancy adjustments while ascending or descending. A non-isopycnal hull, for example one stiffer than seawater, requires continuous addition of ballast to keep it sinking, which must then be pumped out to ascend. A small change in buoyancy in an isopycnal hull will keep it either ascending or descending without further adjustment.

The vehicle can be instructed to transit to a given location, to remain in one spot, or to combine transits and loiters. Figure 14 gives examples of each. It shows the tracks of three buoyancy driven vehicles deployed in Monterey Bay, California over 12.5 days. The vehicles were launched at various locations near shore and were instructed to transit between the waypoints shown in blue. About 0.5 days before recovery they were instructed to head for a target location of 36° 47’N, 122° 01’W. Red symbols are the location of a moored surface buoy.
Figure 14. Tracks of three buoyancy driven vehicles for a 12.5 day period.
(Courtesy of Professor C. Eriksen, Univ. Washington)

Figure credit and further information:

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