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Robotics Trends

The business guide for professionals who use, manage, or create robots and intelligent systems

Run Silent, Run Deep, Run Solo

Autonomous underwater vehicles can go where humans fear to dive, but communications remains a challenge.

By John Edwards

High-flying drones, such as General Atomic's Predator, create headlines in places like Iraq and Afghanistan. But cruising stealthily beneath the waves is an equally impressive fleet of autonomous underwater vehicles (AUVs). These vessels are helping organizations, including the U.S. Navy, major oil companies, and various scientific research bodies retrieve vital information, deactivate mines, support repair and maintenance operations, and handle an array of other vital tasks more efficiently, and in many instances more safely, than would be possible if manned vessels or divers were used.

"Any unmanned application has tremendous benefits," says Dr. Rand LeBouvier, a retired Navy captain who now works in the government military sector at Bluefin Robotics Corp., an AUV manufacturer located in Quincy, Mass. "In addition to the traditional dull, dirty, [and] dangerous applications, as well as saving manpower, money, and time, unmanned underwater systems give you access to places you would never be able to go with a manned system." LeBouvier also notes that sensor-loaded AUVs are bringing to fruition a centuries-old dream of generations of sailors and marine researchers: "a transparent ocean."

Sea Trials

The AUV concept goes back as far as 1957, when University of Washington scientists developed an autonomous craft that was designed to serve as an underwater research vehicle. By the 1970s, AUV projects were under way at the Massachusetts Institute of Technology (MIT) and several other research organizations. Yet computing and other limitations severely restricted the usefulness of early AUVs. Therefore, most complex underwater tasks, ranging from terrain mapping to exploring the wreck of the *Titanic*, were left to manned submersibles, specially equipped surface ships, or remotely operated underwater vehicles (ROVs), which were physically and electrically connected via a tether to a shipboard control station.

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Preparing to launch the University of Washington's Arctic Glider, designed to gather environmental data beneath the sea ice. (Photo courtesy University of Washington.)

Today, thanks to the impressive technology advancements made over the past several decades, AUVs are both more capable and more widely used. The basic model is a craft that looks and functions much like a torpedo, *sans* the warhead. Models come equipped with unique sensors, advanced control systems, and other enhancements. A recent advancement on the traditional AUV design is the so-called "underwater glider," a power-thrifty craft equipped with wings that uses changes in buoyancy to transform vertical up-and-down motion into horizontal propulsion.

"The real strengths of this [the glider] platform are the ability to access difficult, remote locations and to maintain a cost-effective, persistent presence over periods ranging from months to years," says Dr. Craig Lee, principal oceanographer at the University of Washington's Applied Physics Laboratory, located in Seattle. "The small size and relative ease of handling also allows for very diverse mission profiles," he adds. Lee heads a team that develops and refines gliders, such as the Seaglider.

While most gliders are highly autonomous, with an internal computer serving as the vessel's "captain," updated navigational and other operational instructions can be sent to the craft whenever necessary. "They can be piloted from anywhere in the world that allows an Internet connection from devices as small and simple as a smartphone," Lee says. "Fancy control centers aren't necessary."

But gliders also have a downside. "The liabilities are that they are very, very slow [a typical cruising speed of 0.5 knots] and, due to energy constraints and their physical configuration, somewhat more limited in payload handling than the larger classes of propeller-driven AUVs," Lee says.

Sporadic Chatter

As autonomous technology advances and costs drop, AUVs are increasingly replacing ROVs and other traditional deep-sea reconnaissance, exploration, and military technologies. Yet serious challenges remain, with maintaining reliable communications proving to be perhaps the biggest and most intractable problem.

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"Communication undersea is extremely difficult," LeBouvier observes. Seawater is a highly effective RF shield. To communicate via RF, AUVs must surface whenever they need to send or receive signals via satellite or radio. Acoustic communications are limited in range and bandwidth. "An unmanned aircraft is pretty much always in touch with some human operators," notes Justin Manley, vice president of government and public affairs for the Marine Technology Society, an educational and advocacy organization headquartered in Washington, D.C. "In the ocean environment, we cannot get that same real-time connection at very high data rates; it just has to do with the physics of air versus sea water."

Space and power restrictions also compromise radio transceiver and antenna effectiveness. "We have a data pipeline that's only 9,600 baud, so it's a very, very small straw we have to extract data," says Dr. James Bellingham, chief technologist at the Monterey Bay Aquarium Research Institute in Moss Landing, Calif. "What's more, a vehicle is not doing anything useful while it's sending the data back; it's just bobbing around on the surface," says Bellingham, who has worked on AUV projects for more than 20 years.

Slow and infrequent communication opportunities force AUV designers to create vessels that are highly self-reliant. "The way the systems are designed, they are supposed to be able to take care of themselves if you can't communicate with them," Bellingham says. To push as much data as possible through very sparse and thin pipelines, many researchers turn to Twitter-level communication techniques. "You work very hard to find ways to compress data and to only send the data back to shore that you really need to see to make decisions or to understand what's going on," Bellingham says. "You have to be autonomous if you want to be successful," LeBouvier says. "Everything really needs to be either preprogrammed, or the vehicle has to be smart enough to react to the situation."

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The Unmanned Navy

The Navy has recognized the value of AUVs for many years, says Dr. Frank Herr, director of the ocean battlespace sensing department at the U.S. Navy's Office of Naval Research (ONR) in Arlington, Va. "We started working on these vehicles, on the technology, about 15 or 16 years ago," he says.

Herr notes that the early systems, while full of potential, weren't very capable. "They could maintain themselves above the bottom [of the sea] and we could put a sensor on them of one type or another," he says. "Initially, it was a sensor to sense the salinity and the temperature of the ocean, then eventually it became a small camera."

"The military has its own reasons for being places where it might be difficult or dangerous to maintain a surface vessel or very expensive to put a submarine," Bellingham says. "If you can maintain a sustained robotic presence, I think that's a game-changer."

"Military applications tend to focus on things like search and salvage, survey operations, oceanography, environmental protection, and monitoring," LeBouvier says. He notes that the Navy puts AUVs to work in a variety of specialized niches: "research, port and harbor security, ship hull and infrastructure inspection, mine countermeasures, unexploded ordnance discovery, rapid environmental assessment, and anti-submarine warfare, as well as intelligence, surveillance, and reconnaissance." And the number of applications keeps growing. "Every time we use these vehicles, we find new uses for them," LeBouvier says.

Many AUV applications, such as surveying, provide direct military value.

Many AUV applications, such as surveying, provide direct military value. "When you're planning a landing, you need to decide where you want to go many months before you actually put the troops on shore," Bellingham observes. "As a consequence, you're really very vulnerable to the quality of your information about the local environment."

The Navy also views mine clearance as a high-value application. A fleet of small and nimble AUVs can clear a minefield quickly, unobtrusively, and with no risk to humans. "The best way to be able to clear things in stride is to have a lot of assets that are capable of finding and prosecuting the mines," Bellingham says.

"We're making pretty good headway in the area of mine countermeasures and helping to find mines," Herr observes. "We take our requirement from the Navy to get the man out of the minefield."

On the other hand, using AUVs for direct attacks on enemy military assets remains an elusive goal. "As you go to the really hard missions like anti-submarine warfare ... the stakes are higher, the risks are greater, Herr says. "The autonomy system has to be near foolproof, because the kinds of things that the vehicle might encounter are much more difficult for it to deal with, and those [autonomous] things we haven't been able to do yet."

Using AUVs for direct attacks on enemy military assets remains an elusive goal.

While AUVs haven't yet morphed into underwater attack machines, there's little doubt about their future with the Navy. "Having dealt with unmanned air vehicles during my Navy service, I can tell you that it's very comparable to where unmanned air vehicles were 10 to 15 years ago in their stage of cultural acceptance," LeBouvier says. "Militarily, I think we're at the point now where they're beginning to be widely accepted."

Research and Exploration

Academic and other scientific researchers are also turning to AUVs, using the vessels for a wide range of activities related to the marine environment and the world at large. "We now see that they have reached a stage of reliability and applicability [and] that they will become the tools of the future for anybody doing undersea work," LeBouvier says. "The research community certainly has embraced them, although there is not currently a large customer base because of their budget limitations."

Academic and other scientific researchers are also turning to AUVs, using the vessels for a wide range of activities related to the marine environment and the world at large.

At the University of Washington, Lee is spearheading an effort to use AUVs to measure the impact of global warming in polar regions. "Sustained measurements under sea ice are difficult to collect, as are measurements near the ice-ocean interface," he says. To help solve this problem, Lee's team has developed a Seaglider system capable of conducting multi-month missions under full ice cover. "We've successfully used this system in the ice-covered Davis Strait [at the southern end of Baffin Bay, between Canada and Greenland] ... to characterize the annual cycle of fresh water, heat, and volume fluxes," he says. "The missions have typically lasted about five months."

A growing number of businesses, meanwhile, are using AUVs for applications ranging from natural resource exploration to marine repairs and maintenance. "I think the killer app, commercially, is the oil and gas industry, to be able to survey areas that are likely locations for undersea resources," LeBouvier says.

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"There are a variety of things the oil and gas community looks for in the ocean," Manley says. "What they tend to use the AUVs for is to understand the makeup of the sea floor, because when you install an oil rig out in the ocean you need to know what the bottom looks like."

Analyzing submerged structures before and during maintenance and repair work is yet another AUV mainstay. In a high-profile event, the technology was recently used to inspect the hull of the *USS Constitution*—"Old Ironsides." "We were really thrilled with that," LeBouvier says. "We took advantage of the Navy's newest capability to survey the Navy's oldest [ship]."

AUVs are also now playing an investigatory role for commercial users and other adopters. Recently, the Woods Hole Oceanographic Institution on Cape Cod, Mass., worked with Air France to find the black boxes trapped inside the passenger jet that crashed in the South Atlantic in June 2009. The work required the AUVs to operate at depths greater than 2.5 miles in a rugged undersea environment. "Rougher than almost any place that you can think of in the Rocky Mountains," Herr observes. "They had these vehicles looking and mapping, taking pictures, and making bathymetry maps ... searching the area to try and find these black boxes." The search was ultimately successful, and the boxes were brought back to the surface intact.

AUV Swarms

AUV experts see both challenges and opportunities in the years ahead. Manley says AUV developers have long focused on a basic set of design criteria. "I built my first marine robot in 1993, and we always used to talk about power, communications, and navigation," Manley says. "We always wanted our robots to go longer, go farther, [and] we always wanted them to have a better understanding of where they were in the world. We always wanted to hear more from them." While these same goals remain, the focus is on pushing an already existing envelope outward. "In the nearly 20 years since 1993, we've made progress on all of those fronts," Manley observes.

A current goal for the Navy is developing AUVs with autonomous functions capable of providing a basic level of self-defense.

For the Navy, a current goal is developing AUVs with autonomous functions capable of providing a basic level of self-defense. This is a top priority, since today's AUVs are little more than expensive sitting ducks once they're detected by enemy forces. Herr says that building AUVs with autonomous defense capabilities is going to take a lot of work. "We are nowhere near the capability to have a vehicle respond in an autonomous manner against a person trying to find it and come after it," he says. "We would be happy to have the level of autonomy that you find in simple creatures, like ants."

While an AUV capable of firing back at the enemy isn't likely to arrive anytime soon, a fundamental level of self-protection could be achieved by teaching AUVs to cluster together in coordinated groups. A large task force of mini-AUVs, for example, would allow a reconnaissance mission to be successfully conducted even in the face of significant losses. AUV swarms could also be used to deliver enhanced intelligence by providing three-dimensional visual and data observations of situations ranging from oil spills to minefield topographies. "There has been significant work in enhanced autonomous behaviors, teaching swarms of AUVs to work toward a predefined goal without human intervention," Lee says.

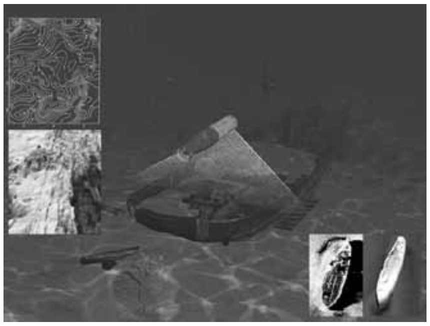
Manley says that building greater autonomy into AUVs will require both time and patience. "Every year we see more sophisticated autonomous behaviors; processing power is always getting more available," he says. Herr agrees: "All of these vehicles are undergoing long-term development, much in the way you watch a young child develop. Everything done ends up being useful for something later that's a little more complex, a little more assured."

Progress in autonomous coordination also includes the promise of conducting operations in conjunction with unmanned aerial vehicles. "Sometimes, there are features in the ocean, or features in the environment, that the aircraft will see—things that it would be useful for the AUV to know as well," Bellingham says. "The aircraft could be used as a part of your sensing network."

But there's a major roadblock standing in the way of seamless AUV-aircraft coordination—communication (again). "When the underwater vehicle is under the surface, it can't communicate with a plane easily," Bellingham says. "It has to use what we call acoustic communications—sound waves that are modulated to provide communication capability." The drawback to acoustical communications lies in the need to use a "gateway"—a buoy or other floating platform positioned on the water's surface. "It has a radio on it, which then can transfer the acoustic communication signal to an RF signal, which then could go up to the plane, and the other way back," Herr says.

As some researchers search for solutions to AUVs' communications problems, others are developing improved sensor technologies with an eye toward providing increased detection sensitivity, better precision, and more types of sampling. Developments in this area will allow AUVs to deliver higher-quality data to shipboard and shore computers and, ultimately, human decision makers. "I think the ability of these vehicles to provide more abstract information is going to be really transformational," Bellingham says. But creating better sensors, like providing more autonomy, is going to be an evolutionary process. "It won't be one event; there will be a series of these things over the next decade," Bellingham predicts.

While science is driving AUV development, money is the force behind the technology's acceptance. "In the long run, it's about economics," Manley says. "Whether it's the economics of military resources or an oil and gas profit motive, ships are expensive," he notes. AUVs, wherever they are deployed, are almost always less expensive and more productive than equivalent manpower-intensive systems. "The technology is really enabling users to get more done and focus their most expensive infrastructure on their most important problems," Manley says. RT



The battleship preparation autonomous underwater vehicle (BPAUV) is part of the mine countermeasures mission module launched from the *USS Freedom* in 2007. (Photo courtesy AUVfest 2008: Partnership Runs Deep, Navy/NOAA, OceanExplorer.noaa.gov.)

Creating better sensors, like providing more autonomy, is going to be an evolutionary process.