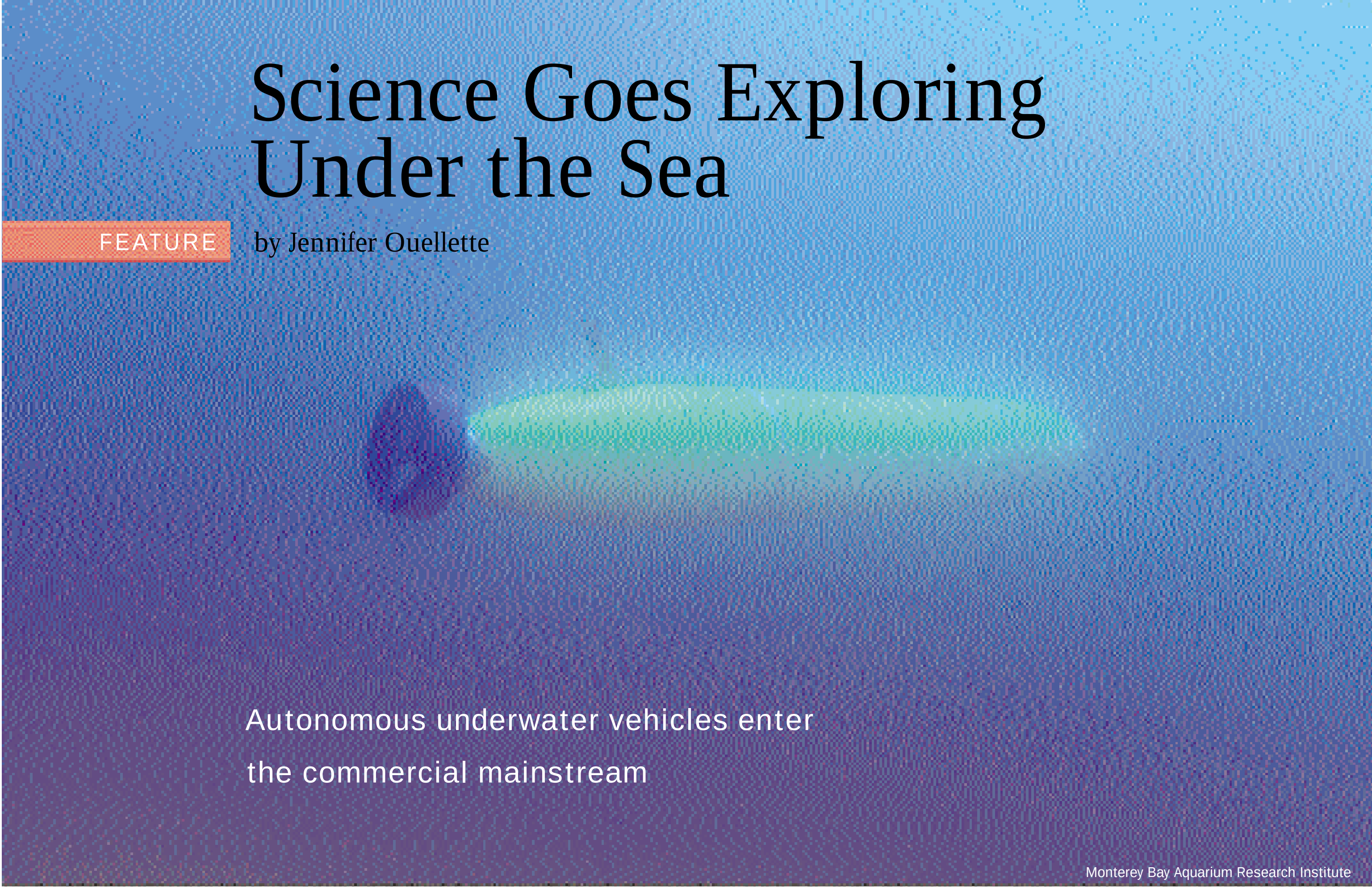
Science Goes Exploring Under the Sea

FEATURE

by Jennifer Ouellette

Autonomous underwater vehicles enter the commercial mainstream



Monterey Bay Aquarium Research Institute

Figure 1. Autonomous underwater vehicle photographed under Monterey Bay, California.

Exploring uncharted ocean depths in specially designed pressurized vessels has long fueled the human imagination, a desire epitomized by Jules Verne's classic novel *Twenty Thousand Leagues Under the Sea*. The dream became a reality in the 20th century with the emergence of manned submarines, bathyspheres, and other underwater vehicles capable of taking humans to unprecedented ocean depths. Today, automation underlies the newest thrust in deep-sea exploration using unmanned underwater vessels (UUVs). The latest incarnations to emerge from oceanographic laboratories are autonomous underwater vehicles (AUVs) (Figure 1).

Once largely confined to military R&D efforts and the rare (and expensive) oceanographic outing, AUVs have become vital resources in such diverse areas as surveying the Arctic Ocean ice pack, seeking the elusive giant squid, tracking fish populations, monitoring environmental conditions, searching for underwater mines, and aiding in high-profile discoveries of the wrecks of historic airplanes and ships. More importantly, in the past two years, AUVs have entered the commercial realm, particularly to assist the oil and gas industries in surveying deep-water regions for potential new energy sources.

AUVs owe their roots to the first manned underwater vessels developed for deep-sea exploration. In 1930, the American explorer Charles William Beebe co-designed the first bathysphere, a spherical steel vessel that could be lowered into the water from a ship, suspended by a cable. Beebe reached a depth of 3,028 feet in 1934, but his submersible had one crucial design flaw: if the cable broke, the occupants would be unable to resurface. In the 1950s, Swiss physicist Auguste Piccard designed the first bathyscaphe, which used lead shot as ballast to submerge and a pressure sphere filled with gasoline to make it buoyant for surfacing in an emergency. It reached a depth of 13,125 feet. In 1960, his son, Jacques Piccard, reached a record depth of about 35,800 feet off the island of Guam with *Trieste*, the second bathyscaphe built by Piccard senior.

Occupied submersibles for deep-sea exploration reached a technological pinnacle in 1974 with the deployment of the American-built *Alvin*, equipped with underwater lights, cameras, a television system, and a mechanical manipulator to collect bottom samples. Its success led to the development of unmanned vehicles that have revolutionized deep-sea exploration. In 1986, Robert Ballard used *Alvin* and a small remotely operated vehicle (ROV) called *JASON Junior* to explore the wreck of the *H.M.S. Titanic*, discovered the previous year.

The development of unmanned vessels was a natural progression from manned operations, says Frank van Mierlo, president of Bluefin Robotics (Cambridge, MA), a company that specializes in building AUVs for military and commercial uses. In the early 1990s, AUVs were rarely used. But by 1997, active underwater mines littered the Persian Gulf floor in the wake of the Gulf War.

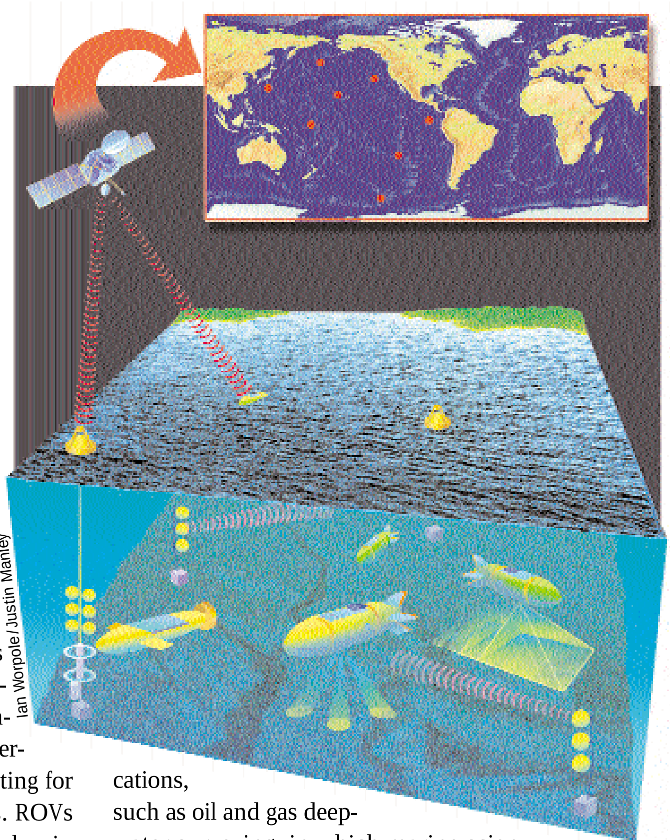

Ian Worpole/Justin Manley

Figure 3. In this autonomous ocean-sampling network concept, underwater vehicles scan the bottom of the ocean, dock on an anchored vertical line between rings via a nose hook, and transmit data via underwater receptors and satellites to central control.

Destroying these mines required that a human place explosives on them and then swim away to detonate them at a distance—a risky venture even under ideal circumstances. “If anything cries out for automation, it’s mine detonation,” says van Mierlo. The U.S. Office of Naval Research agreed, and funding flowed into AUV research (Figure 2).

The rapid development of the Internet required better telecommunications, and the laying of thousands of miles of high-speed, underwater fiber-optic cables to meet that need led to further advances in AUV technology.

Going commercial

The modern UUV industry includes ROVs, which are attached to the platform, or mother ship, by a long cable, and AUVs. ROV operators use video screens and joysticks to direct the submersibles from surface vessels. AUVs operate without such a cord; they are guided primarily by an inertial reference system, with the mother ship correcting for the inevitable drift off course via acoustic signals. ROVs have dominated the commercial sector. The number in use has grown from almost none 25 years ago to more than 3,000 worldwide, according to a 1998 report on the industry by Douglas-Westwood Associates (Canterbury, England), a firm of oil- and marine-industry analysts.

The use of UUVs continues to grow rapidly. The total commercial subsea-industry market is expected to double from 1998 levels to nearly $12 billion in 2003, according

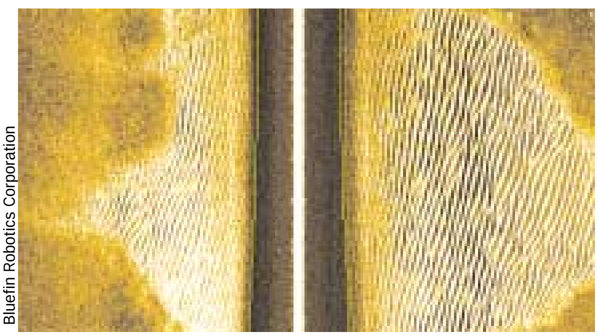
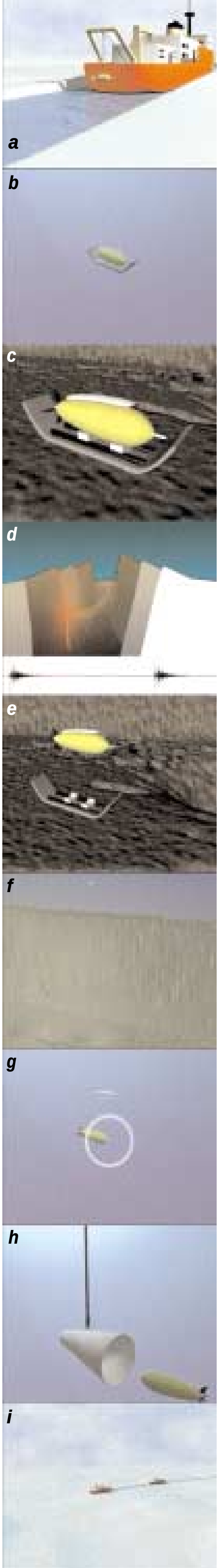

Bluefin Robotics Corporation

Figure 2. Images of sand ripples obtained with high-end commercial sonar equipment during U.S. Navy trials in the Gulf of Mexico.

to Douglas-Westwood. And as demand increases, so does the number of companies supplying UUVs and related surveying services. However, about 90% of the market share is served by a handful of companies worldwide that include Bluefin in the United States, Maridan A/S in Denmark, and Kongsberg Simrad in Norway.

Today, ROVs are losing ground to AUVs in certain applications, such as oil and gas deep-water surveying, in which marine scientists need to increase the distances between the robotic craft and its support vessel beyond that attainable by use of an umbilical cable. Jim Bellingham, who pioneered the AUV laboratory at the Massachusetts Institute of Technology (MIT) and is now director of engineering for the Monterey Bay Aquarium Research Institute (MBARI) in California, notes that AUVs did not perform as well in their infancy as manned vehicles, ROVs, or even the deep-towed systems then used by the oil and gas industries. “We had to find those niche markets that were not satisfied by any of the existing technologies, target them, and carry over their results to more mainstream markets as the technology matured,” he says.

The worldwide oil situation has caused exploratory efforts to shift to deep water. “Today, one out of every three barrels of oil is coming out of the ocean,” says van Mierlo. But for all their autonomy, AUVs require a large ship to support their deep-water exploration, and, hence, they still represent a significant capital investment. “The real bang for the buck that the commercial people get is in fewer survey hours,” explains Justin Manley, who heads MIT’s AUV laboratory. Deep-towed survey systems—which use connected 50-ft lengths of cable with a sensor “towfish” on the end—can spend hours simply turning around because of the long cable. AUVs, in contrast, can turn around in a few vehicle lengths, cutting survey time in half. And time, to industry, is money. Shell International has estimated that AUVs could save it more than $30 million over five years, mostly from an estimated 50% reduction in survey time, especially in deep water.

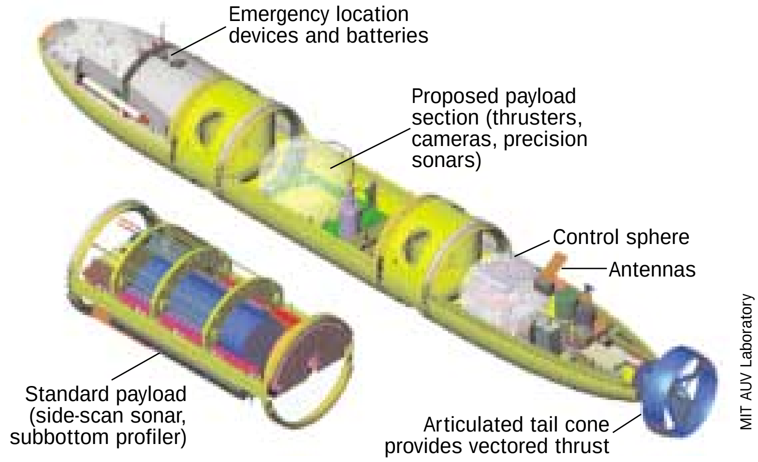


National Science Foundation/Woods Hole Oceanographic Institution/Bluefin Robotics

Figure 4. In the Apogee project, designed to explore under the permanent ice shelf, an underwater vehicle is towed behind an icebreaker (a), free-falls to the bottom (b), conducts experiments (c) on seismic and crystal structure for up to a year (d), is released (e), floats to recovery level (f), jettisons a flotation pack (g), homes into a dock on an acoustic signal (h), and is returned to base for data processing (i).

For all their commercial potential, UUVs will always receive recognition mainly for their use in oceanographic exploration, such as the search for Amelia Earhart's airplane, which used conventional ROVs and towfish. As AUVs become smaller, with corresponding improvements in navigation, sensing, and communications technologies, they are becoming more affordable to marine archaeologists.

Hands-on fieldwork is a key component in MIT's AUV program. This summer, Manley took his team on two expeditions. In June they worked just off Cinqua Terre, Italy, in support of the Generic Oceanographic Array Technology Sonar (GOATS) program, led by MIT professor Henrik Schmidt, which is developing advanced countermeasures against mine warfare. And in July, the team—together with Chrys Chryssostomidis, head of MIT's ocean engineering department, local archaeological experts, and MIT's new AUV, Caribou—headed south to Italy's Tuscan Archipelago to conduct sonar surveys, aided by a small ROV for visual inspections of promising targets, to uncover maritime artifacts of the pre-Roman Etruscans (Figure 5).



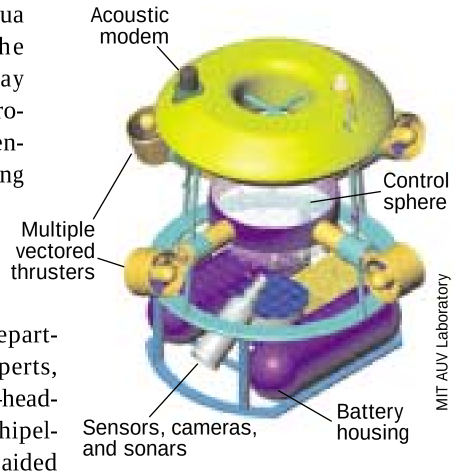


Figure 5. Caribou is an Odyssey-III-class autonomous underwater vehicle built by Bluefin Robotics and operated by the MIT AUV Lab that allows the use of conventional survey systems and an anticipated precision-survey module (above). The envisioned inspection-class autonomous underwater vehicle (left) will build on the basic components of the Odyssey vehicles but provide performance similar to a remotely operated vehicle.

MBARI has three ROV–AUV combinations that enable researchers to make dives about 330 days a year—more than the rest of the U.S. oceanographic research enterprise combined. The institute has sent its units to the largely unexplored eastern Arctic basin (Figures 4 and 6). Researchers have also recorded images of never-before-seen seafloor features and animal species at seamounts, hydrothermal vents, and midwater environments, mostly in the eastern Pacific. Several deep-sea animals collected by ROVs are now on public display at MBARI's sister institution, the Monterey Bay Aquarium.

Mimicking nature

Cutting-edge AUV research focuses heavily these days on biomimetics, the science of developing synthetic systems by using information obtained from biological systems. MIT has a growing menagerie of robotic vessels designed to mimic natural swimmers. Several years ago, researchers there designed RoboLobster to investigate the tracking of chemical plumes in the ocean. "Lobsters are very good at following a nonlinear gradient to get to their food; they can follow chemical signals very effectively," says Manley. RoboLobster "didn't look anything like a lobster, but it tried to sense the way a lobster senses." Such research can help track pollution, red tides, and other plumes in the ocean.

More recently, MIT's department of engineering has developed RoboTuna, a model that is towed through a tank for hydrodynamic experiments designed to learn more about the motions of swimming fish. Next came RoboPike, a free-swimming, 6-in. vessel that "moves and acts like a fish in the testbed," says Manley. He plans to incorporate the lessons learned from such experiments into a new design for one of his Odyssey AUVs, which will essentially replace the back of the unit with a robotic fish tail.

An extension of the biomimetics work envisions creating networked swarms of smaller AUVs, capable of communicating with one another to survey more ground in less time. "If you have a lot of little, relatively inexpensive AUVs, you can afford for a couple of them to break or disappear, but your network can still do its job," says Manley. He has just completed an initial design for a tiny AUV that is 2 in. long and 2 in. wide, and uses off-the-shelf electronic components. But he acknowledges that the AUV's inability to carry much battery power because of its small size will limit its performance.

Nekton Research, a spin-off from Duke University, has made the most progress in developing networked swarms of AUVs. With money from the Defense Advanced Research Projects Agency, Nekton has developed a swarm of 6-in. robotic vessels called Micro-Hunter. Dubbed "the tiniest submarines in the world" by their creators, the vessels are designed to mimic not an entire fish but an individual cell, taking robotic biomimetics to an unprecedented scale.

"Cells are very stupid, but they have to live in a three-dimensional world, and they employ very effective mechanisms to, say, locate an egg if it is a sperm or to seek out light or oxygen," says Chuck Pell, Nekton's vice president of science and technology. Micro-Hunter uses an algorithm to mimic cellular behavior, which was tested against a dynamical model and adjusted accordingly. The result was 6-in. submarines capable of traveling up to 30 nautical miles and operating for 20 h.

However, when the company tried to add sensors, they were bigger than the actual vessels. "Having the platform is one thing, but if you don't have sensors, you don't have a mission," says Pell. So while waiting for sensor miniaturization to catch up, Nekton is developing Ranger, a system consisting of 10 small vehicles each about 2.5 ft long—large enough to carry several sensors. The company has just completed all 10 vessels and will test them this fall in a real-world water environment to see if they can communicate with each other and function as a unit.

"This is absolutely new," says Pell about the Ranger project. "People have been talking about swarms of underwater unmanned vessels for years, and there have been lots of simulations and calculations to support the concept, but nobody has actually put a full swarm in the water." The project should result in some fascinating new physics, such as obtaining three-dimensional pictures of the dynamics of a water column—something scientists have modeled extensively but for which they have never obtained hard measurements.

MIT AUV Laboratory

Figure 6. A Dorado autonomous underwater vehicle on field trials in the Arctic Ocean in late 2001 for the Monterey Bay Aquarium Research Institute.

AUV researchers are also focused on improving the existing technology, particularly in the area of batteries. C&C Technologies (Lafayette, LA), a survey and mapping company, uses AUVs that rely on aluminum hydrogen peroxide fuel cells for power. Fuel-cell recharging is a time-intensive procedure, and the cells add considerable weight. "We would like to use a normal battery instead of a fuel cell," says Phil DeVall, technical program manager for C&C's AUV project. But even regular batteries have their drawbacks. In its older AUVs, for example, MIT used silver–zinc batteries, which limited performance to about 2 kW·h. They were also dangerous to recharge in a pressurized environment because their chemicals gave off poisonous fumes, which had to be completely removed. For its newer AUV units, Bluefin has developed battery packs similar to those used in laptop computers: a sealed unit that the user simply plugs in to recharge.

Improving the quality of data collected on survey missions is another objective. Already, synthetic aperture sonar (SAS) has provided an order-of-magnitude improvement in the image data gleaned from AUV surveys. MIT's Schmidt put the first SAS on an AUV in 1998. Bluefin has four separate SAS development projects under way, and van Mierlo expects to see "the first exciting data sets in this domain" within the next three years. MBARI's Bellingham foresees the eventual development of hybrid ROV–AUVs capable of traveling to wherever they are needed and then plugging a cable into a seafloor network to become an ROV for oil and gas exploration (Figure 3).

However, a large part of the next AUV development phase will focus not on the platforms but on increasingly sophisticated instrumentation and advanced tools, such as high-resolution sonar mapping systems. "The AUVs are just trucks that enable you to take much more sophisticated instrument packages down to the ocean floor," says Bellingham. "They are the mobile component of a larger observation system, and as they are increasingly integrated with those systems, they are going to be used in a lot more exciting ways."