Tracking an Undersea Scent

A robot mimics the lobster's keen sense of smell

By RICHARD LIPKIN

In the shallow Atlantic waters off the New England coast, a crusty lobster crawls among the craggy rocks on the ocean floor. Slow and deliberate, the jointed arthropod negotiates each obstacle with great care, navigating surreptitiously with its five pairs of legs and its tail in the murky sea. Through clouded waters, its eyes, like black beads perched on tiny stalks, can barely see a freshly fallen dead fish several yards ahead.

The lobster pauses, flexing its claws. Then it sweeps the water with two tiny wands jutting from its head. Those wands, or antennules, enable the lobster to smell the water for scents of life — or death. Each antennule sports thousands of hairlike odor sensors, which give the lobster an extraordinarily sensitive sense of smell by which to navigate. Sweeping its antennules through the water, it can detect and track odor plumes, almost like a bloodhound following a scent.

"Lobsters have an unusually keen sense of smell," says Jelle Atema, a biologist at Boston University's (BU) Marine Program in Woods Hole, Mass. "They can detect very low concentrations of chemicals in their environment and then move toward the source. We think they're doing something like what we do with our ears when we locate the source of a sound. They're extremely adept at following small scent signals in a turbulent background."

What if scientists could make use of a lobster's underwater smelling abilities, tapping its chemical sensitivities? Perhaps they could explore a dimension of the physical world and animal kingdom virtually lost to ordinary human experience. Indeed, if engineers could build self-directed sensors to follow underwater chemical signals, then perhaps they could track nutrient flows in the ocean or locate unseen sources of water pollution.

Nearly everyone knows what it's like to be drawn toward the scent of freshly baked cake or repulsed by the smoke from a smoldering cigar. But most people are hard put to imagine, say, successfully sniffing their way blindfolded to the grocery store. For reasons unclear, humans have evolved into visual creatures, their olfactory systems remaining relatively underdeveloped.

Atema

Homarus americanus *has two pairs of odor-sensing antennules.*

Not so, however, for most of the animal kingdom, where creatures live and die by the nose. Odors and chemical signals reveal powerful and subtle details about every animal's environment, relaying information about where to find food, safety, and a mate.

The thought of wandering blindly into an odor cloud, waving two wands atop our heads to sample a scent, and then forming a mental picture of where its source might lie strikes most people as bizarre or comical. Yet lobsters do it, moths do it, and bees do it. Welcome to the world of olfaction.

A fascination with the nature of odor plumes, especially those underwater — about which relatively little is known — led Atema one day into a provocative daydream.

"I had this idea that I wanted to show the world what an underwater odor looks like. I wanted to visualize it," he says. "But to do that, we have to experience the underwater odor world through the kind of sensory equipment used by an animal that thrives in that world, one that has evolved sensors well adapted to the physical characteristics of underwater odor signals. So we chose a lobster."

Atema realized he needed to know more about the lobster's sensing equipment, the sensitivity of its receptor cells, the kinds of chemicals it responds to, and the nature of underwater odor signals themselves. "How does an odor plume move?" he asks. "What are its fluid dynamics? How do odor molecules disperse? And how could an animal use that information to locate an odor's source?"

Daydreaming some more, Atema thought it would be useful to have a robot that behaved like a lobster, so he could test various hypotheses.

Thus was born Robolobster.

Working with Atema, Thomas R. Consi and Clifford A. Goudey, engineers in the Sea Grant Underwater Vehicles Laboratory at the Massachusetts Institute of Technology, designed and built an autonomous underwater vehicle with the capacity to sense chemical signals and to navigate by them, imitating a lobster's behavior. Atema and Consi recently took their invention from MIT to BU's facility in Woods Hole to track salt plumes in a test tank.

"Right now, the vehicle has a bilateral pair of conductivity sensors, placed where antennules would be, that measure salt concentrations in the water," Consi says. "We put the vehicle in a freshwater tank and inject little jets of salt water into the freshwater flow. This creates salt plumes, which we've colored with dye so we can track them. The vehicle is designed to sense and follow the plume, moving upstream toward higher concentrations of salt. This behavior imitates what lobsters do."

Rolling slowly on two wheels and powered by 16 AA batteries, the foot-long, 5-pound Robolobster is learning to "feel" its way upstream as it senses the water's conductivity from the plume's concentration of salt.

"We're working on a system of feedback controls so that it can modulate motion over rough terrain and stay on track," Consi says. "At the moment, we need better control. But the vehicle was designed to move as a lobster does, with the same speed and precision. It can turn on a dime."

The team plans to switch shortly from

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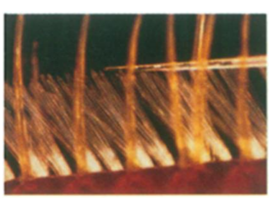
conductivity sensors to chemical sensors, which more closely match what a lobster uses to sense the ocean environment. "That's when the really interesting research will start, because the vehicle will be able to receive signals the way a lobster does," Consi says. "Then we'll add computer programs to interpret the chemical signals, so that it can steer itself toward the source of a chemical emission."

As part of the experiments, Jennifer A. Basil, a research associate at BU's marine program in Woods Hole, measures the chemical signals that reach a lobster's antennules and then observes how the animal uses those signals to track a plume. Meanwhile, Frank W. Grasso, also a research associate at Woods Hole, is programming a neural network computer to mimic parts of a lobster's nervous system. Grasso wants the computer to direct the robot lobster to behave as a live lobster would in the face of the same chemical stimuli. When all systems are go, Consi will hook up the neural network to the vehicle and let it track an odor. The researchers will then compare Robolobster's behavior with that of a real lobster.

"One of the things we're interested in doing is to test several hypotheses about how a lobster senses its environment," Atema says. "For instance, one possibility is that it senses with two antennules, averages the signal, then goes in that direction. That's one paradigm. Another possibility is that it compares information between the left and right antennule every second and makes moment-by-moment decisions about where to move."

Right now, the researchers remain uncertain which scenario is correct,

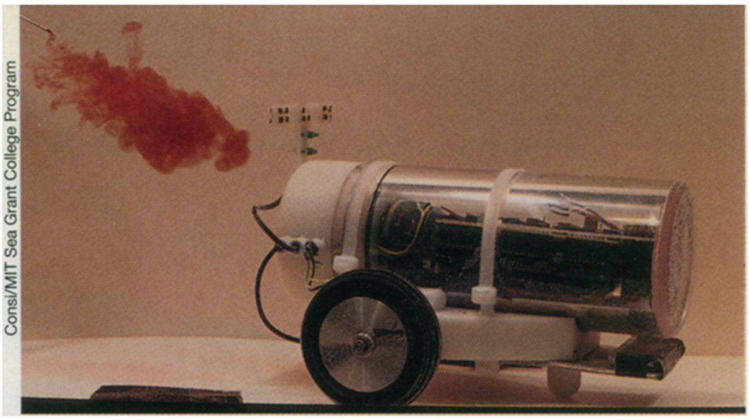


Odor-sensing hairs, the olfactory sensilla, coat the lobster's antennules. They measure 1 millimeter in length and 30 micrometers in diameter.

although they lean toward the moment-by-moment pulse paradigm simply because it's faster. "For the animal to use an averaging technique, it would take about 10 minutes to get a clear sense of where something is," Atema says. "But by then the food would be long gone. An animal can't wait that long to move."

The nature of the underwater signal itself has proved fascinating and elusive, Consi says. Learning how to detect underwater odors presents some unforeseen engineering challenges.

"Underwater odor signals are very tricky to work with from an engineering point of view, since they're so patchy and chaotic," says Consi. "They're completely different from sound and light signals, which are what we, as human beings, are used to using to find things."



Consi/MIT Sea Grant College Program

Robolobster tracks a dye-tinted underwater plume, using changes in salt concentration as a guide.

Take the case of a person trying to locate the source of an unidentified sound. "We've evolved in such a way that, when we hear a sound getting louder, we move toward it," Consi observes.

But suppose we lived by completely different rules. What if someone walked into a room and heard irregular beeps whose volume rose and fell regardless of that person's distance from the source? Tell that person to find the sound's source and the task becomes extremely difficult.

"That's essentially the nature of an underwater chemical scent," Consi explains. "You move along and sense nothing. Then suddenly you smell a patch of odor. Then it drops to nothing again. Then you smell something, then nothing. Eventually you may find some structure in that signal, meaning that you notice certain patterns, or regions of high or low concentration where the scent is stronger or weaker."

"These subtleties help you figure out if you're on the right track toward the source. These are also clues that tell you if the odor is fresh or stale — that is, whether it's just been emitted or whether it's been floating around for a while," Consi adds. "Odor is a very complex signal, especially since water tends to flow turbulently, forming eddies and trails. The chemical signal follows the flow and breaks up into patches. It also moves at [the same speed as the water], a rate comparable to an animal's motion. This is very different from light and sound. Odors come at you slowly and erratically over a period of time."

Ring T. Cardé, an entomologist at the University of Massachusetts-Amherst, points out that the kind of information Robolobster is revealing about the nature of odor plumes has great relevance to other organisms in the animal kingdom.

Moths, for example, follow airborne odor plumes in ways quite similar to those of lobsters in water. "We've recently discovered that odor plumes have a fine-scale structure that gives moths and similar organisms some clues about how to orient themselves," says Cardé. "Those clues help them to straighten out their paths toward the source."

"What's interesting about the robot lobster is that it's revealing details about the spatial and temporal structure of odor plumes," Cardé adds. "Those details suggest that there may be ways of locating odor sources that are more efficient than what we're currently aware of. We're now seeing that a relatively primitive organism, such as a lobster, can use a very sophisticated method to locate an odor source, involving techniques we haven't thought of before."

Thomas A. Christensen, a neurobiologist at University of Arizona in Tucson, concurs. "Before we can understand how the brain processes chemical information, we need to know what are the important features of a chemical stimulus," he says. "Traditionally, people have thought in terms of the quality and quantity of the stimulus. More recently, researchers have come to realize that a chemical stimulus contains much more information than that."

"The underwater robotic experiments will help us understand more deeply information [about location] that a chemical source brings to a lobster in the ocean or a moth flying in an airborne plume," Christensen says, "as well as how that information is used."

At least as important, observes marine biologist Paul A. Moore of Bowling Green (Ohio) State University, is Robolobster's potential to reveal what scientists don't know about sensing chemicals underwater.

"We know so little about this phenomenon in general that the robot should give us some new insights into how animals operate in the marine environment," Moore says. "We have only a vague sense of what many animals are really responding to and what drives their behavior."

There lurks in Robolobster the possibility, some day, of a practical application. Both Atema and Consi envision a small, autonomous, swimming sensor that could monitor the marine environment. Scientists could carry the device to a stream or reservoir, for example, where they believed some underground contaminants were leaching into the drinking supply. They could release the mechanical bloodhound and let it sniff out the problem.

"You could just toss it overboard from a boat and it would find its way to invisible point sources of pollution," says Consi. "It would be like a homing device." □