INFUSION
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Bio-inspired Computing for Robots

- **Living creatures may provide algorithms to enable active sensing/control systems in robots**
- **Active sensing could enable planetary rovers to "feel" their way in unknown environments**

The surface of Jupiter's moon Europa consists of fractured ice over a liquid sea that may contain microbes similar to those on Earth. To explore such extreme environments, NASA needs robots that autonomously survive, navigate, and gather scientific data. They will be too far away for guidance from Earth. They must sense their environment and control their own movements to avoid obstacles or investigate a science opportunity.

To meet this challenge, CICT's Information Technology Strategic Research (ITSR) Project is funding neurobiologists at NASA's Jet Propulsion Laboratory (JPL) and selected universities to search for biologically inspired algorithms that enable robust active sensing and control for exploratory robots. Sources for these algorithms are living creatures.

Rat whiskers

"Rats may provide a good model for designing robust robotic active sensing and exploratory systems," says Mitra Hartmann, a former JPL neurobiologist now teaching at Northwestern University. "Rats explore unknown objects with a series of movements that increasingly refine the information they need, just as humans do."

Hartmann is studying the way rats use their whiskers (*vibrissae*) to explore objects and discriminate texture. Rats have about 60 whiskers, 30 on each side—shorter in front and longer in back. Whereas the longer whiskers move back and forth on the face in a rhythmic behavior known as "whisking," the shorter whiskers cannot move independently of the head. To recognize different features of an object, the rat apparently must integrate information from its small and large whiskers. It rhythmically moves its head to place its shorter whiskers on the object's surface, and synchronizes this placement with the whisking motion of its larger whiskers.

Rats can discriminate the texture of an object down to 90 microns. An algorithm for this ability could help robots segment images of objects into distinct regions for better resolution.

In pursuit of this algorithm, JPL scientists collaborated with researchers at MIT to model a rat whisker as a thin conical, cantilever beam, and then determined the vibration frequency that yields optimal resonance. This led to a formula for determining how a particular whisker will interact with different textures, as the rat moves it at different speeds. "By changing the velocity of its whisker movement," says Hartmann, "the rat could produce the optimal interaction with a given texture."

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Rat (left) and "electric" fish (above) may yield algorithms to enhance robot sensing and control.

Technology Spotlight

Technology
Biologically inspired algorithms for robotic exploratory systems

Function
Provide robots with active sensing and control capabilities

Relevant Conceptual Missions
- Mars Science Laboratory (2009-concept) and subsequent Mars landers
- Europa Hydrobot (concept)
- Other missions to explore the surface and/or oceans of planets and their moons

Applications
- Active-sensing rovers
- Robot fish and aerial vehicles with smart skin for estimating fluid flow, airflow, and turbulence

Features
- Active sensing
- Adaptive sensory filtering
- Autonomous, predictive motor control

Benefits
- Detect position and spatial features of objects even in murky, obscure environments
- Characterize textures
- Stabilize input data while in motion
- Control motion

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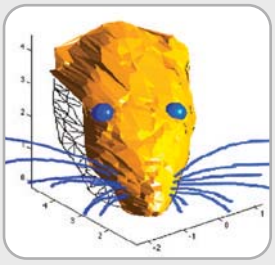
After electrifying the water with an organ in its tail, the electric fish (modeled, left) senses an object (gold sphere) as a dipolar distortion of the electric field (shown in colors around the object).



Models of the fish (above) and rat (far left) could help scientists design "smart" sensor arrays for robots such as the proposed Europa Hydrobot (left, artist's concept).

Is it the same rock when seen from the other side?

"Rats use their whiskers to encode 3-D spatial information on a 2-D sheet of sensors—those found at the base of each whisker, in the cheek," says Hartmann. "An algorithm for this transformation of 3-D spatial information to 2-D spatio-temporal information would be useful in designing robots with synthetic whiskers."

To understand 2-D spatio-temporal sensing, imagine your hand traveling in time over your bedside lamp in the dark to determine its 3-D shape and find the switch. The rat must not only convert 3-D to 2-D, but also maintain what neurobiologists call "perceptual invariance"—recognizing the same object from various points of view. To help it do this, the rat apparently moves its whiskers out of phase with each other in direct relation to the speed of its head movement.

To maintain perceptual invariance, vertebrates apparently calculate and filter out the effect of their own movement. "The cerebellum is thought to be the engine of agility in every vertebrate's brain," says Hartmann. "We think it may specifically be performing state estimation to help control movement during active sensing."

To discover a fast, self-organizing algorithm for dynamic state estimation, the ITSR team is collaborating with Mike Paulin, at the University of Otago, and Larry Hoffman, at UCLA, who study vestibular systems. They placed a frog on a rotating table and plotted the neural "spikes" from the vestibular nerve that connects directly to the cerebellum. By applying a neural network model to the spikes, they accurately reconstructed the frog's head movement. This neural-network model may lead to an algorithm that enables robots to maneuver autonomously in thick, turbulent atmospheres while maintaining perceptual invariance.

Electric Fish

"Weakly electric" fish may provide more clues to finding an algorithm for maintaining perceptual invariance. By generating electrical signals in the water and measuring how those signals are disturbed by nearby objects, the fish can determine object size, shape, and position. This bioelectrical imaging system is called "electrolocation."

Christopher Assad, JPL neurobiologist and principal investigator for this ITSR Project research, is investigating how weakly electric fish from Africa and South America combine adaptive sensory filtering with active motor control during electrolocation. An adaptive sensory filter in the brain, coupled with an enlarged cerebellum, enables the fish to suppress input from its own movement in the water to better sense and locate external objects and other fish.

"Using active electrolocation, the fish can detect and identify objects without seeing them at all," says Assad. "It can even discriminate between different objects based on their electrical resistance and capacitance." Such an electrosensory system could enable NASA robots to explore murky liquid environments. "However," Assad continues, "what we're really looking for are better algorithms for distributed sensor array 'smart skin' systems."

Smart skin

Assad is also studying the fish's lateral line system (LLS) to identify algorithms for estimating fluid flow. The LLS "smart skin" contains hair-cell receptors, called neuromasts, that transmit to the brain critical information such as pressure gradients and surface shear flow. The fish uses its LLS for dynamic feedback control to maintain agile, stable and efficient swimming, and as an "aquatic ear" to detect external disturbances. Assad's university collaborators are currently modeling the sensory image, neuromast array, and central processing of the LLS. They eventually plan to model the entire fish system, including the neuromuscular network that controls swimming. Once defined, these algorithms will help NASA engineers design actively sensing, swimming robots to explore unknown environments such as Europa's subterranean ocean.

—Larry Laufenberg

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