Development of a Miniature, Low-Cost Robot for a Laboratory-Scale Underwater Collectives Testbed

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Abstract

Several species of fish exhibit large-scale schooling, where a many relatively simple organisms seem to behave as a single, self-organizing meta-organism. By contrast, most marine robotics activity so far has focused on using individual robots or at most small-scale collectives, typically consisting of no more than 20 units. Drawing inspiration from fish schools, large-scale collective robotic systems have the potential to open up new applications in the marine domain. These include environmental monitoring in sites of high ecological sensitivity such as coral reefs, gathering data about ocean acidification and climate change, inspections of wreck sites, and search-and-rescue operations over large areas. These systems would be scalable and robust, and would have a low risk of operation in complex environments due to the (relatively) low cost of the individual units.

Presently, however, very little is known about how to design and operate large-scale marine robotic collectives. One reason is that there is a high barrier to entry for this area of research. Even the most accessible platforms consist of robots whose individual price usually exceeds $1000, and whose size is such that the operation of collectives of even moderate magnitudes (e.g., 20 units) requires either large laboratory infrastructure, or in-field operation, both of which are highly expensive. The latter additionally is a less controlled environment, which makes data collection difficult and systematic development a harder problem.

The long-term goal of this project is to provide a complete, laboratory-scale testbed that significantly lowers the barrier to entry for this area of research, which would serve as a stepping-stone for real world implementations. This testbed will consist of a robot that has all the required sensing, communication, and locomotion capabilities to operate in a collective, but is low-cost and small enough that large-scale collectives can be achieved with only modest robotic and infrastructure cost.

The current research phase focuses on the physical design and locomotion system of such a robot, although some sensing capabilities have been added to validate the locomotion capabilities. The robot is 100 mm in the longest dimension and has a component cost of $ 100. The robot is highly maneuverable in 3D, being capable of forward and backward swimming, in-place rotation, and vertical ascent and descent.

The locomotion system consists of four magnet-in-coil (MIC) propulsors. This system sacrifices high-speed locomotion—which is not a priority in small test environments—in exchange for high 3D maneuverability at a low-cost ($1 per propulsor). This is because the MICs allow for a reduction in mechanical complexity as compared to traditional rotary shaft actuators by eliminating the need for a shaft exit through the watertight hull.

The swimming performance of the robot was validated through a series of trials following prescribed 3D paths at consistent and variable depths. Using a visual tracking system and data from on-board sensors, the robot was found to have a forward swimming speed of 0.6 BL/s (BL = body lengths) and a minimum turning radius of 0.5 BL. Using pressure sensor feedback, the actuated dorsal fin for diving (0.17 BL/s), and the positive buoyancy for ascent (0.26 BL/s), the depth of the robot could be controlled within target bands of approximately 1/2 of a body height (30 mm). Successful homing towards an LED rod was demonstrated from a range of starting positions and orientations using feedback from a photodiode mounted on the robot's front, demonstrating the potential for neighbor following, beacon tracking, and local fencing based on optical cues.

In the next steps of the project, the minimal sensing and communication hardware necessary to enable self-organizing behaviors will be explored, allowing for the coordination of several robots into a collective. Applying the algorithmic knowledge gained from the laboratory testbed will reduce the difficulties associated with real-world deployment of sophisticated collectives in high-risk marine environments, accelerating the progress of critical explorations of our marine environments.

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