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Hold the Spot: Evolution of Generalized Station Keeping for an Aquatic Robot

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Abstract

In this paper, we present a strategy to evolve neurocontrollers in aquatic robots capable of generalized station keeping, that is, maintaining a position in the presence of various water flows. Evolved behaviors exhibit a variety of complex fin/flipper movements that enable the robot to react and move against changing flows. Moreover, results indicate that some sensor modalities are beneficial when the robot is placed in novel environments, though little used during the evolutionary process.

Introduction. Increasingly, aquatic robotic systems are being deployed to assist humans in challenging tasks (Tan et al., 2006). Although many systems rely on control from a human, autonomy allows robots to act independently in hostile or remote environments. Station keeping, also known as station holding, involves maintaining a position against external fluid flows, and is exhibited by many biological fish (Arnold, 1974). It is also of interest for aquatic robot sensor platforms that need to remain stationary while gathering data. In such cases, the autonomous control system needs to be able to respond to changing flows.

We previously examined the evolution of station keeping behaviors for individuals facing a single flow during their evaluation and evolutionary periods (Moore et al., 2013). Although successful in this task, individuals failed to maintain station when facing novel flows (i.e., flows that were not encountered during the evolutionary process). In this work, we focus on the evolution of *generalized* station keeping behaviors capable of handling multiple distinct flows. We investigate approaches to this problem through two separate experimental setups that utilize multiple flows during the evolutionary fitness evaluation. Evolved individuals are then evaluated in both previously seen and novel flows.

Results indicate that evolved individuals are able to hold station against flows encountered within and outside of the evolutionary process, exhibiting some generalized behaviors. Furthermore, additional sensor modalities increase an individual's ability to generalize to new flow conditions, even though they do not appear to be beneficial in environments encountered during evolution. This work provides an approach to developing a generalized control strategy for dynamic environmental conditions, and provides insight into the impact of sensory information for evolved neural controllers.

Methods. The simulated robot in this study emulates the form and function of a physical device, seen in Figure 1a. Pectoral flippers are capable of continuous 360° range of motion, while the caudal fin is limited to a ± 90° symmetric range of motion. Sensory information includes inertial data (i.e., linear and angular acceleration at the robot's center of mass) and the previous update's motor commands. Information about the actual state of the motors is not used as most small continuous rotation servo motors do not provide this data. In two of the treatments, we include additional sensory information including the robot's pitch, roll, and yaw, along with the *xyz* flow information.

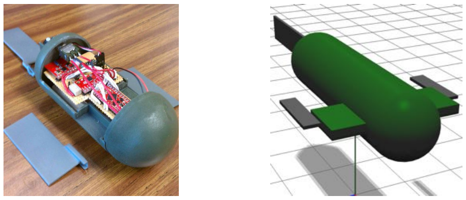
(a) (b)

Figure 1: (a) Physical robot with 3D printed components. (b) Simulated agent derived from physical robot.

The Open Dynamics Engine (Smith, 2013), a 3D rigid-body physics library, is employed as the simulation environment. We extended ODE with a fluid dynamics model, discussed in (Moore et al., 2013), based on hydrodynamic drag adapted from (Wang et al., 2011) and (Sims, 1994). Neural controllers are evolved with the NEAT algorithm (Stanley and Miikkulainen, 2002). Individuals are evaluated based on their distance from the station point at 250ms intervals over a 60s evaluation period. The closer an individual is to the station point, the higher its fitness for that interval.

Experiments and Results. Videos of selected results are available at the following links:

Video 1: `http://youtu.be/MO-ueGP3eG0`
Video 2: `http://youtu.be/HXUwr6WEdLU`
Video 3: `http://youtu.be/HhMTkf0FUfY`
Video 4: `http://youtu.be/05oSypwWhyo`
Video 5: `http://youtu.be/kL-KRjXL0kQ`

Treatments 1 and 2 are conducted in an environment with a gradually changing side-to-side flow. At the start of an individual's evaluation, the flow originates from the front of the robot. The direction of the flow moves to one side, reaching its maximum angular offset of 63.4° at 15s. Halfway through the simulation (30s), the flow returns to the center, then moves to the opposite side with respect to the robot's initial orientation. A second environmental setup in Treatments 3 and 4 focus on holding station against a flow, then moving and stopping again at another flow. Five flows are possible: $-45°$, $-22.5°$, $0°$, $22.5°$, and $45°$, of which two are randomly selected for an individual evaluation. Agents must be able to detect changes in the flow, or lack thereof. A total of nine possible flow combinations are possible during evolution.

Evolutionary results indicate that Treatment 1 (lacking additional sensors) slightly outperforms Treatment 2 during evolution. In Treatments 3 and 4, a reduced sensory capacity also leads to higher fitnesses in environments seen during the evolutionary process. However, in all treatments, evolved agents are able to maintain station effectively in the evolutionary environments.

The focus of this study, the evolution of generalized behavior, assesses individuals based on how they perform in novel flow conditions. Contrary to the evolutionary results, individuals evolved with additional sensory input achieve the best station keeping in novel environments. We hypothesize that the additional sensory information may be extra noise for an evolved ANN in a familiar environment (i.e. one seen during the evolutionary process), but is important information when encountering environments not previously seen.

We test evolved individuals in an environment containing both a change in direction and magnitude of the flow. Here, the flow begins at twice the magnitude encountered during evolution and is strong enough that individuals are physically unable to generate enough thrust to hold station. The flow is reduced after the first 20s of a 60s simulation, allowing agents to swim back towards the station point. Two individuals from Treatment 1 and 4 are shown in Video 5 with an individual from Treatment 4 depicted in Figure 2. Here, sensors are again beneficial in novel environments as the best performing individuals come from Treatment 4, which has the additional sensory information. Behaviors exhibited in this test indicate that these individuals are not evolved to swim against the flows at a steady rate, but can return to station when displaced by stronger, previously unseen flows.

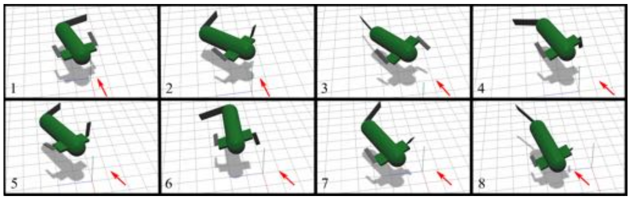

Figure 2: An evolved individual from Treatment 4 exhibits station keeping behavior by swimming back towards the origin after initially being pushed away from the station by a strong flow.

Discussion Unlike previous work (Moore et al., 2013), these treatments were effective in eliciting generalized station keeping. Surprisingly, the additional sensory information does not appear to increase the ability of individuals to hold station in environments encountered during the evolutionary process. However, when placed in previously unseen environments, individuals with extra sensory information are more effective than those relying on a limited set of sensors. This suggests that additional sensory information can be beneficial in unforeseen conditions. Future work includes determining why the additional information is beneficial, and pursuing the evolution of generalized controllers for different tasks.

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