Miniature Biomimetic Robot Fish Research
SAG Final Report Fall 2018

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The Project

The miniature, biomimetic robot fish project aims to develop a small, low-cost robot for use as a swarm agent. Swarms of tiny robots have an increasing area of potential applications, including sensing and collecting data over large areas with a distributed network, monitoring fragile ecosystems like coral reefs, and synthetic biology test beds for swarm algorithm research and education. Mimicking the swimming motion of a real fish increases the hydrodynamic performance of a robot, since fish are incredible swimmers, and would allow for longer missions or the mounting of higher power sensors. Last semester, we developed a prototype robot with three, individually controllable joints which succeeded in propelling itself forwards. We were accepted to the student poster competition at the IEEE/MTS OCEANS 2018 conference in Charleston, where we presented our work this October.

This semester, we have been working to create an untethered version of the robot by bringing all of the electronics inside of the robot itself. One of the greatest obstacles to forward propulsion we encountered last semester was the pull of the tethers connecting the robot to the electronics, restricting its motion. Additionally, having on-board power brings us one step closer to an autonomous platform that will enable research in biomimetics and swarming.

The Team

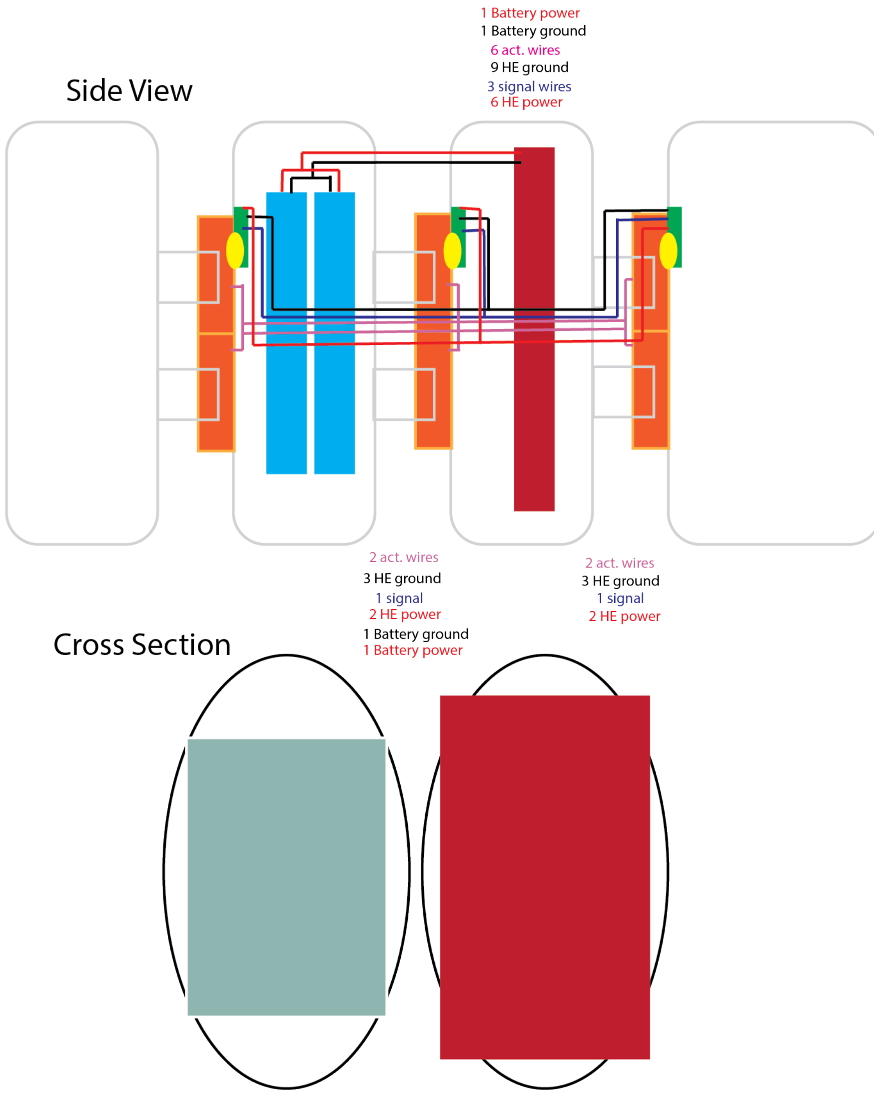
We were lucky to recruit three phenomenal first year students to join our team, including Alex Hindelang, Chris Lee, and Colin Snow. This project would not have succeeded without their dedicated work and willingness to explore the unknown!

Results

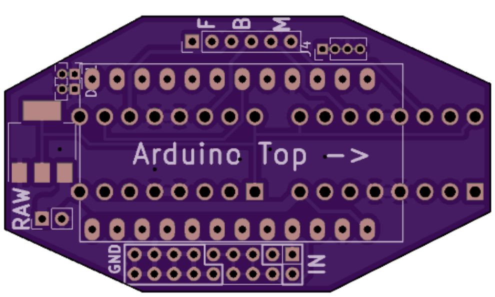
To create an untethered robot, we tackled three general problems: miniaturization of the electronics, waterproofing, and installing sensors to get positional feedback. Our approach was to work on each of these tasks in isolation, concurrently developing solutions that we integrated towards the end of the semester.

Miniaturization

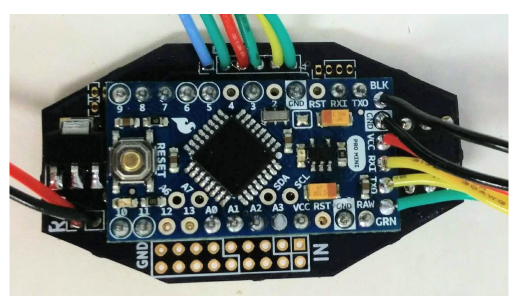
To fit all of the electronics components necessary to control the robot and arrange them in such a way as to make wiring less of a nightmare, the team designed a PCB. The board routed all external connections to H-bridges, angle sensors, and batteries to easily accessible pins and allowed for the setup of master power and ground rails. Additionally, the H-bridge and Arduino in the same segment were able to mesh together without interference, effectively using the limited space. While we want to keep the size of the fish as small as possible, we scaled the original robot's size to accommodate the electronics; this was also an opportunity to improve the parameterization of the CAD files, allowing us to scale the horizontal and vertical dimensions independently.



The wiring diagram was projected onto the available space in the three segments of the robot. The amount of wires and connections was very high, contributing to our decision to create a PCB. It was also challenging to choose a battery with the proper specifications and a geometry that could fit in a small oval-shaped segment.



A PCB was designed to break out the important connections, such as master ground and power rails.



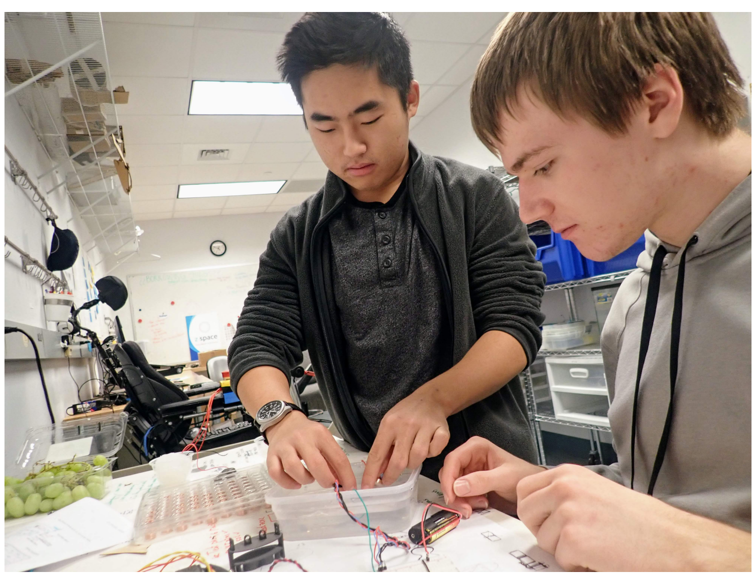
The assembled PCB, Arduino, and H-bridge on the back efficiently utilize the limited space inside of the robot.

Waterproofing

We experimented with a couple of waterproofing techniques: Corrosion X spray and silicone casting. The Corrosion X coats the components in a thin layer of water resistant material and has proven to be extremely effective and easy to apply. While we ran some tests with silicone, especially to coat batteries, casting did not lend itself to quick prototyping. Future iterations of the fish will almost certainly have electronics cast in silicone for robustness.

In the beginning, we also wanted to develop a way to test how waterproof our solutions were. Most water sensing solutions involve either optical or humidity sensors and are designed for sealed capsules rather than silicone-encased electronics. We attempted to use a soil sensor which detected water inside of silicone only if it was in direct contact with it; it was not good enough for our application. In the end, we built a few sacrificial op-amp circuits and tested waterproofness by dunking the electronics and seeing how long they stayed operational. While it was not the most scientific method, it was sufficient to assert that both Corrosion X and silicone were valid choices for waterproofing.

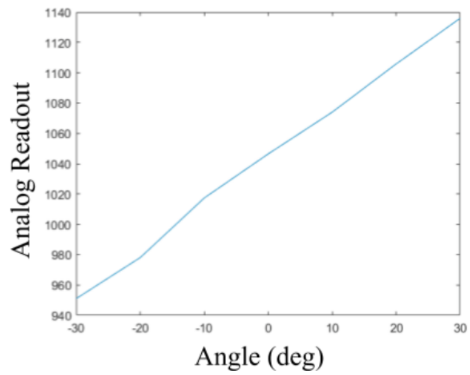
Corrosion X requires a 24-hour drip-drying period. The entire electronics system in the robot was waterproofed in this way.



Waterproofing tests were conducted directly in the water, dunking components, and monitoring their performance.

Positional Feedback

The actuators we are using are low-cost, waterproof, and very small, all qualities that we have determined to be important when making a miniature underwater robot meant for swarming. One drawback of these actuators is their lack of positional feedback - we only know when the actuator has turned all the way to the right or left. For complex, biomimetic motions, we need to be able to control the intermediate positions with a relatively high amount of accuracy. In the previous semester, we approximated the sinusoidal swimming behavior seen in fish by pulsing a pulse-width modulated signal. This semester, we were able to track the resulting motion of the joint by installing angular sensors which measure the Hall effect created by the magnetic fields of the magnet and coils of the actuator. The sensor's readings are proportional to the angle of the actuator, giving us the capability to close the loop on our control schema.



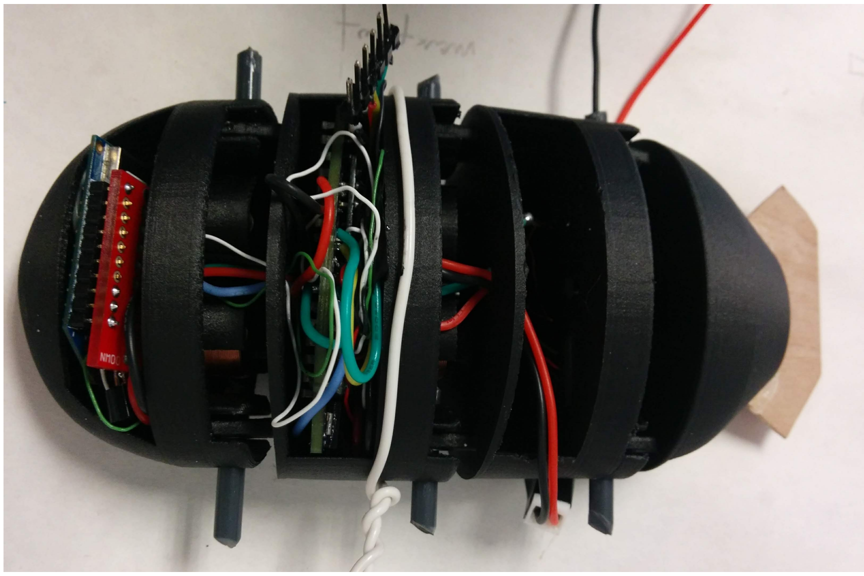
The analog sensor readings were directly proportional to the angular displacement of the actuator, giving us the ability to implement closed-loop control in the future.

Integration

The final integrated prototype for this semester included all of the previous year's components (Arduino and H-Bridges) as well as angular sensors, an XBee radio module to transmit the positional data to a laptop, and batteries. The fish was not internally balanced to be neutrally buoyant; instead, we attached a large piece of foam to the top to prevent the fish from sinking while not impeding its motion. One unresolved challenge has been the robot's power draw; it is pulling almost 2A of current which our batteries cannot support. The main culprit is most probably the XBee radio, which we plan to replace with an on-board SD card.

Next Steps

The untethered prototype that we have developed this semester will enable us to begin work on the biomimetic gait of the robot. Using the angle sensors, we can implement closed-loop control with positional feedback to experiment with straight-line swimming and turning. To reach our final goal of an autonomous data-collecting robot, we will continue to improve the untethered model, adding buoyancy control with a promising ethanol and silicone based engine another robot lab team has created.



The final prototype contains an XBee radio, angle sensors, and on-board batteries in addition to the H-bridges and Arduino from the previous iteration. The robot body was scaled to accommodate all of the components. A piece of foam is attached to the robot to prevent it from sinking while not impeding its motion.