A Biomimetic Actuation Method for a Miniature, Low-Cost Multi-jointed Robotic Fish

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MORA
Miniature Oscillating Robot Agent

MORA (Miniature Oscillating Robot Agent) is a robotic fish designed to demonstrate a low-cost, small-scale biomimetic actuation method for efficient swimming. Our goal is to enable the development of underwater robot swarms that can access tight, fragile environments and gather data from the perspective and scale of real fish.

Miniature, Low-cost Actuator

The magnet-in-coil (MIC) actuator consists of a magnet suspended inside of a coil which aligns with the coil's magnetic field as current is alternated across the coil (Fig. 1). The MIC was developed by Berlinger et al. for swam robotics applications that require a low-cost and relatively simple actuation method [1].

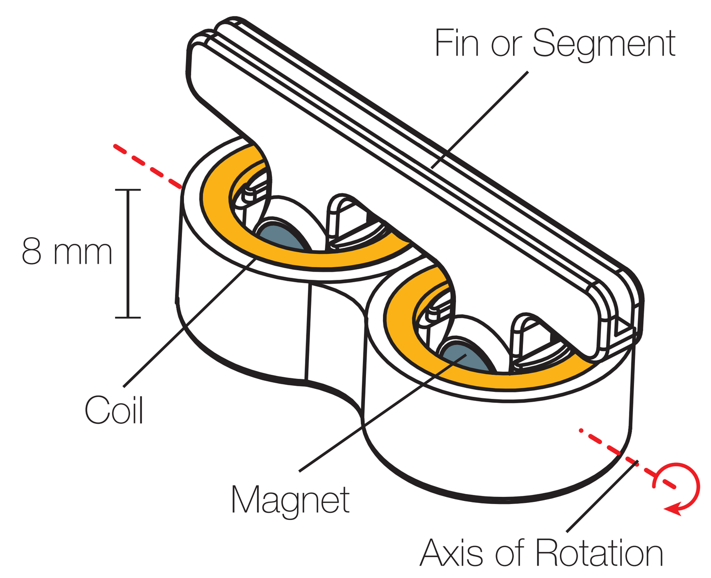

Figure 1: Magnet-in-Coil Actuator

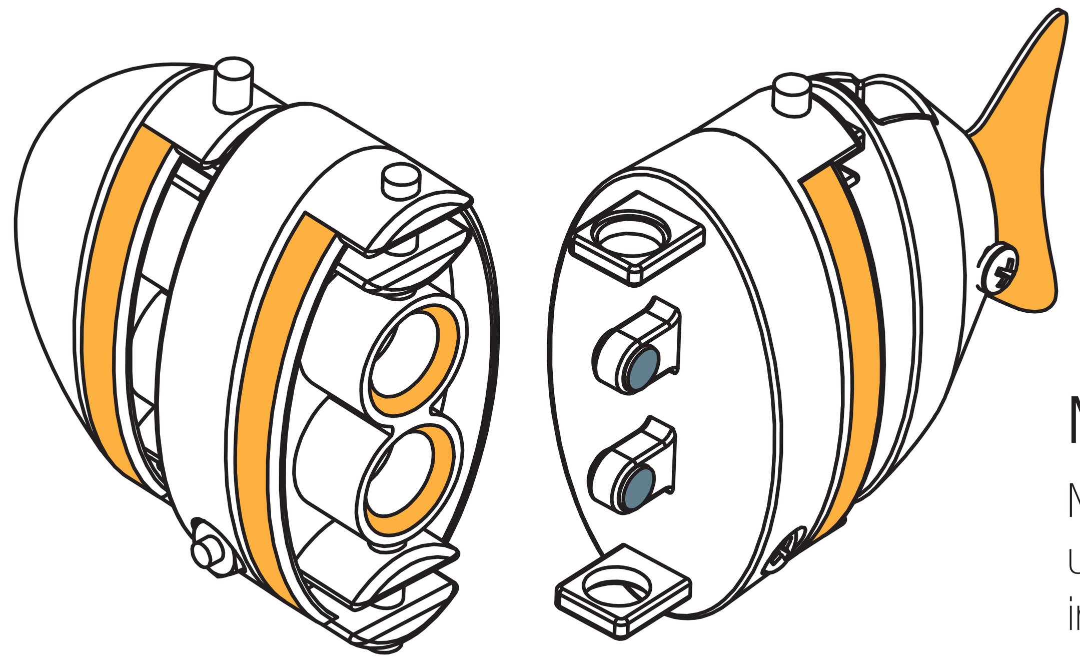

Figure 2: The actuator at each joint of the robot is constructed using two coils and two magnets. The coil leads are attached to signal wires, routed outside of the body, creating a tethered prototype robot fish.

Multi-jointed Arrangement

Multiple MIC actuators ($1/unit) can be used on a single robot without appreciably increasing its cost. MORA (Fig. 2 and 4) uses three MICs in a multi-jointed arrangement to explore bio-inspired swimming gaits for small robot agents. This configuration allows us to study multiple behaviors on the same robot to optimize its speed and efficiency.

[5]

Swarms Need Small Robots

Small, maneuverable robots are optimal candidates for exploring fragile, hard-to-access areas of particular interest to scientists. They could perform tasks such as pipe inspection in tight-fitting spaces or species monitoring from the inhabitants' scale and perspective in coral reefs. These robots could also be assembled into a distributed, dynamic sensing network, creating opportunities for collecting data over large areas and easily scaling search and sense missions.

Efficient, Biomimetic Swarm Agents

Imitating the swimming motion of real fish, who excel at underwater propulsion, can provide a robot with a hydrodynamic advantage and increase its efficiency [2]. Lowering power consumption and increasing speed enables longer missions and the use of higher-power sensors for more detailed data collection. Furthermore, underwater robots with biomimetic actuation have the unique potential to integrate into ecosystems with minimal disruptionto the natural inhabitants [3]. Swarms of biomimetic robots can also provide a synthetic biology testbed for swarm algorithm replication in biological systems.

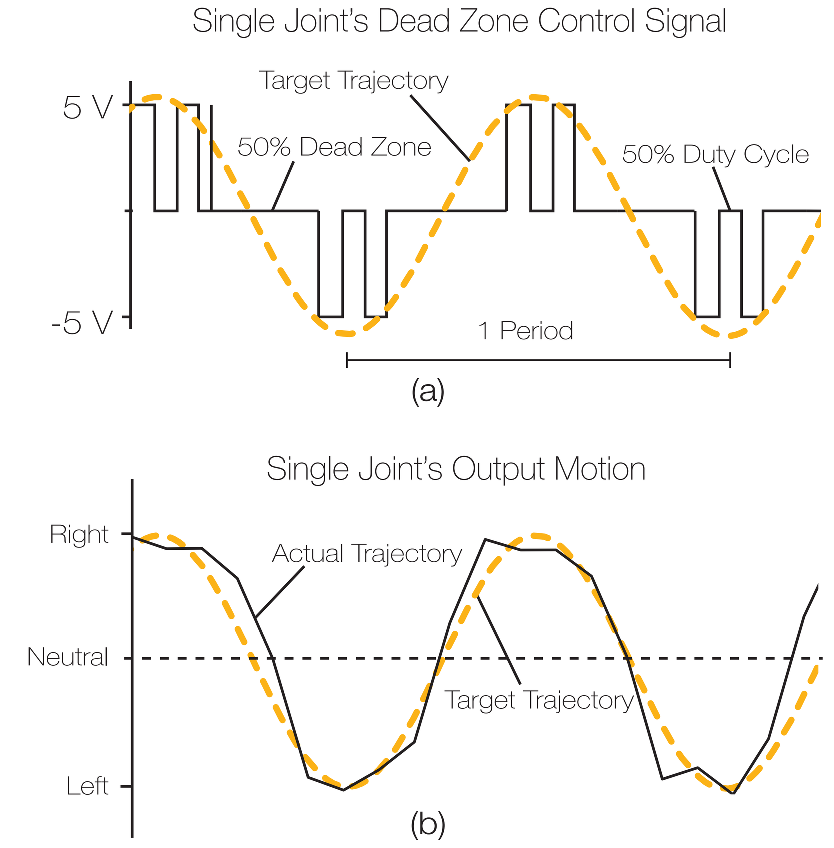

Figure 3: (a) The duty cycle and dead zone parameters are used to limit when the coil receives current. (b) This allows the approximation of a sinusoidal trajectory with the MIC.

Configuring Undulatory Motion

An ideal carangiform swimming motion can be approximated with discrete joints moving in sinusoidal trajectories at various amplitudes and relative phase offsets [4]. By strategically pulsing pulse-width modulated (PWM) signals, we can control each MIC's sine wave output individually, allowing for a highly configurable joint arrangement (Fig 3a). An overhead camera setup and image processing algorithm were used to verify the sinusoidal behavior of the actuator under different settings (Fig 3b).

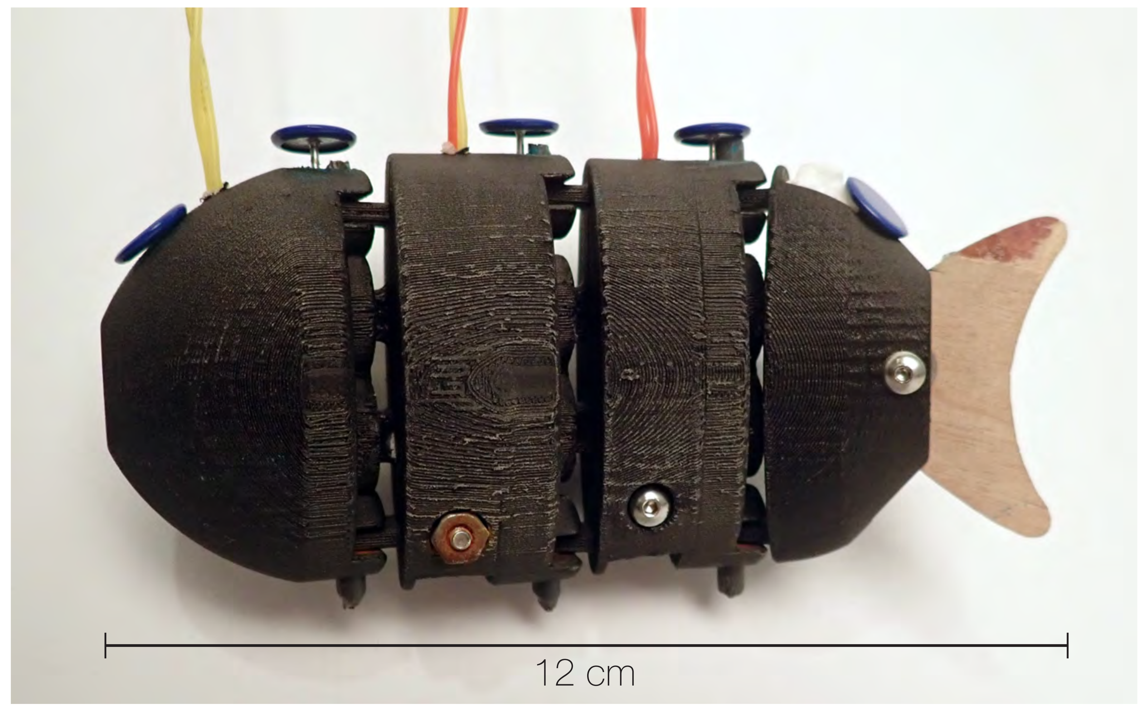

Figure 4: MORA is a tethered prototype, measuring 12cm along the longest dimension, and costs about $50. Its design encourages the use of low-cost components and minimizes the time and filament required to 3D print it.

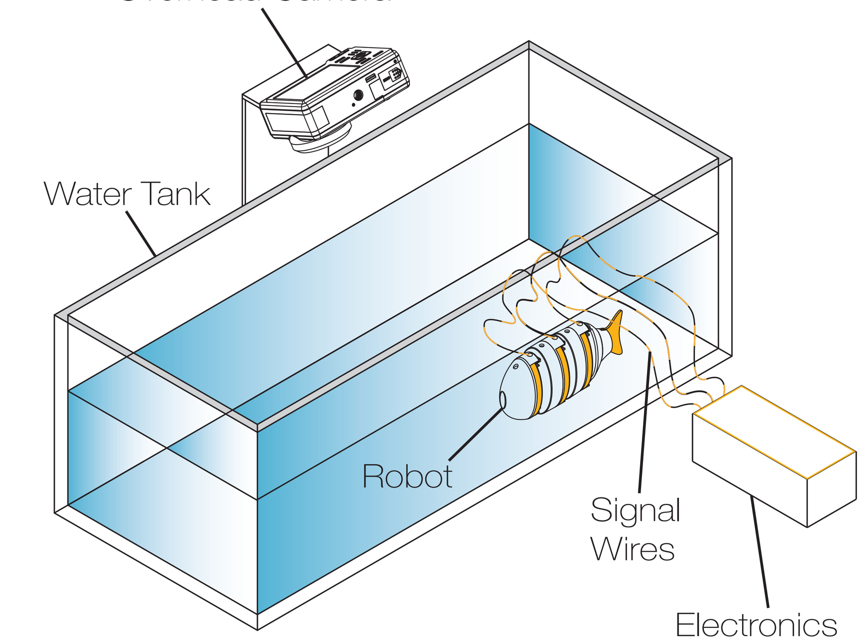

Figure 5: Experimental Setup

Forward Propulsion Experiments

Forward propulsion experiments were performed to evaluate whether MORA's joints could be configured to create an overall constructive, undulatory motion, where each joint's movement augmented the next. Four different combinations of timing sequences and MIC settings (duty cycle, pulse frequency) were evaluated. Our results showed that the robot's top speed of 0.37 body lengths per second was achieved when the head and tail joints moved in opposition to each other, a phenomenon observed in previous works [2] , [4].

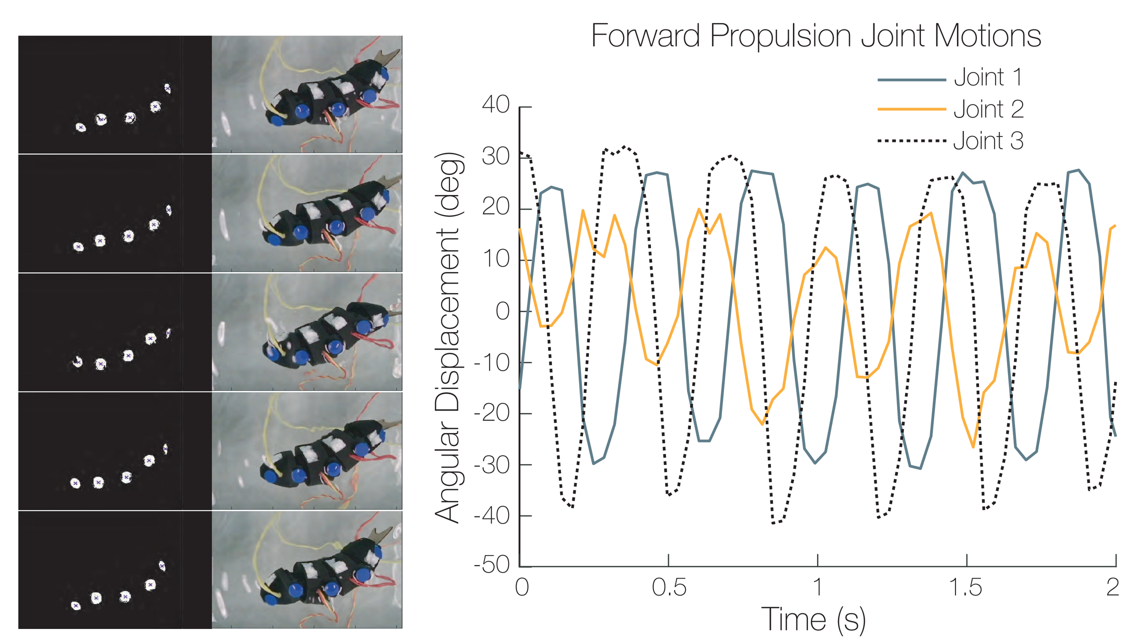

Figure 6: Each individual joint traced a unique sinusoidal trajectory. The fastest swim speed and thus most constructive behavior were achieved by setting the first two joints out of phase, resulting in the head and tail moving in opposition.

Future Work

Improving MORA and its multi-jointed actuation method will enable the development of miniature underwater robots which show promise as robust and efficient agents in a distributed sensing network designed to navigate small spaces and sensitive ecosystems. Due to the autonomous nature of swarms, we are working towards creating an untethered prototype which will additionally increase swimming performance. As we look to replicate more complex motions with MORA, such as turning, finer control of the actuators' motions will be required. While a detailed characterization of the MIC can be derived, developing a closed-loop control system for it would provide a more dynamic response. We are investigating the use of a Hall Effect sensor to track the orientation of the magnetic field of the rotating magnet to be able to calculate the joint's position in real-time.

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References

[1] Berlinger, J. Dusek, M. Gauci, and R. Nagpal. Robust maneuverability of a miniature, low-cost underwater robot using multiple fin actuation. IEEE Robotics and Automation Letters, 3(1):140–147, Jan 2018.
[2] R. J. Clapham and H. Hu. isplash-i: High performance swimming motion of a carangiform robotic fish with full-body coordination. In 2014 IEEE International Conference on Robotics and Automation (ICRA), pages 322–327, May 2014.
[3] Robert K Katzschmann, Joseph DelPreto, Robert MacCurdy, and Daniela Rus. Exploration of underwater life with an acoustically controlled soft robotic fish. 2018.
[4] Jindong Liu and Huosheng Hu. Biological inspiration: From carangiformfish to multi-joint robotic fish. Journal of Bionic Engineering, 7(1):35–48, 2010.
[5] "Coral Reef Drawing At GetDrawings." ClipartXtras, 2017, clipartxtras.com.

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