Design and Creation of a Soft Eel-Inspired Robot using Tri-Chamber Fluid Actuators

Duration: 10 weeks

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Bachelor of Science in Mechanical Engineering

Under the guidance of:

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Proposal:
For this project, I propose to design and manufacture an eel-inspired robot that utilizes 3D printed, tri-chamber soft fluid actuators to allow for flexion of the body of the robot in any direction. This project will use my experience in 3D printing soft fluid actuators, as well as topics covered in my engineering courses to create a robot that has a greater ability to navigate and adapt in a marine environment than previous eel-inspired robots.

Introduction

Robotics is a rapidly growing field that is proving to have global impacts in many different industries. Today, robots are used in factories to perform incredibly precise tasks with far more efficiency than any human could hope to achieve. However, there are certain limitations that current robot technologies face. The materials that these robots are made with consist mainly of rigid materials that form complex mechanical joints in order to create motion. As such, in an unpredictable world, these designs often struggle to adapt when parameters or conditions change. To address this, flexible materials are beginning to be used in robots which seek to mimic the ability to adapt seen throughout the animal kingdom [1].

One animal that research into soft robotics has focused on is the eel. Eels use a method of locomotion which utilizes undulations of their long, flexible bodies to propel them forward. This type of movement is known as anguilliform locomotion [2]. This motion has inspired projects to create soft robots that mimic the undulations of an eel. Particularly, researchers Nguyen and Ho created the preliminary design for an eel robot (see Fig. 1) that uses a series of soft pneumatic actuators which allow for flexing from side-to-side in order to mimic the undulations of eels [3].

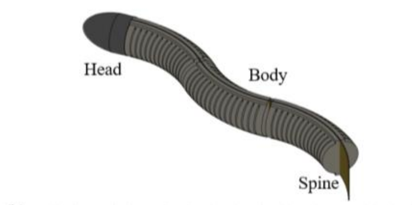

Fig. 1 – conceptual design for eel robot using 2D fluid actuators
Credit Nguyen and Ho [3]

Research Goals and Value

My research will seek to add to the design presented by Nguyen and Ho by adding the ability to travel in three-dimensional paths. This can be done through the use of a tri-chamber soft actuator, which has three actuators spaced evenly about a central axis, as opposed to the two chambers seen in the design by Nguyen and Ho (see Fig. 1). To achieve 3D bending in the proposed eel robot, we plan to adapt a 3D-printed actuator design from Drotman, et al [4] that had been used in a four-legged robot to achieve quadruped walking (see Fig. 2)

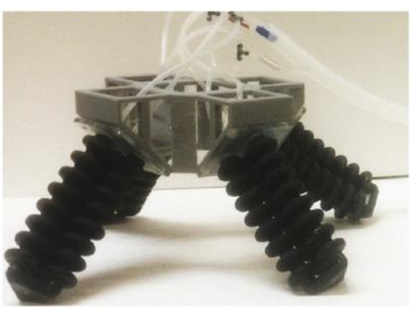

Fig. 2 – quadruped robot with tri-chamber actuators as legs
Credit Drotman, et al [4]

Soft swimming robots like this would be highly maneuverable in marine environments and would be perfectly suited for tasks that require access to small or awkward underwater spaces, or really any task that must be performed underwater. Such tasks could include marine research, maintenance and repair of underwater equipment, and retrievals of lost items. These require the ability to easily move in any direction–up, down, left, or right–a capability which has not yet been explored in soft eel-like robots. This progression of eel-like robots will be a necessary step in making eel-like soft robots a useful tool to people.

This research would furthermore serve as a continuation of research I have been doing for my fellowship project under Professor Scott as a Presidential Fellow. This project has focused primarily on the design and fabrication of soft fluid actuators over the course of the academic year, and I have already seen success in creating 2D flexing with these actuators (see Fig. 3). The PUR program would be an incredible opportunity to make huge progress in this research as creating 3D movement with soft fluid actuators would be the natural next step.

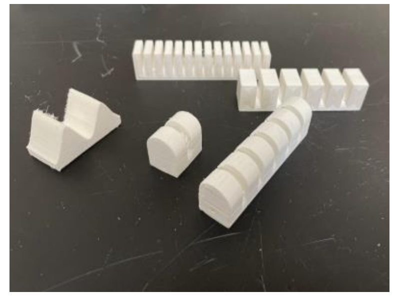

Fig 3 – my own prototype designs for 3D printed fluid actuators

At the conclusion of this research, we expect to have designed and built a soft eel-like robot that is capable of adaptive movement in a marine environment, which can furthermore be used for the applications mentioned above. In order to achieve this there are two main tasks which we will need to complete:

1) Designing a tri-chamber actuator which can be reliably 3D printed
2) Incorporating that design into a full eel-like robot that can move vertically as well as in the horizontal plane

Project Description, Methods, and Outcomes:

This project will incorporate multiple phases that are arranged as follows:

1) Designing and 3D printing the tri-chamber soft actuator and determining materials needed (~ 2-3 weeks)
2) Constructing and wiring the robot using the actuators and incorporating a hydraulic system to control pressure in the actuators (~ 3-4 weeks)
3) Running tests to establish the necessary methods of creating oscillatory motion using the actuators in the robot (~ 2 weeks)
4) Writing up conclusion and results (~ 1 week)

Phase one will focus primarily on the fabrication of the actual tri-chamber actuator itself. The new design will be based on the model designed by Drotman, et al [4], utilizing printing techniques we have been developing over the course of the academic year. The research we have conducted up until now has focused on designing single and two-sided actuators that achieve a similar purpose to the tri-chamber actuator but have more limited degrees of freedom. To print these designs, we have used a printer that only has one nozzle, so due to the lack of support material, our designs have had to be self-supporting during the printing process. We have seen success in achieving this. The challenge with the tri-chamber actuator is that the design is far more complex, but our current results imply that such a design is possible. Additionally, all necessary materials will be ordered during this phase.

Phase two will focus on using the design created in phase one and building the actual eel-robot. The robot will consist of two or more tri-chamber actuators linked together at each end to allow for oscillatory motion, as well as adding a system for actuating the robot. The robot will be actuated using a hydraulic network that will use dosing pumps and pressure sensors to control and monitor the actuators. This network works by pumping water in and out of specific chambers, which creates pressure in those chambers causing them to expand. Sequentially pressurizing chambers along the body of the robot is what can allow us to create the oscillatory motion we seek to achieve.

Initially we will build a tethered design of our robot, where the electronics, pumps, and power source are wired to the robot externally. Once we have perfected this design and studied its motion, we will then look at building a self-contained robot, where all electronics and pumps are fixed within the robot and will also be powered by batteries. Furthermore, we will be writing code for controlling the movement of the robot in this phase. We will also explore the possibility of adding features to either end of the robot, such as a tool on the head to increase utility and a fin on the back to aid in locomotion.

Phase three will focus on achieving locomotion and the ability to steer in any direction while in the water. The 3D nature of the tri-chamber actuators allows the robot to direct itself in virtually any spherical direction. In order to achieve this, we will experiment with actuating certain chambers in different patterns, and record our results in order to create a reliable algorithm for producing any desired motion. An example of the movement we seek to accomplish involves the eel swimming forward for a certain distance horizontal to the ground, then aiming its head upward and swimming in that direction in order to climb, leveling itself out once more, and finally turning to the right.

Communicating Results

The outcome and result of this research will be presented as a poster at Bucknell's Kalman Research Symposium. In addition to this, this work would hopefully lead to a scholarly article publication that would be presented at a professional conference such as the IEEE International Conf. on Soft Robotics (Robosoft), or International Conf. on Robotics and Automation (ICRA).

Faculty Mentor

This research will primarily take place in Professor Scott's lab and under his guidance. In addition to the lab, we will make use of shared labs such as Mooney Lab or the MakerE, and possibly do testing in a water flow channel. Meetings between myself and Professor Scott will take place in person at least three times per week, if not everyday.

1) Rossiter, J. M., & Hauser, H. (2016). Soft Robotics - The Next Industrial Revolution? IEEE Robotics and Automation Magazine, 23(3), 17-20. [7565693]. DOI: 10.1109/MRA.2016.2588018
2) GARY B. GILLIS, Undulatory Locomotion in Elongate Aquatic Vertebrates: Anguilliform Swimming since Sir James Gray, American Zoologist, Volume 36, Issue 6, December 1996, Pages 656–665, https://doi.org/10.1093/icb/36.6.656
3) D. Q. Nguyen and V. A. Ho, "Kinematic Evaluation of a Series of Soft Actuators in Designing an Eel-inspired Robot," *2020 IEEE/SICE International Symposium on System Integration (SII)*, 2020, pp. 1288-1293, doi: 10.1109/SII46433.2020.9025926.
4) D. Drotman, M. Ishida, S. Jadhav and M. T. Tolley, "Application-Driven Design of Soft, 3-D Printed, Pneumatic Actuators With Bellows," in *IEEE/ASME Transactions on Mechatronics*, vol. 24, no. 1, pp. 78-87, Feb. 2019, doi: 10.1109/TMECH.2018.2879299.