Developing a Research Question

Bryan Carlton[1], Aniruddha Anand Damle[1], Anson Kwan[1], Jacob Yoshitake[1]
Team 2: Swimming
[1]Ira A. Fulton Schools of Engineering

I. Question

How can a length-constrained segmented beam with a compliant tail propagate a sinusoidal wave to produce anguilliform locomotion?

II. Tractability

In order to make this project tractable within the time frame of 15 weeks, we will be focusing on tuning our segmented beam to produce motion inspired by anguilliform locomotion or ‘eel-like’ swimming. Additionally, we will be focusing on only trying to tune one position for the segmented beam. This means that we will be only focusing on optimizing the joint stiffness for the mechanism for only one configuration of the system. For the purposes of this project, we will be starting in an ‘S’ configuration and try to flip the peaks of the stable position through a simple input of a servo motor. This will greatly improve the scope of this research because it defines the goal of the research as producing this configuration as opposed to finding the optimal configuration to produce this locomotion. By focusing our research on anguilliform locomotion and defining the configuration that we will use, the scope of the research will produce successful results for this semester.

III. Novelty

For the purposes of understanding the various research spaces that anguilliform locomotion-based robots exist, we used keywords such as ‘anguilliform locomotion’, ‘undulatory motion’, ‘soft robotics’, ‘laminate’, and ‘eel inspired’. From these keywords, we were able to get an understanding of the existing research being conducted on anguilliform-inspired robots within the foldable robotics field.

From these keywords, the most cited source was “A Geometric Approach to Anguilliform Locomotion: Modeling of an Underwater Eel Robot” [1]. This paper discusses the kinematics and simplification of anguilliform locomotion into rigid body segments and defined points of rotation [1]. This paper primarily focuses on using rigid bodies and actuation at every link. Unlike this paper, our research question will be focusing on creating undulations in the body of our system through only a single actuation and tuning our system to propagate the motion. The next most cited source was “Bio-inspired aquatic robotics by untethered piezohydroelastic actuation’ [2]. This journal entry discussed the tuning and utilization of piezoelectric laminates to produce the sinusoidal locomotion that characterizes many underwater movements [2]. Both this paper and our research questions discuss the concepts of single actuated, tunable laminate structures, but this paper focuses on carangiform locomotion which is exhibited in fish.

Additionally, this paper uses the laminate structure as the form of actuation, while our question focuses on a method of propagating a tuned laminate structure that produces anguilliform-like locomotion. The third most relevant and cited source was “AmphiBot I: An amphibious snake-like robot” [3]. The core concept of this paper revolves around a wheeled multi-actuated spine that can either traverse land or water through snake-like or eel-like locomotion [3]. This paper represents how anguilliform locomotion can be accomplished using traditional actuators and linkages. Our question differs entirely from this paper because our objective is to produce this kind of movement using only a singular actuator and a precisely tuned mechanical system. Lastly, the other paper that was most cited for these keywords were “Body wave generation for anguilliform locomotion using a fiber-reinforced soft fluidic elastomer actuator array toward the development of the EEL-inspired Underwater Soft Robot” [4]. This journal article focused on utilizing bellows-based actuators to inflate faces of a soft spine in order to create the curvatures present in eels to create a simplified model and robot [4]. While both this research paper and our question revolve around simplifying the traditionally complex systems that generate anguilliform locomotion, this is achieved in different ways. The goal of our research is to use a single traditional actuator, such as a servo, to produce this locomotion, while this paper focuses on using multiple pneumatic bellows to deform the spine.

IV. Interesting

With the development of newer and faster manufacturing methods, as well as various materials such as ionic polymer-metal composites (IPMCs), Shape memory alloys (SMAs), and magnetostrictive thin films, the development of bioinspired soft-robot locomotion has received a lot of attention and has recently been the topic of discussion between the scientific communities. The scientific and engineering communities have expressed a strong interest in applying biological underwater locomotion to marine robots in order to improve performance in various marine missions such as search and rescue, naval intelligence, and surveillance and reconnaissance. The motivation for eel-like biometric locomotion ranges from underwater sensing and exploration for long-term ecological sustainability to drug delivery and disease screening in medicine.

V. Open-Ended

In addition to our research question, there are a slew of other questions that could be asked. From the way that we defined and structured our research question, our primary focus is anguiliform locomotion and tuning for a single starting configuration. This means that there is an opportunity to conduct more research on optimizing the initial configuration for anguilliform locomotion or adapting the mechanism for different forms of aquatic locomotion as well as terrestrial locomotion. Additionally, even within the scope of our question, there is potential to do a deeper look into optimizing a tail or compliant attachment to propagate the motion produced from the mechanism. Our research question's goal is to start looking into the possibilities for this mechanism, which is just a starting point for a variety of applications and dynamics that can be used with this system.

VI. Modularity

Our question can be applied to a wide range of research topics such as biomimicry, laminate robotics, aquatic propulsion, and unmanned surface vehicles (USV). Because we are recreating the sinusoidal motion of the tail of an eel while optimizing the stiffness of the joints, researchers interested in the locomotion of eels can use the data that we collect and see if they correlate with the motion and stiffness of motion of actual eels. In addition, researchers in laminate robotics could use our research to make an aquatic robot that utilizes the data to design the propulsion mechanism for their system. For researchers interested in aquatic propulsion, they could research the fluid motion and the amount of force produced by the system designed in this research. USV are an up and coming field of research that focus mainly on producing devices and mechanisms that can be controlled remotely in variable viscous fluids and land. Through our research, future work can be done on developing and controlling this mechanism so that it can be applied to this field. There may be other applications of our research to other topics, but these three are the most prominent that we could recognize.

VII. Team Fit

Our team members have a variety of interests and abilities that will be necessary to this research.

Anson Kwan is currently conducting research on simulating and analyzing soft beams to produce anguilliform locomotion and has an interest in crossing over the concept of singular actuation to create complex motion into laminate systems. He has experience with python based simulation as well as using optimization algorithms such as Scipy and CMA-ES to solve and fit complex dynamic systems. Through this research question, he hopes to learn more about laminate structures and how they apply to anguilliform locomotion and how joint design in laminate design affects stiffness and compliance

Jacob Yoshitake has a variety of skills based in 3D modeling and manufacturing. His extensive experience with SolidWorks will allow the team to be able to create 3D models of the robot at a rapid pace, as well as simulate it though either SolidWorks or ANSYS. He also has an understanding of a wide variety of manufacturing techniques (3D printing, laser cutting, welding, milling, lathe, ect) as well as a wealth of experience manufacturing mechanisms that will be paramount to being able to produce a working robot. Though his interests are mostly in aerospace, the research into propulsion of an aquatic robot also interests him.

Bryan Carlton is currently working on a research project in which he is working on another bioinspired design. With this research question, he hopes to learn how to apply biological concepts to robotics in order to provide simpler, effective solutions whether it be in exoskeleton development or an underwater vehicle. This project allows Bryan to research simpler solutions for underwater locomotion while learning new robotic methods. He currently has experience with CAD softwares such as Fusion 360 and Solidworks. He has also worked with electrical design software Cadence. Bryan also has experience in programming languages such as C/C++, MATLAB/Simulink, and a little bit of Python.

Aniruddha Anand Damle is interested in creating a low-cost mechanism that can be used for terrestrial robots. He has a strong background in embedded systems, machine learning, and communication protocols, allowing us to quickly develop functional prototypes. He's also worked with 3D modeling and production techniques like 3D printing, laser cutting, and lathes. He has previously worked on multi-layered PCB design and development, as well as various ARM-based platforms. Although his interest is in Swarm Robotics, he hopes to develop a low-cost muscle design that can be used to build an origami-inspired quadruped robot with this research question.

VIII. Topic Fit

In order for this research to be successful, it will be utilizing the techniques of analysis of geometric kinematics, dynamics, and laminate manufacturing processes for our device that will be taught over this course. In order to determine the joint stiffnesses of the segmented beam, we will need to conduct experimental data and fit the simulated data to it. To achieve this, we will have to solve for the kinematics of the system as well as simulate the dynamics of the model to find the joint characteristics. Additionally, in order to find the optimal joint stiffness to match our desired dynamics and starting configuration, we will need to solve for the dynamics of the system which is a major topic of this course. Finally, the segmented beam will be manufactured using foldable robotics processes. Foldable techniques are critical to answering this question because it allows for the flexibility of easily experimenting with a number of joints and links using inexpensive materials and low manufacturing time. Since varying the stiffness of joints is just a relationship to how much material is removed between the joints and there is a multitude of configurations for how to design the joints, foldable techniques are an ideal solution to prototype our device.

IX. Bibliography

[1] K. A. Melsaac and J. P. Ostrowski, “A geometric approach to anguilliform locomotion: Modelling of an underwater Eel Robot,” *Proceedings 1999 IEEE International Conference on Robotics and Automation (Cat. No.99CH36288C)*, pp. 2843–2848, May 1999.

[2] L. Cen and A. Erturk, “Bio-inspired Aquatic Robotics by untethered piezohydroelastic actuation,” *Bioinspiration & Biomimetics*, vol. 8, no. 1, p. 016006, 2013.

[3] A. Crespi, A. Badertscher, A. Guignard, and A. J. Ijspeert, “Amphibot I: An amphibious snake-like robot,” *Robotics and Autonomous Systems*, vol. 50, no. 4, pp. 163–175, 2005.

[4] H. Feng, Y. Sun, P. A. Todd, and H. P. Lee, “Body wave generation for anguilliform locomotion using a fiber-reinforced soft fluidic elastomer actuator array toward the development of the EEL-inspired Underwater Soft Robot,” *Soft Robotics*, vol. 7, no. 2, pp. 233–250, 2020.