HIGH SCHOOL EDITION
Journal of Student Research
Volume 13 Issue 1 (2024)

A Jellyfish Inspired Soft Robot Powered by Cable-Driven Actuation

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ABSTRACT

Jellyfish's natural propulsion abilities with a soft body has often served as an inspiration for many soft robots due to their size and efficiency, with many robots being based on the ephyra larva stage of a jellyfish. However, most previous jellyfish-inspired robots were constructed of costly actuation systems, as well as being based on the ephyra larva stage rather than an adult jellyfish. To address these issues, a jellyfish-like soft robot was made with 4 cable-driven actuators [19] which were attached to a dome-shaped soft material, mimicking that of the jellyfish. A mechanism using a servo powered the cable-driven actuators, allowing the dome-shaped cavity to contract its bell uniformly. When actuated, the mechanism expels a jet of fluids from the bell, leading to a positive thrust. The result was empirically measured by collecting video data on the robot's performance underwater.

Introduction

Soft robotics present a great potential for surveying delicate and cramped ocean habitats such as coral reefs, and underwater caves, without accidentally damaging fragile objects. Reasons such as these have led to a slow growth in the popularity of biomimicry with marine life such as various fish. This has included aquatic life with various locomotive methods, ranging from that of the knife fish [9], and manta rays [14], to the jellyfish [1, 4, 11].

Jellyfish in particular have been identified to have highly efficient locomotive methods, making them a compelling choice for soft robotic biomimicry [7]. Furthermore, the natural absence of bones in jellyfish may help replicate their natural efficiency with modern soft materials [18]. Jellyfish locomotion is primarily powered by vortex, jet propulsion, and rowing [6].

These locomotive abilities have been replicated in the past using pneumatic [4], iris mechanisms [11]. Dielectric elastomers have also been used to replicate the jellyfish [1]. Much of these efforts were put into replicating the early life stage of jellyfish also known as ephyra, which instead of a dome like bell, have tentacles which are used to thrust itself through water [8].

This paper presents an inexpensive cable-driven actuator mechanism to power a soft jellyfish robot resembling that of an adult jellyfish. The robot was modeled after that of an adult jellyfish in hopes that it improves the jellyfish's locomotive abilities mentioned previously. The system contracts a dome shaped soft jellyfish head, leading to a jet of fluids thrusting the body forwards. The system and robot achieved its goal of being able to thrust itself upwards.

Jellyfish Robot Fabrication

In order to design the mechanism of the robot, the locomotion of the jellyfish needed to be first understood. Jellyfish, in nature, push in the sides of their bells, as well as curling in the edges of their bells. The dome then stretches back to its original position [5]. To replicate this movement, a cable-driven actuator was chosen, as it allowed for soft movement of the bell while allowing manipulation of the degree of actuation. The base of the actuator was a grooved straw of 11 cm with a string through it, which was glued along the edge of one side to make sure it bent in one direction. On the other side, four 2 cm non-grooved straws were added evenly to limit the degree of maximum actuation.

4 of these cable actuators were attached onto a rubber dome of 10 cm in diameter, and 12 cm in height, created by cutting the top of a large uninflated balloon. The actuators were attached in 90 degree angles of each other, on the sides of the robot. Glue was applied as least as possible in order to not hinder the actuation. On the inside of the dome, the 2 cm straws for limiting actuation angles were attached in the same angle as the 4 cable actuators.

After attaching the actuators, two more parts were added in order to ensure the bell didn't collapse into itself. Firstly, a straw of 7 cm with a grooved center was stuck horizontally at the top of each of the actuators. Secondly, another straw was shaped into an "X" shape of 8 cm diagonally, then attached in a 45 degree angle from the actuators on the center on the underside of the dome.

Lastly, a cut was made into the top of the jellyfish in order to fit a servo. The servo's shaft should be at the center of the robot, and so the cut should vary by servo. It is ideal to find a servo with a shaft at its center, as it will cause less issues with balancing the robot. For the robot, a mg996r was used at 6v, which has a torque of 11 kg/cm [17]. It was able to successfully actuate the motor. However, a mg90s, which has a torque of 2.2kg/cm, failed to do so [16]. Both servos were waterproof beforehand with superglue near openings and a 2mm rubber o-ring on the shaft.

Finally, adjustments were made to ensure the balance of the robot. Due to the mg996r having a shaft at one side, as well as it being fairly heavy (55g), adjustments were made in order to make sure the robot doesn't capsize or tilt. Foam was added onto the top of the dome, as well as to its side, on the same side as the servo's body, in order to prevent tilt from the weight of the servo. Furthermore, a 9g weight was hung directly down from the servo to the bottom direction of the bell with a 5 cm stick. This helped lower the center of gravity, preventing it from capsizing from the high center of gravity coming from the servo. This part may vary depending on the servo. The servo cable was controlled by a microcontroller (esp8266, though any others should work) above water, connected by a long wire. The code to control the servo was written with the arduino library, with it being 180 degree rotations of the servo with 1.3 seconds of rest in between.

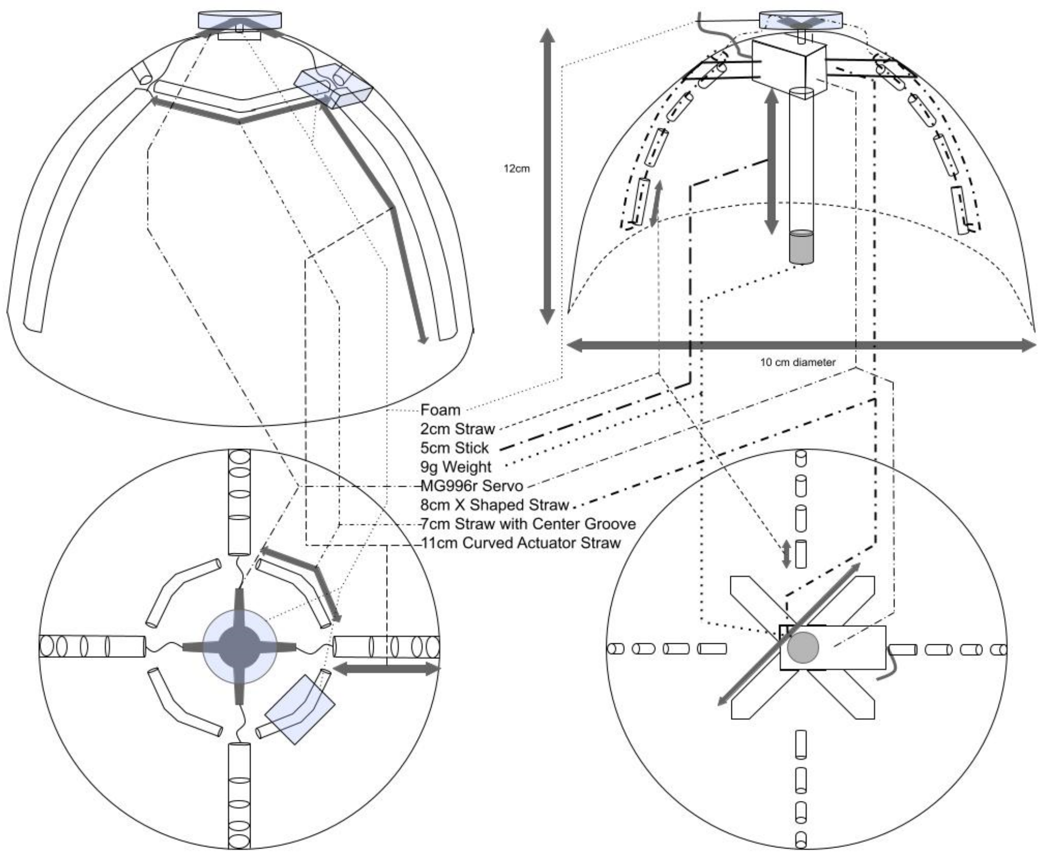

Figure 1. Diagram of the robot

Results and Findings

Results were recorded in a video, in which the robot was successfully able to propel itself upwards 40 cm in approximately 26 seconds.

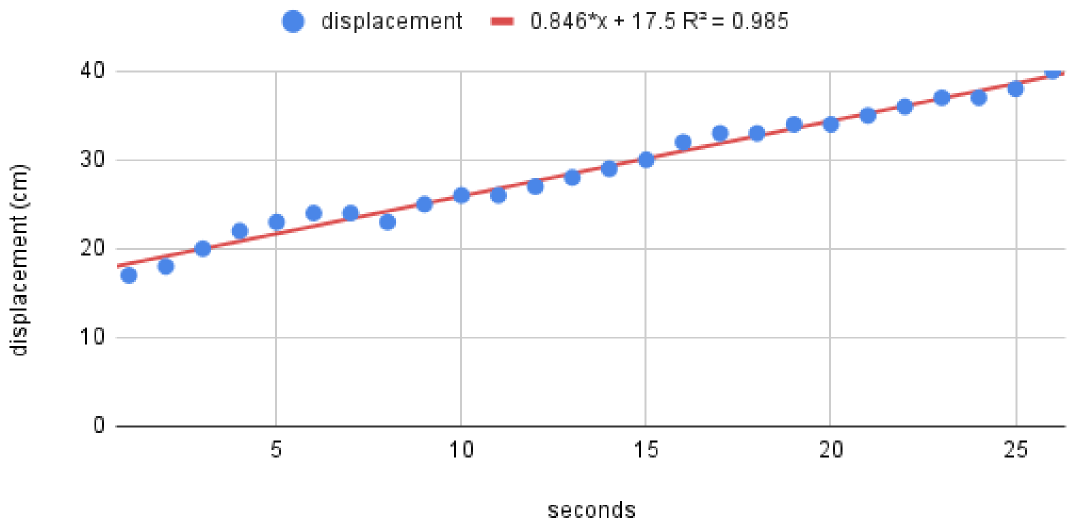

Figure 2. Graph of the displacement of the robot over time (seconds)

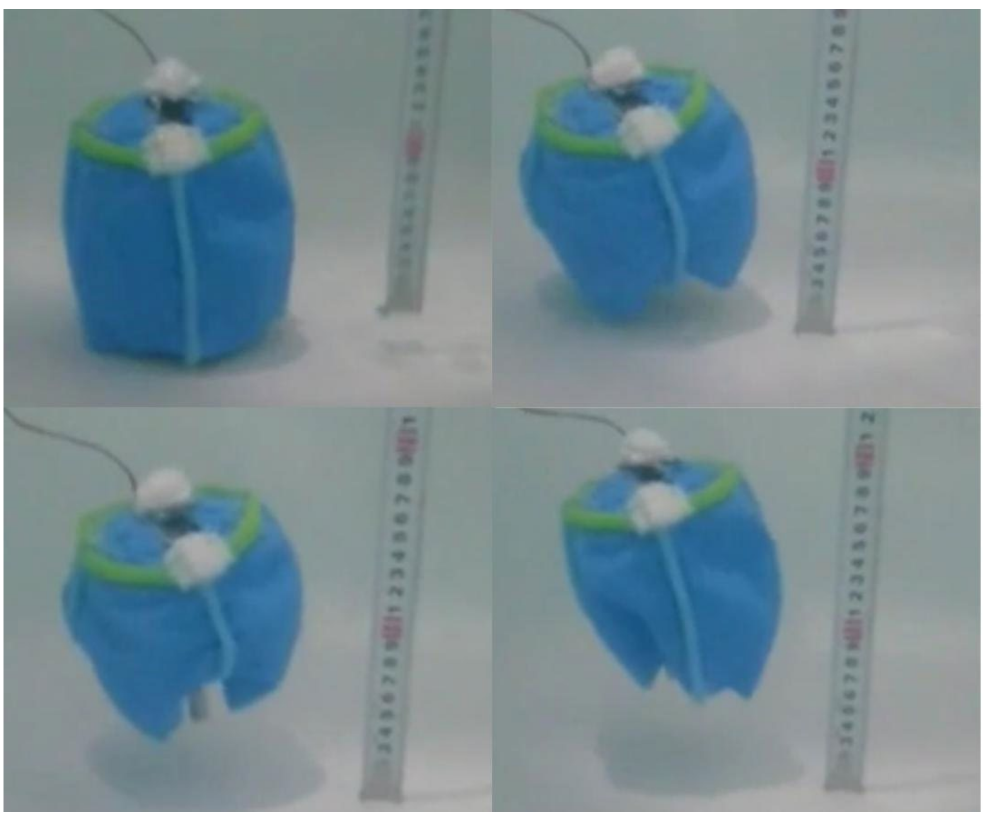

Figure 3. Frames of the test video showing stages within one actuation cycle

Overall, the graph shows a strong positive linear correlation with an r^2 value of 0.985. This suggests the robot has a generally constant speed of around 0.85 cm/s.

In the video it can be seen that the jellyfish-robot, when not moving, slowly falls to the bottom. This movement is mostly canceled out by the upward propulsion which cycles around 2~3 seconds as mentioned in the code. The robot can be seen having a noticeable upward boost, which lasts accordingly with the code. It then slows down and almost stops as the robot detracts. This takes slightly longer than in the code due to water resistance. This repeats without much change in speed.

Conclusion

The primary objective of this paper was to create a soft robot mimicking that of an adult jellyfish, that can actuate and move upwards using inexpensive, common materials. This was achieved, as stated in the results section. The design consists of inexpensive materials, with it being built with rubber balloons, straws, and commercially available servos.

As recognized in the limitation section, there is still much missing from the design such as the ability to move in other directions, as well as a wireless design, and an easily replicable design method. Research and design in these areas could help further develop and increase the design's applicability in practical scenarios.

Limitations

Despite the robot's success in locomotion, there is still much to be desired from the design. A major flaw in the current design is the lack of locomotion other than in the up and down directions. This limits the applicability of the design in open waters, as it is likely that more intricate locomotion is needed in such environments due to environmental obstacles as well as currents. This has been implemented on designs that have been based on younger, ephyra jellyfish-based designs with tentacles. In these designs, only a certain side of tentacles would actuate, forcing an angled movement, allowing for more intricate movements[4]. A similar design could potentially be explored with a soft robot based on an adult (dome shaped) jellyfish, although it may make the actuation more difficult or less efficient compared to ephyra-based designs due to the dome connecting all of the actuators.

Locomotion speed and maneuverability could also potentially be improved via controlling the actuation periods via software, as it has been shown that frequency affects speed in natural jellyfish [13], as well as soft robotic jellyfish [10]. However, this could also be limited by actuation speed of the servos. Therefore, this may also require a change in hardware.

Furthermore, work could be done to make the system wireless. As the logic for the actuator is quite simple, this could be achieved with a wireless microcontroller. This was attempted with an esp8266; however, there were major difficulties in waterproofing the system while maintaining a reasonable size and buoyancy. It may be possible with a custom container with a rubber lid seal. Buoyancy may need to be tuned accordingly with the amount of air in the container.

Lastly, converting the design to be more replicable may help to get a more reliable and uniform design. This could be achieved by having a thin silicon mold instead of the rubber balloon cutout, and flexible 3d printed supports instead of straws such as TPU filament. This should allow for the design to maintain its rigidity while being able to flex and bend for its actuation [15]. This may also aid in the process of waterproofing the system, as parts could be designed for a waterproof fit.

Acknowledgments

I would like to thank my advisor for the valuable insight provided to me on this topic.

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