Design and fabrication of a caterpillar-inspired soft robot that can climb trees and crawl on land

Duration: 10 weeks

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Introduction

As the field of robotics gains more significance, roboticists are exploring ways to broaden robotic applications by overcoming the shortcomings of rigid robots. Over the years, engineers have fabricated and modeled robots as rigid systems linked by joints. The performance of such rigid systems has surpassed human and animal capabilities when performing precise predictable tasks; however, their performance in complex 3D environments is easily surpassed by nature's deformable bodies. For example, Cephalopods achieve high degrees of manipulation without a skeleton, and even vertebrates achieve multigait locomotion using their soft bodies and compliant bones [3]. One approach to solving this problem was creating rigid robots with multiple joints, but the joints are challenging to design and could fail or break easily [2]. A new approach is to create robots with bio-inspired soft deformable bodies that can adjust to complex environments and have multiple degrees of freedom.

A class of soft robots that is of particular interest to this research project is caterpillar-inspired soft robots. Caterpillars, specifically tobacco hornworm caterpillars, have been an inspiration to various soft robots because of their exceptional ability to climb different substrates, navigate uneven terrain, travel through cluttered environments, and adapt to surface deformations. "Branch Bot" developed by Shane Rozen-Levy, et. al (2019) [2] is an example of a soft robot that uses caterpillar-inspired soft structures to achieve vertical and horizontal locomotion along rods, where it uses the same biomechanical phenomenon in its robotic grippers as the prolegs in tobacco hornworm caterpillars (Fig.1).

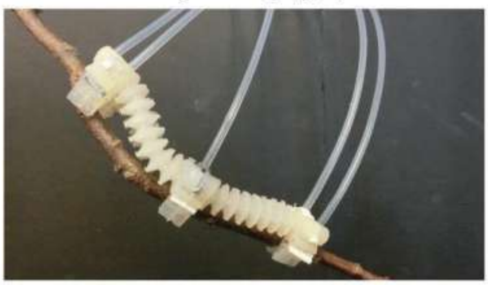

Fig.1 Branch Bot consists of three grippers and a body consisting of two parts with each part consisting of two parallel segments. Each part is controlled by an off-board motor as is each gripper.

Image credit to (Shane Rozen-Levy et. al, 2019).

Project Goals and research value

Our research will focus on fabricating a caterpillar-inspired robot with the same gripping mechanism as "Branch Bot", but with the ability to crawl on flat surfaces and to actively change its direction. Soft climbing robots have the potential to be used in search and rescue missions, space-based projects, environmental monitoring, and in any task that requires accessing locations unreachable by humans or rigid robots such as accessing wires or pipes or high tree branches. However, all of these applications require the ability to navigate flat surfaces and to actively change direction - things that Branch Bot isn't capable of achieving- besides the ability to climb.

At the end of this research project, we expect to have fabricated a caterpillar-inspired soft robot that can climb rod-shaped substrates both horizontally and vertically, crawl on flat surfaces, and actively change its direction, so that it has more potential to be used in one of the applications mentioned above. In order to achieve this result, we have two main tasks to work on:

1) Investigating and developing the design of foot contact points for the robot's grippers to create anisotropic friction while crawling on flat surfaces.
2) Incorporating additional actuation to the robot's body to achieve steerable motion.

Project description, methods, and anticipated outcomes

This project will take place over the following the phases:

1) Initial design of 3D printed parts and determining materials that need to be ordered for control setup (~ 2 weeks)
2) Assembly of initial prototypes, testing and iterating with multiple design parameters for Task 1 (creating anisotropic friction) (~ 3-4 weeks)
3) Developing, fabricating, and testing the design to achieve Task 2 (steerable motion) (~ 3 weeks)
4) Conclusion and writing up results (~ 1 week)

For phase one, the body's and grippers' design developed by Shane Rozen-Levy et.al (2019) [2] will be used as a starting point and will be modified accordingly as the research progresses, where the body will consist of two soft silicone segments with three attached evenly spaced 3D printed grippers. The grippers are designed to passively attach to the substrate and to actively detach from it to progress forward. The robot's body grippers will be controlled through off-board motors connected to the robot through cables that are in turn connected to nylon tendons attached to various parts of the robot. The grippers and 3D printed molds for the silicone body will be designed and printed in this phase. In addition, all materials needed for assembling and controlling the robot will be ordered. Finally, the code controlling the robot's functionalities will also be written in this phase.

During phase two, we'll focus on giving the robot the ability to crawl on flat surfaces, where we'll aim to create anisotropic friction in the foot-ground contact. Anisotropic friction is when there's less friction (lower coefficient of friction) in one direction while the other direction has higher friction (higher coefficient of friction). In order to achieve forward locomotion, the coefficient of friction in the forward direction should be less than that in the backward direction. We propose two approaches to solve this problem, passive flap structures on the feet, and active control of grippers:

<u>A. Producing anisotropic friction through passive flaps:</u>

In their approach to developing an origami-inspired worm robot, C. D. Onal et al. (2013) [1] presented a passive way of producing anisotropic friction through the addition of two angled parallel flaps, one on each end of the robot, where the front flap creates more friction than the back flap during contraction and the back flap creates more friction than the front flap during extension, which allows the robot to move forward only.

During this project, I'm going to design the robotic grippers to be angled like the flaps used in the origami worm robot [1] to allow for crawling on flat surfaces. It's expected that the new angle of the grippers will affect horizontal and vertical climbing; thus, the robot will be tested on various flat surfaces in addition to rod-like surfaces to determine the success or failure of this approach. If this approach is declared successful, further analysis will be done to determine the best angle for the grippers and whether all three grippers or only the terminal two should be angled.

<u>B. Producing anisotropic[1] friction through active control of grippers:</u>

Another proposed approach to giving the robot the ability to crawl on flat surfaces is to actively control each gripper to open and bend on the surface, creating increased friction at that point, and to close, largely decreasing friction at that point, using the same cables that actively control their opening when climbing. To do this, we expect that the gripper's fabrication material will have to be softer than the original 3D printed one. We also expect that the tendon placement on the grippers, the gait pattern of the robot, and the controlling code will have to be modified. This approach is similar to the one used by R. Xie, et al. (2018) [4] in the fabrication of an inch-worm-inspired robot.

For phase three, we'll focus on achieving steerable motion. The robot's deformable body allows it to passively conform to any bends when climbing as the environment acts as an external skeleton to the robot. When crawling on a flat surface, however, the robot must be able to actively change its direction. We are going to modify the robot's design from phase 1 to allow us to add two extra degrees of freedom to each outer side of the front segment by adding tendons to a few folds near the middle gripper. We are expecting that this would cause dynamic and control complications that would have to be resolved as those extra tendons have to be slack enough to not interfere with the compliance of the robot's body to the substrate's shape, and they might have to be actuated simultaneously with the principal tendon controlling the body to avoid tendon slacking. Further modifications to this approach will take place after testing the robot.

Sharing the Results

The results of this research will be shared in the form of a poster presentation at Bucknell's Engineering Student Research Symposium and Bucknell's Kalman Research Symposium. Additionally, the work this summer may build towards a submission for a scholarly conference such as IEEE Robosoft 2022."

Faculty mentoring relationship

Work on this research will primarily take place in Professor Scott's lab under his guidance. Additionally, we plan to make use of shared equipment such as 3D printers in the College of Engineering's maker spaces. Furthermore, several pre-scheduled in-person meetings will take place each week to track the progress of the project over the course of the summer.

References:

[1] Onal, C. D., Wood, R. J., & Rus, D. (2013). An origami-inspired approach to worm robots. *IEEE/ASME Transactions on Mechatronics, 18*(2), 430-438. doi:10.1109/tmech.2012.2210239

[2] Rozen-Levy, S., Messner, W., & Trimmer, B. A. (2019). The design and development of branch bot: A branch-crawling, caterpillar-inspired, soft robot. *The International Journal of Robotics Research,* 027836491984635. doi:10.1177/0278364919846358

[3] Rus, D., & Tolley, M. T. (2015). Design, fabrication and control of soft robots. *Nature, 521*(7553), 467-475. doi:10.1038/nature14543

[4] Xie, R., Su, M., Zhang, Y., Li, M., Zhu, H., & Guan, Y. (2018). Pisrob: A pneumatic soft robot for locomoting like an inchworm. *2018 IEEE International Conference on Robotics and Automation (ICRA).* doi:10.1109/icra.2018.8461189