Pre-Stretched Shell Simulation of Soft Actuators

Vishal Kackar, Yunbo Wang

***Abstract*— In this project we hope to complete the simulation of a bilayer, soft actuator using discrete elastic shell techniques. The goal is to develop a general simulation that considers the change in natural curvature over time in order to mimic the effect of actuation. The simulation should also have the ability to account for miscellaneous forces like drag force and gravity.**

I. Introduction

Though kirigami techniques, soft actuators, and simulations of soft robots have all been researched extensively, all three have yet to be combined into a singular project. Thus, this is the goal of this project. We hope to combine kirigami techniques with soft actuation models in order to create a robust simulation of soft actuators.

II. Reasoning

A. Kirigami Techniques

The need to create increasingly complex robots is hindered by conventional fabrication techniques. Three-dimensional fabrication is difficult, costly, and difficult to scale up, especially if the robot being fabricated is complex. Thus, the need for two-dimensional fabrication is paramount in order to easily produce complex robots. Kirigami techniques provide us a way to map three dimensional shapes to two dimensional maps. By cutting a two-dimensional substrate in a certain way, it is possible to create a more complex three-dimensional shape. As mentioned earlier, two-dimensional fabrication techniques are necessary in order to mass produce complex soft robots. Keeping costs at a minimum while not sacrificing functionality or complexity is another reason to pursue two-dimensional fabrication. Kirigami manufacturing is also faster, cheaper, and much simpler than rapid prototyping, pop-up, and the related origami techniques [1]. In the example of soft robotics in general, kirigami techniques can be used to create robots that are able to morph their structure [2]. This allows for many more degrees of freedom than in typical, hard robotics, and thus allows for soft robotics to be used in a wide variety of situations. Not only are these kirigami skins used to make fabrication of soft robots easier, but they can also be used to augment the performance of soft actuators. In one experiment, researchers were able to increase the friction force of their soft robot by varying the kirigami cuts used [1]. The same paper concludes by saying that kirigami techniques would greatly benefit more than just fluid-driven actuators. Soft robots made from shape memory alloys and polymers are a promising future that we hope to explore in the future.

Ultimately, we believe that kirigami techniques provide the best way to control the shape of the bilayer actuator. By altering the cuts made on the unstretched layer of the actuator, the overall three-dimensional configuration of the actuator can be controlled. Since kirigami techniques are not material specific, they can be broadly applied to a range of materials and purposes [1].

B. Actuation

Another region of focus for this project is to simulate the motion of a soft actuator. Though the actuator is a simple model, it can adequately describe many useful applications, one such application being the movement of a jellyfish [3]. In this experiment, researchers were able to construct a model jellyfish using ionic polymer metal composite (IPMC) as an artificial muscle and cellophane paper as “skin”. By utilizing a kirigami-like design for the jellyfish robot, the researchers were able to find an optimal frequency to control the actuation of the robot to maximize velocity. This sort of experiment is an ideal case of what we hope to accomplish with this project: the ability to model basic actuators in an environment. Robots that follow in this vein have many novel uses ranging from marine research to defense to exploration. The fact that this robot was relatively successful signals that actuation is a very promising path to follow. This experiment is unique in the fact that the actuator that was built had to actuate against the water, which our simulation will be able to model.

Whereas the above example is a biological application of the soft actuator, previous research shows that typical actuators are another promising avenue to look further into [4]. The near-infrared (NIR) bilayer actuator is another design that we aim to simulate. In this example, a bilayer actuator was built using a dopamine polymer and a layer of NOA-63. This system is of interest to use because it can quickly undergo reversible deformation. It can also support a load that is one hundred and twenty times its weight, making it an ideal candidate for simulation. What makes this actuator unique is the fact that it takes advantage of two-dimensional manufacturing.

Actuation is another main goal of our project as having a tool that allows for the modeling of different actuators in various media would very useful.

C. Simulation

The final region of focus centers around matching the experimental results of bi-layered actuators fabricated using kirigami techniques with mathematical or computer simulations. Thorough simulations have historically been difficult to execute, largely due to the many degrees of freedom and nonlinear material effects that are characteristic of soft materials [5]. However, as computer processing speeds improve and more nodes are able to be simulated, accurate simulations for bi-layered actuators are becoming a more feasible goal. Current research on the subject involves the use of nonlinear relaxation being used for kinematic simulation, where the structure is represented as a network of springs, masses, and beams [5]. The researchers also noted that a physically correct simulation does not necessarily imply one that is reflective of reality, which stresses the importance of using experimental results in conjunction with simulation. The simulation published in this research was done on a flexible beam -- we wish to apply similar methods to the more complex geometry of a bi-layered kirigami actuator.

More recently, finite element simulation was used on thin, elastic sheets various strategic cuts meant to generate linear actuation [6]. In-plane stress and out-of-plane displacement was simulated via FEM software and displayed for sheets with cuts that varied in count and geometry. While the planar geometries displayed in this publication are certainly more complex than a simple mass and beam system, in the end they are still solely rectangular sheets. The kirigami cuts made in the middle of the sheets cause deformation and actuation of the middle section, but not the boundaries. There is still minimal work done on sheets that are circular in shape, perhaps even with pieces cut out.

It can be concluded that the simulation of lotus-shaped bi-layered actuators would be a novel avenue to pursue. FEM methods similar to those previously used can be adapted to our new geometry in order to accurately predict the actuation behavior of the structure.

References

[1] *Ji, Mingyang, et al. "Near-Infrared Light-Driven, Highly Efficient Bilayer Actuators Based on Polydopamine-Modified Reduced Graphene Oxide." Wiley Online Library, John Wiley & Sons, Ltd, 9 July 2014.*

[2] *Neville, R., Scarpa, F. & Pirrera, A. Shape morphing Kirigami mechanical metamaterials. Sci Rep* ***6,*** *31067 (2016). https://doi.org/10.1038/srep31067*

[3] *Yeom, Sung-Weon, and Il-Kwon Oh. "A biomimetic jellyfish robot based on ionic polymer metal composite actuators." Smart materials and structures 18.8 (2009): 085002.*

[4] *Ji, M., Jiang, N., Chang, J. and Sun, J. (2014), Near-Infrared Light-Driven, Highly Efficient Bilayer Actuators Based on Polydopamine-Modified Reduced Graphene Oxide. Adv. Funct. Mater., 24: 5412-5419. doi:10.1002/adfm.201401011*

[5] *Lipson, Hod. "Challenges and opportunities for design, simulation, and fabrication of soft robots." Soft Robotics 1.1 (2014): 21-27.*

[6] *Dias, Marcelo A., et al. "Kirigami actuators." Soft matter 13.48 (2017): 9087-9092.*