ME568 Lab 2: Cable-Actuated Finger

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I. Experiment Objective and Setup

A. Background Information

The kinematics of a robot are critical for mapping how it will move within a given workspace. With rigid robots, this is relatively simple since their body morphology is comprised of a set number of degrees-of-freedom (DoF) - consequently constraining their kinematics within a given workspace. Soft robots (hereafter referred to as ”continuum robots”) deform continuously and without restriction, which makes mapping their kinematics difficult.

One method to map the kinematics of a continuum robot is to utilize curve fitting. An example of this would be the Constant Curvature (CC) assumption model which simplifies continuum robot kinematics by approximating the robot as a series of arcs with constant curvature [1].

The purpose of this lab is to fabricate a cable-actuated polymer finger and map its kinematics using the CC assumption model. The generated mapping will be compared to the experimental results to determine if the CC assumption model is sufficient for modeling the behavior of the robot.

B. Actuator Fabrication

The fabrication for each actuator comprised of two segments: polymer curing and servo motor configuration [2]. Two cardboard molds were glued and assembled, tubing was looped through the marked holes, and 50mL of Dragon Skin 10 was poured into each mold. After curing for 30 minutes at 70°C, the actuator was removed from the mold and the tubing was cut (Figure 1). Thread was looped through the holes created by the tubing, and were connected to the servo motor. Arduino code was loaded onto an Arduino Uno Rev3, which was connected to the servo motor (Figure 2). Five different angles for rotation were set and the motor was allowed to run through each angle. Measurements of the thread length, as well as actuator height, were recorded for each angle (Figure 3).

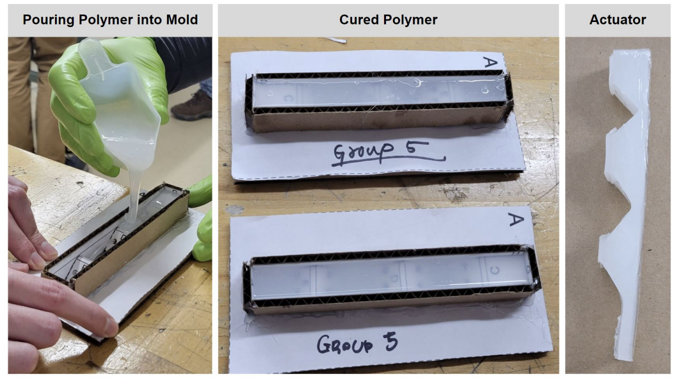

Fig. 1. (From left to right) Steps taken to fabricate each actuator attached to both ends of servo motor. Note that the tubing in the leftmost image has already been looped through the pre- determined holes within the cardboard to form channels for the cables.

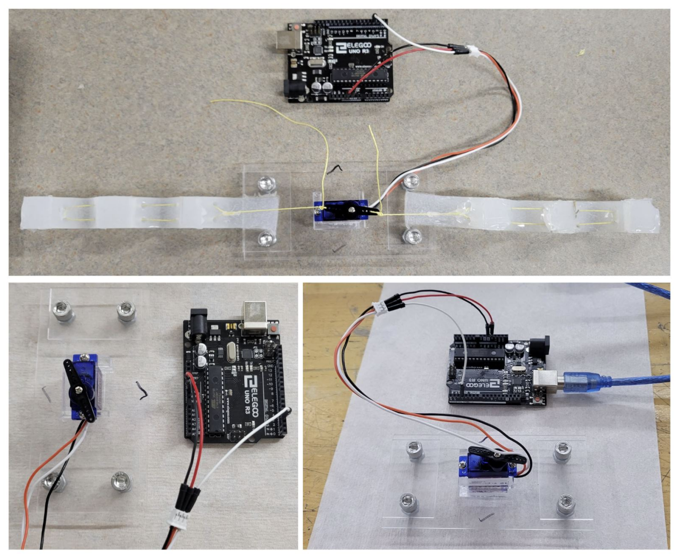

Fig. 2. (Bottom) Wire connections between servo motor and Arduino Uno Rev3 micro-controller. (Top) Servo motor setup with actuators connected motor ends via thread. Note that the thread is looped through the holes formed by tubing inserted before curing.

II. Results

A. Validation of CC assumption model

Validate if the fingers follow the CC assumption model when actuated.

Utilizing the given CC assumption model MATLAB code for calculating vertical distance via length of string pulled, a comparison between the experimental values and the CC assumption model could be drawn.

With the CC assumption model, the length of string pulled and corresponding vertical distance produced a rough bell curve that the experimental data did not conform to (Figure 4). Additionally, although the finger actuation matched the CC assumption model visually, the vertical distances measured did not correspond with each other. Figure 5 supports this since the maximum vertical height for the actuated finger occurred at an angle of 90 degrees, while the experimental maximum vertical height occurred at 145 degrees.

For reference, Figure 6 (Appendix A) depicts the vertical distances achieved by each actuated finger tip for five different servo motor angles: 270, 145, 90, 60, and 45 degrees. Table I (Appendix A) depicts the corresponding changes in string length (the amount of string pulled) per degree measurement taken, and Figure 7 depicts these lengths visually.

Compare your experimental data with estimations from

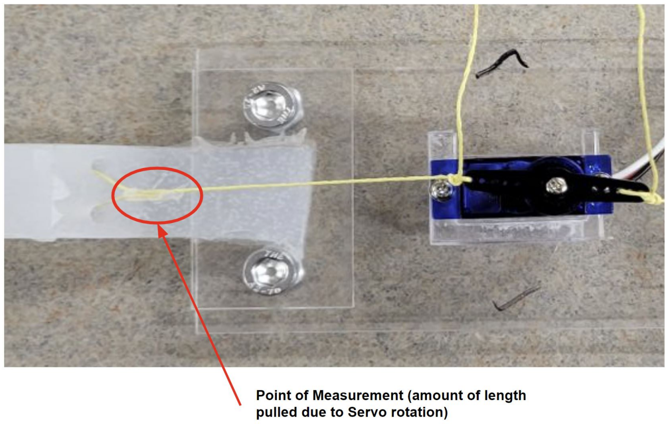

Fig. 3. The red circle marks the assumed "zero" cm mark for measurement. As the servo motor ran through each degree change, the displacement of the mark was recorded as the amount of length pulled. These measurements were utilized for comparison with the CC assumption model.

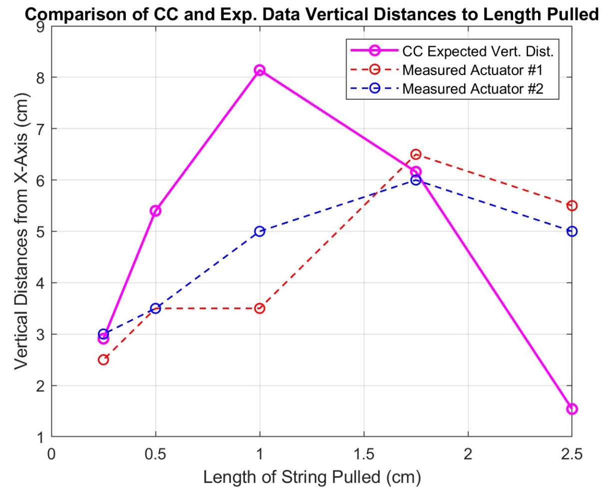

Fig. 4. Comparison of experimental and CC assumption model vertical distances with respect to the length of string pulled.

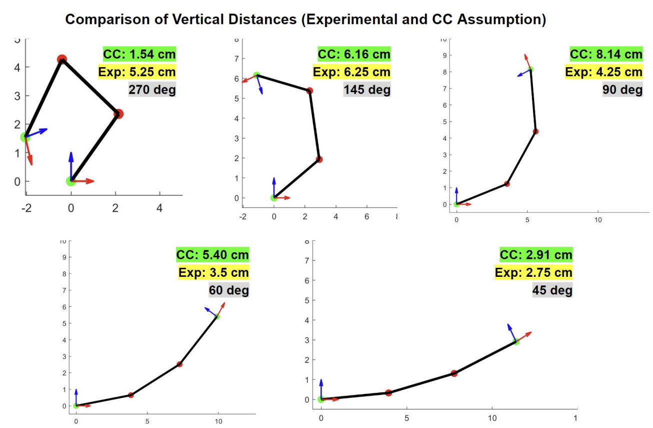

Fig. 5. CC assumption model visualization of each servo angle measurement (calculations for the assumption model were performed by inputting the experimental length pulled measurement). The expected vertical distances are in green highlight, and the experimental vertical distances are in yellow. Degree angles for the servo motor are shown as a reference.

the CC assumption model (report Matlab plot). How well does the CC assumption model model the position of the fingertip? Can you make the data match by multiplying it by a constant correction factor? What are some likely sources of error?

In Figure 5, the analysis comparing experimental data with the CC assumption model via Matlab plotting demonstrates a misalignment between theory and practice. The CC assumption model does not fit the behavior of the tested finger actuator. Rather than each of the "joints" bending simultaneously, the segments bent up in succession from the tip to the base if the base segment was held, or formed an S shape before bending up if the base segment was left free.

The tested actuator's behavior seems similar to the behavior of nearly CC actuators under relatively large load. We believe that the thickness of the actuator between segments was not thick enough to prevent the weight of the segments themselves from acting as too great a load for the actuator to exhibit CC behavior.

Alternatively, the discrepancies between the experimental data and CC assumption model could be due to a lack of available data. Increasing the number of trials would produce a more appropriate mean vertical distance that can be compared with the CC assumption model. Additionally, adding a wider range of servo degrees during data collection could help to produce a more comprehensive scale for comparison instead of utilizing only five data points.

B. Experimental Data and CC Comparison

Choose one of the fingers and plot the tip position at different cable lengths exploiting the fact that you can control the cable length with the servo motor. How does the initial tension of the cable affect performance?

Having initial tension in the cable allows the servo to begin actuating the finger immediately, rather than having to pull until the cable reaches the necessary tension. This manifests in the measured height data as a translation in the x-axis (the length of string pulled), closer to 0 for an increased initial tension. Too much initial tension would translate the plot still further, so that the finger would be curled even without any cable retraction. Therefore initial tension can affect the performance.

C. Alternate Scenarios

Does the finger follow a constant curvature if a small weight is attached at its tip? What if you apply a force on the side?

The finger did not follow a constant curvature in any scenario tested. Consecutive joint actuation (instead of simultaneous bending at all joints), was observed whether the finger was free, its first segment held fixed, weight applied at its tip, or with force applied on its side. We would expect an actuator with nearly constant curvature under no load to display significantly different behavior under load or a side force.

How well would you expect the CC assumption model to fit if the cable was on the opposite side of the actuator with respect to where it currently is?

The body morphology of the actuator in this experiment contributes to how well it will conform to the CC assumption model. The rightmost image in Figure 1 depicts the body morphology of the actuator - note that there are two sides that are critical for answering this question: the side with trapezoids protruding from the main body, and a smooth side.

In this experiment, the cables were attached to the actuator in a fashion that allowed the protrusions in the body to dictate the curling motion observed. As the cables were pulled taut, the tip drove the curling motion inwards towards the robot base. In the CC assumption, a continuous body curls segment-by-segment from the base to the tip. As explained in earlier sections, this segmented curling motion was not observed, which is why this cable attachment method failed to follow the CC assumption model.

However, if the cables were attached in the opposite way, the actuator would curl along the smooth edge instead of the edge with protrusions. This curling motion would more closely conform to the CC assumption model since the protrusions would not dictate the curling motion. Theoretically, the continuous side of the actuator would curl segment-by-segment, following the CC assumption more closely. In order to prove this however, it would be appropriate to perform an experiment in the future comparing both attachment methods to the CC assumption model.

III. Conclusion

In summary, our experiment of analyzing the kinematics of a cable-actuated polymer finger revealed that there were discrepancies in the the CC assumption model and our experimental data. Therefore, these discrepancies displayed that the CC assumption model is inaccurate to predict the behaviour of the continuum robot fabricated in this experiment. We also observed that initial tension in the cable affected the performance of actuation. For additional exploration, we added a small weight on the tip of the robot. Results showed that even with the added weight, the finger did not conform to the CC assumption model. Overall, CC assumption model was not sufficient to model the kinematics of the continuum robot fabricated in this experiment.

References

[1] J. Rogatinsky, "Constant Curvature Modeling Approach," published: Lecture.

[2] *ME568 Lab 2 - Cable-Actuated Finger*.

Appendix A
Additional Figures and Tables

Below are the figures and tables corresponding to raw data taken during the experiment. These are just for reference.

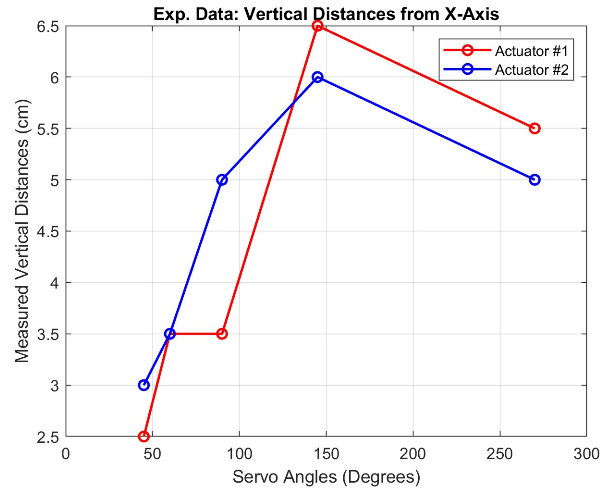

Fig. 6. Comparison of servo motor angle to vertical distance from x-axis achieved by each actuated finger.

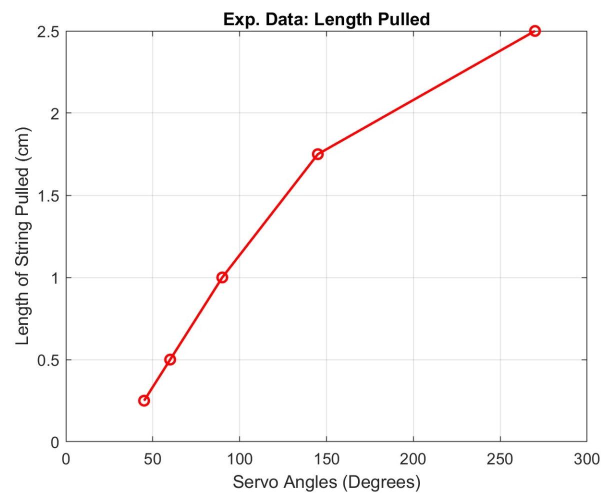

Fig. 7. Comparison of servo motor angle to length of string pulled.

TABLE I
Change in String Length per Degree Measurement

Servo Rotation (degrees)	Length Pulled (cm)	Mean Vert. Dist. (cm)
270	2.5	5.25
145	1.75	6.25
90	1.0	4.25
60	0.5	3.5
45	0.25	2.75

Below is a supplemental figure demonstrating the correlation between servo angle and vertical distances (both experimental and CC assumption model).

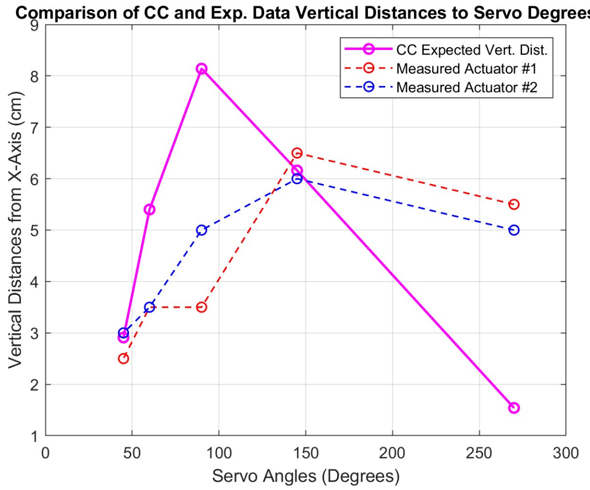

Fig. 8. Comparison of experimental and CC assumption model vertical distances with respect to the servo motor angle.