ME23N - Soft Robotics for Humanity
Stanford University
Mechanical Engineering
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Lab 6: Soft Sensors

(adapted from the soft robotics toolkit: softroboticstoolkit.com)

I. Overview

In this lab we will investigate soft sensors. We will use silicone and conductive fabric to make a stretchable capacitor and we will measure the changing capacitance of the sensor as we stretch it.

Soft sensors are sensors that are on soft robots or other flexible and deformable systems. They can measure a wide variety of different movements and other properties and are sometimes designed to sense multiple inputs at one time. Sensors that go on soft robots need to not interfere with the motion of the robot, so they will either be small enough that they don't affect the robot behavior, or they will be flexible and stretchable. Soft sensors fall into this second category, often being constructed out of the same types of materials that soft robots are made from. Soft sensors have been designed to measure actuation, bending, stretching, contact, and more. Most soft sensors measure an electrical change, i.e. a change in resistance, capacitance, inductance, voltage, or current. Some soft sensors measure optical changes, either using vision to see how a sensor interface is deflecting, or measuring how light scatters through the surface being measured.

Today we will be building a soft sensor that measures change in capacitance. A capacitor is made of two conductive plates separated by a thin dielectric (non-conductive) material. The capacitance (C) is a function of the area of the plates (A), the thickness of the dielectric (d), and a property called the permittivity of the dielectric (ε): $C = \frac{\varepsilon A}{d}$

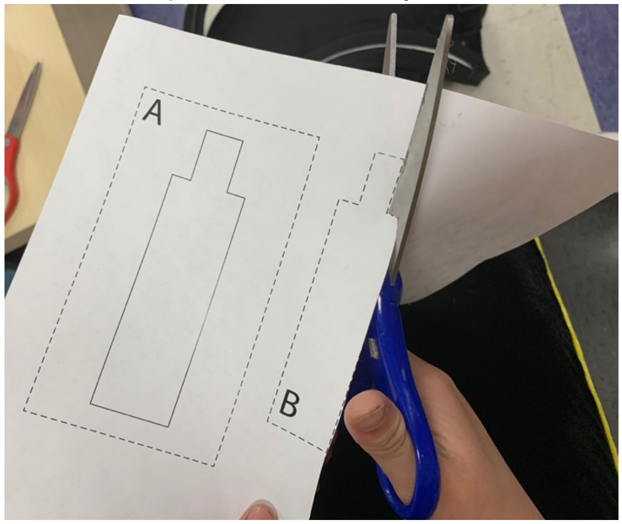
II. Materials and Equipment

- EcoFlex 00-30 (Part A and Part B)
- Conductive Knit Fabric
- Card Stock
- Scotch Tape
- Cardboard
- Mixing Cup and Stick
- Connector wire (Alligator clips) x2
- Jumper wire for testing

- Scissors
- Sharpie
- Hapkit Board
- USB to microUSB cable

III. Steps

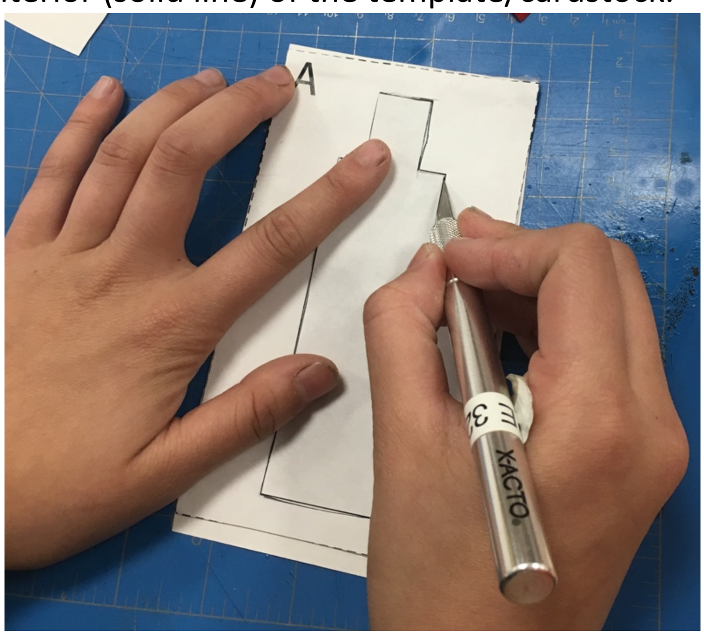
1. Start by cutting out the dotted lines of both sensor templates (included at the end of this document). Set aside template B for later.



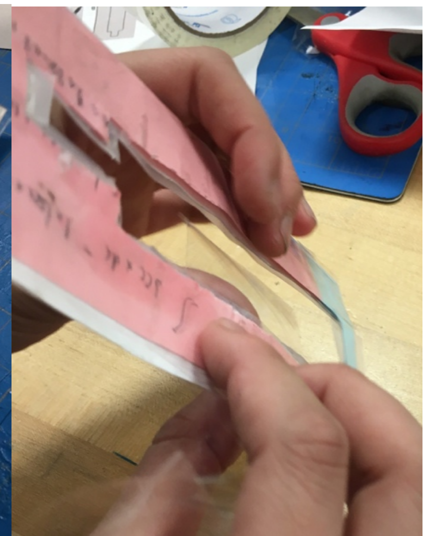
2. Attach template A to the card stock with double-sided tape.

3. Cut out a piece of cardboard the same size as the cardstock.

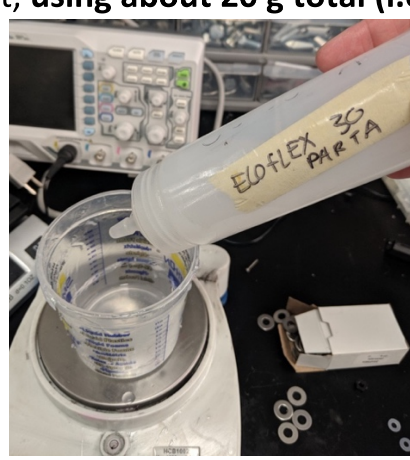
4. Cut out the interior (solid line) of the template/cardstock.

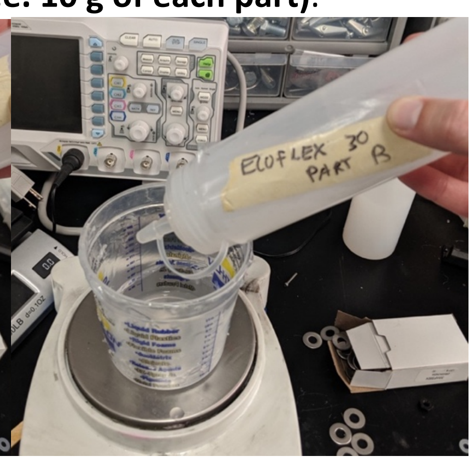


5. Laminate (completely cover) the cardstock and cardboard with tape and attach the cardstock to the cardboard (make sure to leave no gaps in the tape where the silicone can seep into). Wrap the tape through the hole you cut in the cardstock

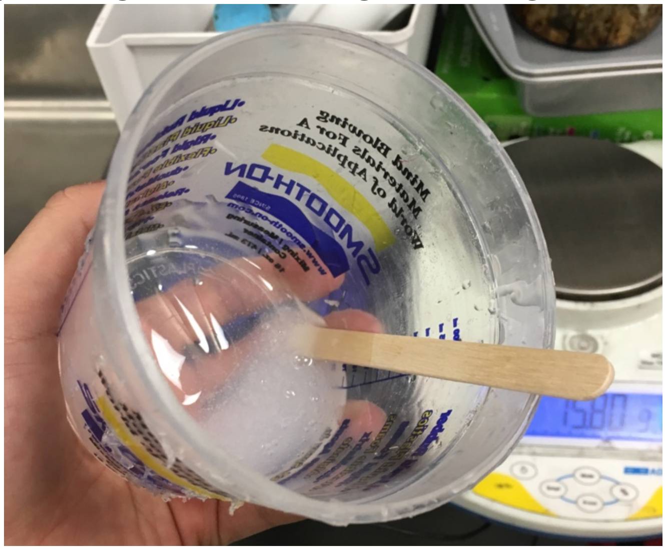




6. Measure out equal parts of EcoFlex 00-30 Part A and EcoFlex 00-30 Part B by weight, **using about 20 g total (i.e. 10 g of each part)**.

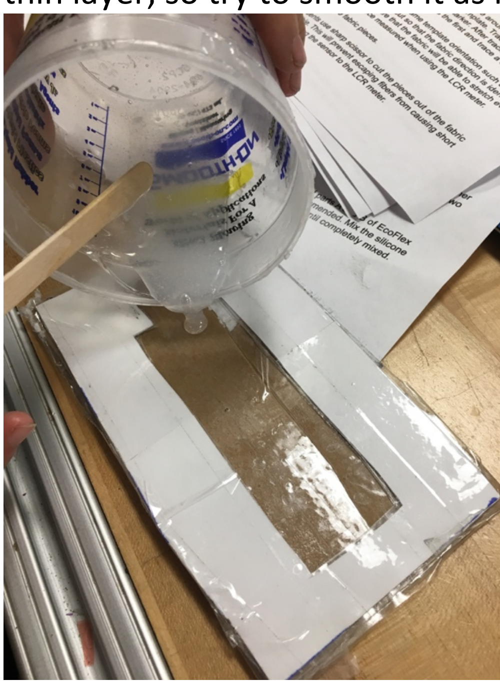




7. Mix the two parts together well using the mixing stick.



8. **Slowly** pour the silicone into your cardstock mold until it is full (you will probably use most but not all of the silicone). If you pour in too much you can level it out and scrape off the extra with the mixing stick. This will be a thin layer, so try to smooth it as much as possible.

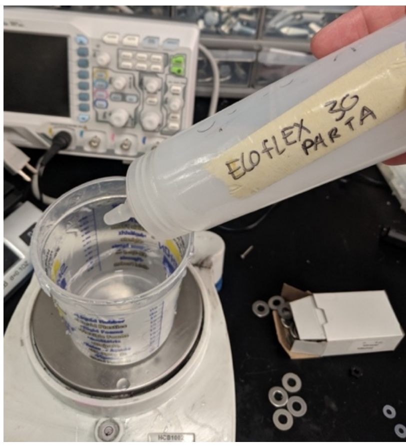
 

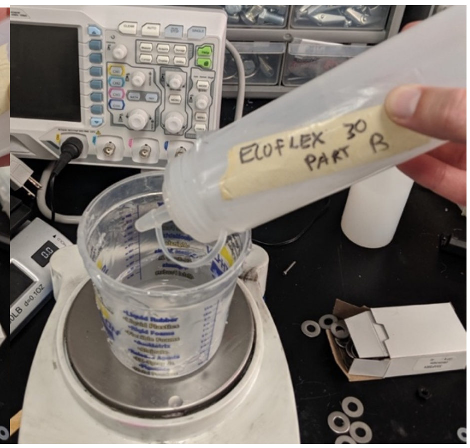
9. Place your cardstock mold into the oven and wait 20 minutes while it cures.

10. Identify the stretchier direction of the fabric. Use template B to trace and cut out two pieces of the conductive knit fabric such that the stretch direction is parallel with the long edge of the template (ask a TA if you are unsure)

11. Take your cured silicone mold out of the oven and test that it is set (should feel rubbery but not tacky or greasy). If it is set, peel the cardstock off the cardboard, leaving the set silicone piece on the cardboard.

12. Measure out equal parts of EcoFlex 00-30 Part A and EcoFlex 00-30 Part B by weight, **using about 10 g total (i.e. 5 g of each part)**. Mix the parts together.





13. Using your mixing stick to spread a thin layer of newly mixed silicone on top of your set silicone. Take one of your fabric pieces and press it into the center of the silicone **(make sure the "shiny" side of the fabric faces outward)**


14. Carefully peel the sensor off the cardboard and flip it over, setting it back on the cardboard with the fabric you just attached face down.

15. Using your mixing stick to spread a thin layer of newly mixed silicone on top of your set silicone. Take the second fabric piece and press it into the center of the silicone **(again make sure the "shiny" side of the fabric faces outward)**

16. Press the fabric and silicone stack gently to push the silicone into the fabric.

17. Return the soft sensor to the oven for another 20 minutes of curing

18. Check that the silicone is set and peel the sensor off the cardboard

19. Peel the narrow tab of the fabric off the silicone so you can attach your alligator clips. Attach one clip to each side of the sensor

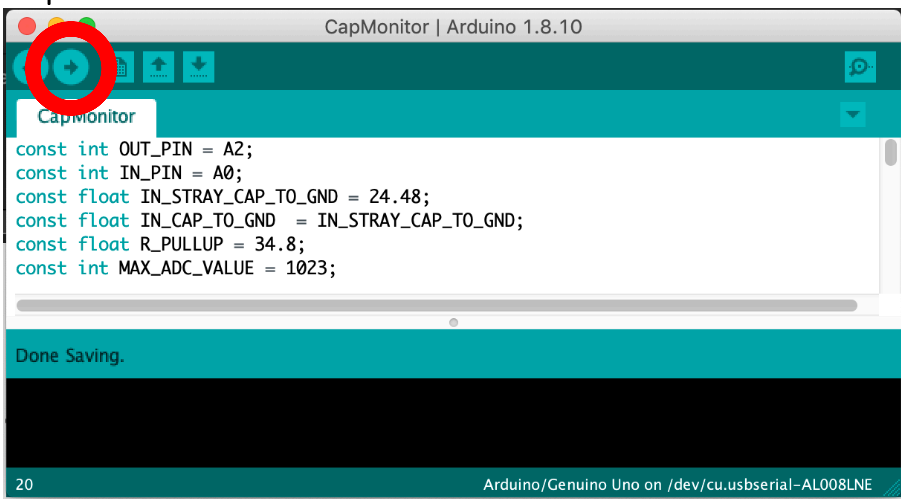
20. Attach your alligator clips to the LCR meter and set it to measure capacitance (either marked only by a “C” or choose the “200pF” setting)

21. Stretch your sensor to test the capacitance change. Make sure to wear gloves, there is no danger to you, but if you electrically connect the two sides of the sensor the capacitive measurement will no longer work.

IV. Sensor Testing and Calibration

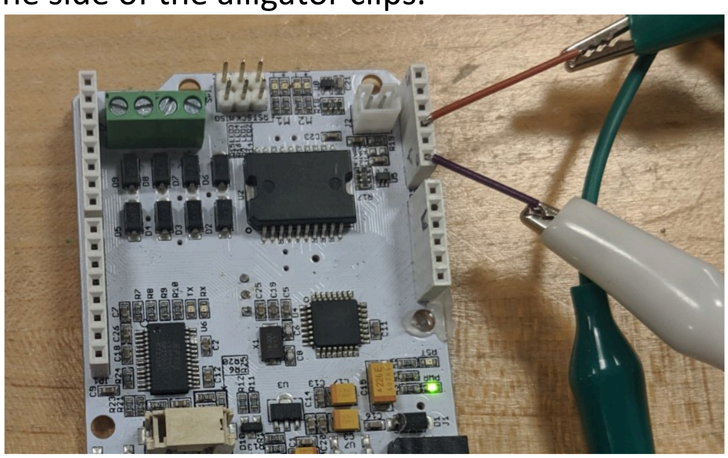
1. In this section, we will test and calibrate your sensor. Since each sensor your make will have a slightly different configuration, each will have a slightly different response to stretching.

2. Start by downloading and opening the capacitor Arduino program ("CapMonitor.ino"). Plug in your board and upload the code onto your Hapkit board.

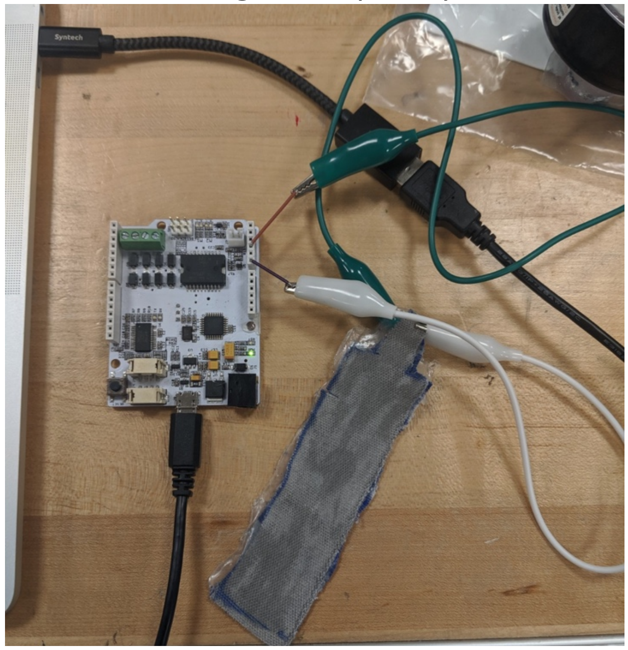


3. Unplug the Hapkit board while you are arranging the wires.

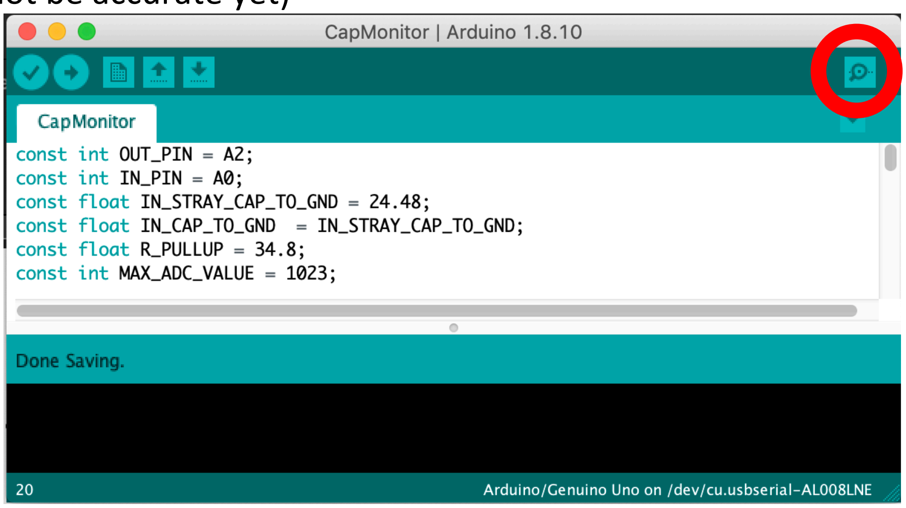
4. Put jumper wires in pins A0 and A2 (labels are on the bottom of the board) and attach one side of the alligator clips.



5. Attach the other side of the alligator clips to your sensor.



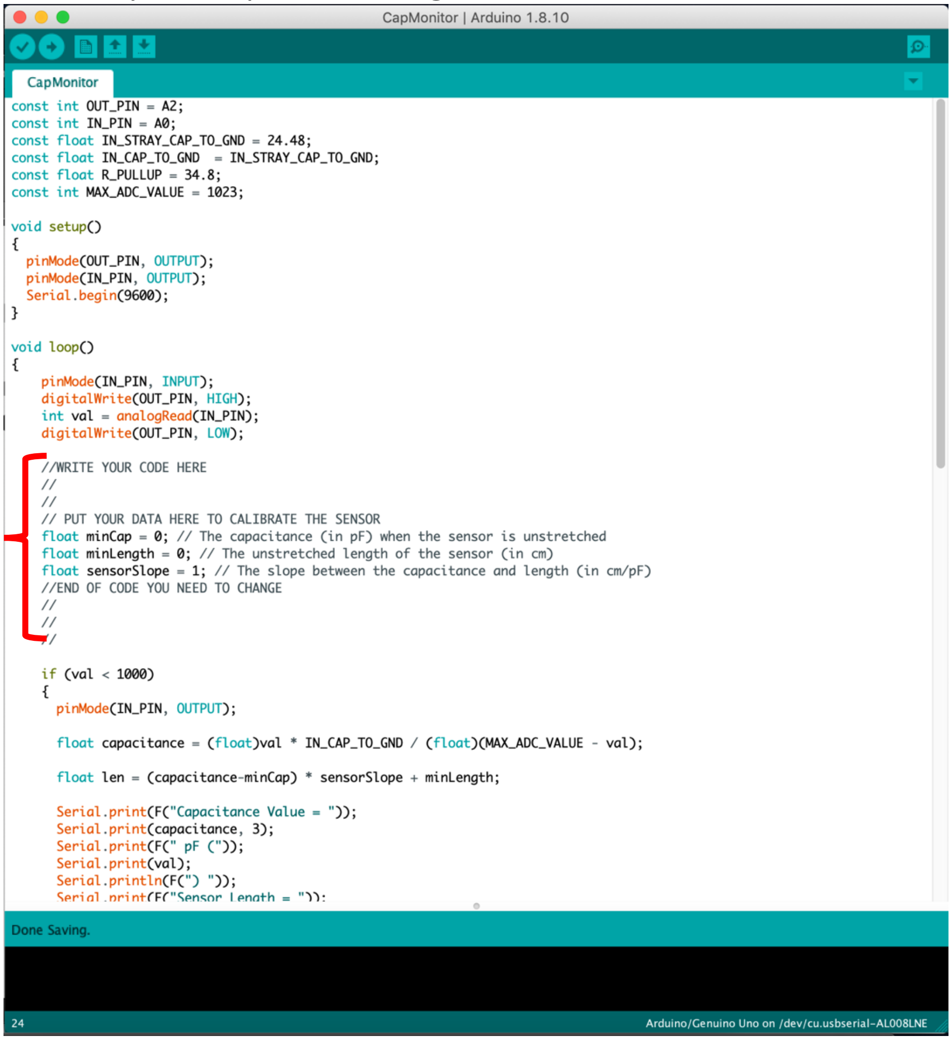
6. Double check your wiring and plug the Hapkit board back into the computer. Open the serial monitor (top right corner of Arduino program). You should be getting readings of the capacitance now (the length readings will not be accurate yet)



7. Record the starting capacitance (pF) and starting length (cm) of your sensor

8. Stretch the sensor and record the new capacitance reading and length. Try a few different lengths of stretch. Calculate the slope of the capacitance to length relationship (cm/pF)

9. Put the three numbers you found into the Arduino code and upload the code to your Hapkit board again.



CapMonitor | Arduino 1.8.10

CapMonitor

```
const int OUT_PIN = A2;
const int IN_PIN = A0;
const float IN_STRAY_CAP_TO_GND = 24.48;
const float IN_CAP_TO_GND  = IN_STRAY_CAP_TO_GND;
const float R_PULLUP = 34.8;
const int MAX_ADC_VALUE = 1023;

void setup()
{
  pinMode(OUT_PIN, OUTPUT);
  pinMode(IN_PIN, OUTPUT);
  Serial.begin(9600);
}

void loop()
{
    pinMode(IN_PIN, INPUT);
    digitalWrite(OUT_PIN, HIGH);
    int val = analogRead(IN_PIN);
    digitalWrite(OUT_PIN, LOW);

    //WRITE YOUR CODE HERE
    //
    //
    // PUT YOUR DATA HERE TO CALIBRATE THE SENSOR
    float minCap = 0; // The capacitance (in pF) when the sensor is unstretched
    float minLength = 0; // The unstretched length of the sensor (in cm)
    float sensorSlope = 1; // The slope between the capacitance and length (in cm/pF)
    //END OF CODE YOU NEED TO CHANGE
    //
    //
    //

    if (val < 1000)
    {
      pinMode(IN_PIN, OUTPUT);

      float capacitance = (float)val * IN_CAP_TO_GND / (float)(MAX_ADC_VALUE - val);

      float len = (capacitance-minCap) * sensorSlope + minLength;

      Serial.print(F("Capacitance Value = "));
      Serial.print(capacitance, 3);
      Serial.print(F(" pF ("));
      Serial.print(val);
      Serial.println(F(") "));
      Serial.print(F("Sensor Length = "));
```

Done Saving.

24 Arduino/Genuino Uno on /dev/cu.usbserial-AL008LNE

10. Open the serial monitor to test out your sensor and calibration

V. Questions

1. How does the soft sensor work? Why do we get a change in the capacitance as the sensor is stretched? From what you learned in lecture about capacitors, how could we get a bigger change in capacitance?

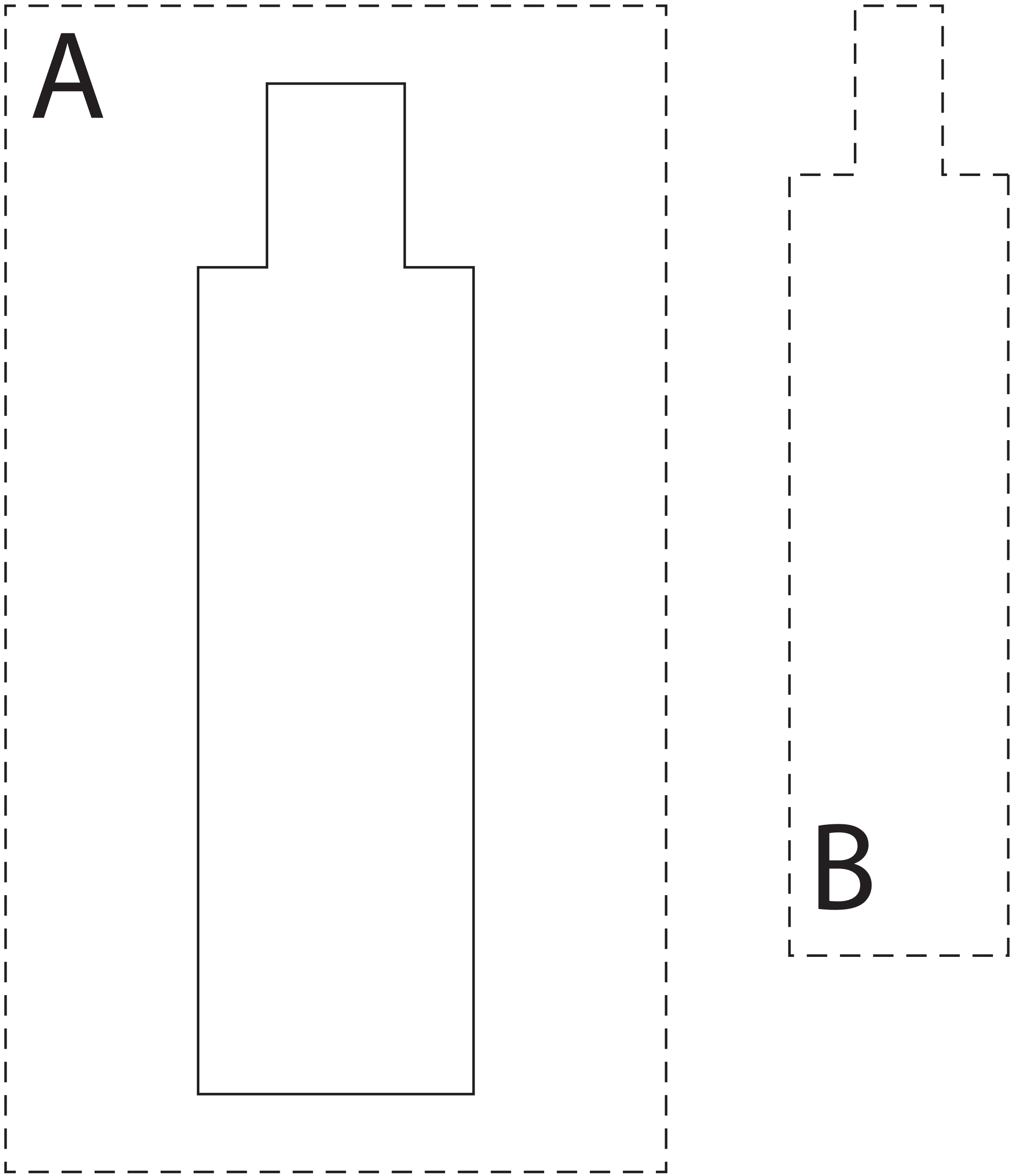
2. What other motions of the sensor cause a change in the reading (twisting, pinching, bending)? How large are the responses to these other motions, compared with the change when stretching? How might this be a problem when using the sensor? And how could it possibly be beneficial?

3. Test and calibrate you sensor with the Hapkit board following the steps in Section IV. Record the starting capacitance and length values and record the sensor reading and length as you stretch the sensor.

4. How linear are the readings you measured? Comment on how well the sensor output measures length after you add your values to the code.

5. What are potential uses for this soft sensor? Imagine potential uses for other types of soft sensors like the ones shown in the lecture.

6. Any other thoughts?



Soft Sensor Guide - Template
Soft Robotics Toolkit, 2017
www.softroboticstoolkit.com