ME568 Lab 7: Soft Sensing

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I. INTRODUCTIONANDFABRICATION

For this lab, we fabricated two new devices. The first is a restive soft sensor and the second a capacitive soft sensor. The fabrication process for both was similar, and both were built on the same base polymer rectangle, albeit with key differences due to the different working principles of each sensor.

The resistive sensor was constructed by using a thin rectangular frame of the desired thickness. Silicone polymer (DragonSkin in this case) was poured into the frame to cast a thin soft rectangle and cured for 5 minutes at 70ºC. A strip of conductive textile is laid out on top of the silicone rectangle in a snaking pattern. Then a thin layer of polymer mixture is spread on top, smoothed, and cured again for 5 minutes. The result is an embedded conductive strip in the material that can stretch and deform, yielding a resistive soft sensor.

The capacitive sensor was fabricated using the same rectangular frame of the desired thickness. Silicone polymer (DragonSkin in this case) was poured into the frame to cast a thin soft rectangle and cured for 5 minutes at 70ºC. On top of this rectangle, a slightly smaller rectangular piece of conductive textile was laid, with its connective tab outside the frame, and then covered with another coat of polymer, taking care not to coat the connection tab. On top of the new coat of polymer, a small strip of fabric was laid to act as a grabbing tab. All layers were once again coated with a top polymer layer and left to cure for another 5 minutes. When the process was over, the entire device was removed from the frame, and the same arrangement of conductive textile and fabric tab repeated on the other side, yielding a mirrored capacitive sensor.

II. ANALYSIS

For the first set of experimentation, we have obtained the voltage reading for increment of length by 0.5mm. Then we calculate the voltage drop across the resistor using the following equation:

$$Vr = 5 \_ Vs$$

Where Vr is is the voltage across the resistor and Vs is the voltage drop across the sensor. Using this we can obtain the resistance by formula :

$$Rs = \frac{Vs . Rr}{5 \_ Vs}$$

Plot for Stretch vs Output Voltage for Capacitive vs Sensor is as follows:

Plot for Stretch vs Output voltage reading for Resistive Sensor is as follows:

From table we can say that as the sensor stretches, i.e. as the length increases, the output voltage reading increases. From the table we can observe that as the resisitve sensor stretches, the output voltage reading decreases.

Fig. 1. Fabricated Sensors

TABLEI
SOFT CAPACITIVESENSOR- STRETCH VS OUTPUT VOLTAGE

Length of the sensor	Voltage Reading	Resistance
10	557	110.098
10.5	0	110.092
11	592	110.0912
11.5	0	110.090
12	603	110.090
	0	
	607	
	0	
	609	
	9	

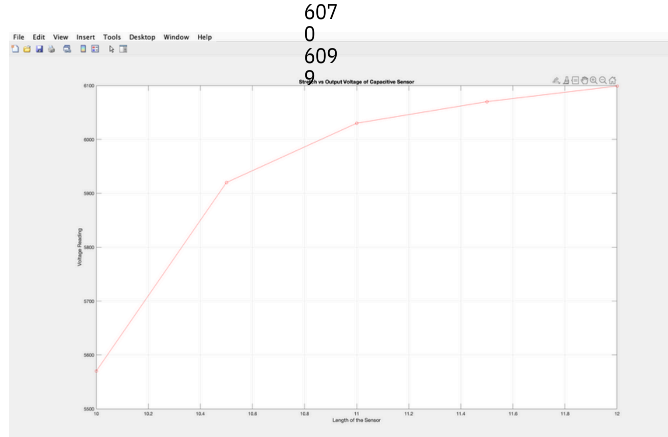

Fig. 2. Stretch VS Output Curve of Capacitive Sensor

For the second experimentation we compressed the sensors with different weights and recorded the output voltage:

Plot for force vs output voltage is as follows:

TABLE II
SOFT RESISTIVESENSOR - STRETCH VS OUTPUT VOLTAGE

Length of the sensor	Voltage Reading	Resistance
6.5	3.9	399.259
7	2	348.333
7.5	3.8 3.87	313.076
8.5	3 3.64	294.411
9.5	3.	282.857
10.	6	282.857
5	3.	
	6	

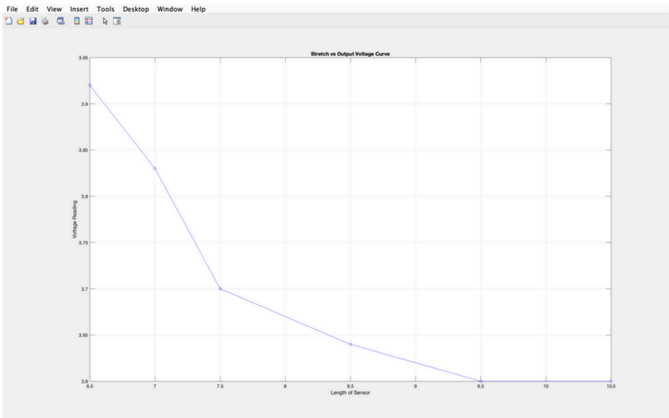

Fig. 3. Stretch VS Output Curve of Resistive Sensor

TABLE III
FORCE VS OUTPUT VOLTAGE FOR RESISTIVESENSOR

1 0Weight applied on the sensor	Voltage Reading
10	3.7
0	7
50	3.7
0	5
	3.7
	3

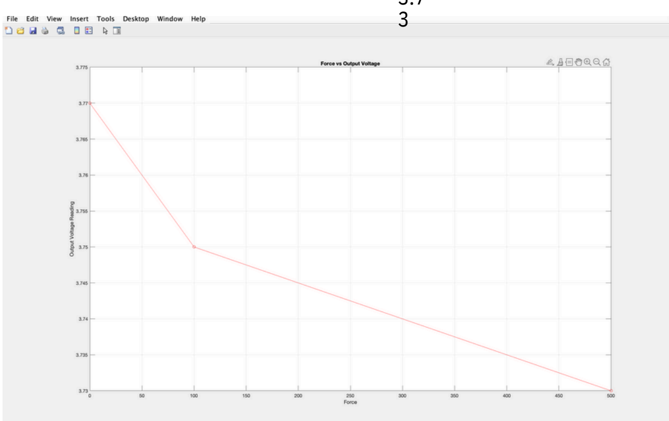

Fig. 4. Force vs Output Voltage Reading of Resistive Sensor

TABLE IV
FORCE VS OUTPUT VOLTAGE FOR CAPACITIVE SENSOR

1 0Weight applied on the sensor	Voltage Reading
50	515
10	2
0	518
50	9
0	522
55	0
0	524
	0
	526
	9

Plot for force vs output for Capacitive Sensor as follows:

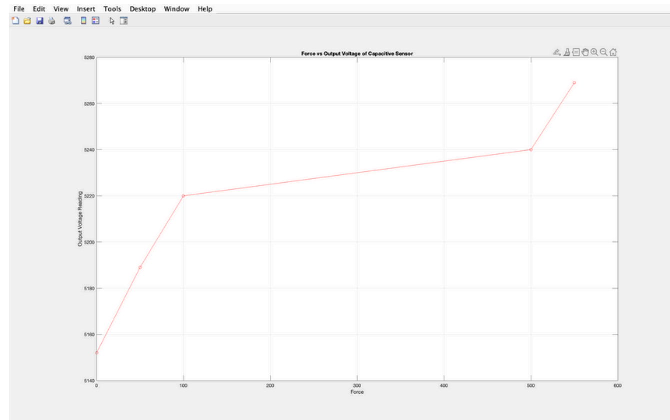

Fig. 5. Force vs Output Voltage Reading of Capacitive Sensor

The third experimentation was done by applying weight on the sensor using a 2L bottle at different volumes of water. The weight of the bottle is approx. 50g and the diameter of bottle is 0.11m. Therefore, we get engineering Stress as 0.0094895 MPa.

TABLEV
STRESS AND STRAIN OF RESISTIVE SENSOR

1Stress	Strain		
Length(mm)	Weight(g)	True Strain	True Stress (MPa)
6.7	46	0.0303053495	0.0094895
7.7	66	0.169418152	0.0110970213
8.2	86	0.2323319774	0.01169391085
8.5	106	0.2682639866	0.01203553285

Plot for Length vs Weight applied on the sensor:

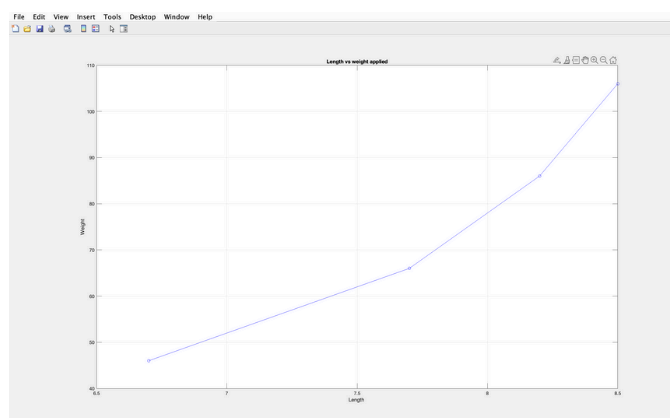

Fig. 6. Length vs Load applied on the sensor

Plot for True Stress vs True Strain for Resistive Sensor:

TABLE VI
STRESS AND STRAIN OF CAPACITIVE SENSOR

1Stress	Strain		
Length(mm)	Weight(g)	True Strain	True Stress (MPa)
10.1	46	0.009950330853	0.00958344605
10.5	66	0.04879016417	0.0095350496
10.9	86	0.08617769624	0.01030654595
11.1	106	0.1043600153	0.01047925485

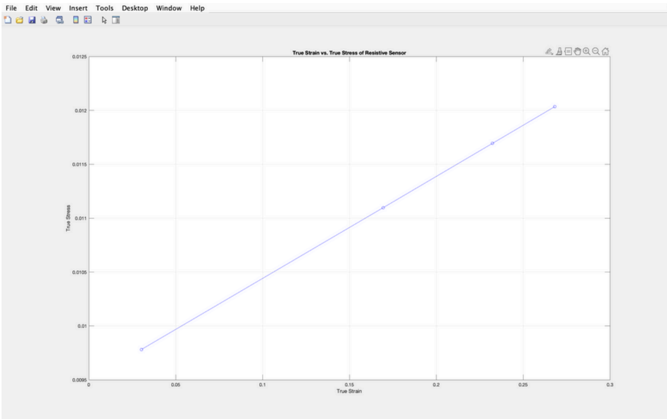

Fig. 7. True Stress vs True Strain for Resistive Sensor

Plot for Length vs Weight applied on the Capacitive sensor:

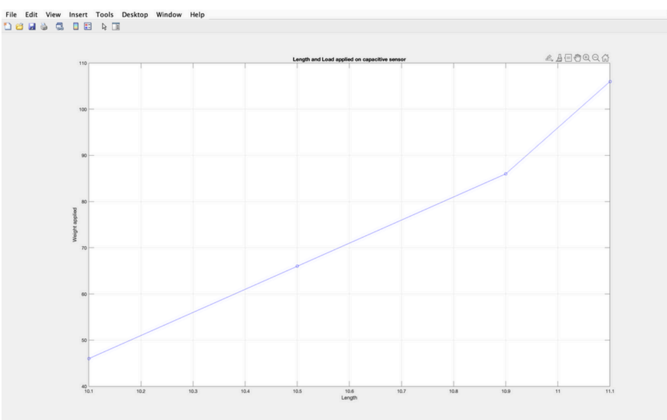

Fig. 8. Length vs Load applied on the Capacitive sensor

Plot for True Stress vs True Strain for Capacitive Sensor:

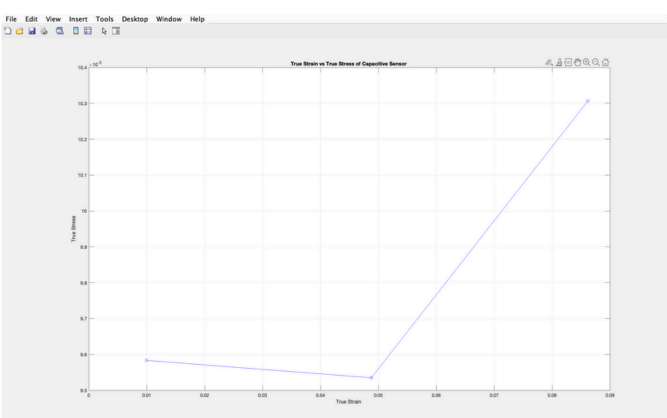

Fig. 9. True Stress vs True Strain for Capacitive Sensor

For the last experiment, we manually bent the PneuNet, McKibben and Fiber-Reinforced actuators to bending angles of 30, 45, and 60 degrees and noted their pressure readings.

TABLE VII
BEND ANGLE VS SENSED ACTUATOR INTERNAL PRESSURE

Bend Angle (°)	PneuNet (kPa)	McKibben (kPa)	Fiber-Reinf (kPa)
30	101.83	102.22	102.98
45	101.38	102.74	103.15
60	101.22	102.99	103.54

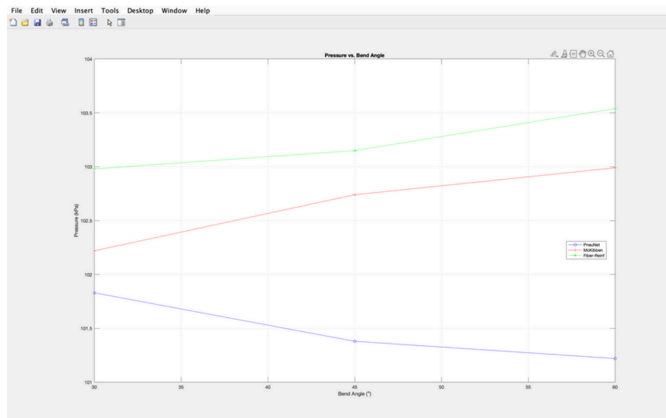

Fig.10. BendinganglesvsPressurevaluesforLab3actuators

III. DISCUSSION

Discuss (supporting your statements with experimental data) how responsive the two sensors are to tension, localized and distributed compression, and shear.

Both sensors responded at least in some form to all forms of stress, but they each responded differently to different types of stress. While the resistive sensor was quite responsive to shear, and very responsive to tension, it responded only slightly to both localized and distributed compression. The capacitive sensor on the other hand, responded very well to both localized and distributed compression as well as tension, but barely responded to shear stress at all. This can be seen in the data plots in section II analysis.

A. Noise Of The Capacitive Sensor

How could the noise in the capacitive sensor's signal be reduced? Consider changes that could be made to the sensor itself, as well as to the external circuitry. During the lab experiments, the capacitive experienced some noise. Soft capacitive sensors yield low power consumption, fast response, and facile fabrication. However, these sensors are susceptible to environmental contaminants like liquid and electromagnetic interference. A remedy to this problem is introducing external hardware to the sensor, like electrical shielding [1]. This would essentially increase the complexity of the entire fabrication process, but it is still relatively simple, as it can be done by coating the sensor with stretchable conductive material. A problem does arise from introducing such material. The new system may develop additional parasitic capacitance – an unavoidable capacitance between circuit components due to proximity– which may become larger than the capacitance of the sensing electrodes [2].

B. Sensor Sensitivity

Discuss and compare the sensitivity of the two sensors to applied strains and forces. Which aspects of the sensor design could be changed to modify their resolution/range Some improvements could be made to the sensors to increase their sensitivity to more types of forces and strains, although these often come with more complex fabrication processes. For the resistive sensor, the direction of strain most sensitive to measurement is the axis along which the zig-zag pattern stretches. Because of this one could for example use a 3D space-filling curve or some other similar arrangement, to lay the strip of conductive textile so that it will stretch well in all 3 directions. This of course presents quite the manufacturing challenge, so perhaps an easier design would just involve more than one 2D conductive strip, which would also make determining the precise direction of strain an easier task. With the capacitive sensor, similar arrangements of multiple sensors can also be very useful, as alongside the data from each individual sensor, insight into the strain and forces can also be gained by comparing the relative measurement differences between sensors. A simple example, is two capacitive sensors placed side to side, enabling good measurement of tension and compression (thanks to the individual sensors) but also of shear stress (thanks to the relative placement of both sensors and the difference in their readings)

C. Approaches To Reduce Sensor Limitations

Simple soft sensors like these are limited by their susceptibility to force coupling. What are some potential approaches for mitigating this limitation?

As mentioned before, a good approach to the problem of force coupling is to design sensing strategies that involve multiple coupled sensors. Having an array of multiple sensors respond with different response curves to the same force, allows you to use the measurements by themselves, and their relative differences to measure individual components of the force, and differentiate between types of stresses. Other approaches can also include designing the physical structure of the robot section containing the sensors, to dampen or nullify stresses that we do not want to measure, and amplify those we do want. Controlling which parts of the sensor are soft and which are rigid, we can artificially reduce the sensors sensitivity to particular types of strain. Combining this with multiple sensors arranged along various axis, it is possible to create sensing arrays that have very little force coupling, and also maintain good sensitivity for a broad range of motion and forces.

D. Pressure Vs. Bending Angle Of Fluidic Actuators

For the pressure-based sensor testing, you will be using the fluidic actuators that you fabricated in Lab 3. Since most of the fluidic actuators are bending actuators, you will be recording the changes in pressure versus the changes in bending angle.

As can be seen in the data plots in section II, all of the actuators from Lab 3 responded in some form to pressure sensing. While the changes in pressure were small, they were nonetheless noticeable. Interestingly, with the Pneu-Net actu- ator we observed a decrease in pressure with higher bending angles as opposed to the increase of the McKibben and Fiber- Reinforced actuators. Testing was difficult due to motions and bending in the tubing leading to the sensor also affecting the pressure readings, as well as drift over time from atmospheric pressure making its way back into the tube through imperfect seals. Despite these noise sources, we found pressure sensing to be quite reliable, and the ease of implementation made the setup quick and simple. This of course, comes with the limitation that the sensing must be done while the actuators are not being inflated. This does defeat the purpose of the actuators, but similar pressure sensing strategies could be used in non-actuated cavities in the robot, or cavities bonded to actuators, to effectively track the motion of the robot, though with lower resolutions of maybe a 1-3 degrees. We would need to perform further testing on inflated or partially-inflated actuators to see if we could reliably correlate an applied force with a pressure differential, assuming the actuation is accomplished with varying the amount of air and not the pressure directly.

IV. Appendix

References

[1] K. Ha, H. Huh, Z. Li, and N. Lu, “Soft capacitive pressure sensors: Trends, challenges, and perspectives,” ACS Nano, vol. 16, no. 3, pp. 3442–3448, 2022.

[2] C. S. Analysis, “What’s the difference between stray and parasitic capacitance?” April 2024. [Online]. Available: https://resources.system-analysis.cadence.com/blog/msa2021- what- s- the- difference- between- stray - and- parasitic- capacitance