JAMES DYSON FOUNDATION UNDERGRADUATE BURSARY

Distributed Sensing in Soft Robotics

PROJECT SUMMARY

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1 Introduction

Soft robotics is revolutionizing the field of robotics with new applications. In contrast to conventional rigid bodied robots, soft robots are made from highly compliant materials, taking inspiration from nature. Soft robots are able to navigate very tight spaces, and could be used, for example, to find and rescue survivors during natural disasters, for making soft, infinite degrees of freedom (DoF) input devices for precision control of machines, or for various medical uses. However, the control of soft robots remains an open challenge, as conventional feedback control methodologies will not work for these infinite DoF robots, due to their deformability and nontrivial interaction with the environment. The goal of my project was to make steps towards being able to reconstruct the shape and position of a soft robot, by using a distributed array of low-cost capacitive sensors.

2 Capacitive Sensors

A capacitor is an electronic component that is used in just about every electronic circuit. Their fundamental function is that they are able to store an electric charge. Their ability to do so is quantified by their capacitance. The main premise behind capacitive sensors is to allow the geometry of a capacitor to change when it is deformed by the soft robot containing it. This will change the capacitance of the sensor, which can be measured. The simplest form a capacitor can take is that of the parallel plate capacitor, as depicted in Figure 1a. To produce capacitive sensors, it was found that using the main soft material used in this project, Ecoflex, as the dielectric for these capacitors, would not allow for sufficient changes in capacitance to be measured upon deformation. Instead, leaving air gaps between plates allowed for capacitance changes to be detected. Using thin copper sheet as the material for the capacitor plates was found to be most effective. Images of some of the capacitive sensors produced for this project can be seen in Figure 1. The usage of stretchable materials, such as textiles or graphite coated Ecoflex was not tested here, but should be the focus of future work.

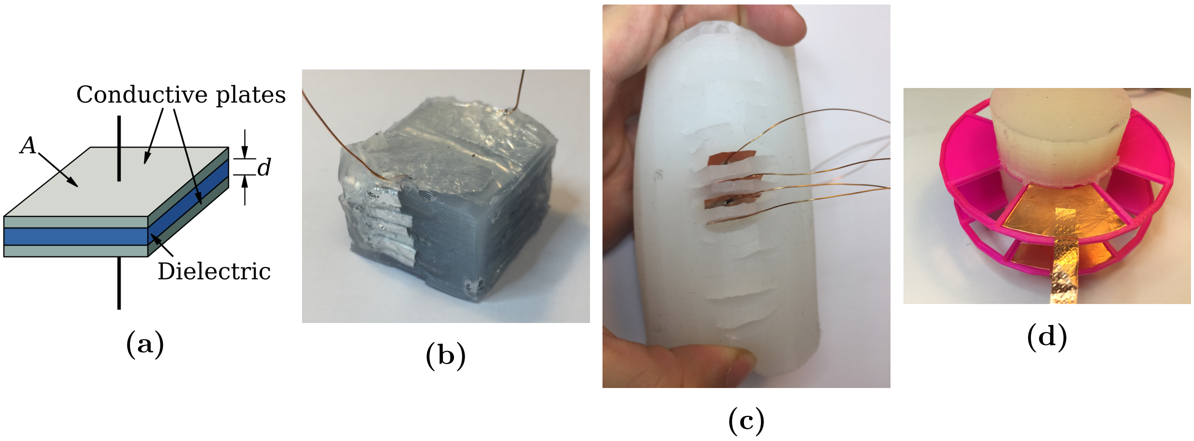


Figure 1: **(a)** A parallel plate capacitor. **(b)** A capacitor made by layering Ecoflex and aluminium foil. This did not give sufficient changes in capacitance, as the Ecoflex is too incompressible. **(c)** A soft cylinder with inserted copper plates to act as capacitor plates. This gave sufficient capacitance change due to the air gaps that open up upon bending. **(d)** A cylinder with embedded 3D-printed 'sensor discs', which each hold 4 capacitor plates. The final prototype was based of this sensor design.

3 Measuring Capacitance

Next, methods to measure the very small capacitances of the sensors were explored. It was found that any methods involving large resistor values, such as RC time constant estimation, would cause environmental noise to drown out any measurements. More success was found using a 555 timer IC configured as an astable oscillator. However, this method requires a separate 555 chip per sensor to be read, making this method very impractical. The best method was found to be using an MPR121 capacitive sensing IC breakout board, as it could allow up to 48 sensors to be read, in a much smaller footprint. These circuits can be seen in Figure 2.

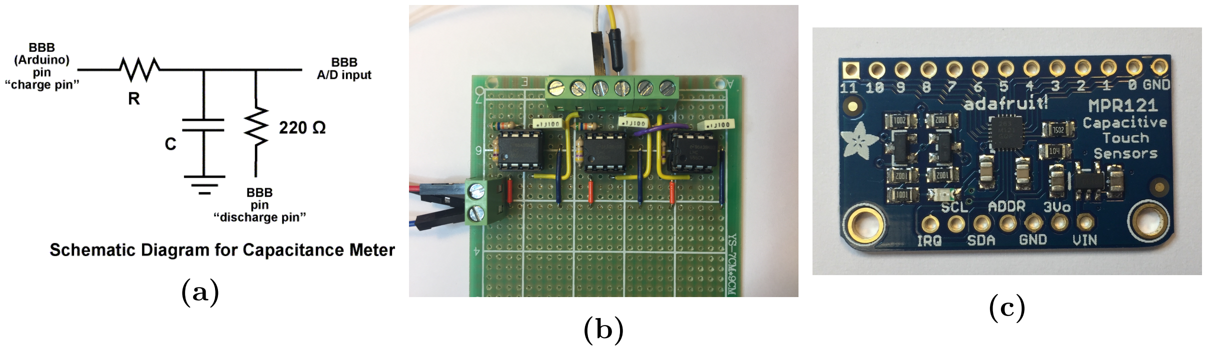
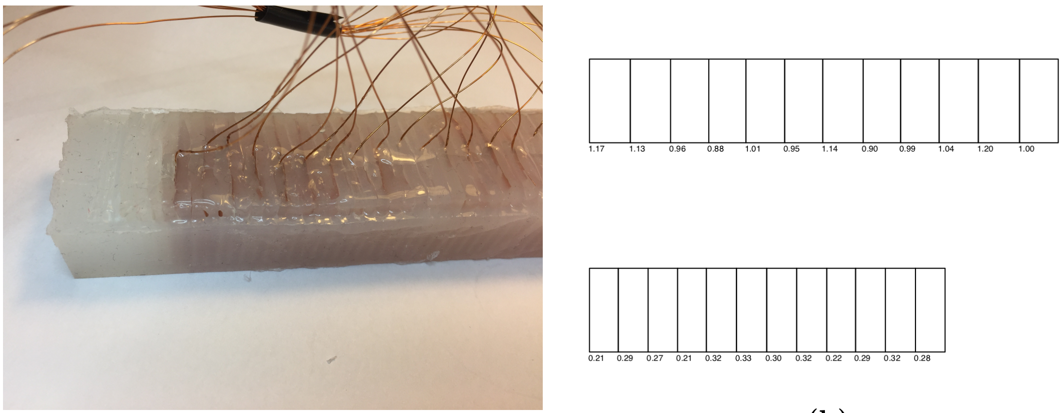


Figure 2: **(a)** A simple RC circuit that, in combination with an Arduino microcontroller is able to measure capacitance. This is only adequate for large capacitances, however. **(b)** 3 capacitance measurement circuits based on the 555 timer circuit, set up as an astable oscillator. An output frequency of this circuit can be measured using Arduino. This circuit was successful, but has a large footprint, as each sensor requires its own circuit. **(c)** The MPR121 chip breakout board. This was able to measure capacitance effectively, and also provides 12 measurement channels, in a very small package. All later stage prototyping was performed using this board.

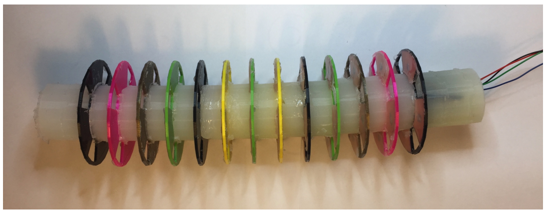
4 Producing Soft Robot Prototypes

Soft robot prototypes were produced using the soft silicone elastomer Ecoflex. A cylindrical bending prototype was produced which allowed air gaps to open up between adjacent sensors. This was found to be a very effective way to obtain measurable changes in capacitance. This fact was exploited in an axial prototype which was produced afterwards (Figure 3). The axial prototype consists of 12 parallel capacitive sensors in a row, which were successfully calibrated and could be used to reconstruct the deformed shape of the prototype. Lastly, a bending prototype was constructed using rigid, 3D-printed PLA sensor discs, which were embedded into an Ecoflex cylinder during the casting process (Figure 4). All wires for the sensors were routed inside the Ecoflex body of the prototype. Two MPR121 chips were used to successfully measure the changes in capacitance in this prototype. A calibration method was established, and used to produce meaningful deformation measurements, from which the shape of the bending prototype could be reconstructed. The shape reconstructions can be seen next tot hte images of the prototypes. For both the axial and the final bending prototype, the calibrated readings can be accessed, to develop a control strategy for those prototypes.

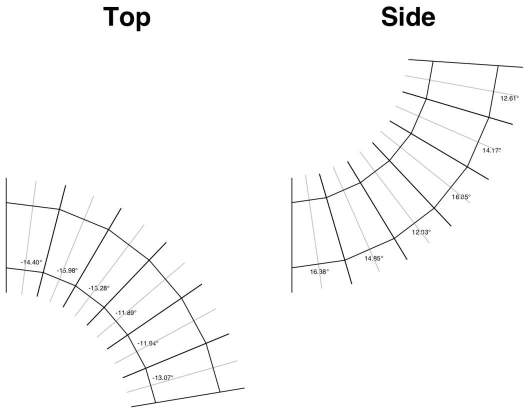


(a) **(b)**

Figure 3: **(a)** The axial prototype **(b)** Representation of the visualization of deformations in the axial prototype.



(a)



(b)

Figure 4: **(a)** The final prototype. **(b)** A representation of the visualization of the final prototype.

5 Conclusions

In conclusion, this project successfully produced soft robot prototypes endowed with distributed arrays of capacitive sensors. These could be read, calibrated and used to aid in developing control strategies for soft robots. Future work should focus on attempting to produce smaller, more compact sensors. To do so, smaller capacitance values should be able to be measured, so work is needed on the measurement strategies too. Flexible materials should also be considered for the production of the soft sensors.