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Summary for the 2019/20 Funded Project:

Capacitive Soft Skin for Shape Estimation

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1 Introduction

This report aims at providing high-schoolers, through the lens of a Master of Engineering project, some insights into the many different types of engineering careers they can pursue. When reading this article, high-schoolers may come across terms that are completely new to them. It is hoped that they will be motivated to Google some brief explanations.

The mentioned project focused on an innovative strain sensor shown in Figure 1, which when wrapped around an object is able to track its 3D shape in real time. The project goal was to explore the possibility of replacing the hazardous raw material of this sensor, carbon-black, with a special textile being both elastic and electrically conductive. (A simple version of textile sensor had already been invented by [2].)

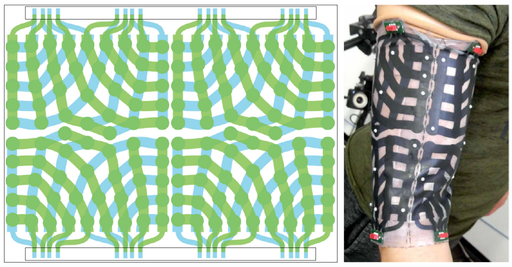
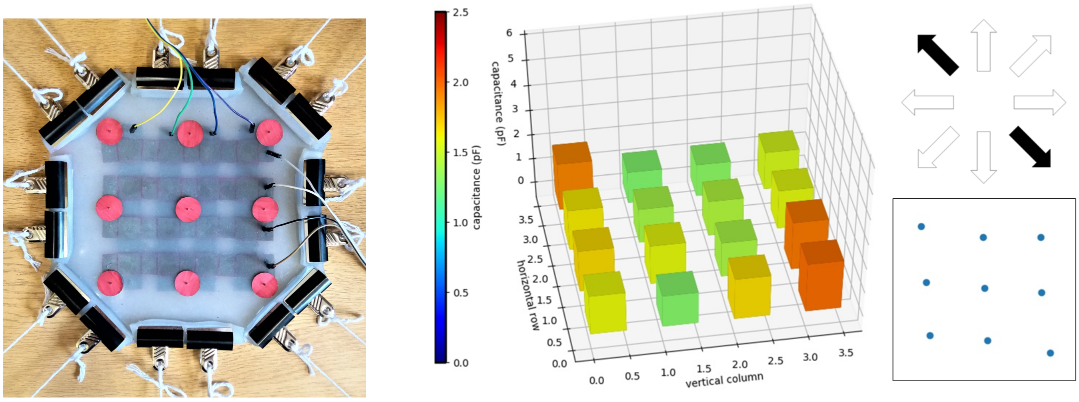


Figure 1: Shape of a human arm monitored by the carbon-black sensor invented by [1].

Therefore, as shown in Figure 2a, a new prototype of the sensor was fabricated out of such textiles. From measurements of the 16 capacitors embedded in the sensor, the 2D shape of the sensor can be deduced (Figure 2b). Further development beyond this project will enable its 3D shape to be reconstructed.



(a) (b)

Figure 2: (a) Textile strain sensor with 9 red markers attached and (b) its 16 measurements the pattern of which can infer either the direction(s) of applied tension or the relative positions of the markers.

2 Overview of Engineering Work Involved

The following subsections introduce how different pieces of work in the project fall into different engineering subjects a university student can choose to study.

2.1 Material Science - Raw Materials of Sensor

Apart from conductive textile, the bespoke strain sensor also consists of a second raw material - silicone. Stacking textile strips (electrodes) and large silicone sheets (dielectric and protective layers) in the way illustrated in Figure 3 produced an array of 16 parallel-plate capacitors. When each capacitor is stretched laterally, its capacitance increases, hence signalling some local deformation of the sensor at its position. The properties of these materials will be taught if a student studies Material Science.

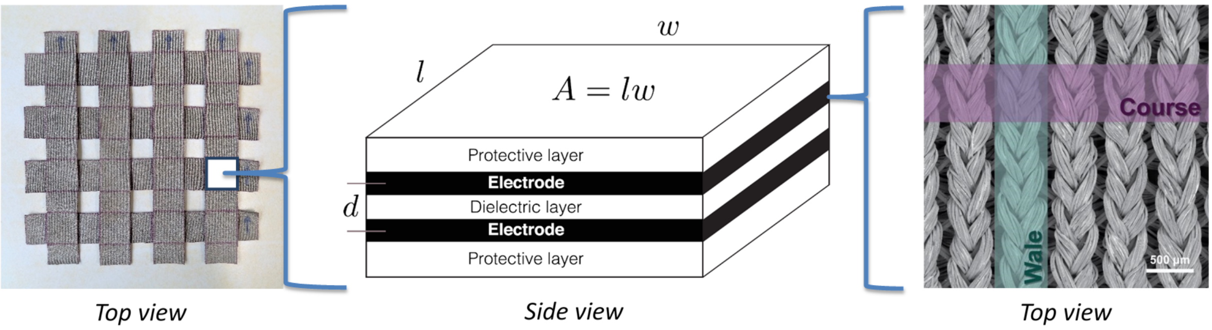


Figure 3: Three levels of sensor architecture - from macroscopic on the left to microscopic on the right.

2.2 Electronics - Circuit for Measuring Capacitances

A circuit was designed to enable measurements from individual capacitors, even though the 16 capacitors are interconnected via the textile electrodes. An electronics engineer need to know not only how to wire different circuit components together to achieve what they desire, but also how to write software which instructs a microcontroller to activate and deactivate the components at the right times.

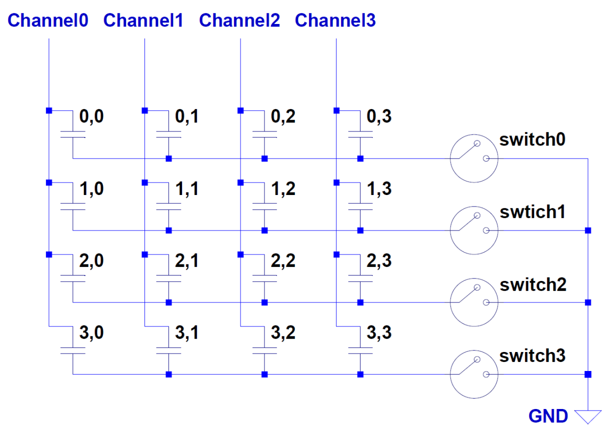


Figure 4: Capacitance-measuring circuit.

2.3 Geometry - Test Rig

In order to derive the capacitance-to-shape relationship for the strain sensor, tensions were applied to it from different directions and its capacitances and shape recorded. A test rig was designed and built so that the tensions applied were more reproducible (Figure 5).

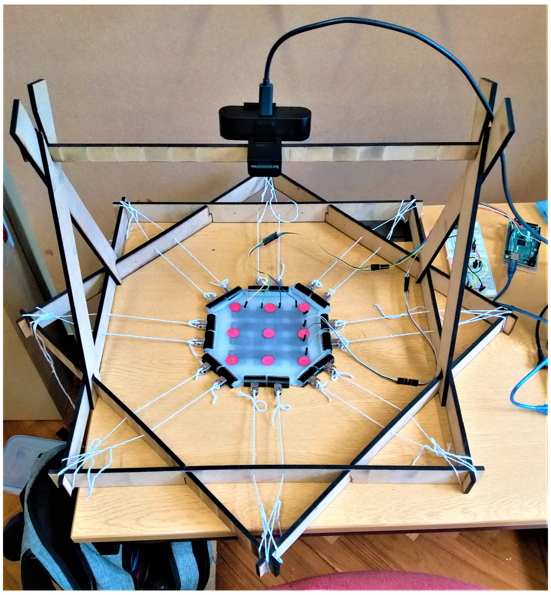


Figure 5: Test rig for standardising deformations and securing camera.

Being proficient in geometry is one of the many basic skills enabling a mechanical or structural engineer to design their machines or buildings.

2.4 Computer Vision - Track Ground-Truth Shape

The 2D shape of the sensor was represented by the relative positions of the 9 red markers. A camera was mounted above the sensor and captured images of the markers in real time. However this was not enough to track their positions - a colour filter needed to be applied to the images so that the red markers were highlighted. It was then from the filtered images that the coordinates of the markers could be obtained. Computer vision engineers, experts of extracting information from images and videos, use a large variety of image processing tools in their normal working lives.

2.5 Software - Synchronise Data from Multiple Devices

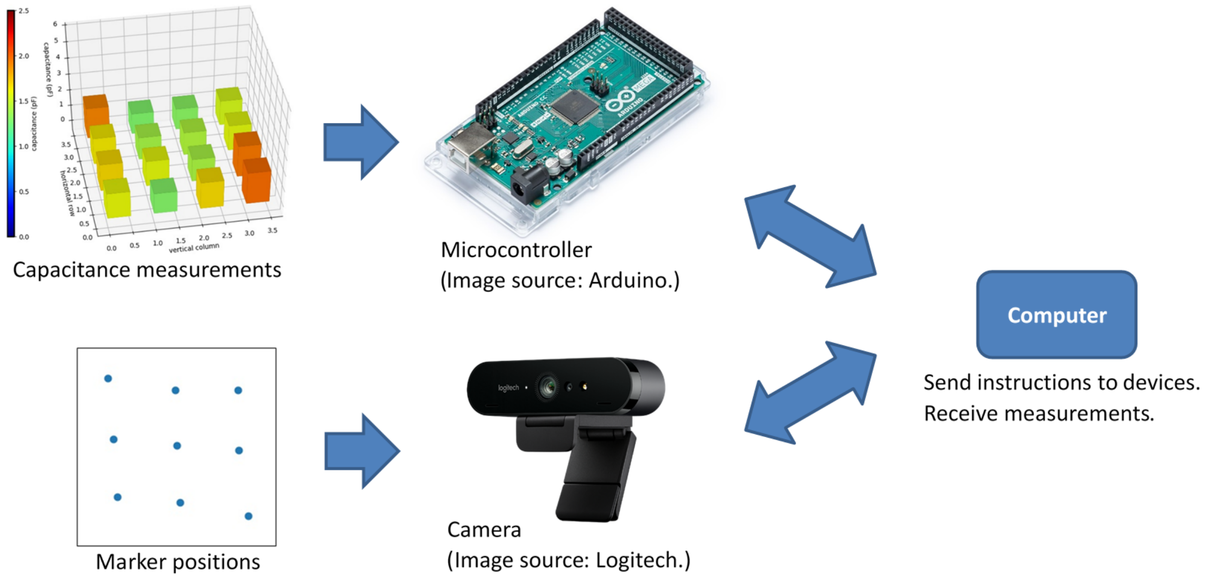


Figure 6: Schematic illustrating that measurements were initiated by a computer sending instructions to devices, and then the measured data got sent back to the computer.

Since capacitances and marker positions were measured by different devices, a central computer was used to instruct the devices to take measurements at the right times, so that matching measurements caused by the same deformation could be read at approximately the same time. Some software developers focus on enabling different devices communicating with each other.

2.6 Machine Learning - Create Shape Estimation Models

The final and most important stage of the project was to deduce from the collected pairs of capacitances and sensor shapes their underlying relationship. A machine learning model was first chosen (Figure 7), then the parameters in the model were tuned according to the collected data.

Advanced mathematics topics such as calculus and linear algebra are essential knowledge possessed by machine learning engineers. They are responsible for discovering insights or deriving relationships from data.

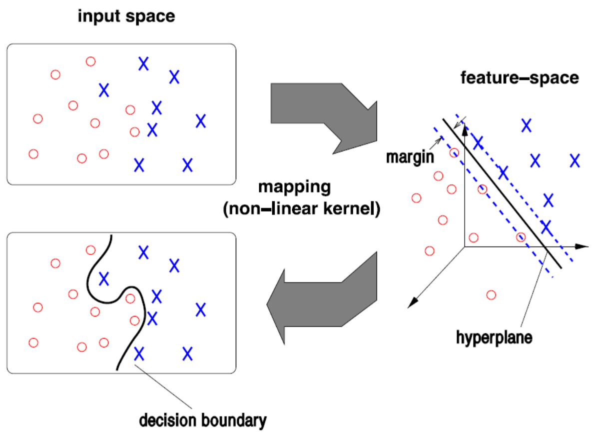


Figure 7: SVM model used to infer the directions of applied tensions from the 16 capacitance inputs. (Image source: [3].)

3 Takeaway for High-schoolers

The project summarised by this report was highly multidisciplinary, which offered the high-school readers a peek into many but not all of the available engineering subjects they can choose to study. Speaking as a graduating university student and future engineer, I would like to end this report with some advice to the readers - although you can choose to study a broad range of engineering subjects, the world highly values specialised engineers. Therefore, start reading and attempt mini-projects, and good luck in your journey of exploring which type of engineering is the most suitable to you!

References

[1] Glauser Oliver et al. "Deformation Capture via Soft and Stretchable Sensor Arrays". In: ACM Trans. Graph. (2019). doi: https://doi.org/10.1145/3311972.

[2] Atalay A. et al. "Batch Fabrication of Customizable Silicone-Textile Composite Capacitive Strain Sensors for Human Motion Tracking". In: Adv. Mater. Technol. (2017). doi: https://doi.org/10.1002/admt.201700136.

[3] Jose Miguel Hernandez-Lobato. 4F10 Lecture: Deep Learning and Structured Data - Support Vector Machines. Cambridge University Engineering Department, 2019.