An approach to validate the design and fabrication of dielectric elastomer tactile sensor

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ABSTRACT

We present an approach for evaluating the design of Dielectric Elastomer (DE) capacitive pressure sensors on robotic graspers. This approach has used the ANSYS software for Finite Element Method (FEM), along with a MatLab script for calculation of capacitance change. The model has been set up with an axisymmetric indenter and frictionless contact. This study has compared several structured dielectric elastomer (DE) pressure sensors with different sub-surface soft padding thicknesses.

The results suggest that:

- For padding that is too thin the contact area will be small with localized compression and sensor sensitivity will be compromised by this;
- For padding that is very thick compared with the sensor thickness –deformation will be spread over a wider area and the signal sensitivity will be somewhat lower; for a given indenter radius of curvature;
- This suggests that there will be an optimal padding thickness for a given contact geometry.

The approach developed and presented in the paper will be helpful for sensor soft sensor design for different applications, such as robotics and bio-instrumentational systems, in particular, the design of graspers to identify and pick up different objects.

Keywords: dielectric elastomers, capacitive sensing, padding, Finite Element Method, compression sensing

1. INTRODUCTION

A Dielectric Elastomer (DE) pressure sensor measures changes in capacitance under an applied load[1]. How it responds will be governed by many factors including sensor design, the materials of which the sensor is made and the substrate upon which the sensor sits.

In this study, we focus on DE pressure sensor design for robotic grippers. Most commercial grippers have a soft substrate we will refer to as padding. Padding enables the gripper to manipulate the object without load concentrations that could result in breakage of a delicate object such as an egg or fruit. In our concept gripper we place a capacitive load-sensing DE sensor above the padding layer. A question we wish to address is: how can we maximize sensor sensitivity in such a design? More specifically we want to address the influence of padding on sensor sensitivity. This issue has been identified by Chen[2] who studied the effects of padding under resistive strain sensors for a co-robot application. He noted that padding thickness influences the sensor's change in resistance.

In this paper, we present a method for designing such a sensor. Specifically we have used a finite element based contact model for predicting the deformation of a sensor sitting atop a padding layer, for a specific set of loading conditions, and then used this information for calculating changes in sensor capacitance.

2. METHODOLOGY

The proposed capacitive dielectric elastomer (DE) sensor with padding/substrate is illustrated in Figure 1. This sensor consisted of one signal electrode and two ground electrodes that are separated by different thickness layers of dielectric; it also includes padding beneath. The capacitance of this shielded sensor[3,4] is given by Equation (1):

$$\boldsymbol{C = \frac{2 * \epsilon_0 * \epsilon_r * A}{t}} \tag{1}$$

Where

C is the capacitance,

A is the area of overlap of the plates,

ε_r is the relative permittivity of the dielectric,

ε_0 is the vacuum permittivity,

t is the thickness of the sensor.

Note: The factor 2 is due to the layer structure of the sensor

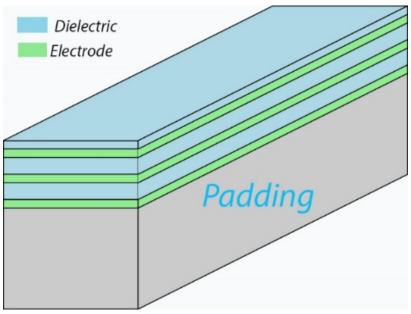


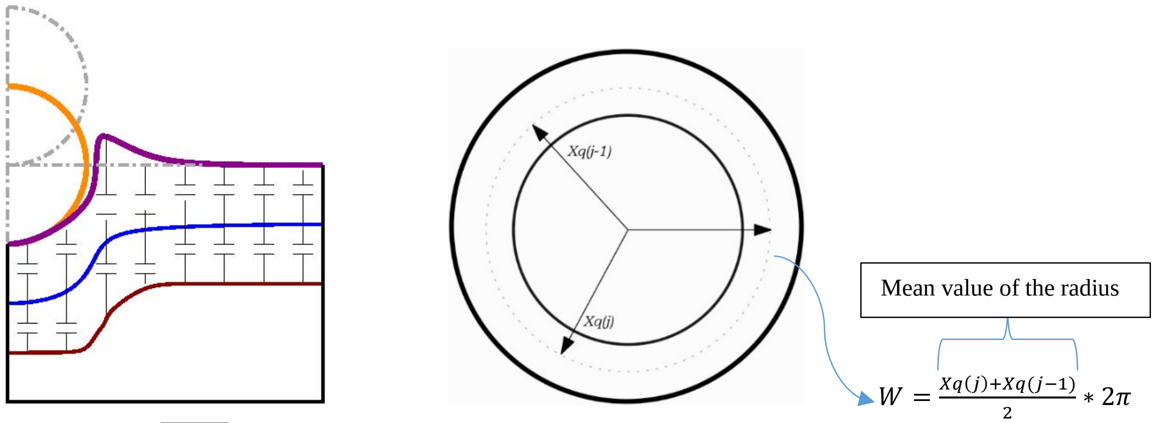
Figure 1. Overview of the shielded capacitive DE sensor with padding

Our goal was to develop a model in order to analyse and verify the relationship between the sensor deformation and capacitance change while different loads are applied and to investigate the influence of padding thickness on sensor sensitivity. We used FEM simulations carried out with a commercial package (ANSYS) to calculate the deformation caused by a spherical indenter. The resulting model displacements were then imported into a Matlab script to calculate the change of capacitance of the device associated with the deformation.

The following assumptions have been made:

1. The rigid spherical indenter diameter (Steel ball) was defined as 10mm;
2. The sensor and padding are composed of the same material (silicone);
3. The range of force was 1N-5N;
4. The element edge length was typically 0.05mm;
5. The contact surfaces were frictionless;
6. The analysis is set in an axisymmetric model;

Figure 2a is a schematic of a deformed DE sensor with two capacitance layers when load is applied from the indenter to the sensor. In Fig.2b we show the proposed sensor capacitance divided into small areas while the sensor deforms. By splitting the sensor into annular rings one element thick (approximately 0.05 mm) we were able to calculate local capacitance changes at a fixed radius from the centre and then sum these changes over the entire sensor.



(a) (b)

Figure 2. (a) The overview of the indenter and the proposed DE sensor deformation with the capacitance layout due to load applied. (b) The top view of the indented sensor area.

The model is based on a 10 mm diameter rigid sphere contacting a circular capacitive DE sensor on its padding. To validate this model, tests were performed on the proposed capacitive DE pressure sensor using an Instron 5866 universal testing machine with the Hioki LCR Meter IM3523 to determine sensor deformation and capacitance change (Figure 3). These experimental results were then compared with our FEM ANSYS model and with the capacitance change calculations using MatLab.

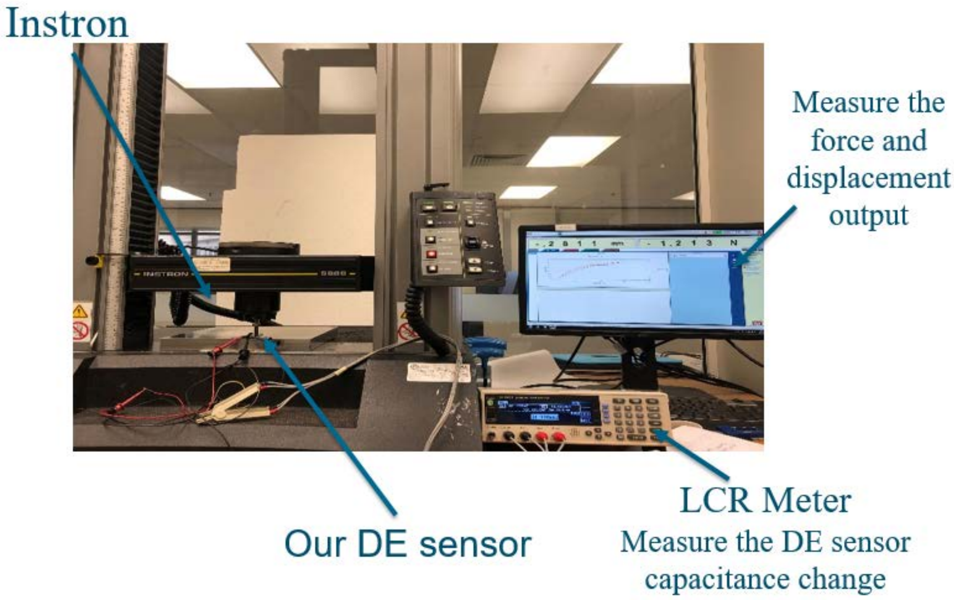


Figure 3. Measurement setup: Instron machine-applied different forces with an indenter in the designed sensor to record displacement and LCR Meter to monitor the sensor's capacitance change.

3. DE SENSOR MODEL DEVELOPMENT AND RESULTS

We fabricated two 2mm thick sensors with padding and a radius of 10mm for the experimental tests. After the fabrication, we measured every layer of thickness using the microscope to find out the actual sensor thickness (layers plus padding) was 1.84 mm. The experimental test was set up as illustrated in Figure 3 with a 10mm diameter indenter in contact with this capacitive DE sensor in compression to monitor the displacement and capacitance change. The applied force was from 1N to 5N at a frequency of 1 kHz with stable temperature. Data was recorded using an Instron machine and a LCR meter connected to sensor for capacitance output.

Figure 4 shows the comparison of the ANSYS modelling and experimental results when force was applied onto two different sensors between 0N to 5N with the changes of displacement recorded. The predicted sensor structure has given very similar deformation results between modelling and the experimental tests. Figure 5 shows the experimental capacitance measurement for the two sensors, and Figure 6 shows the capacitance change (ΔC) between the ANSYS model and the two sensors in the experimental results.

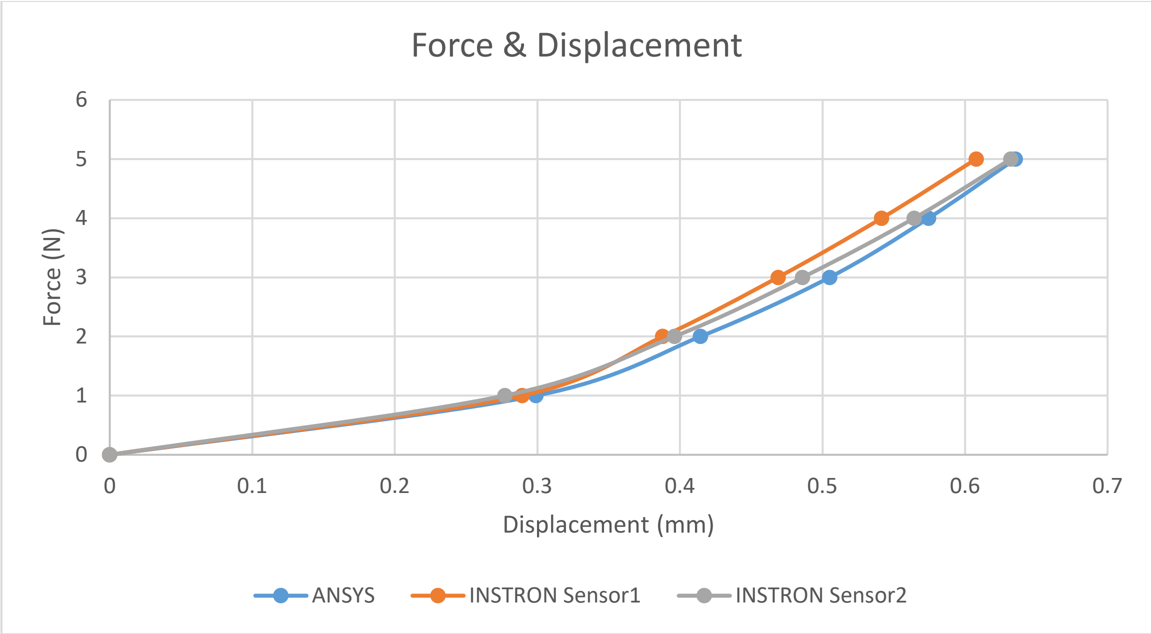


Figure 4. Comparison of FEM simulations with experimental compression measurement using an Instron universal tester. The total thickness of this sensor is 1.84mm, which includes the sensor padding of 1.1mm

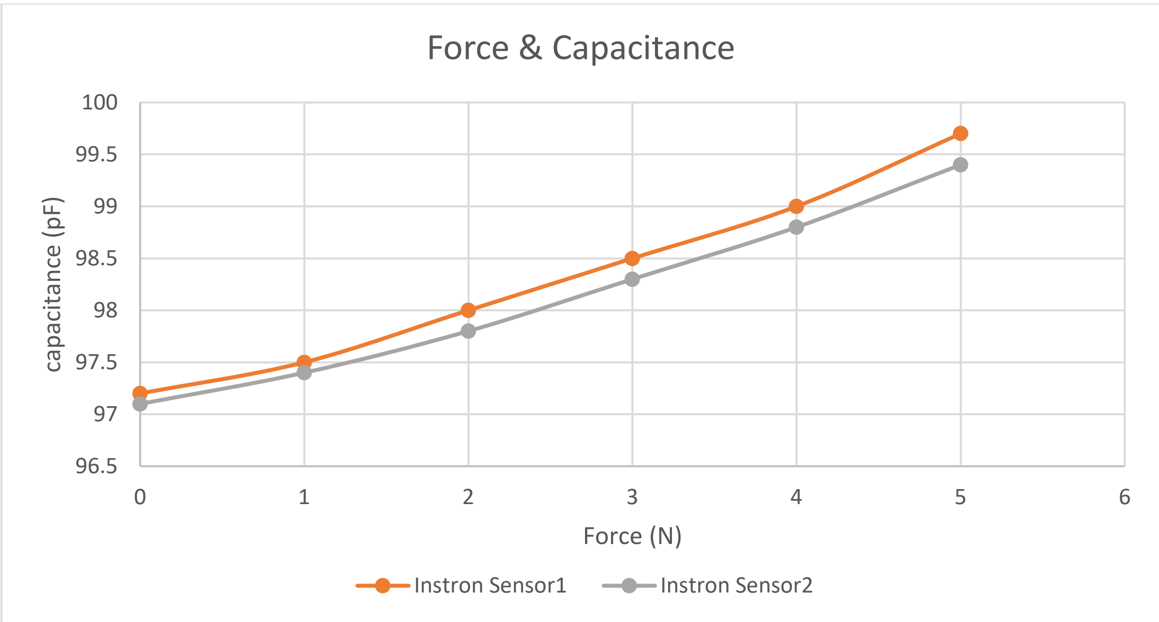


Figure 5. Change in sensor capacitance as a function of applied force on the indenter. (by Instron & LCR Meter)

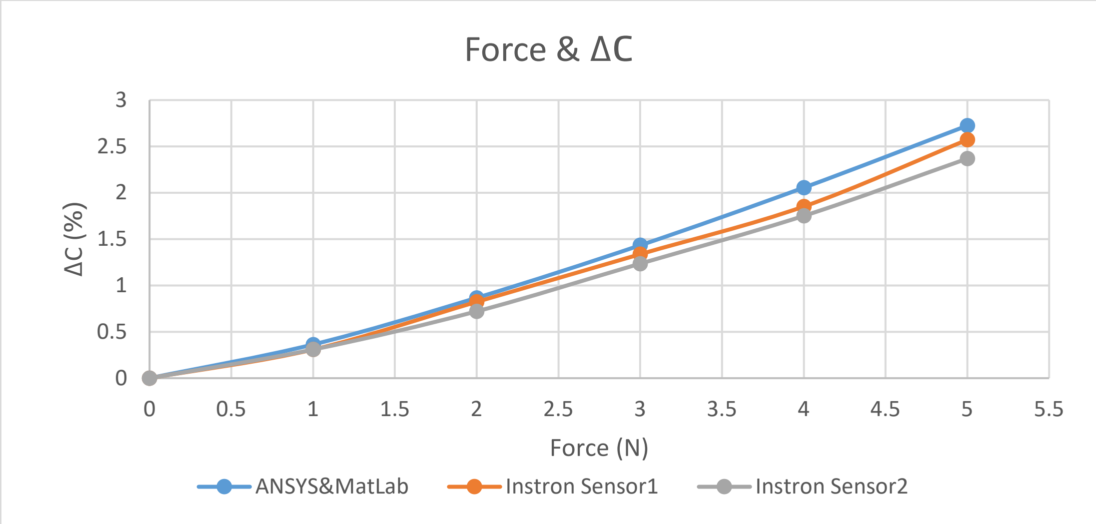


Figure 6. The Delta C changes between the ANSYS modelling results and the experimental test results (by Instron & LCR Meter)

We have used this method to look onto different thickness paddings (up to 9mm beneath with approximately 1 mm thick sensor) and the changes to capacitance when a 10N load is applied, as shown in Figure 7. The result suggests that there is an optimum padding thickness for sensor sensitivity.

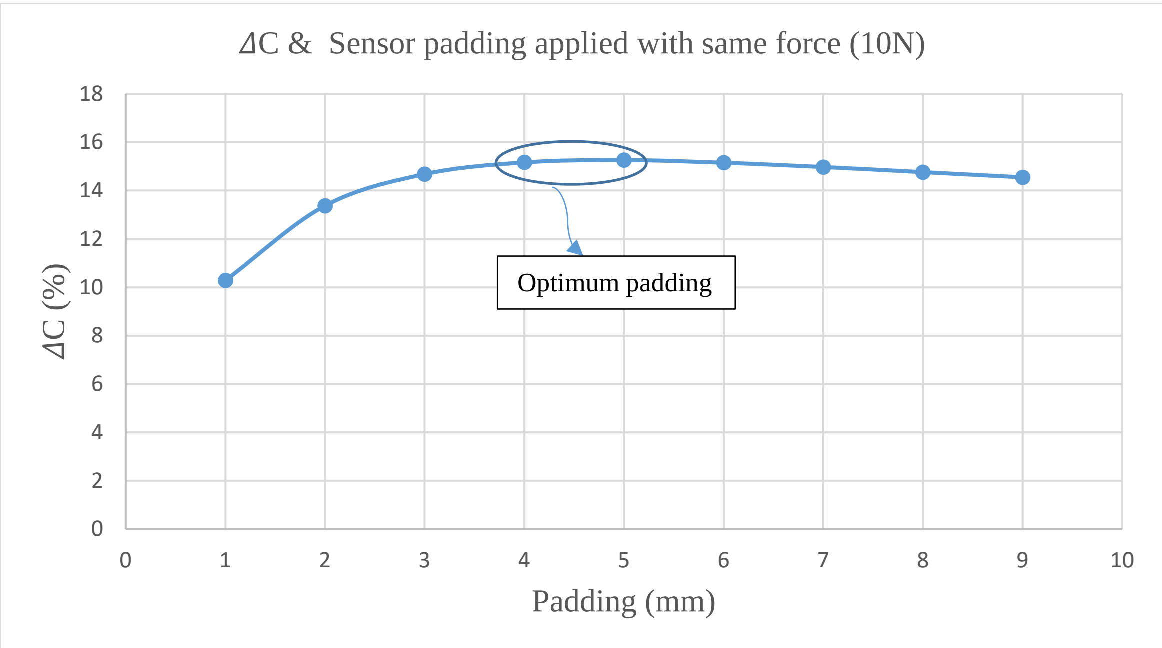


Figure 7. The modelling results of the Delta C changes when 10N load applied in the padding with different thickness

4. DISCUSSION AND CONCLUSIONS

In this paper, a FEM analytical model was developed to assist compression sensor design and fabrication. The simulated results of the design are in good agreement with the results presented for experimental data.

From the FEM analytical model, we simulated sensor deformation and then used this for the calculation of capacitance change. The results clearly show that for the same loading conditions padding in the DE pressure sensor will impact on the sensor's capacitance change and that an optimum padding thickness for good sensor sensitivity could exist. The area of contact or the micro-contacts depends on the load applied, which means, this could be predicted from the load expected for each application.

In conclusion, we have developed a model and method that is able to predict the deformation and resulting changes to capacitance for a DE sensor with different levels of padding beneath it. The sensor characteristics under specific conditions needs to be evaluated. The evaluation of the strain behavior from the elastic region of the standard stress-strain curve to the plastic region needs to be investigated.

Further development will focus on repeat for a range of indenter radii and loads for different sensor layer thickness and paddings. It should include a graphical 3-D model in order to compare it to experimental deformation. Improvements to the model and simulation should allow for multiple types of contact that could include various frictional conditions.

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