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Resistance Tuning of Soft Strain Sensor based on Saline Concentration and Volume Changes

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Abstract. Soft sensors have a wide potential in augmenting the functionality of soft robots for healthcare, by providing information without compromising the mechanical compliance. Soft sensors that are based on ionic solutions are of particular interest, as they can be used for in-the-body medical applications due to their biocompatibility. In this paper, we present a soft strain sensor whose resistance is tuned by varying its volume and its ionic concentration. The study opens up the possibility of creating soft sensors whose electrical properties could be adjusted dynamically in fluidic soft robots, in order to suit specific tasks.

Keywords: Soft sensors · Ionic solution · Microfluidic channels

1 Introduction

Soft robots are being increasingly used in the medical field, with applications in surgery, wearables and implants [1–3]. With their inherent compliance and potential biocompatibility, they are ideal for interacting with the human body. Additionally, given the demands of healthcare technologies and the required accuracy, there is a clear need for soft sensors to increase the autonomy of soft robots without compromising their mechanical properties [4]. Extensive work on soft sensors capable of proprioception and/or pressure sensing based on synthesized conductive elastomers has been carried out [5]. There have also been

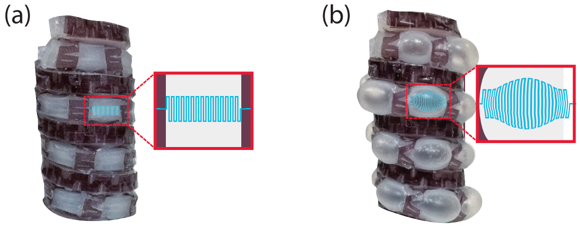

Fig. 1: Conceptual integration of the soft sensor in an implantable soft sensor for tubular tissue regeneration to sense strain/pressure on the tissue [3].

recent developments in the use of ionic solutions and hydrogels, as equivalent and biocompatible conductive liquid for the sensors [6, 7], thus getting closer to soft robots being implemented within the human body. The use of ionic solutions for sensing has been previously explored by investigating piezoresistive effect throughout elastomeric models. The effect of varying parameters such as the input AC frequency or concentration has been studied previously [7], but little work has been done on varying the volume within the same sensor. In this work, we present a soft strain sensor that can be embedded into soft actuators, such as shown in Fig. 1[3]. We characterise its resistance for two different volumes of ionic solution and two different concentrations, demonstrating the potential to tailor the sensor depending on the range of motion to be detected.

2 Materials and Methods

2.1 Fabrication

3D printed moulds printed on a Form2 3D printer were used to cast the soft sensor layers. These layers were made out of Ecoflex 00-30 (Smooth On Inc.), mixed using an ARE-250 Mixer (Thinky), degassed and then poured into the moulds curing at air temperature (Fig. 2). The Ecoflex was then post-cured in the oven for two hours at 80°C and one hour at 100°C. Finally, the sensor layers were bonded together using uncured Ecoflex 00-30, after which the ionic solution was injected and sealed using copper leads. The general dimensions of the sensor are 100x30x3mm, with a 1mm^2 cross-sectional area serpentine channel with an active area of 700mm^2.

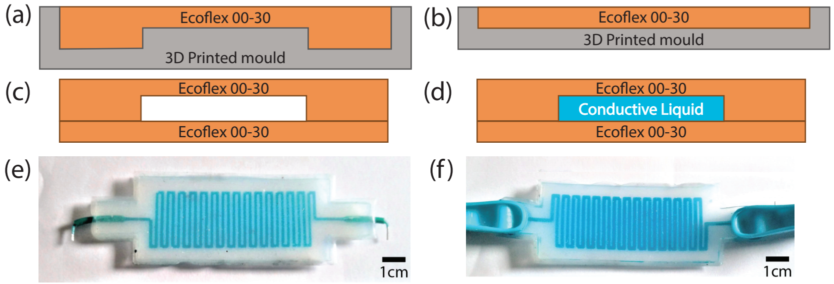

Fig. 2: Schematic of the major fabrication steps. (a) and (b) the layer with the channel and the top layer respectively are moulded and cured separately. (c) The layers are joined using uncured Ecoflex 00-30. (d) The ionic solution is injected. (e) and (f) Photo of the assembled sensor with 1mL and 3mL of ionic solution respectively.

2.2 Experimental Procedure

The sensor was tested under tension using a Zwick Roell Z020 tensile test machine at a speed of 20mm/min. (Fig. 3). For the experiments, two different concentrations - 25% and 33% of NaCl to water by mass - and two different volumes - 1mL and 3mL - were tested. A 15kΩ resistor was connected in series with the soft sensor, and monitored using a NI USB-6009 DAQ board at a frequency of 2.4kHz. The circuit was connected to a Gwinstek SFG-1013 function generator and supplied with a 1V 1kHz voltage sine wave.

The rectified voltage signals were filtered using a moving average with a window size of 240 points. The sensor resistance was then calculated using the voltage divider equation ($R_{sensor} = R_{15k\Omega} \times \frac{V_{supply} - V_{mes}}{V_{mes}}$).

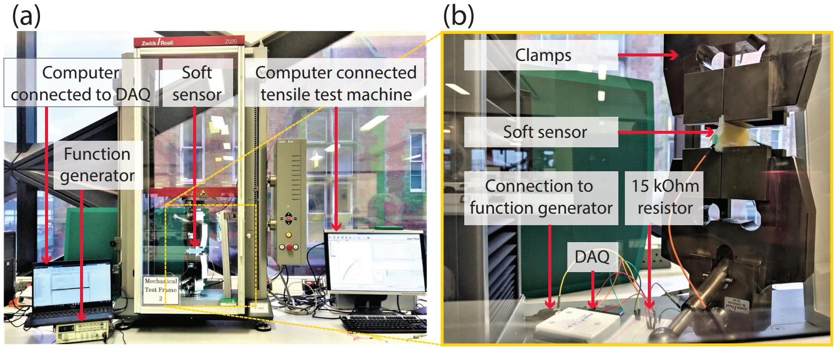

Fig. 3: Experimental Setup (a) Full setup. (b) Enlarged view of the soft sensor attached to the tensile test machine.

3 Results

Fig. 4 shows the average increase in resistance as the sensor was stretched to 20mm for the baseline concentration of 33% and volume of 1mL, as well as the increased volume of 3mL and the decreased concentration of 25%.

The sensor with decreased concentration has a resistance of roughly 10kΩ higher than the baseline sensor throughout the travel. The resistance for the sensor with increased volume is around a third of the resistance as the baseline sensor for the same travel.

4 Discussion

A decrease in the sensor resistance with increased volume is observed, as well as an increase in resistance when the concentration decreased. The decrease in resistivity for the increased volume is in accordance with Pouillet's law, which states resistance as inversely proportional to the cross-sectional area, although more work needs to be done to characterise this effect fully.

The large variation of resistance for an increased volume is also promising. With the resistance ideally equal to the series resistor, the sensor with increased volume would be more accurate for larger displacements, while the sensor with less volume would be more accurate for smaller displacements.

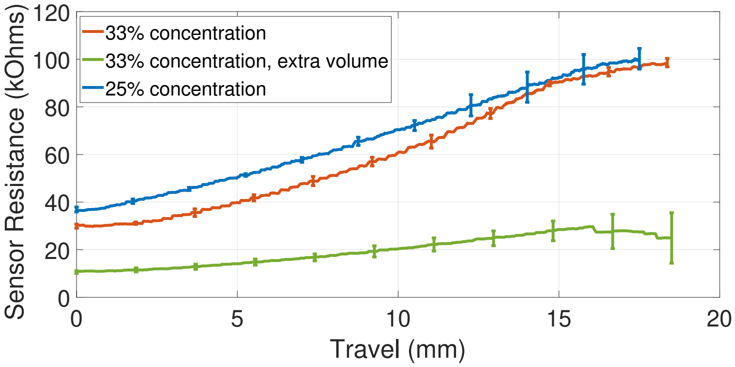

Fig. 4: Sensor resistance vs displacement for the three different testing conditions. The error bars represent one standard deviation across three trials.

5 Conclusion and Future Work

We present and characterise a soft sensor to be integrated as the skin of soft implantable robots. The results in the study are promising and show a potential to tailor not only the concentration, but also the volume of ionic solution for the desired sensing range. As future work, we will investigate techniques to vary the liquid composition of the soft sensors to automatically tune its characteristics. This is desirable when the environment in which the soft robots operate changes.

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