Development of a resistive-based sensor for real time shape detection of a spring based flexible manipulator

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INTRODUCTION

Flexible robots can play a vital role in performing complex surgeries and diagnoses in minimally invasive procedures. Though they are good in adapting to various shapes, their control is difficult. Their flexibility creates uncertainty in their shape which may lead to damage of healthy tissues due to unwanted interactions. Therefore, the requirement of accurate and real time shape sensing is essential to achieve precise motion control of continuum manipulators. Image-based shape sensing [1] can suffer from the use of large radiation doses, dependence on nephrotoxic contrast agents, low resolution, and low signal-to-noise ratio. As an alternative, electromagnetic (EM) based shape sensing approaches are also used. Tully et al. [2] fused EM pose data with a kinematic model to reconstruct the shape of highly articulated snake robot. Song et al. [3] presented shape sensing of a flexible robot using the EM information from sensor and robot length. EM based methods have advantages like miniaturization, no obstruction of the line of sight, high sensitivity, etc. However, they suffer from disturbances due to presence of ferromagnetic material in the workspace. The tracking workspace is also limited on the EM field strength. To deal with these limitations, Sefati et al. [4] used a data driven method of regression modelling by taking information from Fiber Bragg Grating (FBG) sensors for shape reconstruction of a continuum manipulator. Liu et al. [5] used two modules, each consisting of three FBG nodes for shape sensing of continuum manipulators. These techniques show advantages such as fast response, miniaturization, high sensitivity, and negligible EM noise. However, their high cost and poor response to high strains limit their implementation in shape sensing. This paper presents the design of a flexible resistive shape sensor, fabricated by using a commercial conductive rubber, which is intended to detect the bending of a spring based mobile manipulator [6] using a constant curvature algorithm. The sensor shows several benefits in terms of cost, high elasticity, negligible electrical noise, freedom from high radiation doses, and large stretch-ability.

MATERIALS AND METHODS

Reconstructing the shape of a flexible robot requires the estimation of arc parameters. A commercial conductive rubber of 2mm in diameter made of carbon infused rubber from adafruit industries (Product Id – 519, USA) was cut into different lengths to be implemented as resistive sensor integrated in the spring based manipulator, available in the team [6]. Whenever the flexible manipulator bends, the length of the sensor changes and this in turn changes its resistance. Using this change in resistance, the arc parameters of the manipulator curvature can be estimated. The resistance of the material in relaxed state is 140-160 Ohm/cm, with a Young's Modulus E=11MPa. We assume that the sensor doesn't affect the performance of the manipulator because it imposes only an extra actuation force of 1.44% (difference between actuation force of the manipulator with and without sensor). In the next step, a prototype of 30mm length was prepared and used for hysteresis analyses. Using a Universal Testing Machine (Instron, Model-4464, Italy), tensile tests were performed and mechanical hysteresis was determined from the resulting stress-strain relationship. Since the manipulator we consider does not exceed 20% strain, the sample is also subjected to a 20% strain. We performed ten cycles to simulate multiple loading and unloading conditions, varying also the strain rates (10mm/min, 30mm/min, 50mm/min, 100mm/min and 200mm/min) to observe the effects on mechanical hysteresis behavior. A custom testbed was used for electrical characterization. 20% tensile strain, for one cycle and ten cycles, was applied on the sensor using a linear stage. The voltage across the sensor was measured using a DAQ system (NI USB-6259) while the sensor was connected to a DC voltage source through a voltage divider circuit. The voltage and strain data acquired were used for determining electrical hysteresis. Furthermore, one pre-stretched (5%) sensor was embedded on the periphery of the spring-based manipulator with the help of nine 3D printed holders. Five different bending deformations were applied manually by hand (figure 1) and voltage data was acquired at each deformation using the same voltage divider circuit. Finally, the relationship between voltage across the sensor and arc radii of manipulator generated manually was estimated by curve fitting a 3rd order polynomial. The unknown value of the arc radius can be estimated by acquiring the voltage data and using in the determined relationship.

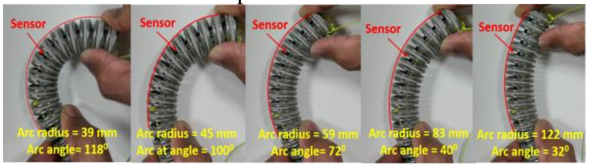

Figure 1: Bending deformations applied to the manipulator

RESULTS

The mechanical hysteresis curve for the sensor is given in figure 2. To stretch the sample to 20% deformation, 2.7 MPa stress is required. In ten cycle experiments (figure 3) at different strain rates, mean hysteresis was found as 21% with standard deviation of 0.6%. The electrical hysteresis behavior of the sensor for single and multiple cycles can be seen from figure 4. The sensor produces 7.8% of voltage change for 20% elongation.

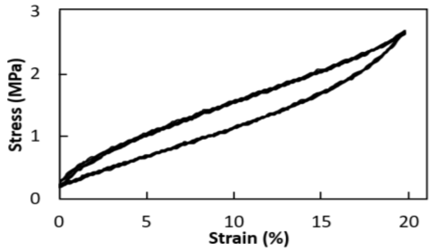

Figure 2 : Mechanical hysteresis for 10 cycles

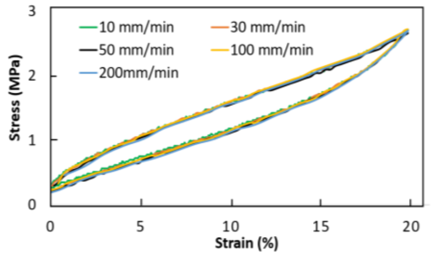

Figure 3 : Mechanical hysteresis at various strain rates

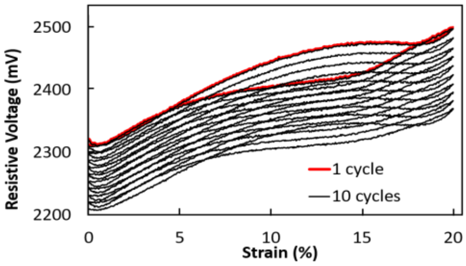

Figure 4 : Electrical hysteresis for 10 cycles

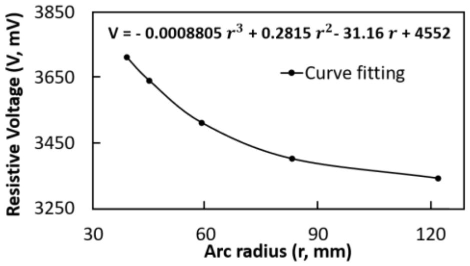

Figure 5 : Curve fitting and sensor calibration process

As discussed in the previous section, for sensor calibration the manipulator was bent into five different known radii manually (figure 1) and the voltage across the sensor was measured. The resulting voltage values were fitted into a third order polynomial with respect to arc radius as shown in figure 5. To verify the accuracy of this relationship generated, now four unknown bending deformations were applied to the manipulator manually and the voltage across the sensor was measured. The arc radius was estimated from the relationship shown in figure 5 and was compared to the arc radius calculated geometrically (figure 6). Finally, the error in the arc radius estimation was found as 3% on average.

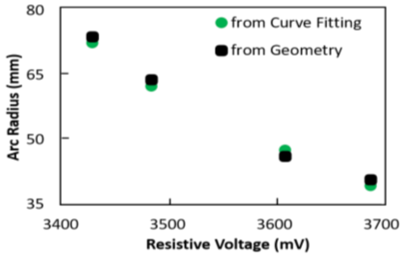

Figure 6 : Comparison of arc radius estimated from curve fitting and from geometry

CONCLUSION AND DISCUSSION

In this paper we present the development of a flexible and stretchable resistive shape sensor using a commercial conductive rubber. The mechanical hysteresis curve is repetitive over 10 cycles. At higher strain rates, such as for 200 mm/min, the hysteresis behavior also remains nearly the same as for low strain rates such as 10mm/min and 30mm/min. In case of electrical characterization, it produces 7.8% voltage change for a deformation of 20%, which is enough to be measured. In successive loading cycles, the resistive voltage across the sensor reduces due to the presence of electrical hysteresis and delay in restoration of the original material behavior of the sensor after each cycle. This analysis of hysteresis can help to increase accuracy of the shape sensing methods. After characterization, the sensor is embedded into a spring-based manipulator and a relation between voltage across sensor and arc radius is determined by fitting a 3rd order polynomial. In future a constant curvature shape reconstruction algorithm will be implemented using three resistive sensors uniformly distributed across the periphery of the manipulator. The presented sensor could also be implemented in other systems such as cable driven manipulators using proper wiring management.

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