Resistivity Characteristics of Piezoresistive Based Transduction Tactile Sensing Using Pressure Sensitive Conductive Rubber Sheet

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Summary: This paper presents the development of a tactile sensor based on pressure sensitive conductive rubber and outlines the resistance measurements performance. This sensor is specially designed for a robotic hand developed at UiTM Faculty of Mechanical Engineering. It exhibits piezoresistive like behaviour whose resistance change with force/pressure enables its applications as tactile sensor. The operating principle and hardware architecture of the sensor is explained. This study results in finding new alternative material selection for tactile sensor which needed more exploration and experimentation in order to discover their potential as tactile sensor for robotic hand as well as other field. In this paper, the working principle and sensor design concept are described. Further, experimental results and analysis of materials resistance characteristics are presented. The test results indicate significant drop of resistance with the increase of applied load.

Keywords: Pressure Sensitive Rubber, Sensor, Piezoresistive.

1. Introduction

Unlike the robots of 20 years ago, today's "intelligent" robots can "sense" changes in their surroundings and can respond accordingly. New developments in sensor technology have been critical to create intelligent robots. Intelligent sensors can monitor variations in temperature, force, torque, weight, position, and other parameters. One of the emerging sensors is the tactile sensor.

According to Dario, tactile sensing can be defined as the detection of the wide range of local and distributed parameters [1]. While Lee and Nicholls interpret tactile sensing as the process of determining the various properties and situations with respect to the contacted object [2]. The definition that was given by Lee and Nicholls is more accurate and appropriate as the sensor should be able to measure every parameter prior to the contact with object such as texture, shape, slip, feedback from contact surface and the correct grasp suitable for the object. Previous scholars like Crowder [3] defines tactile sensing in a simpler way as the tool of perpendicular force detection and measurement at the predetermined sensory area. Bear in mind that the new technology and integrated tactile sensor required more than that. As the emerging on high technology robot such as humanoid, robotic arms, and prosthetic hand, the demand on the high definition and intelligent tactile sensor that go beyond the force detection is a must. Thus it is crucial to study the previous work concerning the development of the tactile sensor in order to explore, improve and develop the new generation of the tactile sensor that can perform task that is similar to human appearance senses of touch as well as other sensing applications.

Previous study had shown the use of various types of transduction principle for the tactile sensor [4]. They are resistive sensors, tunnel effect tactile sensors, capacitive sensors, optical sensors, ultrasonic bases sensors, magnetism based sensors and piezoelectric sensors. Each sensor has its own advantages and disadvantages. Piezoresistive tactile sensor like microelectromechanical system (MEMS) and silicon based touch sensor are appealing because of high sensitivity and high spatial resolution, however the physical properties of silicon that are fragile and brittle in nature limited its application [5]. Magnetic type transduction usage is limited to nonmagnetic medium and not suitable to be used in harsh environment because of signal instability and complex computation [6]. But, the advantages include high sensitivity, no hysteresis and robust. Other types of material used in sensor can be very complicated, excessive wiring, and expensive to produce.

Other than that, the factors that still limit the development of the new definition of tactile sensor is because they are too big to be used without sacrificing the sensing element [7] such as fragility, mechanical stability, robustness and etc. Among sensors that have these limitations is optical sensor based transduction. Although the sensor is superior, the sizes can limit the application of it when comes into flexibility of integrating it with humanoid robot applications. For example, it is reported that a research conducted on miniaturizing optical sensor but still result in bulk size [8][9]. Most of the existing sensors use rigid material as the sensor construction [7] e.g. ceramic and quartz. This rigidity limits the sensor in dynamic application but recently, it is discovered that softer material such as rubber, fluids and powder have more preferable characteristics for contact sensor [10].

Because of that, more research should be done concerning this area by exploring new types of materials that can eliminates the problems constitute the current existing sensor. This study results in finding new alternative material selection for tactile sensor which needed more exploration and experimentation in order to discover their potential as tactile sensor for robotic hand as well as other field.

2. Sensor Working Principle

This sensor uses a material that operate base on resistive transduction principle. It is called pressure sensitive conductive rubber with a Shore A hardness of 45. As the name implies, it is a conductive material when pressure is applied. This material exhibits features whose resistance changes with force/pressure. The resistance comes from the conductive carbon pills that are used to manufacture this material. When there is no present of force/ pressure the particles will be apart from each other and the resistance is infinitely large (>30Ω). With the existence of pressure, the thickness of the material will be decreased and the conductive carbon particles will be contacted with each other thus creating an electrical path/flow that will drop the resistance value at the pressure region. Once the pressure is cancelled, the elastic material returns to its original thickness and so the resistance (Figure 1). The characteristics of the sheet are as follows (Table 1):

Table 1. Characteristics of Pressure Sensitive Conductive Rubber [11].

Characteristics	Data	Conditions
Operating Voltage Range	0-30V	DC or AC
Resistance Without Pressure	>30MΩ	25°C
Min.Resistance Under Pressure	0.1Ω	25°C
Max. Pressure	15kg/cm^2 or 210 psi	25°C
Density	1.75g/cm^2	25°C
% Elongation	70%	25°C
Thickness	0.5mm	-

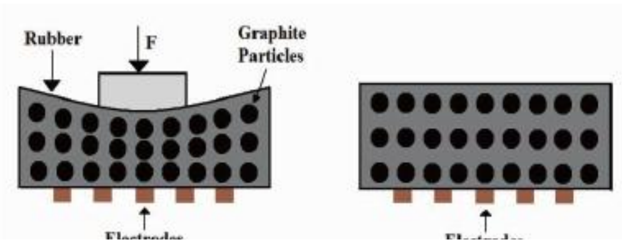

Figure 1. Tactile Sensor based on Pressure Sensitive Conductive Rubber. With and without pressure.

3. Sensor Hardware

The structure of the tactile sensor will be consisted of 3 layers (Figure 2). First layer is the urethane gel (manufactured by EXSEAL.co), second layer is the pressure sensitive rubber (manufactured by ZOFLEX) and third layer is electrode patterned sheet that act as the sensing element. When pressure exerted to the sensor, it will deform the urethane gel and make pressure distribution to the pressure sensitive rubber. The area of pressure contact becomes thin and electrical resistance of the region drops because of the electrical conduction particles contain in the rubber. The change of the electrical resistance will be detected by the electrode patterned sheet to determine the value of pressure load exerted to the sheet. The electrode pattern sheet was made by outsourcing it to the trusted manufacturer. It consists of a multilayer printed circuit board, which was taken into consideration in the design. Thus, 16 elements could be arranged on the sensor. The total size is 1.8 cm x 1.5 cm x 0.5 mm.

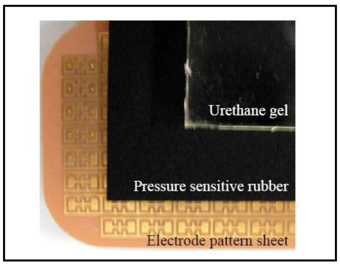

Figure 2. Layer of Tactile Sensor.

The data acquisition system is realized by the design of rigid PCB of sensor electronic board circuit that uses the principle of voltage divider. It changes the variance of resistance that sense by the electrode patterned sheet to voltage variance. To evaluate/measure and process the sensor data, the microcontroller board Arduino Duemilanove is used. But, for the purpose of this paper, the resistivity investigation will be carried out by using resistance value and can be measured by using a multimeter.

4. Resistance Measurement

Three series of experiments were done in order to study the resistivity characteristics of this material. The test was mainly done using the setup as in figure 3. By only utilizing one element from the sensor, various known weights were placed onto the sensor by mean of brass rod and supported by the aluminium rack. The brass rod (diameter 4mm) acts as a probe to exert force onto the sheet with selected sensing elements. Resistance readout was measured by multimeter.

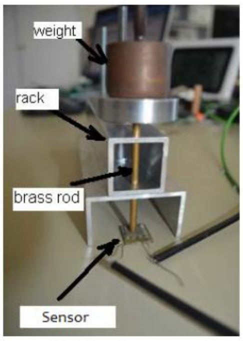

Figure 3. Measurement Setup.

First experiment (Figure 4) was carried out to determine the material resistivity characteristics with respect to different values of weight. To ensure the data reliability, the test was repeated eight times by using the same weight and setup. The weigh loading time was 10s. As for the second experiment (Figure 5), the test was carried to determine the resistivity characteristic of the sheet with varies load from 0kg-1kg and back from 1kg-0kg without ever lifting the weight from the sheet. The author wants to study how the sheet behaves when no loading time was given for it to return to its original shape. Experiment three on the other hand (Figure 6) was to found out the resistance behaviour of the sheet with respect of time with constant 500g load.

4.1 Results of the Experiments

All the data in Figure 4 shown significantly drop in resistance with increase of weight. At <150g, the resistance value for all test are as high as 120MΩ. It only begins to drop rapidly at approximately from 200g to 300g. Only then the resistance drop begins to have similar patterned with each other. This test indicates that over prolonged time and increased weight the value of resistance became stable and reliable.

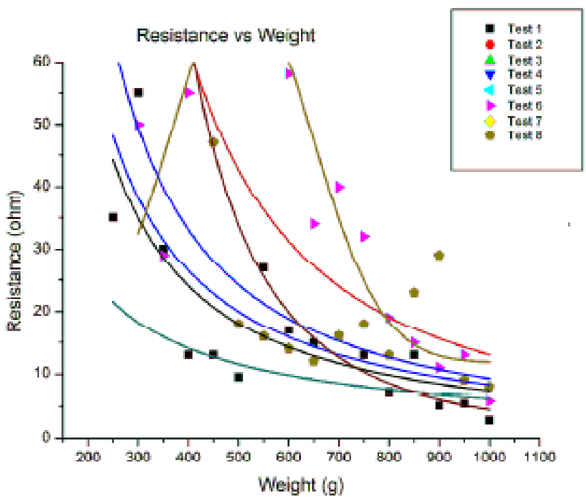

Figure 4. Resistance change with different weight value.

Figure 5 demonstrates that the values of resistance (Figure 5, test 2) were smaller after the load was applied than before (Figure 5, test 1). It is because the sheet does not allow to return to its original form and condition thus creating more electrical path that reduce the resistance value of the sheet. That is why the reproducibility of this material is weak at this condition.

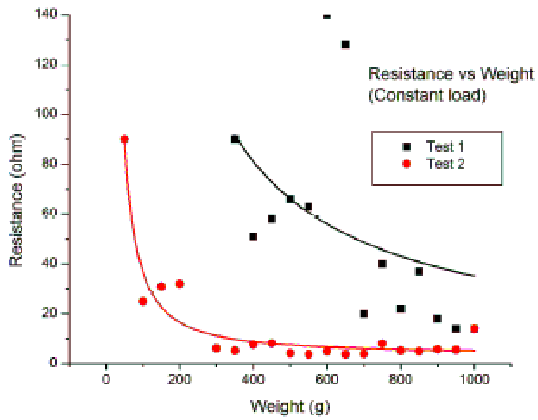

Figure 5. Resistance change with respect to constant load; Test 1 (0-1kg), Test 2 (1-0kg).

Figure 5 on the other hand shows the test result of experiment number 3. All tests except test 3 show significant resistance drop with respect to time. This test shows that, with a given time for the sheet to back to its original form, this material can work well in tactile sensor development.

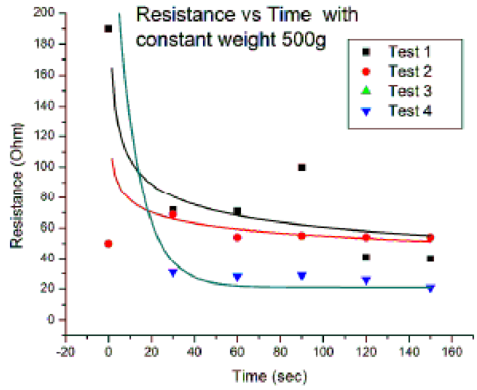

Figure 6. Resistance change with respect of time.

5. Findings

As a conclusion, in this experiment, all the result shown significantly drop in resistance value when load is applied. Through series of experiments we found out that, with a given time that is more than 10 seconds and weight more than 200g the value of resistance will drop significantly and stably. With these experiments we can conclude that this material have a suitability to be used for tactile sensor applications within such range.

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