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Araştırma Makalesi/Research Article

Design and Testing of Flexibility Sensors to be Used in Agricultural Engineering Applications

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Abstract

Flexibility sensors are used to measure bending response of flexible materials which are employed in different technologies. They can be produced with easily available and low-cost materials. Its compactness, lightness and low power consumption makes this sensor ideal for manifold as well as any applications needs to monitor changes in shape or bending behavior. In this paper essential steps needed to design a custom-made, longer and cost effective flex sensor are discussed. It was found that selection of resistor, temperature dependency, and maximum possible length are major criteria to be considered. The best resistor yields the widest range was determined to be 100 Ω with maximum length of 75 cm. Another important finding of the study was the need of temperature compensation.
Keywords: Flexibility, flex sensor, bending, robotics, material science

Ziraat Mühendisliği Uygulamalarında Kullanılabilecek Esneklik Sensörlerinin Tasarımı ve Testi

Öz

Esneklik sensörleri, farklı teknolojilerde kullanılan esnek malzemelerin bükülmeye karşı verdikleri tepkileri ölçmek için kullanılırlar. Kolayca temin edilebilir ve düşük maliyetli malzemelerle üretilebilirler. Kompaktlığı, hafifliği ve düşük güç tüketimi, bu sensörü şekillendirme veya bükme davranışındaki değişiklikleri izlemek için gereken tüm uygulamaların yanı sıra manifold tasarımları için ideal kılar. Bu çalışmada özel üretim, daha uzun ve düşük maliyetli bir esneklik sensör tasarımı için gerekli adımlar tartışılmıştır. Direnç seçiminin, sıcaklığa bağlılığın ve mümkün olan maksimum uzunluğun dikkate alınması gereken ana kriterler olduğu belirlenmiştir. En geniş sensor çıktı aralığını veren resizstansın maksimum 75 cm uzunluğundaki bir sensör için 100 Ω olduğu belirlenmiştir. Çalışmanın bir diğer önemli bulgusu, sıcaklık kompansasyonu gereksinimidir.
Anahtar Kelimeler: Esneklik, esneklik sensörü, eğilme, robotik, malzeme bilimi

Introduction

Rapid developments in all aspects of technology make the components of electronics cost-effective and accessible. This results in use of such technologies in our daily life with more affordable prices (Kızıl et al., 2011). Especially, integration of various sensors with low-cost microprocessors makes it possible to develop prototypes of state-of-the art devices (Beyaz, 2017; Adnan et al., 2012). Of those technologies flex sensors are one of the best examples that are used in robotic systems. In flex sensors, also known as flexion or flection sensors, as the bending of material attached to it changes the resistance of the circuit changes accordingly (Saggio et al., 2016). Saggio et al. (2016) also reported that measurement of flexion can be achieved by means of various sensors such as fiber Bragg grating sensors (Al-Fakih et al., 2012), accelerometers (Luinge et al., 2007) gyroscopes (Williamson and Andrews, 2001), magnetometers (Bonnet and Héliot, 2007), elastic sensors (Saggio et al., 2014), surface acoustic wave (SAW) sensors (Preethichandra and Kaneto, 2007; Zhang et al., 2013), and optical coordinate capturing systems (Beth et al., 2003) etc. However, recent developments in flex sensor technologies enable designers to improve measurement sensibility and related accuracy.

The active material of the sensor is generally made of carbon. As the thin flexible material is bent the sensor generates a signal proportional to the bending action. On the other hand Sarkate (2019) developed a flex sensor using aluminum foil paper which is easily available from the market. He was able to achieve analog values with high accuracies.

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These sensors are being used in various applications such as posture determination (Beyaz, 2017), development of glove for hand gesture recognition (Nisar et al., 2014), wearable triboelectric nano-generators (Xiong and Lee, 2019), robotic hand design (Özkan et al., 2017).

Since flex sensor is responsive to bending actions it has potential to be used in applications in agricultural and biosystems engineering. Frame systems in agricultural structures, especially greenhouse posts and beams, fruit picking devices, land slide identifications, food processing machines, robotic applications etc.

Shrivastava et al. (2015) studied a field-scale multi-tasking robot that employs a flex sensor. The robot is designed to help producers in distance farming. In another study, Megalingam et al. (2017) analyzed different methods in the development of a robotic arm that is suitable for agricultural applications. They used flex sensor in a wearable glove to sense the user's arm movements. Based on the flex sensor data robotic arm is controlled remotely.

Shanmugam et al. (2016) designed a system to monitor the finger disease in turmeric. They used an array of flex sensors to monitor the growth characteristics of the disease. They tested five sets of nodes by measuring the change in flex resistance.

This sensor produce output signals proportional to bending in elements attached to it. There are commercially available flex sensors that can be used in such applications. However, these commercial sensors are sometimes not long enough to be used in specific applications. In this study it was aimed to produce longer flex sensors and test the performance of these sensors under laboratory conditions.

Material and Method

Commercially available flexibility sensors have a length of up to 15 – 20 cm. However, in some agricultural applications such as determination of critical bending in structural materials longer sensors are needed. Since commercially available sensors cannot represent bending motion, longer flexibility sensors have been produced. These produced sensors must be narrow and easy to be mounted to profiles of varying diameters and long enough to fully detect bending motion. For this reason, the maximum length was determined to be 75 cm that is fed by 5 volt. The circuit diagram of the sensor is given in Figure 1.

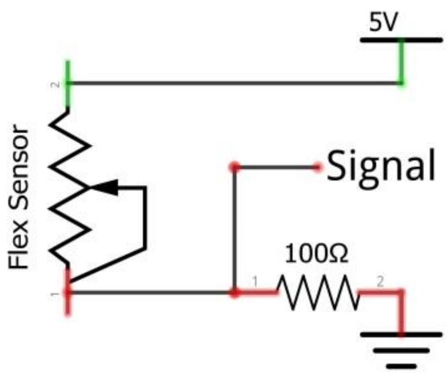

Figure 1. Circuit diagram of the flex sensor

As it can be noticed from Figure 1, the flex sensor is nothing but a resistor. As the bending occurs, resistance of the active element, in our case copper stripe, reduces. This allows more electrons to flow and causing higher sensor outputs. In our testing system, analog input Pin resolution is 10 bits. This value implies that the applied voltage value between 0 and 5 Volts is divided into 2^{10}. That means when a voltage value of 5 is achieved, the sensor output is 1024. In order to convert sensor output values into voltage, following equation is used;

$$V_{out} = S_{raw} \times \left[{}^{5}/_{1024} \right] \qquad (1)$$

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Where; V_{out}: sensor response (V), S_{raw}: analog sensor values of up to 1024.

It was noticed that coating the sensor with laminates yields linearity in results and reduces sensor response time. Therefore, sensors were laminated with 1 mm thick strips on both sides. Then, copper strips of 3 mm wide were placed between these laminated strips. In the middle of these strips, a velostat material is placed to completely cover the conductive zone. They were inserted into heat-shrink tubing to ensure the stability of the sensor and to protect active copper material from humidity (Figure 2).

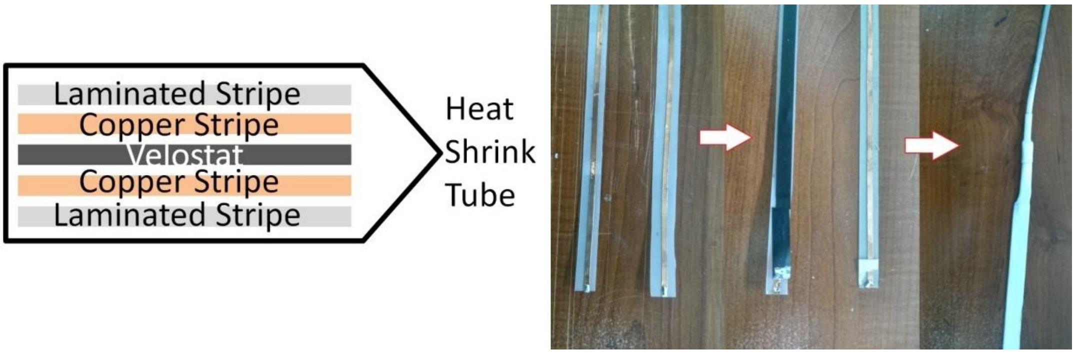

Figure 2. Production of flex sensors

Results and Discussion

The main objective of this research is to evaluate the performance of the custom-designed flex sensor. Therefore, each stage in the development phase should be discussed. The first step was to determine the resistor value. In order to define the angular movement within a certain voltage range a fixed resistor was employed. This allowed division of operating voltage range into equal parts. Different resistor yields different voltage output ranges. In this study it was aimed to achieve the widest voltage range for best precision. Thus, the sensor tested with 12 different resistors. In the test an Arduino Uno microprocessor equipped with an LCD screen was used. The schematic representation and actual test system is shown in Figure 3.

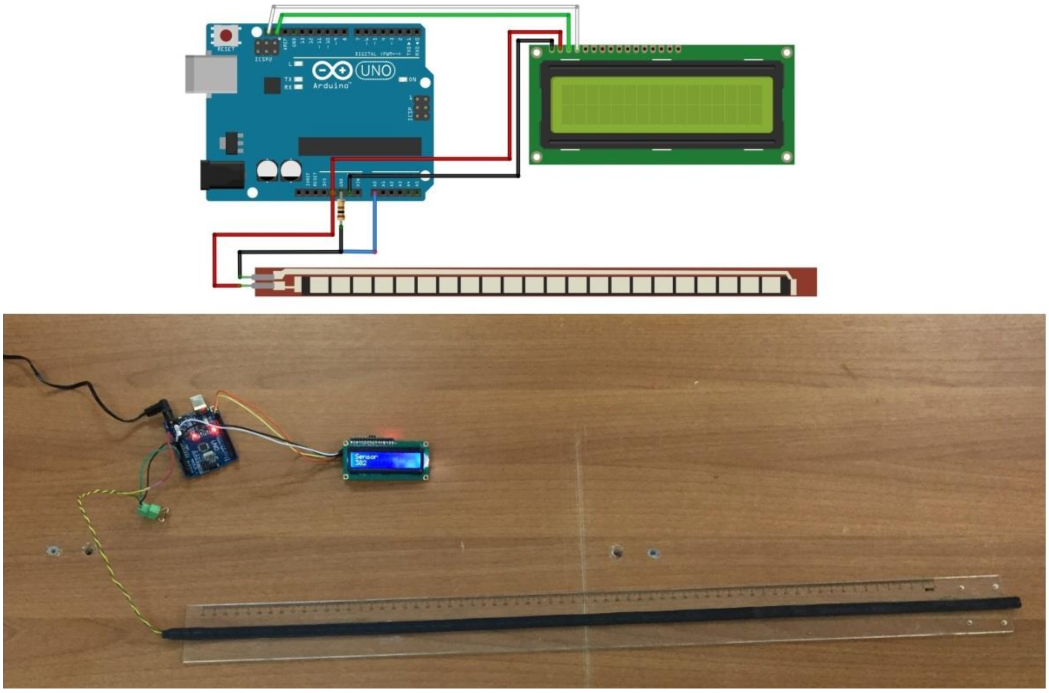

Figure 3. Flex sensor test unit

In the determination of voltage ranges with varying resistance values first sensor response monitored from LCD screen while the sensor is in flat position (at rest). This output represents the

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minimal value attained from the sensor. In order to determine the maximum value, the sensor was bended gradually and output monitored from the screen. As the bending increases, sensor output value increases accordingly. After one point, generally bending angle values greater than 45^o, sensor output remains same. This sensor response was recorded as the maximum value of the range (Figure 3).

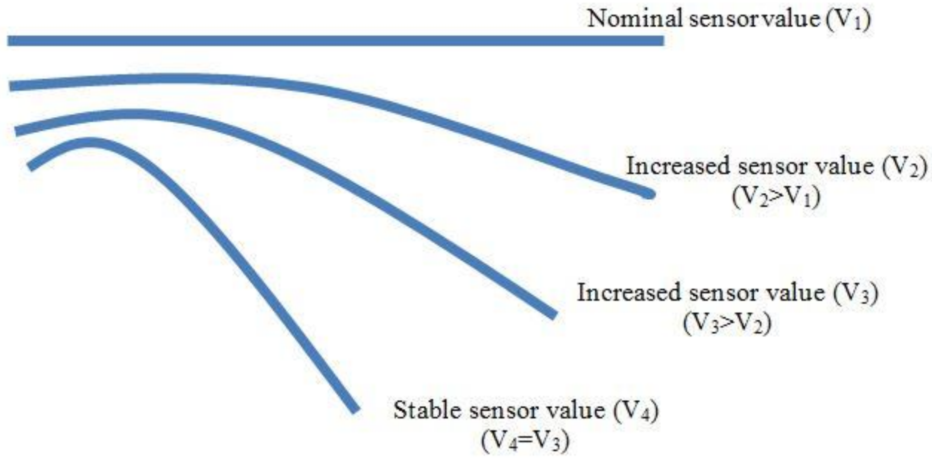

Figure 3. Sensor response change proportional to bending

Of those resistors the widest reading range achieved when 100 Ω of resistance was used. Those resistors and their output voltage ranges are given in Table 1.

Table 1. Different resistors and corresponding sensor responses

Resistor type	Raw sensor response range (S_{raw})	Corresponding Voltage range (V_{out})
10 Ω	48 – 169	0.23 – 0.83
46 Ω	88 – 290	0.43 – 1.42
100 Ω	**460 – 716**	**2.25 – 3.50**
150 Ω	538 – 746	3.63 – 3.64
220 Ω	628 – 820	3.07 – 4.00
470 Ω	746 – 913	3.64 – 4.46
1 k Ω	851 – 968	4.16 – 4.73
5.6 k Ω	982 – 1013	4.79 – 4.95
10 k Ω	1002 – 1017	4.89 – 4.97
33 k Ω	1012 – 1019	4.94 – 4.98
100 k Ω	1020 – 1023	4.98 – 5.00
330 k Ω	1023 - 1024	5.00 – 5.00

Since the sensor is covered with a heat-shrink tube effects of humidity on active sensor material is omitted. However, temperature sensor and temperature interaction should be investigated. A sample flex sensor is exposed to temperatures ranging between 4 and 27 ^oC. The result is plotted in Figure 4.

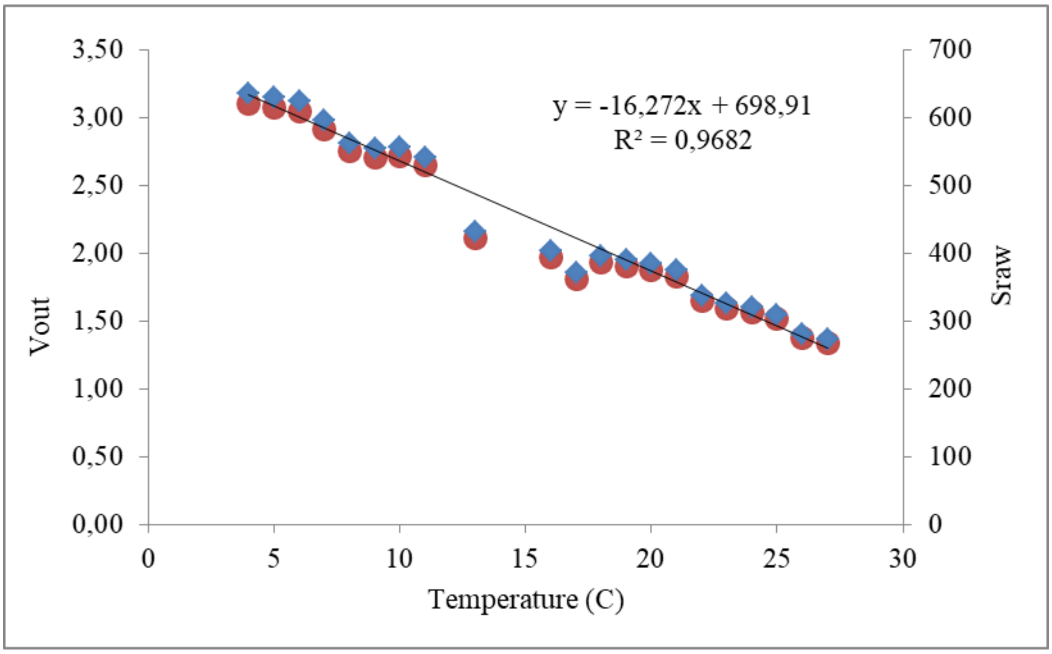

Figure 4. Effects of temperature on sensor response

As shown in Figure 4, sensor yields greater values as the temperature increases. This can be explained by increased electron conduction or decreased resistance by accelerated molecular movements with increasing temperature. Above given linear relationship should be used to compensate temperature effect. However, this particular equation can't be used for all sensors. Our experimental studies demonstrated that each sensor has its own unique response range even though they are all made developed using same materials and procedure.

Conclusions

In this study, manufacturing and testing stages of flexibility sensors used in robotics or other applications developed for agricultural purposes are explained. Although these sensors are commercially available, they are generally small in size. In some applications, short sensors do not provide sufficient performance. Therefore, they must be produced and tested in different dimensions specific to the purpose. The results of this study showed that the most suitable resistance to be used in the development of the sensor is 100 Ω. In addition, it has been determined that sensor performance is affected by temperature changes. The temperature compensation equations of each sensor must be determined. The sensors developed within the scope of this study will be used in the determination of deformations due to the stresses of the structural elements of the greenhouses.

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