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Development and evaluation of resistive pressure sensors from electro-conductive textile fabric

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We introduce another approach to produce a resistive sensor from electro-conductive textile material. Two conductive textile strips, made of stainless steel electro-conductive woven textile fabric, are used as parallel plates and a thin non-conductive woven cotton fabric (spacer) strip is placed between them. We tested the influence of load on the prepared resistive sensor using 0 to 131.2g dead weights. The increase in load resulted in a consistent logarithmic decrease in resistance starting from a cut-off value with no current. The developed sensor is flexible; repeated bending does not affect its electrical property. Moreover, sensitivity was found to be the same after washing, making it suitable to integrate in textile fabric.

Introduction

The use of textiles has been essential to daily life since prehistoric times. Traditional textiles are composed of natural or synthetic fibers and filaments with certain properties and limited functionalities. Looking attractive and fitting comfortably are the basic requirements of textiles dictated by fashion. Recently, textiles are expected to exhibit additional functionalities besides making people warm and comfortable in line with the progression of electronics and digital communication. This led to the development of electronic textiles (E-textiles) or smart textiles. E-textiles consist of fabric that provides advanced and special functions in the form of electronic features or interconnections [1, 2].

E-textiles can be categorized into two types [3], classical and integrated, where the electronic components are embedded into garments and directly integrated into textile substrates respectively. E-textiles have received significant attention as a new technology that can provide added value to the existing wearable applications, including wearable sensors [4]. They have attracted attention in technical and socio-economic fields because of their ability to sense and respond to environmental stimuli [3, 1]. These textiles found ordinary, special and critical applications almost in every sphere of human activities such as mechanically sensitive sensors, electronic skin, flexible transistors, and energy-harvesting and storage devices [1]. Stretchable electronics are integrated in yarns, fabrics, or garments and have attracted considerable interest.

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A sensor is a device that acquires a physical quantity and converts it into a signal suitable for processing (mechanical, electrical, optical) to provide a usable output in response to a specific stimulus [5]. As other E-textiles, the development of flexible and soft pressure sensors is also gaining attention due to applications in wearable electronic devices, soft robotics, and human–machine interfaces [6]. Their preliminary applications have been explored for bio-monitoring of physiological signals, textile keyboards, and touch-pads, etc. Generally, such sensors can be used for medical monitoring of physiological signals, including heart-rate, respiration rate and for commercial applications including keyboard, musical jacket with keypad etc. [7]. However, it has also been recognized that textiles can be used for applications such as drug delivery and fluid collection [8]. For E-textiles, pressure sensors are required to be highly sensitive (especially in the low-pressure range), flexible, comfortable, lightweight, breathable and washable. Most of state-of-art pressure-sensing devices are rigid silicon-based strain sensors fabricated using micro-electromechanical systems techniques [9], which can hardly meet these requirements due to their stiffness and rigid electronic components. Therefore, textile-based flexible pressure sensors, which can be readily incorporated into a garment without much sacrifice of its softness, design versatility, or convenience, are ideal for e-textiles.

Textile-based sensors are always made of textiles and define themselves through their textile structure. Therefore, various textile-based sensor concepts that rely on physical, chemical and thermal mechanisms of action are suitable for integration with textile fabrics. Temperature sensors, Humidity Sensors, Strain and Pressure Sensors are typical examples. Among the electronic sensors, those responding to mechanical stimuli such as strain and pressure have been mostly explored.

In resistive pressure sensors, change in the electrical resistance occurs between two surfaces in accordance with the applied load due to deformation of the geometry of the material [10]. Many resistive sensors consist of two layered substrates; the top substrate is suspended over the bottom one and each substrate is an electrical conductor. When load is applied on the top substrate it indents it so that it partly touches the bottom material area, resulting in an improved contact. These types of pressure sensors are the most common types of sensors, a variety of conductive materials including carbon materials, carbonized polymer sheets, and metallic nano-wires deposited on flexible polymer substrates are used as the conductive layers for textile based resistive sensors [10]. Polypyrrole and PEDOT:PSS are two of the most explored conducting polymers because of their acceptable electrical conductivities and piezo-resistive properties [2]. Single layer resistive sensors on the other hand are mostly based on foams or nonwovens where the load will decrease the porosity,

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resulting in improved conductivity between the top and bottom of the single layer foam [11].

Recently, resistive pressure sensors made of a carbon nanotube (VACNT) forest embedded in a polydimethylsiloxane (PDMS) matrix [12]; opto-piezoresistive effect in p-3C-SiC/p-Si by low pressure chemical vapor deposition (LPCVD) technique [13]; bimodal sensor based on metal−organic frameworks (MOFs) derived porous carbon (PC) and polydimethylsiloxane (PDMS) composite [14]; gold nanoparticle membranes for ambient pressure sensing [15] ultra-high pressure sensor combining a truncated-cone structure and a silicon-on-insulator (SOI) piezoresistive element for measuring the pressure up to 1.6 GPa [16]; pressure-sensitive nanofiber woven fabric sensor by weaving PVDF electrospun yarns of nanofibers coated with PEDOT [17] and flexible, wide range and ultra-sensitive resistive pressure sensor with a foam-like structure based on laser-scribed graphene [18] have been reported.

The common characteristic of these pressure sensors is that they are complex to make, limit breathability and typical not readily washable. Besides, the flexibility is often not as required. These characteristics limit the possibility of using the sensors for textile-based applications. Therefore, it is necessary to have flexible, breathable, and washable pressure sensors to be used in textile wearable application. Moreover, as clothing production cost should be low, the complexity should be limited. This article presents the development and evaluation of a flexible resistive pressure sensor from electro conductive textile fabric. The sensor was evaluated in terms of linear range, washability and flexibility. Finally, the product was used as a footwear pressure sensor for demonstration.

Fabrication Process

We present the low-cost fabrication process of the resistive pressure sensor. Two equal sized 50 mm x 50 mm x 1 mm 100% woven stainless steel electro-conductive fabric strips each having square resistance of 20.3 ohm and 966 GSM were prepared. A 50 mm x 50 mm x 0.2 mm non-conductive woven cotton fabric strip of 120 GSM was also prepared to be used as a thin non-conductive spacer material. Resistance of each strip was measured using a two-point-probe multimeter and conductivity was calculated using

$$\sigma = \frac{1}{\rho} = \frac{L}{RA} \quad (1)$$

where σ = conductivity, ρ = resistivity, A = cross-sectional area of the fabric (50mm x 1mm), R = 0.2 Ohm and L= 50mm. Accordingly, the conductivity of a single electro-

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conductive strip in warp direction was σ = 50 S/cm. The line resistance however over 50mm of fabric is 28 Ohm in weft direction and 4 Ohm in warp direction.

The electro-conductive strips (considered as parallel plates for this work) were connected to electric jumper wires in warp direction for easy integration with Arduino which was used as the measuring device. In practical applications conductive yarns can be used instead. The non-conductive strip was put in between the two conductive plates, so they are fully separated (no direct contact) when pressure is not applied (Fig.1). This has the advantage that there is no power use by the sensor when the sensor is inactive. The total thickness of the constructed sensor is 2.2 mm.

The resistance of the constructed sensor was measured using Arduino at several deadweights at surface contact area of 3.9 cm^2. To maintain fixed surface contact area Euro coins were used by placing one over the top of the other.

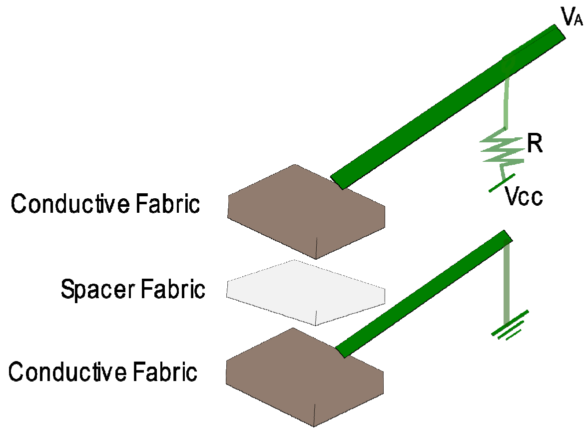

Fig.1. Construction of Pressure Sensor

The developed sensor was repetitively bent to test the bending effect and was also washed to test the effect of washing on sensitivity. The same load and principle was followed to evaluate the effect of pressure on resistance of the sensor after bending and washing.

The measurement was conducted by connecting the Arduino Nano with the computer, Fig. 4. A 232 Ω resistor and a breadboard were used to establish the electronic circuit.

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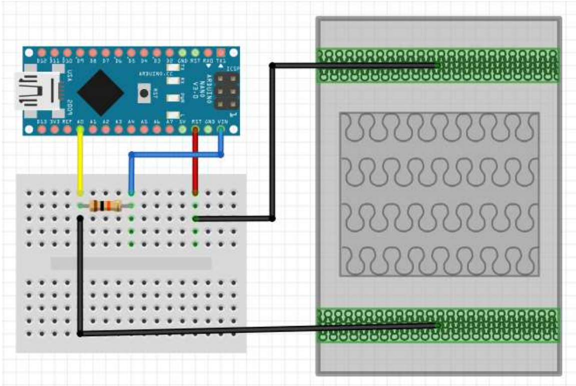

Fig. 2. Resistance Measurement Using Arduino

Results

The pressure sensing capability of the developed pressure sensor, Fig. 3, was determined after construction.

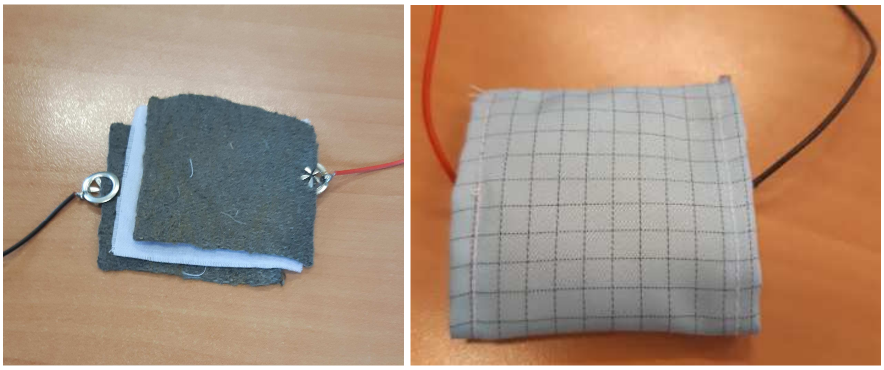

Fig.3. Textile Resistive Pressure Sensor, Left: internal buildup, Right: with cover

In this experiment, resistance below 20 gram was not noticed, showing the non-conductive character of the sensor at low pressures. The result shows that the stability of the resistance value at each load is stable. A twenty-replica average resistance was obtained while loading and unloading and given in Fig. 5. The result showed detection of weight starting only with weights around 20g. Above this, the resistance decreased linearly up to around 100g. At high weights (>2 kg), the resistance is around 153 Ohm. Thus, resistivity has negative linear relationship with the load applied if length and cross-sectional area are assumed constant as in this experiment.

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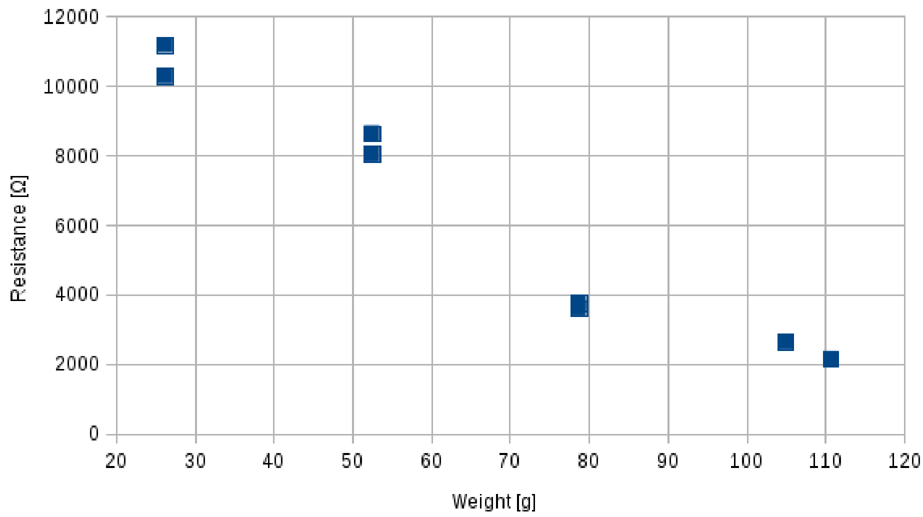

Fig. 6. Effect of Load on Resistance

A linear regression was done in the linear zone, and gives for resistance R=-109 w +13513, with w the weight in gram, w>20, with coefficient of determination equal to r^2=0.94.

Discussion

This resistive pressure sensor is constructed in a way that a capacitive sensor is done; a thin spacer fabric was used to keep the parallel conductive plates away from contact. When pressure is applied the protruding fibers on the surface of the conductive woven fabric pass through the pores of the space fabric and make a connection. The revers occurs when the load is removed. The extent of the load determines the number of protruding fibers to pass through the pores, thus the contact area. The prepared resistive pressure sensor can be used as electrical power switch and pressure sensor in different applications such as footwear technology.

Conclusions

We successfully demonstrated the fabrication of a resistive pressure sensor from electro-conductive textile fabric and non-conductive fabric as spacer. This technique of fabrication is attractive as the sensor is very simple to construct, highly flexible, and washable, which makes it suitable and convenient for integration with cloth. The sensor showed stable pressure sensing capabilities according to a logarithmic law. The resistance is found to decrease with pressure/load. Further investigation is necessary to develop pressure sensors with better stability at different small and heavy loads.

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Notes and references

[1] V. Kaushik *et al.*, “Textile-Based Electronic Components for Energy Applications: Principles, Problems, and Perspective,” *Nanomaterials*, vol. 5, no. 3, pp. 1493–1531, 2015.
[2] W. Weng, P. Chen, S. He, X. Sun, and H. Peng, “Smart electronic textiles,” *Angew. Chemie - Int. Ed.*, vol. 55, no. 21, pp. 6140–6169, 2016.
[3] K. Cherenack, C. Zysset, T. Kinkeldei, N. Münzenrieder, and G. Tröster, “Woven electronic fibers with sensing and display functions for smart textiles,” *Adv. Mater.*, vol. 22, no. 45, pp. 5178–5182, 2010.
[4] C. M. Choi, S. N. Kwon, and S. I. Na, “Conductive PEDOT:PSS-coated poly-paraphenylene terephthalamide thread for highly durable electronic textiles,” *J. Ind. Eng. Chem.*, vol. 50, pp. 155–161, 2017.
[5] B. O. Eke, P. Harcourt, P. Harcourt, F. Egbono, P. Harcourt, and P. Harcourt, “Designing Internet of Things System for Checking Cattle Rustling in Nigeria,” vol. 157, no. 7, pp. 27–35, 2017.
[6] O. Atalay, A. Atalay, J. Gafford, and C. Walsh, “A Highly Sensitive Capacitive-Based Soft Pressure Sensor Based on a Conductive Fabric and a Microporous Dielectric Layer,” *Adv. Mater. Technol.*, vol. 3, no. 1, pp. 1–8, 2018.
[7] J. Edmison, M. Jones, Z. Nakad, and T. Martin, “Using piezoelectric materials for wearable electronic textiles,” *Proc. - Int. Symp. Wearable Comput. ISWC*, vol. 2002–Janua, pp. 41–48, 2002.
[8] D. Morris *et al.*, “Wearable sensors for monitoring sports performance and training,” *2008 5th Int. Summer Sch. Symp. Med. Devices Biosens.*, pp. 121–124, 2008.
[9] M. Liu *et al.*, “Large-Area All-Textile Pressure Sensors for Monitoring Human Motion and Physiological Signals,” *Adv. Mater.*, vol. 29, no. 41, pp. 1–9, 2017.
[10] S. Scheengas and O. Amft, *Smart Textiles*. 2017.
[11] Y. Pang *et al.*, “Flexible, Highly Sensitive, and Wearable Pressure and Strain Sensors with Graphene Porous Network Structure,” pp. 6–10, 2016.
[12] K. Kim, S. K. Hong, N. Jang, S. Ha, H. W. Lee, and J. Kim, “Wearable Resistive Pressure Sensor Based on Highly Flexible Carbon Composite Conductors with Irregular Surface Morphology,” 2017.
[13] A. R. XInZhao Foisal, A. Qamar, H. Phan, and T. Dinh, “Pushing the Limits of Piezoresistive E ff ect by Optomechanical Coupling in 3C-SiC/Si Heterostructure,” pp. 39921–39925, 2017.
[14] X. Zhao *et al.*, “Multifunctional Sensor Based on Porous Carbon Derived from Metal − Organic Frameworks for Real Time Health Monitoring,” 2018.
[15] H. Schlicke, M. Rebber, S. Kunze, and T. Vossmeyer, “Nanoscale membranes of gold nanoparticles †,” pp. 183–186, 2016.
[16] G. Zhang, Y. Zhao, Y. Zhao, X. Wang, and X. Wei, “Research of a Novel Ultra-High Pressure Sensor with,” 2018.
[17] Y. Zhou *et al.*, “Highly sensitive , self-powered and wearable electronic skin based on pressure-sensitive nanofiber woven fabric sensor,” *Sci. Rep.*, no. September, pp. 1–9, 2017.
[18] H. Tian *et al.*, “A Graphene-Based Resistive Pressure Wide Pressure Range,” pp. 1–6, 2015.

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