A Linear Wide-Range Textile Pressure Sensor Integrally Embedded in Regular Fabric

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***Abstract*— This letter presents an improved design of a textile pressure sensor. The sensor is constructed of conductive yarns and a dual-layer piezoresistive polymer as the sensing material. By using intarsia knitting technique, this sensor can be integrally embedded in regular cotton fabric. Experimental results show a linear sensing response over a wide pressure range up to 1000 kPa.**

***Index Terms*— Textile pressure sensor, piezo-resistive polymer, intarsia knitting, conductive yarn.**

I. Introduction

TEXTILE pressure sensors have found important applications in healthcare where forces applied uniaxially by the human body on a fabric surface of the sensor are to be measured [1]. For example, a textile force sensor whose capacitance changes with thoracic expansions is proposed for breath sensing [2], while piezo-electric pressure sensors are used for heart-beat sensing in a cardiorespiratory monitoring application in [3]. A type of textile pressure sensors is constructed by having one or more layers of active polymer, commonly piezo-electric [1] or piezo-resistive [4] polymer, sandwiched between two conductive plates [5], [6]. Both types of polymers are very thin for comfort wear.

Piezo-electric polymer converts an applied force into an output voltage. Due to the high impedance of piezo-electric devices, this signal output can be susceptible to excessive electrical interference, and consequently low signal-to-noise ratio [6]. On the other hand, piezo-resistive polymer converts an applied force into a change in its electrical resistance. Unlike piezo-electric polymers, piezo-resistive polymers are sensitive to even static or very low frequency strains such as those induced by forces asserted by the human body.

It is observed that rarely existing textile pressure sensors could be embedded into regular fabric such that they form a seamless and integral part of the fabric structure. Moreover, as shown in [4] and [6], current piezo-resistive textile pressure sensors of similar structure could only sense up to 800 kPa, which is insufficient for some applications such as gait analysis that requires approximately 1,000 kPa [7].

Manuscript received May 30, 2015; accepted June 23, 2015. Date of publication July 7, 2015; date of current version August 6, 2015. This work was supported by the Strategic Research Investment Fund through the Auckland University of Technology, Auckland, New Zealand, under Grant DS-7502. The associate editor coordinating the review of this letter and approving it for publication was Prof. Kazuaki Sawada.

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Digital Object Identifier 10.1109/JSEN.2015.2453214

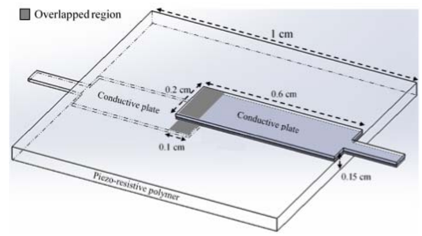

Fig. 1. Three-dimensional structure of the designed pressure sensor.

This letter presents an improved design and prototype of a textile pressure sensor that can be integrally embedded in regular cotton fabric using intarsia knitting technique. Furthermore, by a meticulous adjustment of the relative dimensions and position between the piezo-resistive polymer and conductive plates, this sensor can measure a pressure of up to 1,000 kPa with a relatively linear response to the applied force.

II. Sensor Design

A. Sensing Material

We selected 3M Velostat as the piezo-resistive material as it has high volume resistivity (<500 Ω/cm) and a thickness of only 200 microns. The conductive plates are knitted using Shieldex conductive yarn, which is made of polyamide and coated with 99% pure silver (resistivity <3 Ω/cm).

B. Number of Sensing Layers

While more layers of piezo-resistive material may extend the detected pressure range, it will also increase the creep effect and decrease the sensitivity of the sensor to small pressure changes [3]. After extensive experimentations, a dual-layer piezo-resistive design is chosen for our sensor.

C. Sensor Size

In [6], it was suggested that in order to maintain accurate pressure measurement, the size of a textile pressure sensor should not be smaller than 0.5 cm × 0.5 cm. For convenience, we selected 1 cm × 1 cm to be the sensor size in this letter.

D. Geometry of Conductive Plates

The geometry of the conductive plates in terms of their dimensions and position relative to the piezo-resistive polymer can impact the sensor's performance. The final geometry is determined empirically after a series of experiments. In particular, it is observed that the sensitivity to pressure change is higher if the top and bottom conductive plates have an overlapping region as shown in Fig. 1.

E. Knitted Prototype

Fig. 2 depicts a textile pressure sensor prototyped using the Shima Seiki SIG knitting machine.

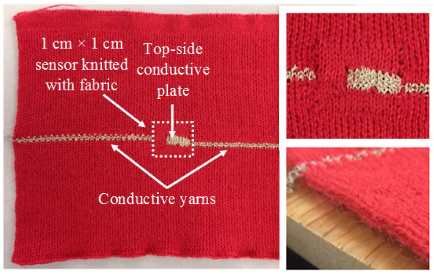

Fig. 2. Knitted sensor prototype.

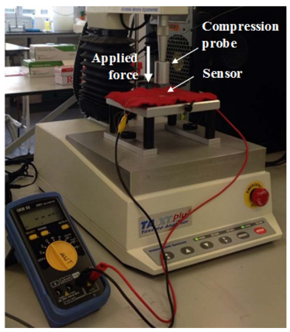

Fig. 3. Calibration setup: The sensor is positioned on a solid platen and a compression probe is used to apply the force.

The prototype is single jersey knitted except for the sensing area, which used intarsia knitting technique to create a tubular pocket. The conductive yarn is knitted from each end to half width of tubular pocket. The conductive path is offset, with one end knitted on front bed of tubular pocket and other on the back. Once the desired pocket sized is achieved, two layers of piezo-resistive polymer (Velostat) are inserted and sealed by transferring stiches from back to front bed, and the conductive end of each side serves as positive and negative poles.

Since both sides of the sensor are now an integral part of the fabric structure, there is less variable clearing between conductive plates, which enhances contact with the piezo-resistive polymer, and therefore reliability of the readings.

III. Calibration and Experiment Results

In order to setup the relationship between the applied force and the sensor reading, calibration of the sensor is performed on a Stable Micro Systems texture analyzer (TA.XTplus), as shown in Fig. 3. The sensor is calibrated under uniaxial compressive forces applied by a compression probe. One side of the sensor bears the whole applied force and the other side faces the solid platen of the texture analyzer.

Initially, when no force is applied, the sensor shows an open status. The applied force is then increased from 1−10 N (in steps of 1 N), 15−40 N (in steps of 5 N), and 50−100 N (in steps of 10 N) and corresponding changes in the sensor's resistance are recorded. Both the resistance and its reciprocal, conductance, are plotted as shown in Fig. 4.

Measurements show that the prototyped sensor can exhibit a relatively linear response in terms of its conductance to

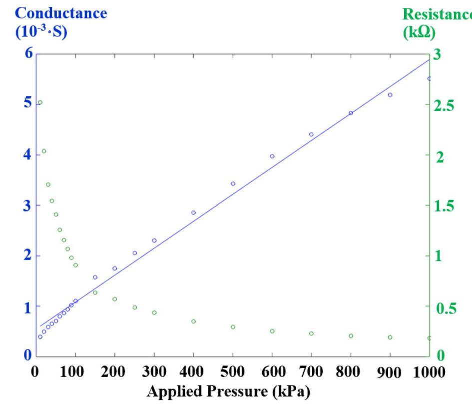

Fig. 4. Sensor's resistance and conductance as a function of applied pressure.

the applied pressure on the sensor. The observed linear relationship between the applied pressure (P) and the sensor's conductance (G) can be modeled as:

$$G = mP + n \rightarrow P = \frac{G-n}{m} \tag{1}$$

where coefficients of the best-fit polynomial determined by Matlab are $m = 0.0534$ S/Pa and $n = 0.5483$ S. Results show that the detectable pressure can be up to 1,000 kPa (100 N/cm^2).

IV. Conclusion and Future Work

In this letter, an improved design of a piezo-resistive textile pressure sensor that can be integrally embedded in regular fabric is presented. Results show the prototyped sensor can detect up to 1,000 kPa with a relatively linear response. However, existing literature lacks a theoretical framework to analyze such a sensor design. Hence, our future work seeks to formulate and validate a model that accurately captures the salient characteristics of our presented textile pressure sensor.

Acknowledgment

The authors would like to acknowledge A. Gupta, G. Fraser, M. Smith, P. Heslop, and F. Joseph of the Textile Design Lab for the support rendered in knitting the sensor prototypes.

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