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Resistive sensors with smart textiles for wearable technology: from fabrication processes to integration with electronics

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Abstract

Smart textiles have received a lot of attention of research in the last decade for their use in wearable technologies [1]. Soft sensors and actuators have been developed for interaction with environment, increase of operator's safety, entertainment and physiological parameters monitoring [2]. This paper reviews the fabrication processes for smart textiles with conductive fibers and analyses the applications of soft sensors (pressure, temperature, etc) as components of e-textiles, the fabrication processes of smart fabrics with different type of fibers and discusses the properties of resistance related to smart sensors fabrication with different metal and polymeric fibers. Finally it is reported an example of a smart textile piezoresistive sensor developed for a smart training shoe for step rate monitoring interfaced to a smart watch.

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Keywords: wearable smart textiles; piezoresistive sensors; smart watch ; training shoe; analog front end.

1. Fabrication processes of conductive smart textiles.

Conductive fibers are the key element to build smart fabrics with known electrical properties (resistance, capacitance etc). The current flow in fabrics depends on: conductive material used, % of conductive fibers, fabric structure, and conductive fiber contact surface. The fabrication technologies that use metal fibers only and a mixture with textile fibers are described. These yarns are produced using textile production technologies. Advanced processes of metallization of polyamide fibers with silver coating are also developed because polyamide gives the yarn strength and elasticity, while thin compliant silver coating guarantees electrical conductivity. Carbon fibers can also be used to produce smart fabrics, for the fact that carbon is a conductive material. They are about 0.005–0.010 mm in diameter, produced from a precursor polymer; the precursor is first spun into filaments and after

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spinning, the polymer fibers are then heated to drive off non-carbon atoms (carbonization). Thanks to carbon electrical properties very low temperature coefficient of resistivity $-0.0005 [1/^{\circ}\text{C}]$ are achieved. Electrons flow along different directions in the fabric depending on the thread: in woven fabrics the current flows in the orthogonal directions of the filaments with almost same resistance while in knitted fabrics the resistance offered in the two orthogonal directions is different (see Figure 1). The functionality of these smart fabrics is exploited to build new resistive soft sensors [3] [4].

2. Resistive smart sensors

The resistance provided by a smart fabric is measured with two electrodes of specified configuration that are in contact with the same side of a material under test this relation depends on the type of material and, for non homogeneous fabrics, even from the orientation of the specimen. Because the lack of standards, manufacturers often adopt their own measurement protocols and provide the value of surface resistance or linear resistance. Because the dependence of resistance from other physical quantity this paper will explore applications of smart textile sensors for textile sensors are able to measure: mechanical pressure, strain, position (potentiometer) and temperature.

For each type of smart textile resistive device is important the characterization of the performances with laboratory test under electrical, mechanical and temperature conditions. This paper presents the characterization of a soft electrical switch element that can be arranged also as a matrix of switches. Some of the innovative aspects of the pressure sensitive fabrics used for a soft switch are: no need of further production steps, low cost, transpiring, semi-transparent, flexible, different activating pressures, matrix switches, large area (up to 50 cm x 50 cm) switches (see left picture in Figure 2), skin compatible materials. These type of soft switches need debouncing analog circuits or debouncing routines when are interfaced directly to microcontrollers such as Arduino [6]. The piezoresistive materials (carbon or polypyrrole) are also used for analog pressure sensors and they are attractive respect to piezoelectric materials. This piezoresistive smart sensor is built by two conductive fabrics layer and a pressure sensitive layer in between. The maximum sensitivity is obtained when the conductive patterns on the external fabric are orthogonal (see left picture in Figure 3). In this way a matrix sensors can be built and interfaced to a column-matrix read out electronics for measuring the spatial distribution of pressure.

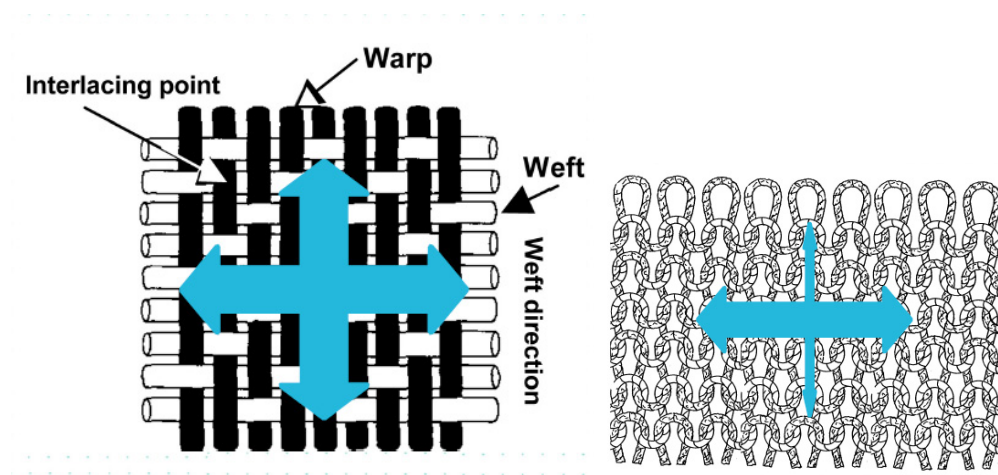


Figure 1: Current density and directions: (Left) in a woven fabric, (Right) knitted fabric.



Figure 2: (Left) Pressure sensitive fabrics used as electronic switch [7]. (Right) Piezoresistive matrix of 8x8 sensors with connectors for column-row readout electronics [7].

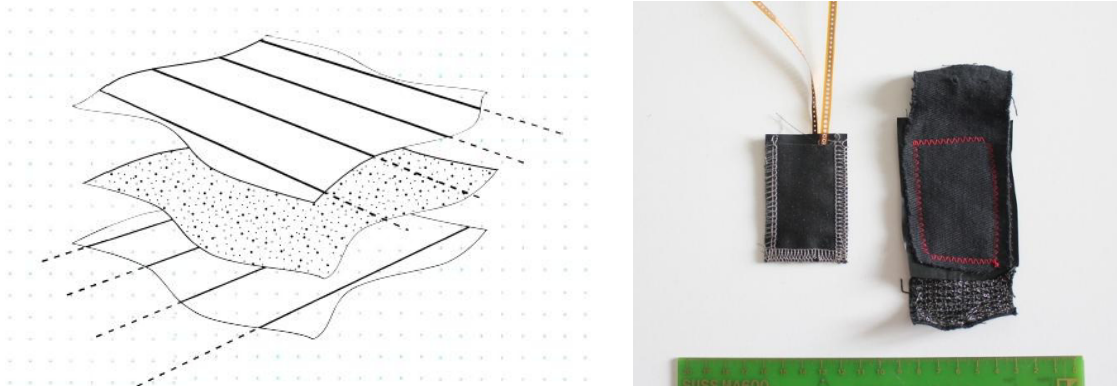


Figure 3: (Left) Structure of a pressure sensitive fabric made of two outer layers with orthogonal conductive patterns and a Velostat (3M™) intermediate layer. (Right) Two piezoresistive sensors based on knitted fabric process with different metal wires: steel and copper.

3. Piezoresistive sensor characterization

Two types of piezoresistive sensors were fabricated with a dimension 60mm x 40mm that is approximately the active area for the insole project. The resistance (R) variation has been characterized when the piezoresistive sensors is not subject to any pressure ($P=0$) and when subjected to a uniform pressure $P=4583 \text{ N/m}^2$. The results for the two piezoresistive sensors (see right picture in Figure 4) are summarized in Table 1.

Table 1. Resistance variation with pressure

Type of sensors	$P=0$	$P=4583 \text{ N/m}^2$
Steel wire	$R = 38\text{k}\Omega$	$R = 3.2\text{k}\Omega$
Copper wire	$R = 870 \Omega$	$R = 140 \Omega$

The advantage of a greater resistance of the steel wire is the lower power consumption when the piezoresistive sensors voltage is measured by a voltage divider with a series resistance of $1\text{k}\Omega$ and power supply of 3.3V. The steel wire model has the advantage of greater compliance and isotropic current flow being built with a 0,07 mm diameter wire. However the lower resistance in the rest condition requires an electronic interface with switched mode power supply and synchronous measurement of the output voltage in order to limit the power consumption. For the above reason the present system has been built with the piezoresistive sensor made with steel wire.

4. Read-out electronics

Finally an application of a piezoresistive sensors modeled as a removable insole developed for monitoring the step rate during training is presented. This device can be used as an odometer, to count steps or strides, but the smart insole can also measure foot contact and lift durations, pressures, spent energy, etc. A shaping analog interface creates pulses through a voltage comparator and then is processed by a low power microcontroller (Transceiver CC1110). The latter sends the information to a programmable watch to visualize if the step rate is within the expected range. A block scheme of the system is shown in Figure 4. In our case the smart watch is the Texas Instruments EZ430. A challenging problem for the sensors with smart textiles are the connections between the electronics and the sensors and at present a viable solution are thin flexible circuit based on Kapton substrate; an example of this type of connections is shown in Figure 3 with two flat connections soldered on the knitted wire mesh.

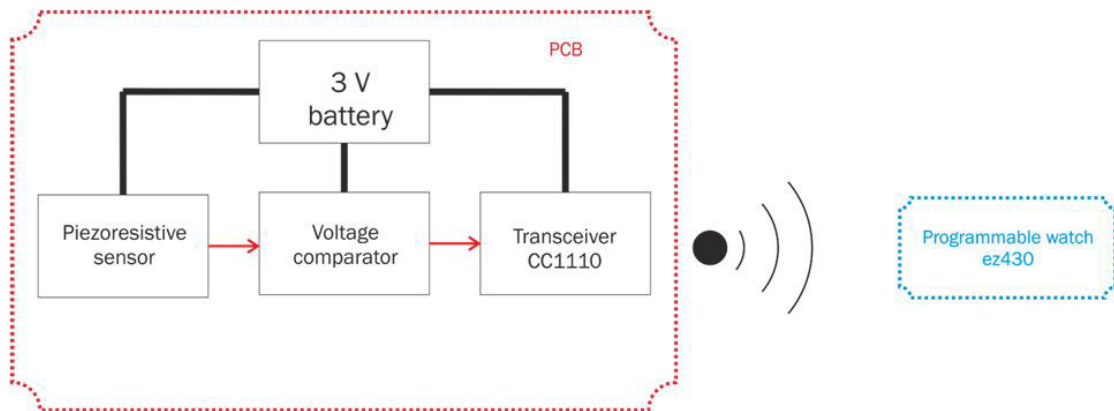


Figure 5: block scheme of the read-out electronics for the smart insole with piezoresistive sensors

5. Conclusions

The technology of fabrication of resistive smart textile has been applied to study and develop a piezoresistive sensor in the form of a removable insole. This piezoresistive sensor when integrated with read-out electronics will be capable of measuring the step rate during training and the information will be easily prompted on the display of a smart watch. The integration of electronics with smart textile sensors and the connections to sensors are challenging research problems that are currently tackled by wearable technology developers.

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