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ELECTROACTIVE FABRICS AND WEARABLE BIOMONITORING DEVICES

Danilo De Rossi°, Federico Carpi°, Federico Lorussi°, Alberto Mazzoldi°, Rita Paradiso*, Enzo Pasquale Scilingo°, Alessandro Tognetti°

° E. Piaggio Interdepartmental Research Centre , Faculty of Engineering, University of Pisa
via Diotisalvi, 2, 56100 Pisa, Italy
Tel: +39-050-553639, Fax: +39-050-550650, e-mail: derossi@piaggio.ccii.unipi.it
*Smartex s.r.l., via Giuntini, 13 – 56023 Navacchio, Pisa, Italy
Tel: +39-050-754350, Fax: +39-050-754351, e-mail: info@smartex.it

Abstract

The implementation of truly wearable, instrumented garments which are capable of recording biomechanical variables is crucial in several fields of application, from multi-media to rehabilitation, from sport to artistic fields. In this paper we discuss wearable devices (a smart shirt, a leotard and a glove) which can read and record the vital signs and movements of a subject wearing the system. The sensing function of the garments is based on piezo-resistive fabric sensors, based on carbon-loaded rubbers (CLR) and different conductive materials.

Keywords:

electroactive fabrics, wearable devices, biomonitoring devices, smart textiles

INTRODUCTION

Multifunctional electroactive fibres and fabrics will give the traditional textile industry a new additional value, the possibility of making daily life healthier, safer and more comfortable, bringing technological advances closer to the public through the use of easy-to-use interfaces between humans measuring devices and actuators.

The fabrication of such multifunctional interactive fabrics represents a potentially important tool for promoting progress, sustainable development and competitiveness in several disciplines such as health monitoring, rehabilitation, ergonomics, disability compensation, sport medicine, telemedicine and teleoperation.

Promising recent developments in material processing, device design and system configuration have enabled the scientific and industrial community to focus their efforts on the realisation of smart textiles. In fact, all components of interactive electromechanical systems (sensors, actuators, electronics and power sources) can be made from polymeric materials, to be woven directly into textile structures (sensing and actuating micro-fibres) or printed or applied onto fabrics (flexible electronics). In particular, intrinsic sensing, actuating, dielectric or conductive properties, compliance, lightness, flexibility and the relative low cost of many electroactive polymers make them potentially suitable materials for the realisation of such systems.

The aim of this presentation is to give a picture of the potential use of smart materials in the realisation of sensing strain fabrics and of actuating systems. In particular, the early stage implementation and preliminary testing of fabric-based wearable interfaces are illustrated with reference to a functionalised shirt capable of recording several human vital signs and wearable motion-capture systems.

Sensing and actuating fabrics

Sensing fabrics

Different fabrication methods have been used to give piezo-resistive properties to garments. The first approach involves coating conventional fabrics with a thin layer of polypyrrole (PPy), a Π-electron conjugated conducting polymer, which combines good properties of elasticity with mechanical and thermal transduction. PPy-coated Lycra fabrics were prepared using the method reported in reference [1].

The technique used at present to create piezo-resistive textiles is based on a coating process applied on both yarns and fabrics. The treatment is performed by immersing the material in a solution of rubber and micro-dispersed phases of carbon (carbon-loaded rubber, CLR). After that, the materials in excess is removed; the conductive elements are then immobilised in the structure through treatment at a temperature of 130°C.

Several studies have been dedicated to the characterisation of these materials [1,2,3,4].
Figure 1 shows an example of response of the two materials in terms of change in electrical resistance for a PPy-based sensor and a CLR-based sensor under stepwise stretching.

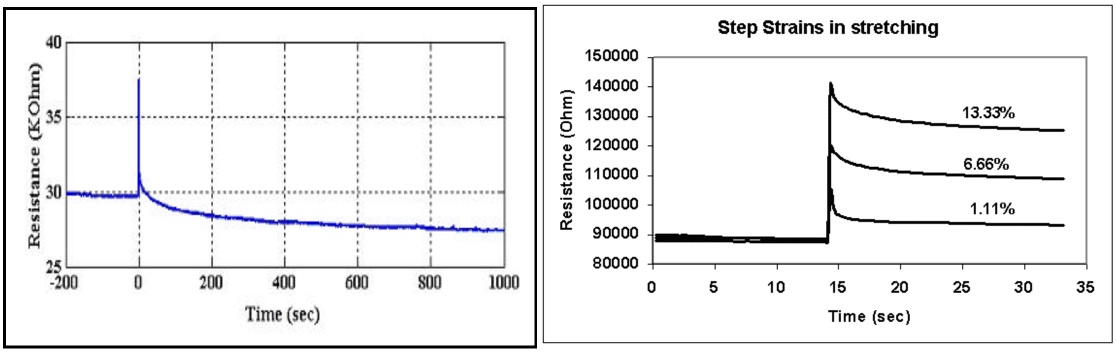


Figure 1. Response in terms of change in electrical resistance for a PPy-based sensor (left) and a CLR-based sensor (right) under stepwise stretching

Actuating fabrics

Electroactive polymer actuators are being studied and developed to be embedded into fabrics, and to endow fabrics with motor functions. Three kinds of electroactive materials (conducting polymers, dielectric elastomers and carbon nanotubes) are under investigation in our laboratory.

Conducting polymers (CP) show a drastic change in electrical conductivity and in the dimensions associated with changes in ionic doping inside the polymer. For these characteristics, conducting polymers are potentially useful in several fields of applications [5]. In particular, it has been shown that conjugated electroactive polymers can exert high forces, much greater than those of natural muscle, and that they undergo volume changes with noticeable variations of elastic moduli when ionic species are forced to penetrate inside their network by electrodiffusion. The electro-chemo-mechanical energy conversion has been studied from the experimental point of view [6,7] and a model elucidating how the doping process influences the polymer molecules has been proposed [8,9]. Since the energy conversion in conjugated CP is mainly diffusion-limited, their response time is quite long. It can be reduced by assembling the CP actuator into very thin elements in parallel. This configuration also increases the force produced by the actuator.

Dielectric elastomers generate strains proportional to the square of the electric field applied between two compliant electrodes, located on the opposite faces of a film of elastomer. Figure 2 shows the strain-field curve measured for a cylindrical actuator using silicone as the dielectric elastomer. They have recently led to simple actuating devices, showing high strains, large force densities, low response times and long lifetimes [10,11]. However, the necessary high driving electric fields presently represent a limitation to the unconditioned use of these actuators.

Carbon nanotube actuative fibres have been made and preliminarily characterised as actuators. Each carbon nanotube can be described as a sheet of carbon atoms rolled up into a tube with a diameter of around tens of nanometers [12]. Their projected superior mechanical and electrical properties (high actuating stresses, low driving voltages and high energy densities) suggest that superior actuating performances can be expected [12]. However, at present the preparation of carbon nanotube fibres must be much improved in order to produce fibres which can demonstrate all their actuating potentialities.

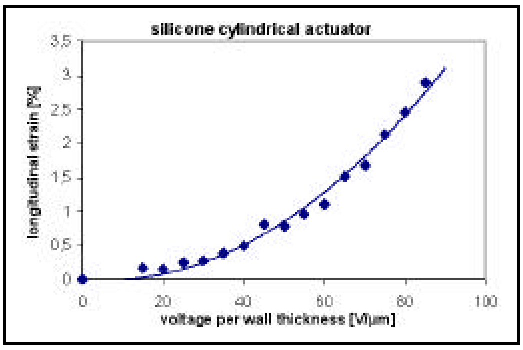


Figure 2. Longitudinal strain versus applied voltage per wall thickness for a silicone cylindrical actuator

Wearable Monitoring Devices

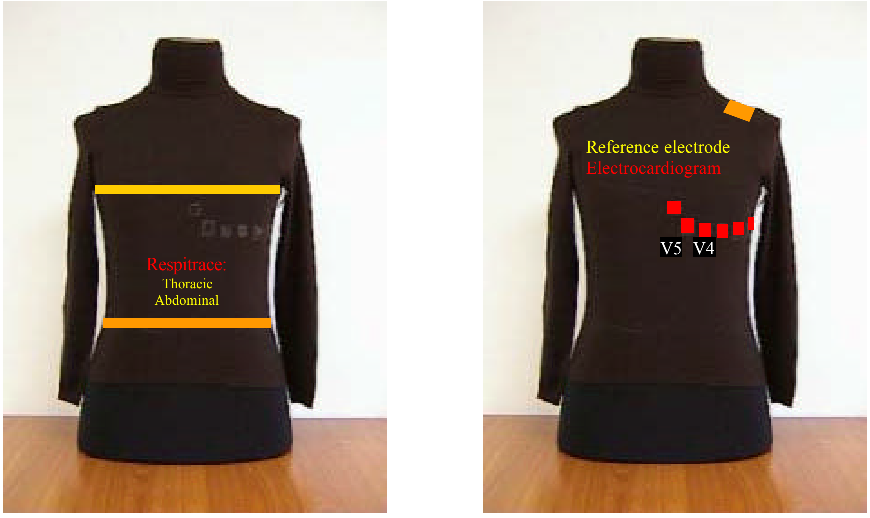
An emerging concept of healthcare, aimed at a continuous monitoring of vital signs to provide assistance to patients, is gaining wider consensus [13]. Advances in both sensor technology and communication technology & data treatment form the fundamental basis for a new generation of healthcare assistance systems.

The use of 'intelligent materials' enables the design and production of a new generation of garments with distributed sensors and electrodes [1,14]. Wearable non-obtrusive systems will permit the user to perform everyday activities with minimal training and discomfort.

Here we report results aimed at the implementation of a functionalised shirt, a leotard and a glove, all able to detect bioelectrical signals and biomechanical movements.

Detecting vital signs

A shirt was functionalised with CLR piezo-resistive fabric sensors, used to monitor respire trace (RT) (Figure 3a), and conductive fabrics, used as electrodes to detect electrocardiogram (ECG) (Figure 3b).



(a) (b)

Figure 3. Positioning of fabric sensors on a smart shirt for RT (a) and ECG (b)

To record the ECG signals, two different square-shaped fabrics (1x1 cm) were used: the first was made with steel threads wound round acrylic yarns, the second with a layer of acrylic/cotton fabric coupled with a layer containing stainless steel threads.

In order to assess their performances, the signal originating from an Ag/AgCl electrode (Red Dot by 3M) was recorded simultaneously with the signal detected by the fabric electrode. The electrodes were applied at positions V4 and V5; the configuration used is shown in Figure 3b. The comparison of the two signals for the bi-layer fabric and the standard electrode is reported in Figure 4. The frequency and amplitude of the response of the fabric electrode were similar to those of the standard one.

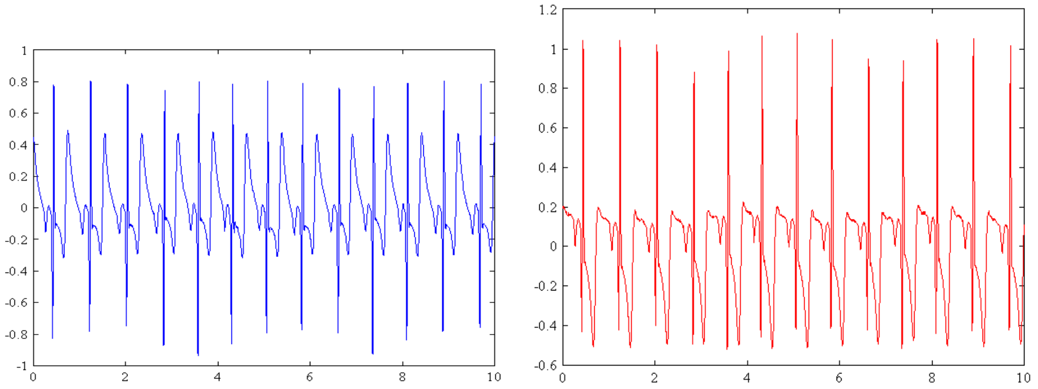


Figure 4. ECG detected with bi-layer fabric (left) and with standard electrode (right)

The respiration trace was monitored by positioning two sensing fabric strips around the trunk at abdominal level. The comparison among the response of the sensor fabric and a commonly used piezoelectric sensor is shown in Figure 5. The results are very satisfactory.

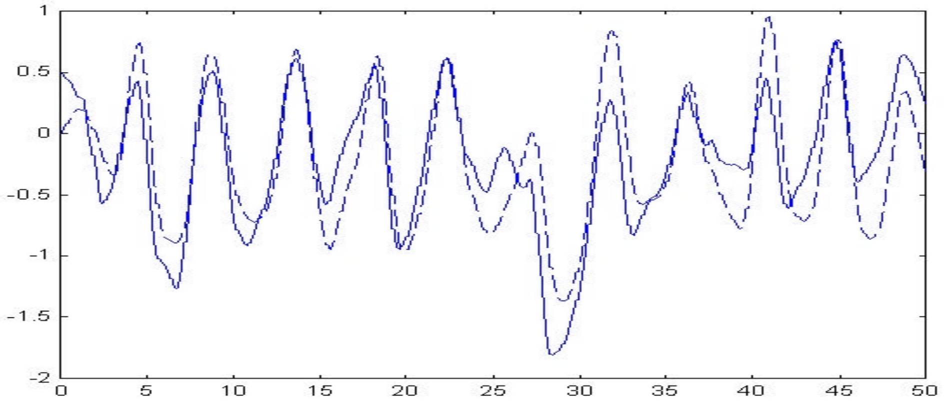


Figure 5. Respiration trace detected with a CLR sensor (continuous line)
and a standard piezoelectric sensor (dotted line)

Smart fabrics for motion capture

Wearable instrumented garments, capable of recording body kinematic maps with no discomfort to the subject and showing negligible motion artefacts caused by sensor-body mechanical mismatch, are crucial in several fields of application.

In most applications, a bottleneck is caused by devices too cumbersome and invasive for the subject, hence a well-fitting functionalised garment would provide strong advantages. In this context a sensing leotard and glove with embedded CLR sensors were constructed. They permit movements of the arms and upper trunk to be recorded (Figure 6), as well as movements of the fingers.
Figure 6 shows that during a trunk flexion the resistance of the right sensor (RS) increases, while that of the left one (LS) decreases. For an opposite movement, the outputs of the two sensors would be exchanged.

Rehabilitation, sport medicine, multimedia and virtual reality are examples of potential fields of application.

An elastic glove was sensorised by an array of CLR piezo-resistive sensors (Figure 7 left), and it was used with a pseudo-3D graphic interface (Figure 7 right). Each interphalangeal joint is covered by a sensor, while at least two sensors are necessary to detect the position of each metacarpal-phalangeal joint and the carpal-metacarpal joint of the thumb.

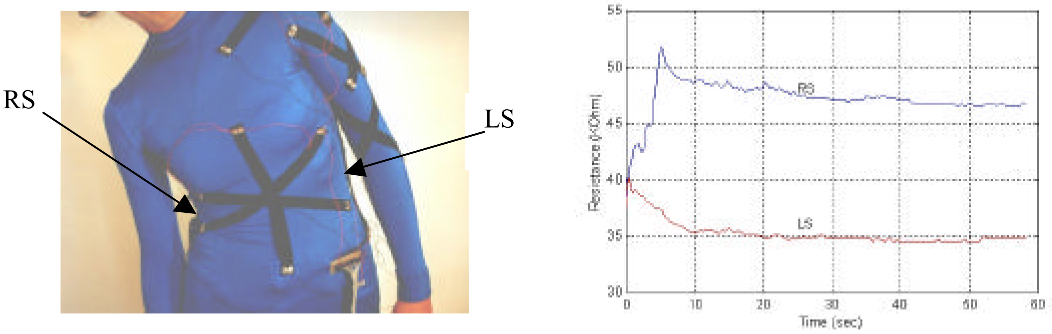


Figure 6. Flexion towards right from rest position (left) and output signals from the sensorised leotard (right)

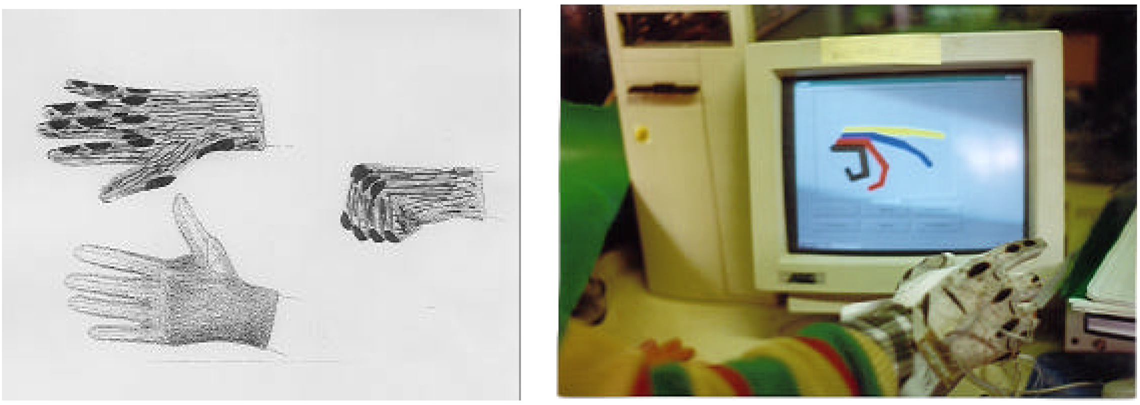


Figure 7. Sensor position on the sensing glove (left) and use of the glove with a pseudo-3D graphic interface (right)

CONCLUSIONS

This work was intended to demonstrate the feasibility of creating smart garments capable of monitoring vital signs and human posture. Further efforts are needed to reach a full integration of actuating and sensing elements in a woven device.

The innovative approach is based on the use of standard industrial processes to realise the active and sensing elements. Results show that electroactive functions can be implemented in the same woven system where vital signs and movements are converted into readable signals, which can be acquired and transmitted to elaboration devices.

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