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Electroactive polymer patches for wearable haptic interfaces

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Abstract— **Fully wearable and unobtrusive sensing will enable the possibility of monitoring people anywhere and anytime, for healthcare, well-being, protection and safety. Many research groups have exploited textiles as the ideal platform for pervasive monitoring. This paper reports advances in electroactive polymer technology oriented to mechanical sensing and actuation within textile interfaces. The preliminary development of a textile-based glove in which electroactive polymers act as force/position sensors and haptic feedback actuators is presented.**

I. Introduction

BODY worn systems, endowed with autonomous sensing, processing actuation, communication, energy harvesting and storage are emerging as a solution to the challenges of monitoring people anywhere and at anytime in applications, such as healthcare, well-being and lifestyle, protection and safety. [1] [2] [3].

Textiles, being a pervasive and comfortable interface, are an ideal substrate for integrating miniaturized electronic components or, through a seamless integration of electroactive fibers and yarns, they have the potentiality to become fully functional systems for remote wearable monitoring. The idea of e-textiles being a viable solution to implement truly wearable, smart platforms as bidirectional interfaces with human body and functions has emerged as a result of the work of independent groups at the very end of last Century. [4] [5] [6] [7].

Since then significant additional progress has been made leading to several platforms exploiting some form of integration of electronic microsystems with garments [8] and inaugurating the area of SFIT's (Smart Fabrics and Interactive Textiles).

Ideally materials employed for wearable devices in electronic textiles should be characterized by intrinsic high compliance, low weight, and ease of processing in several shapes and configurations (possibly in fiber form), in order to preserve the wearer's comfort. Most of these properties are not typically found in commonly used sensors, actuators, electronic components, and power sources, despite their continuous miniaturization.

Differently, very promising developments in organic materials science and technology, as well as in functional design, encourage the realization of "all-organic" wearable devices for e-textiles [9].

In this paper the authors briefly report about advances in electroactive polymer technologies leading to mechanical sensing and actuation electromechanical devices integrated into a textile haptic glove.

Several glove-based systems aimed at acquiring hand movement for rehabilitation or virtual interaction purposes have been developed in the last decades [10]. Instrumented gloves endowed with kinesthetic and haptic feedback devices will enable tele-rehabilitation and tele-operation capabilities.

The preliminary development of a textile integrated instrumented glove in which both sensors and feedback actuators are made of electroactive polymeric materials is presented. Our instrumented glove will be capable of monitoring and classifying hand gesture, sensing contact forces at various locations in the hand (fingertips, palm,..) and also provides vibrotactile cutaneous stimulation in a fully textile. Piezoresistive rubbers (Section II) will be employed to provide the kinesthetic information while dielectric elastomers (Section III) will be used both as contact force sensors and feedback actuators. With respect of the existing solutions our device will be compliant, light and flexible thus enabling its usage in a wide range of applications such as virtual reality, rehabilitation and surgical devices.

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II. SCREEN-PRINTED STRAIN SENSORS FOR HAND POSTURE AND GESTURE RECOGNITION

Measuring and monitoring parameters related to human movement have a wide range of applications.

With this respect an innovative methodology exploiting redundant fabric-based sensor arrays with the intent of reconstructing body gesture and posture has been developed [11]. Piezoresistive rubber sensors have been screen printed onto an elastic fabric substrate with no changes in the mechanical and thermal properties of the fabric, thus maintaining the user comfort unaltered during operation.

The basic concept of the proposed technology is that having a redundant distribution of sensors around the joints to be monitored provides possibilities to associate the sensor status (the set of the actual sensor values) to parameters related to user movements through proper identification procedures. Several prototypes have been realized using this technology to monitor body posture and gesture in rehabilitation and human-machine interaction for disabled people [12].

We are currently exploiting this technology in the realization of an hand sensing interface for finger positions and gesture recognition to be used as an input for virtual manipulation tasks (as shown in Fig. 1).

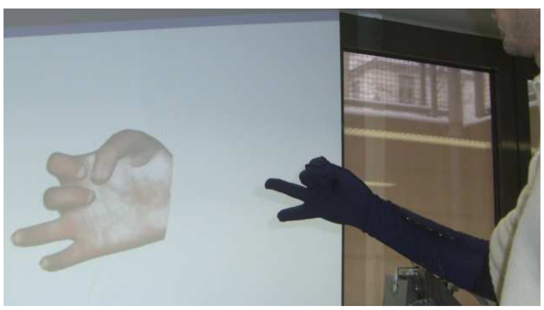

Fig. 1. Sensing glove used in a virtual manipulation task.

The wearable interactive interface is realized by printing a conductive elastomer piezoresistive material on a Lycra®-Cotton glove in which the sensor and connection paths are made of the same elastic and conducting material as described in [12].

As the hand moves, the redundant sensor elements corresponding to different hand segments are subject to changes in length, thus causing changes in the electrical properties of the material. Such changes can be detected by reading the voltage drop across each sensor segment. Data interpretation is based on the assumption that changes in the electrical characteristics of the sensor elements, corresponding to different hand segments, are associated with changes in the hand kinematic configuration. Previous studies [12] demonstrated the possibility of using the sensing glove to reconstruct static postures and measure joint angles by using algorithms based on multivariate interpolation or neural networks. The drawback of these techniques was the consistent calibration effort which may bind the use of such devices in practical situations. The current activity is focused on the development of dedicated algorithms for the extraction of hand gestural information with minimal calibration efforts.

Recent studies were focused on the estimation of the hand aperture during movements simulating hand grasp and release tasks for robot assisted rehabilitation [13]. This study was based on linear regression model having hand aperture as dependent variable and the output of the sensor elements as independent variables. The calibration effort was extremely reduced: only the sensor status corresponding to the positions of open and closed hand need to be stored.

In the present study, long finger flexion-extension recognition has been obtained by means of an updated multi-regressive model having the metacarpophalangeal flexion-extension angles of the four long fingers as dependent variables and the CE sensor outputs as independent ones. The model parameters are identified by measuring the sensor status in two different position: (1) hand totally closed (90 degrees), (2) hand totally opened (0 degrees). The multi-regressive model applied to the sensor inputs has been tested on repeated task of opening/closing the hand (from totally closed to totally opened).

Results of four trials are shown in Fig. 2: it is possible to note that the measured joint angles are highly correlated with the reference measurement signals and that the overall measurement error is very low.

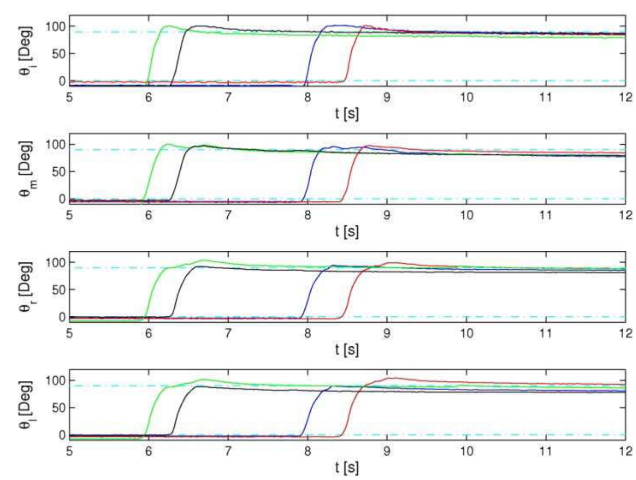

Fig. 2. Measured joint angles obtained by the multi-regressive model. Different colors are related to the different trials. Dashed lines represent the reference angles.

The full reconstruction of hand kinematics could be obtained applying the same technique to other relevant joints. In this case additional calibration position should be foreseen. On the other hand, natural grasping tasks are characterized by intrinsic synergies [14] that reduce the overall dimensionality of the hand kinematic chain (i.e. number of independent degree of freedoms, DOFs). In principle, the knowledge of a reduced DOF number could enable the full reconstruction of hand kinematics.

The presented CE based sensing glove will be integrated with dielectric elastomer based devices described in Section III in order to enable haptic feedback and contact force measurements.

III. Dielectric elastomer vibro-tactile display and force sensor

Aimed at providing users of electronic wearable systems with vibro-tactile feedback controlled by a variety of possible inputs, innovative wearable haptic/tactile displays, compact and comfortable for the user, are needed. To comply with such a need, we are developing devices based on smart materials for actuation made of electromechanically active (or electroactive - EAP) polymers [15]. These materials, and in particular, so-called dielectric elastomer actuators (DEAs), are highly promising to develop lightweight, deformable, efficient, silent and cost-effective electromechanical transducers, with a great potential for haptics [16]. We have conceived and are developing so-called bubble-like hydrostatically coupled dielectric elastomer actuators (HC-DEAs) [17,18]. They rely on an incompressible fluid that hydrostatically couples a DEA-based active part to a passive part interfaced to the user. The device includes the following parts: an electromechanically active membrane, made of a DE film coated with compliant electrodes; an electromechanically passive membrane, working as the end effector in contact with the finger; an incompressible fluid contained between the two membranes. Actuation of the active membrane through a voltage difference applied between its electrodes exerts onto the fluid a pressure, which is hydrostatically transmitted to the passive membrane. The active membrane buckles outwards, owing to its pre-curvature, while the passive membrane follows inwards, driven by hydrostatic transmission. This principle allows for safe transmission and delivery of actuation from the active membrane to the finger, without any direct contact between them (Fig. 3) [17,18].

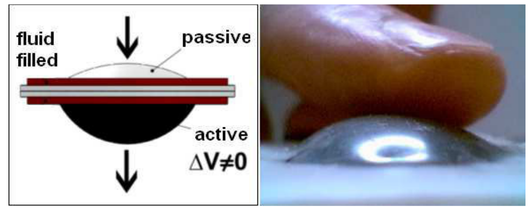

Fig. 3. Hydrostatically coupled dielectric elastomer actuator.

Bubble-like HCDEAs show significant potential for novel vibro-tactile displays. Compared to alternative actuation technologies, HCDEAs combine high comfort for the user (high mechanical flexibility, low specific weight, no acoustic noise, no heating and suitable electrical safety) with high versatility for technical design (ease of manufacturing according to different shapes, scalability, low power consumption and low cost) [17,18].

We are currently using this technology to develop a finger-tip haptic display (Fig. 4). The bubble-like HC-DEA is 2-cm wide and is integrated within a plastic case, so that the passive membrane is in contact with the finger tip, while the active membrane is protected by a plastic chamber. The active membrane is electrically driven by a miniaturized (about 1 cm^3) high-voltage DC/DC converter, which is integrated within the plastic case. The converter is fed with a 0-5V signal to generate a 0-4 kV input for the actuator. The converter will safely work at a low electric power (less than 300 mW) and the user will never be exposed to any high-voltage part of the device.

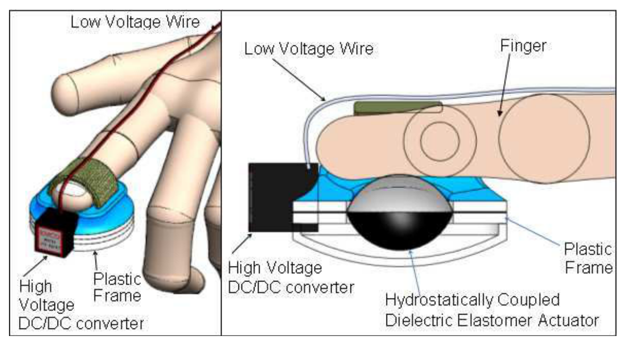

Fig. 4. Design of a finger-tip wearable vibro-tactile haptic display based on electroactive polymer actuators.

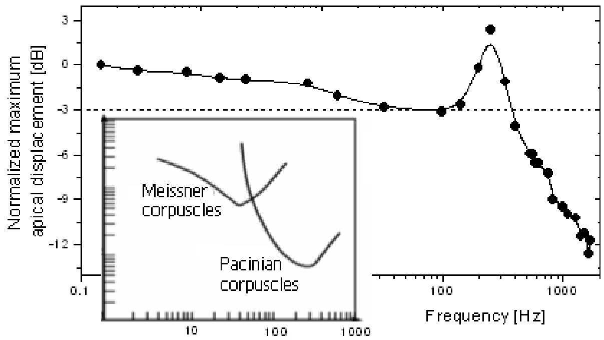

Fig. 5. Frequency response of an hydrostatically coupled dielectric elastomer actuator and (inset) activation threshold of Meissner and Pacinian corpuscles in response to sine-wave mechanical stimulation.

This work is part of a European research project called "CEEDS: The Collective Experience of Empathic Data Systems". The overall system is aimed at providing the user with haptic/tactile feedback, controlled by a variety of inputs delivered by a central controller which manages navigation in virtual environments. The first goal to be achieved in the project is the creation of the sensation of contact with virtual objects. Furthermore, vibro-tactile stimulation is studied as a confirmation feedback upon virtual commands made by the user with fingers (e.g. pressure of keys on virtual control panels). Notably, we have shown that such actuators can be made to exhibit a resonance frequency matching the frequency at which Pacinian cutaneous mechanoreceptors have highest sensitivity, i.e. about 250-300 Hz (Fig. 5) [18]. This is advantageous for optimal stimulation of tactile sensation in vibration mode.

The HCDEA can work as a contact force sensor as well. This is achieved by coating its surface with an elastomeric resistive path, working as a highly deformable piezoresistive sensing element. As a load is applied, the resistance varies accordingly. By monitoring the resistance, the applied force/deformation can be inferred.

IV. Conclusions

This paper described the preliminary development of a textile-based glove in which electroactive polymers act as force/position sensors and haptic feedback actuators.

The kinesthetic sensing interface is realized by the integration of conductive elastomer piezoresistive sensors. Hand movement is reconstructed by the identification of multi-regressive models applied to the sensor outputs. Good results have been obtained in terms of long-finger kinematic reconstruction with reduced calibration efforts.

The haptic-feedback interface is based on dielectric elastomer actuators. Work in progress is aimed at providing users with vibro-tactile feedback, as well as contact sensing, using a technology that is shown to be promising to develop lightweight, deformable, efficient, silent and cost-effective devices.

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