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Characterization of a Novel Data Glove Based on Textile Integrated Sensors

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***Abstract*— The present work is about the realization and the characterization of a novel data glove able to detect hand kinematic configurations. The sensing glove has been realized by directly integrate sensors in the fabric used to manufacture the glove. Main specifications for the realized device are lightness, wearability and user comfort. As a fundamental requirement to address this purpose we have estimated the employment of a material which does not substantially change the mechanical properties of the fabric and maintains the wearability of the garment. To obtain this result, we have integrated sensor networks made by conductive elastomer into an elastic fabric used to manufacture the sensing glove. Electrically Conductive Elastomer composites show piezoresistive properties when a deformation is applied. Conductive elastomers materials can be applied to fabric or to other flexible substrate and they can be employed as strain sensors. To validate the realized device, a function that relates glove sensor values to hand motion has been realized and tested.**

I. AIMS

Our main aim in the present work has been to realize a sensing glove able to detect hand posture and gesture and that can be worn for a long time with no discomfort. As a fundamental requirement to address the purpose we have estimated the employment of a material which does not substantially change the mechanical properties of the fabric and maintains the wearability of the garment. To obtain this result, we have integrated sensors made by Conductive Elastomers into an elastic fabric used to manufacture the sensing glove.

Electrically Conductive Elastomer (CE) composites show piezoresistive properties when a deformation is applied [1], [2]. CE materials can be applied to fabric or to other flexible substrate and they can be employed as strain sensors [3]. These materials represent an excellent trade-off between figures of merit in mechanoelectrical transduction and possibility of integration in textiles.

During the user hand movement, glove sensors detect local deformations on the fabric. The main objective of the work is to formulate algorithms which map sensor values into user hand kinematic configuration.

II. MATERIALS

The sensing glove (Fig. 1) has been realized by directly printing the piezoresistive CE material (commercial product provided by Wacker LTD [4]) on a Lycra/cotton fabric previously covered by an adhesive mask. The mask is designed according to the desired sensor and connection topology. This production process has been widely described in [5].

Fig. 1. The Sensing Glove realized by CE sensors directly integrated in the fabric. Twenty sensors (S_1-S_{20}) are distributed over the hand.

A CE sample of 5mm in width shows an unstretched electrical resistance of about $1k\Omega/Cm$. Quasi-statical characterization [3] has pointed out a gauge factor of about 2. Dynamically CE sensors present peculiar characteristics such us non-linearity in resistance to length transduction and large relaxation times [6], [7]. In a previous work [5] algorithms to compensate the peculiar behavior of CE sensors has been studied and developed.

The mask adopted to realize the sensing glove is shown in Fig. 2. Sensors ($S_1 - S_{20}$) are connected in series and they are represented by the wider black lines of Fig. 1 and Fig. 2. Connections between sensors and electronic acquisition unit

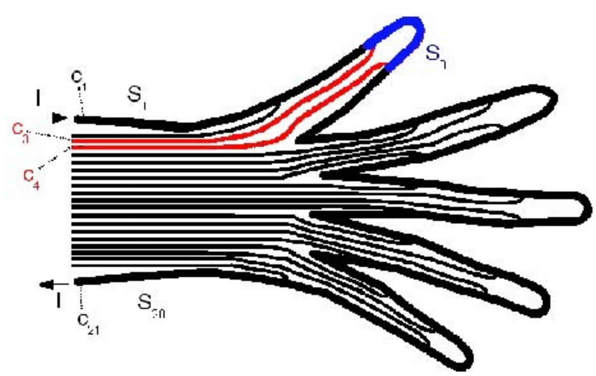

Fig. 2. The mask used for the sensing glove realization. The sensor S_3 on the thumb (blue line) and its connections (red lines) are pointed out.

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$(C_1 - C_{21})$ are represented by the thinner line of Fig. 1 and Fig. 2.

Printing both the set of sensors and connections directly on the fabric by using the same material is a definite merit of our approach. In early prototypes interconnections were constituted by metallic wires, which could bound movements and create motion artifacts.

Since connections are realized by the same material adopted for sensors, they undergo a not negligible change in electrical resistance when the user hand moves. For this reason the acquisition unit front-end has been designed in order to compensate connection resistance variation. The sensor series is supplied with a constant current $\mathbf{I}$ and the voltage falls across consecutive connections are acquired using high input impedance amplifiers (instrumentation amplifiers) following the methodology of [5]. Let us consider the example of sensor S_3, it is a sensor placed in the thumb finger region of the glove and it is represented by the blue line in Fig. 2. Connections of this sensor are represented in Fig. 2 by the two red lines. If the amplifier is connected between C_3 and C_4, only a little amount of current flows through interconnections respect to the one that flows through S_3. In this way, if the current $\mathbf{I}$ is well dimensioned, the voltage read by the amplifier is almost equal to the voltage fall on the sensor that is proportional to the sample resistance. In conclusion, a sensor S_i consists in a segment of the bold track between two consecutive thin track intersections.

Analog signals coming from the glove are then digital converted and elaborated in a PC.

III. Methods

Piezoresistive CE sensors distributed over the glove can detect local fabric deformations produced by user hand movements. The main goal in terms of data interpretation is to formulate Algorithms for mapping raw sensor data (related to local fabric deformation) into hand kinematic configurations. Fig. 3 shows raw signals coming from the glove during an hand movement.

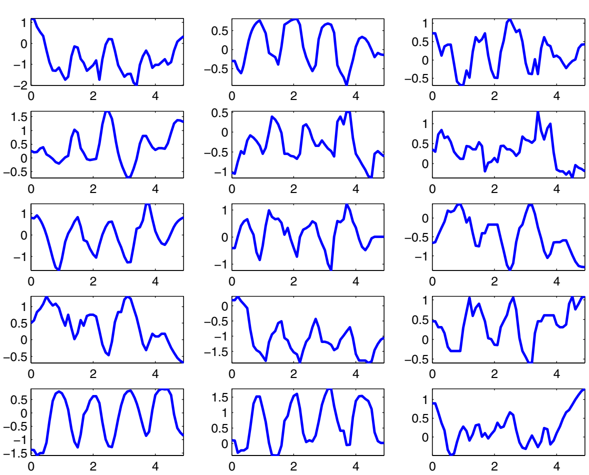

Fig. 3. Sensing Glove signals (normalized data) vs. time (seconds) during natural user movements.

TABLE I

Monitored Hand DOFs

Joint	Finger	Abbreviation
metacarpophalangeal	thumb	th. MPJ
trapeziometacarpal	thumb	th. IJ
metacarpophalangeal	index	ind. MPJ
proximal interphalangeal	index	ind. PIJ
metacarpophalangeal	middle	midd. MPJ
proximal interphalangeal	middle	midd. PIJ
metacarpophalangeal	ring	ring MIJ
proximal interphalangeal	ring	ring PIJ
metacarpophalangeal	pink	pink. MPJ
proximal interphalangeal	pink	pink. PIJ

To achieve hand position classification using the sensing glove it is necessary to construct a function $\mathbf{F}$ which maps the sensor status in user hand kinematic configurations

$$\mathbf{F} : S \rightarrow \Theta \tag{1}$$

where $S \subset \mathbf{R}^k$ is the sensor space, k is the number of sensor, $\Theta \subset \mathbf{R}^n$ is the hand position space and n is the number of degrees of freedom (DOFs) to monitor. In our experiments the 10 hand DOFs ($n = 10$) reported in Table I have been monitored. Due to the number channel limitation of our analog to digital converter 15 sensors of the glove have been used ($k = 15$).

To construct the function $\mathbf{F}$ our approach has been to associate sensing glove data to ones coming from a conventional measurement system. In our experiments, the Cyberglove produced by Immersion corporation [8] has been used to validate our system.

A. calibration

During the calibration phase, the CE glove was worn by a subject together with the Cyberglove. The subject was asked to perform natural hand movements for about one minute. Data from the CE glove and from the Cyberglove were simultaneously acquired and stored in the calibration dataset.

B. Contruction of F

The function F has been constructed in two different ways:

1) Least Square Technique: In the first case F has been obtained by applying a linear regression between the input (sensing glove data stored in the calibration dataset) and the target (Cyberglove data stored in the calibration dataset) of the calibration dataset. In this way we obtained a linear application expressed by the $k \times n$ matrix $\mathbf{A}$, with $k = 15$ and $n = 10$. Fig. 4 shows the application of F to the inputs of the calibration dataset.

2) Neural Network Technique: In the second case F has been calculated by training a multilayer feedforward network using backpropagation algorithms on the calibration data sets. The adopted network, reported in Fig. 5, has 15 tan-sigmoid input layers, 30 tan-sigmoid hidden layers and 10 linear output layers. To train the network the Scaled Conjugate Gradient Backpropagation algorithm has been adopted [9].

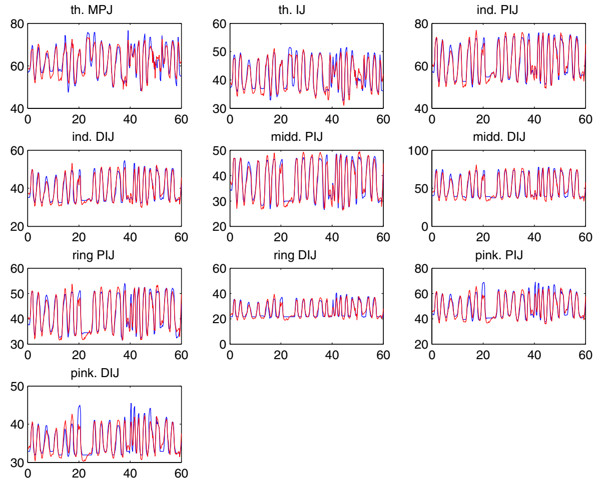

Fig. 4. Application of the function F to the calibration dataset. Red lines represent the F output while blue lines represent outputs from the Cyberglove. Abscissa axis indicates the time expressed in seconds

Fig. 6 shows the application of F to the calibration dataset.

IV. Results

In the test phase, the CE glove and the Cyberglove have been worn by the same subject during natural hand movements. Data from the CE glove has been processed by the map F and outputs has been compared with the ones produced by the Cyberglove.

Results have been encouraging. Test trials are reported in Fig. 7 and Fig. 8.

Both the tested algorithms have shown good results in term of hand position reconstruction, but the algorithm based on the feedforward network has performed better results as it is visible by comparing Fig. 7 and Fig. 8.

V. Conclusions

In the present work results of a research in the emerging field of textile-based smart devices has been presented. Methodologies for the application of fabric CE sensors in the realization of sensorized garments able to detect human gesture, posture and movement have been described.

The main advantage introduced by the realized prototype is the well matching of wearabilty requirements useful for long term monitoring.

The realized sensing glove has shown very promising performances in terms of reconstruction of hand segment positions.

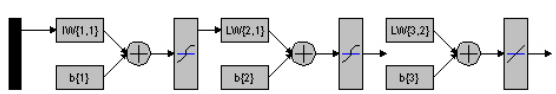

Fig. 5. Feedforward network used to construct the function F

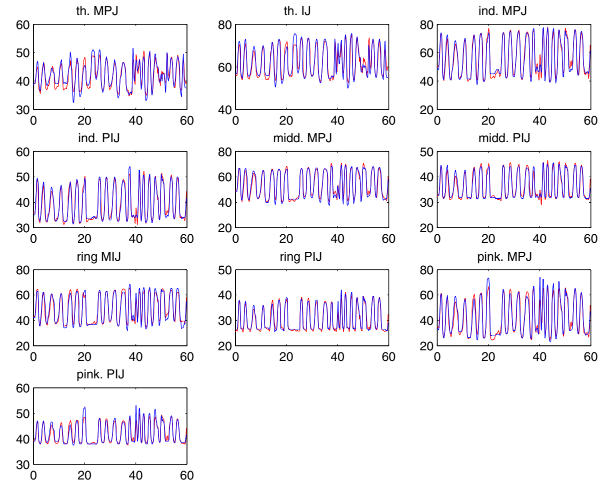

Fig. 6. Application of the feedforward network to the calibration dataset. Red lines represent the F output while blue lines represent outputs from the Cyberglove. Abscissa axis indicates the time expressed in seconds

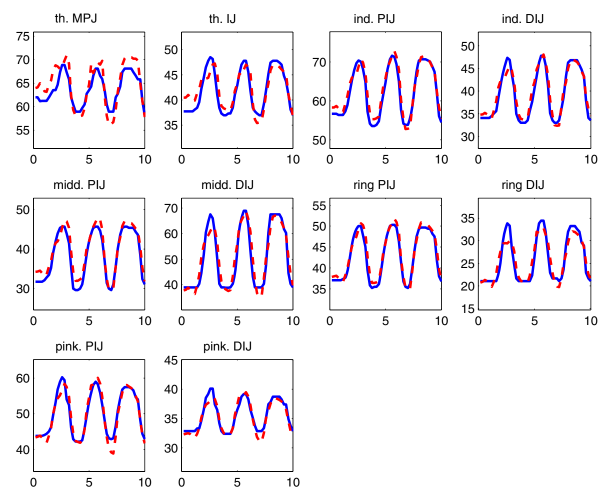

Fig. 7. Results of the application of the least square algorithm . Dashed lines are the CE sensing glove outputs while continuous lines are Cyberglove outputs. Abscissa axis indicates the time expressed in seconds.

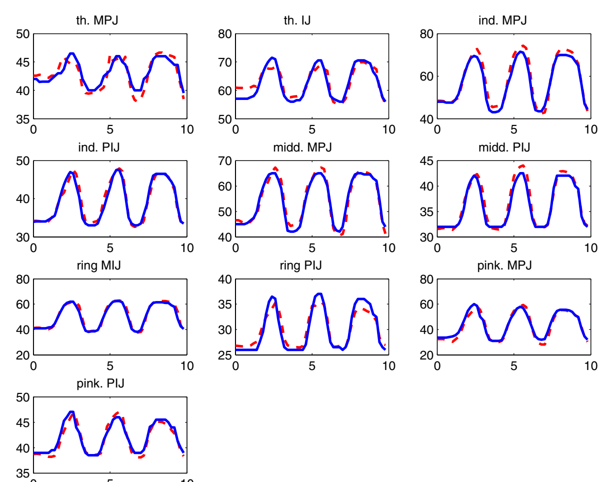

Fig. 8. Results of the application of the feedforward network algorithm. Dashed lines are the CE sensing glove outputs while continuous lines are Cyberglove outputs. Abscissa axis indicates the time expressed in seconds.

Although sensing glove performances are very promising, further methodologies and technical improvements are necessary. In particular, the refinement of the algorithms for signal analysis is a crucial issue. Future developments are oriented on the formulation of algorithms to map sensor values into hand positions minimizing the length of the calibration phase and the dependence on an external reference measuring system.

VI. ACKNOWLEDGMENTS

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