Wearable Kinesthetic Sensors For Body Posture and Movement Analysis

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Abstract

Monitoring body kinematics by wearable, comfortable and unobtrusive devices has fundamental relevance in several biological and technical disciplines. In this paper, the development and implementation of innovative sensing garments capable to detect posture and human body movement by using the electro-mechanical properties of innovative and diffuse conductive-elastomer (CE) sensors are presented. CE films show piezoresistive properties when mechanical deformations are applied. In several applications CEs can be integrated into fabric or other flexible substrate as strain sensors and may be used in biomechanical analysis to realize wearable kinesthetic interfaces able to detect posture and movement of the human body, matching several clinical requirements such as comfort, good fit and unobtrusivity. Currently, CEs behavior presents some peculiar non-linear phenomena and their use requires a complex treatment of the derived signals which will be introduced in the present work.

Figure 1: Sensorized Prototypes for monitoring the upper limb, the lower limb and the hand.

1 Introduction

The analysis of human movement is generally performed by relieving kinematic variables of anatomical segments by employing inertial devices, electromagnetic sensors or cameras integrated in finer equipment as stereophotogrammetric systems. The main drawbacks of wearable sensors available on the market are their weight, the rigidity of the structures that support them, their dimensions and all the other properties which make them obtrusive. In order to avoid all these discomfort during the movement analisys, wearability guidelines have led us to realize a set of garments made of elastic fabric (Lycra) as textile substrate for elastomeric sensors. These are spread without changing the mechanical characteristics of the fabric and confer to the fabric piezoresistive properties related to mechanical solicitations. This property has been exploited to realize a set of sensorized devices, including shirts, gloves and leotards, capable to reconstruct and monitor body shape, posture and gesture (Fig. 1).

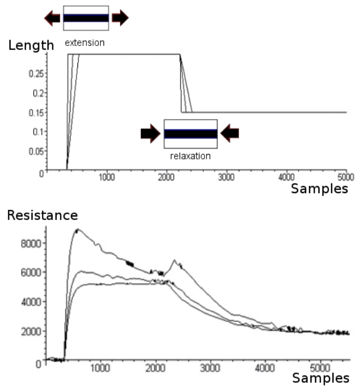

Figure 2: Dynamical response of a CE sensor stretched with elonging and relaxing ramps

2 CE Sensor Production and Characterization

In the production process of a sensorized garment a mixture of silicone rubber and graphite is smeared on a Lycra substrate previously covered by an adhesive mask according to the desired topology of the sensor network. After the CE deposition, the mask is removed and the treated fabric is placed in an oven at a temperature of $130°C$ to speed up the cross-linking process of the mixture. In about 10 minutes the sensing fabric is ready to be employed, showing the following figure of merit.

In terms of quasi-static characterization, a sample of 5 mm width performs an unstretched electrical resistance of about $1k\Omega$ per cm, and its gauge factor (GF) is about 2.8 ($GF = \frac{l(R-R_0)}{R(l-l_0)}$, where R, R_0 are the actual and rest electrical resistance, l and l_0 are the actual and rest length of the specimen, respectively. Moreover we have experimentally proved that Capacity effects showed by the sample are negligible up to $100MHz$, while the temperature coefficient ratio is about $0.08°K^{-1}$.

The dynamical electrical behavior of the analyzed specimen shows some non linear phenomena which are generally not negligible in certain working conditions, notably when fast deformations are applied (Fig 2), requiring a robust treatment of the derived signals. In particular, overshooting peaks in textile relaxing phases suggested us to implement an electro-mechanical model containing a quadratic term related to the strain velocity $\dot{l}(t)$:

$$g(t) = a_1 l(t) + a_2 \dot{l}(t) + a_3 \dot{l}(t)^2$$

whether long transients times can be approximated by a linear combination of exponential functions:

$$y(t) = c_0 + c_1 e^{-\omega_1 t} + \ldots + c_n e^{-\omega_n t}$$

Algorithms for the determination of coefficients a_i, c_i and the values of the poles ω_i have been developed and are described in [1].

3 Motion and Posture Analysis

When a sensorized garment is worn by a user which holds a given position, the set of sensors assumes a value strictly related to it. If the number of sensors is large enough and if the sensor locations are adequate, the values presented by them uniquely characterize the considered position. This fundamental idea has supported us to spread redundant sets of sensors and detect human body position by building maps between the sensor set values and the human body workspaces coded in joint variables. ([2]). The construction of this maps has required the use of a supporting (commercial) human position measurement system used both to calibrate the systems (identifying the maps), by providing joint angles values for basical points in the workspace and to validate the detection method (by verifying data acquired by the wearable sensor device corresponding to position never assumed in the calibration phase). The identification maps have been developed both by using mathematical discrete techniques of clusterization of the workspace and by using continuous piecewise linear functionals obtained by high dimensional interpolation.

4 Results and discussion

CE sensorized systems has been used in a wide field of applications. The sensing glove has been applied as recognizer of the signs of the American Sign Language, obtaining good results in hand posture classification. The Upper Limb Kinesthetic Garment (ULKG) has been used as the posture detector of the upper limb and it is currently applied in

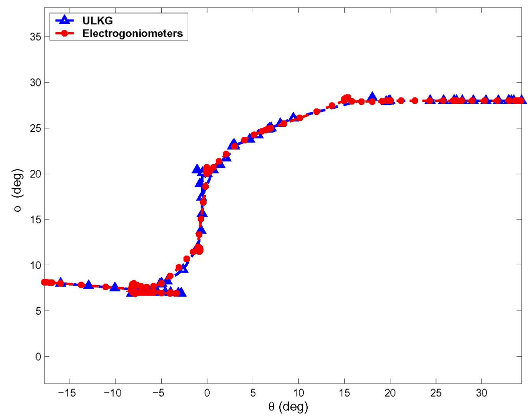

Figure 3: Comparison of elbow flexion angle between ULKG and electrogoniometers

post-stroke rehabilitation tasks. The sensing knee-sleeve is used in sport applications where flexion-extension and intra-extra rotations of the knee joint are continuosly monitorized during athlete's activity. Moreover, the knee-sleeve has been capable to discriminate finer pathological situations such as the femoro-tibial translation. Analogous accurate detection in mechanical pathology of the scapulo-humeral rythm (i.e. impingement) are currently under study.

Accuracy of garments, compared with commercial measurements istrumentation such as electrogoniometers or cameras systems, is very promising and shows discrepancy lower than 5%, as in case of the ULKG, reported in Fig. 4.

Last, but not least, the main result introduced by this technology is the acceptance by patients and athletes which wear sensing garments for long time without complain any discomfort.

References

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