WEARABLE TECHNOLOGY
Development of Polypyrrole Textile Electrodes for Electromyography

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Abstract: Following the work already done, in particular the "textile arm" by the authors, incorporating metallic filaments in the fabric during the weaving process with the aim of capturing surface electromyography signals, we concluded that there was a need to maximise the area of contact with skin to improve the obtained electrodes signals. The main objective of this work is the development of electrodes embedded into textile materials able to capture electromyography signals, using the polypyrrole conducting polymer, both in coating of electrodes directly into the textile fabric and preparing a conductor yarn with this polymer to obtain a knit structure. This work allowed developing wearable technology textile structures for muscle activity monitoring, through the measurement of electromyography signals, keeping simultaneously comfort and easy-care textile characteristics. The signals obtained with this approach had a good definition compared with commercial electrodes and with the great advantage of this procedure can be applied in industrial production.

1 INTRODUCTION

Through times, many have been the fields of science and technology that progressed in separate ways. During the last years, a considerable convergence appeared among some of these fields, with surprising results. The smart technology for materials and structures is one of these results (Lucas, 2007).

1.1 Wearable Technology

The smart textiles concept was firstly defined in Japan in 1989 (Langenhove, 2007). With the discovery of shape memory materials in 19600 and intelligent polymeric gels in the 1970 decade, it was accepted the birth of really smart materials. These have been introduced in textiles only in the 90´s (Langenhove, *et al.*, 2006). Smart textiles can be described as textiles that can feel stimuli from environment, react and adapt themselves to them by integrating functionalities in the textile structure (Langenhove, *et al.*, 2006).

The stimulus, as well as the response may be electrical, thermal, chemical, magnetic or of other kind. The degree of intelligence can be divided into three subgroups:

- Passive smart textiles that only feel, being sensors;
- Active smart textiles that perceive external stimuli and react to them, besides being sensors, they act also as actuators;

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- Truly smart textiles, being one step ahead and able to adapt its behavior to the circumstances (Zhang, 2001).

It would be wonderful to have clothes like our skin, which is a smart material layer. Our skin has sensors to detect pressure, pain, heat, etc. and, together with the brain, can work in a smart manner with environmental stimuli, generating large amounts of perspiration to cool our body when in a hot surrounding and stimulating blood circulation when it is cool. It changes colour when exposed to a high sun radiation level, in order to protect the body, It is breathable and allows moisture penetration, avoids the entry of undesired species, it can be damaged, repaired and regenerate itself. Thus, to study and develop a smart material like our skin is a big challenge (Boczkowska, Leonowics, 2006).

To Bonato (2005), when looking for a better way of life, more and more solutions have been investigated to contribute to a comfort improvement and well-being. The research field is going on and several research groups have already demonstrated a relevant application and the potential impact of this technology is remarkable in clinic practices concerning physical and rehabilitation treatments. Presently, the main use of clinic techniques resides on methods that embed devices into smart clothes on in the patient's body. The wearable technology has a large potential to redirect these techniques into functioning during the normal day life (Bonato, 2005).

The development of small size sensors that can be connected to the body or can be a part of clothes, embed elements into cloth fabrics, open a large number of possibilities to monitor patients during long periods of time. This is of particular relevance to the practice of physical and rehabilitation treatment. The wearable technology allows to clinical staff the treatment of data, acquired at home or by direct observations relating to the impact of clinic interventions in mobility, thus reaching a higher independence level and a better quality of (Bonato, 2005).

1.2 Conductive Polymers

The firs conductive polymer was discovered accidentally by Hideki Shirakawa in 1971 (Shirakawa, Ikeda, 1971) during a reaction with acetylene. From this, it began research to understand the charge transfer mechanisms in these (Neto, 2007).

The key to get a conductive polymer is the presence of conjugate double bonds in the polymer main chain. During conjugation, links between carbon atoms are alternately single and double bonds. Each double bond has a localized bond that gives a strong attraction (σ bond) and a weaker one (π bond). The electrical conductivity in polymers is an effect due to π electron displacement in alternate sequence of single and double bonds (Lucas, 2007), as seen in Figure 1.

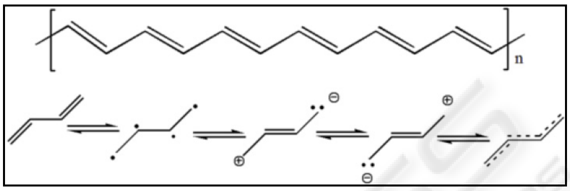


Figure 1: Illustration of π electrons displacement in alternate sequence – electrical conduction (Lucas, 2007).

Conjugation is not enough to assure conduction in a polymer. The doping function is now of an agent seen as polymer charge carrier, as extra or "missing" electrons (hole). One of these holes can be filled by an electron jumping from a neighbor position, creating a new hole and, thus, successively, allowing a moving charge through a long (Lucas, 2007).

Polypyrrole is one of the most studied conductive polymers due to its high conductivity, good environmental stability, harmless and easy to synthesize. Consequently, polypyrrole has advantages in real applications in microelectronics, informatics industry and biomedical information. However, polypyrrole is not soluble in water and in organic solvents, due to the strong intermolecular and intramolecular interaction and crossed polymer chains. For this reason, to overcome the non solubility issue of polypyrrole, many research works have been done (Pires, 2007).

Recently, soluble polypyrrole was synthesized with large dope agents, such as dodecyl-benzene-sulphonate acid (DBSA) and naphtale-sulphonate (Lim, et al., 2005).

According to Dall'Acqua, L. et al. (2006), the affinity of different types of fibers, yarns and fabrics with doped polymers allows production of textile composites having improved electrical properties.

Following the study of Lim., H. K. et al. (2005), a new soluble and conductive polypyrrole, doped with DBSA and combined with a polymeric agent, the poly (ethylene glycol) (PEG).

1.3 Electromyography Signal Acquisition

According to J. Basmajian e C. De Luca (1985) electromyography measures the electric activity resulting from skeletal muscle activation, these being responsible by the support and movement of skeleton.

According to the Hospital Sant Pere Claver Electromyography Unit at Barcelona, electromyography is an electrophysiological study of neuromuscular system; it is not a complementary proof but an extension of a neurological study. This basis of all electrophysiological research is the registration of excitable cells potentials. Electromyography deals with registering of such potentials, self acting in the muscle and electroneurography of evoked potentials, both on the muscle and on nerve branches, by generally electrical stimulation of nerves having anatomic connection with the registering area. The electrical properties of excitable nervous and muscle fibers derive from a semi permeable membrane that separates intracellular and extracellular fluids having different ionic concentration origination a transmembrane potential.

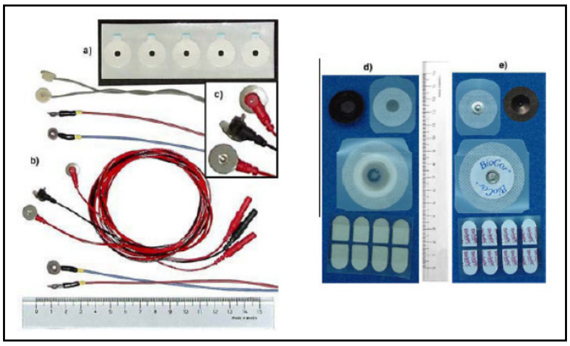
When measuring electromyography signals (EMG’s) electrodes can be used placed inside the muscle (deep electromyography) or electrodes placed on the skin (surface electromyography) (Sousa *et al.*, 2007).

According to the type of acquisition, electrodes may be invasive or not. When an electrode becomes into contact with the body fluid is called invasive, which can be of the yarn or needle type and presents characteristics such as low electrical impedance, this is, it does not need of conductive gel, it acquires larger amplitudes and its power spectrum goes up to 10KHz (Ricciotti, 2006). They are most indicated for clinical analysis, where it is possible to detect the acting potential of a moving unit, as well as exploring an isolated of a deep muscle. The invasive electrodes have several drawbacks, being among them excellent sterilization, the danger of breakage of yarns inside the muscle and, after all, the patient´s (Ricciotti, 2006).

According to Jacquelin Perry (1998), from the 28 main muscles that control each lower member, most of them are surface muscles, being possible to monitor their activity using surface electromyography. During the last years, surface electromyography (sEMG) has become very frequent when studying and treating several muscle dysfunctions, due to the fact that it is a secure technique, easy to use and non-invasive. Most of knowledge fields use EMG signals as starting point to several human muscle system function and dysfunction analysis. Recent studies relate the muscle fatigue process to a displacement of signal spectral contents. Other investigations emphasized the importance of these signals in neuromuscular reeducation of patients having hyperactive muscles by electromyography *biofeedback* (Sartori *et al.*, 2004).

There several ways to configure EMG signal acquisition through electrodes, the most common being those requiring one (monopolar) and two (bipolar) capturing points. The monopolar configuration deals with the potential difference between two points (a capturing and a reference point). The bipolar configuration is characterized by the potential difference between to acquisition points, measured respecting to a third point (reference). Electrodes are normally made of silver coated with silver chloride (Ag-AgCl), since it is a non polarizable noble metal.

The surface electrodes allow capturing signals representing the activity of a muscle as a whole or a group of muscles in a global manner and can be subdivided into passive and active electrodes (Barros, 2005 in: Ricciotti, 2006). The passive electrode is constituted by a metal disk (in general, Ag-AgCl), that must be placed over the skin (Figure 2). To decrease the contact impedance between electrode and skin, it may be required a tricotomy (pile removal from the region where the electrode will be placed), the use of conductive abrasives and gel or paste (Ricciotti, 2006).



a) Adhesive for electrode fixation;
b) Reusable electrodes;
c) Reusable electrodes detail;
d) Reusable electrodes rear view;
e) Reusable electrodes front view.

Figure 2: Examples of commercial passive electrodes (Ricciotti, 2006).

The active electrodes have a magnifying circuit encapsulated near the electrode acquisition place. Generally, these are bipolar electrodes, this meaning that the amplifier used is of differential type. The active electrodes, since they are made of a differential amplifier, require a reference electrode placed ion an inactive region to avoid measurement interference (Basmajian, De Luca, 1985). Such electrodes are also called dry electrodes, since generally do not need to use conducting gel, paste, abrasives or pile (Ricciotti, 2006).

The textile support represents the first functionality level of a wearable technology architectures system, since it comprises the infra-structure to embed the basic functions as energy and data transmission or the sensorial (Rodrigues *et al.*, 2008).

Following work already done, namely the "textile arm" (Rodrigues *et al.*, 2008), where conductive metallic yarns are incorporated into the fabric during weaving with the aim to acquire surface electromyography signals, it was observed the need to optimise the contact region with the skin to improve electrode signal acquisition. Aiming to contribute to problem solving, it is studied now the applicability of polypyrrole as a conductive polymer.

2 MATERIALS AND METHODS

2.1 Printed Polypyrrole Electrodes

2.1.1 Textile Substrate

As textile substrate the dobby fabric developed in the "textile arm" research work was used (Rodrigues *et al.*, 2008), having a compound weave based on heavy twill 3 (Figure 3).

The main fabric characteristics are:

- Cover Factor: 95.3%;
- Weft density (DT): 19 yarns/cm;
- Warp density (DB): 24 yarns/cm;
- Warp yarn – 2/36Nm (45WO/53PES/2EA)
- Weft yarn – 2/50Nm (45WO/55PES)

2.1.2 Reagent Preparation

The pyrrole solution was prepared with: 9% of DBSA – doping agent that reduces inter and intra interactions in polypyrrole chains, improving pyrrole solubility in organic solvents; 9% of PEG – polymeric additive and 82% distilled water.

These reagents are mixed at room temperature with slow stirring (10-15minutes). After, pyrrole is added on a 0.11ml/g ration of the prepared solution. After dissolving completely, the resulting solution was isolated from air. Due to the need of a viscous solution, for coating, a printing paste with only a thickener (6% Sodium Alginate) in water was prepared.

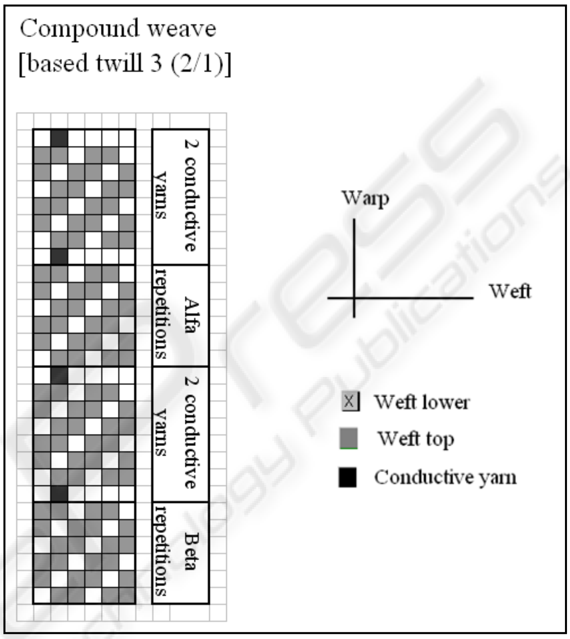


Figure 3: Compound weave module based on 2/1 twill 3 with metallic yarn (Rodrigues *et al.*, 2008).

Since the pyrrole solution is quite unstable, the oxidizing solution must be prepared before, which is more stable. The oxidizing solution was prepared with 20% of APS – oxidizing agent and 80% distilled water.

2.1.3 Electrode Coating Methods

Following, the sodium alginate thickener was added to the pyrrole solution on a 1/1 proportion. After a complete mixing, the resulting paste was isolated from air and kept at low temperature.

The fabric was pre-scoured in a bath containing 1g/l of Invadine LU (CIBA) – wetting agent, at 40ºC during 20 minutes.

For electrode coating the respective area was delimited and, to achieve a good electrode area definition, the liquid oxidising solution was applied first in excess followed by the pyrrole solution thickened with sodium alginate (Figure 4). The coated fabric was kept at room temperature for 15 to 30 minutes and then placed in a woven during 2

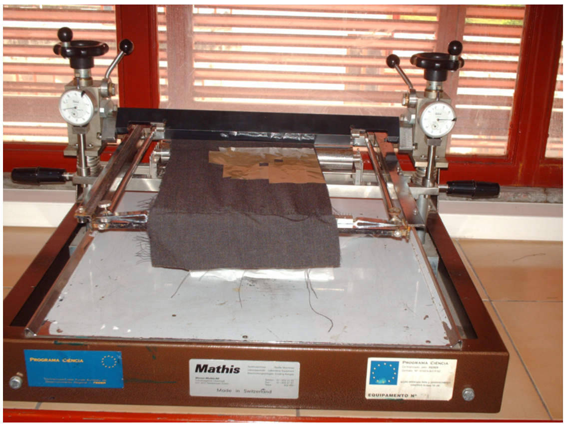


Figure 4: Electrode coating device.

minutes at 100ºC.

To take out polypyrrole in excess from fabric surface and, thus, to improve washing fastness, a 1g/l Reoklen detergent scouring at 50ºC and during 20 minutes was carried out.

2.2 Embroidered Polypyrrole Electrodes

2.2.1 Reagent Preparation

A pyrrole solution was prepared having a ratio of 9ml of pyrrole to 100ml of DBSA and PEG in distilled water, in the same way as described before in 2.1.2. The oxidising solution used was also the same as that employed in electrode coating.

2.2.2 Conductive Yarn Preparation

The chemical polymerization was achieved by making the yarn go through the pyrrole solution and after, through the oxidising solution, leaving exposed at room temperature during 15 minutes and after in a woven at 100ºC during 4 hours. To eliminate excess of polypyrrole at the knit surface and improve washing fastness, a detergent scouring was performed.

2.2.3 Textile Substrate

As textile substrate a jacquard knit was used, being the polypyrrole conductive yarn inserted into the knit structure as shown in Figure 5. For knitting, a 3 ply 100% cotton yarn of 2/32Nm count was used. At the electrode region, a polypyrrole treated 3 ply 100% wool yarn of 2/36Nm count was employed.

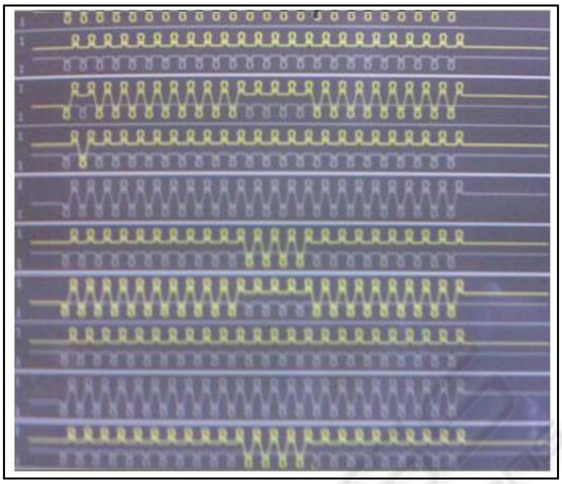


Figure 5: Jacquard knit structure showing electrode positioning.

In Figures 6 and 7 knit images are shown, being emphasized conductive yarn and electrodes.

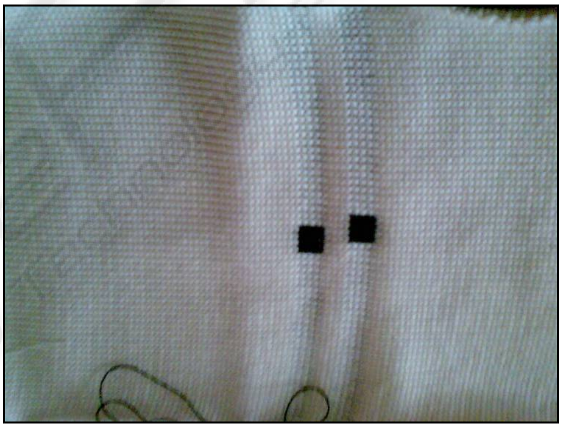


Figure 6: Knit right face with electrodes.

Figure 7: Knit back face with conductive yarns.

3 RESULTS AND DISCUSSION

3.1 Electromyography Signal Acquisition

To acquire surface electromyography signals (EMG), an experimental system was developed made by a lap top computer, a differential amplifier and software for measuring physiological signals (Elektor Electronics, 2007), as shown in Figure 8.

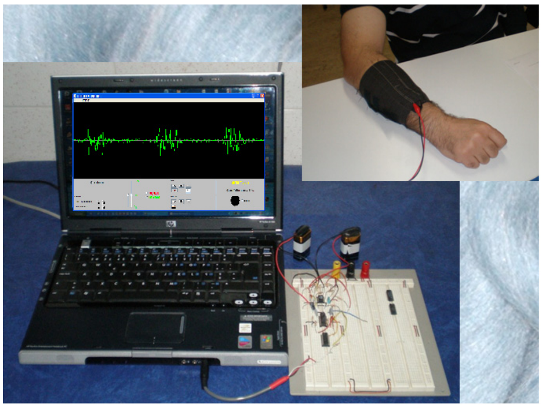


Figure 8: Experimental system for sEMG signal acquisition.

To acquire surface electromyography signals (aEMG), electrodes were placed on the arm and, when hand squeezing a ball, the stimulated muscle contracted. At the beginning, commercial electrodes were used, these being placed on the arm to test the equipment (Figure 9).

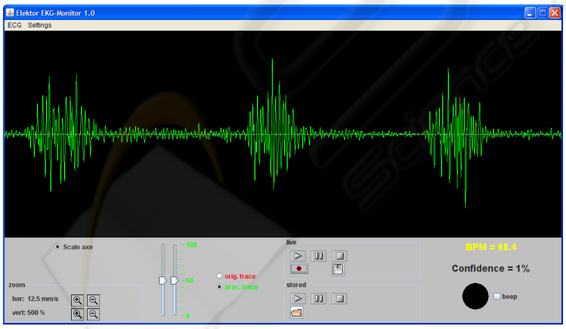


Figure 9: sEMG captured signal using commercial sensors.

Figure 10 shows the signal captured in the case of "textile arm" produced with metallic filament and embroidered electrodes using conductive yarn (Rodrigues *et al.*, 2008). In fact, the signal obtained has a good definition and shows that this method is adequate and can be used to measure the muscle activity, for example, in rehabilitation.

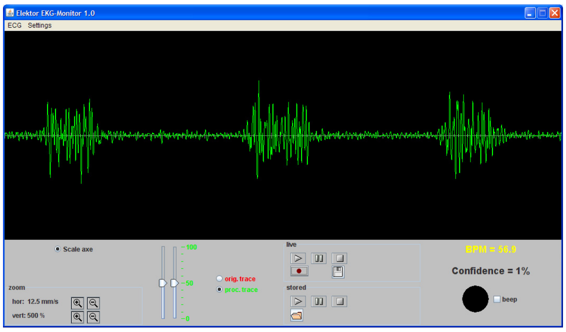


Figure 10: sEMG captured signal using hand embroidered electrodes with metallic yarns (Rodrigues *et al.*, 2008).

However, this method doesn't show a good industrial feasibility, mainly because electrodes have to be hand embroidered. For this reason, it became necessary to develop embedded electrodes into textile materials able to capture electromyography signals and, at the same time, maximise the area of contact with skin to improve the acquired signals by electrodes. These signals captured by the "textile arm" made with printed polypyrrole electrodes are shown in figure 11. Also, the obtained signals with the electrodes of the knit structure made with polypyrrole treated yarns are shown in figure 12.

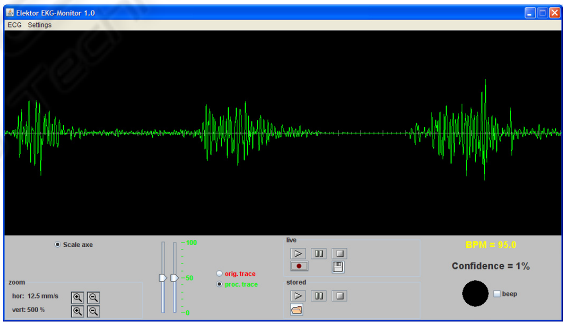


Figure 11: sEMG captured signal using polypyrrole coated electrodes.

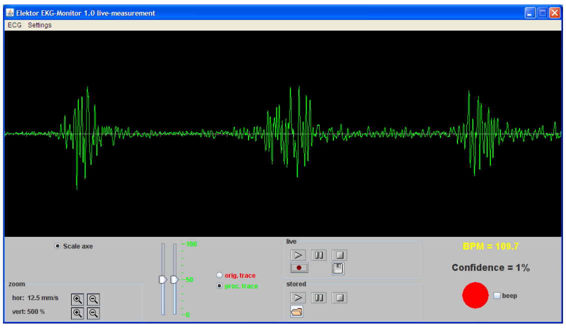


Figure 12: sEMG captured signal using polypyrrole knitted electrodes.

This data shows that we can obtain good definition signals with the advantage that may have industrial applicability.

4 CONCLUSIONS

In this research work electrodes for wearable technology were developed, enabling simultaneously a high level of integration, to keep textile properties, the conductive polymer properties and the signal capturing through substrate functionality. Analysing the clarity of acquired signals it can be concluded that they are similar, the solutions found presenting, compared to commercial sensors, the same advantages than the hand embroidered electrodes in the "textile arm" (Rodrigues *et al.*, 2008), this is, textile comfort, mobility, cleanness and maintenance, etc. Besides these, they also exhibit advantages at industrial feasibility level.

The acquired results are satisfactory, considering the possible advantages of these may present sport and clinical rehabilitation level and even considering research work on neuromuscular development. Thus, this work presents the development of textile solutions that, being improved, both from the textile point of view, through incorporating electronic devices, and counting on the informatics contribution, gather potentialities to perform in future an important role in people's quality of life.

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