Fully integrated embroidery process for smart textiles

Isabel G. Trindade*, P. Spranger*, F. Martins*, R. Miguel*, M. Santos Silva*

*R&D Unit of Textile and Paper Materials, Universidade da Beira Interior
Rua Marquês D ´ Ávila e Bolama, 6201-001, Covilhã, Portugal, itrindade@ubi.pt

ABSTRACT

In this article, the design, process and characterization of textile sensors for vital signals sensing are presented. Textile electrodes and piezoresistive sensors and respective interconnect plate for the monitoring of cardiac and pulmonary signals, were fully produced with a 6-head digital embroidery machine and electrically conductive commercial yarns. The waveforms were acquired via PC with a data acquisition module and Labview program. The signal to noise ratio of textile electrodes having surfaces that were either textured or smooth accordingly with the embroidery pattern used, were analyzed with Matlab. The quantitative method indicated differences between the two types of textile electrodes but performances comparable to Ag/AgCl gel electrodes. The sensors and respective interconnect plate, all realized with textile fabrics and threads by means of an embroidery machine, have a compact design, are lightweight, washable and suitable for integration in clothing. The method of production only involves the embroidery stitching technique, and has great versatility in terms of sensor size, surface texture and integrating materials.

Keywords: textile electrodes, embroidery technique, vital signals, piezoresistive elastic, integration.

1. INTRODUCTION

Wearable electronics combining low-power circuits, wireless transmission and advanced packaging have allowed important breakthroughs in medical applications [1] and smart clothing [2], [3] with functionalities to monitor and record vital signals in ubiquitous and non-invasive ways. These were considered strategic to lower morbidity and health care costs associated to diseases of the circulatory system. Holter monitors (ambulatory electrocardiography devices) are currently used to capture a patient electrocardiogram (EKG) for one to three days, using standard gel electrodes (between three and ten) taped to patients' skin. The EKG data is analyzed afterwards by doctors to evaluate the patient´s cardiovascular condition. Although Holter systems are portable, the patients feel the cables connecting the electrodes to the electronic unit as intrusive and uncomfortable.

Wearable technologies to monitor vital signals had a strong impulse around 2000 with public and private funded projects that produced important outcomes, such as the French VTAMN [4], the EU Wealthy [5] and MyHeart [6] and the American LifeShirt [7]. The Wealthy system consists of elastic garments made by seamless knitting technology, integrating knitted electrodes to capture EKG signals and piezoresistive sensors for pulmonary ventilation (PV) monitoring, realized with fabrics of lycra, coated with carbon-loaded rubber and a commercial electroconductive yarn [8]. The electrodes and interconnects were knitted with electrically conductive yarns, consisting of stainless steel surrounded by twisted cables of viscose. Hydrogel membranes placed between the knitted electrodes and the skin were necessary to improve signal to noise ratio (SNR) and minimize skin irritation [9]. A handheld electronic unit was used for signal conditioning, processing, storage and wireless GPRS cellular communication [8]. The LifeShirt used gel electrodes and embedded textile sensors for plethysmographic respiration monitoring and a small personal controller held in a pocket to capture signals and transmit data via Bluetooth [10]. The VTAM system also consisted of a T-shirt integrating smooth, dry ECG electrodes, with leads and treatment modules incorporated into textile woven fabrics. It used a motherboard, transmission module and power supply mounted on a belt that was connected to the VTAM T-shirt through a microconnector [11]. Screen printed silver paste has also been proposed to produce planar fashionable circuit board (P-FCB) electrodes and to perform wire bonding of electronic chips on fabric [12]. A flipChip on flex intermediate connection layer, having higher density than textiles can provide, was proposed to interconnect high density silicon chips to textile fabric [13]. More recently, an active belt integrating washable textile electrodes from TITV Greiz, and two cell-phone plugs (1.6cm x 2cm) for signal processing was proposed [14]. Nowadays Holter systems have very small dimensions, but connecting to Ag/AgCl gel electrodes through long cables hanging on the chest of the user, and efforts continue to improve the performance of textile sensors and interconnects, and the electronic systems integration in clothing, involving the interface electronics – textiles. A question often put forward is what are the main challenges to manufacture smart textiles? Large and small companies debating these questions, point out the difficulty to combine Textile and Electronic Manufacture processes. There is a dilemma concerning where to put the interface on technical level in the supply chain between the electronic manufacturing service and the textile manufacturing service [15]. Another challenge concerns availability of human resources with competences to deal with interface textile / electronics manufacturing.

The embroidery technique has been proposed as a technique with great potential and versatility for smart textiles [16] and was used to produce soft electrodes for neonatal intensive care EEG monitoring [17].

In this work we present a technique that may be suitable for large scale production, and that offers versatility in terms of materials and product design to costume demand.

2. DESIGN, MATERIALS AND PRODUCTION

For the monitoring of EKG, circular shape sensors, consisting of two layers of fabrics, were fully produced with a 6-head embroidery stitching machine. One fabric layer had defined a circular embroidery pattern produced with electrically conductive threads; the other fabric layer, the back side of the sensor, integrated a snap fastener applied by pressure with a matrix. The sensor and integrated electrode had diameters of 25 mm and 16 mm, respectively. Two types of embroidery patterns were produced, designated smooth and textured, corresponding to the morphology of the surface of the electrodes to address the adhesion and stability of the contact electrode – skin. The snap fasteners allowed to attach any kind of pair of electrodes to an interconnect plate, in an interchangeable manner, and to obtain a direct comparison of SNR performance between textile and gel electrodes. The interconnect plate was produced by layering a semi rigid foam between two fabrics, one of the fabrics having defined the interconnects between female snap fasteners that hold the textile electrodes and snap fasteners that connect to the electronic data acquisition module. The electrically conductive wires were protected and electrically insulated with embroidery patterns made with traditional yarns of polyester. Fig. 1 are shown photos of textile and gel electrodes and respective interconnect plate.

For the monitoring of pulmonary ventilation, a piezoresistive elastic thread was stitched to an elastic band in a sinusoidal-like pattern with the embroidery machine.

The textile electrodes were made with electrically conductive yarns Silverpam 250 from the French manufacturer Tibetech. The gel electrodes were Ag/AgCl Cleartrace RTL – 1700C from ConMed, USA. The PV sensor was made with a piezoresistive elastic thread, Elitex HE, from the German manufacturer Imbut Gmbh.

The production process is versatile and does not require intermediate steps in a clothing´s manufacture workshop. In Fig. 2 is shown a snapshot view of the production process

a)

b)

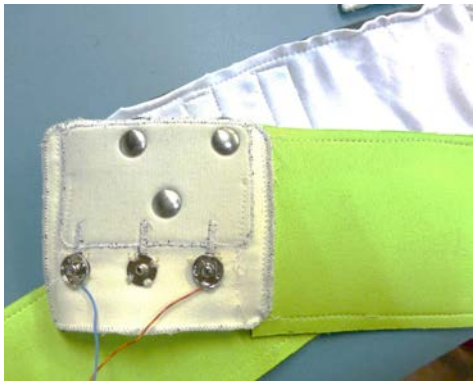
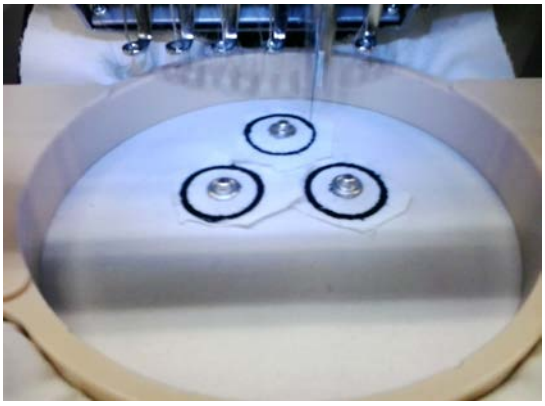


Figure 1:. a) Photo with pair of textile electrodes attached to interconnect plate through snap fasteners, commercial Ag/AgCl gel electrode and back side of textile electrode;

a)



b)

Figure 2: Photo views of production process of textile electrodes (a) and PV sensor (b) with a 6-head embroidery digital machine.

of the EKG and PV sensors with a SWF digital embroidery machine.

3. EXPERIMENTAL

An elastic and adjustable chest band made of neoprene and integrating the interconnect baseplate and the piezoresistive sensor was used with a male volunteer, seat motionless in a relaxed position. The interconnect baseplate was positioned on the left side of the thorax, in the region of the fifth intercostal spaces, with the two electrodes spaced apart 4 cm from center to center.

The two electrodes and the terminals of the PV sensor were connected to two differential analog inputs of a programmable data acquisition unit, NI-DAQ 6212, with PC/USB interface. A Labview program, using a band-stop Bessel filter of order 6 to remove the 50 Hz interference signal of the environment, allowed the displaying and recording of the waveforms. The PV sensor had a static resistance of 30 Ohms and was connected to a voltage divider circuit supplied with a 9V battery.

The SNR of the textile and gel electrodes were obtained with a Matlab program. The program extracted from each experimental data file, 50 waveforms and applied a smooth function, with a span = 150, to remove any baseline distortion or shift and the P and T segments. From the raw and correspondent smooth data matrixes, the program calculated for each k experiment of a specific type of electrode, the mean values of signal amplitude, $V^{s,k}$ of the QRS complex, and noise amplitude, $V^{n,k}$, correspondent to the average absolute value of amplitude based on 100 points of a segment away from the QRS complex, and described by the following equations:

$$V^{s,k} = \frac{1}{50}\sum_{i=1}^{50}\left(\left|V_{\max}^{s,k,i} - V_{\min}^{s,k,i}\right|\right) \quad (1.1)$$

$$V^{n,k} = \frac{1}{50}\sum_{i=1}^{50}\left(\frac{1}{100}\sum_{j=1}^{100} 2\cdot\left|V^{n,k,j}\right|\right) \quad (1.2)$$

The SNR is given by the ratio of the mean values of signal to noise,

$$SNR^{k} = 20\log\frac{V^{s,k}}{V^{n,k}} \quad (1.3)$$

For each type of textile electrodes, 20 sequential experiments were performed, by replacing the pair of the electrodes with another similar pair, and the mean SNR and respective standard deviation were calculated.

In Fig. 3 is shown the mean SNR and standard deviation (error bars) that were obtained with the experimental method and the two types of textile EKG sensors and the gel electrodes. The textured electrodes exhibited a SNR performance very similar to that obtained

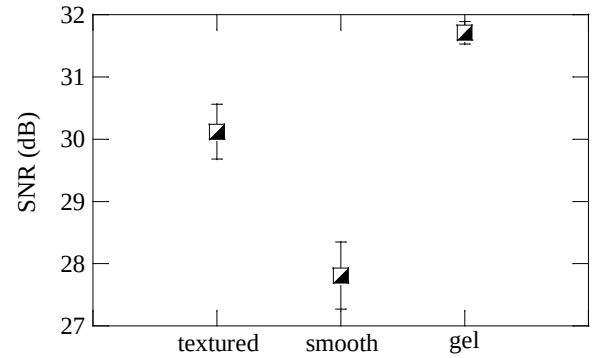


Figure 3: SNR ratio amplitude of textile and gel sensors.

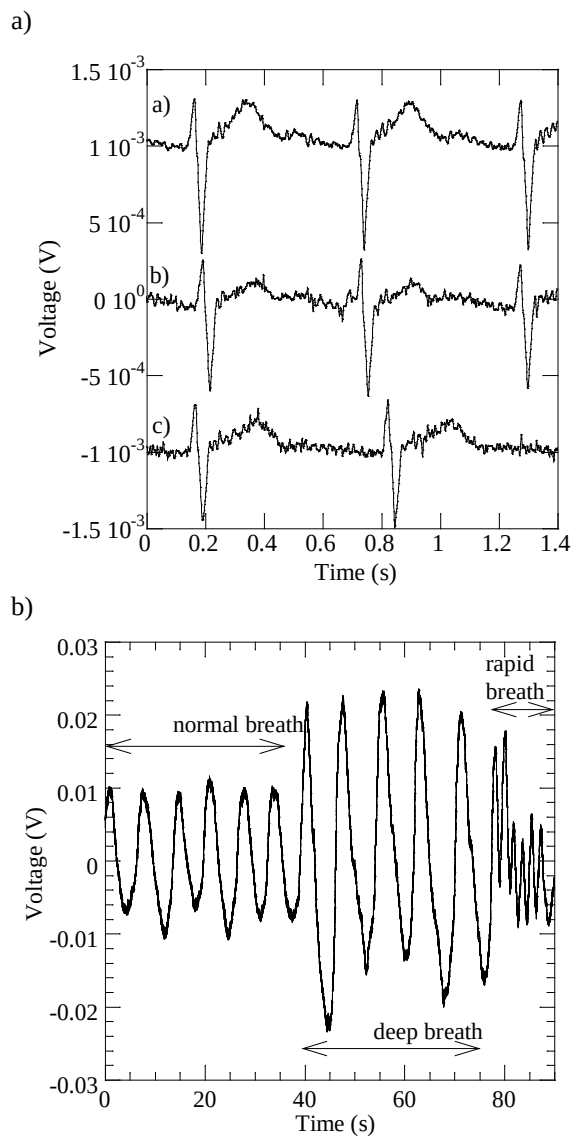


Figure 4: a) ECG waveforms obtained with gel and textiles sensors, where (a) gel electrodes, (b) textured electrodes, (c) smooth electrodes; b) PV response to normal, deep and rapid breath rates.

with the gel electrodes, followed closely by the smooth electrodes. The results suggest that the textured surface may provide better contact resistance between the electrodes and the skin. The SNR results presented in here are considerably better than those reported by other authors, for both types of textile electrodes. In particular, our results are with gel electrodes are very similar those reported by other researcher, of 31.5 dB [12], but our textured electrodes, with a SNR ≅ 30 ± 0.5 dB, are considerable y better than those presented in the literature [12], [18].

Raw ECG and VP waveforms are shown in In Fig. 4. In agreement with the SNR results, the textile electrodes show higher noise than gel electrodes. The PV sensor exhibits good signal amplitude, but further tests will be conducted in terms of robustness and signal stability.

The textile electrodes and rectangular test structures having defined on fabric identical embroidery patterns were submitted to 20 washing cycles with a Linitest machine following the guidelines of the ISO 105 of 1978. The electrical resistance of the test structures was monitored between washing cycles and no variation was obtained. The textile electrodes also show identical SNR amplitudes to those un-washed. While the electrically conductive yarns are relatively fragile, the compact embroidery patterns provide the sensors with high robustness and good washing resistance.

4. CONCLUSIONS

The proposed embroidery method may be suitable for large scale production. The design, materials and embroidery method produced textile electrodes with good performance of SNR. The method offers high degree of versatility to produce costume sensors and interconnects to electronic modules for signal processing and wireless data transmission.

ACKNOWLEDGMENTS

This work was financed by FEDER funds, through the Operational Program Factors of Competitiveness – COMPETE and by National Funds through FCT – Science and Technology Foundation, under the grant PTDC/EEI-ELC/1838/2012. P. Spranger and F. Martins would like to thank FCT for the scholarship support.

REFERENCES

[1] K.D. Wise, "Wireless integrated microsystems: Wearable and implantable devices for improved health care Solid-State", Sensors, Actuators and Microsystems Conference, Transducers, 1-8 (2009).

[2] L. V. Langenhove, C. Hertleer, "Smart clothing: a new life", Int. J. Cloth. Sci. Tech. 16, 63-72 (2004).

[3] M. Suh, K. Carroll and N. Cassill, "Critical Review on Smart Clothing Product Development", Journal of Textile and Apparel, Technology and Management, 6, 1-18 (2010).

[4] VTAMN project: Bioclothes for ambulatory telemonitoring, RNTS 2000, French Ministry Res. New Technol., France.

[5] Wearable Health Care System (IST-2001-37778, EU funded project)

[6] Wearable Health Care System (IST-2003-507816, EU funded project)

[7] Vivometric: LifeShirt System.

[8] R. Paradiso, G. Loriga, and N. Taccini, "A Wearable Health Care System Based on Knitted Integrated Sensors", IEEE Trans. on Inf. Tech. in Biom., 9, 337-344 (2005).

[9] R. Paradiso, G. Loriga and N. Taccini, "Knitted Bioclothes for Health Monitoring", Proceedings of the 26th Annual Int. Conf. of the IEEE Eng. in Medicine and Biol. Soc., San Francisco, 2165-2168 (2004).

[10] K. J. Heilman and S. W. Porges, "Accuracy of the LifeShirt (Vivometrics) in the detection of cardiac rhythms", Biol. Psychol., 75, 300-305 (2007).

[11] F. Axisa, P. M. Schmitt, C. Gehin, G. Delhomme, E. McAdams, and A. Dittmar, "Flexible Technologies and Smart Clothing for Citizen Medicine, Home Healthcare, and Disease Prevention", IEEE T. Inf. Technol.B. 9 (3), 325-336 (2005).

[12] K. Mankodyia, Y. A. Hassan, S. Vogt, H. Gehring, U. G. Hofmann, "Wearable ECG Module for Long-term Recordings using a Smartphone Processor", Proc. 5th International Workshop on Ubiquitous Health and Wellness, UbiComp 2010, Copenhagen, Denmark, Sept. 26, 2010.

[13] G. Tröster, T. Kirstein, P. Lukowicz, "Wearable Computing: Packaging in Textiles and Clothes", 14th European Microelectronics and Packaging Conference, Friedrichshafen, Germany, 2003.

[14] E. R. Post, M. Orth, P. R. Russo, N. Gershenfeld, "E-broidery: Design and fabrication of textile-based computing", IBM Syst. J., 39, 840-859 (2000).

[15] L. Pieterson, K. Os, F. Abeelen, S. Luitjens, G. Zhou, Philips Sense and Simplicity: Conformal Lighting, Smart Fabrics Conference, London, 2011.

[16] J. Yoo, L. Yan, S. Lee, H. Kim, H. Yoo, "A Wearable ECG Acquisition System With Compact Planar-Fashionable Circuit Board-Based Shirt", IEEE T. Inf. Technol. B. 13 (6), 897-902 (2009).

[17] J. Löfhede, F. Seoane and M. Thordstein, "Textile Electrodes for EEG Recording – A Pilot Study", Sensors 12, 16907-16919 (2012).

[18] S. Kim, S. Leonhardt, N. Zimmermann, P. Kranen, D. Kensche, E. Müller, C. Quix, "Influence of contact pressure and moisture on the signal quality of a newly developed textile ECG sensor shirt", Proceedings of the 5th International Workshop on Wearable and Implantable Body Sensor Networks, Hong Kong, China, 2008.

[1] Universidade da Beira Interior, Rua Marquês D´Ávila e Bolama, 6201-001, Covilhã, Portugal, itrindade@ubi.pt.