TEXTILE BASED ELECTRODES FOR ECG AND EMG MEASUREMENTS

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ABSTRACT

Biopotential signals are an important tool for monitoring our health and thanks to the evolution of technology, they are being increasingly used in several areas. There are however some problems with conventional electrodes such as irritation that need to be surpassed and textile electrodes may represent a good alternative.
This paper proposes a design approach for textile based electrodes developed by our research group, in which the construction of the electrodes is based on 3D surface design of weft knitted structures, which increases thickness and allows to improve the permanent contact between electrode and skin, thus contributing for the solution of one of the problems identified by the research community.

Key Words: TEXTILE BASED ELECTRODES, ECG, EMG, WEARABLES, CONDUCTIVE YARNS, KNITTING

1. INTRODUCTION

To measure bioelectric potentials, namely electrocardiography (ECG), electromyography (EMG), it is generally accepted that the most adequate material is made of Ag/AgCl, due to be almost non polarizable, in particular for low frequencies [1]. These electrodes can be rigid or flexible and can use adhesive, suction or some kind of compression. To reduce the skin-electrode impedance and improve the signal quality it is usual to perform a skin preparation by shaving, cleaning with alcohol solution and use disposable wet electrodes in which a conductive gel is applied between the skin and the electrode. However, this solution promotes irritation and the gel deteriorates when long time monitoring is required [1,14,15,16]. Thus dry electrodes could be a valid alternative for replacing the scientifically accepted solutions used nowadays, in particular if there is no need for prior skin preparation. This necessity is also related with a crescent population, namely the elderly population who may need a permanent and constant supervision. The advent of the global networking and massive data access through wireless communications provides the physicians with the means to continuously follow their patients, and a last step is thus required to connect the latter to the cloud: to use an ubiquitous monitoring system for the user. It is here where the textiles can bridge the gap that still exists. Textile fabrics are used in close contact to the skin, so a fabric with integrated sensors would be the perfect solution.
Several studies have been made in order to propose alternatives to conventional electrodes by using textile based solutions, involving different textile technologies such as weaving, knitting, nonwoven, embroidery or finishing. One of the first works proposed a method of monitoring a user using a bed sheet where conductive yarns were woven [2]. Woven fabrics were also used by [3,4,5,6] with conductive yarns. These kind of electrodes present a dimensional stability which is of importance in terms of impedance. Other approach involves applying a layer of conducting paste on a textile fabric. More recent materials such as graphene [7] or carbon nanotubes were used in solutions that were deposited on top of textile fabrics, as well as conductive polymers pastes [8,9]. Knitting is other very common technique for developing electrodes and based on this technology, several studies have been done usually using conductive yarns. A comparison of three different knitted electrodes, made with

different conductive yarns for ECG is presented in [12], a knitted band with integrated electrodes for sEMG are studied by [10], and [11] presents some of the available techniques for producing knit based electrodes, [13] presents a weft knitted electrode and test it in several different conditions, namely under water. Non-woven fabrics were also explored, as [14] presents a work in which multilayered dry electrodes are obtained by screen printing conductive inks on this particular textile substrate.

These studies also tried to give answers to the difficulties that were detected with the use of textile electrodes. Comparisons between the proposed textile electrodes (dry and wet) and Ag/AgCl electrodes or gold standards were performed by several research teams and the results show that are no significant differences for EMG [6,10] as well as for ECG [7,8,17] or bioimpedance [18]. Other studies refer to the importance of the area of the electrode, being verified that larger areas may contribute for the reduction of noise [19] and for the quality of the signal [14,17]. Putting in place and maintaining the initial position is also an important problem and several researches have studied the subject [20], indicating that the position where the electrodes are placed and movement while registering the waveforms greatly affects the resulting signal. Also the most adequate form to maintain in place was studied in [21], where the authors suggest to fix the electrodes in a cross-type method instead of chest-belt type. Pressure is an accepted mean of maintaining the electrode in place, and [14, 22] propose a specific range that will allow a better contact with skin, as well as the use of padding [22], which increases the contact with skin and thus improves the signal’s quality.

In our research we studied and developed techniques to embed electrodes in textile fabrics, electrodes made exclusively with fibre materials, taking advantage of the jacquard capabilities on weft knitting machines, as well as embedding electric tracks for signal transportation. Based on the specifications and demands of the above mentioned research and inspired in 3D surface design, the team designed special weft knitted structures, capable to project the area with the conductive fibrous materials and by this mean improve the contact with skin. These structures will be presented in the next section.

2. TEXTILE ELECTRODES DESIGN

2.1 General considerations

The following sections will discuss some of the issues that the group considers as being important for the development of textile electrodes. The selected technology was weft knitting and in particular single face weft knitting. The reason for selecting this particular textile technology is due to the fact that textile electrodes are intended to be used in close contact to the skin. One can find several products in the market, particularly for sports where the single face weft fabric is used, usually light and easy to wear garments. The objective is to produce a textile product as a t-shirt in which the sensors are already integrated and do not need to be removed whenever a maintenance procedure needs to be performed. The t-shirt should be easy to be dressed and the connections to the acquiring system should be straightforward.

The raw material plays a fundamental role in textile electrodes performance. Due to the intrinsic elasticity of knitting fabrics, the impedance of the textile electrode can change as its dimensions also change. Thus, a conductive yarn should present a constant resistivity even when it is stretched. The most popular conductive yarns are metallic fibers blended with polymers (stapple yarns) or polymer fibers coated with a metallic layer. While the blends present a different behavior in terms of resistivity when relaxed or under traction, yarns made of polymers coated with metallic layers apparently do not present this property. On the other hand, the process of coating may influence the behavior of the yarn: the maintenance can degrade the quality of the resulting signal, or the layer can build small cracks in the surface when submitted to traction or even with wearing, thus reducing or even interrupting electrical conductivity. If the mechanical properties of the yarn are important when determining the yarn input tension for a regular yarn, in the case of yarns with a conductive layer assumes paramount importance. It is essential to guarantee that the yarn does not suffer excessive traction, in order to avoid cracks and thus the loss of conductivity.

The structure used for the production of the textile electrode can play a decisive role regarding its performance. Flat knitted structures, such as jersey, present an important advantage which is uniformity. This is an important characteristic in the standard electrodes, where one can find a homogenous layer of a particular material, such as silver. These structures behave very well when in constant contact with the skin. However, even with compression this contact may not be permanent and for this reason padding stands out to be a good aid. The experience of this research team during the past years suggest to use specific structures in which a 3D effect can promote a more permanent contact with skin. The specific design of these structures should allow the area where the conductive yarn is placed to rise from the plane usually considered on textile fabrics. These structures are the result of the combination of the three fundamental knit loops. For this particular case, the team selected the combination of normal and floating loops. The following pictures present different examples, where can be observed the effect of rising the structure into the third dimension, thus increasing the thickness. This will improve and maintain the contact between the electrode and the skin.

Figure 1. Textile electrodes produced for EMG using two specially design structures which result in an increase on thickness of at least about 100% when compared with the thickness of the surrounding fabric.

2.2 Proposed design for the electrodes

From the study made by our team, the best candidate in terms of conductive yarn is the Elitex®. This particular yarn is made of polyamide filaments covered by a nanolayer of silver. The resulting yarn is made of 34 filaments resulting in a very soft and flexible yarn when compared with other counterparts. It was used yarns with 110 dTex, presenting a resistivity of approximately 60 Ohm/m. Our experience also showed that this particular yarn presents a very good stability in terms of resistance variability when submitted to traction and its behavior remained the same after several experiments and maintenance procedures. Together with this yarn, a bare elastane filament is used from CREORA® (22 and 44 dTex), being knitted with the plating technique. The use of elastane with a specific yarn input tension allows the resulting structure to rise and thus increase the thickness of the electrode and improve the compression effect. The 3D effect is possible by using specific structures. So, several structures were studied and the team was able to propose some combinations that result in an increase on thickness. The repetition modules of some structures are presented in figure 2, in which the conductive yarn replaces the base yarn, usually polyester or polyamide. The structures involve the use of float loops combined with normal and/or tuck loops, and the float loops allow to form shapes that rise out of the plane into the third dimension. The effect of traction in the course direction also promotes the increase in thickness due to this special design.

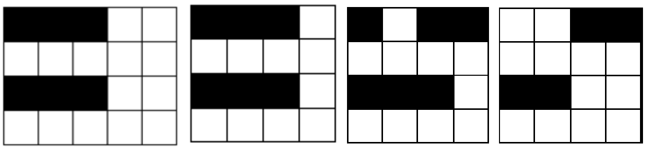

Figure 2. Repetition modules of the selected structures for developing the electrodes shown in figure 1 and in the following figure. The white squares represent normal loops and the black squares represent float loops.

An improvement was also made in the electrodes by adding columns with loops hold and not being knitted during some courses. The technique essentially involves the retaining of some loops in the same course for a specific number of courses in the needle's hook and staying out of work, while the remaining ones proceed with the production of the structure. During this phase, the base yarn is changed with the conductive yarn and the electrode is thus produced. In a determined course, the needles that are holding those loops and not working start knitting again which will result in closing a small tube, increasing the thickness several times, and thus replacing the need of padding. Figure 3 illustrates some examples of electrodes made with this technique.

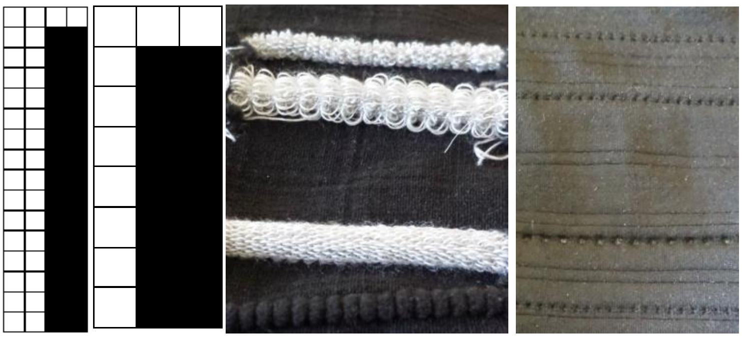

Figure 3. Repetition modules (two first images at left side) that are combined with the structures illustrated in figure 2, resulting in the fabrics in center and right side. The image in the center is the backside of the fabric, with the electrodes in a light colour, which will be in contact with skin. The image at the right show the front side of the knitted fabric, where the electrodes are not visible.

3. RESULTS

The following pictures present some results obtained with the proposed electrodes. In figure 4 a t-shirt was produced using the proposed design for the electrodes, in this case for ECG measurement. The placement of the electrodes was selected in order to minimize the interference of the signal with movement while monitoring, and the t-shirt presents a high compression, above 10 mmHg. The experiments made showed that although there was a significant disturbance on the signal due to movement, ECG could be extracted after proper signal processing. As stated by other researchers, the electrode's area was important in obtaining a signal with less disturbances.

Figure 4. T-shirt with textile electrodes (left), the ECG signal obtained while standing but without movement (center), a detail of a similar electrode produced using a different base yarn and t-shirt (right).

Figure 5 presents the resulting signals of electrodes being used for EMG. In this particular example, a commercially available soft Ag/AgCl electrodes with adhesive electro gel and dimensions 2.6x2.0cm are compared with a pair of knitted electrodes with the proposed structures in this paper. The textile electrodes were separated 2.0 cm between them and 0.3x5.0 cm. Dimensions according to SENIAM recommendations were also produced and tested, giving results that were similar to the conventional electrodes.

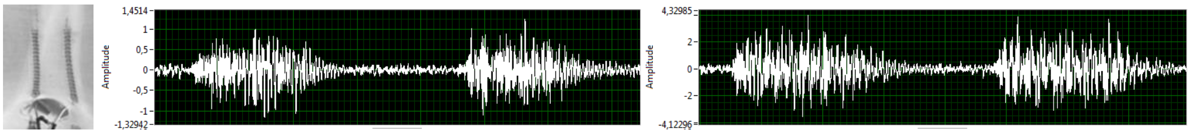

Figure 5. Textile based electrodes developed with the above mentioned techniques for EMG (left image) and waveforms obtained with coventional electrodes (center image) and textile electrodes (right image).

4. CONCLUSIONS

Several issues rise when is intended to develop textile based electrodes. In this paper a brief revision was made regarding the research involving the proposal of dry or wet textile electrodes and some considerations were made concerning their design based on the recommendations of several studies and the experience of our research team. The proposed electrodes are made using weft knitting technology, with conductive yarns that are inserted in the adequate positions, specially designed structures and adequate compression. The selected structures were able to increase several times the fabric thickness, thus improving the contact with the skin. This proposed design may avoid the use of padding and, combined with compression, maintain the electrodes with a stable area and in the correct place. Experiments were made by comparing the signals obtained between textile electrodes and conventional electrodes and the results are similar to the ones presented by other research teams.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. N Meziane, J G Webster, M Attari, A J Nimunkar1, Dry electrodes for electrocardiography, *Physiological Measurement*, 2013, Vol.34, No.9
2. Ishijima, M., Cardiopulmonary monitoring by textile electrodes without subject-awareness of being monitored, *Med. Biol. Eng. Comput.* 1997, Vol.35: 685.
3. Xueliang Xiao, Sandeep Pirbhulal, Ke Dong, Wanqing Wu, and Xi Mei, Performance Evaluation of Plain Weave and Honeycomb Weave Electrodes for Human ECG Monitoring, *Journal of Sensors*, 2017, Article ID 7539840.
4. H. Chen et al., A wearable sensor system for neonatal seizure monitoring, *IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN)*, Eindhoven, 2017, 27-30.
5. H.-Y. Song, J.-H. Lee, D. Kang, H. Cho et al, Textile electrodes of jacquard woven fabrics for biosignal measurement, *The Journal of The Textile Institute*, 2010, Vol. 101, Iss. 8.
6. G. Li, Y. Geng, D. Tao and P. Zhou, Performance of electromyography recorded using textile electrodes in classifying arm movements, *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Boston, 2011, 4243-4246.
7. Murat Kaya Yapici, Tamador Alkhidir, et al, Graphene-clad textile electrodes for electrocardiogram monitoring, *Sensors and Actuators B: Chemical*, 2015, Vol. 221, 1469-1474.

8. Gordon Paul, Russel Torah, Steve Beeby, John Tudor, Novel active electrodes for ECG monitoring on woven textiles fabricated by screen and stencil printing, *Sensors and Actuators A: Physical*, 2015, Vol. 221, 60-66.
9. Yun Zhou, Xin Ding, Jingwei Zhang, Yaru Duan et al, Fabrication of conductive fabric as textile electrode for ECG monitoring, *Fibers and Polymers*, 2014, Vol. 15, Issue 11, 2260–2264
10. S. A. Lee, M. O. Kim, T. Gang and Y. Choi, Development of knit band electrodes for multi-channel sEMG measurement, *2017 14th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, Jeju, South Korea, 2017, 827-829.
11. R. Paradiso and M. Pacelli, Textile electrodes and integrated smart textile for reliable biomonitoring, *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Boston, 2011, 3274-3277.
12. M. A. Mestrovic, R. J. N. Helmer, L. Kyratzis and D. Kumar, Preliminary study of dry knitted fabric electrodes for physiological monitoring, *2007 3rd International Conference on Intelligent Sensors, Sensor Networks and Information*, Melbourne, 2007, 601-606.
13. M. Silva, A. Catarino, H. Carvalho, A. Rocha et al, Study of vital sign monitoring with textile sensors in swimming pool environment, *2009 35th Annual Conference of IEEE Industrial Electronics*, Porto, 2009, 4426-4431.
14. M. A. Yokus and J. S. Jur, Fabric-Based Wearable Dry Electrodes for Body Surface Biopotential Recording, *IEEE Transactions on Biomedical Engineering*, 2016, vol. 63, no. 2, pp. 423-430.
15. Markus Weder, Dirk Hegemann, Martin Amberg, Markus Hess et al, Embroidered Electrode with Silver/Titanium Coating for Long-Term ECG Monitoring, *Sensors*, 2015, Vol.15, No.1, 1750-1759.
16. Xinchi Yu, Anna Boehm, Wilko Neu, Boudewijn Venema et al, A wearable 12-lead ECG T-shirt with textile electrodes for unobtrusive long-term monitoring – Evaluation of an ongoing clinical trial, *EMBEC 2017, NBC 2017, IFMBE Proceedings*, vol 65, 703-706.
17. Vaidotas Marozas, Andrius Petrenas, Saulius Daukantas, Arunas Lukosevicius, A comparison of conductive textile-based and silver/silver chloride gel electrodes in exercise electrocardiogram recordings, *Journal of Electrocardiology*, 2011, Volume 44, Issue 2.
18. J. C. Marquez, F. Seoane, E. Valimaki and K. Lindecrantz, Textile electrodes in electrical bioimpedance measurements – a comparison with conventional Ag/AgCl electrodes, *2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Minneapolis, 2009, 4816-4819.
19. M. M. Puurtinen, S. M. Komulainen, P. K. Kauppinen, J. A. V. Malmivuo et al, Measurement of noise and impedance of dry and wet textile electrodes, and textile electrodes with hydrogel, *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*, New York, 2006, 6012-6015.
20. T. Pola and J. Vanhala, Textile Electrodes in ECG Measurement, *2007 3rd International Conference on Intelligent Sensors, Sensor Networks and Information*, *Melbourne*, 2007, 635-639.
21. Cho HS., Koo SM., Lee, J. et al., Heart Monitoring Garments Using Textile Electrodes for Healthcare Applications, *J Med Syst* , 2011, Vol.35, No.189.
22. Cömert, Alper, Honkala, Markku, Hyttinen, Jari, Effect of pressure and padding on motion artifact of textile electrodes, *BioMedical Engineering OnLine*, 2013