Wearable Textile Electrodes for ECG Measurement

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Abstract. *The electrocardiogram (ECG) is one of the most important parameters for monitoring of the physiological state of a person. Currently available systems for ECG monitoring are both stationary and wearable, but the comfort of the monitored person is not at a satisfactory level because these systems are not part of standard clothing. This article is therefore devoted to the development and measurement of wearable textile electrodes for ECG measurement device with high comfort for the user. The electrode material is made of electrically conductive textile. This creates a textile composite that guarantees high comfort for the user while ensuring good quality of ECG measurements. The composite is implemented by a carrier (a T-shirt with flame retardant) and sensing electrodes embroidered with yarn based on a mixture of polyester coated with silver nanoparticles and cotton. The electrodes not only provide great comfort but are also antibacterial and antiallergic due to silver nanoparticles.*

Keywords

Conductive textile, ECG, wearable electronics.

1. Introduction

The electrocardiogram (ECG) is one of the most important parameters for monitoring of the physiological state of a person. Currently available systems for ECG monitoring are both stationary and wearable, but the comfort of the monitored person is not at a satisfactory level because these systems are not part of standard clothing. Conventional stationary systems often use suction cup electrodes or adhesive electrodes. The wearable monitoring systems use metallic, textile or conductive polymeric electrodes or contactless sensing. Both solutions can be inconvenient and poorly applicable for long term ECG monitoring of patients and athletes. The use of existing methods for electrical potential sensing are not at a satisfactory level of comfort in applications of preventive ECG measurement, especially in monitoring of stress factors of rescue workers, fireman or soldiers. The low comfort of the existing solutions therefore limits the applicability of these methods.

One of the promising applications of ECG monitoring is also monitoring of excitation level in persons working under great physical and mental stress. This includes soldiers, firefighters, police officers and rescue workers in mines. Stress in these professions has a major impact on the quality of their work, but also of their life [1]. High levels of stress factors have an impact on the rescue itself – they can prolong the response time and increase the chance of mistakes. This directly increases the danger to health, life or property. It is, therefore, advantageous for the rescue operation management to react quickly to increased stress of workers and to stop or reduce their exposure to stress.

The means for measuring ECG can be divided into two basic groups. The first one is the technology for ambulatory ECG measurements that need to perform measurements with high accuracy and QoS (Quality of Services) of these systems. The second category can be described as a device for mobile measurement, especially designed for athletes [2] or for long-term ECG monitoring during a specified period of examination of patients [3]. The second category also includes the systems for optimization of the dosage of drugs that affect the activity of the patients.

The currently available wearable ECG monitoring systems use several types of electrodes. Adhesive electrodes are commonly used in commercial Holter monitors. Also, many systems use textile electrodes embedded in clothing [4], [5], [6], [7]. Other approaches use hand held electrodes [8] or contactless sensing [9].

This article is therefore devoted to the development and measurement of wearable textile electrodes for

ECG measurement device with high comfort for the user. The electrode material is made of electrically conductive textile. This creates a textile composite that guarantees high comfort for the user while ensuring good quality of ECG measurements. The composite is implemented by a carrier (a T-shirt with flame retardant) and sensing electrodes embroidered with yarn based on a mixture of polyester coated with silver nanoparticles and cotton. The electrodes not only provide great comfort but are also antibacterial and antiallergic (due to silver nanoparticles).

The rest of the paper is organized as follows: Section 2 describes wearable electronics, Section 3 denotes construction of T-shirt with textile electrodes, Section 4 presents experimental results, Section 5 describes evaluation and the conclusion is presented in Section 6.

2. Wearable Electronics

With the development of electrically conductive textile materials included in the various types of clothing, a new area of applications called wearable electronics is formed. Heated textile structures [10] or textile antenna structures directly implemented in the clothes [11] can be therefore realized. Similar technology can be used for realization of wearable textile electrodes for ECG sensor, which can be part of standard clothing.

Following characteristics are preferred for the realization of these electrodes:

- It is necessary to use a textile material with sufficiently high conductivity, which can be pre-defined and propose suitable composition of textile material [12] (providing sensing of electrical signal with a sufficient quality).
- Textile material must be cotton based fabric (high comfort on contact fabric and skin, thanks to the use of cotton blended yarn).
- Textile electrode should be a fixed part of the clothes (easy application of the system and position stability of the electrode).
- Complete textile product should allow standard maintenance (washing and ironing).
- Fabric with galvanic plating surface cannot be used (implementation on non-cotton substrates causes skin irritation because of synthetic fibers, upper material is copper, which oxidizes, or nickel, which is allergenic).
- Electrodes require sufficient adhesion to the pectorals (to ensure sufficient difference of electrical potentials between electrodes).

3. Construction of T-shirt with Textile Electrode

For ensuring the above requirements the T-shirt was designed and patterned from a knitted fabric modified for reducing flammability (used for rescue workers and firefighters with sustained high wearing comfort). Rectangles of electrically conductive textile fabric in knitted design were sutured on the position of the pectoral muscles. The material has the following textile and electrical parameters:

- Fineness of yarn 29,5 tex.
- Silverstat 60 %, 40 % PES.
- Surface conductivity of 1,2 Ω/square, measured using the method [13].

The knitted fabric is realized from a blended yarn of the composite containing silver nanoparticles, which provide electrical conductivity of the yarn and the resultant knitted fabric. The content of silver nanoparticles provides corrosion resistance of textile electrodes, antibacterial and antiallergic properties, mechanical and electrical stability when exposed to sweat. The design of blended fabric made from conductive yarn enables traditional maintenance of T-shirts (washing, ironing) and long-term stability of surface conductivity of the electrodes with a high number of wash cycles.

The textile electrodes were rectangular in shape, with dimensions 70 × 100 mm. They were positioned so that they contacted the upper chest immediately below the clavicles, Fig. 1. In order to provide a sufficient potential difference, the electrodes were positioned 100 mm apart.

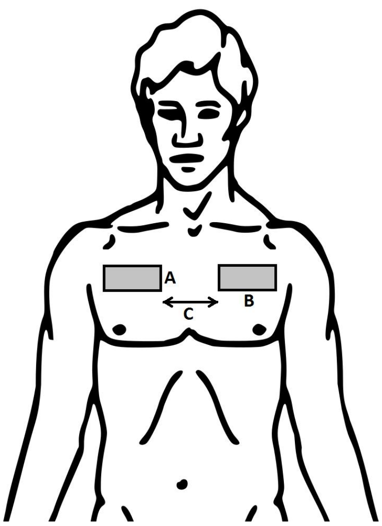

Fig. 1: Placement of textile electrodes (with using [14]).

4. Experimental Verification

The suitability of the textile electrodes for ECG recording was verified by experimental measurements. Specifically, we compared the ECG recorded using the textile electrodes with the ECG measured by a high quality reference measurement system.

During the measurement the subject was lying in the supine position, and was instructed to relax his muscles. This position minimizes the presence of muscular artifacts, and allows evaluating the quality of a pure ECG.

The signal was first recorded using two metallic electrodes positioned on the subject's fingers (the right and left index finger). The measurement system also used the third electrode that was positioned on the right middle finger, and was driven by a noise suppression circuit [16], [17]. The placement of the electrodes is shown in Fig. 2. From our previous measurements we know that this methodology provides a high quality ECG recording; therefore, we used it as a reference for the evaluation of the ECG recorded with the textile electrodes.

Once the reference record was obtained, we proceeded with the ECG recording using the textile electrodes. This measurement used only 2 leads without any active noise suppression. The electrode placement is shown in Fig. 4.

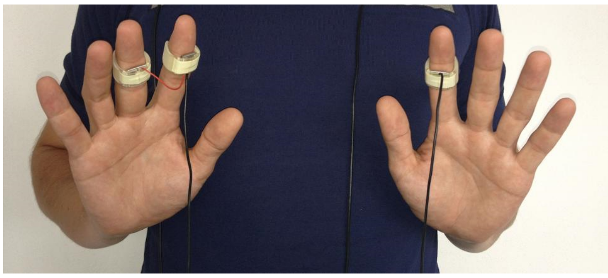

Fig. 2: Electrode placement for three-lead ECG measurement.

The measurement electronics implemented high pass and low pass filters with cut-off frequencies 0,1 Hz and 200 Hz, respectively. Once the signals were digitized (the sampling frequency was 800 Hz) they were further filtered with a set of notch filters with the center frequencies at multiples of 50 Hz. This filtering efficiently suppressed the power line interference.

It is expected that during the movement the ECG signal will contain various kinds of movement artifacts (especially the muscular artifacts and baseline wonder). However, these artifacts can be well dealt with using the digital signal processing techniques [15].

Measurement results of the reference ECG signal are shown in Fig. 3. The ECG record has clearly recognizable P waves, QRS complexes and T waves.

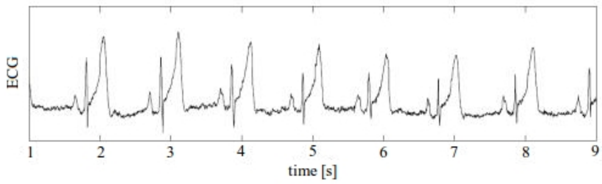

Fig. 3: The waveform of the three-lead measurement method. This record serves as a reference for the evaluation of the measurement performed with the textile electrodes.

Fig. 4: Placement of textile electrodes.

The ECG record obtained using the textile electrodes is shown in Fig. 5. Similarly to the reference record the signal appears to be clear with well recognizable P waves, QRS complexes and T waves.

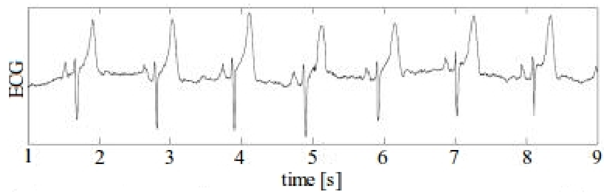

Fig. 5: Signal measured with two lead arrangement using textile electrodes.

The comparison of measured signals is better shown in Fig.6. The amplitude of the individual waves of ECG signal obtained using the textile electrodes is smaller than ECG reference signal, which is caused by different electrode placement. Both measurements clearly show P waves, QRS complexes and T waves, which results in the ECG measurement with textile electrodes is applicable method and it can be advantageously used in applications for ECG measurement.

5. Conclusion

Test arrangement of wearable textile electrodes for ECG measurement showed the suitability of this plan

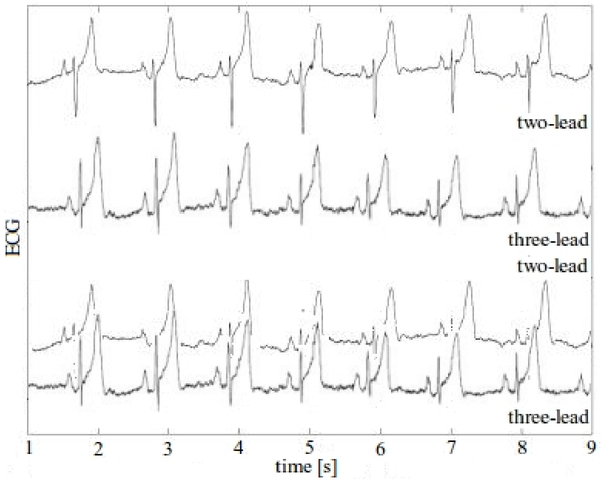

Fig. 6: Comparison of the measured signal with two-lead (using textile electrodes) and three-lead (ECG reference signal) arrangement.

in the Proof of Concept phase. It is possible to clearly distinguish the P wave, QRS complex and T wave from received signals and it is possible to measure the heart rate. Furthermore, it was observed only insignificant baseline wonder which indicates stable contact between the conductive textile electrode and the skin.

The result is the prototype of textile product designed as a T-shirt enabling capture ECG signals using two leads directly on the body of the monitored person who is not troubled by the presence of the electrodes. Implementation of this type of wearable textile electrodes allows standard methods of maintenance (washing, ironing), keeps high user comfort and simultaneously ensures sensing of electrical potentials for ECG measurement in sufficient quality. As shown, the quality of the measured signal using wearable textile electrodes for ECG sensor with two leads is comparable to the signals measured by the reference method, which incorporates active noise suppression using a third electrode.

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References

[1] PRATI, G., L. PIETRANTONI and E. CICOGNANI. Self-efficacy moderates the relationship between stress appraisal and quality of life among rescue workers. *Anxiety, Stress & Coping*. 2010, vol. 23, iss. 4, pp. 463–470. ISSN 1061-5806. DOI: 10.1080/10615800903431699.

[2] VARNAUSKAS, E., P. BJORNTORP, M. FAHLEN, I. PREROVSKY and J. STENBERG. Effects of physical training on exercise blood flow and enzymatic activity in skeletal muscle. *Cardiovascular Research*. 1970, vol. 4, iss. 4, pp. 418–422. ISSN 0008-6363. DOI: 10.1093/cvr/4.4.418.

[3] ACHILLI, A, M. SASSARA, S. FICILI, D. PONTILLO, P. ACHILLI, C. ALESSI, S. DE SPIRITO, R. GUERRA, N. PATRUNO and F. SERRA. Long-term effectiveness of cardiac resynchronization therapy in patients with refractory heart failure and "narrow" QRS. *Journal of the American College of Cardiology*. 2003, vol. 42, iss. 12, pp. 2117–2124. ISSN 0735-1097. DOI: 10.1016/j.jacc.2003.08.024.

[4] LEE, Y.D. and W.Y. CHUNG. Wireless sensor network based wearable smart shirt for ubiquitous health and activity monitoring. *Sensors Actuators B Chemical*. 2009, vol. 140, iss. 2, pp. 390–395. ISSN 0925-4005. DOI: 10.1016/j.snb.2009.04.040.

[5] LOPEZ, G., V. CUSTODIO, J.I. MORENO. LOBIN: E-textile and wireless-sensor-network-based platform for healthcare monitoring in future hospital environments. *IEEE Transactions on Information Technology in Biomedicine*. 2010, vol. 14, iss. 6, pp. 1446–1458. ISSN 1089-7771. DOI: 10.1109/TITB.2010.2058812.

[6] YOO, J., Y. LONG, L. SEULKI, K. HYE-JUNG and Y. HOI-JUN. Awearable ECG acquisition system with compact planar-fash-ionable circuit board-based shirt. *IEEE Transactions on Information Technology in Biomedicine*. 2009, vol. 13, iss. 6, pp. 897–902. ISSN 1089-7771. DOI: 10.1109/TITB.2009.2033053.

[7] MERRITT, C. R., H. T. NAGLE and E. GRANT. Fabric-based active electrode design and fabrication for health monitoring clothing. *IEEE Transactions on Information Technology in Biomedicine*. 2009, vol. 13, iss. 2, pp. 274–280. ISSN 1089-7771. DOI: 10.1109/TITB.2009.2012408.

[8] POLLONINI, L., N. O. RAJAN, S. XU, S. MADALA and C. C. DACSO. A novel hand-held device for use in remote patient monitoring of heart failure patients-design and preliminary validation on healthy subjects. *Journal of Medical Systems*. 2012, vol. 36, iss. 2, pp. 653–659. ISSN 0148-5598. DOI: 10.1007/s10916-010-9531-y.

[9] OTTENBACHER, J., L. JATOBA, U. GROSSMANN, W. STORK and K. MULLER-GLASER. ECG electrodes for a context-aware cardiac permanent monitoring system. In: *World Congress on Medical Physics and Biomedical Engineering 2006*. Seoul: IFMBE Proceedings, 2007, vol. 14. pp. 672–675. ISSN 1433-9277. ISBN 978-3-540-36839-7.

[10] VOJTECH, L. and M. NERUDA. Self-drying planar textile materials with electrically conductive structures. In: *15th International Symposium MECHATRONIKA 2012*. Prague: IEEE, 2012. pp. 1–5, ISBN 978-1-4673-0979-0.

[11] DAHAL, R., D. MERCAN, L. VOJTECH AND M. NERUDA. Textile Antenna for 50 ohm Applications. *Advances in Electrical and Electronic Engineering*. 2012, vol. 10, no. 4, pp. 229–234. ISSN 1336-1376.

[12] NERUDA, M. and L. VOJTECH. Verification of Surface Conductance Model of Textile Materials. *Journal of Applied Research and Technology*. 2012, vol. 10, no. 4, pp. 579–585. ISSN 1665-6423.

[13] VOJTECH, L. and M. NERUDA. Modelling of Surface and Bulk Resistance for Wearable Textile Antenna Design. *Przeglad Elektrotechniczny*. 2013, vol. 89, iss. 2b, pp. 217–222. ISSN 0033-2097.

[14] HAGGSTROM, M. Pioneer plaque man upper body as diagram template [online]. 2009 [cit. 2013-07-07]. Available at: `http://commons.wikimedia.org/wiki/`.

[15] BORTEL, R. and P. SOVKA. *Real-Time Robust Heart Rate Estimation Based on Bayesian Framework and Grid Filters*. Medical Applications of Intelligent Data Analysis: Research Advancements. IGI Global, 2012, pp. 67–90. ISBN 978-1-4666-1803-9. DOI: 10.4018/978-1-4666-1803-9.

[16] HOSPODKA, J. and R. BORTEL. Amplifier for Biological Signal Sensing with Efficient Common Mode Rejection. In: *2011 International Conference on Applied Electronics*. Plzen: University of West Bohemia, 2011, pp. 161–164. ISSN 1803-7232. ISBN 978-80-7043-987-6.

[17] HOSPODKA, J. and R. BORTEL. *System for Biological Signal Measurement with Noise Suppression* [patent]. Czech Republic. Urad prumysloveho vlastnictvi, 302454. 2011.

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