Application of Textile Electrodes in Medical Telemetry

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Abstract –**Textile sensors and, in particular, textile electrodes are becoming more widely used in medical practice because of their characteristics: quick response, flexibility in electrode design, low price/cost-effectiveness. The objective of this paper is to discuss questions related to the design, the performance evaluation and the use/ implementations of textile electrodes in the context of long-term ambulatory (telemetric) measurements. The applications of textile electrodes are summarized according to sensor features as well as to different applications for registration of biomedical signals, predominantly related to the heart activity of patients with cardiovascular diseases.**

Keywords – **telemetric monitoring, textile sensors, textile electrodes, wearable technology.**

I. Introduction

The development and implementation of new materials, innovative technological solutions, as well as the use of modern communication, interfaces and protocols, is a prerequisite for the wider use of telemetry (ambulatory) monitoring of high-risk patients. By its nature, telemetry is a remote recording of vital biological parameters and processes without the need for real time contact between doctor and patient [1], [2], [3], [4].

A study connected to the first telemedical applications [5] shows that 39.8% of the specialists consider emergency telemedicine to be crucial to health care without analogue.

The same study estimates that the introduction of innovative technology solutions in this area will lead to a 23% increase in the beneficial outcomes during medical intervention. With the development of technology and broadening of the scope of telemedicine, more in-depth analyses and statistics are emerging on the basis of experience. Multiple international studies [6], [7], show that rapid and timely response to sudden cardiac events reduces mortality and significantly increases patient's chances of survival. Cardiovascular diseases are among the leading causes of prolonged disability or early mortality, which makes the timely diagnosis of the early symptoms a critical issue [8], [1].

The introduction of wearable technology solutions which combine today's advances in electronics and communication technology with innovative cardiac recording capabilities is a giant leap in the development of ambulatory monitoring. An important element in their development is the new type of textile electrodes which allow a continuous and reliable recording of the electrocardiographic (ECG) signal with minimal discomfort of the monitored person. The following requirements to the electrodes are defined as the main element in body registration systems:

- not to add noise to the records;
- not to irritate the skin or cause allergic reactions in cases of long-term record;
- to allow for fast and reliable mounting on the body surface;
- to be affordable;
- to be reliable with disinfectants and withstanding laundering and ironing.

All of these requirements apply to textile electrodes and their modifications relevant to the wearable systems.

Traditionally used conventional electrodes are made of conductive rubber or metallic steel (stainless) plates, requiring the use of gel to minimize the contact impedance on the skin-electrode contact area. With some patients there are evidences of skin irritation and/or allergic reaction. Signal quality is worsening within a certain time interval due to drying of the gel substance [9].

The remaining part of the paper presents features, parameters, results from experimental tests, as well as trends for the future development and application of textile electrodes in the telemetry studies.

II. Types, parameters and applications of textile electrodes

The data analysis related to different types of electrodes, with their design and operating parameters, as well as their applicability in the explicit practical implementations, are presented in Table 1. The parameters show that textile electrodes are comparable to conventional ones.

The specific data for the textile electrodes used in wearable technology [10] are presented in [11], [12] (Fig.1).

Fig. 1. Textile electrodes

Their undeniable advantage is that the textile-based electrodes are an integral part of the patient's clothing and/or his/her bedding, and they also provide palatable comfort to the patient in comparison to the conventional electrodes.

Textile electrodes could be implemented in elastic bands that are integral parts of the garment or placed on the different parts of the body - chest, wrist, neck, and others. Typical configurations are presented here (Fig. 2), including:

- fitting to the surface of electrodes that are in direct contact with the patient's body;
- embroidery of special conductive threads on the fabric;
- printing of a chemical reagent on the textile carrier using special technology.

Different materials can be used to make flexible textile electrodes, such as: metallized polymer films and fabrics, carbon fibers, conductive polymers or flexible polymeric composites filled with conductive nanoparticles [13], [14].

Fig. 2. Continuous monitoring systems using textile electrodes [12]

Different technological methods are tested for their implementation, including techniques to screen [15] the production of bi-component fibers with a metallic core through coating conductive polymers with a viscous polymer material containing 65-70% metal particles directly on the fabrics [16], incorporating conductive polymers in fibers [17], metal coating by physical vapor deposition [18], galvanic coating by atomization, electroplating of fabrics or knitting/weaving of conductive yarns (fibers with fine metallic microparticles) [14]. Recently, a combination of graphene and soft textile fabrics has been presented, resulting in the reduction of electrode cost [3].

The enlarged image of PEDOT is shown in Fig. 3. (Poly (3,4-ethylenedioxythiophene) - coated PVDF nanofiber web after the vapor-phase polymerization of EDOT with electrospinning and its Energy Dispersive X-ray (EDAX) spectrum. Spectral EDAX PEDOT is used as a conducting polymer in the vapor-phase electrospray polymerization process [14].

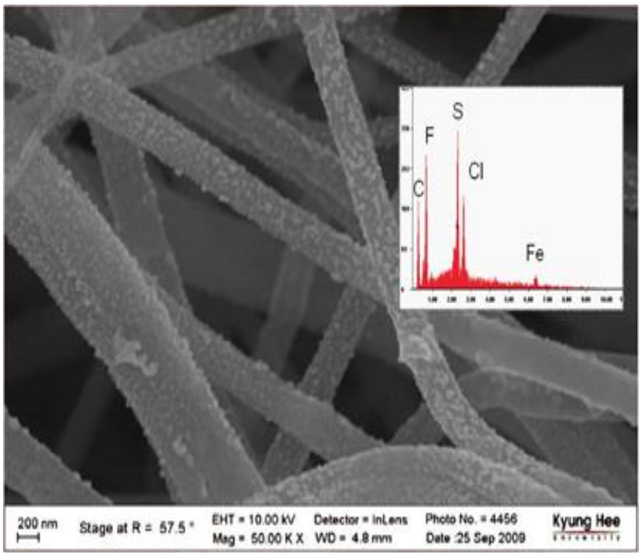

Fig. 3. PEDOT coated PVDF / FeCl nanofiber band (embedded) EDAX spectrum [14]

Fig. 4 depicts the PVDF nanofibers realized with a metallic silver coating (Ag) on the textile electrode which provides high conductivity of the electrodes (). Silver is among the most easily accessible metallic coatings, so the silver mirroring reaction is usually used to create commercial biopotential sensors [14].

The challenge in using textile electrodes is to ensure a reliable contact between the electrode surface and the skin. For this purpose, the textile electrodes must be combined with elastic tissue [19].

Another possible application of textile electrodes, namely capacitive sensors, is presented in [13]. The results obtained in experimental studies, with standardized weights and with a biological structure with parameters analogue to the human tissue, indicate that the sensor is highly sensitive to mechanical influences.

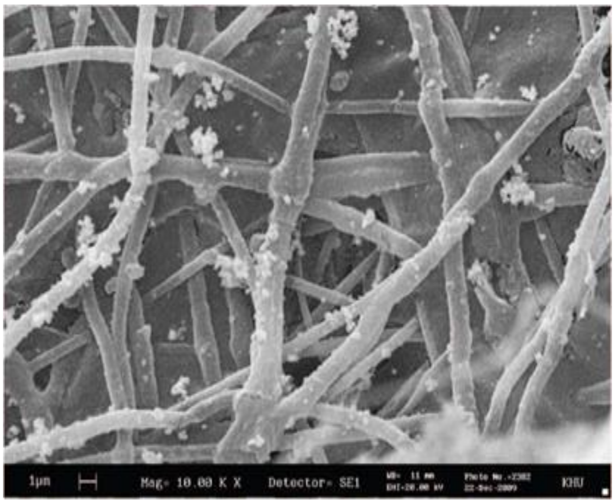

Fig. 4. Ag folded PVDF coating [14]

An important criterion in choosing textile electrodes is their size. Puurtinen et al. have inspected varied sizes of textile electrodes and have confirmed the well-known fact that the impedance of the skin-electrode contact area increases by decreasing the size of the electrode [20]. Marozas et al. have established that textile electrodes with a contact area less than 4 cm^2 can result in distortion of the low-frequency spectrum of the signal [9].

In comparison to conventional ones, dry textile electrodes more often cause greater noise (including baseline drift and power line disturbances) in ECG measurements. For larger-sized textile electrodes, the noise characteristics are comparable to those of gel electrodes, which means that a dry textile electrode with sufficient size is appropriate for ECG monitoring.

The comparative characteristics of the ECG signal recorded by conventional gel electrode and by three different sizes of dry textile electrodes are presented in Fig. 5 [18].

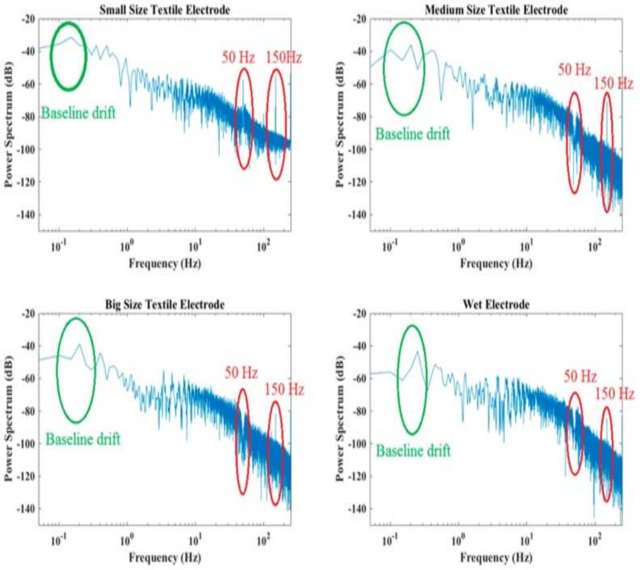

Fig. 5. Comparative characteristics when using three sizes of dry textile electrodes in ECG signal monitoring compared to traditional electrodes [18]

III. AMBULATORY CARDIAC MONITORING SYSTEMS USING TEXTILE ELECTRODES

At present, several real-time heart rate monitoring systems have been implemented and put into practice.

WEALTHY (Wearable Health Care System) is based on a textile carrier and is developed to monitor patients with cardiovascular problems/disturbances [22]. The clothing is designed to be comfortable enough in everyday use and includes piezoresistive threads that act as sensors with strain gauges as well as 30% steel (stainless) yarns shaping electrodes. The system records ECG, breathing, temperature and activity. The reliability of the ECG captured by electrodes is realized through hydrogel membranes, which provide the necessary contact in the skin-electrode area. Respiratory resistance is monitored with the help of the piezoresistive features of highly elastic tissue made of carbon-based rubber [23]. Sensor data is transferred wirelessly to a computer, smart device (mobile phone, tablet) or a PDA (Fig. 6).

The *MyHeart* system is analogus to the WEALTHY system. It is designed to recognize critical situations in patients with cardiovascular failure and allows for vital signs and emergency response monitoring, as well as ECG monitoring through the embedded textiles [24].

The system is intended for digital monitoring of physiological signals indicating the onset or pre-existing presence of cardiac activity abnormalities that allows for on-time intervention.

Lifeshirt from Vivometrics is Lycra-based specialized clothing, which is a multi-purpose ambulatory system designed to monitor heart rate. It is one of the first to be machine-washable. *Lifeshirt* measures both ECG, breathing, movement and positioning of the human body. Additional parameters can also be followed: pulse oximetry, blood pressure, temperature, electroencephalo-graphy or electro-ocular.

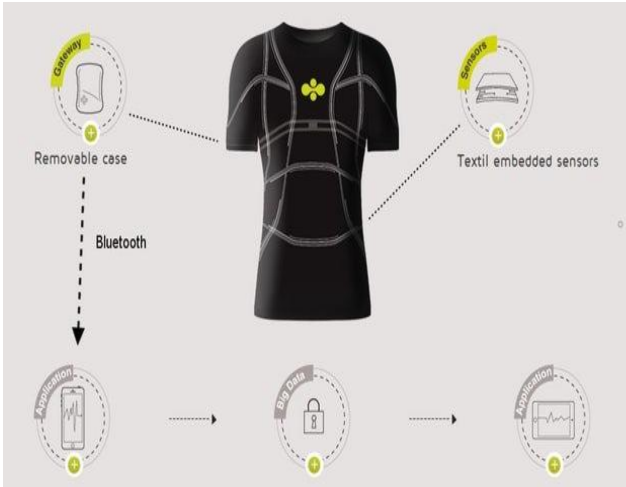

Fig. 6. *WEALTHY* system for continuous monitoring with built-in textile electrodes

The records from the Lifeshirt sensors are transmitted via Bluetooth to a PC station and processed with specialized program products. The system has been tested in over 90 research cases exploring its capability to oversee a vast field of medical conditions [13][12] (Fig. 7).

The arrangements for telemetric monitoring of EEG and EMG signals and their tracking are Analogous.

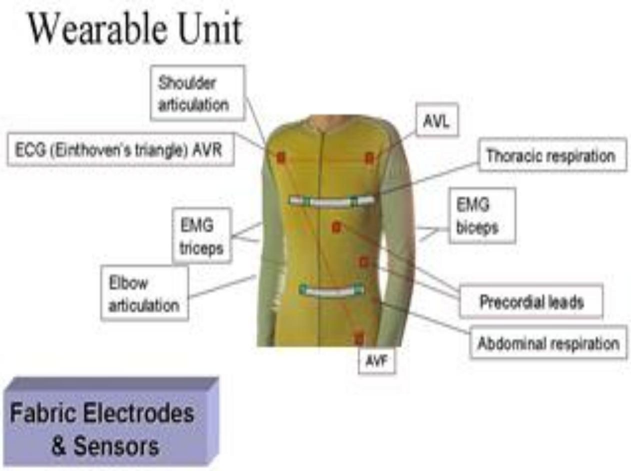

Fig. 7. Multifunctional biomedical parameter monitoring suit based on a textile carrier with built-in textile electrodes

IV. CONCLUSION

The study of the practical application of telemetry systems undoubtedly proves the advantages of their application for long-term monitoring of high-risk patients.

Improving the quality of their work and increasing their application capacity in biomedical telemetry monitoring systems is in direct relation with the demand and the development of new solutions for implementing innovative conclusions and designers solutions. The reduction of the cost of the final product, as well as the application of new materials, elements and technological solutions, such as textile electrodes, is a serious step in this direction.

Among their main strengths is maintaining the maximum level of comfort and mobility of the patients, which ensures that the degree of activity and social integration is maintained, as well as allowing patients to continue their normal lifetime during telemetric monitoring and / or time of active treatment and rehabilitation.

Textile electrodes do not require additional maintenance and consumables. They do not cause allergic reactions and irritation to the skin, allowing for trouble-free surveillance over a long period of time, which cannot be achieved with conventional gel electrodes.

Textile electrodes are lightweight and convenient for long-distance transport, which makes them indispensable for emergency medical care applications when the monitored person is out of the health establishments and in remote hard to reach areas. They are also very useful if there is a need to monitor patients who do not have permanent assistance but need to be under strict constant medical supervision.

They have a high degree of flexibility that enables them to be easily and quickly implemented in any form of wearable technologies while at the same time have/preserve a high level of resilience for multiple amplitude deformations. Textile electrodes are easy to maintain - they can take treatment with disinfectants, laundry, ironing, and therefore allow patients to have a high level of hygiene.
And last but not least, they are affordable, easy and fast to produce.

References

[1] P. Jian and A. Tiwari, "Heart monitoring systems - A review," Computers in Biology and Medicine, pp. 1-13, 2014.

[2] E. Valchinov, A. Antoniou, K. Rotas and N. Pallikarakis, "Wearable ECG System for Health and Sports Monitoring" 2014.

[3] M. Yapici and T. Alkhidir, "Intelligent Medical Garments with Graphene- Functionalized Smart-Cloth ECG Sensors," Sensors, no. 1, 2017.

[4] S. Tabakov, I. Iliev, I. Jekova and I. Kanev, "Portable System for Telemetry of Patients with a Pacemaker," IX National Conference with International Participation ELECTRONICA, 2018.

[5] D. Deborah, "Market Targets 1997," Telemedicine Magazine, 1997.

[6] J. Marenco, P. Wang, M. Link, M. Homoud and N. Estes III, "Improving survival from sudden cardiac arrest. The role of the automated external defibrillator", Journal of the American Medical Association (JAMA), 285, pp. 1193-1200, 2001.

[7] A. Xiang, T. Orathai and K. George, "Investigating the Performance of Dry Textile Electrode for wearable End-Uses," The Journal of The Textile Institute, 2018.

[8] I. Iliev and K. Kostikova, "Telemetry of high risk patients with cardiovascular diseases," 2014.

[9] V. Marozas, A. Petrenas, S. Daukantas and A. Lukosevicius, "A comparison of conductive textile-based and silver/silver chloride gel electrodes in exercise electrocardiogram recordings," Journal of Electrocardiology, pp. 189-194, 2011.

[10] S. Ajemi and F. Teimouri, "Features and application of wearable biosensors in medical care," Journal of Research in Medical Sciences, 2015.

[11] M. Catrysse, R. Puers, C. Hertleer and L. Van Langenhove, Towards the Integration of Textile Sensors in a Wireless Monitoring Unit., 2003.

[12] P. Grossman, "The Lifeshirt: A multi-function ambulatory system monitoring health, discase, and medical intervention in the real world," Studies in Health Technology and Informatics, pp. 133-141, 2004.

[13] I. Iliev, G. Nikolov, S. Tabakov and B. Tzaneva, "Experimental Investigation of Textile Planar Capacitive Sensors," in XXVII International Scientific Conference Electronics - ET2018, Sozopol, 2018.

[14] I. Tong, Y. Sun, E. Tae, W. Hun, J. Kap, J. Eung and R. Sadleir, "Nanofiber Web Textile Dry Electrodes for Long-Term Biopotential Recording," IEEE Transactions on Biomedical Circuits and Systems, 2013.

[15] G. Paul, R. Torah, S. Beeby and J. Tudor, "The development of screen printed conductive networks on textiles for biopotential monitoring applications," Actuators, pp. 35-41, 2014.

[16] L. Rattfält, M. Lindén, P. Hult, L. Berglin and P. Ask, "Electrical characteristics of conductive yarns and textile electrodes for medical applications," Medical & Biological Engineering & Computing, pp. 1251-1257, 2007.

[17] S. Tsukada, H. Nakashima and K. Torimitsu, "Conductive Polymer Combined Silk Fiber Bundle for Bioelectrical Signal Recording," Plos One, 2012.

[18] N. Silva, L. Gonçalves and H. Carvalho, "Deposition of conductive materials on textile and polymeric flexible substrates," Journal of Materials Science: Materials in Electronics, pp. 635-643, 2013.

[19] A. Comert, M. Honkala and J. Hyttinen, "Effect of pressure and padding on motion artifact of textile electrodes," BioMedical Engineering OnLine, 2013.

[20] M. Puurtinen, S. Komulainen, P. Kauppinen, J. Malmivuo and J. Hyttinen, "Measurement of noise and impedance of dry and wet textile electrodes, and textile electrodes with hydrogel," in Engineering in Medicine and Biology Society, New York, 2006.

[21] X. An and G. Stylios, "A Hybrid Textile Electrode for Electrocardiogram (ECG) Measurement and Motion Tracking.," Materials 2018, 11 2018.

[22] R. Paradiso and K. Wolter, Wealthy-A wearable health care system: New frontier on E-Textile, 2005.

[23] Paradiso, R.; Pacelli, M., "Textile electrodes and integrated smart textile for reliable biomonitoring," in IEEE Engineering in Medicine and Biology Society. Conference 2011, 2011.

[24] G. Loriga, N. Taccini, D. De Rossi and R. Paradiso, "Textile Sensing Interfaces for Cardiopulmoranary Signs Monitoring," in IEEEEngineering in Medicine and Biology 27th Annual Conference, Shanghai, 2005.