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Experimental study of the performance of textile electrodes in emergency situations and long-term monitoring

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ABSTRACT

Cardiovascular diseases and anomalies represent some of the most serious socially significant health challenges in contemporary medical practice. In response to the growing need for effective monitoring and timely diagnosis, recent years have seen increased interest in innovative telemetric systems for remote monitoring of high-risk patients. These technologies enable continuous care, improved quality of life, and early intervention, while overcoming the limitations and inconveniences of conventional monitoring methods.

A key aspect of successful implementation of such systems is their integration into the daily lives of patients, with emphasis on comfort, discretion, and reliability of the collected data. In cases of emergency and critical situations, rapid response capabilities are of paramount importance. In this context, wearable technologies—particularly intelligent textile systems with embedded sensors based on conductive materials—have emerged as a promising solution. They allow continuous real-time recording of physiological parameters without disrupting the patient's normal activity. Moreover, they can be used in emergency scenarios and in hard-to-reach locations, as they are lightweight, portable, and user-friendly.

This study explores the potential of intelligent textiles as part of telemetric solutions for cardiovascular system monitoring, highlighting their advantages, challenges, and prospects for clinical application.

KEYWORDS
Biomedical signals; ECG monitoring; healthcare; telemetry; textile sensors; smart textile; wearable technologies

1. Introduction

Intelligent textile systems for continuous online monitoring of patients from high-risk groups are among the modern achievements of telemedicine practice [1–9]. Figure 1 presents a block diagram illustrating the functionality of such a system.

The biomedical parameters monitored by intelligent textile systems are wirelessly transmitted to an intermediate station (hub) located near the patient (typically within 100 meters). The presented diagram illustrates the organization of biomedical signal acquisition and transmission during long-term monitoring. The intermediate station may be a portable computing device (notebook or PDA – Portable Data Assistant), or a GSM device. The recording unit establishes a mobile connection via a smart device to a remote specialized center, where the data is processed and decisions are made regarding further medical response.

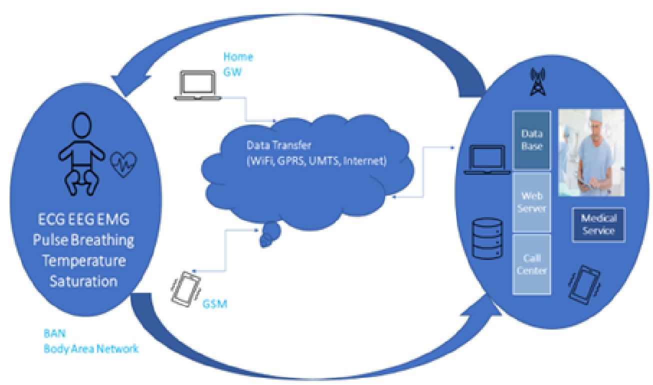

Figure 1. Block Diagram of a WBAN (Wireless Body Area Network).

The wireless interface, which ensures seamless data transmission between the portable devices and the source, is a key element in the described system. According to preliminary

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research, the most widely used short-range wireless communication standards include: IrDA, AM/FM, IEEE 802.11, Bluetooth, and Zigbee. Among these, Bluetooth and Zigbee—due to their similar characteristics—are considered the most suitable for integration into portable telemetric systems. In clinical practice, where noise resistance and data transmission reliability are critical, Bluetooth holds a clear advantage.

Key Requirements for an Intelligent Textile System for Continuous Monitoring and Emergency Cases:

- Biocompatibility – All components must be hypoallergenic to avoid skin irritation and chemically inert to ensure safety during prolonged contact with the body.
- Electrical Safety – The materials and components used must comply with safety standards for operating with electrical signals near the human body.
- Minimal Signal Interference – The system should not introduce additional noise or artifacts into the recorded biosignals, ensuring high measurement accuracy.
- Easy Integration into Textile Carriers – The design of the sensors and electronic components should allow seamless embedding into garments or accessories without compromising their functionality.
- Compact Size and Lightweight – To ensure patient comfort and mobility, the system must be small and lightweight.
- Low Power Consumption – Energy efficiency optimization is critical to extend operating time without recharging.
- Affordable Cost – To be applicable in widespread clinical practice, the system must be economically viable.
- Durability under Washing and Mechanical Stress – Textile components must retain their functionality after repeated use and maintenance.
- Stable Wireless Communication – Reliable real-time data transmission to medical platforms or mobile devices is essential.
- Modularity and Upgradeability – The system should allow easy addition of new sensors or functionalities based on patient needs.
- Data Security and Privacy Protection – Encryption and secure handling of personal medical data during transmission and storage must be ensured.
- Automatic Calibration and Self-Diagnostics – To minimize the need for technical maintenance and enhance system reliability.
- Intuitive User Interface – Easy to use by both patients and medical personnel, with data visualization and alert functionalities.

Following extensive research, as described in previous studies [10, 11, 12], textile-based sensors (electrodes) were selected for investigation in the present case (Figure 2).

Figure 2. Textile Electrodes

Motivation: The aim of the present study is to demonstrate the suitability of textile electrodes to provide sufficiently high-quality recordings of bio-potentials comparable to those obtained with conventional electrodes so that they can serve as a reliable basis for diagnostics in the monitoring of:

- High-risk patients in their daily activities;
- Emergency situations, where the system can be used as a portable solution in hard-to-reach areas, under adverse environmental conditions, in remote locations during expeditions, excursions, or rescue operations in mountainous terrain or during natural disasters.

2. Materials and Methods

The study was conducted under laboratory conditions as part of the development of an algorithmic sequence for designing and manufacturing an intelligent textile system for continuous monitoring of patients in pediatric wards.

For the measurements, a portable wireless electrocardiographic system—ECG_Blue (Figure 3)—was used. It records cardiac activity through standard peripheral and chest [13, 14, 15] bio-potential leads. The system is certified by SGS under certificate number GB 09/78668.

Figure 3. Portable ECG System ECG_BLUE

A laptop, tablet, or notebook is required as the recording and visualization device.

The key advantage of the selected system is its wireless data transmission via a Bluetooth interface, which fully meets the requirements for equipment mobility, compact dimensions, and low weight. These features make it an ideal solution both for daily monitoring of high-risk patients and for use in emergency situations.

- The portable ECG_Blue system is fully comparable in performance to advanced specialized electrocardiographic systems. It operates at a sampling rate of 1000 Hz and a resolution of 10 bits.

- The implementation of the present study was carried out under laboratory conditions using a 4-electrode configuration (peripheral leads – I, II, III, aVR, aVL, aVF), recording bio-potential signals from a real patient.

- To ensure a valid comparison and assess the performance of the textile electrodes, two sets of electrodes of the same model were used—one untreated and the other washed. Additionally, recordings were made using conventional “clip-type” electrodes from the ECG_Blue system kit.

3. Results and Analysis

To calibrate and verify the normal operating mode of the portable system, measurements were conducted using standard “clip-type” electrodes.

Figure 4 shows a screen recording of an ECG signal (from which heart rate data can be extracted and calculated), obtained from a real patient using conventional standard electrodes.

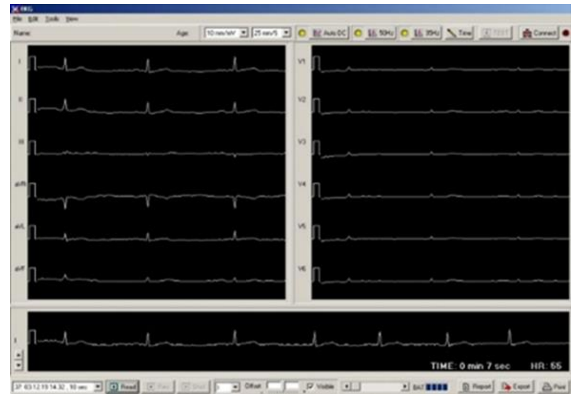

Figure 4: Full Reference ECG Recording Obtained Using Conventional Electrodes

Figure 5: Close-Up Extract of the Recorded ECG Showing the Graphical Quality of Cardiac Activity Monitoring Using Standard Clip-Type Electrodes.

Figure 5: ECG Recording of a Patient Obtained Using Conventional Electrodes

Figures 6 and 7 respectively present the working windows with lead graphs from the system during the ECG measurements, using untreated and washed textile electrodes of the selected bordered model.

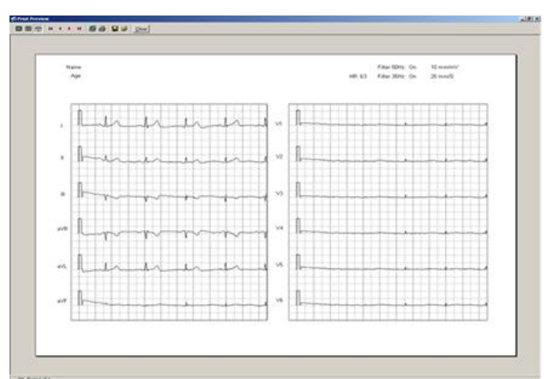

Figure 6: ECG Recording Using New Bordered Textile Electrodes

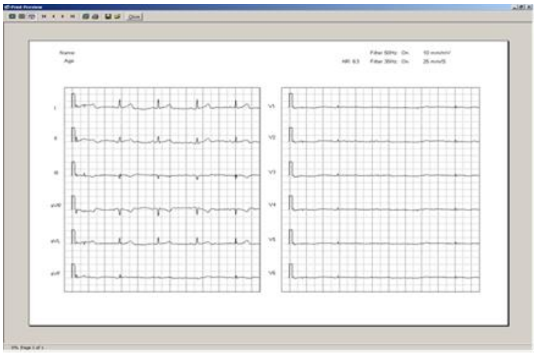

Figure 7: ECG recording using textile electrodes with edging after 10 washing cycles

4. Discussion

The results of the conducted experimental measurements clearly confirm the reliability of the textile electrodes with edging when used with the portable electrocardiographic monitoring system ECG_Blue. The obtained bio-potential recordings demonstrate high quality, comparable to that of standard medical electrodes, both in terms of visual interpretation and quantitative indicators.

A particularly significant observation is that the textile electrodes retain their functional characteristics even after multiple maintenance treatments, including between 10 and 50 washing cycles, as part of the upkeep of the smart textile system. Despite structural changes caused by mechanical deformations during use, the electrodes continue to provide stable and accurate bio signal registration.

These results confirm the potential of edged textile electrodes as a reliable component in wearable telemetry systems for continuous cardiovascular monitoring. In addition to their technical advantages, they offer a high level of comfort and adaptability to the patient's daily life, making them especially suitable for long-term use in both clinical and home environments.

Further research is planned to investigate the long-term durability of the electrodes under various operating conditions, as well as to optimize their design for even lower power consumption and improved integration with mobile health platforms.

Figure 8 illustrates the final comparison between three ECG signal graphs recorded from the same patient under identical measurement conditions—using conventional electrodes, followed by new textile electrodes, and then textile electrodes treated with 10 washing cycles.

Conventional electrodes

Untreated textile electrodes

Treated after 10 washing cycles textile electrodes

Figure 8: ECG recording of a patient obtained using textile electrodes with edging (untreated and after 10 washing cycles)

5. Conclusions

The comparative analysis between the quality of ECG signals recorded using standard conventional clip-type electrodes and the examined textile electrodes leads to the following conclusions:

- Textile electrodes possess the necessary properties for recording biomedical signals from the surface of the body.
- Textile electrodes are suitable for integration into intelligent textile systems for long-term monitoring, as they provide the required signal quality for biomedical diagnostics.
- The data obtained using textile electrodes are comparable to those recorded with standard electrodes. The observed signal

noise can be smoothed using software applications that process the data during acquisition for interpretation.

- Washing treatment of the textile electrodes preserves the signal values, which remain within acceptable limits, ensuring the reliability of studies conducted with their use. The increase in noise level is minimal, and the data remain fully comparable to those obtained with standard electrodes.

- Within the useful frequency range, the values of the recorded bio signals do not undergo critical changes. This leads to the conclusion that, regardless of treatment with detergents, exposure to electrolytes, and accompanying deformations, the electrodes retain their functional properties, and the signals obtained with their help remain suitable for use.

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