WEARABLE INTELLIGENT TEXTILE SUITS FOR TELEMETRY MONITORING IN PEDIATRICS

Elena Nikolova*, Borislav Ganev* and Elitsa Gieva**
Department of Electronics, Faculty of Electronic Engineering and Technologies*
Department of Micrelectronics, Faculty of Electronic Engineering and Technologies**
Technical University of Sofia
8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria
{ lenny, b_ganev, gieva }@tu-sofia.bg

Abstract – **The growing demand for opportunities for continuous online monitoring of biomedical signals leads to the rapid development of wearable technologies. The introduction of intelligent textile systems and materials in medical practice greatly facilitates the work of medical teams. With their help, diagnosis and treatment can be obtained anywhere, anytime, at an affordable price, without the need for patients to visit a medical center. When working with patients, especially in pediatric wards, the key issue is to preserve their ability to maintain daily activity within their habits, freedom of movement, movement, taking certain positions without interfering with the collection, recording and analysis. of biomedical signals. This would facilitate the process of accepting the monitoring and would lead to the provision of regularly received data on vital signs with the necessary quality for their diagnosis and treatment by the medical teams. Also, with the introduction of wearable technology, it is possible for a medical professional to take care of more patients, as well as to monitor their condition remotely, giving instructions to change treatment when necessary.**

Keywords – **ECG; electrocardiography; intelligent textiles; online health monitoring; pediatrics; textile electrodes.**

I. INTRODUCTION

Among the main advantages of intelligent textile systems is the preservation of complete comfort and freedom of movement of the monitored patient, high hygiene standards, along with the ability to respond quickly and adequately in case of violation of the monitored indicators.

As a specific category of patients, children (especially those up to 1 year of age) need the maximum degree of preservation of their daily activity, demanding significantly higher freedom of movement, comfort and high levels of hygiene, along with ensuring the high quality of the monitoring of the vital signs necessary for their treatment.

The developed and executed children's suit for continuous online monitoring focuses on a new concept of the way of dressing. Its aim is to provide child patients with the easiest and fastest service by focusing on restricting their freedom of movement as little as possible. The model is based on the application of textile electrodes for ECG monitoring and recording.

Figure 1 shows a block diagram of a continuous monitoring system comprising three main parts.

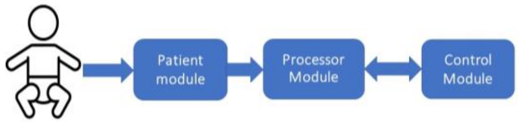

Fig. 1. Block diagram of a developed continuous monitoring system

A. Patient module

The patient module includes intelligent textile materials and/or built-in sensors and transducers – active components which pre-process the registered information partially or completely. They are realized mainly through analog circuits (amplifiers, filters), normalizing the received signals by frequency and amplitude and eliminating the interference superimposed on them.

The key requirements for this part of the module are:

- the elements do not irritate the skin and are chemically inactive;
- not to introduce additional disturbances in the registered signal;
- their construction allows easy installation or implementation in the textile media themselves.

B. Processor module

The microcontroller in the processor module provides a computing resource for accurate data acquisition and analysis. In addition to their momentary interpretation, databases are created according to set parameters. They store and compare the newly received biosignals with the historical ones, sorting them, evaluating and generating a reaction according to possible scenarios.

C. Control module

Processed data enters the control (doctor's) module, implemented through a personal computer and appropriate software. The module can be physically remote from the patient, with data transfer to and from it being carried out via a wireless connection. It manages and maintains the continuous process of remote monitoring, with the possibility for feedback to the processor module.

Key requirements for the telemetry system for monitoring the cardiac activity of high-risk patients are: speed of data exchange, possible interference of signals and ways to filter

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them, reduction (or complete elimination) of incorrectly generated alarms by adapting existing (or creating new) algorithms for recognizing life-threatening conditions as well as two-way communication between the patient and the doctor module.

A key task is to provide maximum comfort for the patient by bringing the monitoring mode as close as possible to the daily one. Therefore, the application of intelligent textile systems and materials, textile sensors, conductive textiles, changing their functions according to the impact of external stimuli, would lead to a significant optimization of online telemetry tracking systems.

The biomedical indicators set for tracking by intelligent textile systems are transmitted wirelessly to an intermediate station (concentrator) located near the patient. Figure 2 shows a scheme of organization of registration and transmission of biomedical indicators during continuous monitoring. The intermediate station can be a portable computer system (notebook or PDA-Portable Data Assistant), or mobile. The recording device communicates with a remote specialized center using a mobile connection via a smart device.

The wireless interface provides seamless data transfer between portable devices and the source. Bluetooth is the most suitable for installation in portable telemetry systems due to its proven in clinical practice noise resistance and reliability of data transmission.

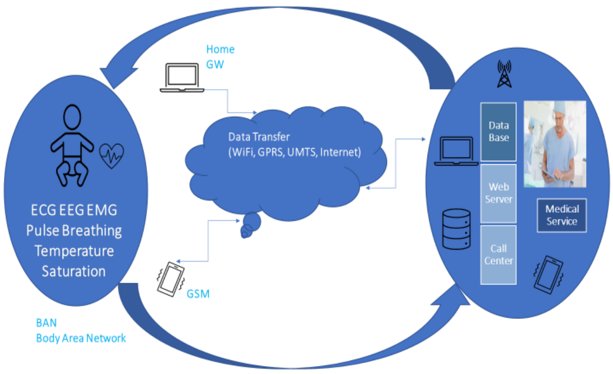

Fig. 2. WBAN (Wireless Body Area Network) block diagram

There are two significant disadvantages in the implementation of textile-based medical monitoring systems [1-4]: the **high impedance in the contact area** of the sensor with the body surface and **the movements of the clothing** accompanying its operation. Historically, many studies have been devoted to various remote monitoring solutions in pediatrics in the last 10-15 years [5-7]. The aim of introducing new technological solutions and methods for analysis, processing and reporting of signals provided by intelligent textiles is to bring the accuracy of the monitored parameters and their comparability with those performed with specialized stationary equipment to a higher degree [8-11].

II. Complete Construction of the Product

The specific requirements to the nature of children's clothing require a detailed approach to every aspect of the costume. It ensures the smooth mobility and activity of children, promoting freedom, comfort and independence of patients undergoing continuous medical monitoring [12-15]. The product does not allow the introduction of disturbances in the registered biovoltages and covers high hygiene standards. The material of the intelligent textile suit provides a high degree of ventilation, moisture permeability, flexibility, elasticity and softness to the touch.

Fig. 3. View of the product

In addition to the specified requirements for children's clothing and in order to implement the basic idea, the product meets some general conditions such as:

- to correspond to the changes in the proportions of the children's physique and to their dimensional features, organized in the respective standards;
- be designed for multiple use in hospital and inpatient settings;
- to tolerate the application of various treatments.

Justification for the choice of the product – as a result of literature research, consultations with medical specialists and testing of samples of textile sensors, as a maximum functional and meeting the criteria textile product in accordance with the conditions for continuous on-line monitoring – a model of a children's body with an implemented system for continuous registration and interpretation of bio-signals. The system will be implemented in **Option 1** - with sensors. **Option 2** is also possible - with embroidered sensors of conductive thread.

The resulting device is a reusable children's body/t-shirt intended for clinical or home use. It allows the performance of different in nature and permissible by prescription body movements.

In the general case, the design methodology is designed for sizing and geometric construction of the main details for all standard size groups. The construction algorithm also allows designing for children's figures with deviations from the conditionally accepted as normal dimensional features.

The product has short/long (according to the season) sleeves and covers the body from the neck curve through the chest area and the waist to the subcutaneous area. Along the length, the bottom fastening is with ordinary or spring-loaded "tick-tack" buttons. The fastening on the sleeve is made with the same type of buttons - their number is two or three for short sleeves, and five for long sleeves. Their diameter is 10.0, 12.5 or 15.0 mm, depending on the size group.

The whole product has left- or right-side fastening according to the prescriptions for movement of the upper limbs and the type of treatment.

The two main details - front and back - are whole, without additional cuts and bends and permanently joined in one side seam. Along the lines of the neck curve and the length, the body has an edging band.

To ensure a tighter fit to the body along one side seam, the two main parts (front and back) are permanently connected with a seam, and the other has a fastening, which is a continuation of the fastening of the sleeve with buttons type "tick- so” - two in the shoulder and three or four on the sleeve, as illustrated in Figure 4. One sleeve is cut along the line of the outer and inner seam, where button fastenings are provided. The other sleeve is single-stitched as illustrated.

Fig. 4. Fastening

The bodysuit is designed so that its dressing (and undressing) is maximally facilitated, ensuring the attachment of a personalized elastic band with a width of (5.0 - 6.0) cm on its inner side.

The tape acts as a chest bandage, which is interchangeable and corresponds to the physical characteristics of the child's body in this area. It has the possibility of appropriately positioning in relation to the body surface and has a range for controlled tightening. It houses the sensors that are fixed to the child's body by means of a system such as "buttonholes and buttons". Two of these buttonholes are fixed to the side seams, ensuring the location of the strap as well as tight continuous contact with the surface of the child's body (Figure 5).

On the inside are sensors that pass through braided buttonholes (in the central part of the chest) and are fixed to the child's body. In the way their location is established, close continuous contact with the body surface is provided, which is necessary for extraction of biosignals with the required quality for monitoring.

The stationary sleeve has an "inner pocket", which houses a laminated unit consisting of a controller and a battery (Figure 5). A "tunnel" is made along one edge of the elastic band through which a cable is passed, connecting the controller from the sleeve with the sensors in the chest area.

The bodysuit constructed in this way can be put on and taken off quickly, easily and without the need for unnecessary movement of the child.

The buckle-type fastening system ensures secure positioning of the sensor and tight contact with the body, as well as the possibility to remove the tape from the main textile carrier (in this case body) and to be changed, washed, etc.

The material from which the intelligent textile suit is made provides a high degree of ventilation, moisture permeability, flexibility, elasticity and softness to the touch. The product meets high criteria regarding hygienic properties. The tape is made of a polyamide base with included elastomer.

Fig. 5. Sensors and controller

The elements intended for implementation in the textile system and the ones intended for recording the biosignals (or embroidered sensors) are located in the front upper part of the product, in the area of the solar plexus, at the border of the diaphragm and the lower end of the sternum. Their location is in accordance with the way that facilitates their service and activity as much as possible.

The second developed model is a T-shirt for the age group of 3-10 years. Figure 6 shows the model of the T-shirt, the construction of which is similar to that of the body described in detail above.

Fig. 6. Model of a children's T-shirt for the age of 3-10 years

III. Hardware

The patient`s module ensure registration and transfer of biomedical signals from the intelligent textile system to the processor module and vice versa. It is subject to removal during hygienic procedures in connection with its smooth operation. All electronic components and cables making the necessary connection are located in places that do not disturb the comfort of patients, as well as being protected from voluntary or involuntary removal from the textile system by patients. Figure 7 shows block diagram of the patient`s module.

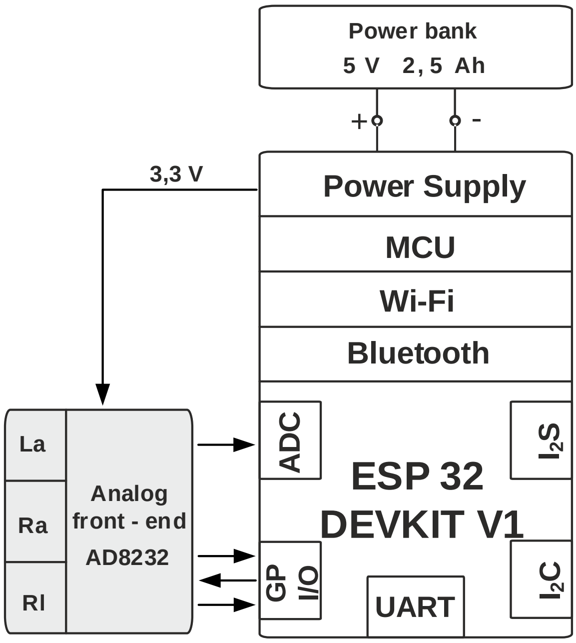

Fig. 7. Block diagram of the patient`s module

The developed patient`s module for monitoring of basic vital parameters it`s based on Integrated Circuit (IC) AD8232 from "Analog Devices". In essence, is an analogue front-end signal conditioning chip for a single-lead heart-rate monitor. It is especially suitable for portable ECG monitors, fitness and sports equipment for reading biometric data in wireless systems, as well as systems for collecting and processing bio-signals. The IC it`s used in typical configuration recommended by the manufacturer. For the three-electrode configuration, settings are set to the values shown in Table 1.

Table 1. AD8233 settings

Label	Position	Setting
S1	FR_EN	Fast restore disabled
S2	DC	DC leads detection on
S3	EN	Operation enabled
INPUT BIAS SELECTION	P3	Input bias set by RLD

It provides us the option of monitoring the direct contact between the patient's body and the electrodes, which gives an additional opportunity to reduce energy consumption, and gives direct feedback of the quality of measured signal.

Pre-processing of the ECG signals from the AFE provides the necessary amplification, filtering and removal of ECG noise. Pre-treatment of bio-signals is usually performed by AFEs, which provides better quality of the studied signal [16]. This AFE provides rapid recovery of the ECG signal after a possible lead disconnection, not only conditioning of signals in terms of amplification and filtration.

Low-pass and high-pass filters carry out the filtering of the measured signal. The cut-off frequencies of a bipolar high-pass filter is selected to remove motion artefacts and the semi-cellular potential of electrodes. Additional noise is removed, from a two-pole low pass filter with additional gain, using a Sallen-Key configuration. The built-in input instrumentation amplifier guarantees high common mode rejection and removes semi-cellular electrode potential.

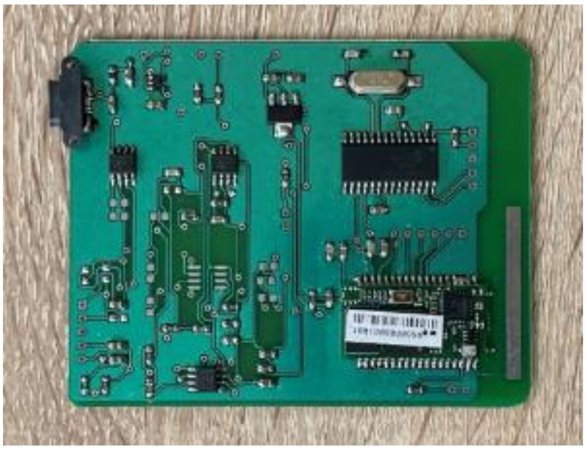

Fig. 8. PCB of the patient`s module

An ESP32-based development board was used. It represents a system on chip with built-in MCU, Wi-Fi and Bluetooth interfaces.

The data is transmitted via the Wi-Fi or Bluetooth interface and additional filtered by a moving average filter in LabVIEW environment. The sampling frequency is set to 250 Hz. Figure 9 shows ECG measurement of real patient. Other modules, shown on Figure 1 are implemented as software blocks.

When the node send`s data, additional parameters such as device ID, battery level and time are concatenated with data packet.

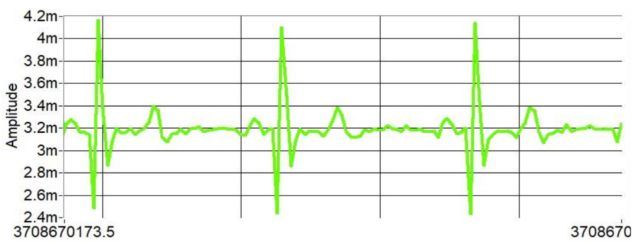

Fig. 9. ECG signal

In order to prove the suitability of the textile electrodes for incorporation into an intelligent textile system for online monitoring, an experimental measurement of the ECG signal was performed. As a preliminary result of the hardware test, the suitability of the textile electrodes to record an ECG signal with the quality required for medical diagnostics was proved (Figure 9). In real conditions in pediatric wards a study is forthcoming, which requires additional training and special permission.

When conducting studies with infant patients, the possibility of audio transformation (sonication) of the ECG and transmission of the signal through a monitoring system (baby monitor) will be assessed.

To implement the intelligent textile system for continuous monitoring, two models of textile electrodes for recording bio-signals were selected and tested [18], illustrated by a photo in Figure 10.

- Model 1, without edging, is a round disk with mass m≈0.7 g, thickness δ≈4 mm and diameter d≈45 mm. It is made out of polyurethane foam, and the surface that comes into contact with the body is covered with a conductive knitted fabric of silver threads. On the other side, the disc is covered with a knitted fabric of PA.

Figure 10. Textile electrodes with edging and without edging

- Model 2, with edging, is made of polyurethane foam, but with much less thickness. It is edged on the periphery in order to improve its stability during installation and operation. The diameter is the same as the previous model, but has a denser structure - its mass is about 2.6 g at a thickness of about 3 mm. The model is made as a "sandwich structure". On the contact side it is covered with a conductive knitted fabric of silver threads, and on the other side it is rubberized. A wiring hole is drilled in the center of the disc, and the connection is made by means of a fastening system type "eyelets".

The power supply (battery) is placed in a special (S-shaped) pocket, and is removed from the node during washing and other necessary maintenance procedures in order to preserve its functionality. Structurally, this is achieved by having the wiring and batteries implemented in the area along the side seams, and if necessary, the seams of the curve of the collar are used. The same places were used for the controller. A power bank with a capacity of 4000 mAh is used. The average consumption of the unit is in the range of 110 ÷ 130 mA, which provides autonomous operation of about 12 hours, with sufficient energy reserve to ensure continuous operation of the node for a sufficiently long period. The model of the power bank is P324.95.

IV. Conclusion

The developed comprehensive wrapping system supports the work of medical teams in continuous online monitoring of ECG signal of patients in pediatric wards. A patient`s module board and textile carrier have been designed and implemented. The experimental results obtained with the help of the textile electrodes are presented. It is planned to minimize the size of the controller board and its consumption. Next steps are to optimize the design of the textile system and to develop varieties for other sizes of the children's group - T-shirts, bandages.

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