MATTRESS TOPPER WITH TEXTILE ECG ELECTRODES

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Abstract: *The contribution focuses on construction design and verification of functionality of a mattress topper with incorporated textile ECG electrodes, designed for sensing, transmission and monitoring electrical activity of hearth (ECG) without direct contact with human skin. Sensoric part of the mattress topper consists of a system of active textile capacitive ECG electrodes made from electroconductive textiles incorporating microelectronics. The ECG electrodes are together with a grounding electrode integrated into construction of a cover of the mattress topper. The measuring segment comprises an independent control unit, receiving and processing the measured biomedical data and transmitting them to a computer for further processing. A prototype of a cover of the mattress topper has been developed on the base of an own proposal and its functionality has been verified experimentally by direct measurement of the ECG signal generated by a probant's body.*

Keywords: *textile electrode, capacitive sensing.*

1 INTRODUCTION

Electrocardiogram (ECG) sensing represents a traditional diagnostic method often used to monitor human health and diagnose potential cardiovascular diseases. The conventional method of ECG sensing uses electrodes and electroconductive gel in direct contact with skin surface of an examined person. A special feature of this type of measurement is high quality of measured signal due to low transfer resistance between the electrode and the skin (when using an electroconductive gel). On the other hand, long-term measurement is discomfortable and can cause allergic skin reaction in some cases.

In recent years, capacitive sensing of ECG signal avoiding direct conductive contact between the electrode and the skin of an examined person is being developed. This unconventional method of capacitive sensing has been successfully integrated e.g. into office armchairs, car seats or beds [1, 2]. Monitoring of heart rate variability during sleep based on capacitively coupled textile electrodes on a bed was described by the scientists from Seoul National University, College of Medicine, Seoul, Korea. They developed and tested a capacitively coupled ECG measurement system on a bed using capacitively coupled electrodes and conductive textiles [3]. Scientists from Research and Development, Daimler AG Boeblingen, Germany developed a system of non-obtrusive ECG measurement by capacitive sensors in various patient fitments, e.g. stretchers, hospital beds, wheelchairs etc. They compared contact and contactless ECG measurements by shielded textile electrodes to display the potential of contactless monitoring of human vital functions [4]. Results of the experiments showed that the contactless recordings are of sufficient quality and that they can be used for further standard ECG analysis like QRS-complex detection.

An own proposal of a cover of a mattress topper incorporating a system of ECG electrodes based on electroconductive textiles is described in this contribution. The innovation is our developed application and evaluation device for displaying and archiving the ECG of a person lying on mattress topper.

2 DESIGN AND CONSTRUCTION

2.1 Capacitive measurement of ECG

Principle of capacitive ECG sensing is shown in Figure 1. An active ECG electrode constitutes one plate of a plate condenser and surface of human skin constitutes the second plate of the plate condenser. A dielectric layer is placed between these two plates; the most frequently this layer is a layer of cotton clothing in which a lying person is dressed during measurement. Capacity of such a condenser is calculated according to the formula:

$$C = \varepsilon_0 \varepsilon_r \frac{S}{d} \quad (1)$$

where: *S* is surface of condenser plate, *d* is distance between the condenser plates ε_0 is permittivity of vacuum and ε_r is dielectric permittivity.

If surface of an electrode is 25 cm^2 (5x5 cm), dielectric material is a cotton fabric with 0.5 mm thickness and 2.077 permittivity [5], capacity of the plate condenser will be approximately 92 pF.

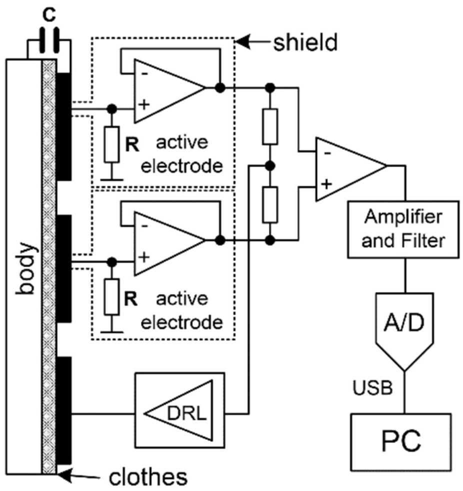

Figure 1 Block diagram of capacitive ECG sensing

The active ECG electrode incorporates a low-noise operational amplifier in connection of a voltage tracker. Static charge of the condenser is discharged by means of *R* resistor. Combination of *C* condenser with *R* resistor creates a filter whose limit frequency is calculated according to the formula:

$$f_c = \frac{1}{2\pi RC} \tag{2}$$

If value of the resistor will be 2 GΩ, then the limit frequency of the filter will be 0.87 Hz. Such a filter will enable to remove unacceptable biological artefact caused by breathing.

2.2 Textile sensors and ECG electrodes

An advantage of textile electrodes is pleasant hand, elasticity and ability to adapt to contours of a human body what enhances comfort of a man during ECG measurement. Several types of conductive fibres and textiles with various functional properties are available on the market at present. An electroconductive single jersey with specific electric resistance of 1.5 Ω/10 cm has been used in construction of the textile ECG electrodes. This single jersey is made from 100% fibre with core from polyamide and shell from pure silver. The single jersey is 0.2 mm thick and weighs of 180 g/m^2. The electroconductive fabric was used to prepare eight textile sensors (Figure 2a) with dimensions of 5x5 cm (negative electrodes) and one textile sensor with dimensions of 5x30 cm (positive electrode). The sensors constitute a sensing component of the active ECG capacitive electrodes. Electronics of the ECG electrodes has been placed on a flexible board and connected conductively with the textile sensor. The electrically conductive knitted fabric, which was used to prepare the textile sensors, was also used to shielding the electronics (Figure 2b). Construction of the ECG electrode is shown in Figure 2.

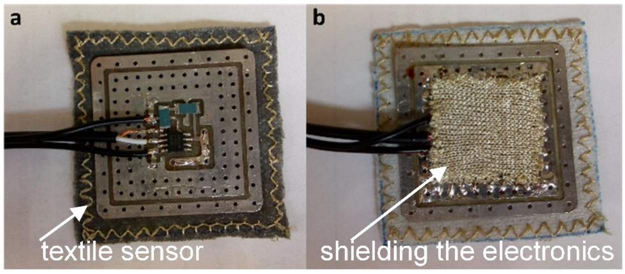

Figure 2 Active ECG electrode. Setting of the electronic components from the back side of the electrode (a), shielding the electronics by a conductive fabric (b)

2.3 Proposal of a cover of the mattress topper

Sensoric component of the cover of the mattress topper are active ECG capacitive textile electrodes (8 pcs) with incorporated microelectronics (marked 1 up to 8) and a reference active ECG capacitive textile electrode (marked 0). Setting of the electrodes on the upper face side of the cover of the mattress cover is shown in Figure 3. A passive DRL electrode, placed on the cover of the mattress topper as well, is used to supress technical artefacts, primarily interferences from the electrical power network. The ECG electrodes constitute an eight lead system of ECG measurement, where the electrodes No. 1-8 are negative electrodes and electrode No. 0 is a positive one. Connection of the electrodes is placed under the cover of the mattress topper and terminated by 25 outlet connector connected to the control unit.

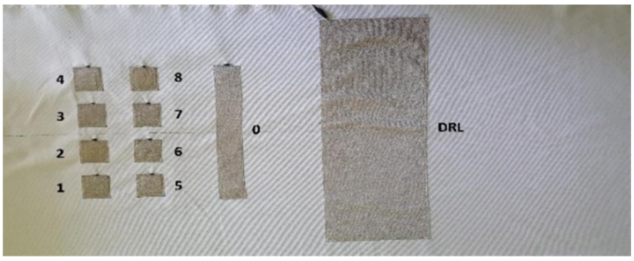

Figure 3 A prototype of the cover of the mattress topper

The control unit collects signals from the electrodes, performs further analogical processing, digitalisation of the signals and their transmission to a computer by means of universal serial bus (USB) interface. A basic component of the control unit is an integrated eight-channel circuit ADS1198, 16-bit analogue-digital (AD) transducer with internal reference and adjustable amplification and sampling frequency. The ADS1198 chip is controlled by ATmega328P microcontroller by means of serial peripheral interface (SPI). The microcontroller provides communication with a personal computer by means of universal asynchronous receiver transmitter (UART), which is converted to the USB interface by FT232RL converter. A prototype of the control unit and its connection to the cover of the mattress topper is shown in Figure 4.

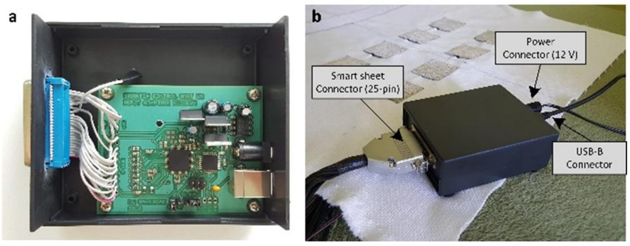

Figure 4 A prototype of the control unit (a) and its connection to the cover of the mattress topper

3 RESULTS AND DISCUSSION

Functionality of the cover of the mattress topper has been evaluated on a person lying on his back for 1 hour (Figure 5). The subject wore nightdress made from 100% cotton fibre. Sampling frequency was adjusted to 250 Hz. Amplification was adjusted to value 6 for all channels with the exception of channel No. 2 and No. 3.

Figure 5 A probant lying on the developed mattress topper

Signal in these channels exceeded the range on amplification 6 and therefore amplification in these channels was reduced to 4. DRL circuit was active and signal for DRL circuit was derived from all input channels. Raw ECG record is shown in Figure 6. The channels are arranged in lines, i.e. channels No. 1 and No. 2 are shown in the first line. It is obvious from the figure that signals in the channels are influenced by noise differently and show also different offset. This phenomenon is caused by local differences in distribution of electrical potential on the skin, accumulation of static charge and different pressure of the electrodes.

Although DRL circuit has been used and electronics of the active electrodes have been shielded, the output signals comprise considerable noise on the frequency of 50 Hz as it is evident from the power spectral density (PSD) in Figure 7.

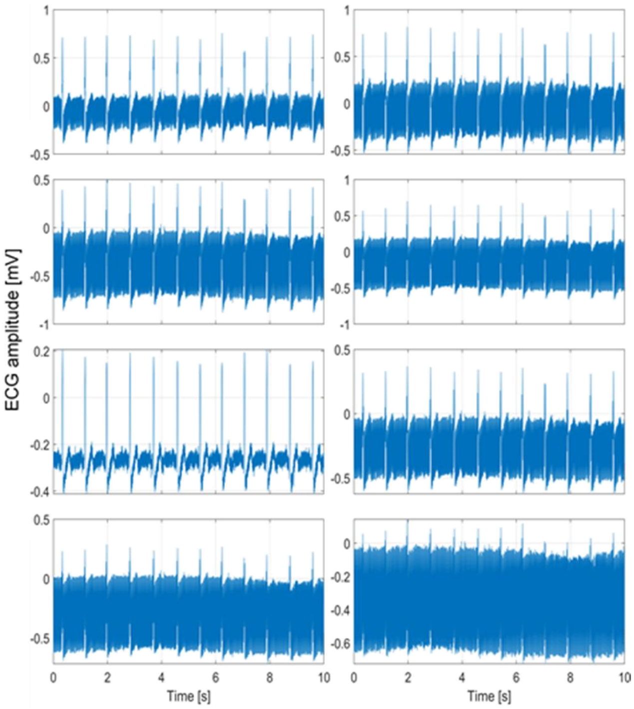

Figure 6 Raw eight-channel ECG record measured from the cover of the mattress topper

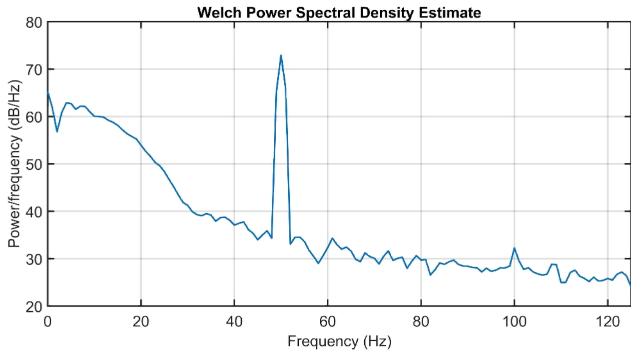

Figure 7 Power spectral density (PSD) of the channel

A narrow-band filter for 50 Hz, applied to all channels, has been proposed to reduce the noise. ECG record after application of the filter is shown in Figure 8.

The main problem is electrostatic charge and movement artefacts. The movement artefact causes saturation of the operational amplifier inputs and it can take even several seconds until the signal has been stabilised again. Solution of this problem consists in application of a special electronic circuit grounding temporarily inputs of the operational amplifier as soon as a signal gets outside the measuring range [6].

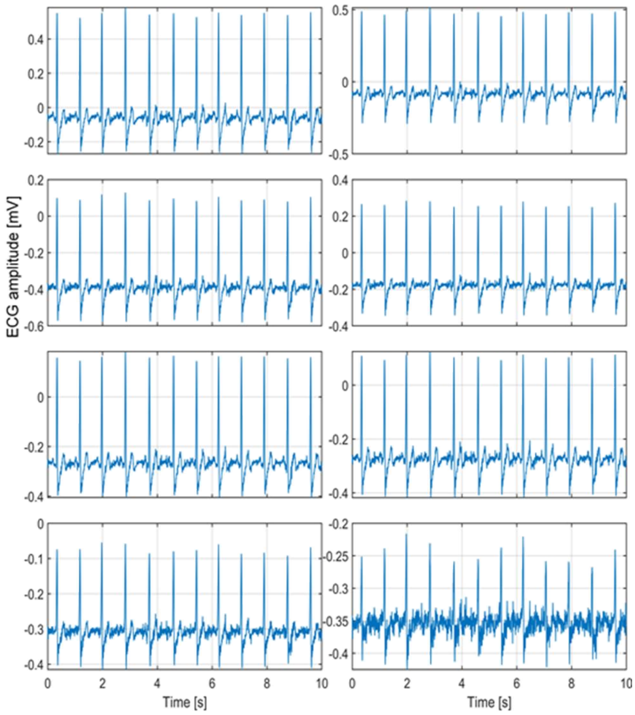

Figure 8 Filtered eight-channel ECG record measured from the cover of the mattress topper

4 CONCLUSION

The proposed prototype of the cover of the mattress topper enables ECG monitoring on capacitance principle in lying position. This method of measurement is comfortable in comparison with the standard sensing – it is not necessary to apply any electroconductive gel, attach the electrodes, power cables and carry data collection unit. These advantages enable comfortable ECG monitoring not only in the hospitals but also remote monitoring in the home environment. Further enlargement of functionalities of the designed mattress topper will be implementation of textile position sensors into construction of the topper. Their task will be to monitor movement of a patient and improve sensing of ECG signal from the textile active ECG electrodes. We are currently working on the protection of textile ECG electrodes from damage during maintenance by washing, chemical cleaning and mechanical damage, e.g. abrasion.

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