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Sleeping ECG and body position monitoring system

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***Abstract* - A textile-based ECG system for sleeper is presented. The electrode in the system is supported by a foam pad to ensure good contact as well as comfort to the wearer, and a flexible rubber to ensure that the electrode will electrically connect to the wearer only when pressed. Eight electrodes are multiplexed such that exactly two electrodes are pressed to connect the wearer no matter how the wearer lies. When the wearer lies in different positions, he/she will press different two electrodes, and then the morphology of the output ECG signal will be different accordingly. By this feature, the system can not only detect ECG but also determine the position of the sleeper.**

I. INTRODUCTION

HEART disorders are the leading causes of death; however, more than half of these deaths can be prevented in advance by using a reliable and cost-effective monitoring system combined with accurate signal analysis [1]. ECG is the most popular monitoring device, while most traditional ECG devices need wires and adhesive electrodes, which restricts their application being operated by trained clinicians and in hospitals. To solve this problems, several wearable ECG devices with textile-derives are proposed to date but these devices also suffer from body movements, electro-skin impedance and electrode positioning [2] [3] [4]. As a result, the heart-rate estimation becomes difficult since the ECG by the wearable textile sensors presents high baseline wandering and highly noisy due to the movable electrodes and the resulting unfixed contacts, especially when the wearer is in motion [5]. In a previous study, an unobtrusive ECG measurement through clothing on the bed was demonstrated [6]. To improve its accuracy, an advanced technique of automatically detecting and selecting the optimum electrodes for the system needs to be developed.

It is well known that a slight variation in the lead/source configuration may result in substantial effects on signals. [7]; furthermore, misplacement of electrodes can also alter the morphology of the received ECG signals [8]. This gives the possibility to determine the positions of the electrodes on the patient based on the different morphologies of the ECG signals.

In this paper a textile-based ECG system for sleeper is proposed, in which the electrodes are multiplexed in the configuration such that it will always contact two electrodes on the wearer, so that technique of automatically selecting the optimum electrodes is no longer needed. The electrodes, modified from our previous design [9], are made of flexible stainless steel textile [5] to be wearable with comfort, and washable. The method to measure and analyze the ECG signals from the wearable electrodes is also developed, by which both the heart rate and the position that the wearer lies on can be determined.

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II. SYSTEM DESCRIPTION

The system, shown in fig. 1, is comprised of eight textile electrodes embedded on a shirt and a control box, which is comprised of two-lead ECG amplifier, filter, microcontroller (MSP430, by Texas Instruments), and wireless transmitter. The system and the wearer under test are shown in fig. 2.

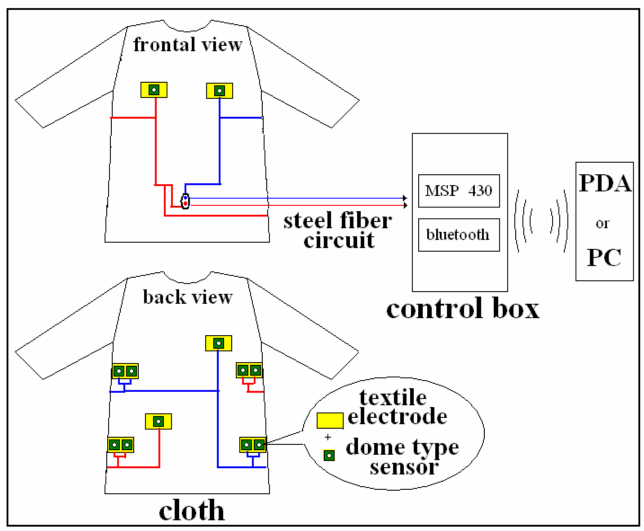


Fig.1. the block diagram of the system

Fig.2. the system and the wearer under test.

Two types of textile electrodes are developed. The direct type is that the textile electrode is directly knitted on the shirt, as shown in fig. 3. The indirect type is that a thin foam pad is inserted between the shirt and the textile electrode, as shown in fig. 4. On the opposite side of the shirt, the dome shape sensor with stainless steel conductive fiber is installed. The detail of the dome shape sensor will be described in next section.

There are two electrodes installed at the anterior, posterior and bilateral sites of the shirt, respectively, and each electrode may connect to one or two dome-shaped sensors. Lying with any position, the wearer will inevitable press two of the electrodes such that they will contact the underlying conductive fiber to conduct the ECG signals to the control box.

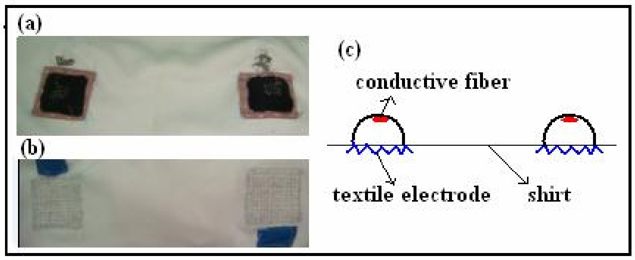


Fig.3. the direct type: The textile electrode is knitted on the shirt and directly contact to the conductive fiber when pressed. (a) The dome-shape sensor, (b) the textile electrode, (c) the side view schematic structure

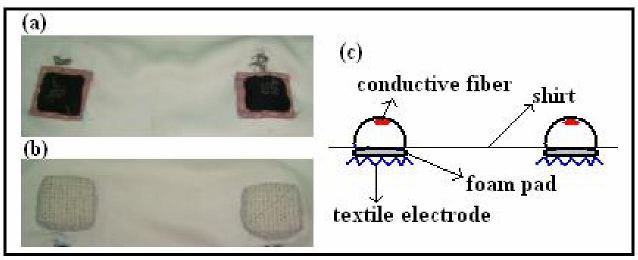


Fig.4. the indirect type: A thin foam pad is inserted between the shirt and the textile electrode. (a) the dome shape sensor, (b) the textile electrode, (c) the side view schematic structure.

III. MATERIAL AND METHOD

A. ECG circuits

The ECG signal is measured by using a two-lead ECG amplifier and filter circuit. AD8220 gives high gain on differential mode signal and eliminate the common mode noise, from the textile electrodes. Then the signal is fed to a 0.03 Hz high-pass passive filter and then a 40 Hz eighth order Bessel low-pass active filter, compliant to the AAMI EC38 standard. The filtered signal is then fed to the 12-bit ADC of the MSP430 microcontroller, and then transmitted to PC. All circuits are fully powered by batteries and well isolated from the earth or any other circuits, so it is unnecessary to use three-lead ECG circuit in the system to reduce the 60 Hz interference.

B. Dome shape sensor, textile electrode and multiplexing

Since the textile electrodes contact the wearer directly, its comfort and durability should be taken into consideration. After one year try-and-error on five male and five female adult subjects, the following specifications of dome-shaped sensor and textile electrode are determined. Wires consisted of 30% stainless steel fiber and 70% traditional fiber is used in the textile electrode for comfort. The substrate of the dome-shaped sensor is made of Styrene Butadiene Rubber (SBR), with the size of the 2.5*2.5*0.7 cm^3, shown in fig. 3a and 3b. The diameter of the conductive stainless steel fiber sewed on the SBR substrate is 0.2 mm. The sizes of the textile electrodes are finally chosen to be 8*3 cm^2 or 3*3cm^2, depending on the sites where they installed, as shown in fig. 1. We have tested 4*4 and 5*5 cm^2 electrodes and they showed no significant difference with the 3*3 cm^2 electrodes. However, 2*2 cm^2 electrodes performed worse than 3*3 cm^2, probably because that it is too small so that sometimes it is out of the area the wearer lies on.

The conductive fiber on the SBR substrate will not touch the electrode beneath until pressed, i.e., the sleeper lies on it. The feature makes all sensors easily multiplexed without technique of automatically selecting the optimum electrodes.

For the size of the electrodes located on lateral sites of the shirt, 8*3cm^2 are found to be better to keep closely contact while moving. Two dome-shaped sensors were set on one single lateral sites electrode and linked together through a conductive fiber such that at least one of the dome-shaped sensors is compressed no matter how the wearer turns his or her body. However, rectangular foam is hard to be manufactured and fastened for the indirect type of electrodes. Therefore, instead of one, two dome shape sensors are separately set on one rectangular electrode for both lateral sites.

The anterior electrodes are set close to the nipples of the wearer, with the distance of 16 cm. The left posterior electrode is set on the opposite site of the left anterior electrode, and the right posterior electrode is set 10 cm below the opposite site of the right anterior electrode. The distance between the lateral electrodes on the same side is 9 cm.

To verify the durability of the shirts under test, we wash them every working day by washing machine for six months and observe their ECG signal, the results showed no significant difference.

C. Evaluation of the system

Two parameters are used to evaluate the system: the signal to noise ratio (S/N), and the immunity to motion artifact. S/N is determined by taking the peak to peak amplitude of the R wave as signal, and the amplitude of the baseline as noise. Immunity to motion artifact is measured through the use of known reference movements to generate common artifact, and then the resultant signals by the textile electrodes are visually inspected and compared with the ones by conventional electrodes [10].

V. RESULTS

All the ECG signals shown below are from the same subject for comparison.

1) The signals with conventional electrodes

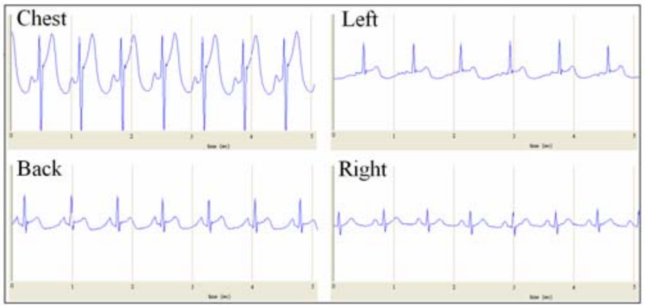


Fig.5. ECG signals with conventional electrodes.

2) The signals by the direct type electrodes

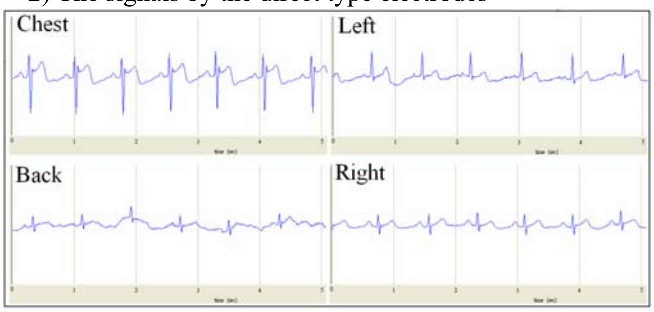


Fig.6. ECG signals with direct type electrodes

3) The signals by the indirect type electrodes

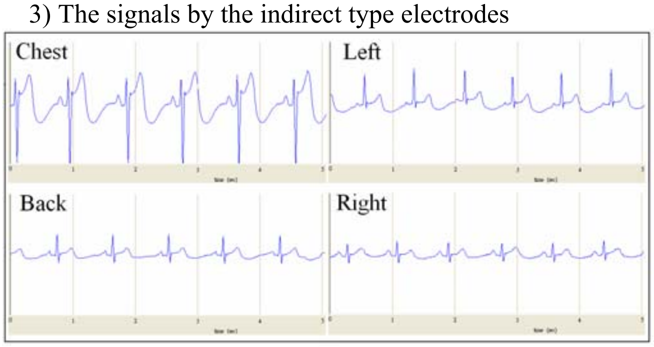
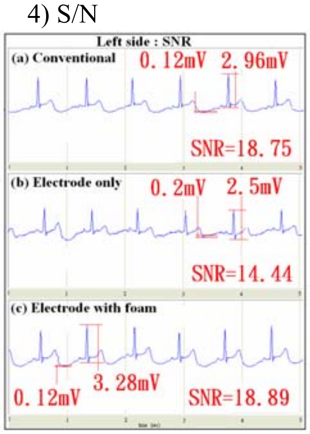
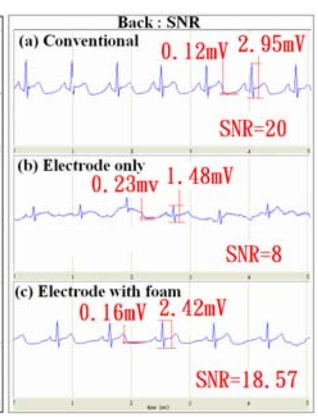


Fig.7. ECG signals with the indirect type electrodes

4) S/N

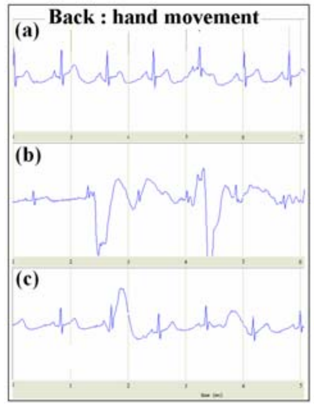


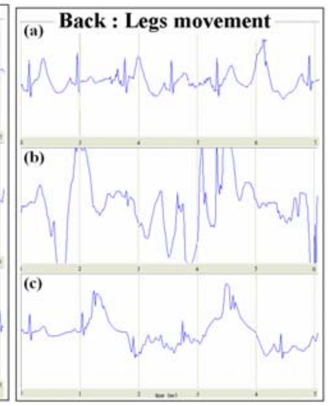


Left: Fig.8 the ECG signals while subject lying on his left side.
(a)conventional electrodes; (b)the direct type; (c)the indirect type.
Right: Fig.9 the ECG signals while subject lying on his back side.
(a)conventional electrodes; (b)the direct type; (c)the indirect type

5) The signals with motion artifact

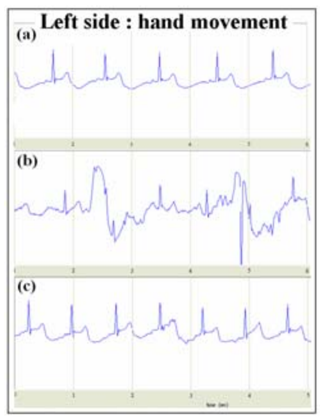
a. subject lying on back.

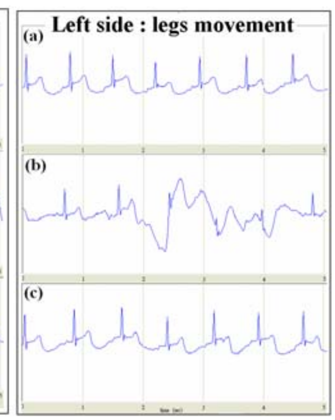




Left:Fig.10. the ECG signals while subject lying on back with two hands movement
(a) conventional electrode ; (b) the direct type ; (c) the indirect type.
Right:Fig.11. the ECG signals while subject lying on back with two legs movement
(a) conventional electrode ; (b) the direct type ; (c) the indirect type.

b. subject lying on left side.





Left:Fig.12. the ECG signals while subject lying on left with two hands movement.
(a) conventional electrode ; (b) the direct type ; (c) the indirect type.
Right:Fig.13. the ECG signals while subject lying on left with two legs movement.
(a) conventional electrode ; (b) the direct type ; (c) the indirect type.

6) The signals by the system with inversed bilateral electrodes

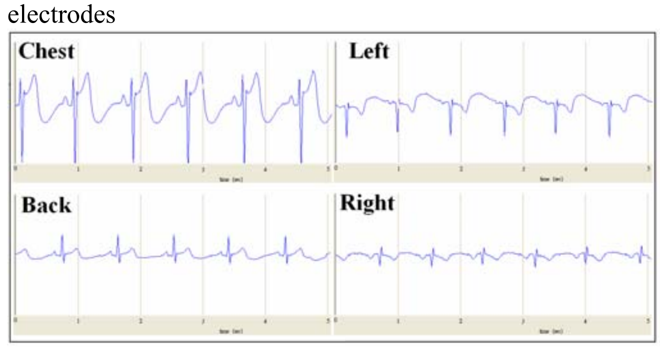


Fig.14. The ECG signals obtained by the modified system, in which the both electrodes on the same side are inversely connected.

VI. DISCUSSION

The ECG signals, as shown in fig. 5, with the conventional electrodes is obviously different from the standard 12-lead ECG, because of the sites of the electrodes are different. However, the R peaks are still easily to be identified. The amplitudes and the S/N shown in fig. 6 are significantly smaller than fig.5; because of the direct type electrodes give poor contact to the sleeper's body. The amplitudes and the S/N of fig. 7 are significantly larger than fig.6. It can be explained the foam pads help the electrodes to better contact the subject. Assume the weight set on each textile electrode is 3 kg and the size of the electrode is 3*3 cm^2, then the contact pressure is $3kg*9.8/3*3cm^2$ = 33 kPa, which is significantly greater than 6 kPa [11]. Therefore, the amplitudes and the S/N are improved by the foam pads.

The S/N with different types of electrodes and lying positions are shown in table 1. It shows that the indirect type is better than the direct type and there are not significant different between conventional electrode with the indirect type.

Position\ electrode	conventional	direct	indirect
On left side	18.75	14.44	18.89
On back	20	8	18.57

Table 1: S/N with different electrodes and position

The ECG signals are degraded significantly by movement. By comparing fig. 10~13, we found that indirect electrodes perform better than the direct ones. It can be explained once again that it is because of the foam pad.

In fig. 5~7, the phases of the R peaks of all sleeping positions are the same.

For easily identify the sleeping position from ECG signals, we switch the wires from the two electrodes of the bilateral sites, so that the phases of the right and left side signal are inverse to the ones of the chest and back signals, shown in fig. 14. The method to determine the lying position by the morphology of the ECG signals can be derived from fig. 14 and summarized in table 2. By viewing the phase and the amplitude of the signal, the lying position can be determined.

Phase\ amplitude	large	small
in	Chest	Back
out	Left	Right

Table 2: determining the lying position by the phase and amplitude of the ECG signal

Besides, it is also shown that the T wave of the chest position is larger than the one of the back position, and the P wave of the right position is larger than the one of the left position. It is helpful to determine the lying position.

Fig. 15 shows the four lying positions determined by the system.

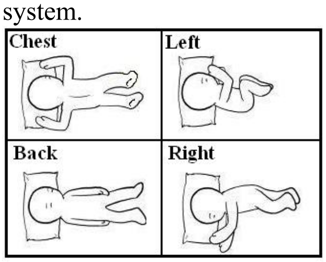


Fig. 15 the four lying positions

VII. CONCLUSUON

The system shown in this paper can detect the ECG signals of the healthy sleeper, with enough immunity to motion artifact, no matter what position the sleeper lies on. Furthermore, the system can determine the position of the sleeper by the morphology of the ECG signals. The system gives clear R peaks so that it can be used for arrhythmia and heart rate monitoring. However, the ECG signals obtained by the system are different from the standard ones. It is therefore, necessary to investigate before apply it to other medical application. For future study, artificial neural network is planned to be applied to analyze the morphology of the ECG signals; furthermore, to make the system adaptive to individual subjects with different ECG features.

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