Smart Clothes with Bio-Sensors for ECG Monitoring

P.Sakthi Shunmuga Sundaram, N.Hari Basker, L.Natrayan

Abstract: Aging society leads to more demands on health care system. The study shows that cardiovascular diseases are the most common and threatening diseases to the elderly. Moreover, more and more elderly live alone recently. Therefore, a total solution for elderly home care leads the way. In this study, we develop smart clothes to record three lead electrocardiography (ECG). Our system consists of (1) the conductive fiber clothes with four electrodes to acquire physiological signals, (2) a gateway to digitize, process and upload raw data to the server, and (3) the service server to analyze data and make a health profile. The system had been applied to the elderly community to evaluate performance. The experiment results show the average accuracy of ECG data is 86.82%. Thirty-five volunteers (age > 65, 15 male and 20 female) feel the smart clothes comfortable and easy to use than the traditional medical device.

Index Terms: Smart Wearable Device; Smart Clothes; Long-Term Care; Electrocardiography; Bio-Sensor

I. INTRODUCTION

The advance of medical technology, average life expectancy increase rapidly lead the apparent trend to an aging society in many countries [1,2]. Aging society causes the growth of health expenditure. Therefore, the demands on health and aged care systems germinate rapidly [3]. The study shows that approximately 75% of the elderly have one or more chronic diseases, among which cardiovascular disease is one of the most common diseases. Currently, cardiac patients rely on regular health checks to assess the condition. But the examination period in hospital is short, may not diagnose the potential risk of the disease. Only long- term, continuous monitoring, and recording of daily cardiac physiological signals can cause early warning and prevention. Besides, more than 28% elderly populations (8.8 million women, 3.8 million men) currently live alone in the United States [5]. In case of emergency, nobody can provide them first aid treatment. Therefore, elderly health management becomes a critical issue. To meet this demand, in the past decades, many successful healthcare applications have been presented to monitor user's electrocardiography. However, these systems still have some drawbacks [6, 7]. For example, the Holter, a portable device for continuously monitoring the electrical activities of the heart for 24-72 hours, can provide 12 Leads ECG non-real-time records. But the methods are awkward and uncomfortable for long-term use, so it's not suitable for elderly home care. Since the limitation of electrode setup, size and price of the record, the holter just can be used in clinical diagnosis but losing the end-user viewpoint [8]. Jie Wang developed the wireless Sensor-Based Smart-Clothing Platform for ECG Monitoring [9]. But this system adopts a fabric electrodes technology to record only one lead ECG signal. In this study, we propose a total solution of healthcare platform for the elderly. In this proposed system, it provides light, cheaper and comfortable sensing device, long-term (more than 40 hours and rechargeable) and continuously ECG signal collection and transmission. Our system consists of smart clothes with four electrodes to collect three lead ECG signals, a gateway to digitize and transmit the ECG data by Bluetooth to the smartphone and the back- end analysis system to analyze ECG data.

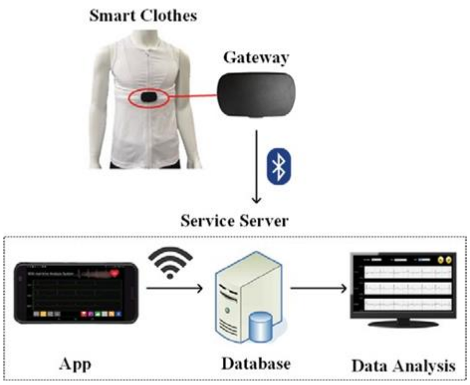

Fig. 1 System architecture

II. MATERIALS AND METHODS

The overall system architecture is shown in Fig. 1. Our system consists of three parts including (1) Smart clothes measure three first physiological signals (Lead I, Lead II, and Lead III). (2) Wireless Gateway digitizes the ECG signal, removes noise and uploads data to smartphone or tablet. It can also save ECG raw data in SD card real time. (3) The service server displays ECG waveform, stores the data into the database, and analyzes R-peak of the collection data. Smart clothes are made of conductive fibers. To make the elderly more convenient to put on smart clothes, they are designed with a front zipper which is shown in Fig. 3(a). There are 4 electrodes (Fig. 3(b)) on smart clothes. Electrode I and II are on each side of the shoulder. Electrode III and IV are below each side of the armpit (about 10cm below).

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Lead I is the voltage between the electrode II (LA, left arm, confident) and electrode I (RA, right arm). Lead II is the voltage between the electrode III (LL, left leg, positive) and electrode I (RA, right arm). Lead III is the voltage between the electrode III (LL, left leg, positive) and electrode II (LA, left arm). The relationship between the electrodes and the leads is shown in Fig. 2.

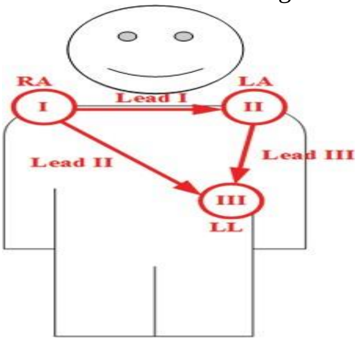

Fig. 2. The relationship between the electrodes and the leads

In order to improve the quality of receiving signal, the electrodes are filled with cotton (Fig. 3(d)). With this improvement, the probability of the electrodes to be contact with skin will increase. (a) The smart clothes are designed with front zipper. (b) Position of electrodes. (c) The original electrode. (d) Electrode filled with cotton

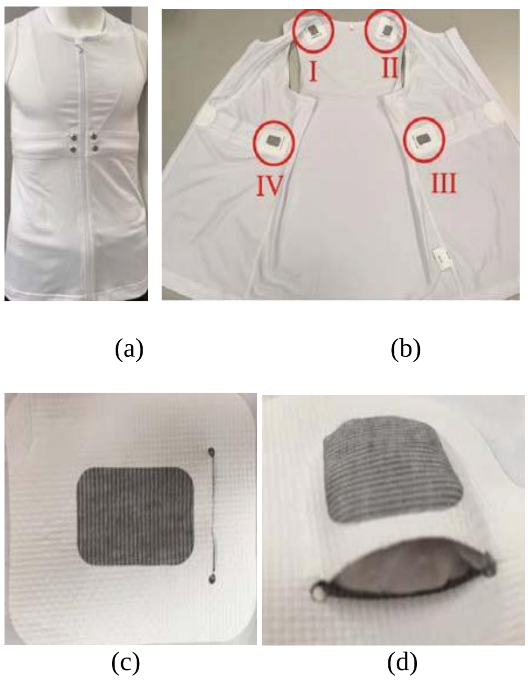

Fig. 3. (a) The smart clothes are designed with front zipper. (b) Position of electrodes. (c) The original electrode. (d) Electrode filled with cotton.

Gateway

The hardware architecture of the gateway is shown in Fig.4 the gateway is composed of three units: signal sensing unit, signal control unit and network communication unit. The sample rate of the gateway is 250 Hz, and the memory size of the gateway is 8 GB. The battery cans continuous operation up to 40 hours. The gateway sent the ECG signal captured by smart clothes to service server by Bluetooth. The packet format of the gateway is shown in Fig. 5.

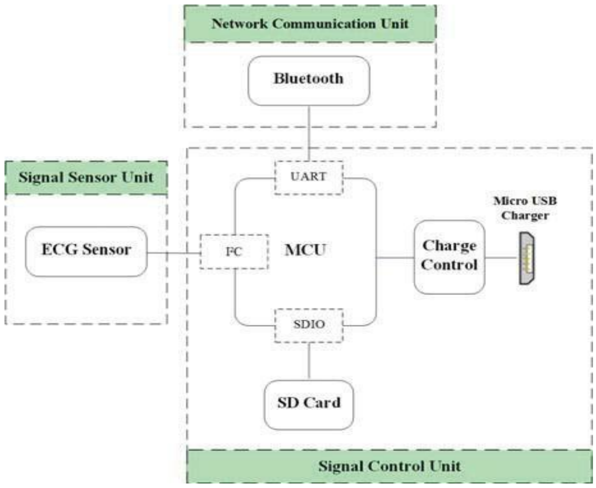

Fig. 4. The hardware architecture of the gateway

Header	Bluetooth Counter	ECG Lead I	ECG Lead II	ECG Lead III

Fig. 5. The packet format of the gateway.

A. Service server

The service server consists of an android app, a cloud database, and an analysis system. The android app receives the ECG data sent by the gateway, display real-time ECG waveform, and upload the data into cloud database. The analysis system analyzes ECG data using QRS detection algorithm [9]. The QRS detection procedures are introduced to analyze raw ECG data. First, a noise filter use 7 orders EMD (Empirical Mode Decomposition) to enhance the QRS complexes and suppress other parts of the ECG and noise. Second, uses a novel QRS morphology analysis algorithm called MWqrs to differentiate between QRS complexes and artifacts. The QRS detection procedures are shown in Fig. 6. After analyze the R-peak, we calculate the beats per minute (BPM) values by using RR interval. For example, if the heart rate is 60 BPM, there will be about 60 R-peaks in 1 minute. By using equation (1), we can calculate the accuracy.

$$\text{Accuracy} = \frac{\text{The number of distinguishable R peaks}}{\text{The total number of R peaks}}$$

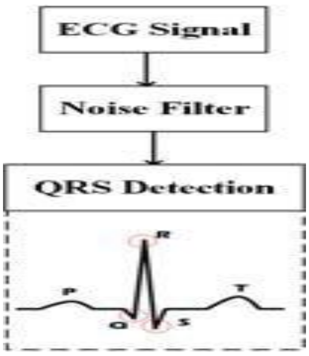

Fig. 6. The QRS detection procedures.

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III. EXPERIMENT

In order to evaluate the recognizing quality of ECG signal which is collected from the electrodes on the smart clothes and the ECG gateway, we recruit 35 participants (age > 65, 15 male and 20 female) to perform an experiment. All of the participants wear the smart clothes with ECG gateway to do the activity experiment and long-term wearing experiment. Fig. 7 demonstrates the actual experiment. All experiment procedures are shown as following.

Fig. 7. The actual experiment setup.

1) Let the participants put on the smart clothes.

2) Activity experiment: To find out the influences of specific activities for ECG signal, the participants were designated to do the following 6 activities [10, 11].

a) Stand and sit: Posture change from sitting on a chair to standing up and vice versa

b) Raise left hand: Up and down movement of left arm

c) Raise right hand: Up and down movement of right arm

d) Raise both hands: Up and down movement of both arm

e) Twist waist left-right-left: Twisting left-right-left body movement at the waist while standing for five times

f) Get up and go test: Participants take to rise from a chair, walk three meters, turn around, walk back to the chair, and sit down

3) Long-term wearing experiment: To compare the effects of water on signal quality, the experiment is divided into two phases. Each phase lasts five days. Participants are asked to wear the smart clothes with ECG gateway at least four hours per day. In Phase 1, we let participants do nothing but wear the smart clothes. In Phase 2, we rub some water one the four electrodes before participants put on the smart clothes.

4) Each 5 minutes ECG raw data is recorded as an independent file and be stored into the SD card.

5) We retrieve all data from SD card every morning.

6) Calculate the accuracy of each file by the R peaks.

IV. RESULT ANDDISCUSSION

We calculate the average accuracy of phase 1, the mean and deviation of average efficiency to be 82.57 and 10.28. Likewise, we estimate the average accuracy of period 2, the mean and variance of average accuracy to be 91.08 and 7.6. Through the experiment, we found that participants wearing fitting clothes have better average accuracy. It's because tight clothes can let the electrodes flat on the skin and reduce the ECG artifact. On the other hand, participants wearing loose clothes have worse average accuracy. It is because the electrodes of smart clothes are easy to separate from the surface of skin since the activity of participants. Then we compare the effects of water on signal quality between phase 1 (none) and phase 2 (with water). The experiment results show the average accuracy of phase 2 increase 8.51%. The average accuracy of phase 1 (none) and phase 2 (water) is shown in Fig. 8. We also discovered in phase 2, because of the use of the water, the signal we received will have less artifact and higher quality. The signal quality is shown in Fig. 9

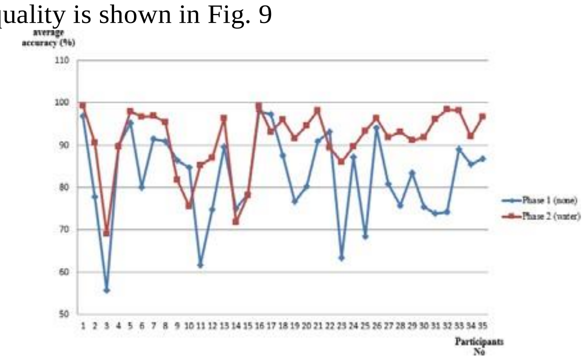

Fig. 8. Average accuracy of phase 1 (none) and phase 2 (water).

(a)

(b)

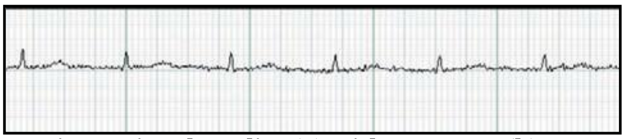

Fig. 9. Signal quality (a) without water (b)

with water.

The results of activity experiment show the influences of specific activities for ECG signal, the illustration are shown as following.

1) Stand and sit: ECG signal no significant change.

2) Raise left hand: When the participants raise their left side, electrode II (LA, left arm) and electrode III (LL, left leg) will include displacement (shift up), so Lead I, Lead II and Lead III signal will be affected. The ECG diagram is shown in Fig. 10.

3) Raise right hand: When the participants raise their right hand, electrode I (RA, right arm) and electrode IV (RL, right leg) will include displacement (shift up), so the Lead I and Lead II signal will be affected. The ECG diagram is shown in Fig. 11.

4) Raise both hands: When the participants raise their both sides, all the electrodes will displacement (shift up), so Lead I, Lead II and Lead III signal will be affected. The ECG diagram is shown in Fig. 12.

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5) Twist waist left-right-left: When the participants twist their waist left-right-left, the waveform of 3 Lead ECG signal will form "S."

The ECG diagram is shown in Fig. 13.

1) Get up and go test: ECG signal no significant change

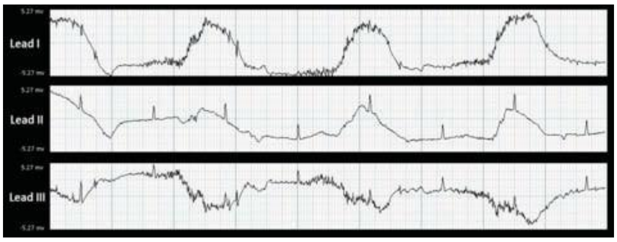

Fig. 10. The ECG diagram of activity "raise left hand".

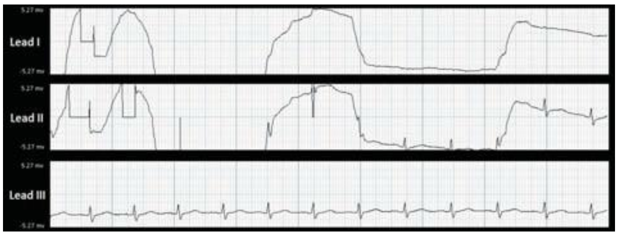

Fig. 11. The ECG diagram of activity "raise right hand".

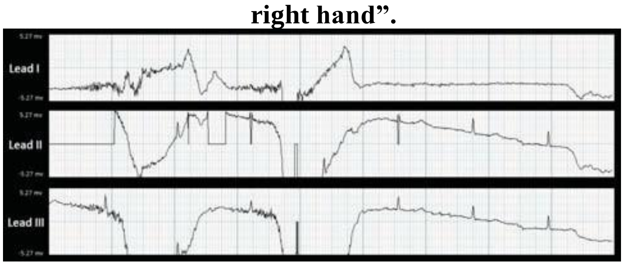

Fig. 12. The ECG diagram of activity "raise both hand".

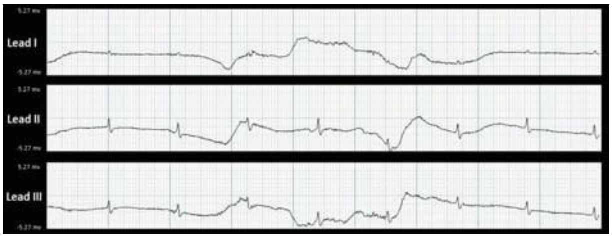

Fig. 13. The ECG diagram of activity "twist waist left-right-left".

According to the results of activity experiment, the movement of the upper extremities is the critical factor that will influence the ECG signal. For example, when the participants raise their right hand, Lead I and Lead II signal will be affected, but we still can receive the perfect signal of Lead III. If our smart clothes can collect only a single lead of ECG signal, in this situation, our service server can't analysis the ECG signal in this period of time. That's why we developed the smart clothes with 3 leads rather than a single point.

V. CONCLUSION

In this study, we develop a smart clothes system which can record 3 lead ECG to long-term monitoring elders' cardiovascular status. Most of the participants feel comfortable when wearing our bright clothes and consider it is easy to use than the traditional medical devices. The experiment results show that the average accuracy of 3 lead ECG data is more than 85%. The main factors that affect the performance of the ordinary skill is a movement of electrodes and the conductivity of the water. Through this study, use smart clothes for elder home care shows a certain degree of credibility.

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