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Belt-type Wireless and Non-contact Electrocardiogram Monitoring System Using Flexible Active Electrode

Kang Moo Lee[a], Seung Min Lee[a], Kwang Suk Park[b]

[a]*Interdisciplinary Program of Bioengineering, Seoul National University, Seoul, Republic of Korea*
[b]*Department of Biomedical Engineering, College of Medicine, Seoul National University, Seoul, Republic of Korea*

Correspondence: Kwang Suk Park, College of Medicine, Seoul National University, 110-799, 28, Yongon-dong, Jongno-gu, Seoul, Republic of Korea. E-mail: pks@bmsil.snu.ac.kr, phone +82 2 2072 3135

Abstract. Electrocardiogram (ECG) measurement using capacitively coupled electrode is a well-know method to get the ECG signal without direct skin-contact. In this paper, the belt-type system which measures ECG without direct skin-contact is designed and tested. The system consists of developed flexible active electrode (FAE), a driven-right-leg electrode and a module for signal processing and data acquisition. The FAE has the merit of enlarging contact area. It helps to increase signal-to-noise ratio (SNR) compared to rigid and flat electrode. The measured ECG data are transmitted to a laptop computer using a Bluetooth device. The feasibility of applying the developed system to ambulatory ECG monitoring was validated by measuring ECG data during a treadmill exercise at the speed of 5km/h and 7km/h. As a result, ECG obatained from the developed wearable belt-type system was stable if a person was in a state without excessive motion. Our system is wireless and capable of non-contact ECG measurement so that it is adequate for long-term ECG monitoring.

Keywords: non-contact ECG measurement, capacitively coupled electrode, flexible active electrode

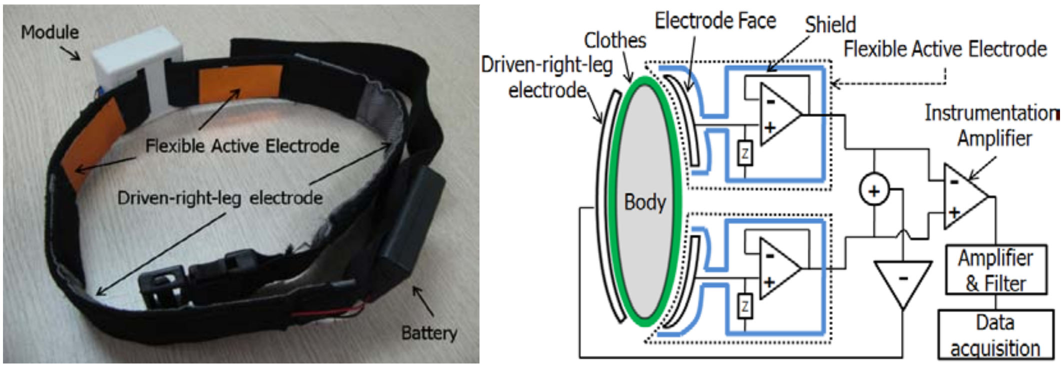
1. Introduction

Cardiovascular disease (CVD) is one of the main causes of mortality worldwide. Especially, CVD is the leading cause of death among people aged 60 years or older [World Health Organization, 2002]. Therefore, it is necessary to monitor cardiovascular functions continuously for early detection and treatment of cardiovascular anomalies, especially for high-risk patients. Electrocardiogram (ECG) is a useful signal for monitoring cardiovascular functions because it detects the condition of the cardiovascular system.

The conventional ECG electrodes such as Ag/AgCl electrodes employ conductive adhesive or electrolytic paste to ensure good contact to the subject. However, this makes a person feel uncomfortable and causes skin irritation. In addition, it is not durable and reusable. Therefore, such electrodes are inadequate for long-term ECG monitoring in daily life.

To overcome these problems, there have been previous studies on ECG recording without direct skin-contact using capacitively coupled electrode (CC-electrode) [Lim et al., 2006; Lim et al., 2007]. The non-contact ECG measurement using CC-electrode is based on capacitive coupling between the electrode and the skin. ECG can be measured over clothes as a result of capacitance of coupling and an ultra high input impedance of electrode [Lopez et al., 1969; Ueno et al., 2007]. In this study, developed flexible active electrodes (FAE) were used to measure ECG over clothes [Lee et al., 2010]. The FAE has the merit of enlarging contact area. It helps to increase signal-to-noise ratio (SNR) compared to rigid and flat electrode.

We proposed wireless and non-contact ECG measurement system using developed FAE. The entire system was embedded in a belt. The feasibility of applying the developed system to ambulatory ECG monitoring was validated by measuring ECG data during a treadmill exercise.



(a) (b)

Figure 1. *(a) Developed belt-type ECG monitoring system with flexible active electrodes and conductive sheet as driven-right-leg electrode. (b) A block diagarm of the system (z=5GΩ).*

2. Materials and Methods

2.1. Flexible Active Electrode

The FAE extends greatly the contact area between skin and electrode. It consists of a pre-amplifier, electrode face and shielding plate. The size of FAE is 18 cm^2 (6 cm x 3 cm) and thickness is 0.2 mm. Compared with commercial Ag/AgCl electrode, the impedance between skin and electrode increases according to cloth thickness or cloth type. Therefore, ultra high input impedance is required to obtain good signal quality over clothes. OPA124 (Texas Instrument) which has 100TΩ input resistance and 1 pF input capacitance is used for pre-amplification. Biasing resistance, the path for bias current, is 5GΩ.

2.2. Measurement System and Data Acquisition

Fig. 1 (a) shows the setup of electrodes and the module for data acquisition on the belt and Fig. 1 (b) shows the block diagram of the developed belt-type sensor unit. The system consists of two FAEs, instrumentation amplifier (INA114, Burr-Brown), filters, amplifier with a total gain of 100, microcontroller (ATmega128, Atmel) and Bluetooth module (Parani-ESD200, SENA) as shown in Fig. 2. To reduce the noise, two signals from FAEs were averaged and inverted by amplifier and then fed back to the body via conductive fabric sheet which was employed for driven-right-leg electrode to contact uniformly to the body over clothes. This method was similar to the driven-right-leg method [Winter et al., 1983]. The signal was digitized at the sampling rate of 450Hz with 16bit resolution by an A/D converter (AD974, Analog Devices) and was transmitted to laptop computer through Bluetooth protocol between sensor module and laptop computer.

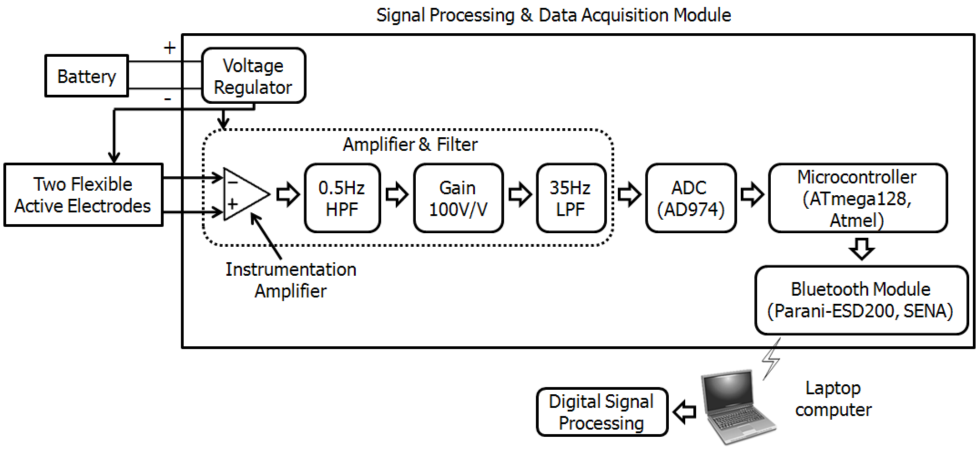


Figure 2. *A block diagram of a module for signal processing and data acquisition.*

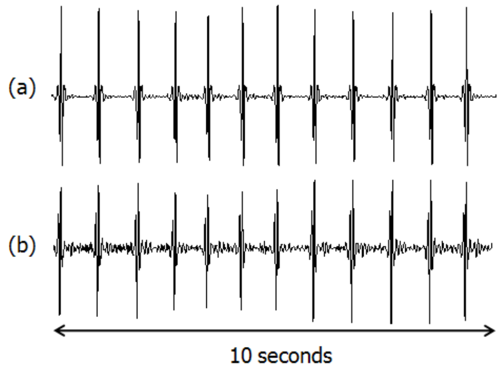


Figure 3. *Simultaneously measured ECG from (a) Ag/AgCl electrode, (b) flexible active electrode.*

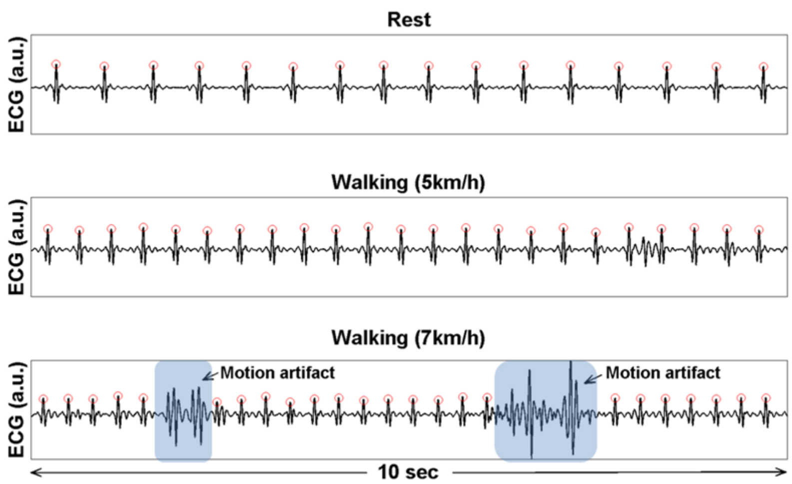


Figure 4. *Band-pass filtered ECG waveforms obtained by developed belt-type system at rest and during treadmill exercise.*

2.3. Digital Signal Processing and Feature Extraction

ECG was filtered by band-pass Butterworth filter with 10~30Hz cutoff frequency to detect QRS complex effectively. P waves and T waves were significantly attenuated after filtering ECG. We focused on detecting R-peaks because P and T waves were insignificant in most ECG recordings [Rangayyan, 2002]. Also, the electromyogram (EMG) affecting the ECG signal as physiological interference was reduced by filtering. R-peaks of ECG were detected by the Pan and Tompkins peak detection algorithm [Pan et al., 1985].

2.4. Evaluation of the system

ECG with Ag/AgCl electrodes for comparison

The FAE was used in our system. To validate its performance, indirect skin-contact ECG obtained by FAEs was measured simultaneously with the ECG with lead I position obtained by Ag/AgCl electrodes. ECG obtained from FAEs was compared with ECG obtained from Ag/AgCl electrodes. The signals were digitized at the sampling rate of 1000 Hz with 16bit resolution using Biopac system (MP-150) and was filtered by band-pass filter with 10~30Hz cutoff frequency. The signals were measured with a 23 year old healthy male subject wearing the belt on a normal cotton cloth of 620 um thickness.

ECG Measurement during treadmill exercise

To validate the feasibility of applying the developed system to ambulatory ECG monitoring, ECG was measured during a treadmill exercise by the subject wearing the developed device. Treadmill exercise was performed starting with 5 minutes of rest and 5 minutes of warm-up followed by incremental 5 minute stages, walking at the speed of 5km/h and walking at the speed of 7km/h.

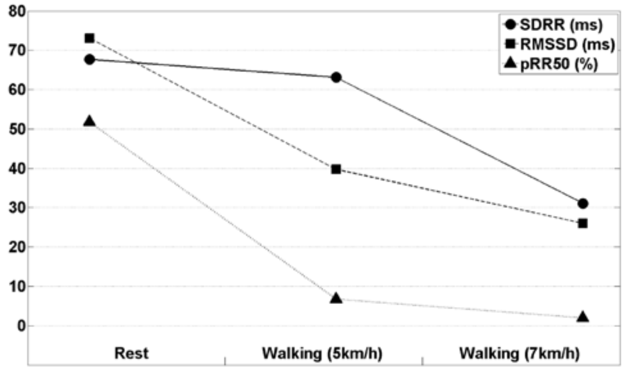


Figure 5. *Changes in time domain parameters of the HRV at rest and during treadmill exercise.*

Table 1. *Time domain parameters of the HRV at rest and during treadmill exercise*

Section	*Rest*	*Treadmill exercise (5km/h)*	*Treadmill exercise (7km/h)*
SDRR (ms)	67.67	63.12	31.09
RMSSD (ms)	73.10	39.71	26.04
pRR50 (%)	51.77	6.73	1.99

3. Results

Fig. 3 shows ECG recordings obtained by Ag/AgCl electrode and FAE. It shows that R-peaks of ECG waveform obtained by FAE are synchronized to those obtained by Ag/AgCl electrode. Thus, ECG measurement over clothes using FAE is a reliable method for detecting R-peaks. Fig. 4 illustrates band-pass filtered ECG recordings from 10 Hz to 30 Hz using the developed belt-type measurement system under the rest status and the treadmill exercise status. ECG signals measured at rest and during walking at the speed of 5km/h were relatively stable compared to ECG measured during walking at the speed of 7km/h. Since motion had a greater effect on ECG signal during walking at the speed of 7km/h, ECG was deteriorated and R-peak was undetectable at the duration of motion artifact.

4. Discussion

ECG from the developed system was successfully measured over a normal cotton cloth when the motion artifact was not occurring. Since we focused on detecting R-peaks, the other components of ECG waves were attenuated by filtering the signal. Although we could not distinguish P and T waves from the ECG waveform, R-peaks were well detected.

Using R-peaks, RR-intervals are calculated by time interval between adjacent R-peaks. The heart rate variability (HRV) parameters are derived from the RR-intervals and they reflect the state of the autonomic nervous system (ANS) as well as the state of the cardiac health [Acharya et al., 2006]. Based on ECG data obtained during the rest and the treadmill exercise, we computed the following HRV parameters in the time domain: the standard deviation of all RR-intervals (SDRR), the root-mean-square of successive differences of the RR-intervals (RMSSD) and the percentage of the successive RR-intervals differing higher than 50msec (pRR50). The duration which was difficult to detect correct R-peaks because of motion artifact was excluded. Table 1 and Fig. 5 show the gradual reduction in all values of the parameters from rest to walking at the speed of 7km/h. This means a shift of the autonomic balance towards a more sympathetic dominance [Bigger et al., 1989]. Since the developed device can obtain R-peaks of ECG waveform synchronized to those obtained by conventional Ag/AgCl electrodes, it could be used for deriving HRV parameters and monitoring of ANS activity.

The developed device using FAE has a problem in that it is sensitive to motion artifacts. ECG can be deteriorated by the motion artifacts when the person has large movements. To reduce the motion artifacts, the FAEs have to be fixated tightly on the chest by the belt. However, this makes a person wearing the device feel uncomfortable because of the fastening force of the belt. On further study, reducing the effect of motion is required to use this device in daily life. Also, we will do a long-term monitoring using the developed system.

5. Conclusions

To overcome the problems of conventional Ag/AgCl electrode, we have developed and evaluated the belt-type wireless and non-contact ECG monitoring system using FAE. ECG obtained by the developed device was synchronized with the simultaneously measured ECG obtained by Ag/AgCl electrodes. However, the system could be easily affected by motion artifacts due to movement between the body and the FAE. Therefore, the effect of motion should be minimized through further studies. If a person is in a state without excessive motion, developed system appears to be useful for long-term ECG monitoring.

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