Development of Capacitive Coupled Ambulatory ECG System to alleviate Motion Artifact

1st YoungHwan Kang
dept. Electronic Engineering
Hanbat National University
Daejeon, Korea
kangyh2@naver.com

2nd YeunHo Joung
dept. Electronic Engineering
Hanbat National University
Daejeon, Korea
yhjoung@hanbat.ac.kr

3rd JongTae Ihm
dept. Industry-University Convergence
Hanbat National University
Daejeon, Korea
jtihm@hanbat.ac.kr

***Abstract*—In this paper, we propose a long-term ambulatory ECG system that has capacitive coupled electrodes to alleviate the effect of motion artifacts. The electrode has extra ground electrode to remove the triboelectricity generating by friction between electrode and garment. A 270 nm SiO_2 layer was coated on the stainless electrode to achieve pure capacitive characteristics between the skin and the electrode. ECG signal and acceleration data were obtained with an Ag/AgCl electrode and a proposed electrode at running environment. Principal frequency components of the acceleration data were extracted by FFT (Fast Fourier Transform) and the components have inversely transformed to compare distortion of the ECG signals in motion. A much smaller ECG voltage variation in accelerating conditions was obtained with SiO_2 coated electrode.**

Keywords—ambulatory ECG, capacitive coupled electrode, silicon dioxide, motion artifact

I. Introduction

Worldwidely, the morbidity and mortality rate of cardiovascular diseases has been consistently increasing due to the advent of a super-aged society [1]. The heart-related diseases bring issues in silent triggering accidents, long hospitalization, super high health and medical cost of society, etc. Therefore, there is a need for a monitoring system for heart activity to prevent sudden health-related accidents. Nowadays, the most common and accurate way to monitor the heart is electrocardiography (ECG). There are several different types of ambulatory ECG such as Holter, event recorder, and external loop recorder [2]–[4]. Those systems are used in real life to detect irregular and specific cardiac conduction signals, but the systems have a vulnerable point in motion artifact (motion noise). Therefore, an implantable loop recorder is inserted underneath the skin to remove the noise. The motion artifact brings senseless signals and longer wearing time as long as 2weeks to 1 month to gather interpretable data. Convention ECG system has been used Ag/AgCl which has electrolytes between the skin-electrode interface [5]–[8]. The gel-type electrolyte has a function for electrical conduction on the interface, but the gel makes mechanical contact issues in motion conditions. Capacitive coupled method has been studied to overcome the direct electrical connection of the ECG system with Ag/AgCl electrode. Instead of the gel, the capacitive method has a dielectric material layer to store electrical polarization generated by charge accumulation on the skin produced by cardiac conduction activity. The dielectric material for ECG can be categorized as cotton, rigid insulator, ceramic, glass, etc. [9], [10]. Medical devices should be developed with considerations, such as reliability, biocompatibility, durability, convenience, etc. In this paper, we have chosen silicon dioxide as a dielectric layer due to its good biocompatibility, harden surface, high resistive characteristics, and easy spray coating fabrication method. By the dielectric material coating, our electrode has almost perfect capacitive characteristics with high resistivity over 200 MΩ. This true capacitive coupled ECG electrode has merits in electrical connection due to the principle of the capacitive method. Therefore, the ECG signals of the charge accumulation on the skin are much more stable than Ag/AgCl in motion status. Usually, the electrodes are placed under the garment. Then the electrodes could encounter triboelectricity by the cloth movement. Our system has an additional ground electrode to bypass the tribo-noise to the ground in motion.

In this paper, we add an accelerator to the proposed ECG system to quantize signal distortion in motion. And the system is connected with the Ag/AgCl and the proposed electrodes, separately. The ECG signal and acceleration data were simultaneously obtained by each electrode system and analyzed by FFT and inverse Fourier Transform.

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II. ECG Measurement System

A. Capacitive Coupled Electrode

We have spray-coated 270nm silicon dioxide layer on 30 μm stainless electrode for the dielectric material. The silicon dioxide layer has a relative permittivity of 4.0, a resistivity of 10^{16} Ω/cm, biocompatibility of grade 0, and a hardness of 9H. The electrode is operated by the capacitive principle. In real usage conditions, another capacitance is produced by triboelectricity between the electrode and cloth. Therefore, we add a ground layer between the electrode and cloth to make bypass the triboelectricity. The total thickness of the electrode is 250 μm. This thin and flexible electrode makes a good following of skin movement [11].

B. ECG Measurement Circuit

The ECG measurement system is operated by standard bipolar limb lead. The system has a buffer, DRL circuit, instrumentation amplifier, 1st order bandpass filter(0.67 ~ 150 Hz), 10bit ADC, Microcontroller Unit, accelerometer, and Bluetooth. The sampling rate of the accelerometer was 200 samples per second. In the ECG signal, 500 Hz sampling rate was designed to satisfy the Nyquist frequency which is at least twice as bigger as analyzing the signal frequency of 100 Hz which is the target frequency of the ECG signal.

C. Experimental Environment

Figure 1(a) describes an elastic garment for firming the electrodes and placements of each electrode of RA-RL and LA. The ECG signal and acceleration value were stored and displayed on a mobile terminal while 30-year-old male was running at 10 km/h on the treadmill as shown in figure 2(b). The measurement was performed with each electrode condition (Ag/AgCl and proposed electrode) in the same experiment environment.

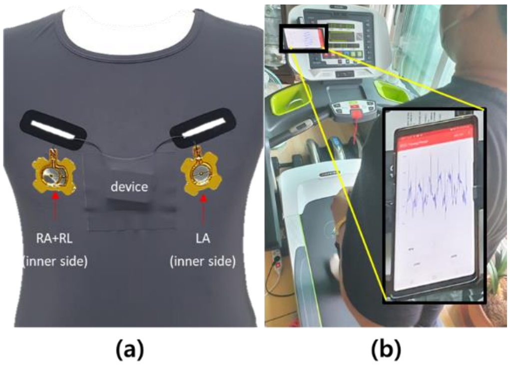

Fig. 1. Experimental environment. (a) electrode placement in elastic garment (b) app display at running.

III. Result And Discussion

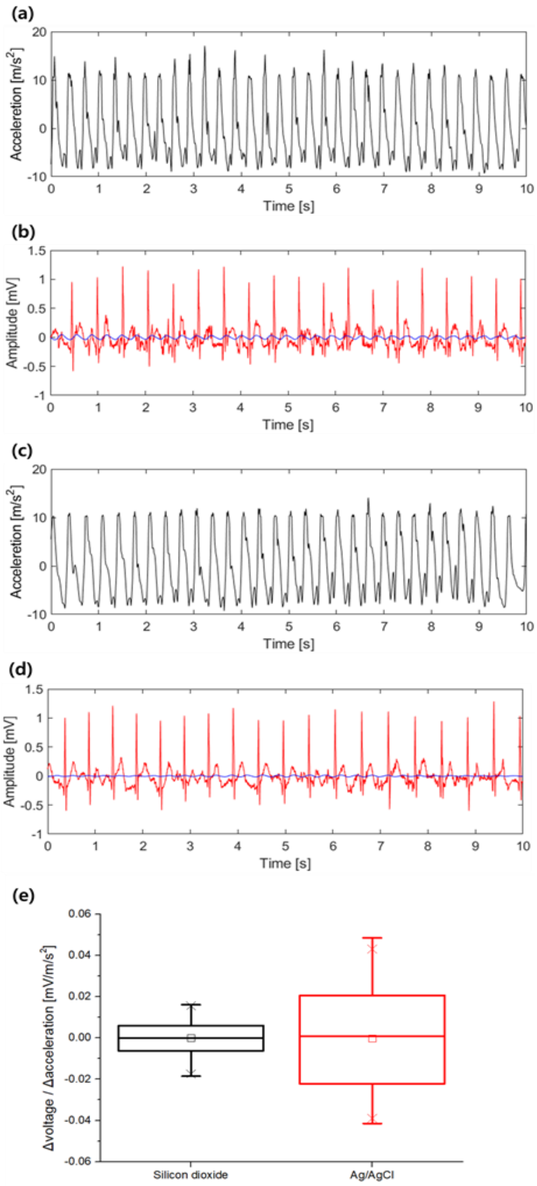

Fig. 2. Experimental result. (a) acceleration data and (b) ECG signals(red) and inverse transformed signal(blue) measured with Ag/AgCl electrode (c) acceleration data and(d) ECG signals(red) and inverse transformed signal(blue) measured with the capacitive coupled electrode (e) box plot of calculated result(voltage change/acceleration change)

Figure 2(a) and figure 2(c) describe variations of acceleration value with each electrode connected system (Ag/AgCl electrode and capacitive coupled electrode) during the running. The distortion of ECG signals was analyzed by the correlation between the acceleration values and the ECG signals. Frequency components of the acceleration were analyzed from the data by FFT. 0.5% principal frequency among the frequency components was extracted and then the inversely Fourier-transformed ECG signals were correlated with the acceleration value at the principal frequency. Figure 2(b) and figure 2(d) describe ECG signals of the Ag/AgCl electrode and capacitive coupled electrode with the red line. In the figures, the blue line indicates the ratio between the variation of ECG voltage and acceleration variation at the principal frequency. The average ratio in the whole movement was summarized in figure 2 (e). The result shows that the proposed capacitive coupled ECG system can measure more stable ECG signals than conventional ECG system with the Ag/AgCl electrode at a moving environment.

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