PORTABLE DEVICE TO MONITOR AUTONOMIC NERVOUS SYSTEM ACTIVITY THROUGH CLOTHES

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Abstract: Heart rate variability (HRV) reflects the autonomic nervous system (ANS) activity and HRV parameters are extracted from electrocardiogram (ECG) signal. However, the conventional ECG electrodes such as Ag/AgCl electrode make a person uncomfortable due to electrolytic paste or conductive adhesive used for ensuring good contact between electrode and skin. In this study, the portable device with capacitive electrodes was designed to monitor ANS activity through clothes. By using capacitive electrodes, ECG can be measured without direct skin-contact through capacitive coupling between the body and the electrodes. To evaluate the possibility that the ANS activity can be monitored using the capacitive electrode system, HRV parameters extracted from the capacitive electrodes were compared with HRV parameters extracted from Ag/AgCl electrodes. Results showed that there was no significant difference between the HRV parameters of two different electrodes.

1 INTRODUCTION

It has become clear that autonomic nervous system (ANS) activity is highly related with pathogenesis of diseases such as chronic heart failure, ventricular arrhythmias and sudden cardiac death (Packer M et al., 1996, PJ Podrid et al., 1990, HV Barron et al., 1996). Therefore, continuous and long-term ANS monitoring is important for early detection and treatment of these diseases. Heart rate variability (HRV) has been used to monitor the ANS activity because it reflects the interplay between the sympathetic and parasympathetic function of the ANS (U. Rajendra Acharya et al., 2006, Conny M. A. van Ravenswaaij-Arts et al., 1993). HRV is usually measured from electrocardiogram (ECG) recordings. However, ECG measurement using conventional ECG electrodes such as Ag/AgCl electrode is not adequate for long-term measurement because of the conductive adhesive or electrolytic paste. It makes a person feel uncomfortable and causes skin irritation. To overcome these problems, there have been previous studies on ECG recording without direct skin-contact using a capacitive method (Lim YG et al., 2006, Lee SM et al., 2010). ECG can be measured through clothes by the capacitive coupling between skin and electrode. Since the impedance between skin and electrode is increased according to the type and thickness of the clothes, high input impedance of the electrode is necessary. Thus, capacitive electrode has the preamplifier, which has ultra high input impedance.

In this study, a portable and simple device that permits measuring ECG using the capacitive electrodes is proposed. We evaluated the possibility that the ANS activity can be monitored using the developed portable device by comparing time domain parameters of the HRV obtained from the capacitive electrodes with the parameters obtained from conventional Ag/AgCl electrodes.

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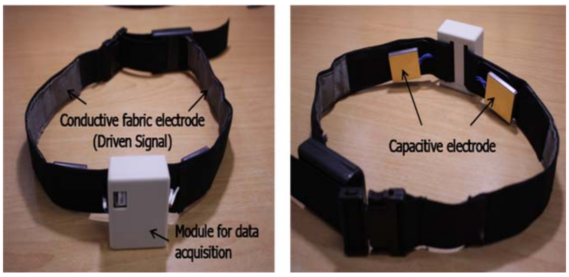

(a)

(b)

Figure 1: (a) Developed portable device with capacitive electrodes. (b) A person wearing the developed portable device.

2 MATERIALS AND METHODS

2.1 Capacitive Electrode

It consists of a pre-amplifier which has ultra high input impedance, electrode face and plate for shielding circuit. The ultra high input impedance is required to obtain good signal quality because of the impedance between skin and electrode. OPA124 (Texas Instrument Inc.) is used for pre-amplifier. Also, there is a biasing resistance, 5GΩ, for the path of bias current. The size of electrode is 12 cm^2 (4 cm x 3 cm) and thickness is about 1 cm.

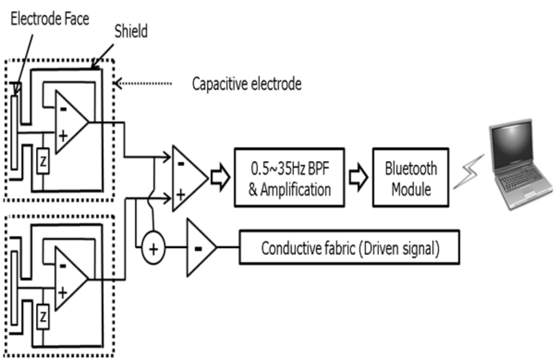

Figure 2: A block diagram of a module for data acquisition.

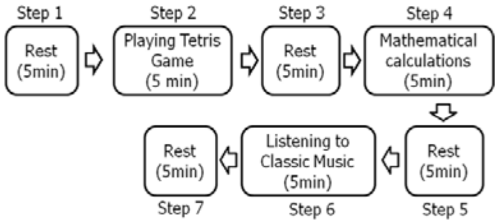

Figure 3: Experiment protocol to induce the change of autonomic nervous system.

2.2 Measurement System

Figure 1 (a) shows the developed portable device. It consists of two capacitive electrodes, conductive fabric electrodes, and a module for signal processing and acquisition. The device is fixated on the wearer's chest as shown in Figure 1 (b). Figure 2 shows a block diagram of the module. ECG was filtered by band-pass filter with 0.5-35 Hz cutoff frequency to remove a respiration and external noise. The driven signal, which was generated by negative amplification of averaged signal from two capacitive electrodes, fed back to the body via conductive fabric electrode to improve signal to noise ratio (SNR). The signal was digitized at the sampling rate of 450 Hz and was transmitted to a computer using Bluetooth module (Parani-ESD200, SENA).

2.3 Experiment

A 25-year-old healthy male subject wearing the developed belt on a normal cotton cloth of 680 um thickness performed the experiment under the seven steps: 1) rest, 2) playing Tetris game, 3) rest, 4) mathematical calculations, 5) rest, 6) listening to classic music, 7) rest as shown in Figure 3. ECG using the capacitive electrode system was measured simultaneously with ECG using Ag/AgCl electrodes for 5 minutes in each state. The Pan and Tompkins peak detection algorithm was used to detect R-peaks of ECG (Pan J and Tompkins WJ, 1985), which were used to calculate RR-intervals. We extracted the following time domain parameters of HRV to validate the device: the standard deviation of 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).

Table 1: Time domain parameters of HRV.

Parameters	Electrode type	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Averaged RR-interval (ms)	Capacitive	768.07	753.97	751.75	733.16	771.94	826.37	733.62
	Ag/Agcl	768.07	753.97	751.75	733.16	771.93	826.37	733.63
SDRR (ms)	Capacitive	57.07	41.91	47.48	49.35	69.17	71.29	58.49
	Ag/Agcl	57.08	41.73	47.64	49.36	69.07	71.69	58.61
RMSSD (ms)	Capacitive	65.23	56.18	54.39	63.96	86.5	84.59	68.65
	Ag/Agcl	65.15	55.75	54.71	63.99	86.24	85.31	68.81
pRR50 (%)	Capacitive	50.9	44.08	37.19	52.33	60.39	60.77	55.04
	Ag/Agcl	51.67	43.83	38.44	52.83	60.11	60.22	55.28
Heart rate (beats/min)	Capacitive	78.12	79.58	79.81	81.84	77.73	72.61	81.79
	Ag/Agcl	78.12	79.58	79.81	81.84	77.73	72.61	81.79

SDRR, standard deviation of RR-intervals; RMSSD, root-mean-square of successive differences of RR-intervals; pRR50, percentage of the successive RR-intervals differing higher than 50msec

3 RESULTS AND DISCUSSION

Figure 4 illustrates the simultaneous ECG recordings from Ag/AgCl electrodes and capacitive electrodes. It shows that R-peaks of ECG waveform from the developed device using the capacitive electrodes are synchronized to the waveform obtained through the Ag/AgCl electrodes. Therefore, the ECG obtained by our device without direct skin-contact is a reliable waveform for detecting R-peaks and deriving RR-intervals.

The time domain parameters of HRV obtained from the developed device with capacitive electrode had no significant difference with the HRV time parameters obtained from the Ag/AgCl electrode as shown in Table 1. Thus, our portable device can be used to monitor ANS activity through clothes. Figure 5 shows the changes in HRV parameters at each step. The RMSSD and pRR50 were high when the subject was listening to classic music. This means a shift of the autonomic balance towards a more parasympathetic dominance. Since our system can monitor ANS activity without any conductive adhesive or electrolytic paste, it could be used for long-term ANS monitoring.

There are several problems that we have to solve on further study. Firstly, ECG can be deteriorated by the motion artifacts when the person has large movements. It is required to reduce the effect of motion to use this portable device in daily life. Secondly, the capacitive electrodes have to be fixated tightly on the chest by the belt. Thus, the person wearing the device can feel uncomfortable because of the effect of fastening force of the belt.

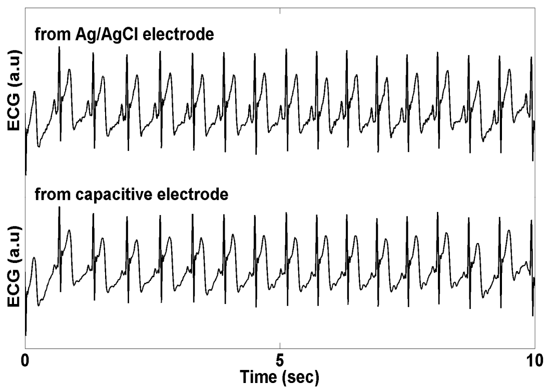

Figure 4: Simultaneous ECG recordings from Ag/AgCl electrodes and capacitive electrodes.

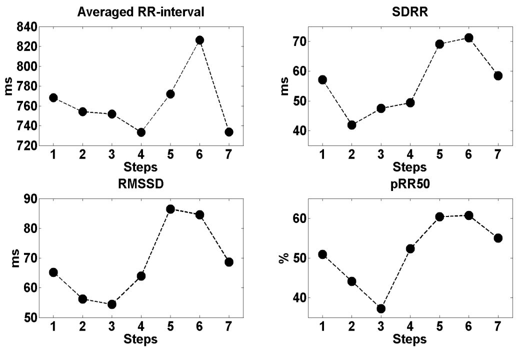

Figure 5: Changes in time domain parameters of HRV at each step.

Thirdly, the signal quality from the device can be changed by the thickness of the inserted cloth. Figure 6 shows the ECG recordings obtained through our device from the subject wearing a cotton cloth with different thicknesses of 680 (a), 1370 (b), 2750 (c), and 5560 (d) um. The common mode noise was increased according to the increase of the thickness of the cloth. It could be difficult to detect correct R-peaks from ECG recordings with a cloth thickness of 5560 um. Thus, HRV parameters for ANS monitoring could be derived wrongly. Our developed portable device can be more practical by solving these problems.

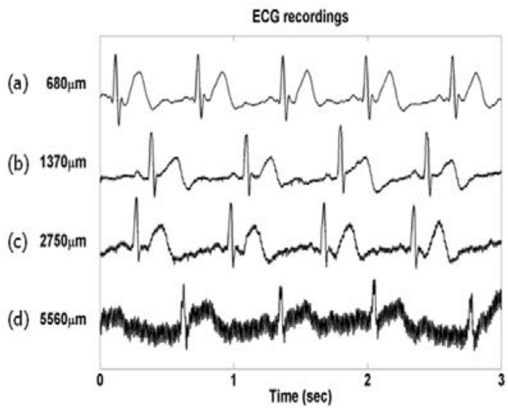

Figure 6: ECG waveforms from the subject wearing a cotton cloth with different cloth thicknesses.

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