CHARACTERISTIC ANALYSIS OF ELECTRIC TEXTILE SENSOR USING HEART RATE VARIABILITY

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Abstract: In this paper, we verify the conduction significance by using analytic aspect of heart rate variability. In lying and standing condition, between Ag/AgCl electrode and electric textile sensor, heart rate variability yields very similar results. However, in rapid moving conditions, we faced tremendous noise in observed electrocardiogram such as baseline wander (drift), power line interference, and electrode contact noise. Despite these results, we find the possibility of electric fabric as a kind of sensor in wearable conditions.

Introduction

Electric fabrics and electric textiles are also researched as a basic structure of wearable sensor by various methods and experiments [1-3]. Moreover, a lot of studies about the acquisition of electrocardiogram (ECG) and other bio-information from wearable sensors are already in progress[4]. Advent of the '*textrodes*', a new means of electric textile sensor unit, shows that a new type of sensor technology is emerging[5]. In spite of these developments, characteristics or significance about electric textile sensors are not defined enough to be applied. In dry-normal condition, significance of the electric textile electrode has already been verified from a heart rate variability(HRV) viewpoint [6]. However, for practical use, significance verification is a very essential premise in dynamic conditions such as walking and running. In this paper, we define the characteristics of textile sensor and find the significance between Ag/AgCl electrode and electric textile sensor not only in static condition but also in dynamic conditions.

Materials and Methods

We measured ECG with a textile sensor whose size is 4 x 4 cm using dual channel BIOPAC MP150 systems. Textile sensor is used for bio-electrical measurement, and MP150 is used for acquisition of ECG signals (Lead II). Channel 1 and Channel 2 were nearly positioned to reduce the error caused by different positioning. For more convenience, we used an elastic band to contact electric fabric to the skin. Tension of the elastic band is controlled so that the examinees do not feel any inconvenience such as breathing with difficulty and feeling heavy in the chest. Figure 1 shows the elastic band-electric textile sensor implementation model and figure 2 shows the illustration of experimental concept. In figure, 3 we can observe the practical implementation of elastic band-electronic fabric sensor. For the inspection of significance, Ag/AgCl electrode is used as a comparative case, and we adapt heart rate variability. In this experiment, we measure the ECG from a healthy male person in lying, standing, walking and running conditions. For dynamic movement testing, we use treadmill to maintain fixed speed and condition during experiment (walking 4 km/h, running 8 km/h).

Furthermore, in this experiment, the measured or calculated parameters are RR interval, HR per minute, LF, HF, and LF/HF using non-parametric or parametric analysis. We calculate mean and standard deviation in RR interval and HR case, and power from power spectral density in LF, HF case. Power of each frequency band is the result from assuming that LF band is 0.04 ~ 0.15 Hz and HF band is 0.15~0.35 Hz[7-9].

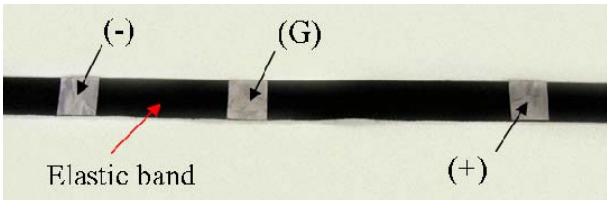

Figure 1: Elastic band and electric textile electrode. (+) electrode is located on left chest and (-) electrode is located on right chest. (G) is located on back.

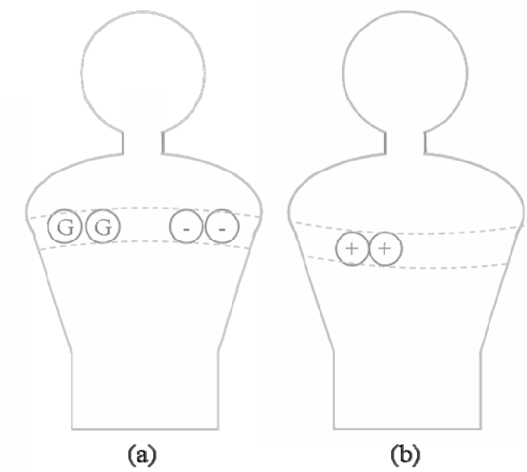

Figure 2: Location of dual-channel electrodes (LEAD II). Dashed line represents elastic band. Each set of electrode include (+), (-), and G. One set is Ag/AgCl electrode and the other is electric textile sensor electrode. (a) Anterior view. (b) Posterior view.

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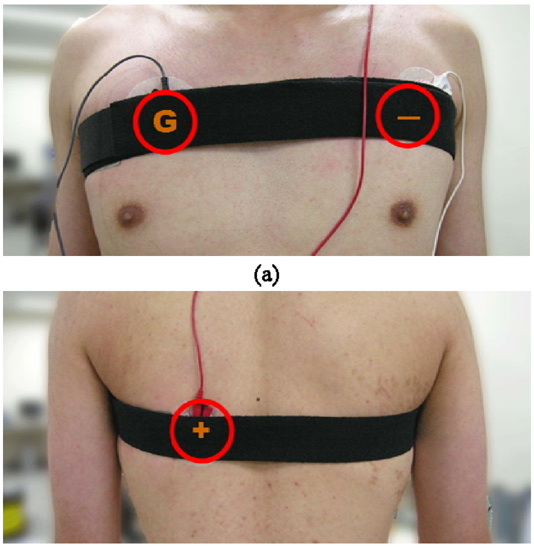


(a)

(b)

Figure 3: Implementation of dual-channel electrodes (LEAD II). Electric fabric is located under the elastic band(near the Ag/AgCl electrode). (a) Anterior view. (b) Posterior view.

Because we only use short-term ECG signals, VLF parameters whose frequency bands are 0~0.04 Hz were ignored.

To obtain RR interval we use various filters and spatial-velocity algorithm[10]. For example, we use band pass filter (BPF), cascaded integrator comb (CIC) filter, moving average integrator, and low pass filter (LPF) to obtain a purified ECG signal. BPF, LPF reduce high frequency and low frequency noise, and moving average integrator smoothes out the signal. Especially, CIC filter has R-wave enhancement characteristic[11]. Simple processing method is represented in figure 4.

BPF has the 5~20 Hz pass band and CIC filter has 10.74~24.36 Hz pass band. Because R-wave is included in these frequency bands, these filters reduce the noise whose frequency range does not match the filter's frequency band. Table 1 shows experimental parameters. In this experiment, we control external environment and both channels to maintain similarity.

Table 1: Experimental parameters

ECG measurement	Value
Temperature	25 °C
Humidity	25 %
Total time	600 seconds
Sampling frequency	1000 Hz
Sampling resolution	16 bits
Cut-off frequency (LPF)	150 Hz
Cut-off frequency (HPF)	0.005 Hz
HRV analysis	Value
Band pass filter	Passband 5~20 Hz
CIC filter	Passband 10.74 ~ 24.36 Hz
Moving average integrator	50-point
Low Pass Filter	Pass band 0~20 Hz
Re-sampling	4 Hz
AR model order	30th order

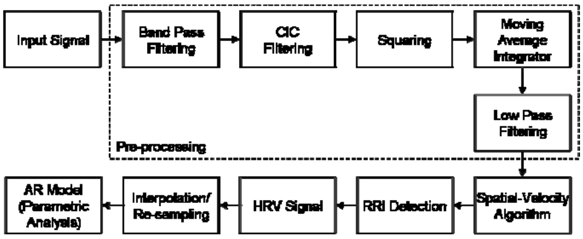
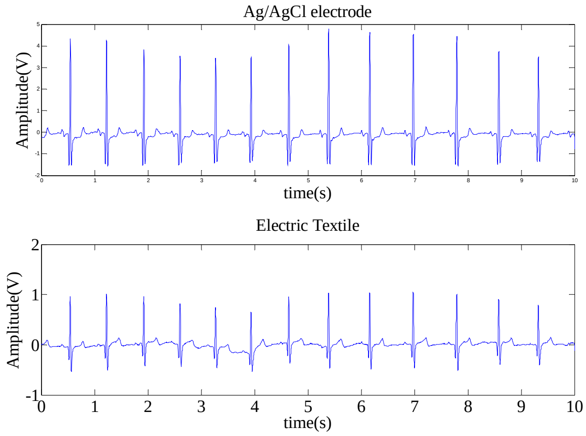


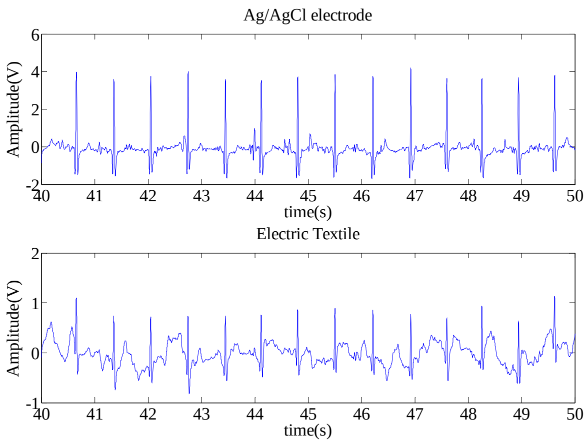
Figure 4: Signal procseeing block diagram. Bandpass filter has 5~20 Hz passband and CIC filter has R-wave enhancement characteristic. Moreover, 50-point moving average integrator and 0~20 Hz low pass filter is used to reduce high frequency noise component.

Results

From the experiment, we obtained dual channel ECG and HRV signal of each conditions. In figure 5, we find the signal distortion by changing movement and conditions. By intuition, we know that the signal distortion is increased by increasing human motion and activity. The Upper graph in (a) indicates channel 1, ECG from Ag/AgCl electrode, and the lower graph indictes the ECG from electric fabric sensor.



(a) In lying condition



(b) In standing condition

Figure 5: Comparison of waveform from Ag/AgCl electrode and electric fabric electrode.

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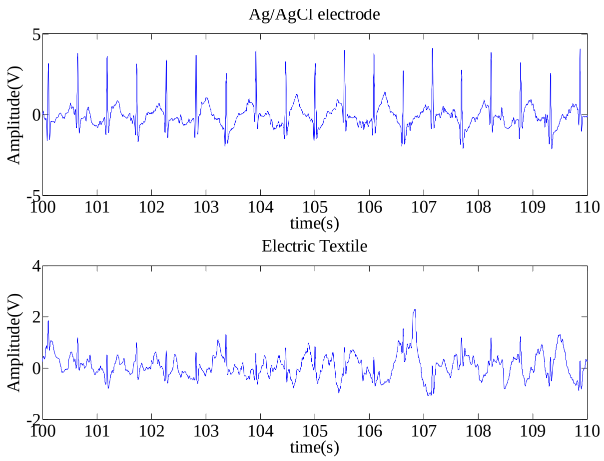
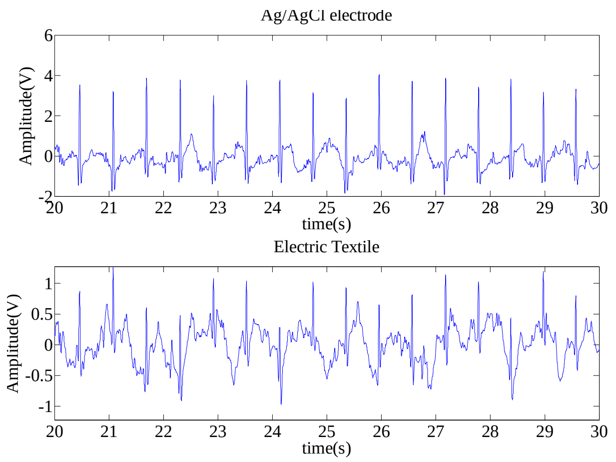


(c) In walking condition



(d) In running condition

Figure 5: Comparison of waveform from Ag/AgCl electrode and electric fabric electrode. *(Continued)*

In the case of electric fabric, we find baseline noise and reduced signal amplitude. These distortions are generally ignored because it has no significant effect on the analysis of HRV.

Table 2 shows the experimental results with 4 cm by 4 cm electric textile in various conditions. Comparing both of the results, from Ag/AgCl electrode and electric fabric, we could find very high similarities on LF and HF viewpoint in static condition such as lying and standing. It appears that the maximum error is 2.5 %, which means, simillarity is more than 97.5 percent in this case.

In spite of these simillarities, there are tremendous noise in moving condition. In moving conditions, LF/HF ratio has a maximum of 46 % error compared with results of Ag/AgCl electrode.

Discussion

In these results, we can find the difference between Ag/AgCl electrode and electric fabric as a sensor. An important fact is time-inconstancy characteristic of the electric fabric. From Table 2, compared with total beat error rate, LF component and HF component error rate showed great sensitivity. However, we have to consider both static and dynamic conditions of the results. Though we cannot be sure of the significance on HRV viewpoint in dynamic condition (walking/running), in static condition (lying/standing) we can find high significance in results between different kinds of electrode. Therefore, we can assume that the noise have an effect on ECG signal in moving condition, strong enough to change the signal amplitude-axis and time-axis. From the statistics, we find that the time-axis change is not an important factor in roughly calculating ECG. However, in analyzing HRV, tiny variation on time-axis can cause tremendous error rate on frequency-axis.

Conclusion

HRV analysis using electric fabric as a kind of electrode has the significance in static condition. However, electric fabric has some problems that need to be solve to we used practically. We think that there are three representative problems such as moving artifact related to skin-contact problem, significance in any other conditions, and durability. As we know from this experiment, in practical conditions such as slow and

Table 2: Beat detection and parametric analysis of heart rate variability

Category		Beat detection					Parametric Analysis(AR model)						Statistics	
Condition/ Electrode		Beat	FP	FN	Failed Detection	%	LF	Err (%)	HF	Err (%)	LF/ HF	Err (%)	Mean RR (s)	Mean HR (s)
Lying	Ag/AgCl	456	0	0	0	0	0.0341	-	0.0088	-	3.8627	-	0.653 ± 0.025	92.05 ± 3.51
	e-fabric	456	0	0	0	0	0.0347	2%	0.0088	0 %	3.9220	1.5 %	0.653 ± 0.025	92.05 ± 3.53
Standing	Ag/AgCl	458	0	0	0	0	0.0120	-	0.0100	-	1.2037	-	0.650 ± 0.028	92.50 ± 3.95
	e-fabric	458	1	0	1	0.22	0.0123	2.5%	0.0099	1 %	1.2322	2.4 %	0.651 ± 0.031	92.31 ± 4.35
Walking	Ag/AgCl	517	0	0	0	0	0.0061	-	0.0031	-	1.9567	-	0.579 ± 0.019	103.69 ± 3.40
	e-fabric	517	5	1	6	1.16	0.0050	18 %	0.0041	32 %	1.2238	37 %	0.580 ± 0.026	103.59 ± 4.60
Running	Ag/AgCl	706	0	1	1	0.14	0.0164	-	0.0141	-	1.1631	-	0.425 ± 0.038	140.88 ± 6.34
	e-fabric	706	9	18	27	3.82	0.0084	49 %	0.0133	6 %	0.6316	46 %	0.421 ± 0.080	142.36 ± 3.92

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fabbric sensor abrupt movement, moving artifact and electrode contact problem work as a major interference in the analysis of ECG signals. Therefore, to use electric fabric sensor in wearable conditions, especially on HRV analysis, the development of robust electrode-skin contact method and optimal signal processing algorithm must be considered as a precedence work.

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