Heart Rate Variability Analysis for Significance Between Ag/AgCl Electrode and Electric Textile Sensor in Wearable Condition

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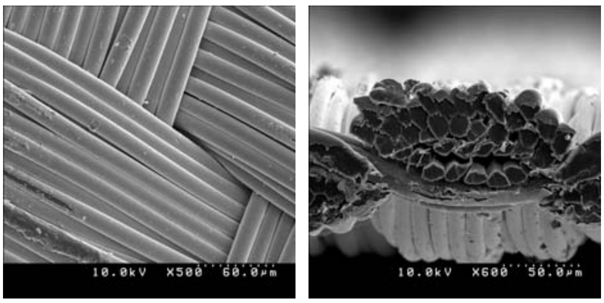
Abstract: Significance verification of electric fabric compared with existing electrode is very useful for the wearable and ubiquitous healthcare. In this paper, we verified the significance between Ag/AgCl electrode and electric fabric in dry-normal condition through heart rate variability analysis. We can find 98 % or more similarity about low frequency and high frequency which is important parameter for the heart rate variability analysis between two different electrodes in experiment. From this result, we confirmed that the power spectral density of low frequency, high frequency component from the electric fabric has high similarity compared with the result of heart rate variability from Ag/AgCl electrode in dry-normal condition.

Keywords: Heart Rate Variability, Automatic Nervous System, Textile Sensor, Fabric Electrode, Wearable Computing

1. INTRODUCTION

Healthcare range is widened from hospital to home and everywhere in recent. With this trend, new concept of medical equipment is needed for ubiquitous healthcare such as biomedical signal acquisition, analysis and communication devices [1]. From this point of view, electric fabric is attracted as a new type bio-electrode for ubiquitous healthcare. Moreover, research about electrocardiogram (ECG) measurement using electric fabric already makes steady progress in different methods and fields [2-4]. Although ECG measurement technique using electric fabric is developed, it is not verified about the significance of electric fabric compared with Ag/AgCl electrode and other usefulness up to the present.



(a) (b)

Fig. 1 Pictures of electric fabric are obtained by scanning electron microscope. (a) fabric front section (600 magnification), (b) fabric cross section (500 magnification).

Heart rate variability (HRV) is a useful factor for the analysis of human autonomous nervous system [5,6]. A research of periodic changing of the circulatory system started at nineteenth century, and it developed rapidly during latest 15 years [7]. From this studies, it is defined whether the sympathetic and parasympathetic nerve system works correct, and HRV became one of the significant factor to diagnose cardiovascular problem and human autonomous nervous system [5]. Therefore, electric fabric could be effectively used for ubiquitous healthcare if significance of HRV between electric fabric and Ag/AgCl are verified. In this paper, we define the significance of the electric fabric using HRV analysis in dry-normal condition as a fundamental study of significance verification.

2. ELECTRIC FABRIC

We use electric fabric as an electrode, and this fabric has each thread with conducted coating. Fig. 1 shows the structure of electric fabric, it scanned with scanning electron microscope (SEM) at the front section with 600 magnifications (a) and at the cross section with 500 magnifications (b).

Electric fabric has non-linear characteristic because the variable impedance characteristic and acquisition parameter variation are shown by changing the fabric contact surface sizes on skin. Therefore, this characteristic causes the difference from Ag/AgCl electrode. It is very important how to contact the electric fabric on skin as close as possible and to choose what kind of fabric whose characteristic is properness to use. For a solution of these problems, researchers progress the study about electric fabric, and even they use the term such as ‘textrodes’ or ‘e-fabric’ to represent new type of electrode [8].

In this paper, we use the fabric whose characteristic is interception of the electromagnetic interference (EMI). Its impedance characteristic is as follows.

From Fig. 2, electric fabric has the advantage in acquiring bio-signals, it has the disadvantage in reducing the noise because it has very low impedance compared with Ag/AgCl electrode (more than 20 kΩ, dry-normal condition) [9].

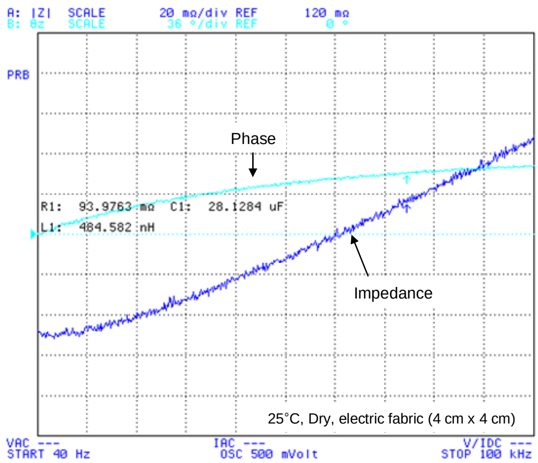


Fig. 2 Impedance characteristic of the electric fabric (4 cm x 4 cm)

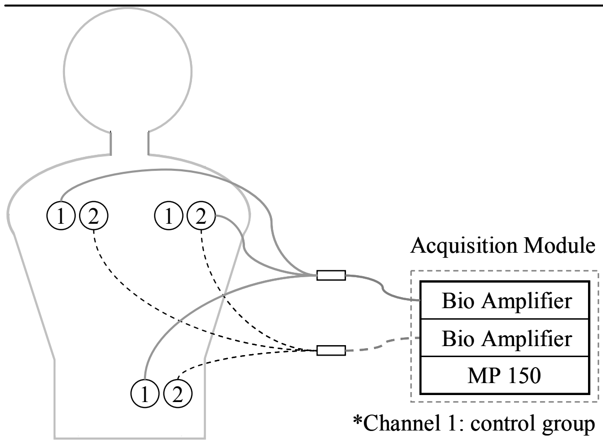


Fig. 3 Dual-channel ECG acquisition method using BIOPAC System, inc. MP 150

3. HEART RATE VARIABILITY

HRV is the common method to analysis human autonomous nervous system. HRV spectrum analysis start from fourier series, but it is actually adapted as a form of fast fourier transform (FFT) and auto-regressive (AR) model. For example, power spectrum density is generally used for spectrum analysis, and we can use this spectrum to analysis bio-mechanism according to each own frequency band [10,11].

There are three important frequency bands in HRV analysis. First, frequency band between 0.04 ~ 0.15 Hz, called ‘mayer wave’, is defined low frequency (LF). LF component is related to control of blood pressure. Second, frequency band between 0.15 ~ 0.45 Hz is defined high frequency (HF), related to respiration control. Third, frequency band between 0 ~ 0.04 Hz is defined very low frequency (VLF), related to control of body temperature, vessel movement, and other cardiopulmonary mechanism [5,12,13].

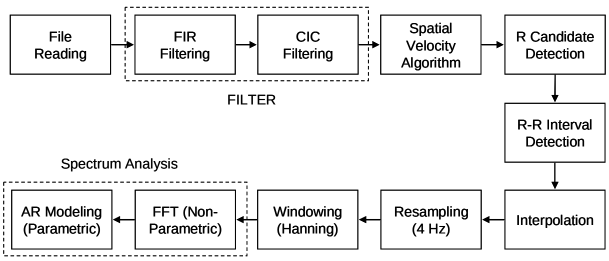


Fig. 4 Process for the HRV analysis (includes spectrum analysis)

4. EXPERIMENTAL METHODS

Experimental methods classify them into two large sections, ECG measurement using electric fabric and HRV analysis. With this experiment, we verify the significance of electric fabric as a kind of electrodes in dry-normal condition.

4.1 ECG measurement

For simultaneous measurement, we used the dual channel ECG acquisition technique (LEAD II). Each electrode was attached on nearby points, and as shown in Fig. 1, we used two BIOPAC Systems, inc. MP 150 modules for ECG acquisition. Channel 1 records ECG as a reference, and channel 2 records ECG as an experimental group from Ag/AgCl and electric fabric. Experiment was performed by comparing the result between Ag/AgCl electrode and electric fabric for comparison with existing method. Moreover, considering more broad range application, we used 2 cm x 2 cm, 4 cm x 4 cm, and 6 cm x 6 cm size electric fabric in experiment. Each experiment performed with time interval, and it has no relationship between experiments. For more exact result, we control the respiration rate 15 Hz (1 respiration / 4 sec), room temperature 25 °C, and humidity 25 % for maintenance of dry-condition and HRV spectrum. We measured an ECG from normal adult (25-years, male) during 10 minute with sampling frequency 1 kHz and sampling resolution 16 bits. General information about this experiment is represented in Table 1.

4.2 Heart Rate Variability analysis

For HRV analysis, we process each stage as shown in Fig. 5. Especially, for noise reduction and R-peak enhancement, we use double stage filter. First FIR low pass filter for 60 Hz noise reduction, and second is cascaded integrator comb (CIC) filter for R-enhancement [14]. In this case, FIR filter has 27.5 Hz cut-off frequency as a low pass filter and CIC filter has 10.74 ~ 24.36 Hz passband as a bandpass filter.

After filtering, we obtained RR intervals by using spatial velocity algorithm and thresholding. Spatial velocity algorithm makes it possible to find the RR candidate by calculating the acceleration at the R point. In this case, we set 10 ms as a time delay for the spatial velocity algorithm. Moreover, for prevention of candidate detection at low-amplitude level, we use the amplitude thresholding method additionally. Final HRV spectrum could be obtained after interpolation, re-sampling and windowing. Not re-sampled HRV signal could not proper the spectrum analysis because it has different time-interval. Therefore, interpolation and re-sampling is the necessary process for spectrum analysis.

In this paper, we use cubic-spline interpolation, because it has relatively less distortion for original signal compared with other interpolation methods, and we set 4 Hz as a re-sampling frequency [15]. Furthermore, we used AR model whose order is 30th and 1024-points FFT as a reference for spectrum analysis. Conditions and parameters about HRV analysis are represented in Table 1.

Table 1 Experimental conditions and 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
Respiration control	15 Hz
HRV analysis	**Value**
CIC filter	Passband 10.74 ~ 24.36 Hz
FIR filter (50th order)	fc = 27.5 Hz, LPF
Re-sampling	4 Hz
AR model order	30th order
FFT	1024 point

Table 2 Comparison of results from different electrodes for significance verification

Category		Non-parametric (FFT)						Parametric (AR model)						Statistics	
electrode		LF (ms2)	(%)	HF (ms2)	(%)	LF / HF (ms2)	(%)	LF (ms2)	(%)	HF (ms2)	(%)	LF / HF (ms2)	(%)	Mean RR (s)	Mean HR (s)
Ref.	AgCl	444	-	234	-	1.8986	-	333	-	205	-	1.6215	-	0.860 ± 0.031	69.87 ± 2.61
	AgCl	443	99.7	235	100.4	1.8818	99.1	333	100	206	100.5	1.6174	99.9	0.860 ± 0.031	69.87 ± 2.61
Test 1	AgCl	415	-	376	-	1.1046	-	465	-	379	-	1.2274	-	0.870 ± 0.035	69.19 ± 3.38
	e-fabric (2 x 2)	416	100.3	378	100.5	1.0992	99.5	466	100	380	99.7	1.2270	100.2	0.870 ± 0.035	69.19 ± 3.38
Test 2	AgCl	114.4	-	81.4	-	1.4053	-	238.9	-	51.2	-	4.6691	-	0.915 ± 0.054	66.12 ± 5.84
	e-fabric (4 x 4)	114.3	99.9	81.3	100.1	1.4071	100.1	238.4	99.9	51.2	100	4.6592	99.9	0.915 ± 0.054	66.12 ± 5.84
Test 3	AgCl	109.3	-	98.0	-	1.1151	-	73.2	-	55.4	-	1.3287	-	0.994 ± 0.049	60.60 ± 3.80
	e-fabric (6 x 6)	107.4	98.3	98.6	97.9	1.0889	97.7	73.2	100	54.9	99.6	1.3340	100.3	0.994 ± 0.050	60.65 ± 3.92

V. RESULT

We calculate LF, HF, and LF/HF values as a comparison reference from each experimental in dry-normal condition. Moreover, we calculate RR and heart rate (HR) with analysis result. Fig. 5 and Fig. 6 show the spectrum with AR model. Fig. 5 represent when both channel use Ag/AgCl electrode, and Fig. 6 represent when channel 1 is Ag/AgCl, and channel 2 is electric fabric. We can find the similarity or difference from the result of spectrum analysis. Graphically, we consider that the result of both channels have high similarity by intuition in this experiment. As we mentioned before, each experimental performed under dependent condition from other experiments, therefore the result has different characteristic in spite of a same experimental object.

Measured or calculated parameters in this experiment are RR interval, HR per minute, LF, HF, and LF/HF from 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.

Total experimental result is shown in Table 2. From these results, we consider that both the result, from Ag/AgCl l

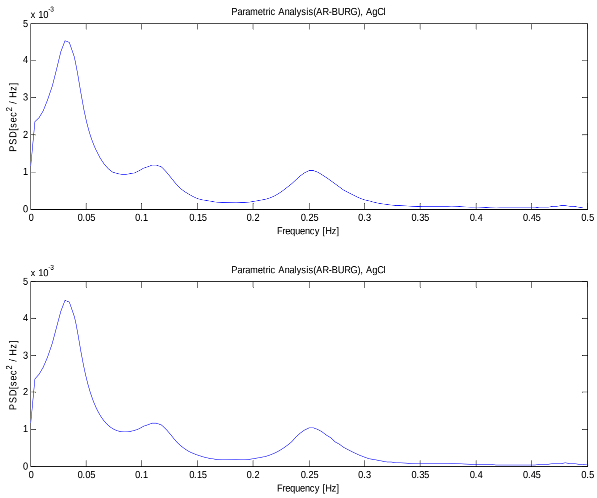


Fig. 5 Spectrum analysis with AR model
(Channel 1: Ag/AgCl, Channel 2: Ag/AgCl l)

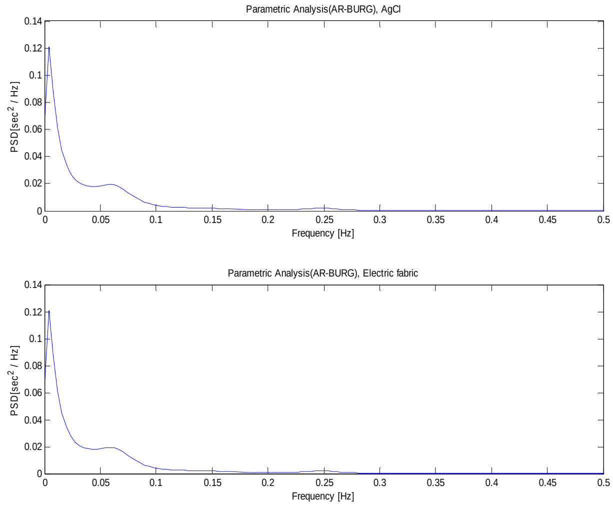


Fig. 6 Spectrum analysis with AR model
(Channel 1: Ag/AgCl, Channel 2: electric fabric, 4 cm x 4 cm)

electrode and electric fabric, have very high similarity. Maximum similarity is 100 %, and minimum similarity is 97.9 %. Therefore, in this case, errors are less than about 2 %.

VI. CONCLUSION

As we seen before, HRV analysis using electric fabric as a kind of electrode has the significance in dry-normal condition. However, electric fabric has some problems they need to solve. We think that there are three representative problems such as moving artifact related to skin-contact problem, significance in any other conditions and durability. In this experiment, moving artifact and wet or hot conditions are ignored, because data were collected in lying condition. However, if data were collected in moving condition or any other circumstance, moving artifact and skin-contact have to be considered as a considerable noise. Not only this problem, but durability which follows wash or wear out also has to be considered.

Therefore, research about skin-contact method for reduction of moving artifact and about electric fabric durability related its long-term performance is needed for its practical use. In these points of view, additional subject about in other conditions such as wet, hot, and cold must be researched for constant significance with already mentioned subject, moving artifact and durability.

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