PERFORMANCE EVALUATION OF ELECTROCARDIOGRAM MEASURED USING CAPACITIVE TEXTILES ON A BED

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Abstract: Devices for Ubiquitous-Healthcare have been currently developed to monitor health state unconsciously. Especially, measuring electrocardiogram (ECG) non-invasively on a bed has an advantage of long-term monitoring. We developed a simple and easy-to-use ECG measurement system on the bed with conductive textile sheets. It was arranged through experiments to monitor ECG more stable. Three male subjects participated in our experiment to measure ECG with four postures; a supine, prone, right lateral, and left lateral posture. Error rates of heart rate variability and correlation of RR-intervals were analyzed to evaluate the performance of the designed system. The results showed that the performance of the developed system was affected by environmental conditions, posture types and subjects.

1 INTRODUCTION

Ubiquitous-Healthcare (U-Healthcare) which is to provide medical services whenever and wherever people are has been popular and many researchers have studied. Ishijima measured ECG signals using conductive textiles on a bed (Ishijima, 1993). Tamura gathered ECG from a bath (Tamura et al, 1997) and Andreoni showed a method of getting ECG on a chair and steering wheel (Andreoni et al, 2000). However, the measured ECG morphology is different from that of a conventionally used measurement system such as Ag/AgCl, due to an instinct property of capacitive electrode. Therefore, it is necessary to find other elements to analyze the measured ECG data rather than morphology of capacitive ECG. On the other hand, heart rate variability (HRV) is still remained as an evaluation index because time index of R-peak seems very similar to normally measured one. HRV provides information of the interplay between the sympathetic and parasympathetic nervous systems (Rajendra Acharya et al, 2006) that autonomic nervous system can be monitored.

Capacitive ECG measurement on the bed has many benefits. What a subject does not move often during sleep is the best merit, since capacitive ECG is suffering from motion artifacts. Furthermore, as we lie on the bed for one-third of our daily life, a large amount of ECGs are measured. Especially, for hospitalized patients, they attach electrodes to their bare skin to monitor ECG on the bed that makes them uncomfortable due to gel typed electrodes and wires. For these reasons, RR-intervals and HRV parameters using capacitive electrodes one the bed should be verified to evaluate the diagnostic ability of the developed system for U-Healthcare.

In our previous study, we proposed a 12-channel capacitive-coupled-electrodes array to measure ECG on the bed (Hong Ji et al, 2010). Even though a performance of ECG signals obtained using the array was enough good to use, it was uncomfortable to monitor ECG for a long time, because it stuck out on the bed and was designed with hard-typed capacitive electrodes. Moreover, electrodes that were not contacted to a body had noise, and even electrodes contacted with the body showed different ECG amplitudes for various body postures.

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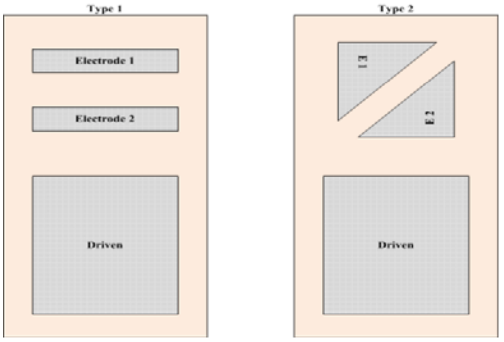

Figure 1: Two kinds of capacitive textile designs.

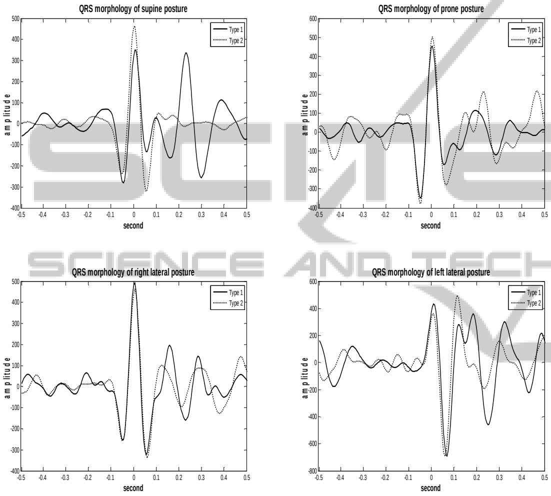

Figure 2: The amplitudes and ECG morphologies of two models.

In this paper, we introduce capacitive electrodes made of textile sheets with a modified shape and contact areas to perform properly with easy to use. We also verified the ability of the developed system, focusing on the HRV analysis comparing capacitive textiles with Ag/AgCl electrodes.

2 MATERIALS AND METHOD

2.1 A Design of Capacitive Textile Electrodes

Capacitive textiles were employed for ECG measurement electrodes and a driven electrode. Two textile electrodes were placed on an upper area of the bed in parallel as shown left in Figure 1. Driven was put on a lower part of the bed to cancel common noise of the body. The size of textiles for ECG referred to a reference (Kin-fai et al, 2008).

Figure 3: The final design of capacitive textile (silicon pad).

Figure 1 shows two kinds of electrode placement designs. Left one (type 1) is a normally designed measurement system and the other (type 2) is designed based on the notation that heart electric activity transmits obliquely to the body. To verify two models, measured capacitive ECG signals were averaged with Matlab 2008b to figure out which design had an stable amplitude with four postures; a supine, prone, right lateral, left lateral posture. The amplitudes and ECG waveforms of two types are shown in Figure 2.

Taken as a whole, type 2 showed stable R-peaks compared to type 1. However, in the point of view of usefulness and easiness to install, a whole measurement system is too big that covers most of the bed when including the driven sheet. To make them more practical and easy to use, the shape of two electrodes and a driven was redesigned to take only the upper part of the bed. An improved model of type 2 is shown in Figure 3. Driven was divided into three parts to contact with the body as wide area as possible. Capacitive textiles were fixed on silicon to make it easy to install on the bed.

2.2 A Design of Driven Electrodes

Noise exists everywhere including electromagnetic pulses from electrical apparatus, power line interference, and static electricity. To reduce these, common voltage of the body should be minimized. Larger area of electrodes shows smaller impedance between the body and the measurement system that will minimize the common voltage (Winter et al, 1983).

With this reason, a driven electrode was expanded as possible. Driven signals are obtained by inverting the summated measured signal from two capacitive electrodes.

Table 1: Results of HRV analysis in time domain and frequency domain. SDNN: The standard deviation of the RR-intervals. RMSSD: The roof mean square successive difference of intervals. pNN50: The number of successive difference of intervals which differ by more than 50 ms expressed as a percentage of the total number of ECG cycles (Rajendra Acharya et al, 2006). LF: Power in low frequency range. HF: Power in high frequency domain. nLF: LF Power in normalised units. nHF: HF power in normalised units. LH/HF: Ratio LF/HF.

		Error rate in time domain (%)				Error rate in frequency domain (%)					Correlation of RR-intervals
Subject	Posture	SDNN	RMSSD	pNN50	mean of HR	LF	HF	nLF	nHF	LF/HF	
1	Supine	1.06	2.38	17.65	<0.001	0.64	2.10	0.85	0.60	1.42	0.987
	Prone	2.90	9.65	10.71	0	0.97	8.33	5.39	3.52	8.59	0.991
	Right lateral	0.71	0.35	35.07	0	0.77	3.51	1.49	1.19	2.63	0.925
	Left lateral	6.21	12.95	16.00	0	0.29	12.19	6.75	4.90	11.12	0.988
2	Supine	15.71	26.92	0	<0.001	4.79	37.54	44.64	13.78	67.77	0.948
	Prone	1.32	12.15	133.33	<0.001	3.45	12.46	7.26	9.21	18.17	0.916
	Right lateral	0.79	1.66	0	<0.001	0.36	3.06	2.03	1.29	3.32	0.999
	Left lateral	2.83	6.80	18.18	<0.001	0.80	6.41	3.80	1.55	5.27	0.975
3	Supine	0.60	3.82	7.14	<0.001	0.68	2.86	0.52	1.70	2.25	0.995
	Prone	0.93	6.73	28.79	0.001	0.17	2.44	0.94	1.65	2.54	0.974
	Right lateral	0.32	1.49	2.63	0	0.04	4.04	0.98	3.01	3.85	0.999
	Left lateral	0.58	1.78	21.95	0.005	1.08	4.58	1.97	3.66	5.41	0.996
Average		2.83	7.22	24.29	0.0008	1.17	8.29	6.38	3.84	11.03	0.974

2.3 Method

3 healthy male subjects participated in this experiment, with 27.7 ± 2.5 years aged. Subjects lie with four postures; a supine, prone, right lateral, and left lateral posture. ECG was recorded for 5 minutes in each posture with 500Hz sampling rate using Biopac MP 150 (Biopac system Inc, USA). The system was put on the upper part of a mattress and Ag/AgCl electrodes were attached on both wrists for reference. HRV parameters and RR-intervals were calculated and we compared those of capacitive ECG to those of reference ECG.

3 RESULTS

Differences of reference and capacitive ECG for each parameter were calculated using error rate (1).

$$\text{Error Rate} = 100 * \frac{(\text{ref. value} - \text{cap. value})}{\text{ref. value}} \qquad (1)$$

Calculated HRV error rates in time domain and frequency domain are shown in Table 1.

Error rates of SDNN, RMSSD, and pNN50 showed 2.83, 7.22, and 24.29, respectively. Error rates of LF, HF, nLF, nHF, and LF/HF were 1.17, 8.29, 6.38, 3.84, and 11.03, respectively. An average value of heart rate (HR) for five minutes was almost same between reference and capacitive ECG. An average value of correlation of RR-intervals showed 0.97 that was a high correlation.

4 DISCUSSION

A correlation of RR-intervals showed 0.974 that means the developed system can be used for heart rate monitoring. However, HRV parameters showed relatively low correlation between capacitive ECG and reference. Especially for pNN50 with prone posture, subject 2 showed very a poor error rate. When measuring capacitive ECG from subject 2 with prone posture, the signal was a little noisy that may affect the result value. However, even though excluding this subject, pNN50 for prone posture showed poor performance. Subject 1 and 3 showed good performances when they lie with supine posture and subject 2 showed good error rates in right lateral posture. In frequency domain, performance abilities are differ from each subject and each posture. This probably is due to the differences in R wave transient path way (R axis) for each subject.

Generally high correlation of RR-intervals showed low error rate that implies a high signal quality of the capacitive ECG tends to reveal accurate HRV parameters. Therefore, to estimate autonomic nervous system, the array, shape and size of capacitive textiles should be needed to be redesigned. Moreover, capacitive ECG with high signal to noise is strongly required to measure HRV correctly. We also found that ECG morphologies for each posture are different from each other that could be used for detection of sleep postures like a reference (Hong Ji et al, 2010).

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