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Non-restrictive Heart Rate Monitoring Using an Acceleration Sensor

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Abstract— **Daily long-term monitoring of heart rates is important for health management. An analysis of heart rate variability can facilitate the early discovery of a illnesses. In this study, we paid attention to the method of measuring resting heart rate over long term. An acceleration sensor was set inside the down kilt as it opposing to subject's left chest. Mechanical vibration from heart activity is carried to the acceleration sensor through the down quilt. As a result, periodic vibration was measured successfully and this vibration was proved to be in high correlation with the R wave of ECG. The same results were obtained even in case of lying in a left lateral position.**

I. Introduction

LONG-TERM monitoring of heart rates is important for health management. An analysis of heart rate variability can facilitate the early discovery of a variety of illnesses and health conditions. For example, high blood pressure [1]-[3], diabetes [4], and obesity [5] are accompanied by a decrease in heart-rate variability, while psychological stress [6], lack of exercise [7] and other factors are also known to affect heart-rate variability. Research has also been conducted in relation to the prognosis of heart diseases, particularly following myocardial infarction [8].

In many cases, in these types of studies, researchers analyzed heart-rate variability by using the resting heart rate because the resting heart rate variability can be an index of sympathetic or parasympathetic dominance according to the frequency of the variability studies [10]. To analyze heart rate for such prognosis of lifestyle-related diseases, we should measure the resting heart rate through a long term. We pay attention to the method by which the heart rate was measured in lying position.

Recently, electrocardiograms (ECG) have come to be used commonly as a means of measuring heart rate. ECG is make the most sense for measuring heart rate, however, there are two problems when it is used over long-term. One is feeling of confinement resulting from the wires. There should be no restraint placed on resting heart rate measurement, otherwise subjects will not able to continue measuring their heart rate long term. Moreover, heart rate is considered a common indicator for the condition of the autonomic nervous system. Even a slight feeling of restriction resulting from having wires attached to one's body may affect autonomic nervous reactions, and therefore may influence heart rate. The second problem is rashes resulting from having electrodes attached to the skin. Because heart rate must be measured over long term, skin stress becomes a problem.

Given these issues, we need for a method that could measure resting heart rate in a static position, in such a way that the subject is completely unaware that the measurement is being taken. In this research, we propose the new method of non-restrictive measurement of resting heart rate in a lying position using an acceleration sensor set inside the down quilt.

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II. Methods

A. Subjects

A total of six healthy males with a mean (±SD) age of 22.4±1.5 years, mean height of 171.4±5.9cm, and mean weight of 61±7.7kg agreed to participate in tests designed to evaluate the performance of proposal method. They did not have any preexisting heart disease. We got a nod from these subjects after fully explaining the purpose of the experiment, the procedure, and potential risk, and ensuring that they understood completely.

B. Experimental system

We introduce the experimental system to achieve the method of non-restrictive measurement of resting heart rate in a lying position. Fig.1a) shows an outline of the experimental system. A small acceleration sensor is installed in the middle layer of a down quilt. When the subject lies down and is covered with the down quilt, the minute mechanical vibrations resulting from the subject's heart activity are transmitted to the down quilt, and the acceleration sensor picks up this vibration. The acceleration sensor is sewn into the down quilt directly above the left side of the anterior chest, which is the location of the heart. This system employs a piezoelectric acceleration sensor and was set as its sensitivity axis (z-axis) oriented to the earth's gravity.

a)

b)

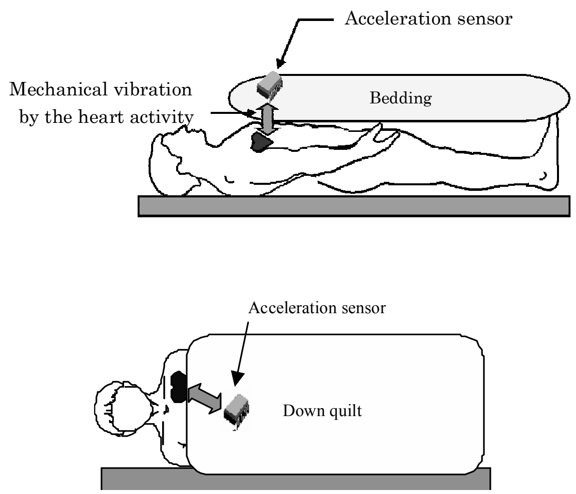


Fig.1. Outline of the experimental system at a) supine position, b) lateral position

The subject's position while having a lie-down may adversely affect non-restrictive measurement of the resting heart rate; no problems should occur if the subject is in a lateral position, as we will discuss later. As shown in Fig. 1b), the sensitivity axis of the acceleration sensor installed in the down quilt is always perpendicular to the surface of the down quilt, so the sensitivity axis of the acceleration sensor still faces the heart when the subject is in a lateral position. As a result, the sensitivity of measurements using this experimental system depends more on the distance from the heart to the sensor than on the subject's position.

Table1 shows the specifications of the piezoelectric acceleration sensor (MA3-01Aa; Micro Stone Co., Ltd.).

TABLE1
Specifications of Acceleration Sensor

Data item	Value
Range of detection	±1 ms^{-2}
Sensitivity of detection	1.9 V/ ms^{-2}
Response frequency	0.8～1000 Hz
Resonance frequency	10～15 kHz
Size	W20.5*D12.5*H5 mm
Electrical requirements	0.5 mA
Weight	4 gr

This table indicates that the sensor has a built-in amplifier, and a comparatively high-sensitivity output of 1.9 V per 1 ms-2 of acceleration. This sensor also features high linearity and a response frequency over 0.8 Hz, so it prevents the heart activity vibrations from overlapping with the vibration caused from respiration. Furthermore, the sensor is small and light, so even when installed in the down quilt, it did not disturb the subject, and a low-consumption current of 0.5 mA allows for long-term measurements under battery power. The original resonant frequency is between 10 and 15 KHz, which is sufficiently high in comparison to the frequency of mechanical vibrations generated by the heart's activity. Heart activity data obtained with this acceleration sensor was taken at 1000 Hz by a 12-bit A/D conversion board (PCI-3153, Interface Corp.,) and was stored in a PC for further analysis.

C. Experimental procedure

The measurements were performed in the Ritsumeikan University. To evaluate our method, resting heart rate (HR) was obtained by the system described above along with ECG measurements for the same period of time.

In experiments, the subjects were asked to lie quietly on their backs, and were then covered with down quilt equipped with the acceleration sensor. The resting heart rates of the subjects were measured for 5 minutes after the 5 minutes rest. In subject's position, the first was a supine position, and, next, left lateral position. At this time, the changing position was limited as the experimenter directed it.

Next, we measured the heart activity of one subject through an entire night by using proposal method. Because we assumed that the state of sleeping is the most common in lying position in our living. Measurement time was six hours and 45 minutes.

III. Results and Discussions

A. In a supine position

Fig. 2 shows an example of a detected heart-rate signal in a supine position by using our system and ECG for 30 seconds in subject Y.A. As shown in this graph, high-frequency noise overlaps the heart rate signal by the experimental system, but the peak is obtained at the same position as the ECG-R wave. Furthermore, its peak value is large (max. acceleration: 0.06 ms-2) enough to detect automatically by using threshold scheme. It demonstrates proposal heart rate measuring method is effective.

Table 2 shows the results of experiments on six subjects, where "N" is the peak detected heart rate by the experimental system for five minutes, "Mean," "Max," and "Min" is the mean, maximum and minimum peak amplitudes. As shown in this table, we were able to obtain resting heart rate measurements for all subjects. Regarding the amplitude of acceleration in a comparison of Mean accelerations, the largest difference obtained was 0.02ms-2, for subjects Y.H and K.Y. Possible reasons for this difference are the deterioration of acceleration resulting from the contact condition of the sensor.

Fig. 3 shows the relationship between the peak times of the ECG signal (x-axis) and those of the acceleration signal (y-axis), obtained from Subject YA detected in supine position for five minutes; the graph shows a clear linear relationship between these two peak times. The average correlation coefficient for the six subjects was 0.98.

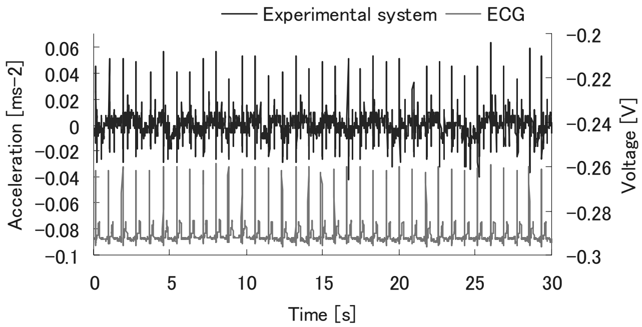


Fig.2. Detected signals by using experimental system and ECG when subjects were in a supine position

TABLE2

Results of heart rate measurement by using experimental system in a supine position

Subject	N	Mean [ms^{-2}]	Max [ms^{-2}]	Min [ms^{-2}]
y.a	345	0.04	0.07	0.02
k.y	323	0.04	0.06	0.02
y.h	337	0.05	0.08	0.03
k.s	368	0.04	0.07	0.02
k.n	340	0.04	0.07	0.03
n.s	345	0.05	0.08	0.03

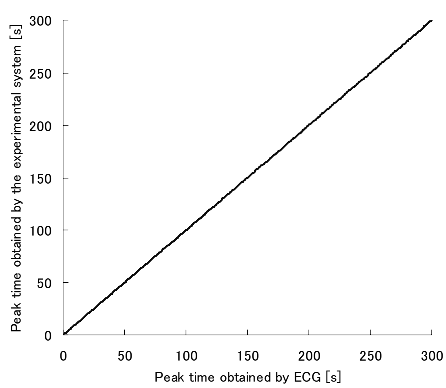


Fig. 3. Correlation between peak times obtained by ECG (x-axis) and peak times obtained by the experimental system (y-axis)

B. In the lateral position

To clarify the effects of position, we conducted the same heart rate measurements with subjects lying in the left lateral position. Fig. 4 shows a 30-second record of subject Y.A., along with ECG measurements for the same period of time. The results show that it was possible to distinguish the peaks while the subject was lying in the left lateral position in the same way as the peaks resulting from ECG R waves.

Table 3 shows the resting heart rate measurement results of six subjects in the left lateral position, and data from subjects in a supine position were compared with those from subjects in the left lateral position. The mean peak output values for subject N.A. was 0.05 ms-2 in the left lateral position, which are lower than the detected signal when the subject was in a supine position; nevertheless, they are sufficiently large to enable peak detection.

With regard to the correlation coefficient, the average value of the six subjects was 0.93; this was 0.5 lower than the value obtained in the supine position.

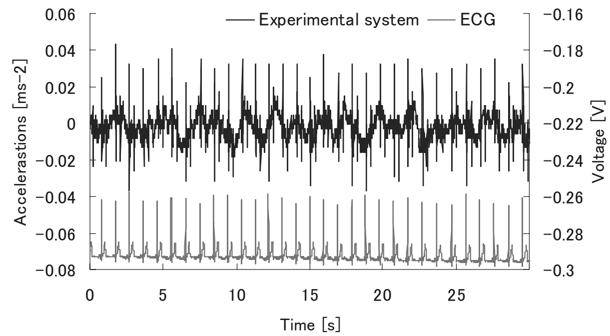


Fig. 4. Detected signals by using experimental system and ECG when subjects were in a left lateral position

TABLE3

Results of heart rate measurement by using experimental system in the left lateral position

Subject	N	Mean [ms^{-2}]	Max [ms^{-2}]	Min [ms^{-2}]
y.a	340	0.03	0.04	0.02
k.y	338	0.03	0.05	0.01
y.h	248	0.03	0.05	0.02
k.s	419	0.03	0.05	0.02
k.n	334	0.03	0.04	0.02
n.s	326	0.05	0.07	0.03

C. Measurement through all night

In one subject, using this method makes it possible to achieve non-restrictive heart rate measurement throughout all night. Fig. 5 shows the original waveform from the acceleration sensor through all night on subject N.S. and as this graph shows, aside from the components representing heart activity, it is possible to identify significant variations thought to result from body movement.

We calculated the instantaneous heart rate during sleep, excluding regions thought to be clearly a result of body action. Fig. 6 shows results of heart rate validation obtained from acceleration sensor, and those of heart rates obtained from an ECG measured at the same time. As the diagram illustrates, variations are visible in the acceleration rate, similar to the instantaneous heart rates calculated from the ECG. As the diagram illustrates, though high-level voltage amplitude by body movement overlaps HR by acceleration sensor, the show variations similar to the HR as calculated from the ECG.

Table 4 shows the variables of the HR for each hour during sleep. 'Data efficiency' refers to the value in which the number of peaks detected by the acceleration sensor is divided by the number detected by ECG. 'Correlation efficiency' shows the correlation between the R-R intervals detected by ECG and those detected by the acceleration sensor.

As shown in Table 4, it was not possible to measure heart activity over the entire sleeping period throughout the night. The Data Efficiency throughout the night ranged from 87.6%~99.0%, confirming that it was possible to measure the HR using this method. Even in the period from 5 to 6 hours, where maximum data was lost, the data efficiency was 87.6%, confirming that heart activity can be detected.

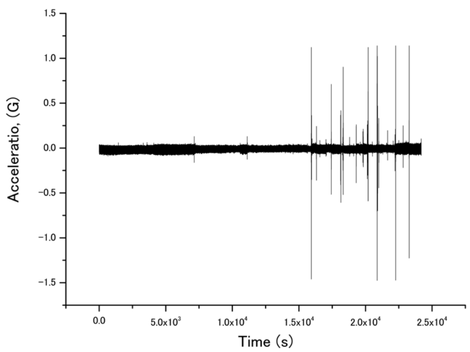
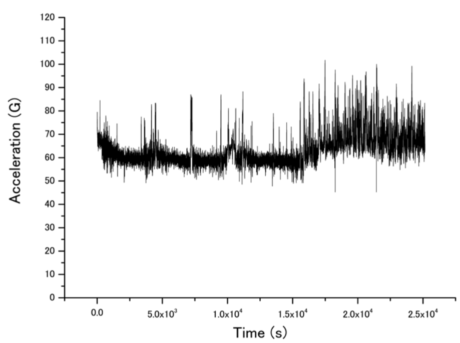


Fig. 5 Raw signals obtained by acceleration sensor through all night

a)



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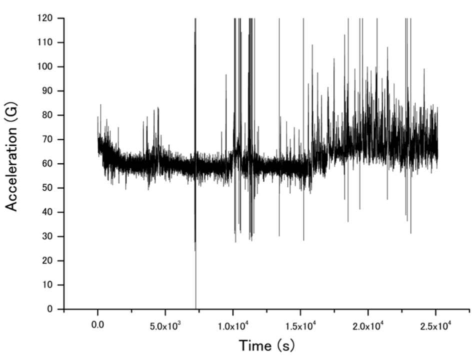

Fig. 6 Results HR; a) by ECG, b) by acceleration sensor through all night

TABLE4
Results of measurement throughout the night

Time (hours)	1	2	3	4	5	6	3/4
Data efficiency (%)	99.0	98.4	96.6	94.5	95.1	87.6	94.4
Correlation coefficients	0.99	0.67	0.57	0.50	0.95	0.76	0.82

IV. CONCLUSION

In this research, we demonstrated that it is possible to measure resting heart rate using a non-restrictive method, which in it is only an acceleration sensor set inside a down quilt. The advantage is that signal cables do not bother the subject. In any case, we think this method makes it possible to reduce the psychological and physical burden imposed on the subject and achieve non-restrictive resting heart rate measurement throughout long period.

In the case of using through all night, however, we could not obtain high-accuracy heart rate such as short-term measurement. So we are planning to solute this problem by setting several acceleration sensors on the quilt.

We consider this method may be used in a number of other applications, including monitoring heart rate for the bedridden elderly and others confined to a bed for long periods of time. Moreover, by establishing links with alarm systems, mobile phones, and other network terminals, this method can also be used to assist in the monitoring of the elderly.

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