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Relationship analysis between BCG features and blood pressure

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***Abstract*— Hypertension, one of lifestyle-related diseases, is a cause of life-threatening diseases such as cerebral hemorrhage. In particular, non-dipper hypertension, in which blood pressure does not decrease during nighttime sleep, is considered to be a disease with a high risk. Blood pressure monitor using a cuff requires compression of the artery. It is difficult to measure without disturbing sleep. Therefore, we focused on the ballisto-cardiogram (BCG) based blood pressure estimation method that does not use a cuff. BCG is a biological signal that can be measured without attaching a sensor to the body. BCG is a biological signal composed of vibrations caused by heartbeat, and research on estimating relative blood pressure is attracting attention. In this study, we analyzed the relationship between features extracted from BCG and blood pressure.**

Keywords—Ballistocardiogram, blood pressure, estimation, feature extraction

I. Introduction

In modern society, transportation facilities have developed and opportunities for walking have decreased, and people are lacking exercise. Due to the busyness of our daily lives, people tend to consume junk food that can be easily purchased rather than eating health-conscious meals. The number of patients suffering from lifestyle-related diseases due to chronic lack of exercise and disordered eating habits is increasing. Hypertension is one of lifestyle-related diseases. Since lifestyle-related diseases develop because of the accumulation of daily lifestyle habits, the incidence of lifestyle-related diseases is particularly high among elderly people. According to 2018 data, 72% of men in their 60s and 51% of women in their 60s have high blood pressure [1].

Hypertension is often asymptomatic and difficult to detect early. An effective way to detect hypertension is to monitor blood pressure routinely. Such monitoring helps detect abnormalities in many cardiovascular functions, not just hypertension. However, it is troublesome to perform daily monitoring using a cuff-type blood pressure monitor that is generally used at present. In addition, one of the problems of hypertension is a symptom in which blood pressure does not decrease during sleep at night (non-dipper hypertension). Blood pressure during sleep at night is usually lower than during the day [2]. However, there are some hypertensive patients whose blood pressure does not decrease during sleep at night, and such non-dippers are said to have a high risk of developing life-threatening diseases such as cerebral hemorrhage. ABPM (ambulatory Blood Pressure Monitoring) is used for blood pressure monitoring during sleep at night. ABPM is also a cuff-type blood pressure monitor, which imposes a burden on the subject. Compression from the cuff may also interfere with sleep. Due to the pressure from the cuff, the patient may be conscious of the measurement and may not be able to measure the correct blood pressure for the same reason as white coat hypertension [3].

BCG (Ballisto-Cardiogram) based blood pressure estimation method is one of the effective methods for such nighttime blood pressure measurement. BCG is a biological signal obtained by acquiring minute vibrations of the body due to heartbeat with a pressure sensor. Since it can be measured when the pressure sensor is in contact with a part of the body, BCG can be obtained unconsciously by installing a sheet-type pressure sensor on a bed or cushion [4, 5]. Therefore, it is not affected by an increase in blood pressure such as white coat hypertension and is suitable for long-term blood pressure measurement such as during nighttime sleep. The purpose of this study is to develop a blood pressure estimation method using BCG.

II. Method

A study was conducted by Su et al. [6] that attempted to estimate relative blood pressure in BCG-based blood pressure estimation. In [6], exercise raises blood pressure. Therefore, the estimation of blood pressure during sleep addressed in this study differs from [6], although similar features were used. An example of a BCG waveform is shown in Fig. 1. The features that are often used in the BCG waveform are the I wave, J wave, and K wave, which are large vibration waves. In this study, we also used a combination of these features.

The analysis procedure of BCG feature quantity is shown.

1. Feature extraction

The amplitude values and times of the I, J, and K waves are obtained from the BCG waveform, and the following features are extracted.

- Extract features of amplitude values. The amplitude values of the I, J, and K waves are I-amp, J-amp, and K-amp, respectively.
- Extract time features. The time from I wave to J wave, the time from J wave to K wave, and the time from I wave to K wave are defined as IJ-time, JK-time, and IK-time, respectively. The percentage of IJ-time in one beat is defined as BCG-IJrate. The percentage of IJ-time in the BCG main waveform of one beat is IJK-IJrate.
- Extract the features of the difference in amplitude value. IJ-amplitude, JK-amplitude, and IK-amplitude are the amplitude difference between I and J waves, between J and K waves, and between I and K waves, respectively.

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- Extract the features of the absolute value of the amplitude. Let IJK-amp be the sum of the absolute values of the I wave, the J wave, and the K wave.
- Extract the features of the area created by the BCG waveform. It is a feature including both amplitude and time, and is called BCG-area.
- Extract the feature value of the maximum value of BCG. The maximum value of one beat is BCG-max. The time between the maxima of one beat is JJ-time.

2. *Feature analysis*

Analyze the extracted features. Multiple blood pressure values and BCG features are included in one record. First, the correlation coefficient between the feature and the blood pressure in the same record is obtained. After that, the coefficient of variation of the correlation coefficients of all records is obtained. As a result, correlation coefficient and coefficient of variation corresponding to each feature are obtained. The features are ranked according to the correlation coefficient and the coefficient of variation, respectively, and these ranks are averaged. Analyze the feature values with higher ranks by applying multiple regression analysis.

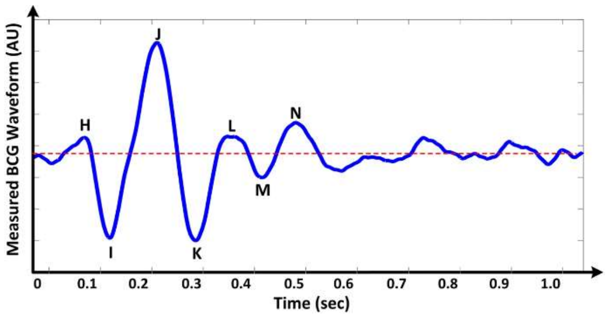

Fig. 1. BCG waveform of one beat [4].

III. EXPERIMENT

The subjects were 3 males (A, B, and C) in their 20s and 1 female (D) in their 20s. Subjects slept supine on the BCG sensor for 30 minutes (Fig. 2). BCG signal and blood pressure were acquired simultaneously in this environment. BCG signals were acquired at a sampling frequency of 500 Hz (TAOS AiSleep) . Blood pressure was measured with a cuff-type continuous blood pressure monitor (Omron HBP-2070NX). Blood pressure was obtained at 2-minute intervals, and BCG features of 10 beats before and after blood pressure measurement were used.

The features explained in Section II were extracted from the acquired BCG signal. Several features were selected by ranking the correlation between the feature and blood pressure and the variability of the correlation. The two highly ranked features were JJ-time and BCG-area. JJ-time is related to heart rate and BCG-area is related to cardiac output. It was found that these two features are strongly related to blood pressure. Figure 3 shows the results of estimating blood pressure using these two features. This scatterplot is the result for one record. Table 1 shows the correlation coefficients between predicted values and measured values for all records. These results show that relative blood pressure can be estimated.

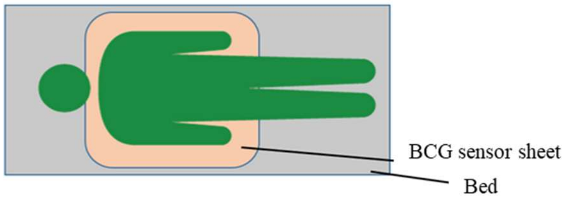

Fig. 2. Experiment environment.

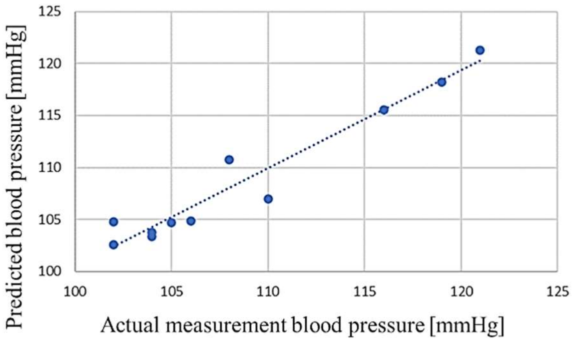

Fig. 3. Scatterplot of actual blood pressure and predicted blood pressure within record 1.

TABLE I. Result of Experiments

Record No. & Subject	*Correlation Coefficient*
Record 1 (Subject A)	0.98
Record 2 (Subject D)	0.77
Record 3 (Subject B)	0.89
Record 4 (Subject C)	0.89
Record 5 (Subject A)	0.97
Record 6 (Subject A)	0.91

IV. FUTURE WORK

The BCG signal is less constrained, but on the other hand, it is more susceptible to noise. As a future work, it is necessary to develop a signal analysis method that improves the S/N ratio of the BCG signal.

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