Techniques for estimating blood pressure variation using video images

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***Abstract*— It is important to know about a sudden blood pressure change that occurs in everyday life and may pose a danger to human health. However, monitoring the blood pressure variation in daily life is difficult because a bulky and expensive sensor is needed to measure the blood pressure continuously. In this study, a new non-contact method is proposed to estimate the blood pressure variation using video images. In this method, the pulse propagation time difference or instantaneous phase difference is calculated between two pulse waves obtained from different parts of a subject's body captured by a video camera. The forehead, left cheek, and right hand are selected as regions to obtain pulse waves. Both the pulse propagation time difference and instantaneous phase difference were calculated from the video images of 20 healthy subjects performing the Valsalva maneuver. These indices are considered to have a negative correlation with the blood pressure variation because they approximate the pulse transit time obtained from a photoplethysmograph. However, the experimental results showed that the correlation coefficients between the blood pressure and the proposed indices were approximately 0.6 for the pulse wave obtained from the right hand. This result is considered to be due to the difference in the transmission depth into the skin between the green and infrared light used as light sources for the video image and conventional photoplethysmogram, respectively. In addition, the difference in the innervation of the face and hand may be related to the results.**

I. Introduction

As a generally used sphygmomanometer, the oscillometric type in which cuff is wrapped around an upper arm is widely used. This type of sphygmomanometer provides the average of blood pressure over several heartbeats, and measuring the blood pressure everyday enables the diagnosis of high blood pressure [1]-[4]. On the other hand, it is difficult to know the sudden blood pressure change caused by such as the straining during exercise, excessive stress, and an abrupt change in ambient temperature. Such a change in blood pressure frequently occurs in everyday life and may pose a danger to human health depending on the situation. For example, thermal stress called a heat shock caused by a temperature change [5]-[8] during bathing is a serious problem. These dangerous events may be sensed beforehand if we can measure the blood pressure change in everyday life without attaching a sensor to human bodies.

In late years, the video image analysis of the photographed skin of a human body attracts an attention as a technique to acquire biological information with non-contact measurement. This technique is expected to be widely spread because we own so many devices to capture the video images such as a smartphone and high-speed cameras have become much less expensive. Some methods to estimate heart rate and breathing rate using the video image have been proposed in the precedent studies [9]-[13], but studies on blood pressure have not been reported. Therefore, the purpose of this study is to propose a non-contact method to estimate the blood pressure information from video images of a human body and also to validate the effectiveness.

II. Methods

We focus on the pulse transit time (PTT) as a method to obtain blood pressure information from video images. The absolute value of the blood pressure cannot be obtained from PTT [14], but it would be possible to monitor the sudden blood pressure change, as the purpose of this study. The concrete analytical techniques are explained below.

(1) ROI setting

A median filter of 5×5 pixels is applied to the whole image of each frame for smoothing the image; then, a rectangular region of interest (ROI) is manually set inside the image. In this study, three regions of interest were set as ROI: the right palm area, forehead area, and left cheek area. Furthermore, imaging photoplethysmography (iPPG) is obtained for each frame by calculating the average of the brightness of green in each ROI.

(2) Filter processing

Because the information on body movement and breathing-related change is also contained in the iPPG in each ROI, a filter processing is performed to remove them. A fifth Butterworth filter to pass 0.7–2.0 Hz is used. This roughly fits the ingredient of 40–120 bpm, which is within the range of the heart rate variability of healthy people.

(3) Propagation time difference

As shown in Fig. 1(a), the PTT, which is correlated with

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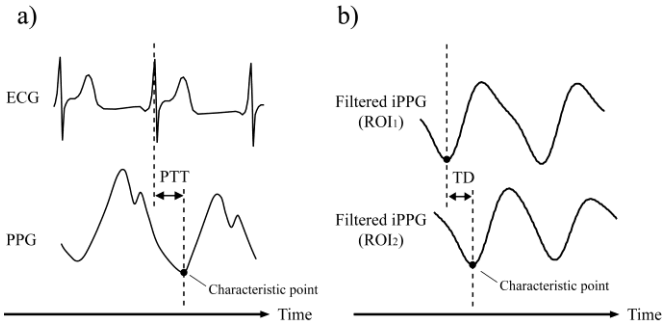

Figure 1. Definitions of a) pulse transit time (PTT) and b) pulse propagation time difference (TD).

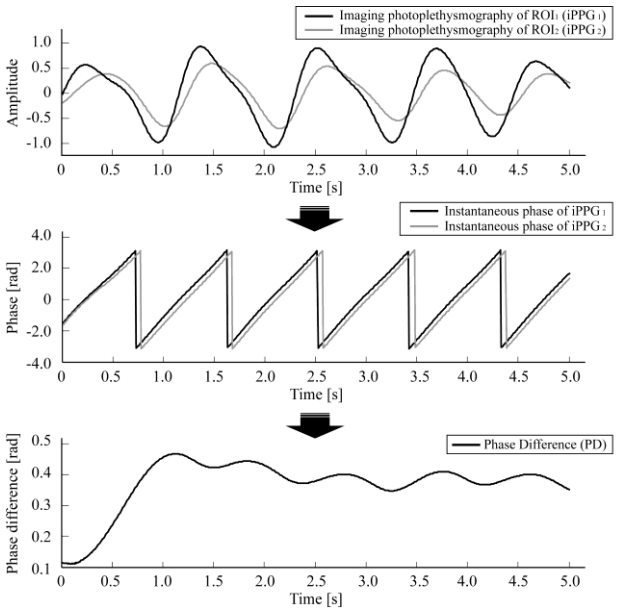

Figure 2. Calculation of phase difference (PD).

blood pressure variability, is obtained from the time difference of the R wave of ECG and the characteristic point of photoplethysmogram (PPG) that is measured with a photo sensor attached to a finger. In this study, iPPGs at different two ROI are used instead of ECG and PPG, and the pulse propagation time difference (TD) is calculated as an index equivalent to PTT as shown in Fig. 1 b). Here, the minimum points of iPPGs are used as the characteristic points of PPG.

(4) Instantaneous phase difference

The detection accuracy of the characteristic point for deriving PTT is directly related to the estimation accuracy of the blood pressure. However, there are various methods of determining the characteristic point, and the most optimal one is not yet clear [15]. Therefore, without detecting the characteristic point, the instantaneous phase difference (PD) was calculated as a technique to obtain information equivalent to PTT. An example of PD calculation is shown in Fig. 2. Hilbert transformation was performed on the iPPGs obtained at two different places of ROI to derive the instantaneous phases. PD was calculated by subtracting the instantaneous phase obtained at ROI closer to the heart (ROI_1 in Fig. 2) from the other (ROI_2 in Fig. 2).

III. Experiment

Test subjects were 20 healthy adult men of 22.8 ± 1.1 years of age. Valsalva maneuver was performed as a load to intentionally change their blood pressure. The five minute test included one minute of rest, one minute of Valsalva, and three minutes of rest.

Blood pressure was monitored using a blood pressure sensor (PORTAPRES Model-2; Finapres Medical Systems) attached to the left middle finger of the subject. From the blood pressure signal, the maximum value in each beat was obtained as systolic blood pressure (SBP). Furthermore, both ECG and PPG from the left forefinger were acquired to obtain the conventional PTT and compare it with the proposed indices. Each measurement signal was recorded with a sampling frequency of 1 kHz using a 16-bit A/D converter (MP150; BIOPAC System Inc.).

Together with the biological signal measurement, the face and the right palm of the subject was photographed using a video camera (TGX02c; Baumer Co., Ltd.). The number of pixels of the image was 440×400 pixels, and the frame rate was 140 fps. A pedestal was placed to hold the face and the right palm, and the palm was turned toward the camera such that the face and the right palm were photographed in the same image. The distance between the camera and the face was approximately 100 cm. A white LED light source was placed at the side of the camera such that the illuminance at the target was 1000 lux.

IV. Results

A. Propagation time difference

Figure 3 shows the change of SBP and TD of a typical subject. The combinations of the regions in each TD are as follows:

TD_1: forehead – left cheek
TD_2: right hand – left cheek
TD_3: right hand – forehead

During the breath hold, SBP increased gradually after it dropped. And SBP recovered after the breath hold. This is the typical pattern of SBP changing in Valsalva maneuver. In Fig. 3, both TD_2 and TD_3 using iPPG in the hand show a change resembling that of SBP. In addition, TD_3 of this subject took a negative value in the latter part of the test. This means that the characteristic point of iPPG in the hand appeared earlier than that in the forehead. On the other hand, TD_1, which is TD between forehead and left cheek regions, did not change as much as the other two TDs.

Figure 4 shows the average and the standard deviation of all subjects with respect to the cross-correlation coefficient of each TD and SBP. Although it was expected that TD have a negative correlation against SBP because TD should contain the same information as PTT, a positive correlation was

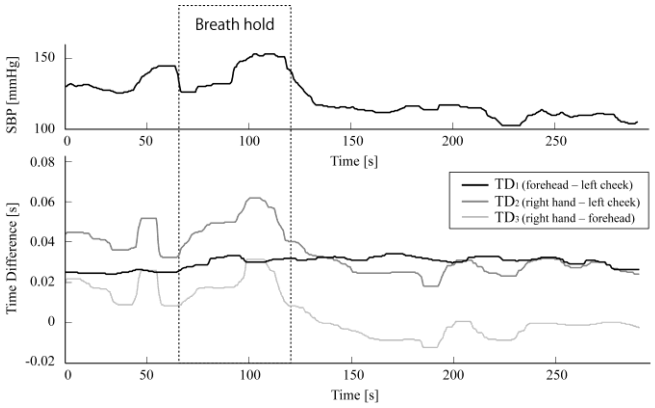

Figure 3. Changes of systolic blood pressure (SBP) and pulse propagation time difference (TD) derived from the iPPG of a typical subject.

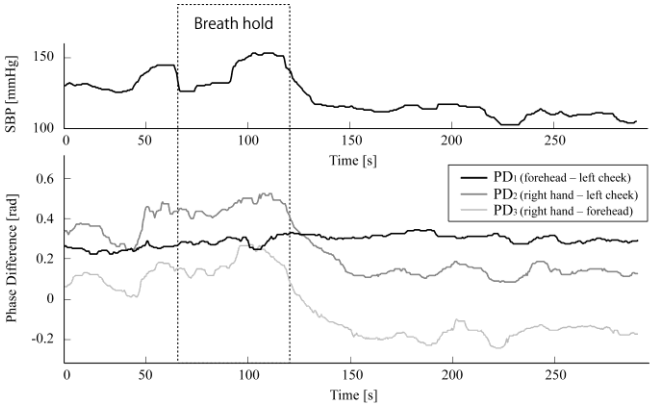

Figure 5. Changes of systolic blood pressure (SBP) and phase difference (PD) derived from the iPPG of the same subject as in Fig.4.

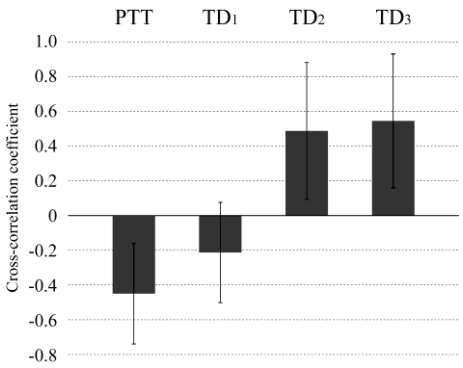

Figure 4. Averaged cross-correlation coefficients of systolic blood pressure (SBP) and pulse propagation time differences (TDs) of all subjects.

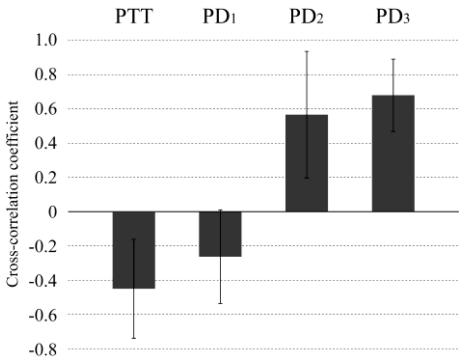

Figure 6. Averaged cross-correlation coefficients of systolic blood pressure (SBP) and phase differences (PDs) of all subjects.

obtained both in TD_2 and TD_3 including in the hand.

By contrast, TD_1 was negative correlated with SBP, and the strength of the correlation disregarding the polarity between TD_1 and SBP was low compared to the other TDs.

B. Instantaneous phase difference

PD was calculated in the same combinations of regions as for TD, and the results of PD_1, PD_2 and PD_3 were obtained. Figure 5 shows the change of SBP and PD for the same subject as in Fig. 3. As with TD, PD_2 and PD_3 using iPPG in the hand show a change resembling that of SBP.

Figure 6 shows the average and the standard deviation of the cross-correlation coefficient of SBP and PD of all subjects. The results were similar to those for TD in that PD including the region in the hand is positively correlated with SBP. This result shows that TD and PD have similar information on blood pressure variability. However, the value of the cross-correlation coefficient between SBP and PD was slightly higher than that of SBP and TD.

V. DISCUSSION

The value of the cross-correlation coefficient between SBP and PD was slightly higher than that of SBP and TD as shown in Fig. 4 and Fig. 6. This result suggests that PD is more robust against short-term noise and artifacts in the iPPG than TD because PD is calculated based on a global pattern of the iPPG waveform while TD is based on a part of the waveform.

Besides, the experiment shows a positive correlation between the blood pressure variability and the values of TD and PD derived from the iPPG of two regions (hand and face). This result is contradictory to the principle of conventional PTT [14].

A possible reason would be the difference in the transmission depth of the light, which is used in this study, into the skin. The transmission depth of the light is defined as the depth where the intensity of the light incident on the skin decreases to 1/e (37%). The transmission depth of the green light (wavelength is 525 nm) used for iPPG is 300 μm and that of the infrared light (wavelength is 800 nm) conventionally used for PPG is 1200μm [16]-[17]. Therefore, iPPG mainly captures the blood flow in capillary vessels in the shallow skin surface, containing information different from that of the conventional PPG capturing the information on the bloodstream of arteries [18].

On the other hand, because the sympathetic nerve is activated by the Valsalva test in this experiment, it is likely that the vascular resistance of peripheral arterioles increases, comparably decreasing the blood flow into the skin surface

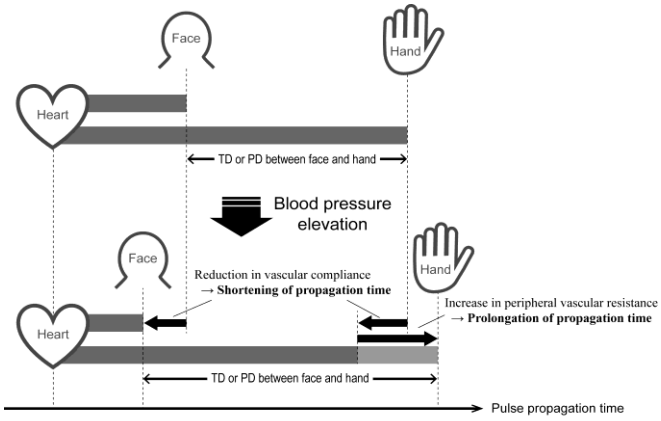

Figure 7. Explanation about possible reasons for the positive correlation between SBP and the values of TD and PD.

decreases in comparison. As a result, it is thought that, while the afflux of blood due to pulsation is delayed in the skin surface of the hand, constriction does not occur in the vessels of the face, which are controlled both by sympathetic and parasympathetic nerves [19], and therefore the delay of the pulsation does not occur in the process of blood moving from the artery to the skin surface. Thus, it is very likely that this difference is reflected in the positive correlation with the blood pressure variability. Fig. 7 is a diagram explaining reasons for the positive correlation between SBP and the values of TD and PD, which were mentioned above.

VI. Conclusion

This study proposes a non-contact technique to estimate the blood pressure variability using the pulse wave obtained as a camera image (iPPG).

In addition, we performed an experiment to examine the accuracy of the proposed technique using a camera image acquired by intentionally changing the blood pressure by the Valsalva test. As a result, the propagation time difference and the phase difference obtained using the iPPG of hand and face are positively correlated with blood pressure, which is different from the conventional pulse propagation time difference. However, the strength of the correlation disregarding the polarity was at the same level as the conventional pulse propagation time. The results seem to suggest that the iPPG mainly reflects the information on the capillary of the skin surface and is affected by the difference in the innervation of the face and hand.

The current issue is a large difference in the indices between individuals and the uncertainty of optimal measurement conditions. The future problem is to search for a body part that can more strongly reflect the blood pressure information better than face and hand, and establish a technique to use the two-dimensional image information.

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