https://doi.org/10.2352/issn.2169-2629.2019.27.49

Improvement of blood pressure estimation from face video using RGB camera

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Abstract

In this paper, we investigated the correlation between blood pressure (BP) and image-based pulse transit time (iPTT) acquired from only face using RGB camera. In general, the value of iPTT can be calculated from a transition time at peaks of hemoglobin amount which is extracted from RGB values of the camera. The transition time of peaks is obtained by time of the peak at the face and the palm. In the previous research, it is known that there is a correlation between BP and iPTT. Therefore, blood pressure can be estimated by acquiring iPTT from video taken using RGB camera. However, it is necessary to take video of face and palm simultaneously in this conventional iPTT measurement method. It is difficult to take the video of face and palm simultaneously. In order to solve this problem, we investigated whether iPTT can be acquired from a single part of body. At first, we took a video of face and palm using a high-speed camera and investigated whether the pulse wave flow can be observed. As a result, we were able to observe the propagation of the pulse wave in the regions of face and palm. Hence, iPTT acquisition from the single part of body is expected to be possible in these two parts. Next, we set a region of interest (ROI) on the chin and the forehead for the face, and the center of the palm and thenar for the palm. Then, pulse waves were extracted from each region, and iPTT was calculated from each part. We found that iPTT acquired from face is long and stable, but iPTT acquired from palm is short and unstable. Moreover, we examined the correlation between blood pressure and iPTT acquired from face. Consequently, a correlation was found between blood pressure and iPTT acquired from only face.

1. Introduction

Blood pressure is an important indicator of the physical health. The blood pressure generally refers to the pressure inside the artery, and the value of the blood pressure depends on the amount of blood sent out from the heart, the elasticity of the blood vessel, the viscosity of the blood. Blood pressure changes greatly by the contraction of the heart, and there are two types of blood pressure: maximum value (systolic blood pressure) and minimum value (diastolic blood pressure). When blood pressure is high, cardiovascular disease progresses unconsciously, and there are risks of causing life-threatening complications such as heart failure, myocardial infarction, cerebral infarction and cerebral hemorrhage. It is possible to detect illness earlier by measuring the blood pressure on a daily basis. Blood pressure is also the important indicator to monitor the condition of patients being treated at hospitals.

Current measurement methods of blood pressure are invasive and contact type. This can be serious obstacle for people suffering from skin diseases, infants and elderly people. In addition, movement of the body is restrained because it is necessary to attach a dedicated equipment on the body, thus it causes mental stress and discomfort to the patient. Therefore, it is desired to realize a simple and non-contact blood pressure measurement that does not require the dedicated measuring equipment. As one of the methods to estimate blood pressure, a method using pulse transit time (PTT) has been proposed [1]. PTT means the time taken for pulse wave propagation. That is obtained from photoelectric pulse wave meter and electrocardiograph. Since this time difference (PTT) correlates with blood pressure, blood pressure can be estimated.

In the recent research, a new method for estimating blood pressure has been proposed [2]. A method of estimating blood pressure with non-contact type has been proposed by acquiring iPTT from video of the face and palm. It is suggested that it is possible to realize non-contact and non-invasive blood pressure measurement by using this method. However, the limitation of the taking a video is extremely large because it is necessary to take a video of face and palm simultaneously.

In this research, therefore, we propose a non-contact, non-invasive, and low-restrictive blood pressure estimation method that uses only face video. In Section 2, we will introduce methods for acquiring the pulse wave in contact and non-contact. In Section 3, we will introduce the principle of non-contact blood pressure estimation. In Section 4, we will introduce proposed method. In Section 5 and 6, we will describe experimental method and result. Finally, in Section 7, we will conclude our research.

2. Methods for Estimating Pulse Wave

Pulse wave can be defined by the pulsation of blood vessels accompanying blood ejection of the heart. Pulse wave is changed by blood pressure change and volume change of the peripheral vasculature associated with the heartbeat.

2.1. Contact Method

In the contact type measurement of pulse wave, a measuring equipment called a photoelectric pulse wave meter is used. There are two types of photoelectric pulse wave meter, reflection type and transmission type. In this paper, we explain the reflection type. In the reflection type, infrared light, red light, and light of green wavelength around 550 [nm] are irradiated toward the skin. Blood in the artery is mainly organized by oxygenated hemoglobin and the deoxygenated hemoglobin which have characteristic of absorbing incident light. This characteristic can be used to extract the amount of the oxygenated hemoglobin. Therefore, a pulse wave can be acquired by the above method.

2.2. Non-Contact Method

In order to acquire a pulse wave in a non-contact, a method using an RGB camera has been proposed. That is called image-based photo plethysmography (iPPG). Verkruysse *et al.* proposed method for acquiring pulse waves by calculating temporal changes in average pixel values of G signals of ROI [3]. The method using the G signal is most common as it requires a small amount of calculation and is simple. However, it is known that it is weak against noise such as flicker of illumination light and the accuracy is not high. Therefore, many improved iPPG methods were proposed for robust measurement [4-7]. In this paper, we introduce one of the improved methods in next paragraph.

Fukunishi *et al.* proposed iPPG method which acquires pulse wave with high accuracy with robustness against illumination [8]. In this method, the pulse wave is acquired using skin pigment separation proposed by Tsumura *et al.* In this iPPG method, the video of the skin is separated into three components of hemoglobin, melanin, and shadow using a pigment component separation [9]. The hemoglobin component correlates with the skin blood volume. Set the ROI in the hemoglobin component and calculate the average pixel value in the ROI. The temporal change in the average pixel value means the pulse wave. The acquired pulse wave includes noise caused by the influence of body motion or the like. This noise is called a trend, which needs to be removed. This process is called detrend. Detrend is realized by approximating the signal with a low order polynomial and subtracting the polynomial from the signal. Next, in order to remove high frequency noise, a band-pass filter is applied to the acquired pulse wave. That filter transmits a band of 48 to 120 [bpm], which is a frequency band of the pulse rate. The shaped pulse wave is acquired by this processing. It is known that iPPG using skin pigment separation is more accurate than iPPG using G signal.

3. Conventional Method for Estimating Blood Pressure

In this section, we describe the conventional method of acquiring pulse transit time (PTT) and image-based pulse wave propagation time (iPTT). We also describe the method of estimating blood pressure from PTT and iPTT.

3.1. Pulse Wave Transit Time (PTT)

The pulse wave propagates along the artery from the heart to the end of the body. The time taken for the pulse wave to propagate between certain portions of the blood vessel is called a pulse transit time (PTT). Pulse wave velocity (PWV), which is the speed of pulse wave propagates between body parts, can be obtained by dividing this PTT by the distance between the parts. The following relational expression is established:

$$\mathrm{PWV} = \frac{L}{\mathrm{PTT}} \tag{1}$$

Here, L presents the difference in distance to the heart of the two measured sites.

3.2. Contact Method of PTT Measurement

PTT can be acquired a pulse wave at two different points on the body surface. PWV can be measured from PTT and the distance between the two points on the body surface [10]. As a contact type measurement method of PTT, there is a method using an electrocardiograph and a photoelectric pulse wave meter. In this method, the cardiac output start time is measured by the electrocardiograph, and pulse wave arrival time at the fingertip is measured by the photoelectric pulse wave meter. This time difference is PTT. Fig. 1(a) shows definition of PTT.

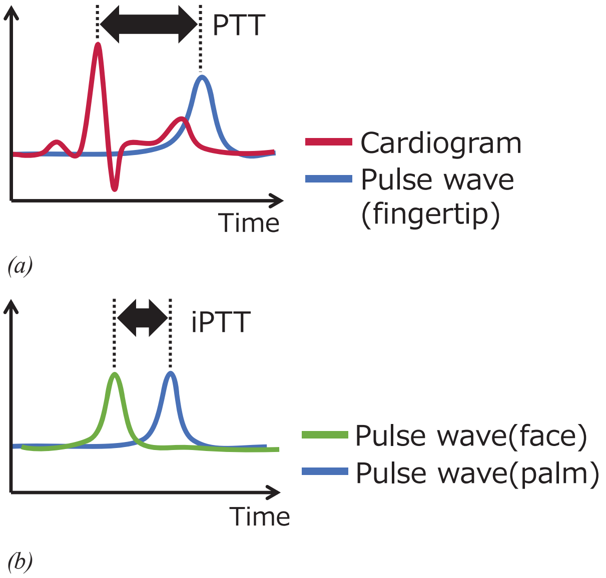


Figure 1. *Definition of indicator: (a) PTT, (b) iPTT*

3.3. Non-Contact Method of iPTT Measurement

For measurement of iPTT, we use iPPG using skin pigment separation that is described in section 2.2. It is possible to measure the iPTT by measuring pulse wave at two places in the body surface and measuring the time difference of the pulse wave. It is known that the part where the pulse wave can be acquired by iPPG is limited to the face, the palm, the sole, thus it is difficult to acquire the pulse wave from other places [11]. It is thought that this is affected by the thickness of the skin. Fig. 1(b) shows definition of iPTT.

The value of iPTT largely fluctuates due to the deviation of the peak caused by the noise included in the pulse wave, and the error becomes extremely large because iPTT is a very short time. If the iPTT is a long time, the deviation of the peak with respect to the time of the entire iPTT becomes small. As a result, the error becomes relatively small. In order to reduce the error of iPTT, iPTT must be obtained from two locations, close to the heart and far from the heart. Therefore, iPTT is acquired using a video of a face and a palm which is easy to acquire a pulse wave.

It is necessary to obtain the time difference of the pulse wave acquired from the two parts to measure iPTT. iPTT can be obtained by calculating the time difference of the peak of pulse wave.

3.4. Estimation Method of Blood Pressure

There is a correlation between PWV and blood pressure. An expression representing this relationship quantitatively is Moens-Korteweg's equation [12]. Moens-Korteweg's equation is expressed by the following equation.

$$\mathrm{PWV} = \sqrt{\frac{E_{inc} \times h}{2r\rho}} \tag{2}$$

Here, h presents the blood vessel wall thickness. r presents the radius of the vessel. ρ presents blood density. E_{inc} presents Young's modulus of blood vessel wall.

The Moens-Korteweg's equation is approximated to an expression using blood pressure and blood vessel radius as parameters [13]. An approximate expression of Moens-Korteweg's equation is expressed by the following equation.

$$\mathrm{PWV}^2 = \frac{\beta P}{2\rho} \qquad (3)$$

Here, β presents stiffness parameter that means the hardness of a blood vessel. P presents blood pressure. From this equation, when the blood density ρ and the stiffness parameter β are constant, the PWV also increases as the blood pressure P increases. From the above, it can be seen that there is a correlation between PWV and blood pressure. Section 3.1 explained that PTT is the distance L between measured parts divided by PWV. Therefore, there is a negative correlation between PTT and blood pressure. blood pressure estimation can be realized by formulating this relationship.

4. Proposed Method for Estimating Blood Pressure

In the conventional method, it was necessary to take a video of face and palm at the same time. In this section, we propose a method to measure iPTT from only face.

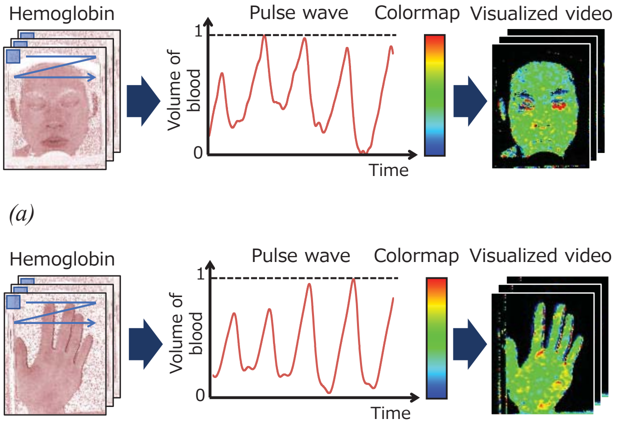
4.1. Visualization of Blood Flow Propagation

According to the previous research, it is known that the parts where pulse waves can be acquired are limited in the face and the palm. PTT is acquired by simultaneously taking the video of the face and palm. Therefore, the limitation of the person to be measured is large when estimating blood pressure since the face and the palm are taken video at the same time. In this experiment, pulse wave propagation is visualized to investigate whether there is a place where iPTT can be acquired at a single part of body.

Visualization of pulse wave propagation is performed in the following procedure. First, a video of a skin is divided into small areas. Next, the hemoglobin component is extracted using skin pigment separation, and a pulse wave is acquired for each divided region. Finally, the area of the skin is colored with a heat-map to be red in the region with high value of the pulse wave and blue in the region with low value. In the visualization of pulse wave propagation, a high frame rate video is required to show the state of propagation accurately. In this experiment, we take a video with 1000 [fps] using high speed camera. The procedure of visualization method is shown in Fig. 2.

4.2. Position of ROI for Measurement of iPTT

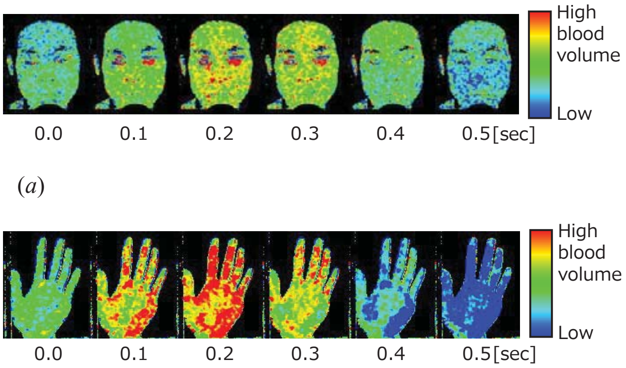
The pulse wave propagation in the face and palm region acquired by visualization are shown in Fig. 3. These figures show the change of pulse wave propagation during 0.5 second. Fig. 3(a) shows the transition of the peak of pulse wave from the chin to the forehead in the face region. The result of visualization in face region is reasonable since the blood vessel extends from the neck to the forehead, and the pulse wave propagates in this direction. In addition, Fig. 3(b) shows transition of the peak of the pulse wave around the thenar in the palm area. The result of this visualization in palm region is also reasonable since blood vessels pass under the thenar. From the above results, it was found that the propagation of the pulse wave can be confirmed in the face and palm region. Therefore, iPTT can be acquired at a single part of body by setting the ROIs for chin and forehead in the face region, or thenar and center of the palm in the palm region.



(a)

(b)

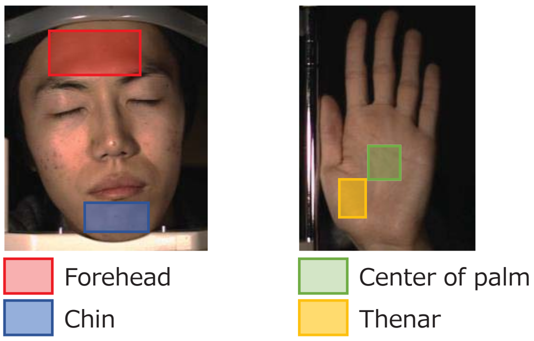
Figure 2. *Procedure of pulse wave visualization: (a) face region, (b) palm region*



(a)

(b)

Figure 3. *Visualization of pulse wave using RGB camera: (a) face region, (b) palm region*



(a) (b)

Figure 4. *ROI setting for measurement of iPTT: (a) face region, (b) palm region*

As a preliminary experiment, we measure iPTT by setting the ROIs in the chin and forehead, and thenar and center of the palm. The ROIs set for the face and the palm are shown in the Fig. 4. As a result, stable iPTT was obtained from chin and forehead. However, the iPTT acquired from the palm frequently became a negative value and was unstable. This is because the ROI that can be set for the palm is small and iPTT is short. For the above reasons, we set ROIs for chin and forehead to acquire iPTT. Survey is necessary for iPTT from chin and forehead because it is shorter than iPTT from face and palm, and iPTT from chin and forehead is unknown whether it is correlated with blood pressure.

Therefore, in this research, we investigate the correlation between iPTT and blood pressure obtained by setting ROIs for the chin and forehead in the face region.

5. Experimental Method

In the experiment, blood pressure, PTT by contact method and iPTT are measured. PTT is used to verify the accuracy of iPTT.

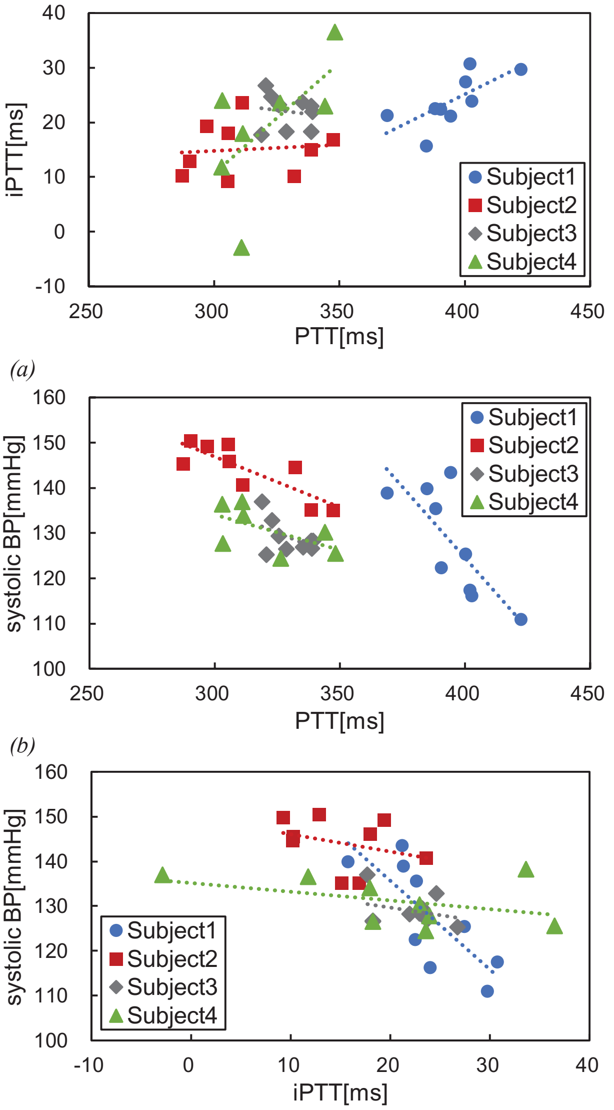
5.1. Experimental Setup and Subject

Experimental environment of this experiment is shown in Fig.5. Blood pressure is measured using a continuous sphygmomanometer (*ClearSight*) capable of measuring blood pressure continuously. The electrocardiogram and the photoelectric pulse wave are measured using a vital monitor (*ProComp*) for the PTT measurement by the contact type. This can acquire a plurality of biological signals. We measure electrocardiogram and pulse wave at 2048 [fps] using vital monitor. As a camera to acquire a pulse wave, we use high speed camera (*MEMRECAM Q1m*). This camera can take a picture in linear RGB color space. In this experiment, the resolution is set to 1280 × 1024[px], the frame rate is set to 500 [fps], and the bit depth is set to 12[bit], and we take a video for about 8.6[sec] in darkroom. We use an artificial sun rump (*SOLAX*) as the light source. That has components of all wavelengths in visible light. A list of equipment is shown in Table 1.

Table 1. Details of experimental equipment

Experimental equipment	Details
High speed camera *MEMRECAM Q1m* (nac Image Technology Inc.)	・Maximum resolution: 1280×1024[px] ・Maximum frame rate: 2000[fps] (1280×1024[px]) ・Maximum recording time: 8.7[sec] (1280×1024[px], 500[fps]) ・Bit depth: 12[bit]
Continuous sphygmomanometer *ClearSight Finger Cuff/HRS EV1000 NI* (Edwards Lifesciences Corporation.)	・Time continuous acquisition of blood pressure, cardiac output, oxygen saturation etc. ・Measurable non-invasively
Electrocardiograph and plethysmography *Vital monitor ProComp* (Thought Technology)	・Measurement is possible with a maximum of 2048 [Hz]
Illumination *Artificial sun light SOLAX 100W* (SERIC LTD.)	・Output light close to the spectral distribution of sunlight

Figure 5. *Experimental environment*



(a)

(b)

(c)

Figure 6. *Relationship among multiple acquired parameters: (a) PTT and iPTT, (b) PTT and systolic BP, (c) iPTT and systolic BP*

Table 2. Relation between PTT and iPTT

Participants	PTT [ms]				iPTT(chin and forehead) [ms]				Correlation
	Mean	SD	Min	Max	Mean	SD	Min	Max	r (PTT vs iPTT)
1	394.64	13.88	368.69	422.10	23.93	4.44	15.78	30.75	0.7107
2	312.56	20.39	287.11	347.12	15.07	4.58	9.25	23.60	0.0986
3	329.78	7.80	318.85	339.16	21.96	3.00	17.71	26.75	-0.1497
4	320.96	17.46	302.81	348.14	20.66	11.01	-2.86	36.50	0.6243

Table 3. Relation between PTT and systolic BP

Participants	PTT [ms]				Systolic BP [mmHg]				Correlation
	Mean	SD	Min	Max	Mean	SD	Min	Max	r (PTT vs SBP)
1	394.64	13.88	368.69	422.10	127.88	11.25	111.00	143.60	-0.7747
2	312.56	20.39	287.11	347.12	144.09	5.52	135.20	150.50	-0.8272
3	329.78	7.80	318.85	339.16	129.01	3.49	125.25	137.00	-0.5029
4	320.96	17.46	302.81	348.14	131.14	5.06	124.50	138.20	-0.5730

Table 4. Relation between iPTT and systolic BP

Participants	iPTT(chin and forehead) [ms]				Systolic BP [mmHg]				Correlation
	Mean	SD	Min	Max	Mean	SD	Min	Max	r (iPTT vs SBP)
1	23.93	4.44	15.78	30.75	127.88	11.25	111.00	143.60	-0.7820
2	15.07	4.58	9.25	23.60	144.09	5.52	135.20	150.50	-0.3217
3	21.96	3.00	17.71	26.75	129.01	3.49	125.25	137.00	-0.2900
4	20.66	11.01	-2.86	36.50	131.14	5.06	124.50	138.20	-0.4235

Subjects in this experiment are healthy 4 men from 22 to 25 years old. For these 4 subjects, we explained risks in writing and verbally, and obtained their consent.

5.2. Experimental Procedure

The subjects are asked to have enough rest, and after the rest we measure PTT, iPTT, and systolic BP (SBP) with the above-mentioned experimental environment. And then, the subjects are asked to do exercise that is bending and stretching legs to change their blood pressures. As the result, we could measure the above values with the various blood pressures. The procedure of the experiment is as follows. First, measurement is performed for about 8.6 seconds three consecutive times after the rest. Next, after performing bending and stretching exercises three times, the same measurement of about 8.6 seconds is repeated three times. Finally, after five bending and stretching exercises, the same measurements are repeated three times. In such a procedure, measurement is performed nine times in all three states in a rest state, after a small load, and after a large load. The nine measurements are performed consecutively. This experiment is done in one day.

6. Result

The relation between PTT and iPTT is shown in the Table 2. The relation between PTT and systolic BP is shown in the Table 3. The relation between iPTT and systolic BP is shown in the Table 4. In the table, mean value (Mean), standard deviation (SD), Minimum value (Min), Maximum value (Max) are used for evaluation. The average times of iPTT (chin and forehead) for all subjects were 15.07 to 23.93 [ms] and it was found that it was able to obtain stably.

6.1. PTT vs iPTT (Chin and Forehead)

The relationship between PTT obtained by contact type and iPTT (chin and forehead) is shown in Fig. 6(a). There was a positive correlation between the two subjects. In addition, there was no correlation in one subject and a small negative correlation in one subject. Relatively strong positive correlation was observed between subjects 1 and 4 with correlation coefficients of 0.7107 and 0.6243 respectively. Positive correlation should be observed between PTT and iPTT. However, only two subjects were observed positive correlation. In subjects with narrow range of PTT, we can observe that the correlation tends to be small.

6.2. PTT vs Systolic BP

The relationship between PTT obtained by contact type and systolic BP is shown in Fig. 6(b). Strong negative correlation is observed among all the subjects, and the correlation coefficient is about -0.5029 to -0.8272. In subjects with narrow range of blood pressure, we can observe that the correlation tends to be small.

6.3. iPTT (chin and forehead) vs Systolic BP

The relationship between the iPTT obtained by setting the ROI on the chin and forehead, and the systolic BP is shown in Fig. 6(c). A negative correlation is observed among all subjects, and the correlation coefficient is about -0.2900 to -0.7820. In subjects with small change of blood pressure, we observe that the correlation tends to be small. It is considered that the iPTT contains error and the correlation became small because the body movement of the subject 4 was large. For this result, the correlation was found between iPTT acquired from the only face and systolic BP although there was a subject with a weak correlation.

7. Conclusion and Future Work

In this research, we found that it is possible to acquire iPTT from the only face part in the video. Moreover, correlation was found between iPTT (chin and forehead) and systolic BP. Conventionally, it is difficult to realize the blood pressure estimation in real environment due to the large restriction of posture. This method will realize the non-contact, non-invasive, and low-restrictive blood pressure estimation easily. However, it is necessary to improve the accuracy in order to realize this method in real environment.

In this research, different regression equation is required for each individual to obtain blood pressure. However, relative change of blood pressure can be obtained from iPTT without regression equation. Therefore, it can be considered that it is possible to detect sudden blood pressure fluctuation from video of the face using the RGB camera in the future.

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