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Non-Contact Video Based Estimation of Pulse Transit Time using Quantitation Method of Hemoglobin Level

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Abstract

Blood pressure is usually measured with a contact device called a sphygmomanometer cuff. Recently blood pressure can be easily measured with portable devices such as smart watches that take advantage of the progress of mobile technology. Even with the use of mobile devices, contact measurement is still required, which is one of the biggest limitations for monitoring.

In this paper, we propose non-contact video based estimation method of pulse transit time (PTT) based on the quantitation method of hemoglobin level. The correlation between PTT measured by the proposed method and the blood pressure measurement with sphygmomanometer cuff was between -0.5792 to -0.7801, which confirms the effectiveness of the proposed method.

1. Introduction

Blood pressure is related to the functional status of heart and blood vessels and one of the most important vital signs. The measurement of blood pressure is crucial to detect hypertension patients, to prevent, control and follow up with them. In most cases, it is measured with sphygmomanometer cuff, which requires the subject to remain still. It restricts the frequency and convenience of usage.

With the progress of mobile devices, new measurement techniques show up recently. OMRON [1] announced the blood pressure measurement for smart watch. However it still requires contact measurement, which limits application from a wide variety of use cases. In order to expand the usage, non-contact vital sensing techniques have been studied for several years. Verkruysse et al. [2] demonstrated the measurement of the blood volume pulse (BVP) signal under ambient light. McDuff et al. [3] proposed the method of remote BVP measurement and heart rate variability spectrogram (HRVS) measurement using a multi band camera. Karapetyan, et al. [4] also demonstrated remote BVP measurement with a smartphone device.

For the non-contact measurement of Pulse Transit Time (PTT), which is the gap between two blood volume pulses at two parts of the body, Shao et al. [5] developed non-contact PTT measurement using a conventional camera. The method measures the green channel in the hand and face region and calculates PTT using the delay in the peak times. Murakami at el. [6] measured PTT with the green channel peaks with regions of the hand and ankle and evaluated the relation with blood pressure. On the other hand, Tsumura el al. [7] proposed a method to estimate hemoglobin level and blood amount from a biological color image. The method potentially improves the accuracy of estimation of BVP timing since the amount of blood and hemoglobin level are correlated with BVP.

In this paper, therefore, we propose a non-contact video based estimation method of pulse transit time (PTT) using the quantitation method of hemoglobin level. In section 2, we present how to extract hemoglobin information from a biological color image. In section 3, we describe the method of obtaining BVP and PTT. In section 4 and 5, we describe the experimental results and conclusion, respectively.

2. Extraction of Hemoglobin Information from a Biological Color Image [7]

Figure 1 shows the skin model of hemoglobin level estimation. Human skin can be roughly classified into two layers, epidermis and dermis. Epidermis has melanin pigments, and dermis has hemoglobin pigments. Some of the incident light illuminated onto skin is reflected on the surface as surface reflection. Others go into the epidermis and dermis. In those medium, the light undergoes internal reflection where it bounces randomly and comes to the surface of the skin. In the process of internal reflection, some of the light is absorbed by the melanin and hemoglobin pigments. The modified Lambert-Beer law is an approximate model of internal light behavior. The spectral radiance $L(x,y,\lambda)$ of internal reflection is

$$L(x,y,\lambda) = e^{-\rho_m(x,y)\sigma_m(\lambda)l_e(\lambda)-\rho_h(x,y)\sigma_h(\lambda)l_d(\lambda)}E(x,y,\lambda) \quad (1)$$

where $E(x,y,\lambda)$ denotes the spectral irradiance of incident light at point (x,y), $\rho_m(x,y)$, $\rho_h(x,y)$ denote the concentration, $\sigma_m(\lambda)$, $\sigma_h(\lambda)$ denote absorption area melanin and hemoglobin respectively, and $l_e(\lambda)$, $l_d(\lambda)$ denote light path in the epidermis and dermis layers. By putting polarization filters in front of the illumination and camera, we can ignore surface reflection. Camera signal $v_i(x,y)$, $i = R,G,B$, can be modeled as

$$\begin{aligned} v_i(x,y) &= k\int L(x,y,\lambda)s_i(\lambda)d\lambda \\ &= k\int e^{-\rho_m(x,y)\sigma_m(\lambda)l_e(\lambda)-\rho_h(x,y)\sigma_h(\lambda)l_d(\lambda)}E(x,y,\lambda)s_i(\lambda)d\lambda \\ &\quad (i = R,G,B) \end{aligned} \quad (2)$$

,where $s_i(\lambda)$ denotes the spectral sensitivity of a camera, k denotes coefficient of camera gain.

Spectral reflection of skin is smooth and it is roughly correlated with camera sensitivity. We approximately assume $s_i(\lambda) = \delta(\lambda_i)$.

We assume spectral irradiance of incident light $\overline{E}(\lambda)$ is uniform over the observation area, and the shading coefficient,

$p(x,y)$, is accounts for the concavity and convexity of the surface. We derive

$$E(x,y,\lambda) = p(x,y)\bar{E}(\lambda). \tag{3}$$

Camera signal $v_i(x,y)$ can be simply rewrite as

$$v_i(x,y) = ke^{-\rho_m(x,y)\sigma_m(\lambda)l_e(\lambda)-\rho_h(x,y)\sigma_h(\lambda)l_d(\lambda)}p(x,y)\bar{E}(\lambda) \tag{4}$$

By taking the logarithm of both sides of Equation (4), we derive

$$\boldsymbol{v}^{\log}(x,y) = -\boldsymbol{\rho}_m(x,y)\boldsymbol{\sigma}_m - \boldsymbol{\rho}_h(x,y)\boldsymbol{\sigma}_h + p^{\log}(x,y)\boldsymbol{1} + \boldsymbol{e}^{\log} \tag{5}$$

where

$$\begin{aligned}
&\boldsymbol{v}^{\log}(x,y) = [\log v_R(x,y) \quad \log v_G(x,y) \quad \log v_B(x,y)]^T,\\
&\boldsymbol{\sigma}_m = [\sigma_m(\lambda_R)l_e(\lambda_R) \quad \sigma_m(\lambda_G)l_e(\lambda_G) \quad \sigma_m(\lambda_B)l_e(\lambda_B)]^T,\\
&\boldsymbol{\sigma}_h = [\sigma_h(\lambda_R)l_d(\lambda_R) \quad \sigma_h(\lambda_G)l_d(\lambda_G) \quad \sigma_h(\lambda_B)l_d(\lambda_B)]^T,\\
&\boldsymbol{1} = [1 \quad 1 \quad 1]^T,\\
&p^{\log}(x,y) = \log(p(x,y)) + \log(k).\\
&\boldsymbol{e}^{\log}(x,y) = [\log E_R(\lambda_R) \quad \log E_G(\lambda_G) \quad \log E_B(\lambda_B)]^T
\end{aligned} \tag{6}$$

Figure 2 shows the relation of the RGB signal and each component. The observational RGB vector $\boldsymbol{v}^{\log}$ consists of shading component $p^{\log}$, melanin absorption component $\boldsymbol{\sigma}_m$, hemoglobin absorption component $\boldsymbol{\sigma}_h$ and illumination component $\boldsymbol{e}^{\log}$. In order to estimate each component, we place two restrictions and two assumptions. The first restriction is that the shading component $p^{\log}$ changes along $\boldsymbol{1}$. The second one is the skin color plane that defines the relation between melanin absorption component $\boldsymbol{\sigma}_m$ and hemoglobin absorption component $\boldsymbol{\sigma}_h$. The first assumption is statistical independence of melanin and hemoglobin component. The second assumption is the color of the illumination is stable during the experiment. With those restrictions and assumptions, we can estimate the amount of each component using independent component analysis (ICA).

Figure 3 provides the estimation result of melanin, hemoglobin, and shading components. We can see the mole and pigmented spot in the melanin component and pimples from the hemoglobin component. The shading image looks reasonable to describe the facial structures.

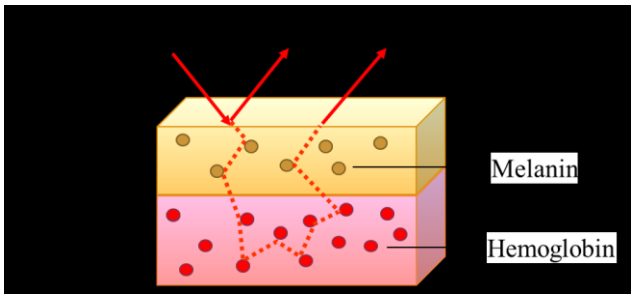


Figure 1 Skin Model for the Estimation Method of Hemoglobin Level [7]

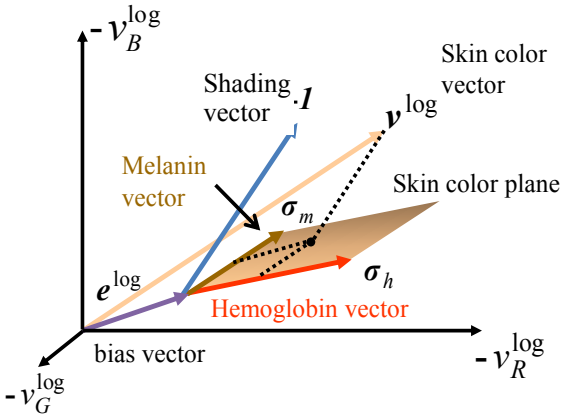


Figure 2 Model of Observation signal

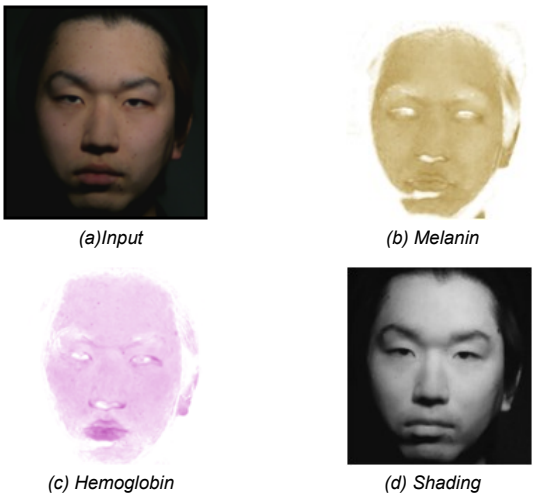
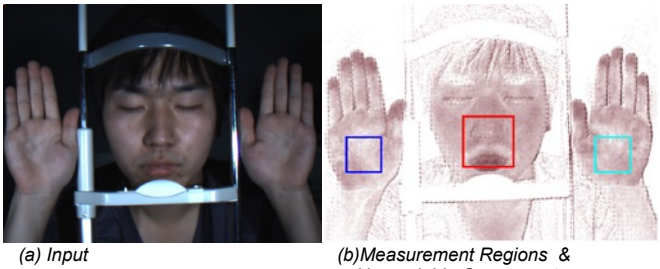


Figure 3 Estimation result of Melanin, Hemoglobin and Shading components



(a) Input (b)Measurement Regions & Hemoglobin Component

Figure 4 BVP and PTT measurement Environment

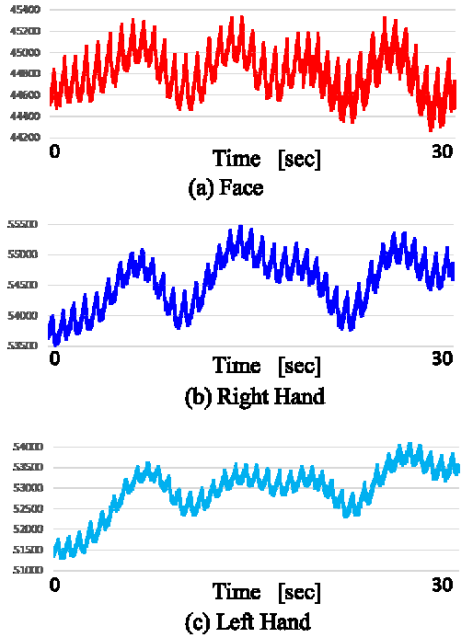


Figure 5 BVP of Measurement Regions

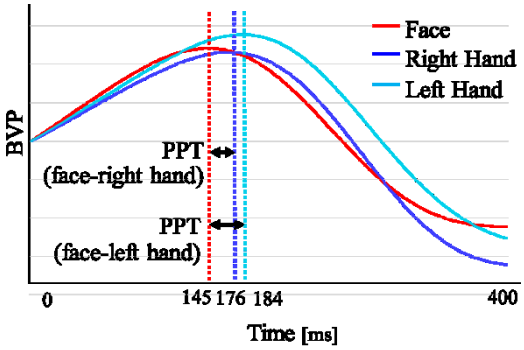


Figure 6 PTT Measurement

3. Setup for BVP and PTT Measurement

In this section, we describe the BVP and PTT measurement scheme.

Figure 4 shows an experimental environment. The video images of the subject's face and hands are taken from a distance of 3 meters. We used a Point Grey Grashopper3 (GS3-U3-23S6C) camera. All videos were recorded in color (30-bit RGB with 3 channels × 10 bits/channel) at 380 frames per second (fps) with pixel resolution of 640 × 480 and saved in AVI format on the laptop. The illumination was an artificial solar light (SOLAX XC-100). The subject put his head on chin-rest and forehead-rest in order to keep the subject as still as possible. Using each frame, we estimate the amount of hemoglobin with the method of Section 2. Figure 4(b) indicates the hemoglobin component of the input image and measurement region. We put measurement region (ROI) on the face, right hand and left hand with pixel sizes of 120 × 120, 70 × 70 and 70 × 70, respectively. We calculate the average value of the hemoglobin component in each ROI.

The temporal change of the hemoglobin component in the face, right hand and left hand regions are shown in Figure 5. Each wave has 37 peaks in 30 seconds.

The peak time differences of each hemoglobin component behaviors indicate PTT as shown in Figure 6. In Figure 6, PTT between face region and right hand is 31 ms (=176-145) and PTT between face region and right hand is 39 ms (=184-145).There is a slight difference. In the paper we use an average of those two PTT's to obtain a representative PTT.

4. Experimental Results

In this section, we first explain the experimental procedure and then the experimental results. The purpose of the experiment is to check the feasibility of our PTT method. For the purpose, we evaluated the correlation between PTT estimated with our proposed method and a blood pressure that is measured by a conventional sphygmomanometer (OMRON HEM-7132).

In order to evaluate a wide variety of blood pressures, we asked subjects to do a squat exercise during repeated videos capture and blood pressure measurements. We evaluate blood pressure using systolic pressure, which is maximum blood pressure, and a mean arterial pressure(MAP), which is the average over a cardiac cycle. MAP can be approximately determined from measurements of the systolic pressure P_{sys} and the diastolic pressure P_{dias}

$$MAP \cong P_{dias} + (P_{sys} - P_{dias})/3. \quad (5)$$

Evaluation results are shown in Figures 7 and 8. The horizontal axes in Figures 7 and 8 are systolic pressure and a mean arterial pressure, respectively. The vertical axis is PTT measured by the proposed method. In the evaluation, we measure PTT and blood pressure repeatedly although we only evaluate a few subjects. The correlation between PTT and systolic pressure is between -0.6050 and -0.7546, and the correlation between PTT and mean arterial pressure is between -0.5792 and -0.7801. We confirmed

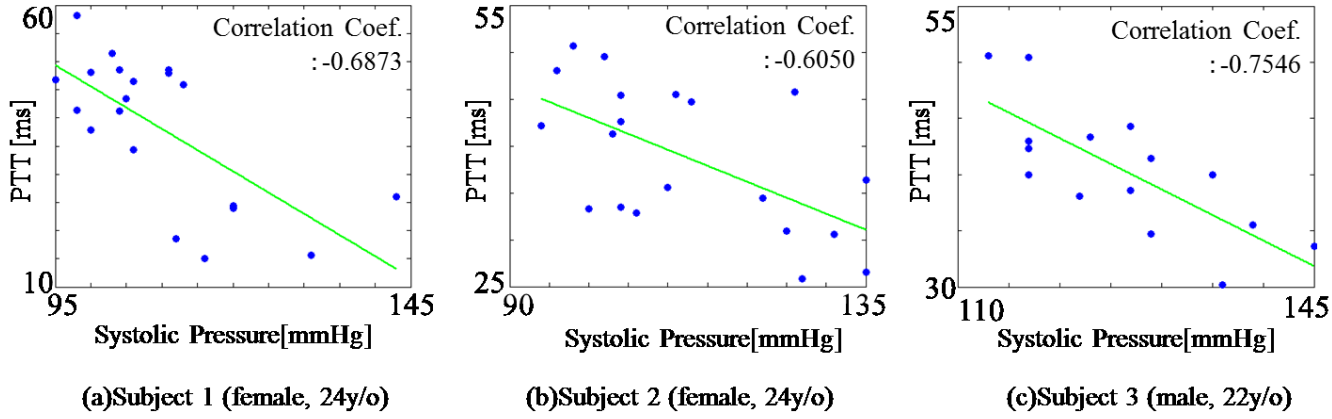


Figure 7 Maximum Blood Pressure and PTT

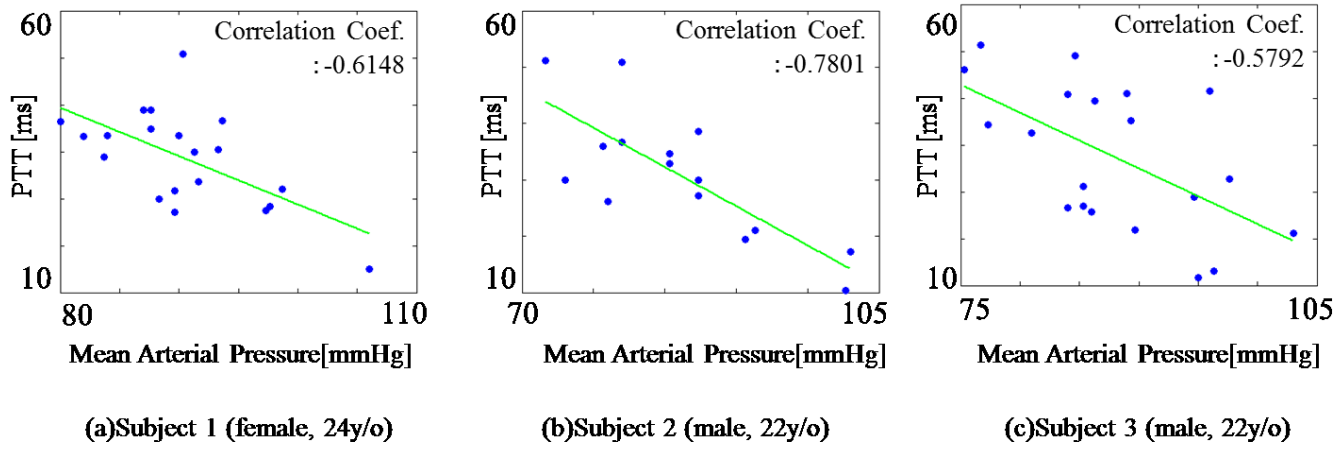


Figure 8 Average Blood Pressure and PTT

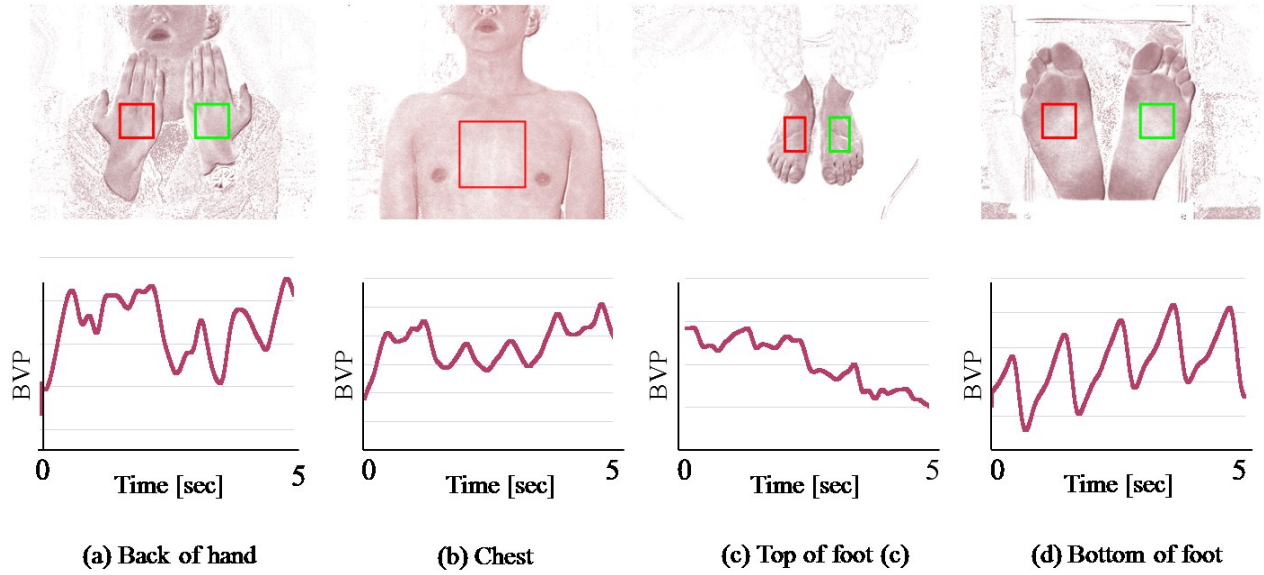


Figure 9 BVP estimation result in Different Body Regions

a high correlation between the proposed method and conventional sphygmomanometer.

We also measure BVP at several body parts as shown in Figure 9. The bottom of foot, palm and face as shown in Figure 4 are suitable to detect BVP. We can see period waves. On the other hand, the back of hand, chest and top of foot are not suitable to detect BVP. Wave shape is not periodic and unstable. This may be caused by the difference in skin thickness. This is a research subject for future work.

5. Conclusion

We proposed a non-contact video based estimation method of pulse transit time (PTT) using the quantitation method of hemoglobin level. We also evaluated the correlation between PTT measured by the proposed method and blood pressure measured by a sphygmomanometer cuff. As a result, we achieved a correlation between -0.5792 and -0.7801, which confirms the effectiveness of the proposed method.

In this paper, we only evaluated Asian subjects. We have to confirm the effectiveness for Caucasian and Negroid subjects as well. Improvement of the hemoglobin estimation model might improve the stability of the PTT measurement.

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