Non-Contact Blood Pressure Estimation Using Video Pulse Waves for Ubiquitous Health Monitoring

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***Abstract* — A non-contact measurement method for estimating blood pressure using video pulse waves has been developed. During fluctuation in blood pressure caused by respiratory arrest, the video pulse waves were measured by using a video camera to calculate the pulse transit time difference (PTTD) from a proximal part to a distal part with respect to the heart. Blood pressure was estimated by a multivariate regression model with the PTTD, heart rate and the pulse amplitude (PA) as explanatory variables. It was suggested that the variation among individuals could be suppressed by using correlation between the model parameters and the changes in the PA.**

I. Introduction

To prevent lifestyle-related diseases, daily-life health monitoring may be useful. For this purpose, many kinds of wearable devices have recently been developed to obtain heart rate, respiration rate, physical activity, and so on. However, it is desirable to develop remote and non-contact measurement methods for obtaining biological information without any special devices and without any conscious equipment operation.

It is notable that video cameras can non-contactly extract information on human dynamic blood perfusion [1-3], which is based on the fact that hemoglobin included in blood vessels absorbs green components of ambient light and then the intensity of reflected light changes with flux and reflux of blood perfusion of the skin. Such pulsatile signals are called "video pulse waves." Video pulse waves enable us to obtain not only heart rate but also information on blood pressure in a remote and non-contact fashion. This is because the change in blood pressure affects the shape of pulse waves and the propagation characteristics of pulse waves from the heart to peripheral vessels.

One method [4] is based on the acceleration pulse wave whose shape feature values are changed with blood pressure. In general, however, video pulse waves are noisier than photo-plethysmograms and thus shape feature values may vary too much to measure accurate blood pressure. Other method [5] utilizes the pulse transit time difference (PTTD) [6] between a proximal part and a distal part of the body. In the literature [2], it has was reported that the PTTD in the video pulse wave between the face and the palm correlated well with blood pressure measured by a blood pressure monitor with a cuff.

In the present study, we have proposed a method using other pieces of information extracted from video pulse waves as well as the PTTD to obtain more accurate blood pressure.

II. Methods

Figure 1 shows the experimental setup. The participant's face and hand were fixed with a chin rest and a hand rest, respectively. A color video camera (Baumer; TGX02c; Fig.1c)) with a frame rate of 120fps was used to take video image (640 × 480 pixels) including two regions of interest (ROIs): palm (Fig.1a)) and cheek (Fig.1b)). A continuous blood pressure sensor (Biomedical Instrumentation; Portapres; Fig.1e)) was used to measure blood pressure at the middle finger of the left hand at the rate of 1 kHz.

The video pulse wave signal was extracted from mean intensity of the green component of the video signal over each ROI as shown in Fig.2. A band-pass filter with the pass-band between 0.8Hz and 1.5Hz was used to limit the signal to cardiac frequency components. As shown in Fig. 3, the foot to foot interval (*FFI* [s]) is defined as the time interval between two adjacent foots of a pulse wave. The heart rate (*HR* [bpm]) is calculated as the reciprocal of the

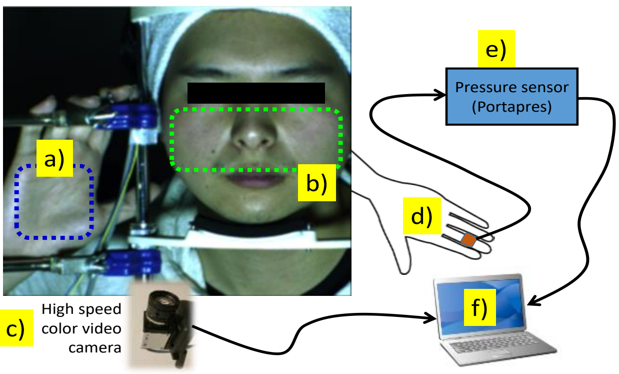

Fig. 1 Experimental setup. a) Palm (distal part). b) Cheek (proximal part), c) High speed video camera. d) Finger probe for pressure sensing. e) Pressure sensor (Portapres). f) Personal computer.

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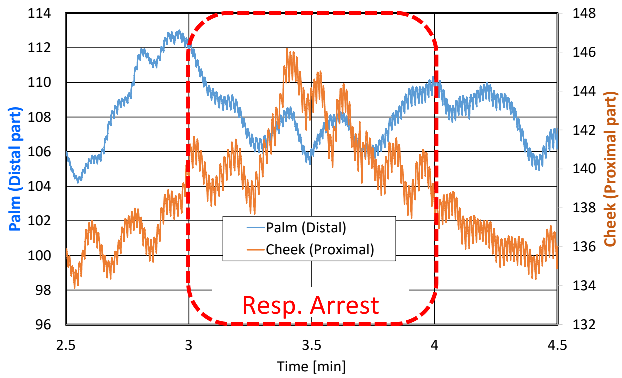

Fig.2 Examples of video pulse waves. Respiratory arrest was performed during the time interval surrounded by the broken line.

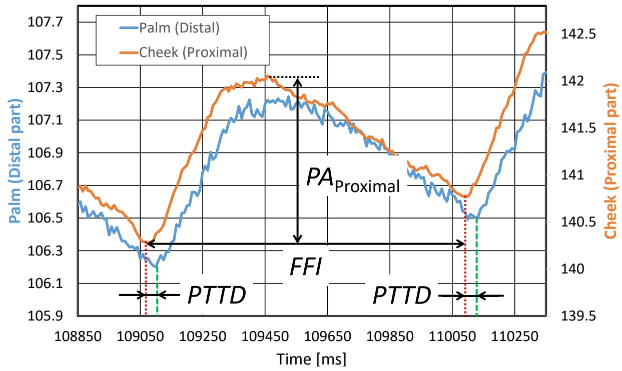

Fig.3 Definition of foot to foot interval (*FFI*), pulse amplitude (*PA*), and pulse transit time difference (*PTTD*).

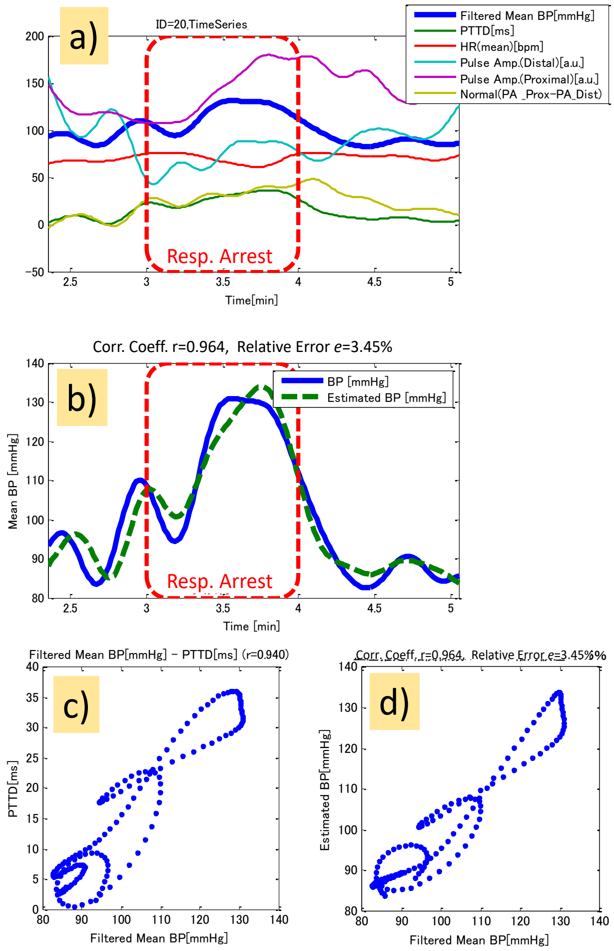

Fig.4 Example of blood pressure estimation (the case of the maximum correlation coefficient; participant ID=20). a) Time series after a low-pass filter. b) Actual *BP* and its estimate. c) Correlation plot between *BP* and *PTTD*. d) Correlation plot between actual *BP* and its estimate.

FFI multiplied by 60. The pulse amplitude (*PA* [a.u.]) is defined as the difference between the maximum and minimum values over one beat. The pulse transit time difference (*PTTD* [ms]) is defined as the time difference between foots of two waves corresponding to the two ROIs (the proximal and distal parts from the heart).

Let $k = 0,1,2\cdots$ denote discrete time with the resampling period of 1s, $\boldsymbol{x}(k)$ an input vector, $\hat{y}(k)$ an estimated output (mean blood pressure), $\boldsymbol{b}$ coefficient vector, and $\varepsilon(k)$ a residue. A multivariate regression model represented by (1) was used, in which $\boldsymbol{b}$ was identified with the least squares method.

$$\hat{y}(k) = \boldsymbol{b}^{\mathrm{T}} x(k) + \varepsilon(k) = [b_1 \;\; b_2 \;\; b_3 \;\; b_4] \cdot [1 \;\; PTTD(k) \;\; HR(k) \;\; PA_{\mathrm{Proximal}}(k)]^{\mathrm{T}} + \varepsilon(k) \quad (1)$$

where $PTTD(k)$ [ms], $HR(k)$ [bpm], $PA_{\mathrm{Proximal}}(k)$ [a.u.] are the time series of the pulse transit time difference, heart rate, and the pulse amplitude of the cheek (proximal part). We can propose many other models whose input vector consists of variable combinations of many parameters extracted from the video pulse waves. In this study, we chose a simple combination of the parameters which are strongly related to the change in blood pressure such as (1).

To ascertain this algorithm, twenty healthy students participated. A participant was sitting at rest condition for 7 minutes within which one minute-long respiration arrest was performed to cause a drastic change in blood pressure.

III. RESULTS AND DISCUSSION

Figures 4 and 5 are examples of blood pressure estimation (from 2min 20s to 5min 10s) given by the multivariate regression model (1). These are, respectively, the results from participants with the maximum (*r*=0.964, estimation error: 3.45%) and minimum (*r*=0.179, estimation error: 5.79%) correlation coefficients. In each figure, a) is

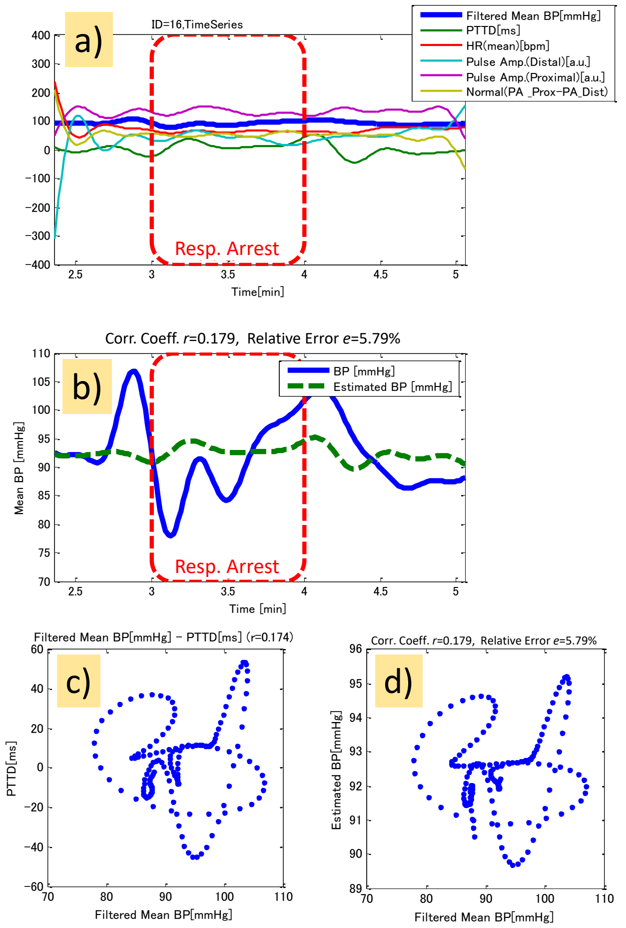

Fig.5 Example of blood pressure estimation (the case of the minimum correlation coefficient; participant ID=16). a) Time series after a low-pass filter. b) Actual *BP* and its estimate. c) Correlation plot between *BP* and *PTTD*. d) Correlation plot between actual *BP* and its estimate

the time series after a low-pass filter with a cut-off frequency of 0.05Hz, b) is the correlation plot between mean blood pressure (BP) and the PTTD, c) is the actual value of BP and its estimate, and d) is the correlation plot between the actual value of BP and its estimate.

The mean values of over the total 20 participants are as follows:

Correlation coefficient: r=0.582 (±0.199)
Estimation error: e=5.3[%] (±1.66)
b_1: Bias=109[mmHg] (±56.7)
b_2: PTTD=0.224 (±0.434) [mmHg/ms]
b_3: HR=-0.233 (±0.59) [mmHg/bpm]
b_4: PA_Proximal=-15.9 (±26.8) [mmHg]

Of course, identification of the coefficients of the multivariate regression model needs the true value of blood pressure. A simple method for estimating blood pressure without using the true value is to use each mean value of coefficients b_1-b_4 over the total 20 participants. Applying this method, we obtained the result as follows:

Correlation coefficient: r=0. 294 (±0.33)
Estimation error: e=14.0[%] (±6.09)

The values resulted in too lower correlation and too worse error to apply the model to practical use. To improve this defect, we should use other feasible information except the true values of blood pressure. One of such information may be the correlation relationship between the coefficients and the difference in the PTTD, the heart rate, or PA between before and after respiratory arrest.

IV. Conclusions

In this study, a multivariate regression model with explanatory variables obtained from the video pulse wave was used for non-contactly estimating mean blood pressure. The mean estimation error was small in the case of use of each participant's model but in the case of use of the model with mean coefficients over all participants, estimation accuracy was worse. It was suggested that to improve this defect, we should use other feasible information except the true values of blood pressure such as the correlation between the coefficients and the variation in information extracted from video pulse waves.

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