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Feasibility Study of Pulse Width at Half Amplitude of Camera PPG for Contactless Blood Pressure Estimation

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Abstract— **Non-contact blood pressure (BP) estimation with imaging photoplethysmogram (PPG) that can be acquired by camera is a promising alternative to cuff-based technology because of its nature of pervasive, low-cost, and being continuous. Most of the non-contact BP estimation methods are based on the principle of pulse transit time (PTT) as being used for wearable cuffless BP measurement. However, PTT-based method on the one hand requires simultaneous capture of images of multiple skin sites with the sites being at a distance from each other; and on the other hand, it can only partially reflect BP changes according to previous studies. In this paper, we propose to use a different camera PPG feature that has not yet been fully studied – pulse width at half amplitude (PWHA) for the evaluation of BP in a non-contact way. PWHA can be obtained from a single-site camera PPG, and it can indicate BP changes. The relationship of PWHA and BP was analyzed on 16 healthy subjects with BP changes induced by deep breathing and stepping exercise. The results showed that beat-to-beat PWHA can well track dynamic BP changes, and it is inversely related to BP across the sampled population and within each individual with about 80% individuals having high correlations. The findings suggest that PWHA can reflect the dynamic changes in cardiovascular characteristics and thereby BP changes, demonstrating the feasibility of imaging PWHA for non-contact BP estimation beyond the PTT method.**

Clinical Relevance— **This provides a potential new method for non-contact BP, which allows BP monitoring at home, clinical setting, and public places in a pervasive manner. It reduces contacts between persons during a pandemic and offers an ever-present way to monitor BP.**

I. Introduction

Cardiovascular diseases (CVDs) are the leading cause of mortality and a major contributor to disability in the world. High systolic blood pressure (SBP) is one of the principal modifiable risk factors of CVDs. Hypertension is a major public health challenge, and it is highly prevalent. According to the Global Burden of Disease (GBD) Study 2019, hypertension affects approximately 9 of 10 adults worldwide, and is associated with increased rate of death and years lived with disability [1]. Convenient and accurate BP measurement is, therefore, crucial in the prevention, diagnosis and management of hypertension and its related CVDs [2].

Non-invasive and unobtrusive method for BP measurement has drawn more and more attention with advances in Internet of Things (IoT), sensors and mobile technology and due to its great potential to overcome the existing cuff-based method that is intermittent, obtrusive and of low level of adherence. As a result, cuffless BP measurement that is enabled by wearable health sensing has been extensively studied [3]. It is usually based upon the principle of pulse transit time (PTT), and various studies about PTT method for cuffless BP measurement have been conducted, including sensing modalities, calibration models, algorithms, and validation, the details of which can be found in [4]. In addition to wearable cuffless BP measurement, non-contact technologies have also been explored for ubiquitous monitoring of BP at home and public places [5]. Contactless BP measurement has its particular advantages over its contact counterpart in application scenarios such as monitoring patients in burn injury, screening during pandemic to reduce contact between people, and measuring BP with an ever-present way; it can also potentially offer a more accurate measurement, as it gets rid of the contact pressure between sensor and skin that may influence the local blood fusion. Non-contact BP is mainly based upon camera photoplethysmography (PPG) that can be acquired using normal video cameras [6, 7]. Camera PPG is similar to contact PPG, but, by contrast, it can be performed at a distance using ambient light rather than a dedicated light source. Most of the works on camera PPG focus on heart rate and respiratory rate detection [8, 9]. In recent years, attempts have been made to estimate BP using imaging camera, and most of them are based on PTT method [10-14].

In 2015, Murakami et al. reported and analyzed the relationship between BP and the non-contact pulse transit time (PTT), where the PTT was obtained by recording two areas of human skins (wrist and ankle) with a single imaging camera [13]. Similarly, other studies have used PTT that was captured simultaneously from face and palm to relate with BP [10]. Another study by Shao et al. presented a similar PTT-based method for BP monitoring; however, PTT was calculated from simultaneously recorded ballistocardiogram (BCG) and PPG signals acquired by a single camera rather than two PPG signals [11]. The main problem with the non-contact PTT-based BP estimation is that images of two parts of the body must be captured at the same time with these two parts at a distance (e.g., face and palm), otherwise it is very difficult to measure the time delay. This greatly limits the recording posture of the subject thus restricting its application. Though studies have conducted to estimate BP from PTT that was obtained from the video of one part of the body (e.g., face), such PTT does not demonstrate its full potential to track BP changes [14]. To overcome the challenges of camera PTT

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(cPTT) method, Patil et al. has used other PPG morphological features including systolic amplitude, pulse interval among others to predict BP with a neural network method [12], but the estimation accuracy was quite limited.

In a previous study, we found that the pulse width at half amplitude (PWHA) of contact PPG is the most relevant indicator of invasive continuous BP compared with more than 200 other features extracted from PPG [15]. This is consistent with other studies. For example, Teng and Zhang has showed the correlation of PWHA and BP [16]. Very recently, Djeldjli et al. conducted the analysis of the 16 features that are extracted from contact PPG and camera PPG, and found that there is high agreement between the features including PWHA recorded by contact and non-contact methods [17]. However, the potential of PWHA of camera PPG for BP estimation has not been studied yet.

In this work, we investigate the feasibility of using PWHA acquired by camera PPG as a single feature to identify changes in BP so as to provide a non-contact method for measuring BP in an unobtrusive manner. The relationship between PWHA and BP changing trend as well as BP values under different circumstances have been evaluated.

II. Methodology

A. Camera System Setting

The RGB camera used for this study is IDS UI-3180CP-C-HQ Rev. 2.1 (NOIP1SE5000A-LTI, CMOS sensor, global shutter). The camera lens is ZLKC 2/3'' 50mm F/1.4 (Model HM5014MP5). Figure 1 shows the setup of the camera system for acquiring videos of the forehead region of the subjects. A captured video is recorded and saved in the uncompressed .AVI format.

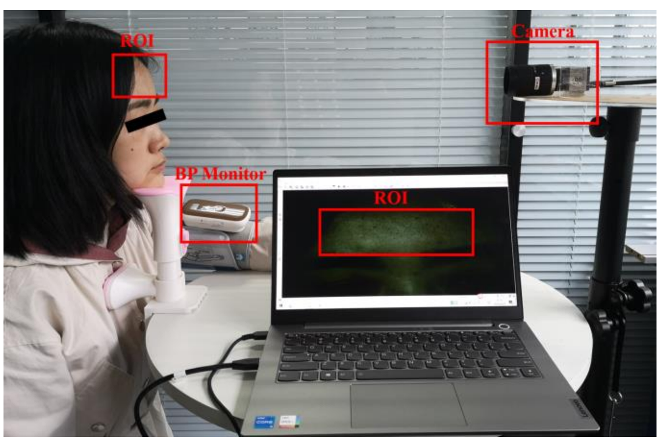

Figure 1. The camera recording system.

Video signals were recorded at 30 frames per second (fps) with a pixel resolution of 1024×768 pixels. The forehead region is selected as the region of interest (ROI) because it is not only least affected by facial activities, but also absorbs more light than other facial areas. We define the ROI area as 800×400 to extract PPG signals from the video.

B. Pulse Width at Half Amplitude (PWHA)

The pulse width at half amplitude (PWHA) is the width of the pulse (in time) at half of the systolic peak amplitude – the PPG intensity difference between the PPG peak and valley. The definition of PWHA is shown in Figure 2.

PWHA was originally used for evaluation of cardiac output and systemic vascular resistance by Awad *et al.* [18, 19]. Given its competence to reflect hemodynamics, Ding et al. explored its relationship with invasive continuous BP and found that PWHA has a stronger correlation with BP than other PPG morphological parameters including pulse transit time, PPG amplitude, and so on [15].

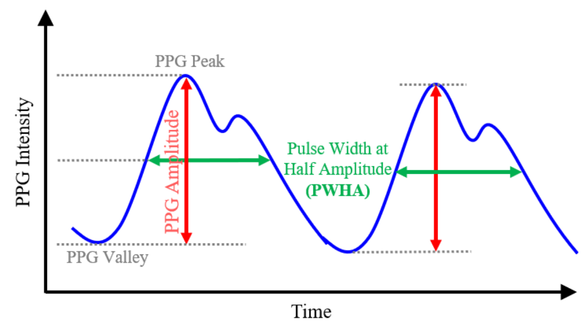

Figure 2. The illustration of pulse width at half amplitude (PWHA).

C. Experiment

To validate the potential of imaging PWHA to evaluate BP, we conducted experiment on 16 healthy adults (8 males), who are nonsmokers and without family history of CVDs. Subjects aged between 18 to 35 years old (mean age: 24.3±4.8 years) with their average resting SBP of 122±16 mmHg (range 98-151 mmHg) and resting DBP of 78±11 mmHg (range 59-110 mmHg). Reference BP was measured by a brachial cuff-based oscillometric BP monitor (Kang.cn, model: KT-135).

The relationship of PWHA and BP was evaluated with subjects at rest state and with subjects undergoing maneuvers which could induce dynamic BP changes. The experimental protocol (Figure 3) involves acquiring forehead video and BP with subjects (*i*) at rest while sitting for 3 min, (*ii*) doing deep breathing (DB) at the rate of 6 breaths per minute for 3 minutes, and (*iii*) after conducting the one-minute stepping exercise for 3 min. During the recording under each of the condition, intermittent BP was measured about every 1 min, so there are 11 pairs of BPs measured for each subject. All the subjects volunteered to participate and gave their informed consent prior to the experiment.

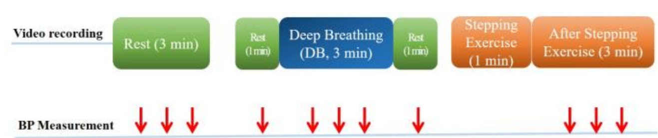

Figure 3. Experimental protocol.

D. Signal Processing and Data Analysis

Camera PPG was obtained by a robust PPG extraction approach called POS that uses the multi-wavelength combination of RGB signals to remove non-cardiac disturbances (e.g., motion, lighting changes) [20]. It was then preprocessed with moving mean filter and zero-phase filter to reduce the quantification noise. We then calculated the PWHA by detecting the peak and valley of the PPG signals.

We averaged the values of PWHA that occurred 30 seconds before the time point when cuff-based BP reading was obtained. We then assessed the variations of average PWHA with BP at different states, and for each individual for all circumstances. A scatter plot is used to visualize the covariances of PWHA and SBP for all the subjects and for each individual. Pearson correlation coefficient of PWHA and BP was also calculated for each individual.

III. RESULTS

We qualitatively analyzed the potential of PWHA to track dynamic BP changes and its relationship with intermitted BP. Figure 5 shows the beat-to-beat changes of PWHA of a representative subject at rest, during DB and after acute exercise. It can be observed that PWHA is quite stable and lingered near the mean value. While during DB, it exhibits an obvious rhythm of the controlled breathing pattern, indicating its fluctuation with BP. Right after the one-minute stepping exercise, PWHA responses to an increase in its values as BP reduced dramatically about 2 min after the subject stopped stepping.

PWHA also associates with BP to a considerable degree (Figure 6). Under all conditions, PWHA changes were inversely related with BP, i.e., the higher the BP, the lower the PWHA (Table I). The change of PWHA with SBP is more significant than with DBP, and the variation tendency is more noticeable after doing acute exercise compared with at resting state and during DB.

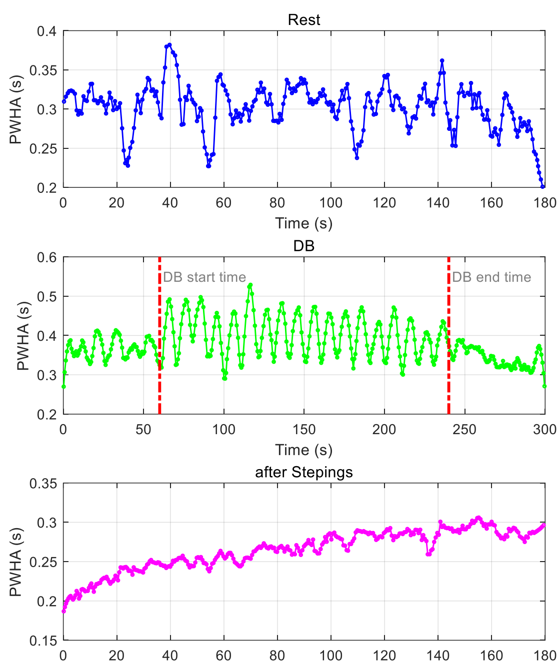

Figure 5. The variation of Pulse Width at Half Amplitude (PWHA) with time in different circumstances – at rest (upper panel), while doing deep breathing (DB, middle panel) and after doing stepping exercise (lower panel).

TABLE I. THE STATISTICS OF PWHA AND BP UNDER DIFFERENT CONDITIONS

Conditions	PWHA (s)	SBP (mmHg)	DBP (mmHg)
At rest	0.3796±0.0577	122±16	78±11
During DB	0.3986±0.0477	116±16	77±14
After stepping	0.3255±0.0729	141±21	85±13

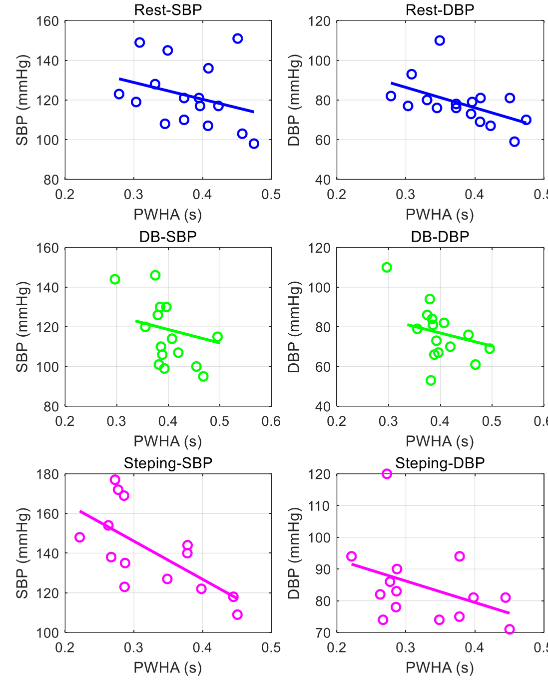

Figure 6. The scatter plot of PWHA and SBP (left panel) and DBP (right panel) at rest (upper panel), during DB (middle panel), and after doing stepping exercise (lower panel).

We further plotted the scatter diagram of PWHA and SBP for each individual, and calculated their correlation coefficient. As reflected in Figure 7, PWHA has a consistent negative correlation with SBP for almost all the subjects. Generally, after doing the stepping exercise, SBP significantly increased with a reduced PWHA, and PWHA were higher at rest and during DB when SBP is in a normal range. As highlighted by the correlation coefficient, PWHA was highly correlated ($|r| > 0.7$) with SBP for about 80% of all the subjects.

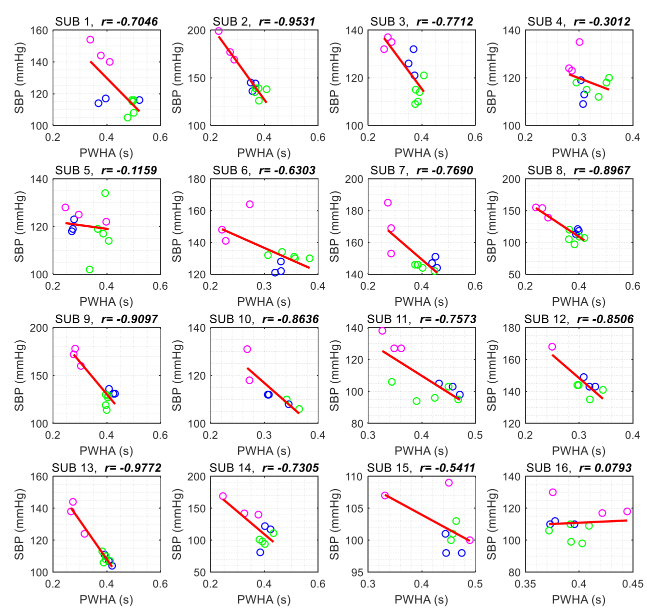

Figure 7. The scatter plot of PWHA and SBP for each individual subject at rest (blue), during DB (green), and after doing stepping exercise (magenta), and the fitted line (red) with the Pearson correlation coefficient (***r***).

IV. Discussion and Conclusion

There have been some attempts in the recent years towards contactless and pervasive BP monitoring via camera; Jeong et al., for example, applied a speed video camera to obtain cPTT and examined the correlation between the PTT and BP, where cPTT was calculated from the recorded videos of the face and palm area of a subject [10]. Though they found a good correlation between cPTT and BP on 7 subjects, but such method requires the subject to be in a specific posture, which limits its application. In this study, we proposed PWHA that can reflect the cardiac output and vascular resistance, and tested the variations of PWHA and BP in response to cardiovascular activities induced by DB and acute exercise. Compared with the widely used PTT method that is based upon small skin patches distant from each other, the proposed method can measure BP with a single site video recording, and the measurement involves more skin pixel and is more robust to camera sensor noise and quantization noise.

We found that the variations of PWHA were associated with those of BP under all different conditions, with PWHA changed negatively with BP. Of note, the gradient of the fitted line between PWHA and SBP was larger after the stepping exercise than at rest and during DB. This could be explained by the fact that systemic vascular resistance falls in exercise due to vasodilatation in active skeletal muscle vascular beds, leading to increased blood flow that results in elevated BP. It then gradually recovered to the normal state after the exercise [21]. Furthermore, PWHA and BP demonstrated high correlations in most of the individuals. Our findings therefore imply the influence of vascular resistance that evaluated by PWHA on BP regulation. This is similar to the findings by Millasseau et al. that the time delay between the systolic and diastolic peaks indicates the arterial stiffness [22]. The results demonstrate the importance of PWHA for indicating BP changes so as to improve the accuracy of cPTT-based BP measurement with camera.

However, some limitations of this study are worth noting. First, the sample size was not large enough. The lack of beat-to-beat monitoring of the BP is another limitation. Future research should be directed toward the development of BP estimation model by integrating PWHA with other BP indicators including PTT for the improvement of accuracy.

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