BLOOD PRESSURE ESTIMATION USING VIDEO PLETHYSMOGRAPHY

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ABSTRACT

Remote sensing of vital physiological signs allows for unobtrusive, nonrestrictive and non-contact assessment of individual's health. By using video plethysmogram obtained by digital camera recordings of patient's face or hands, health parameters such as heart rate, respiratory rate and heart rate variability have already been investigated. In this paper, time-domain video plethysmogram from forehead was used for calculation of pulse transit time, which is related to blood pressure. Synchronous measurements of non-contact video plethysmogram, 12-channel electrocardiogram and invasive blood pressure were performed on three subjects. Our results demonstrate that pulse transit time method can be equally efficient with non-contact VPG signal, with error mean and standard deviation of 9.48 ± 7.13 mmHg and 4.48 ± 3.29 mmHg, for systolic and mean arterial pressure, respectively. Additionally our findings show that delay in pulse transit time, calculated from two different VPG signals from forehead and palm, could provide clinically useful measure of changes in systolic blood pressure.

Index Terms— video plethysmogram, blood pressure, pulse transit time

1. INTRODUCTION

Blood pressure (BP) is considered as one of the most important vital signs in assessment of the general physical health of an individual. Prompt identification of elevated BP or hypertension can potentially decrease the risk of complications from variety of cardiovascular diseases, such as coronary artery disease, heart arrhythmias, congestive heart failure etc. [1]. Commonly used cuff-based measurement methods capture only current overview of BP values, which can easily be affected by nutrition, stress, drugs, age, exercise etc. With recent advances in healthcare technology, ubiquitous and unobtrusive BP measurement methods using wearable sensors and cameras are expected to be available in the near future [2][3].

Non-contact vital signs sensing has attracted considerable attention in recent years, due to the possibility of convenient and nonrestrictive estimation of individual's health parameters. By using video recordings of different parts of the body, such as face and hands, important vital signs including heart rate, respiratory rate and heart rate variability can be estimated with satisfying accuracy [4][5]. This concept is based on video plethysmography (VPG), which is a non-invasive technique for the measurement of color variations at the skin's surface by using video camera as photo detector. Video recordings of patient's skin are used for extraction of beat-to-beat pulsatile signal, also known as photoplethysmogram (PPG)[6], which is caused by arterial pulsations in the blood flow.

Previous studies have tested contact finger-based PPG in combination with electrocardiogram (ECG), for the calculation of pulse transit time (PTT) parameter, which is closely related to the blood pressure [7][8]. The main objective of this study is to assess whether non-contact VPG signals can provide enough accurate estimate of pulse transit time in order to predict BP values under different conditions. Synchronized ECG and VPG signals from forehead and palm are collected, along with invasive arterial BP values used as a reference. In addition, we have tested if phase delay between two different VPG signals from forehead and palm, could provide clinically useful measure of changes in systolic blood pressure.

2. METHODS

2.1. Experimental procedure

This study was carried out in three healthy male individuals, aged 46 ± 1.7 years, with no history of cardiovascular disease and taking no regular medications. Informed consent was obtained from the participants. The experiment procedure was divided into three sessions, namely baseline session and two post-exercise recovery sessions. Baseline recording was obtained while individuals were at rest, while post-exercise recovery sessions were recorded after subjects performed self-paced running in place for 4 minutes.

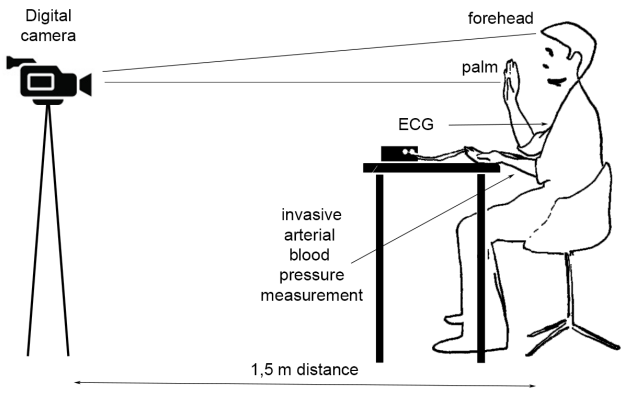

Fig. 1. Experimental setup

Our initial testing included simultaneous video recordings of patient's face and palm, ECG signal and cuff-based measurements of BP. However, as a result of cuff-based measurements, large variations and errors in BP values in post-exercise recordings were observed. Therefore, we have selected to perform invasive measurement of arterial blood pressure (ABP) during video recordings. Due to the fact that invasive BP measurement requires close medical supervision, number of participants was reduced. All participants were hospital employees at Oslo Intervention Centre and thus had knowledge about the health risks related to the invasive measurements. Three medical doctors were present during the experiment.

Experimental procedure is depicted in Fig. 1. Video recording of the patients face and palm was obtained by commercial digital camera with sampling rate of 25 frames per second (fps) and pixel resolution of 720×576. Duration of all recordings was 3 minutes. Simultaneous acquisition of ECG and BP was conducted. The ECG signal was acquired using a standard 12-lead configuration, where only lead II was tested, with sampling frequency of 500 Hz. Invasive intra-arterial BP monitoring was used for all measurements, where catheter was inserted into radial artery and calibration was performed for each subject. Invasive BP values were measured with LiDCOPlus device and sampled at 1 Hz.

2.2. Extraction of video plethysmography signal

Video plethysmography signal is extracted from the video recordings of patient's face and palm, by executing several signal processing operations, as suggested in [4]. First, forehead region of the patient's face was selected for the extraction, as it contains higher strength VPG signal, compared to the other regions of the face [9]. Each tracked region was separated into red, green and blue (RGB) components, where spatial averaging of all pixels in region of interest (ROI) provided three raw signals containing red, blue and green measurement values. Raw source signals were separated by Independent Component Analysis (ICA)[10], where component with highest frequency peak in heart rate frequency band (0.6 – 4 Hz) was selected. Band pass filter (63-point Hamming window) was applied to selected ICA component for heart rate frequency band, while 5-point moving average filter was chosen for the removal of motion artifact.

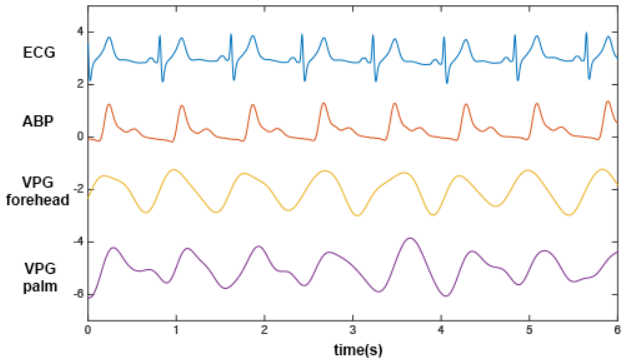

Fig. 2. Synchronized ECG, ABP and VPG signals from one individual for post-exercise recovery recording

Synchronized physiological signals (ECG, ABP and VPG from forehead and palm) were resampled to the 500 Hz frequency by using cubic-spline interpolation, as shown in Fig. 2. Peaks of invasive ABP waveform (ABP) are almost identical with peaks in VPG signal from palm, as it takes small amount of time for blood pressure wave to travel from radial artery to palm. Forehead-based VPG signal appears sooner than VPG signal from palm, while ECG precedes all other signals.

2.3. Estimation by using pulse transit time

Blood pressure wave propagates through the arterial walls, from the aortic valve through peripheral site. Pulse transit time presents the time interval between the passages of the arterial pulse wave at two consecutive sites (proximal and distal). Most common replacement for the proximal waveform is ECG signal and its R peak as the start of time interval, while contact photoplethysmography was usually tested as the distal waveform. Finger-based photoplethysmography proved to be most convenient measurement of contact PPG signal, where PTT is calculated as time interval between R peak and characteristic point in PPG waveform.

Previous research demonstrates that VPG signals are mostly analyzed in frequency domain for the estimation of heart rate, heart rate variability and respiratory rate [4][5]. On other hand, time-domain features of VPG signal, such as inter-beat intervals and time interval between systolic and diastolic peak, closely correspond to contact-based measurement of PPG signal from finger [11]. Therefore, the main objective of this paper is to determine if non-contact PPG signal obtained from the digital camera recording can

be used in blood pressure estimation. We have tested reflection-mode VPG signals from forehead and palm as two distant arterial waveforms. Since VPG signal from forehead has higher SNR, pulse transit time was obtained as the distance between R peak of ECG signal and foot of the VPG signal from the forehead. The location of the foot point was selected as it is minimally affected by the wave reflections [12]. In order to reduce the influence of the respiratory system, we have selected an average value of PTT for 10 successive cardiac cycles. The relation between systolic blood pressure and pulse transit time was evaluated by linear regression model

$$BP = a \cdot PTT + b \quad (1)$$

where a and b constants were acquired for baseline and first post-exercise recording. Obtained model was tested for second post-exercise recording.

In addition to PTT estimation that requires ECG signal, another approach was tested which is based on the difference in PTT (PTTD) between two distal points. PTTD can be measured directly by using only VPG signals on both points (e.g. forehead and palm), which was previously done in [13] with toe and finger. However, movement and light artifacts resulted in noisy VPG signals, which is why finding the peak distance in time domain was not straightforward. As seen in Fig. 2, peaks in palm VPG signal are found at the same sample point as their corresponding forehead peaks, sometimes appearing before or after forehead peak. In order to accurately calculate distance between two points, phase delay estimation was performed in frequency domain by measuring average phase delay at the heart rate frequency for palm and forehead signals. For the reference, value of heart rate frequency was determined from ECG and ABP signals. Two VPG signals from forehead *VPGf(t)* and palm *VPGp*(t) were split into N windows of 12 sec and 11 sec overlap. For each window $\{W_f(t;i)\}_{i=1}^{N}$ and $\{W_p(t;i)\}_{i=1}^{N}$, index of the peak of absolute value of its Fast Fourier Transform (FFT) was found $\{I_f(i)\}_{i=1}^{N}$ and $\{I_p(t;i)\}_{i=1}^{N}$, corresponding to the heart rate frequency. The absolute phases at these points were found for each window in forehead and palm VPG signal. Two estimates of phase delay were calculated

$$PD_1 = \Phi_{\mathrm{ff}} - \Phi_{\mathrm{pf}} \quad (7)$$
$$PD_2 = \Phi_{\mathrm{pp}} - \Phi_{\mathrm{fp}} \quad (8)$$

where Φ_{xy} is absolute phase calculated in window of x VPG signal at peak point found in window of y VPG signal. Discontinuities are detected in phase delay if differences between successive samples exceeded defined threshold value. If a discontinuity was found in one estimate, the other one was used. Otherwise the average value of the two phase delays was taken.

3. RESULTS

The relationship between pulse transit time and systolic blood pressure was analyzed by computing its linear Pearson correlation. Results were significant ($\rho < 0.05$) for all 9 recordings, with correlation -0.7163 ± 0.0761 (Fig. 3).

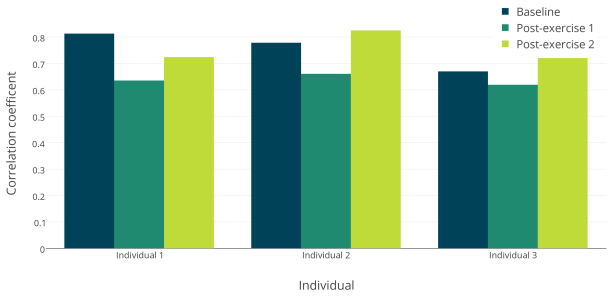

Fig. 3. Comparison of correlation coefficients (*PS* vs. $PTT_{VPGforehead}$)

Simple linear regression model from (1) was created for each individual based on the data gathered from baseline and post-exercise recordings. Additional post-exercise recording was used for systolic and mean arterial blood pressure estimation. Table I contains absolute mean and standard deviation estimation errors from measured and estimated beat-by-beat values of systolic and mean arterial pressure for PTT calculated with ECG and VPG from forehead. For all measurements, total absolute mean error and standard deviations are 9.48 ± 7.13 and 4.48 ± 3.29, for systolic and mean arterial pressure, respectively.

Table 1. Mean and standard deviation in beat-by-beat systolic and mean arterial blood pressure estimation using PTT

Patient	Error systolic pressure (mmHg)		Error mean arterial pressure (mmHg)	
	Mean	Std	Mean	Std
1	9.679	3.9684	3.115	1.9193
2	11.0903	7.8757	6.7587	3.5557
3	7.6905	9.5737	3.5823	4.3976

Bland-Altman plot [14], shown in Fig. 4, demonstrates the agreement between the systolic BP measured by invasive procedure and the calculated systolic BP as a linear function of PTT in post-exercise recording data by using patient's individual linear function parameters. Phase delay in pulse transit time and systolic blood pressure showed lower correlation coefficients (-0.6045 ± 0.0399) compared to the pulse transit time calculated from ECG signal (Fig. 5).

4. CONCLUDING REMARKS

We have studied the relationship between blood pressure and pulse transit time using non-contact VPG and ECG signals under different conditions. The delay in pulse transit time measured at forehead and palm did not correspond to

the PTT measurement using synchronized ECG signal and VPG signal from forehead.

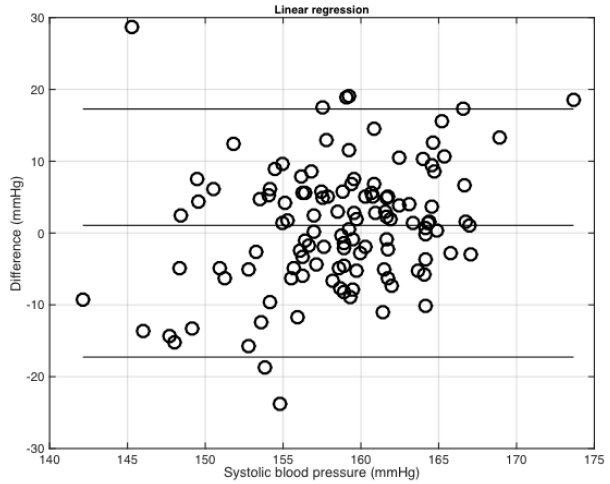

Fig. 4. Bland-Altman plot

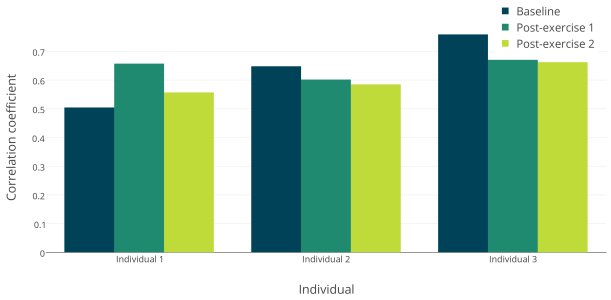

Fig. 5. Comparison of correlation coefficients (P_S vs. $PD_{VPG_{forehead\text{-}palm}}$)

The reasons may be due to reflection of the pressure waves, different flow distributions inside arterial tree, and position of the raised hand. Moreover, the difference in mean and standard deviation compared to invasive pressure indicates that such methods can be used by users who are interested in trends and fluctuations rather than in absolute value. The proposed method can be improved further using large number of recordings and machine learning techniques and can potentially be a technology for daily monitoring the systolic and mean arterial pressure values.

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ACKNOWLEDGEMENT

This study is part of the "Norbotech project", supported by the Norwegian Ministry of Foreign Affairs Program in Higher Education, Research and Development (HERD) in the Western Balkans 2010-2015 within the field of ICT.