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Continuous blood pressure estimation based on multiple parameters from eletrocardiogram and photoplethysmogram by Back-propagation neural network

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ABSTRACT

The cuff-less continuous blood pressure monitoring provides reliable and invaluable information about the individuals' health condition. Conventional sphygmomanometer with a cuff measures only the value of the blood pressure intermittently and the measurement process is sometimes inconvenient. In this work, a systematic approach with multi-parameter fusion has been proposed to estimate the non-invasive beat-to-beat systolic and diastolic blood pressure with high accuracy. The methods involve real-time monitoring of the electrocardiogram (ECG) and photoplethysmogram (PPG), and extracting the R peak from the ECG and relevant feature parameters from the synchronous PPG. Also, it covers the creation of the topological model of back-propagation neural network that has fifteen neurons in the input layer, ten neurons in the single interlayer, and two neurons in the output layer, where all the neurons are fully connected. As for the results, the proposed method was validated on the volunteers. The reference blood pressure (BP) is from Finometer (MIDI, Finapres Medical System, Netherlands). The results showed that the mean ± S.D. for the estimated systolic BP (SBP) and diastolic BP (DBP) with the proposed method against reference were −0.41 ± 2.02 mmHg and 0.46 ± 2.21 mmHg, respectively. Thus, the continuous blood pressure algorithm based on Back-Propagation neural network provides a continuous BP with a high accuracy.

1. Introduction

Blood pressure is the pressure exerted by the blood flowing in the blood vessels. The blood pressure is an important health indicator, with values varying between systolic blood pressure (SBP) to diastolic blood pressure (DBP) in each cardiac cycle. Hypertension is one of the significant induction factors of cardiovascular diseases (CVDs) [1], nephropathy and heart failure However, hypertension is highly prevalent due to low awareness rate and cure rate, which further enhances the development of CVDs, nephropathy and heart failure induced by hypertensive heart diseases. Thus, the continuous blood pressure measurement is essential for the early prevention, detection and diagnosis of CVDS, nephropathy and heart failure.

The conventional 24-h blood pressure measurement adopts the cuff-based oscillography and auscultatory approaches. Its limitations include its discontinuous features and uncomfortableness. The study on the continuous blood pressure measurement with regard to the pulse transit time has attracted attention from several research institutions and companies for centuries. In 1628, William Harvey put forward the blood circulation concept for the first time in relation to the movement of the heart and blood [2]. Isaac Newton conducted a study on the mechanical problems of blood circulation in 1700 [3]. The fluid dynamics Euler equation pointed out the pulse wave propagated in the artery due to the ventricular contraction in 1705 [4]. British physicist Thomas Yang first discussed the relationship between pulse wave velocity and arterial elasticity in 1808. He deduced the elastic wave propagation velocity formula which is full of the ideal fluid [5]. In 1878, Moens measured the pulse wave velocity (PWV) propagation and

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proposed the Moens-Korteweg formula [6].The following researches about the continuous blood pressure based on pulse transit time are mostly derived from this formula. In 1957, Lansdown put forward that the relationship between the pulse wave transit time and the arterial blood pressure is linear, and it is relatively stable over a period in an individual [7]. Asmar et al. showed that the pulse wave velocity is significantly correlated with the age and the systolic blood pressure.

Recently, the research on the continuous blood pressure based on the pulse transit time has achieved new progress. Chen et al. [8] proposed a nonlinear relationship model estimating the systolic blood pressure by combining two separate components: a higher frequency component from extracting a specific frequency band of pulse arrival time and a lower frequency component from the intermittently acquired systolic blood pressure measurements with an auscultatory or oscillometric system. The results have shown that the correlation coefficients between the estimated values and invasively obtained systolic blood pressure reached 0.97 ± 0.02 (mean $\pm$ SD), however, an extra cuff was still required to measure the blood pressure and the whole process was inconvenient. The paper [9] also suggested that the continuous cuff-less blood pressure estimation using the pulse transit time and photo-plethysmogram intensity ratio coming from respiration signal whose mean absolute difference improved to 4.09 mmHg, 3.18 mmHg and 3.18 mmHg for SBP, DBP and mean BP, respectively, but this method had additional respiration signals except the electrocardiogram and photo-plethysmogram. Wu et al. [10] cited new concepts of classification tree to estimate the systolic blood pressure by correlated variables (body mass index [BMI], age, exercise frequency, alcohol intake, smoke level, etc.). However, the measurements suffered from low precision and the probabilities of the absolute difference between the measured and predicted values of the SBP under 10 mmHg were 51.9% for men and 52.5% for women using the back-propagation neural network.

In analyzing the previous studies, a novel method was proposed by the multi-parameter fusion algorithm with back-propagation neural network to estimate the systolic and diastolic blood pressure to further improve their accuracy, the synchronous electrocardiogram (ECG) and photoplethysmogram (PPG) provide relevant physiological features. including pulse transit time, the amplitude of systolic, diastolic peaks, dicrotic notch point, and the minimum PPG value, the time interval between the two neighboring of the systolic and diastolic peaks, dicrotic notch point, and the pulse height difference between systolic and diastolic peaks; difference between systolic peak and minimal point in the same period; along with the systolic and diastolic areas, total area, and the area ratio.

This article is organized as follows: part II elaborates the continuous blood pressure measurement theory. Part III discusses the continuous blood pressure methodology and materials. Part IV evaluates the method performance. Part V deals with the paper's findings and conclusion based on the method used.

2. Theory

The researches on continuous blood pressure have drawn a lot of attentions from institutes and colleges. The two main existing methods include the method based on PPG and that based on pulse transit time. However, the method based on only photoplethysmogram or pulse transit time has limitions, due to unstable photoplethysmogram measurement as well as inconsistent relationship between pulse transit time and blood pressure measurement with a high accuracy. As blood pressure is the joint result of mulitple parameters, a method based on multiple parameters is proposed.

2.1. Existing theories

2.1.1. Relationship between PPG and blood pressure

The study on continuous blood pressure measurement using PPG has shown some progress. Suzuki et al. [11] have presented a method using 2-element Windkessel model based on PPG signal to estimate blood pressure. According to the results, its overall error in estimating BP keeps within 10% of that of a commercially available digital BP monitoring device. Chua et al. [12] have elaborated the method using photo-plethysmogram amplitude to measure SBP during sleep. The correlation between pulse amplitude and Systolic BP is significantly strong. Jeong et al. [13] have demonstrated the relationship between photo-plethysmogram components and blood pressure. Direct current (DC) component, which reflects the changes in blood volume, decreases with the increase of alternating current (AC) component which shows the variations in vascular compliance and resistance. The correlation coefficients are 0.939 between SBP and the foot of DC component, and 0.942 between DBP and the peak of DC component. Even under the condition of increased pulse pressure, AC component could predict the increase in vascular resistance from a stable pulse blood volume. These studies support the possibility that PPG may be used for easy and noninvasive SBP measurement. However, the shape of photo-plethysmogram could change with temperature, measurement position and measurement manner. Thus, BP measurement using photo-plethysmogram is alone unstable and inaccurate.

2.1.2. Relationship between pulse transit time and blood pressure

Researches have shown that pulse transit time (PTT) is directly related to blood pressure and PWV [14,15]. In the past, PWV was measured by using a galvanometer and ultrasound techniques. In recent years, PTT is identified by conducting synchronous ECG and PPG. Fig. 1 shows The ongoing research defines PTT as different time intervals between (a) ECG R-wave and the following pulse peak of PPG, (b) ECG R-wave and PPG pulse onset, (c) ECG R-wave and the minimal amplitude on PPG upslope, as well as (d) ECG R-wave and the maximum peak of PPG's first or second derivative. As the research is making progress, the diverse PTT-BP models are proposed based on different experimental backgrounds. Although these researches have shown the direct relationship between PTT and blood pressure, there has been no study on the consistent relationship between PTT and blood pressure measurement with a high accuracy.

Thus, it is not enough to use a single PTT parameter or PPG amplitude to estimate blood pressure to measure accurate

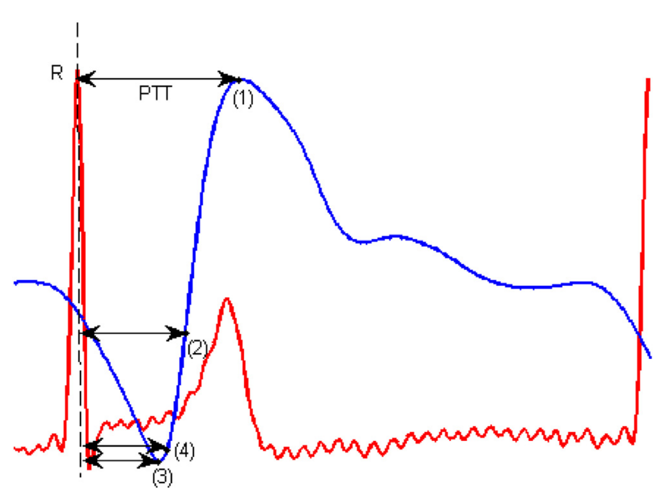

Fig. 1. Definition of Pulse Transit Time.