A New Modeling Methodology for Continuous Cuffless Blood Pressure Measurement

Xiao-Rong Ding, *Student Member, IEEE,* Yuan-Ting Zhang, *Fellow, IEEE*, Hon Ki Tsang*, *Senior Member, IEEE*

Abstract*—Continuous blood pressure (BP) monitoring in a noninvasive and unobtrusive way can significantly improve the awareness, control and treatment rate of prevalent hypertension. Pulse transit time (PTT) has become increasingly popular in recent years for continuous BP measurement without a cuff. However, the accuracy issue of PTT-based method remains to be solved for clinical application. Some previous studies have attempted to estimate BP with only PTT by using linear regression, which is susceptible to arterial regulation and may not reflect the actual relationship between PTT and BP. Furthermore, PTT does not contain all the information of BP variation, thereby resulting in unsatisfactory accuracy. In this paper we establish a cuffless BP estimation model from a physiological perspective by utilizing PTT and photoplethysmogram (PPG) intensity ratio (PIR), an indicator we have recently proposed for evaluation of the change in arterial diameter and the low frequency variation of BP, with the consideration that PIR can track changes in mean BP (MBP) and arterial diameter change. The performance of the proposed BP model was evaluated by comparing the estimated BP with Finapres BP as reference on 10 healthy subjects. The results showed that the mean ± standard deviation (SD) of the estimation error for systolic and diastolic BP were -0.41 ± 5.15 and -0.84 ± 4.05 mmHg, and mean absolute difference (MAD) were 4.18 and 3.43 mmHg, respectively. Furthermore, the proposed modeling method was superior to one contrast PTT-based method, demonstrating the proposed model would be promising for reliable continuous cuffless BP measurement.

I. Introduction

High blood pressure (BP), also known as hypertension, is a common and dangerous condition. According to a recent report in Lancet [1], it is the biggest contributor to early death globally. One of the major reasons for the high fatality statistics of hypertension is that it is a “silent killer” usually without any warning signs or symptoms. As a result, the awareness, control as well as treatment rate for hypertension are very low [2]. It is therefore necessary to monitor BP regularly and even continuously rather than intermittently to detect hypertension early and prevent it from developing. Current commonly used BP measurement devices are based on auscultatory and oscillometric approaches which can only provide a snapshot of BP and require an inflation cuff that may cause discomfort, thus impropriate for long-term BP monitoring. Compared with the cuff-based methods, pulse transit time (PTT) method provides a promising alternative for BP measurement in a beat-by-beat basis and in an unobtrusive manner. PTT refers to the time for the carrying of pulse wave information by pulse signal from one location to another in the cardiovascular system [3], and it can be derived from two pulse signals that originate from the cardiovascular system, for example, electrocardiogram (ECG) and photoplethysmogram (PPG). There has been considerable recent interest among biomedical engineers and clinical researchers in PTT-based method for BP estimation [4, 5], owing to the advantages of PTT as a noninvasive and continuous technique with low-cost and ease of use, and most importantly, its ability to track BP changes. Most of the non-occlusive BP estimation with PTT methods rely on the recording of pulse wave velocity (PWV) through the Moens-Korteweg (M-K) equation [6] and the exponential correlation between arterial elastic modulus and arterial pressure [7]. Because of the reciprocal relationship between PTT and PWV, i.e., PWV=L/PTT, where L is the distance for the pulse wave travelling between two locations, PTT can be projected into BP with calibration procedure.

Despite the potential advantages of PTT-based cuffless BP estimation, there are several significant challenges ahead before its large scale application. The accuracy and calibration are two of the most important issues to be resolved; particularly accurate measurement of BP is essential to diagnose, treat and guide management. The underlying reasons for the unacceptable accuracy of most PTT-based BP measurement methods include: 1) most of the studies use PTT alone to predict BP; nevertheless, our previous studies [8, 9] find that PTT primarily reflect the high frequency variation of BP; 2) PTT and BP were modeled with linear regression [10, 11], which would be susceptible to dynamical change of BP, since the relationship between PTT and BP are far more complicated than linear regression. Our recent study [12] suggests that the PPG intensity ratio (PIR), the ratio of PPG peak intensity to valley intensity, can reflect the low frequency variation of BP; and it was derived from PPG signal based on Beer-Lambert law that it is influenced by the change of the arterial diameter within one cardiac cycle. We have used PTT and PIR for estimation of pulse pressure (PP) and diastolic BP (DBP), respectively, from the perspective that PTT can track the high frequency variation of BP, while PIR can track its low frequency variation, based on the M-K equation and the Windkessel model, respectively [9]. In this paper we propose a new cuffless BP model from a different point of view, in

This work was supported in part by the Guangdong Innovation Research Team Fund for Low-cost Healthcare Technologies in China, the External Cooperation Program of the Chinese Academy of Sciences (Grant GJHZ1212). Asterisk indicates corresponding author.

Xiao-Rong Ding and Yuan-Ting Zhang are with the Department of Electronic Engineering, Joint Research Centre for Biomedical Engineering, The Chinese University of Hong Kong, Hong Kong, China (xrding@ee.cuhk.edu.hk; ytzhangapple@icloud.com).

*Hon Ki Tsang is with the Department of Electronic Engineering, The Chinese University of Hong Kong, Hong Kong, China (e-mail: hktsang@ee.cuhk.edu.hk).