The Cuffless Arterial Blood Pressure Estimation based on the Timing- Characteristics of Second Heart Sound

M. Y. M. Wong, X. Y. Zhang and Y. T. Zhang

Abstract—**Continuous and non-invasive monitoring of blood pressure (BP) is important to prevent hypertensive patients from stroke and heart attack. However, most of the prevalent BP devices can provide solely intermittent measurements. In this study, a novel parameter RS_2, defined as the time interval from the R wave of electrocardiographic (ECG) signal to the peak of second heart sound of phonocardiographic (PCG) signal, was used for BP estimation. Experiment was conducted on 66 normal and 19 abnormal subjects during resting condition.**

The results of this study showed that estimation error of systolic BP (SBP) and diastolic BP (DBP) was 2.0±7.5 mmHg and 0.9±5.1 mmHg respectively. 94.7% of the difference between measured and estimated SBPs was within ± 2 standard deviations in the Bland Altman plot. 93.4% of the difference between measured and estimated DBPs was within ± 2 standard deviations in the Bland Altman plot. The preliminary results illustrated that the RS_2 is a promising parameter for continuous and non-invasive estimation of BP in homecare and mobile healthcare.

I. Introduction

NEARLY one billion people worldwide suffer from hypertension [1]. Continuous and non-invasive monitoring of blood pressure (BP) is important to prevent hypertensive patients from stroke and heart attack. However, most of the prevalent BP devices are cuff-based which can provide solely intermittent measurements of systolic BP (SBP) and diastolic BP (DBP). Prolonged cuff inflation may also induce skin irritation, bruising, venous pooling and congestion [2].

To overcome the drawbacks of cuff-based BP measurement, BP estimation based on pulse transit time (PTT) -approach is one of the possible techniques to provide continuous BP monitoring. PTT refers to the duration for a pressure pulse to travel between two measuring sites in the arterial system [3]. Several authors reported that PTT was inversely related to BP under various conditions [4]-[6]. Conventionally, PTT is recorded as the time interval from the R wave of electrocardiographic (ECG) signal to the upstroke of photoplethysmographic (PPG) signal. Recently, a new parameter, RS_2, defined as the time interval from the R wave of electrocardiographic (ECG) signal to the peak of second heart sound (HS_2) of phonocardiographic (PCG) signal, was proposed as an alternative to PTT for providing continuous monitoring of BP [7]. The previous results showed that RS_2 was inversely correlated with SBP and that the estimated SBP by the RS_2-approach was in good agreement with the BP measurements when the signals were processed by an optimal linear prediction. Nonetheless, subjects recruited in the experiments were only limited to normal young individuals. In this project, the BP estimation based on the RS_2-approach was examined on 85 subjects in different age groups and with different levels of cardiovascular diseases.

Fig. 1 illustrates the definitions of PTT and RS_2. Namely, PTT and RS_2 are the time intervals measured from the R wave of ECG signal to the foot of PPG signal and to the peak of HS_2 of PCG signal respectively.

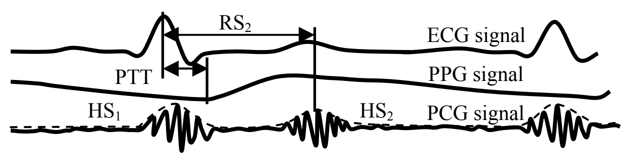

Fig. 1 An illustration shows the definitions of PTT and RS_2 (HS_1 and HS_2 refer to the first and second heart sound respectively).

II. Materials and Methods

The clinical test was carried out at the Joint Research Centre for Biomedical Engineering of The Chinese University of Hong Kong and at a local clinic in Shenzhen, China. The test was conducted on 66 normal subjects (aged 36±13 years, 36 females) and 19 abnormal subjects (aged 54±10 years, 8 females). 18 of abnormal subjects were diagnosed with hypertension.

A self-designed stethoscope was implemented for detecting ECG and PCG signals simultaneously on the chest wall. A PPG sensor was also integrated into the stethoscope head for recording PPG signal at the same time. All signals were sampled at 1 kHz and recorded for 45 seconds by a data acquisition system (Model DI-220, DATAQ Instrument WINDAQ, USA). SBP and DBP were measured simultaneously by auscultatory method and an automatic BP machine (Model HEM-907, OMRON, Japan).

At the beginning of the experiment, the subject was asked to sit down and rest for 3 minutes. The subject then placed the stethoscope on the chest wall by his/her right hand while ECG, PCG and PPG signals were recorded simultaneously. BP was measured simultaneously by auscultatory method and the automatic BP machine afterwards. The subject rested for 2 minutes and signal recordings followed by BP

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measurements were repeated for three times. After the experiment, all trials were visually checked and analyzed offline. The beat-to-beat PTT and RS_2 were firstly calculated and the average values of PTT and RS_2 were calculated in the sequential steps. Measured BP was calculated to be the average of the readings from auscultatory method and automatic BP machine in each trial. The values of PTT, RS_2 and BP of the first trial were used for calibration. The accuracy of the estimated BP was evaluated using an estimation error which was defined as the difference between the estimated BP and the measured BP. Mean and standard deviation of the estimation error was calculated.

III. Results

Table 1 showed the mean standard deviation of estimation error when BP and PTT as well as BP and RS_2 were fitted by least square method. It was shown that the mean standard deviation of estimation error achieved by RS_2 was very close to that achieved by PTT. Since PTT was known as a potential parameter for providing continuous monitoring of BP, the similar error achieved by both RS_2 and PTT confirmed that RS_2 was possible to be an alternative to PTT for providing BP estimation during the resting condition.

Table 1
The Mean Standard Deviation of Estimation Error When BP and PTT as well as BP and RS_2 Were Fitted by Least Square Method

	SBP (mmHg)	DBP (mmHg)
BP~PTT	3.1	2.2
BP~RS_2	3.2	2.3

Table 2 showed the means and standard deviations of BP estimation errors using the RS_2-based approach. The BP estimation error was smaller than 5±8 mmHg. Fig. 2 illustrated the Bland Altman plots of BP estimation. It was shown that the 94.7% of the difference between measured and estimated SBPs was within ± 2 standard deviations. Meanwhile, 93.4% of the difference between measured and estimated DBPs was within ± 2 standard deviations.

Table 2
The Means and Standard Deviations of BP Estimation Errors

SBP error (mmHg)	DBP error (mmHg)
2.0±7.5	0.9±5.1

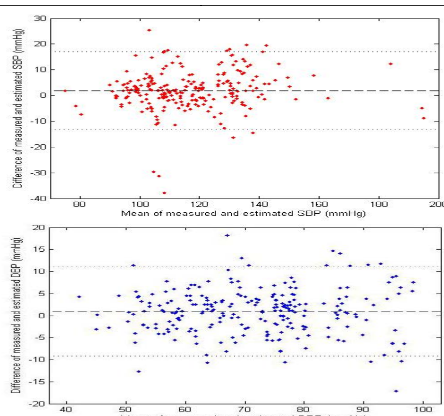

Fig. 2. The Bland Altman plots of BP estimation (The dotted lines represented the corresponding ±2 standard deviations).

IV. Discussion and Conclusion

Poon et al. used PTT to estimate BP on 85 subjects, thereof the standard deviation of the error between the estimated and measured SBPs was 9.8 mmHg and that of DBPs was 5.6 mmHg [8]. Zhang et al. recently used RS_2 measured from young normal subjects to estimate BP and showed that standard deviation of estimation errors were less than 8 mmHg and 5 mmHg for SBP and DBP respectively when the signals were processed by optimal fitting [7]. The result in the present study demonstrated that the estimation error of SBP and DBP on 85 subjects, including normal and abnormal subjects, were 2.0±7.5 mmHg and 0.9±5.1 mmHg respectively.

The smaller estimation error in present study might associate with the differences in protocols and the amount of abnormal subjects in present and previous studies. Firstly, measurements from auscultatory method and automatic BP machine were preformed simultaneously in the present study whereas they were performed sequentially in Poon's study. The sequential BP measurements might induce error to the measured BP and result in larger estimation error. Secondly, nearly 75% of trials in the previous study were estimated by using the calibration sets obtained at least one week ago, which was believed to increase BP estimation error to some extent. Furthermore, there were only 19 abnormal subjects participated in this study whereas more than 50 abnormal subjects attended the previous study [8]. As a result, different experimental protocols as well as smaller proportion of abnormal subjects would partly explain the smaller BP estimation error in the present study.

It should be noted that subject recruitment and experimental procedures in current study did not strictly follow the requirements of international standard. Further experiment is needed to evaluate the accuracy of current technique for continuous monitoring of arterial BP.

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