Pressure Dominated PTT Calculation and Its Relation with BP

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Abstract—**Pulse transit time (PTT) which can be obtained from the peaks of r-wave of Electrocardiogram (ECG) and pulse wave, is promising for non-invasive continuous blood pressure measurement. However, there are different kinds of waves can be employed in this method, namely pressure pulse wave (PPW), photoplethysmography (PPG) and modulated magnetic signature of blood (MMSB). It is critical to clarify the relationship between those three kinds of pulse waves for practical applications. In this paper, the relationship between blood pressure (BP) and three different types of pulse wave is investigated experimentally. It is found that the MMSB and the PPW measured at the same position have a fixed phase difference. This means that we have to established different models for MMSB and PPW to obtain accurate blood pressure. We calculate blood pressure based on PPG and PPW, respectively. We find that both PPG and PPW shows high dependency on systolic blood pressure, while PPW appears to be more reasonably correlated with diastolic blood pressure (DBP). This implies that PPG may be not a good signature for blood pressure measurement. A model on the relationship between those three pulse waves is proposed. The different relationships between three pulse waves and BP are explained based on that model.**

Keywords—pulse transit time (PTT), blood pressure, pulse wave

I. INTRODUCTION OF PTT BASED BP CALCULATION

Cardiovascular diseases have become primacy of kinds of diseases, which is seriously doing harm to people's health. Continuous blood pressure (BP) monitoring is essential in prevention and diagnosis of cardiovascular diseases, and more and more attention is paid to non-invasive blood pressure measurement.

Pulse Transit Time (PTT) is currently accepted as an indirect method to measure blood pressure [2, 3]. It is obvious that PTT has high correlation with BP [1]. PTT is normally defined as the time interval between the generation of the pulse wave in the cardio aortic and the pulse wave when it propagates to artery peripheries [4]. It seems that the peak of R wave of Electrocardiography (ECG) signal is always regarded as the sign of the start of pulse wave. However, the end of PTT is varied slightly for different methods when measuring. With photoelectric sensor, the peak of the photoplethysmography (PPG) signal of finger pulse-oximetry is viewed as an end sign. With piezoelectric sensors, the peak of the pressure signal of radial artery is seen as an end sign. Furthermore, with magnetic sensor, the peak of Modulated Magnetic Signature of Blood (MMSB) signal is treated as an end signal.

However, the principles behind these three methods are not the same. The pressure signal travels along the arterial wall while the PPG signal and MMSB signal propagate in the blood. Thus the relation of these PTT with BP is varied as well. Previous study shows that the PTT obtained by PPG (or MMSB) and ECG signals is highly correlated to the systolic blood pressure (SBP). Yet the reason of this is not clear. And little information can be acquired for diastolic blood pressure (DBP) [5]. This paper discusses the relation between PTT and BP in details, and presents a more precise description about their correlation.

II. RELATION BETWEEN PTT AND BP

The measurement of PTT is consistent with the measurement of Pulse Wave Velocity (PWV), since PWV is inversely proportional to PTT. Thomas Young points out the quantitative description of PWV in 1808. According to his research, for incompressible fluid in flexible tube, the velocity of the wave, c, is

$$c = \sqrt{\frac{hE}{2\rho R_0}},$$

where h is the thickness of the arterial wall, E is the Young's modulus, R_0 is the radius of the arterial, ρ is the density of the blood.

After Young, large amount of ideas have been raised to calibrate this relation with more parameters [6]. However, for a small period of time, the parameters of arterial remain unchanged for a certain person. But the Young's modulus is related to the blood pressure. The Young's modulus increases with the rise of blood pressure, which results in the rise of PWV. This refers to the correlation between PWV and BP.

III. EXPERIMENT SETUP

In order to testify the ideas above, experiments are conducted to measure MMSB, PPG, ECG and pressure pulse wave at the same time.

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TABLE I. EXPERIMENT EXPLANATION

	Signal			
	PPG	***ECG***	***Pressure Pulse Wave***	***MMSB***
Sensor Type	Photoelectric	---	Piezoelectric	magnetic
Position	Finger	Left arm and left leg[a]	Radial artery	Radial artery
Tackling points	Peaks	R-wave peaks	Peaks	Peaks

[a] Only two leads are adopted.

The raw data is obtained from Agilent oscilloscope shown in Fig. 1 as a snapshot.

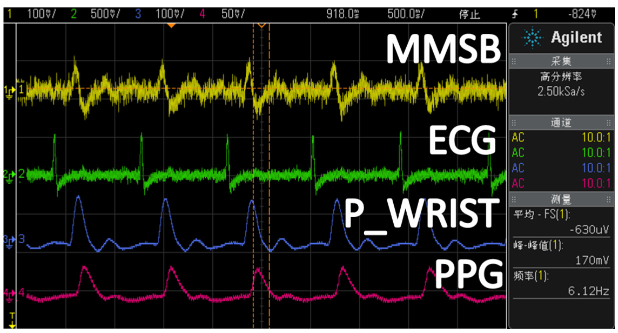

Fig. 1. Snapshot of signals in the oscilloscope *(the yellow one is the MMSB signal, the green one is the ECG signal, the blue one is the pressure pulse wave signal and the purple one is the PPG signal).*

As can be seen from Fig. 1, the pressure pulse wave signal and the PPG signal is clear while the ECG and the MMSB signal is coupled with slight noise due to the cross-coupling of these signal and power frequency interference. However, the R-peak of the ECG signal is obvious enough for calculation PPT.

The SBP and the DBP is measured while the four signals are acquired. The volunteers should keep stable to guarantee the accuracy of the measurement. The variation of BP is realized by taking exercise, for instance running. The BP variation curve is presented in Fig.2. Repeat the measurement to observe the statistics regularities.

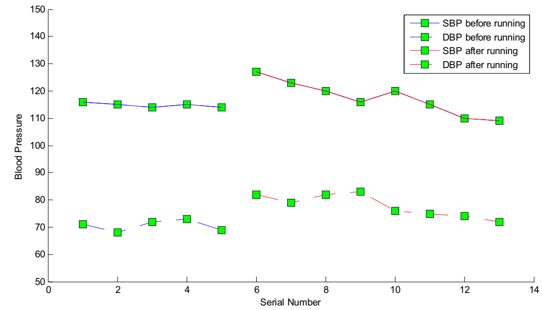

Fig. 2. The tendency of the blood pressure variation curve before and after running

IV. RESULTS AND ANALYSIS

A. Data Processing and PTT Calculation

For each snapshot in the oscilloscope, there should be five to seven entire pulse periods. Extract the peaks of these signals and calculate the PTT respectively. According to the references and previous study, correlation between BP and the reciprocal of the square of PTT is calculated. And the result is summarized in Table 2.

TABLE II. EXPERIMENT EXPLANATION

	ECG R-peak with different signal to calculate PTT		
	MMSB	***PPG***	***Pressure Pulse Wave***
Correlation with SBP	0.4817	0.6960	0.8375
Correlation with DBP	0.4005	0.5215	0.6099

B. Discussion and Analysis

- The MMSB and the PPW measured at the same position have a fixed phase difference. This means that we have to established different models for MMSB and PPW to obtain accurate blood pressure.
- Both PPG and PPW show high dependency on systolic blood pressure, while PPW appears to be more reasonably correlated with DBP.
- The magnetic signal is coupled with ambient noise. Therefore the correlation is weak compared with the other two. Further exploration should be conducted in the shield to avoid the magnetic noise.

V. Summary and Conclusion

The relation between PTT and BP is complicated. Previous study demonstrates the PTT calculated by r-wave on ECG and peaks of pulse wave is highly related with SBP. But for DBP, the correlation is weak. With proper adjustment, such as subtracting the pre-ejection period, it seems that PTT is highly related to DBP [5, 7]. However, the cost is that the adjusted PTT will be no longer highly related to SBP. With the concept proposed in the paper, the former PTT is calculated by points mainly dominated by SBP; however the latter one varies the dominant factor that resulting in the variation of the correlation.

The tendency of all the PTTs calculated with pulse waves acquired by different methods shows correlation with BP. However, due to the difference in generation of the signals, the correlation is varied. To get the exact BP value, it should be determined that how much the PTT depend on SBP and how much on DBP.

C. Improved Model to Explain the Phenomena

The data calculated directly is PTT, which is inversely proportional to PWV. Therefore the PTT is highly correlated to the BP when the pulse wave is propagating alone the artery as discussed in section Ⅱ.

In a cardiac cycle, the ventricular contraction causes the ejection of blood which increases the blood pressure and the aorta is dominated by SBP. The state of SBP spreads along the artery as the propagation of pulse wave. When the systolic blood pressure (SBP) is generated at the cardio aortic, it does not influence the periphery arterial at the very beginning. Then the arterial wall is dominated by diastolic blood pressure (DBP) while the pressure wave is propagating. This implies the PTT measured by pressure sensor should be more correlated with DBP. However, for the PTT measured by photoelectric sensor which reflects finger pulse-oximetry, the wave travels in the blood fluid, and the arterial is dominated by SBP while the PPG wave is propagating. This implies the PTT measured by photoelectric sensor should be more correlated with SBP.

Considering this idea from another perspective will display the relation between the PTT and BP in a much more clear way. If SBP is concerned, the PTT should be calculated by the specific points where the arterial is dominated by SBP; if DBP is concerned, the specific points should be dominated by DBP. However, it is nearly impossible to choose a specific point only dominated by DBP or SBP, therefore the PTT we get is partially dominated by DBP, and partially by SBP.

Further study includes measuring the dependent ratio for SBP and DBP and obtaining new points to calculated PTT to get higher correlation with SBP and DBP respectively.

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