Pulse Transit Time Extraction from Seismocardiogram and its Relationship with Pulse Pressure

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Abstract

In this research Seismocardiogram (SCG) signal was used for timing the proximal pulse while pulse-plethysmogram (PPG) was used for timing the dorsal pulse for computing pulse transit time (PTT). Lower body negative pressure (LBNP) was applied for gradually reducing the pulse pressure in 9 subjects. The correlation between the pulse pressure and PTT derived using SCG was studied. It was determined that a significant correlation existed between PTT and pulse pressure for 7 out of the 9 subjects studied with an average significant correlation of 0.88±0.05. The results from this research show a potential application for a system including SCG and PPG to be used in an estimation or trending of pulse pressure.

1. Introduction

Continuous monitoring of blood pressure is important for the treatment of hypertension. Unobtrusive and inexpensive methods for estimation and measurement of blood pressure can assist such monitoring. Pulse pressure is the difference between systolic pressure and diastolic pressure. An elevated value for pulse pressure is considered as a risk factor for cardiovascular disease [1]. A value significantly higher than 40 mmHg can be considered abnormal. On the other hand, a significant drop in pulse pressure can be considered as a sign of hemorrhage and blood loss [2].

Pulse transit time (PTT) is the time that it takes a pulse wave to travel between arterial sites or to get from the proximal side of the artery to its distal site. PTT is inversely proportional to blood pressure. Being simple to measure, PTT is proposed as a method for continuous, cuff-less blood pressure estimation [3]. Comparison of blood pressure estimation using PTT and the cuff-based method is presented in [4].

Pulse arrival time (PAT), on the other hand, is equal to the sum of PTT and pre-ejection period. PAT is determined using electrocardiogram (ECG), as the proximal pulse, and pulse-plethysmogram (PPG) is normally used as the distal pulse for both PTT and PAT estimations. Using ECG for the timing of the proximal pulse could cause error in estimating blood pressure because it also includes the isovolumic contraction period [5].

In this research, we have used SCG as the proximal pulse for calculating PTT. SCG is a low frequency chest acceleration recorded by accelerometers [6]. There is a certain point on SCG signal corresponding to the aortic-valve opening time (AO). The AO point on SCG is used as the starting moment of PTT [7]. The idea behind estimating PTT using SCG is similar to the one discussed in [8] and is further explored in this paper for its relationship with pulse pressure.

We have used a finger PPG as the distal pulse in this paper. The PPG data is used as a reference to locate the AO point on SCG that always occurs before the peak of PPG. The pulse transition time is then calculated from AO point to the foot of the up-going slope of PPG which is shown in Figure 1 for couple of heartbeats.

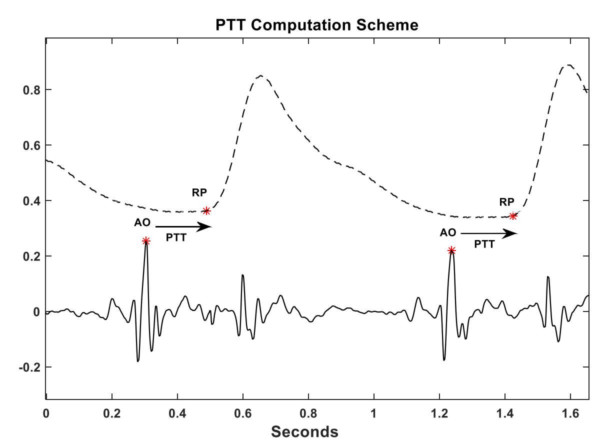


Figure 1. Illustration of pulse transit time computation using simultaneously recorded SCG and PPG signals. PPG signal (top) with rise point (RP) marked and SCG signal (bottom) with AO point marked (red star).

2. Methods

2.1. Data Collection

Simultaneous ECG, PPG, and SCG signals were collected from 9 subjects (age: 28.2±4.5 years, height: 170.1±7.3 cm, and weight: 66.1 ±11.7 Kg) who went through a graded lower body negative pressure. The experimental set up of data recording under LBNP condition is shown in Figure 2.

All signals were sampled at 1 KHz. Subjects were lying supine inside the LBNP chamber initially at rest, gradually the pressure inside the chamber was reduced to -20mmHg, after this point the pressure was reduced at a decrement of 10 mmHg up to -60 mmHg, after this stage the LBNP pressurization was stopped and subject was at rest again. At each stage, subjects were kept for a period of twelve minutes. Some subjects got to the stage of pre-syncope or felt uncomfortable and stopped the experiment earlier than scheduled.

For reference systolic and diastolic blood pressure were measured using an off the shelf cuff based blood pressure monitor from Omron (HEM-7321-E). All other signals were recorded using National Instrument data acquisition system and processing was done using MATLAB.

All data were recorded at Aerospace Physiology Laboratory at Simon Fraser University, Canada. The study was conducted under an ethics approval from Simon Fraser University and informed consent forms were signed by all participants. There was a registered nurse present during all data acquisitions, as required by the ethics approval, and for the safety of the participants.

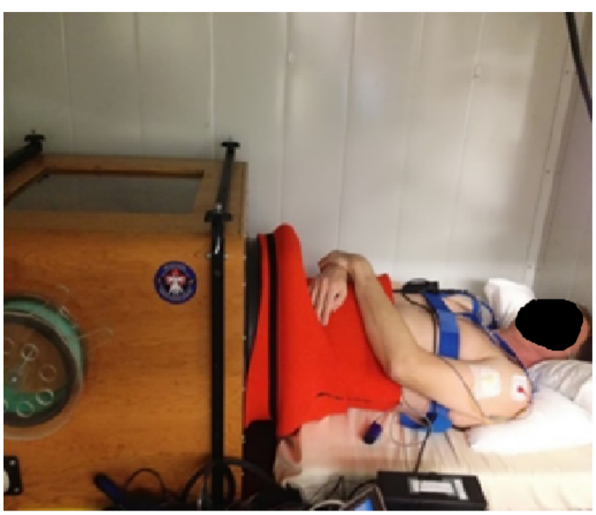


Figure 2. Experimental set up of data acquisition under lower body negative pressure condition.

2.2. PTT Measurement Algorithm

The first step towards PTT computation was to detect a peak point in the finger PPG signal. An algorithm was developed for this which was similar to the one proposed in [8]. After detecting PPG peaks a backward window of 500 milli-seconds was used to detect the AO point in the SCG signal. PTT was computed as time difference between AO point, in the SCG signal, and a rise point, in the PPG signal. Rise point was detected by subtracting the slope value from the PPG peaks; we found this value to be 140 ms on an average.

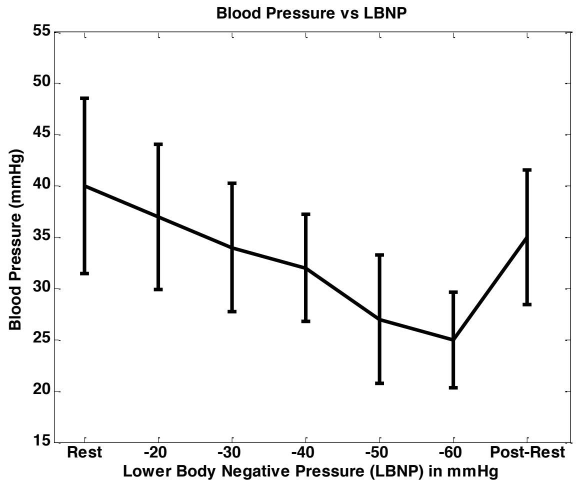
3. Results

While data acquisition the systolic and diastolic blood pressure values were also recorded, as mentioned earlier. Pulse pressure from this was calculated as a difference between the systolic and diastolic blood pressure. Figure 3 shows the averaged value of pulse pressure over 9 subjects and their changes with different stages of LBNP. It is clear that that pulse pressure dramatically decreased from resting stage (40 mmHg) to -60 mmHg stage (25 mmHg) which was the main goal of using an LBNP to start with. The goal here was to compare the pulse pressure values with computed PTT values under each level for all 9 subjects, and then, study the degree of correlation of SCG derived PTT has with pulse pressure.

Theoretically, PTT, being inversely proportional to pulse pressure, should increase with decrease in pulse pressure values. Figures 3 shows the variation in stage-by-stage average pulse pressure and PTT values for all 9 subjects. It can be observed from Figure 3 that PTT has a significant increase in the values at -60 mmHg compared to resting stage and then dropping down with increase in pulse pressure during post rest stage.

Next, after determining the PTT values, correlation of PTT values with pulse pressure values was computed for each subject. The strength of correlation was determined by computing correlation coefficient r and its p value. The result of this is summarized in Table 1. From Table 1, we conclude that on a subject-by-subject basis the PTT correlated significantly with pulse pressure, p values less than the significance level (0.05) indicates significant correlation. It was found that the p value for correlation between PTT and pulse pressure was below significance level (0.05) for all subject except subject 3 and 4 for which the correlation was not significant.

Apart from subject by subject correlation of pulse pressure with PTT, the correlation between stage-by-stage average pulse pressure values with stage-by-stage average values of PTT was also computed. We found these values to be 98% negatively correlated with a p value of 0.0001. See Figure 3 for the plot of these values.



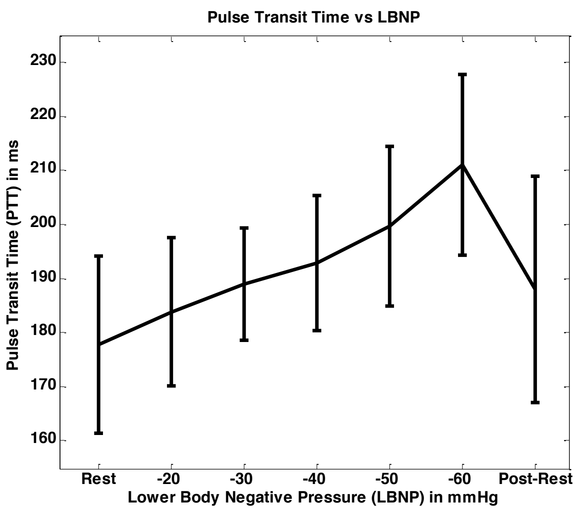


Figure 3. Variations in average pulse pressure *(top)*, and pulse transit time *(bottom)* for different stages of LBNP as obtained from all the 9 participants in this study.

Table 1: Correlation of Pulse Pressure with Pulse Transit Time for each subject measured by correlation coefficient r.

SUB #	PTT (r)
1	0.86
2	0.79
5	0.89
6	0.88
7	0.95
8	0.94
9	0.86
Average	**0.88±0.05**

4. Discussion

In this research, we explored SCG as a signal that can be potentially used to measure PTT and the fact that these measured values correlate with pulse pressure values measured using a cuff based blood pressure monitor; SCG can be used as a signal to non-invasively and continuously estimate pulse pressure. The work presented in this paper was an extension of our previous work to correlate these PTT timings with blood pressure [8].

We studied the variation in PTT induced by LBNP and processed 30 good cardiac cycles for estimating the PTT because we believe that 30 cardiac cycles should be good enough to estimate the blood pressure. In all subjects, AO point on the SCG was used for timing the proximal pulse except for subject 1 and 9 where accurately detection of AO point was difficult due to data condition, in which case IM point of SCG was used for measuring PTT. The variation in PTT for individual subjects was as we had expected, except for subject 3 and 4, where the PTT did not increase with decreasing pulse pressure which resulted in poor correlation between pulse pressure and PTT for those subjects, the r and p values for subject 3 was 0.40 and 0.36 respectively, whereas the r and p values for subject 4 was 0.30 and 0.51 respectively.

Overall, some promising results were achieved but further work is needed and more participants are also required to generalize the outcomes. In future work correlation of beat-by-beat blood pressure values with beat-by-beat PTT can be investigated to yield a more accurate result. Also, a study for computing correlation of PAT with pulse pressure can also be conducted to assert if SCG can be a better candidate over ECG for timing the proximal pulse and hence in estimating pulse pressure.

Pulse pressure has been proposed in the past as a good indicator of hemorrhage [2] and such a technology could be potentially used for monitoring and detection of hemorrhage. Certain features extracted from SCG have been also shown to indicate the blood loss simulation by LBNP [9]. Addition of a PPG device could potentially increase the sensitivity of the system.

In such a device, there would be no need for ECG to annotate the SCG signal and the PPG replaces the ECG signal as the reference. Nevertheless, developing a system capable of estimating the actual values, compared to a system estimating individual trends, requires prior calibration with another blood pressure monitoring device that can be investigated in a future work.

5. Conclusions

In this paper we introduced a SCG based alternative technique for computing PTT. In this method AO point in a SCG was used for timing the proximal pulse. On an average with decrease in pulse pressure; induced by a lower body negative pressurization an increase in PTT was found. The results of this research also showed a correlation between PTT and pulse pressure for all subject except for 2 subjects. Thus, SCG could be potentially used in a technology for timing proximal pulse in order to continuously estimate or trend blood pressure.

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