

# A Wearable Cuff-less system for Continuous Monitoring of Blood Pressure

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## ABSTRACT

Continuous monitoring of Blood Pressure (BP) has a significant value for Cardiovascular Diseases (CVDs), but the conventional BP apparatus are commonly Cuff-based, which becomes a great hindrance for long term BP measurement particularly during night. Through this project, we propose a wearable Pulse Transmit Time (PTT) system for continuous BP measurement. This wearable device is capable of measuring the PTT for one minute at a time interval of every 30 minutes, which is compared against the standard oscillometric ambulatory BP monitor. A new method has been proposed to eliminate the misalignment of BP and PTT recording time which occur due to the different measurement principle of the two BP devices. The proposed method uses defined criteria to remove the transients in PTT from the raw data, which is then interpolated, low pass filtered and resampled to synchronize at the time when BP was recorded. The correlation between PTT and Systolic Blood Pressure (SBP) and the difference between estimated and reference SBP obtained during night time through the proposed method is found to be improved. Hence, the averaged SBP over a long period can be successfully measured by the proposed wearable PTT system and it shows high potential to be used for overnight SBP monitoring.

## Keywords

Cardiovascular diseases, Cuff-less, mobile health, pulse transit time (PTT)

## 1. INTRODUCTION

The Blood Pressure is the main significant reason for many Cardiovascular diseases(CDV's). So, it is necessary to measure the blood pressure frequently. This wearable Pulse Transmit Time (PTT) system is used for continuous measurement of BP. It will measure the Blood pressure of the patient for one minute at a time interval of every 30minutes. It

removes the transients in PTT from the raw data, which is then interpolated, low pass filtered and resampled to synchronize at the time when BP was recorded.

## 2. BLOCK DIAGRAM

The Block Diagram of the Wearable cuff-less system for continuous monitoring of blood pressure is shown in figure 1.1.

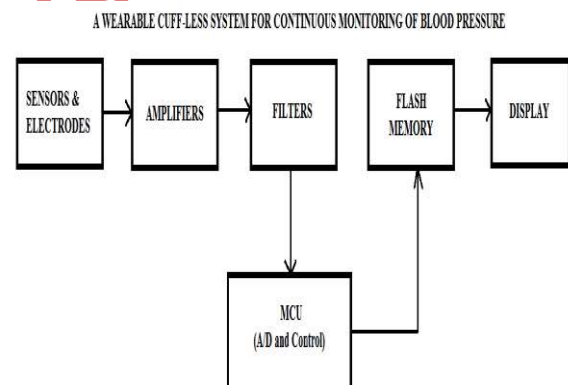


Fig 1.1 Block Diagram of a wearable cuff-less system for continuous monitoring of blood pressure

## 3. DESIGN METHODOLOGY

This proposed design is used to develop ambulatory ECG and PPG measurement. ECG is measured by the three electrodes in which two e-textile electrodes are sewed in the armband wrapped around the left arm and the other one is an adhesive Ag/AgCl Electrode which is placed on the right side of the subject's thorax. One electrode on the Armband works as an common electrode with right leg driven circuit to actively cancel common mode interference. PPG is measured by Near Infrared LED emitter and a phototransistor in reflective mode. The acquired ECG and PPG signals are amplified and filtered by BPF which are then



In the Microcontroller part, the Correlation of ECG and PPG signal will be done by removing the transients in PTT from the raw data, which is then interpolated, low pass filtered and resampled to synchronize at the time when BP was recorded.

Atmega 8 has 8 Kbytes of In-System Programmable Flash with Read-While-Write capabilities, 512 bytes of EEPROM, 1 Kbyte of SRAM, 23 general purpose registers. It has 10-bit accuracy, a programmable Watchdog Timer with Internal Oscillator, an SPI serial port and five software selectable power saving modes. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions.

In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption.

### 3.4 Measurement of Reference BP

Finapres and Portapres were often used as the reference BP measurement devices in previous in-laboratory studies. Since these devices, a standard 24-h ambulatory BP meter was chosen to be the reference in the current study. The reference device measures intermittent BP at intervals of around 30 minutes to evaluate the performance of the PTT-based method over a 24-h period.

The measurement principle of this 24-h ambulatory BP monitor, however makes it difficult to obtain synchronized BP and PTT measurements during a 24-h period. First, although the two devices were set to have the same sampling rate (one sample per 30 min), they tend to be out of sync a few hours after the start of the study due to the built in sampling pattern of the 24-h ambulatory monitor. Second, using a cuff inflation to trigger the recording of PTT can better synchronize the two devices but such a design was not adopted due to other practical issues: 1) if a physical cable was used to connect the two devices that were placed on the two arms of a subject, it would cause great inconvenience to the subject and therefore the design is not recommended by the doctor; 2) if wireless communication such as Bluetooth was used, the heavy power consumption of the wireless module is found to be impractical for the 24-h study. Third, it is essentially difficult to synchronize PTT with BP at exactly the same beat due to the intermittent nature of the oscillometric measuring principle of this ambulatory BP monitor. Specifically, the oscillometric BP device which measures BP detecting the maximal oscillation in a sphygmomanometer cuff caused by blood flow, assumes that BP do not vary a lot during the measurement period. This may be the reasonable for a well control still during the whole procedure.

### 3.5 Data Analysis

The acquired ECG and PPG were low pass filtered with cutoff frequency of 30 and 16Hz, respectively. For each 1-min episode of ECG and PPG, PTT was derived as the time interval between the R-peak of ECG and the point with maximum slope on the rising edge of PPG. Data segments with poor signal quality due to motion artifacts were manually discarded before further analysis

To investigate the relationship between BP and PTT during daytime and night time separately the 24-h data of each subject were divided into two segments, daytime and nighttime, according to the subjects sleeping and waking time. Since BP and PTT were measured intermittently by two individual devices as well as the limitation of oscillometric BP measurement mentioned earlier, resampling should be performed to align PTT recordings at the time when BP was measured. Due to the low sampling rate in data acquisition high frequency components of the PTT variability would not be able to be captured. Therefore, a low pass antialiasing filter was applied before resampling. In addition PTT may be misleading.

## 4. RESULTS

The correlation between BP and PTT has been studied extensively in the past to explore the potential of PTT as a surrogate of BP. According to Moens-Kortweg equation it is known that when BP changes the pressure dependent vascular elasticity will change thus inducing a change on pulse wave velocity and a reverse change on PTT. Thus pulse wave propagation based model described the physiological basis of the negative correlation between beat to beat BP and PTT. It is however unknown whether this relationship still holds for BP and PTT over a much longer period. In this paper, the 24-h ambulatory study was conducted to explore the relationship between intermittent BP and PTT within 24h in an unattended out of laboratory setting. Due to the differences in measuring principles of the cuff based and PTT based cuff less BP measurement methods, it is impossible to measure the two BP exactly at the same time point. Therefore, resampling is needed to calculate the correlation between PTT and BP. Limited by the very low sampling rate, i.e., sampling at 30-min interval, it would be unable to capture the HF fluctuations in both BP and PTT, as known to the sampling theorem. Therefore, BP and PTT should be first low pass filtered before interpolating. It is found that the correlation between the smoothed SBP and PTT was larger than that between the raw SBP and PTT, which suggest that the relationship between SBP and PTT is frequent dependent. This result is consistent with the conclusion of Liu's study which found that the ratio of the low frequency and High Frequency, i.e., LF/HF ratio, of SBP was about four times larger than that of PTT.

## 5. CONCLUSION AND FUTURE WORK

In this study, an armband based wearable device was developed for long term BP measurement based on PTT method. 24-h take home study was conducted to evaluate the accuracy of this device. To overcome the difficulties of misalignment in time between the recordings from the PTT based wearable device and the oscillometric based reference device a new analysis method was proposed to preprocess PTT.

The results showed that the correlation between SBP and PTT during nighttime was significantly improved by the proposed method with the difference between the PTT based estimation and the reference SBP. The results are further improved after smoothing SBP. Therefore this study provides a complete and effective solution for nighttime SBP measurement, which is known with the significant clinical value for cardiovascular risk screening.

In future, a larger cohort study including more healthy subjects and patients with CVDs will be conducted to further validate this wearable device for overnight BP monitoring.

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