Development of IoT Based Cuffless Blood Pressure Measurement System

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Abstract. Hypertension, commonly known as high blood pressure, is a major concern for people globally and in Malaysia. The hypertensive patient must commute to the hospital visiting their physician regularly for blood pressure (BP) monitoring using a cuff-based device. The patient may feel uncomfortable and pain when the device inflates the cuff and tightens around the arm for a BP measurement. Hence, to overcome this problem, this paper proposed a cuffless BP measurement using pulse transit time (PTT). In this method, a delay time between the peak of Photoplethysmogram (PPG) signals at the fingertip and the earlobe were correlated with BP. These signals were transferred to a computer via Arduino uno microcontroller and analyzed by the MATLAB R2019a software. A preliminary result shows that the developed system is able to record PTT and display the estimated BP value on the ThingSpeak webpage and ThingView apps. With the IoT platform, the cuffless BP can be monitor remotely, and the results can be store on the cloud healthcare system for hypertensive management.

1. Introduction
Hypertension is a major public health issue, especially in developing countries [1], and is known as a “silent killer” because it has no symptoms [2]. According to the World Health Organization’s report in 2013, approximately 17 million deaths per year occur due to cardiovascular disease, out of which complications of Hypertension account for 9.4 million deaths [3]. The report stated that the number of people with Hypertension who are undiagnosed, untreated, and uncontrolled increases in a country with an increased population and is weak in the healthcare system. In Malaysia, the prevalence of Hypertension was relatively higher in the older age group, in men, and in those with low educational attainment or lower household income level [4]. The blood pressure (BP) reading of a normal healthy individual is around 120 millimeters of mercury (mm Hg) for systolic pressure and 80 mm Hg for diastolic pressure. American Heart Association (AHA) states that the BP reading that exceeds 130 per 80 mm Hg is defined as Hypertension. Hypertension is divided into four stages which are prehypertension, mild Hypertension, moderate Hypertension, and severe Hypertension for stage 1, stage 2, stage 3, and stage 4, respectively [5]. The person who suffers from severe Hypertension is advanced to monitor their BP reading with their physician once a month to avoid health complications such as kidney and heart failure, stroke and blindness. In practice, BP is measured using an oscillometric method requiring a cuff to squeeze the brachial artery. This method has a disadvantage where an individual with
stiff arteries and wide pulse pressures, the mean arterial pressure may be significantly underestimated. The method also does not work well during physical activities, and the most significant problem is the bulkiness and discomfort of the inflatable cuff [6]. The air pump limits the minimization of equipment while repeating occlusion of arteries disturbs the normal routine users, especially in the sleeping environment. Therefore, one of the most promising cuff-less continuous BP monitoring methods is based on the pulse transit time (PTT) method. For this method, the delay time between two physiological signals related to the blood flow, namely the Photoplethysmogram (PPG), are calculated and correlated with the BP.

In literature, it has been reported that the PTT is inversely related to BP [7-8]. Nitzan et al. showed that the PTT between finger and toe significantly decreases with systolic BP [9]. Estimating the PTT from two different measuring points, such as between the sternoclavicular joint and the earlobe, was studied by Jeong et al. [10]. The findings show that they can estimate systolic blood pressure (SBP) in different body postures with a single equation. Amin et al. designed an optical system to measure continuous and cuff-less BP using two PPG signals with 55 mm separation between the two transducers [11]. Their result shows that the mean percentage errors (n = 15) between the cuff method and the PTT method of SBP and diastolic blood pressure (DBP) were 6.3 mmHg± 2.5 % and 10.9 mmHg ± 3.9 %, respectively.

In this project, the PTT was calculated based on the delay time between PPG at the fingertip and earlobe. The fingertip and ear region are preferable for PPG detection because this region comprises a high density of arterioles, which have the highest blood pressure content compared with capillaries, venules and veins [12]. In addition, the PTT measurement based solely on PPG signals requires a more simple circuit compared to the technique that uses Electrocardiogram (ECG) measurement [13]. The novelty of the developed system is on the internet of things (IoT) based system, which will be embedded into the wearable device to monitor the BP remotely. Through the IoT platform, the hypertensive patient could be measuring their blood pressure at home without commuting to the hospital regularly, and the doctor was able to monitor the patient BP reading remotely. Besides, the IoT platform is able to store all the patient’s BP data in the cloud healthcare system for future reference.

2. Methods
The development of this project is divided into four stages, as shown in Figure 1. Stage 1 requires a signal from PPG sensors and undergoes analog to digital conversion. Stage 2 included the development of the algorithm for blood pressure measurement by MATLAB R2019a software. Stage 3 is to establish internet connectivity between the ThingSpeak application and MATLAB R2019a software for real-time monitoring. Stage 4 is utilizing to observe the performance of the system on blood pressure measurement displayed at ThingSpeak and ThingView application.

![Figure 1. Block diagram of PTT measurement system.](image-url)
The hardware part of this project is the Arduino Uno microcontroller board and two PPG sensors. The first pulse sensor is placed at the earlobe, and the second sensor is placed slightly further from the heart, which is at the index fingertip. The LED illuminate skin by its light into the body parts, and the sensor captures the amount of light reflected sensor for the PPG measurement. These two PPGs signal is sent to Arduino Uno microcontroller circuit to convert the analogue signals to digital values. The data was then sent to the computer and analyzed by the MATLAB R2019a software. The software is used to remove unwanted noise of the PPG signals and determine the peak of the PPGs signal for PTT calculation. The PTT value obtained is then implemented in the algorithm for the designation of blood pressure measurement. Next, the BP readings are sent to the patient and their physician through an online platform via ThingSpeak and ThingView application. MATLAB R2019a software is programmed with the ThingSpeak framework and channel ID in order to establish the internet connectivity for the IoT application. Figure 2 shows the flow chart of the project operation.

![System flowchart](image)

**Figure 2.** System flowchart.

The prototype of the developed PTT device is shown in Figure 3. The initial experiment has been performed by a healthy female volunteer aged 23 years old to verify the performance of the device. The device is attached to the volunteers along with a BP monitor (OMRON HEM 907) for the calibration of BP and PTT. The calibration is performed by using an exercise bike held at the electronic medical
laboratory of UTHM. The volunteer is asked to pedal the bike for 20 minutes in the range of 70 to 80 revolutions per minute (RPM). The measurement of an OMRON BP monitor and PTT was simultaneously taken ten times before and ten times after the constant exercise. The calibration curve obtained through the exercise is implemented in the Matlab algorithm to estimate BP, and the result is displayed through the ThingSpeak and ThingView applications.

Figure 3. Prototype of PTT monitoring device

3. Result and Discussion
The raw PPG signals obtained by the pulse sensor are prone to noise from 50Hz power line interference and motion artefacts [14]. Generally, high-frequency noise can be filtered out using a low pass filter, but cancellation of movement noise is hard to achieve [15]. The noise in PPG measurement distorts the shapes of the signal, and such distortion results in wrong diagnoses in peak detection. However, the quality of these signals can be improved by applying a denoising technique using a digital filter [16]. In this project, a linear phase FIR (Finite Impulse Response) filter is implemented using Matlab software to remove unwanted noise in PPG signals. Typically, the range of PPG signals is between 0.5 Hz to 4 Hz [17]. Therefore, the cut-off frequency of the filter is set to 4 Hz to remove the high-frequency noise on the PPG signals. Figure 4 shows the filtered PPG signals. Generally, the filtered signals show a better signal-to-noise ratio (SNR) compared to unfiltered signals.

Figure 4. Filtered PPG signals.
The algorithm for peak detection was based on the find peaks function in the Matlab Signal Processing toolbox. The find peaks determine the maximum point based on a data sample that was larger than its two neighbouring samples. If the peak was flat, the function returned only the point with the lowest index. A threshold level was set to ensure the maximum point detected referred to the peak of PPG signals. Next, the calculation of PTT value is based on the difference between the peak value of PPG signals at the fingertip and the peak value of PPG signals at the earlobe in the time domain. As shown in Figure 4, the average delay time between the PPG finger and the PPG ear was 25 ± 6.5 ms.

In this project, a calibration curve of BP and PTT was obtained through bike exercise. Next, the algorithm was implemented in the Matlab software to convert the PTT value to the BP measurement and send the data through the IoT platform. The systolic and diastolic pressure data were visualized into two graphs simultaneously, as shown by Figure 5(a) for the ThingSpeak application and Figure 5(b) for the ThingView application. The data is auto-refresh within every second, and it will automatically be stored and displayed once the user measured their blood pressure.

![Figure 5.](image)

(a) ThingSpeak application, (b) ThingView application.

The transmission of data to ThingSpeak application and ThingView application is within one minute after the measurement of blood pressure is taken from the subject. Besides, since ThingSpeak application has its cloud and ThingView application have a feature that automatically refreshed data every second thus, the estimate blood pressure is transmitted much faster than other online application. Moreover, it is also embedded with a safety feature, which is a private channel mode that could ensure the confidentiality of the blood pressure measurement for the hypertensive patient, and only those who have its channel ID could view the blood pressure measurement. The resulting form of the cuffless BP device is compared with the BP recorded by using OMRON BP monitor. The mean error and standard deviation (SD) for estimated SBP are 22.6 ± 20.6 mmHg and for estimated DBP is 1.6 ± 1.2 mmHg. According to the American Association for the Advancement of Medical Instrumentation (AAMI) standard, blood pressure estimation, for both SBP and DBP, must have an absolute value of mean error less than 5 mmHg and the error standard deviation less than 8 mmHg [18]. The results show a weak correlation between PTT and SBP (correlation coefficient, r = 0.4) and a strong correlation between PTT and DBP (r = 0.9). The weak correlation between BP and PTT had been reported by other authors [6][19]. PTT measurement between two PPGs pulses means that the pre-ejection period (PEP) is excluded in PTT calculations, thus reduce the correlation between BP and PTT [20].
4. Conclusion

In a nutshell, this project is very crucial and needed to be implemented in health care technology all over the world due to its capability to display blood pressure measurement in distant through non-invasive technique that deployed a tiny cuff around the fingertip and earlobe. This is convenient for all hypertensive patients since it no longer used the oscillometric cuff that caused numbness all over the arm after several measurements. Besides, this project also enables patients to measure their blood pressure everywhere without commuting to hospital and could reduce the physician's workload because all blood pressure measurement is stored securely within ThingSpeak cloud. The initial finding for the cuffless BP monitoring looks promising and more volunteers are needed to validate the performance of IoT-based cuffless BP measurement.

Acknowledgement

The research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot H765).

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