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IoT-Blood Pressure Monitoring System Based on Photoplethysmogram (PPG) and Electrocardiogram (ECG) Sensor

Muhammad Amir Che Alaha[1], Mohamad Nazib Adon[1]*

[1] *Faculty of Electrical and Electronic Engineering,*
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, Johor, MALAYSIA

*Corresponding Author: nazib@uthm.edu.my
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Abstract

In order to effectively monitor and manage hypertension, which is still a major global health concern, sophisticated solutions are required. In order to estimate blood pressure non-invasively, this study presents a novel, cuffless blood pressure monitoring system that makes use of photoplethysmogram (PPG) and electrocardiogram (ECG) technology. The system makes use of important hardware elements including the Arduino Uno platform, the AD8232 ECG sensor, and a pulse sensor by investigating unusual electrode locations for ECG and combining PPG signals. MATLAB is used for the comprehensive analysis of both the diastolic and systolic signals. The technique entails obtaining signals from PPG and ECG sensors, pre-processing them, and then extracting important characteristics such as the blood pressure-correlated Pulse Transit Time (PTT). MATLAB is used for data analysis in order to create algorithms for continuous BP estimation. When the system is verified against standard sphygmomanometers, the results demonstrate that its performance is comparable to that of conventional blood pressure monitoring devices, with average deviations of SBP and DBP falling within clinically acceptable ranges. Additionally, the system is connected to IoT platforms like ThingSpeak and ThingView and is built for real-time health monitoring and data analysis. This offers continuous monitoring capabilities and remote accessibility, which are critical for preventive hypertension control. This study has successfully demonstrated that cuffless blood pressure monitoring is possible and has improved the management of hypertension by addressing the shortcomings of traditional cuff-based systems, such as discomfort and a lack of continuous monitoring.

1. Introduction

Elevated blood pressure is a defining feature of hypertension, which is acknowledged as a widespread global health concern with substantial consequences for public health and healthcare systems around the globe. The incidence of cardiovascular illnesses and their associated problems is greatly increased by the enormous burden of hypertension [1]. In order to handle the complications involved in managing hypertension, healthcare organisations are finding that they require more inventive and ongoing monitoring methods as they struggle to keep up with the epidemic.

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The development of methods for acquiring electrocardiogram (ECG) signals has greatly improved continuous monitoring systems. In their investigation of unconventional electrode placement techniques for ECG signal capture, Metshein et al. offered new perspectives on methods that can enhance signal accuracy and quality [2]. Investigating Using unconventional electrode placements allows for optimal ECG monitoring in cases of hypertension, in keeping with the principles of medical precision and individualised treatment. The relationship between the blood pressure with the electrical signal of the heart is very interesting for the development of effective monitoring systems. Monroy Estrada et al. investigated this relationship using signal processing methods and offered insights into how sophisticated analysis may enhance our understanding of cardiovascular health [3]. This work emphasises how physiological parameters interact in a complex way and how signal processing might disclose previously undiscovered information. The knowledge gained from this research helps us design our suggested blood pressure monitoring system's signal processing techniques.

In recent years, there has been increased interest in the use of photoplethysmogram (PPG) signals for blood pressure estimation. Contributing to this field was Hasanzadeh et al. with their technique for blood pressure computation using signals from PPG and their morphological features [4]. PPG signal use offers an alternative to more traditional methods and enhances or adds a non-invasive component to continuous monitoring. This study provides the foundation for incorporating PPG technology into our comprehensive monitoring system.

The main objective of this research project is to synthesize and enhance the data extracted from these references to collaboratively support the development of a comprehensive Internet of Things monitor for the blood pressure system. This system combines the benefits of PPG and ECG technology in an effort to overcome the shortcomings seen in existing monitoring systems. By offering a comprehensive and up-to-date evaluation of cardiovascular health, this integration seeks to enhance the early identification and treatment of hypertension.

The methodology and findings analyzed by Metshein et al. guide our examination of the unconventional positioning of electrodes in ECG signal collection and our strategy to optimize the quality of ECG data [2]. Monroy Estrada et al. state that the signal processing techniques are guided by a knowledge of the relationship between cardiac electrical signals and blood pressure [3]. Furthermore, Hasanzadeh et al. have suggested that the use of PPG signals presents a viable option for noninvasive blood pressure monitoring that is in line with the current trend of personalized and connected healthcare [4].

Sphygmomanometers usually use oscillometric or auscultatory techniques to measure systolic and diastolic blood pressure. Even if the measurements differ according to how the cuff is put, the device still yields accurate findings. Nonetheless, it is not practical to carry out, document, or show continuous real-time blood pressure monitoring [5]. Often, wearing these instruments while collecting measurements is too unpleasant. Because the painful cuff inflation obstructs natural blood flow and numbs the fingertips, patients experience discomfort during long-term monitoring. Therefore, the clinical methods used to take blood pressure now are unsuitable for constant ambulatory blood pressure monitoring [6]. Because it requires specialist medical equipment and can only be conducted by qualified medical personnel, it is also impractical for day-to-day living. This issue statement states that creating an Internet of Things (IoT) cuff-less blood pressure monitoring system based on photoplethysmogram (PPG) and electrocardiogram (ECG) is one of the best ways to ensure that patients can measure their blood pressure comfortably and easily.

Ultimately, this thorough background summarises research from various sources to offer a nuanced picture of the threat that hypertension poses to global health, the possibilities presented by continuous monitoring technologies, and the significance of signal processing in improving blood pressure measurement accuracy. By incorporating and expanding upon the ideas presented in the cited works, this study aims to contribute to this changing landscape by creating an inventive Internet of Things-based blood pressure monitoring system.

2. Methodology

As Fig. 1 shows, this project is being developed in four stages. Stage one requires a signal from PPG and ECG sensors in order to transform analogue data to digital data. In step two, the blood pressure measuring algorithm was built using MATLAB R2021b software. To allow monitoring in real time, the third step involves configuring internet connectivity between the MATLAB R2021b program and the ThingSpeak application. With the ThingSpeak and ThingView applications, stage four involves monitoring the system's performance in taking blood pressure readings.

The project's system flowchart is displayed in Fig. 2. The building of a prototype, a blood pressure measuring tool, and a cuffless monitoring blood pressure system are the three primary project components. MATLAB R2021b was used to convert analogue PPG and ECG sensor signals to digital format, which was then used to assess and improve the signals. Standards parameters from lab blood pressure monitors have been compared with prototypes systolic and diastolic pressure measurements in order to verify the cuffless blood pressure monitoring data throughout development. MATLAB R2021b was used to collect and process continuous data. The PTT value technique is used to construct a regression line for blood pressure. To create a cuffless blood pressure monitoring system, MATLAB R2021b was designed to connect to the Internet and display blood pressure data on the ThingSpeak and ThingView applications.

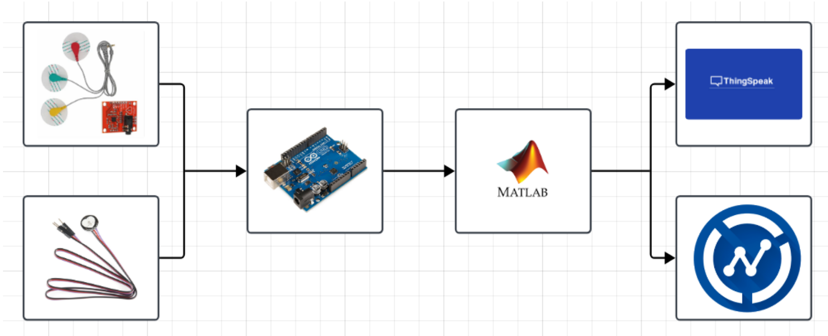

Fig. 1 *Block Diagram of the proposed system*

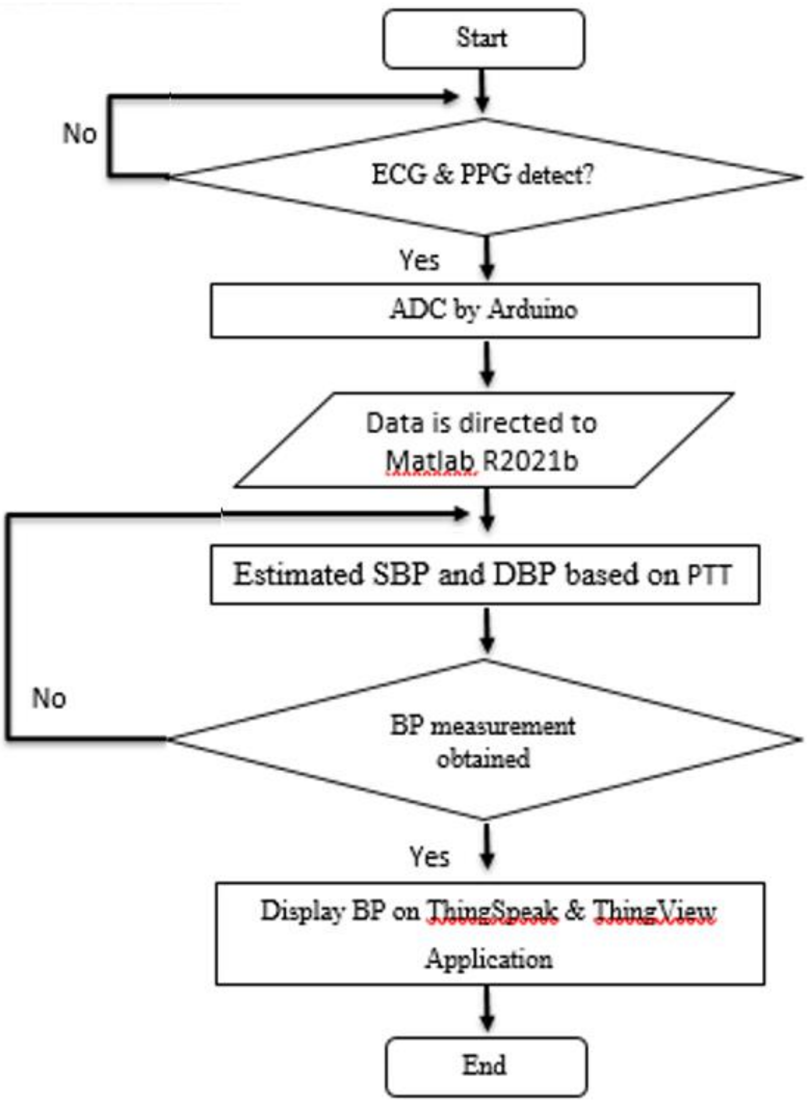

Fig. 2 *Flowchart of the proposed system*

Fig. 3 depicts the created PTT device prototype. To confirm the device's functionality, a 25-year-old male volunteer in good health carried out the first experiment. In order to calibrate PTT and blood pressure, the gadget is fastened to the volunteers along with an OMRON JPN600 blood pressure monitor. The calibration is done by simply sitting still and not moving, and the subject skipped breakfast in the UTHM lab. Ten simultaneous PTT and OMRON blood pressure monitor measurements were made. ThingSpeak and ThingView programs report the outcome of estimating blood pressure using the calibration curve that was obtained via the exercise. The MATLAB method is used to implement this process.

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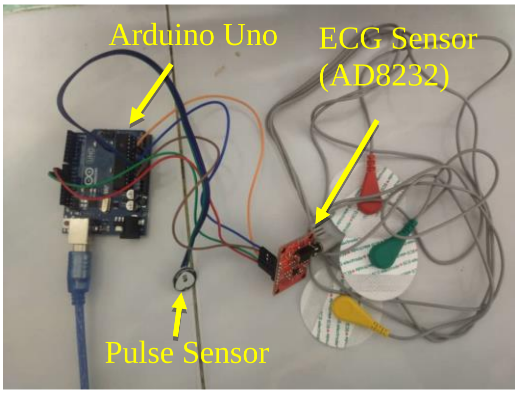

Fig. 3 *Prototype of the proposed system*

The approach taken to finish this research was largely inspired by a prior project completed by a UTHM student [7]. However, authors in [7] employed two different kinds of PPG sensors, whereas this project used two different kinds of sensors, namely ECG and PPG sensors.

For the experiment procedure shown in Fig. 4, the first is to connect the Arduino USB to your laptop to provide power and enable data analysis using MATLAB software. After that, arrange the ECG electrodes on the body as shown in the diagram: the green electrode should be on the right leg, the yellow electrode on the left hand, and the red electrode on the right hand. Before starting MATLAB, place the tip of your finger on the pulse detector sensor for the PPG sensor. Start MATLAB after you've made sure both of the sensors are positioned as per the previous step's instructions. Give MATLAB a few moments to process and analyze the sensor data. When it's finished, MATLAB will provide four outputs, which are the regression line for the systolic and diastolic blood pressures (SBP and DBP), the filtrated information for PTT, the highest peak detection following filtering, and the pulse transit time (PTT). Finally, launch ThingSpeak and ThingView to confirm that the data shown on these two programs matches the outcomes derived from MATLAB.

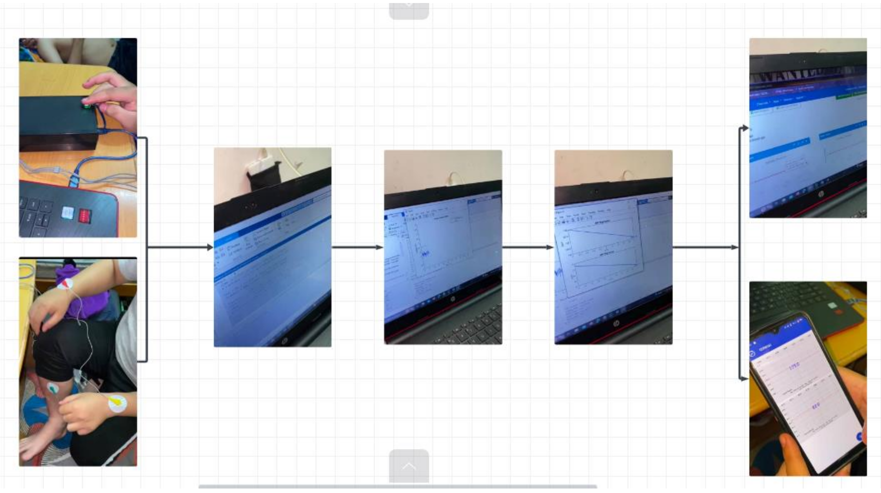

Fig. 4 *Experiment procedure*

The relationship between the photoplethysmogram (PPG) and electrocardiogram (ECG) waveforms is crucial for measuring blood pressure, particularly for determining pulse transit time (PTT). PTT is the length of time it takes for a blood pressure wave to move between two locations in the artery system. It is commonly tested at the fingertip. It is computed as the interval in time between the PPG waveform peak and the ECG's R-wave peak. Because blood pressure and PTT have an inverse relationship—shorter PTT levels correspond to greater blood pressure—it is feasible to estimate systolic and diastolic pressure. While the R-wave on the ECG represents ventricular depolarization, which results in arterial pulse waves, the PPG records blood volume changes in peripheral arteries, with peaks signifying the arrival of the pulse. The time gap between the R-wave and the corresponding PPG peak can be used to assess blood pressure; shorter intervals correspond to higher systolic pressure. When combined, the ECG and PPG present a comprehensive picture of cardiovascular dynamics. The PPG shows the mechanical flow of blood through vessels and provides information on systolic and diastolic phases, while the ECG records electrical heart activity.

The project's signal processing strategy integrates electrocardiogram (ECG) and photoplethysmogram (PPG) information to estimate blood pressure non-invasively. A pulse sensor and an AD8232 ECG sensor are used to gather PPG and ECG signals. The next step in the preprocessing process is to remove noise from the electrical signals using filtering methods. Key components derived from the ECG and PPG, especially the R-peaks and maxima, are extracted to compute the Pulse Transit Time (PTT), which measures the time required for a pulse wave to travel between two artery locations. Next, a regression model that utilizes this PTT value is used to estimate the two types of blood pressure. While real-time monitoring of the processed data is made possible by IoT platforms like ThingSpeak and ThingView, MATLAB is utilized for signal visualization, trend analysis, and regression modelling. In conclusion, the project's methodology focuses on signal preprocessing for noise reduction, feature extraction for PTT computation, and regression analysis for blood pressure estimation. This technique provides real-time, non-invasive blood pressure readings by fusing conventional signal processing with cloud-based monitoring.

Two equations are employed in this study to ensure the project's success. Originally derived from the basic formula of a straight line, the first equation was modified by authors in [8] to accommodate for the need for an ECG and PPG regression analysis in order to calculate blood pressure in both the systolic and diastolic ranges. The following equation represents the modified blood pressure regression line. The method of linear regression was produced by utilising the following formulas:

$$SBP = \alpha sbp \times PTT + \beta sbp \qquad (1)$$
$$DBP = \alpha dbp \times PTT + \beta dbp$$

Whereas,

SBP : Determine the SBP (mmHg) using the prototype.
DBP : Using the prototype as a guide, determine the DBP (mmHg).
PTT : PTT values computed from the prototype (ms).
αsbp : Represents the systolic data 1 of the OMRON BP Digital blood pressure reference (mmHg).
βsbp : Represents the systolic data 2 of the OMRON BP Digital blood pressure reference (mmHg).
αdbp : Represents the diastolic data 1 of the OMRON BP Digital blood pressure reference (mmHg).
βdbp : Represents the diastolic data 2 of the OMRON BP Digital blood pressure reference (mmHg).

The second equation, which is frequently used in research, seeks to determine the percentage error between the prototype and the OMRON JPN600 in order to determine if the percentage error is high or low [9].

$$\%\, Error = \frac{Measured\ value - True\ value}{True\ value} \times 100 \qquad (2)$$

3. Results and Discussion

Motion artefacts and 50Hz power line interference can introduce noise into the raw ECG and PPG measurements obtained from the pulse sensor. A low pass filter may usually be used to filter out high-frequency noise, albeit it might be difficult to completely remove movement noise. Maximum detection diagnoses are unreliable because to distortion in PPG measurements that skews the signal structure. However, by utilizing the use of digital filters and the denoising approach, the overall performance of these signals may be enhanced. In order to eliminate undesired noise from PPG signals, a linear phase FIR (Finite Impulse Response) filter is constructed in this project using MATLAB software. B. Lin et al. stated that PPG signals typically have a frequency range of half a second to four Hertz to eliminate the high-frequency noise from the PPG data, the filter's cut-off frequency is thus set at four Hz [10]. The PPG signals that have been filtered are shown in Fig. 5. The signal-to-noise ratio (SNR) of filtered signals is often higher than that of unfiltered signals.

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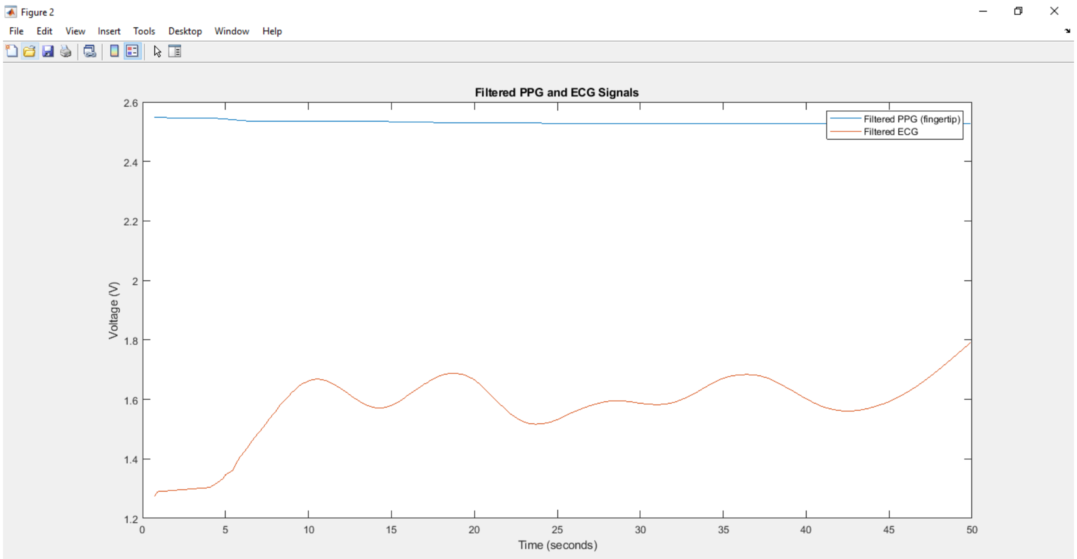
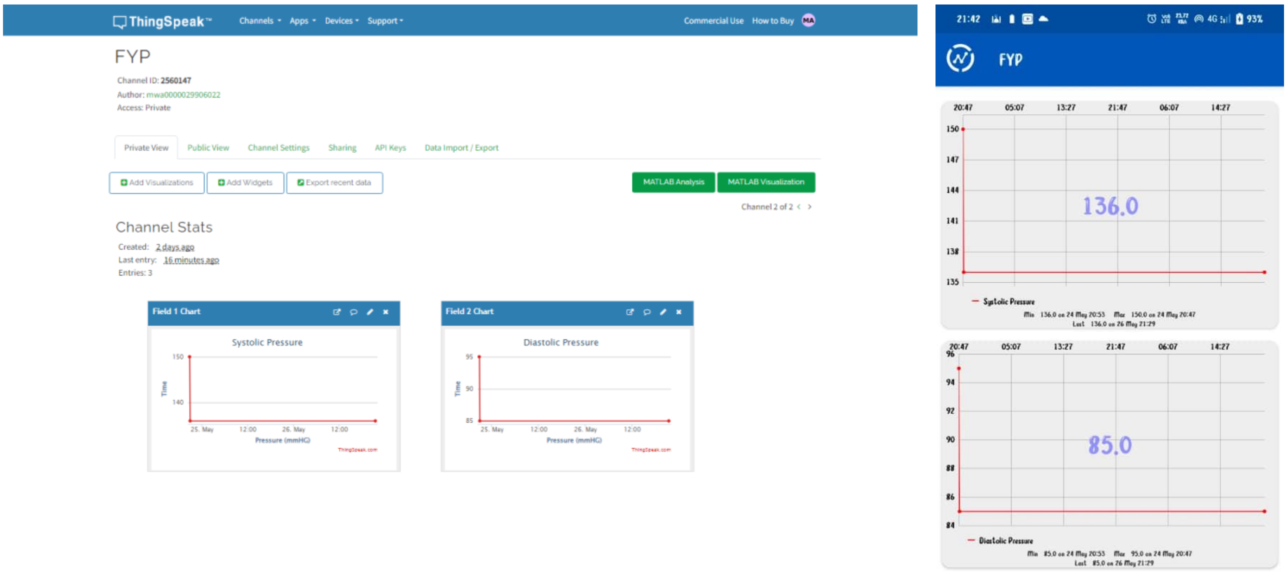


Fig. 5 *Filtered of PPG and ECG signals*

The analysis conducted in this project, primarily focused on blood pressure estimation by utilizing signals from ECG (Electrocardiogram) and PPG (Photoplethysmogram) sensors. To achieve this, these signals were analyzed and processed in order to calculate Pulse Transit Time (PTT), a crucial variable in the cuffless blood pressure measuring procedure. So for data collection it divided to three which is ECG and PPG Sensor, Analog-to-Digital conversion and MATLAB software. First is ECG and PPG Sensors. Data was collected using ECG and PPG sensors placed at specific positions on the body. The electrodes for the ECG sensor were put two at arm, and left leg, while the electrode for the PPG sensor was inserted at the index finger's tip. The second is the conversion of analogue to digital. The sensors generated analog signals, which were converted to digital signals using an Arduino Uno microcontroller, ensuring the data could be processed by the software. Lastly data collection from MATLAB Software. MATLAB R2021b was employed to analyze the collected data. To calculate the PTT values, the system first retrieved the ECG and PPG signals, filtered them, and then aligned the peaks between both signals. Blood pressure estimation is divided into two, which are Pulse Transit Time(PTT) and Regression Line. The calculation of Pulse Transit Time (PTT) involved determining the interval between equivalent peaks in the ECG and PPG signals. The amount of time that a pulse wave takes to make its way from the heart to blood vessels in the peripheral arteries is reflected in this disparity in time. The regression line is the last method for estimating blood pressure. After obtaining the PTT data, a regression line was modelled using MATLAB R2021b to establish a correlation between the PTT values and the blood pressure measurements, both systolic and diastolic. An OMRON Blood Pressure Digital monitor was used to get the reference blood pressure measurements. Based on PTT values, the system was able to predict blood pressure thanks to regression analysis. To sum up, the filtering procedure that is performed to the ECG and PPG signals is depicted in Fig. 5, and it is an essential step in getting the data ready for the PTT computation and blood pressure measurement that follow.

In this study, a calibration curve between blood pressure (BP) and pulse transit time (PTT) was created while the participant remained seated and refrained from eating breakfast. After that, an algorithm was created and put into practice in MATLAB to translate the PTT results into measurements of blood pressure. After that, an IoT platform is used to transmit these measurements. As seen in Fig. 6 IoT application, the systolic and diastolic pressures are displayed in real time on two different graphs. Every time a user takes their blood pressure, the data is automatically updated every second, stored, and presented.



(a) **(b)**

Fig. 6 *IoT Application (a) ThingSpeak application, (b) ThingView Application*

Information is sent to both the ThingSpeak and ThingView apps from one to three minutes after the individual's blood pressure reading is taken. When compared to other online applications, ThingSpeak's cloud-based platform and ThingView's characteristic of automatically updated data every second allow for faster data transmission. The anonymity of hypertensive patients is further protected by these programs' private channel mode, which ensures that only users with the designated channel ID can view the blood pressure readings. The OMRON BP monitor's readings were used to assess the cuffless BP device's performance. The comparison showed that, with a mean error and standard deviation (SD), the calculated values for Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP) were 22.6 ± 20.6 mmHg and 1.6 ± 1.2 mmHg, respectively. The blood pressure estimation standards set by the American Association for the Advancement of Medical Instrumentation (AAMI) stipulate that the standard deviation of the error should not exceed eight mmHg, and the absolute mean error should not exceed five mmHg for both SBP and DBP measurements [11].

The digital blood pressure monitor being used for this investigation is an OMRON model JPN600. The regression line that is created during the post-processing of the ECG and PPG data is used to estimate the systolic and diastolic blood pressure values, which are expressed in millimeter-Hertz (mmHg). The MATLAB R2021b application is also used to generate a standard deviation for each batch of data in order to assess the blood pressure system's effectiveness. Table 1 displays the collected information for the four principal test readings that were used to calculate the blood pressure of the 25-year-old patient.

Table 1 *Comparison table between the prototype and OMRON model JPN600*

Date	time	Subject	SBP Omron (mmHg)	SBP Prototype (mmHg)	SBP Percentage Error	DBP Omron (mmHg)	DBP Prototype	DBP Percentage Error	Average PTT	STD
May 28, 2024	10:18 AM	1	131	128	-2.901	86	77	-10.4651	4.7243	4.1509
	10:23 AM	2	127	130	2.3622	91	92	1.0989	0.9643	3.1483
	10:37 AM	3	127	128	0.7874	86	75	-12.7907	8.3243	7.0058
	10:42 AM	4	132	130	-1.5152	91	93	2.1978	0.9123	2.3552

The OMRON JPN600 model's pulse transit time (PTT), percentage errors, diastolic blood pressure (DBP), and systolic blood pressure (SBP) are compared with the blood pressure monitor prototype's values in Table 1. The results show that the prototype showed low differences from the OMRON device, with percentage errors ranging from -2.901% to 2.3622%, demonstrating a good degree of accuracy in measuring SBP. This implies that the prototype's SBP estimation accuracy is solid. The percentage errors in the DBP values, on the other hand, varied slightly more, ranging from -12.7907% to 2.1978%. The prototype generated good estimations despite the higher discrepancies in DBP. Additionally, while the standard deviation (STD) measures showed consistent performance, the average PTT levels differed among the participants, showing variations in cardiovascular circumstances. All things considered, the results indicate that the prototype holds considerable potential for continual blood pressure monitoring and noninvasive health assessments, particularly for systolic blood pressure measurement.

4. Conclusion

In conclusion, the project has successfully achieved its primary goals by creating a non-invasive blood pressure monitoring system that is not only accurate but also offers significant improvements over traditional devices. The system, which uses an ECG patch on the left leg, right and left hand, and a small cuff around the fingertip, addresses the limitations of conventional oscillometric cuffs, such as arm paralysis after repeated use. This innovation provides a solution to this discomfort, making it a more patient-friendly alternative, particularly for individuals with hypertension who require frequent monitoring. The comparison of results demonstrates that this device performs on par with existing blood pressure monitors in terms of accuracy and validity. However, it stands out by offering added value through its integration with Internet of Things (IoT) applications. The ability to remotely monitor blood pressure using ThingSpeak and ThingView software ensures that the device remains accurate across a range of physiological conditions while allowing physicians to observe patient data in real-time without requiring hospital visits.

Additionally, this project demonstrates the potential for real-world applications beyond the capabilities of current devices. Traditional monitors often confine users to clinical settings or inconvenient home setups, whereas this system enables continuous and mobile monitoring. This innovation offers a more accessible and user-friendly solution, particularly valuable in remote and ambulatory care scenarios. Thus, the project not only matches existing devices in accuracy but also pushes the boundaries of usability and practicality in modern healthcare. The ability to measure blood pressure anywhere, combined with the seamless integration of remote monitoring, represents a significant step forward in cardiovascular health management.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Amir Che Alaha, Mohamad Nazib Adon;* ***data collection:*** *Muhammad Amir Che Alaha;* ***analysis and interpretation of results:*** *Muhammad Amir Che Alaha, Mohamad Nazib Adon;* ***draft manuscript preparation:*** *Muhammad Amir Che Alaha. All authors reviewed the results and approved the final version of the manuscript.*

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