CHAPTER 6

THE DEVELOPMENT OF BLOOD PRESSURE DEVICE USING PULSE TRANSIT TIME (PTT)

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6.1 INTRODUCTION

Cardiovascular disease-related deaths, accounting for over 17 million deaths globally, are primarily caused by hypertension, a significant risk factor [1]. High blood pressure is a silent condition, with 61% of Malaysians with hypertension undiagnosed [2]. Hypertension is a sustained elevation of blood pressure, with systolic and diastolic pressures of 140 mmHg or greater. Uncontrolled or improperly controlled hypertension increases cardiovascular, cerebrovascular, and renal morbidity and mortality. In Malaysia, heart attacks and strokes are the leading causes of mortality.

Blood pressure (BP) is a vital indicator of cardiovascular health and can be influenced by physical exertion, depression, medications, and emotions. Three variables reflect blood pressure: systolic (SBP), diastolic (DBP), and mean arterial pressure (MAP) [3].

Electrocardiography (ECG) is an essential method for monitoring heart health, based on the electrical activity generated by the sinus node on the right atrial wall. ECG displays a distinct voltage pattern over time, with the QRS complex being the most well-known [4]. A plethysmogram represents arterial oxygenation against time and the relationship between blood volume and time. Photoplethysmography (PPG) is an optical technique used to detect plethysmography signals that measure arterial oxygen saturation [5]. Cuffless blood pressure devices based on Pulse Transit Time (PTT) have been developed to address this issue.

According to a previous related paper, PTT is the time it takes for a pulse wave to travel from the heart to a specific body location, such as the finger or earlobe. Variations in blood pressure, heart rate, and arterial wall compliance affect PTT. Blood pressure increases arterial wall tension and rigidity, shortening PTT, while decreasing arterial wall tension and stiffness. The PTT-based method estimates blood pressure by applying the relationship. A statistical technique was used to determine the correlation between blood pressure and PTT from ECG and photoplethysmography [6]. Stefan Kochev, in his 2020 study, intended to model the relationship between blood pressure and ECG using time-series feature extraction. The researchers hypothesized that there is a relationship between blood pressure and ECG signals, and they proposed a methodology that involved considering ECG signals as time series data and employing a time series feature extraction method to extricate pertinent information [7].

In this study, the PTT is measured from the R-peak of the ECG to the P-peak of the PPG. The ECG electrode is attached to the chest while the PPG is placed on the fingertip.

6.2 METHODOLOGY

The development of this project is divided into three stages as shown in Figure 6.1.

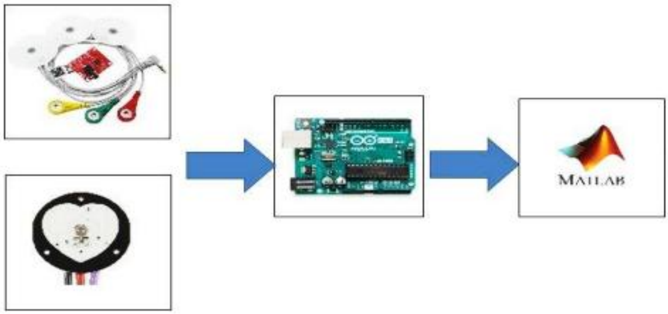

Figure 6.1: Block Diagram of Blood Pressure Measurement using PTT

The hardware block diagram for this project consists of an Arduino Uno microcontroller board, an ECG sensor (AD8232), and a PPG sensor (Pulse Rate sensor). Three ECG sensor electrodes are placed on the chest, while the PPG sensor is located away from the heart at the tip of the index finger. This configuration measures the PTT from both sensors. This project used MATLAB R2021b software to analyze and display.

Figure 6.2 shows a system flowchart of the project. The project has three main components: prototype development, a blood pressure measurement system, and a cuffless blood pressure monitoring system. Signals from PPG and ECG sensors were analyzed and amplified by converting them from analog to digital using MATLAB R2021b. For cuffless development, to validate cuffless blood pressure monitoring measurements, reference variables from laboratory blood pressure monitors were used to compare with prototype systolic and diastolic pressure measurements. Continuous data were collected and then processed using MATLAB R2021b. A blood pressure regression line is generated by applying the PTT value algorithm.

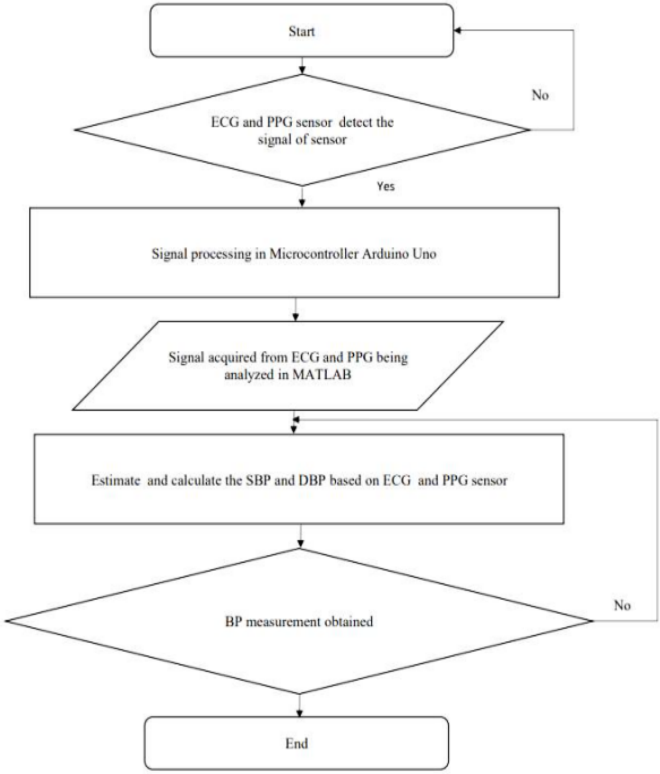

Figure 6.2: System Flowchart

Figure 6.3 shows a prototype of the project. The hardware component is necessary for capturing the physiological signals (ECG and PPG) from the user, processing them to extract relevant data, and providing a means to display or transmit blood pressure measurements. It provides the necessary functionality for accurate and reliable blood pressure monitoring and serves as the device's physical infrastructure. After the blood pressure device prototype is constructed, it is then connected to the MATLAB R2021b software to directly program the ECG and PPG sensors for the required signal visualization on MATLAB figures and the requirements for further signal processing stages. The connection of the ECG and PPG sensor to the Arduino Uno Microcontroller board is displayed in Figure 6.3. There are 5 pins involved for ECG which is connected to analog, voltage, ground, LO- and LO+ pins. The PPG sensor consists of 3 pins connected to analog, voltage and ground pins.

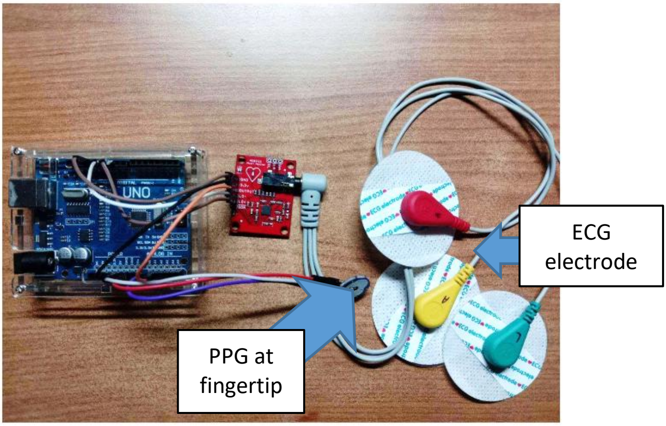

Figure 6.3: Prototype of the project

The experimental data has been performed by three healthy female volunteers aged 25 years old to verify the performance of the device. The device is attached to the volunteer along with the blood pressure device Ezyswiss MX-101 for calibration. Calibration is performed when the subject is in a resting state. Each subject's measurement is taken twice.

6.2.1 EQUATIONS

The objective is to formulate a linear equation that best describes the relationship between these variables. Eq. (1) and Eq. (2) represent the linear regression models for SBP and DBP, respectively.

$$SBP = \alpha_{sbp} \times PTT + \beta_{sbp} \quad (1)$$

$$DBP = \alpha_{dbp} \times PTT + \beta_{dbp} \quad (2)$$

Where,
α_{sbp} and α_{dbp} are the slopes of the coefficient of systolic and diastolic blood pressure change in PTT, respectively.
β_{sbp} and β_{dbp} are intercepts for SBP and DBP, respectively, and determine the starting point of the SBP and DBP regression line regardless of PTT.

6.3 RESULTS AND DISCUSSION

Since the ECG sensor signals are generated at 1.5V and the ECG signal source voltage is 3.3V, the ECG sensor is designed to generate output signals at a lower voltage level. This voltage reduction could be the consequence of the ECG sensor's integrated signal conditioning, amplification, or normalization circuitry. Typically, these circuitry components are included to improve signal quality, eliminate noise, and guarantee compatibility with subsequent processing or recording systems.

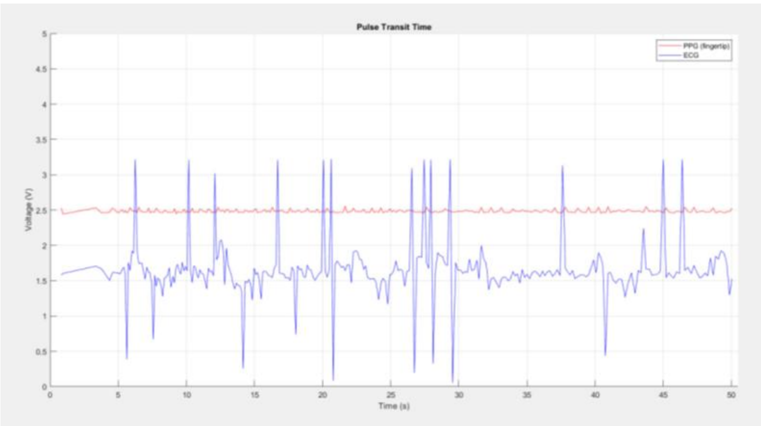

Figure 6.4: Raw signal of ECG and PPG

Figure 6.4 shows the raw ECG and PPG signals. The ECG and PPG signals from the prototype are then processed using MATLAB R2021b, involving three phases: pre-processing, signal processing, and post-processing. Preprocessing ensures clean signals, improved visibility, and eliminates unwanted components. Signal processing techniques include filtering and peak detection to improve signal quality and clarity. Peak detection algorithms identify and locate peaks in ECG and PPG waveforms, representing specific cardiac events. Signal filtering is applied to obtain stable and clean signals, enhancing signal quality and removing unwanted noise or artifacts. A Butterworth filter with a filter order of 5 and a half-power frequency of 0.05 is used to attenuate high-frequency components while preserving low-frequency components related to PPG and ECG signals.

The filtered ECG and PPG signals are analyzed to detect peaks corresponding to specific events or characteristics. The number of peak locations for PPG and ECG signals is adjusted to be identical. The find peaks function is used to identify peaks, with a parameter of 0.5 to minimize the distance between adjacent peaks. PTT is calculated as the time difference between the corresponding maxima in PPG and ECG signals. The average peak value is computed to produce the average PTT value. The mean PTT (AveragePTT) and standard deviation of PTT (StandardDev) are calculated to provide information on the mean and standard deviation of PTT. Post-processing calculates the PTT value and generates blood pressure regression lines for SBP and DBP, as shown in Figure 6.5.

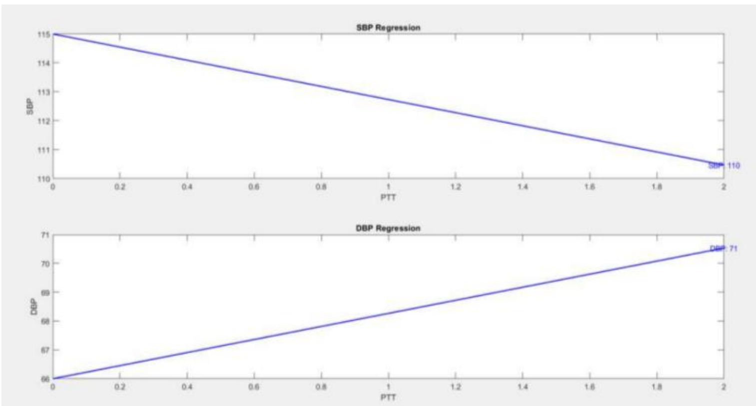

Figure 6.5: Blood Pressure regression line for estimating the SBP and DBP prototype

6.3.1 TABLE OF COMPARISON BETWEEN EZYSWISS MX-101 AND PROTOTYPE DEVICE

Table 6.1 compares the Ezyswiss MX-101 and the prototype blood pressure device in measuring SBP and DBP for three subjects. Table 6.2 shows the percentage error between measurements evaluates the device's precision compared to a standard monitor, revealing positive and negative percentage errors.

Table 6.1: Comparison of the SBP and DBP between Ezyswiss type MX-101 and prototype

Subject	SBP Ezyswiss MX-101 (mmHg)	SBP prototype (mmHg)	DBP Ezyswiss MX-101 (mmHg)	DBP prototype (mmHg)
1	112	115	65	70
2	106	104	69	70
3	120	122	77	78

Table 6.2: Error scores of the SBP and DBP prototype according to Ezyswiss type MX-101

Subject	SBP percentage error (%)	DBP percentage error (%)
1	2.68	7.69
2	-1.89	1.45
3	1.67	1.30

6.4 CONCLUSION

In conclusion, this project is extremely important and must be implemented in healthcare technology worldwide due to its ability to display blood pressure measurements remotely using a non-invasive technique that deploys a tiny cuff around the fingertip and an ECG patch on a specific part of the chest. This is convenient for all hypertensive patients because the oscillometric cuff, which caused arm paralysis after multiple measurements, is no longer used. Moreover, this project enables patient to measure their blood pressure everywhere without commuting to the hospital. Also, this device can be monitored by a physician without having to face to face.

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