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DEVELOPMENT OF CUFF-LESS CONTINUOUS BLOOD PRESSURE MONITORING SYSTEM USING PULSE TRANSIT TIME TECHNIQUE WITH IOT

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Abstract

Blood pressure (BP) Blood pressure (BP) is one of the vital indicators that must be checked for hypertension and cardiovascular health by measured systolic and diastolic blood pressure. The current blood pressure detection method uses an oscillometric. This method required inflation and was followed by deflation of the cuff. However, the selection of the correct cuff size is important for accurate BP measurement and misdiagnosis of hypertension also leads to psychological stress and unnecessary exposure to adverse side effects. This paper presents the cuff-less BP device which is based on the Pulse Transit Time (PTT) with Blynk apps to facilitate blood pressure monitoring. The MAX30102 sensor is used to get an estimate of Systolic and Diastolic BP. After that, the data acquisition from the photoplethysmography (PPG) signal will be sent to the application through the WiFi module ESP8266. The result showed an accuracy and tolerance systolic parameter with an average of ±5% followed by diastolic with an average of ±8% comparable to cuff-based Non-invasive Blood Pressure (NIBP). This cuff-less device can be concluded as a device that is easy to use at any time, especially for home use where it is a portable and wireless device.

Keywords: Blood pressure (BP), Pulse transit time (PTT), photoplethysmography (PPG), Cuff-less BP, Non-Invasive Blood Pressure (NIBP).

1.0 Introduction

High Blood Pressure or Hypertension is a primary and most reliable measurement for continuous patient monitoring for their personal health care and patient cardiac system. It is observed that stress is the main reason for many severe diseases, and cardiac disease is also one of them. Hypertension is rarely accompanied by any symptom, and its identification is usually through screening of continuous monitoring of blood pressure (Singh & Singh, 2015). BP measurement at home is used increasingly for the management of hypertension. Several approaches for cuff-free BP measurement, both invasive and non-invasive methods, have been established in a wide range of research; thus a non-invasive methodology based on pulse transit time (PTT) has been established that can measure BP (Zhang et al., 2020). In simpler terms, pulse transit time is the time it takes for a pulse wave to transit from the heart to the site where a ading is obtained, in this context, the fingertip. This time is related to the propagation velocity of the pulse wave. The pulse wave travels along with the elastic arterial walls. The physiological reason for the elastic nature of the arterial wall is to buffer the pulsatile ejection of blood from the heart and to provide constant flow in the capillary beds. The pulse wave velocity (PWV) can describe the state of the artery. The speed at which the arterial pressure wave travels is directly proportional to blood pressure (BP).

2.0 Related Work

This section discussed about parameters that be measured and evaluated from this Cuffless Blood Pressure and NIBP device. This parameter is specifically for systolic and diastolic blood pressure. This section also introduce the principle of measure and the estimation of the blood pressure using the PTT.

2.1 Blood Pressure

Table 1: Classification and Prevalence of Elevated Blood Pressure for Adults (Kario et al., 2018)

Classification	SBP (mmHg)	DBP (mmHg)	Prevalence in Malaysia
Optimal	<120 and	<80	32%
Normal	<130 and	<85	20%
High Normal	130 – 139 and/or	85 – 89	17%
Hypertension			
Stage I	140 – 159 and/or	90 – 99	20%
Stage II	160 – 179 and/or	100–109	8%
Stage III	≥180 and/or	≥110	4%

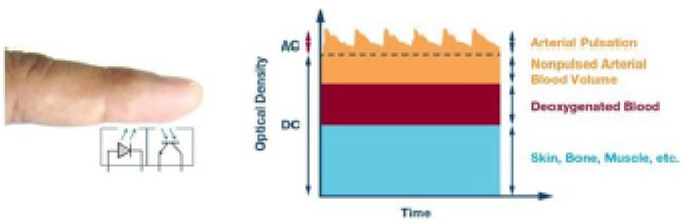
Blood pressure is the force exerted by blood against the artery walls. Arteries transport blood from the heart to the parts of the body. Throughout the day, blood pressure generally rises and falls (*High Blood Pressure*, 2021). Blood pressure is measured in two parts: systolic and diastolic. Systolic blood pressure (SBP) is the pressure in the arteries while the heart beats, and diastolic blood pressure (DBP) is the pressure in the arteries when the heart rests between beats. Hypertension is defined as a persistent increase of systolic blood pressure of 140 mmHg or higher

and/or diastolic blood pressure of 90 mmHg or higher (Kario et al., 2018). This definition is based on the average of two or more adequately measured, seated blood pressure readings taken during two or more clinic visits. When SBP and DBP are classified differently, the greater category should be used to classify the individual's blood pressure.

2.2 Principle of Measure: PPG

The pressure wave varies periodically between two extremes which are systolic and diastolic and it causes dilation of the arterial walls. Moreover, on its path, it moves faster than the blood flow (Chia & Kario, 2020). This pressure can be detected by measuring the variation of the oxygen content of the blood, caused by influx of oxygenated blood on the arrival of the pressure wave. The PPG signal is used to determine and register the variations in blood flow in the body, which occur at each heartbeat. The PPG is captured by a pulse oximeter that is composed by a light source and a light detector: It detects the cardio-vascular pulse wave that propagates through the body.

The PPG signal has an AC and a DC component. The AC component is the result of pulsating changes in arterial blood volume that is synchronous with the heartbeat. The DC component is related to the average blood volume and to the tissues. The AC component must be filtered out from the DC component in order to get the needed pulse signal. These concepts are visualized in Figure 1.



a) b)

Figure 39: Principle of photoplethysmography (PPG) measurement. **(a)** Schematics of the LED and the receiver: the LED emits light at the specific wavelength at which the absorption of the oxy-hemoglobin is maximum; the receiver collects the back scattered light. (b) The PPG signal is composed by a DC component, due to the not-changing part in the tissue and the AC component due to the blood whose concentration of oxy and deoxy–hemoglobin changes as the pulse (Chia & Kario, 2020).

The arrival of the pressure wave is visible as the first peak on the PPG waveform (Lazazzera et al., 2019). The direct wave of the PPG waveform (systolic component) is the result of pressure transmission from the aortic root to the distal place where the signal is acquired. The second part (diastolic component) is formed by pressure transmitted from the ventricle along the aorta to the lower body where it is reflected back along the aorta to the distal place. The upper limb provides a common channel for both the directly transmitted pressure wave and the reflected wave and, therefore, has little influence on the contour of the PPG signal.

3.0 Methodology

This section is essential in order to complete this research investigation properly. The Pulse Transit Time approach was utilized to detect systolic and diastolic parameters using the MAX30102 sensor. This sensor and NIBP are used in this instrument to retrieve patient data. Figure 2 illustrates the methodological process in more detail.

3.1 Block Diagram of the Operating System

Figure 2 shows a block diagram of the hardware architecture for Cuffless BP Monitoring process. This block diagram cover the system's components, which include three main parts: inputs, processes, and outputs for generating PPG signals simultaneously. Each part provides a particular function, and the block diagram in Figure 7 illustrates how each component is linked. The first three blocks are packed inside that represent an input. The input sensor is responsible for detecting and sending signals to the microcontroller which is the MAX30102 sensor. The PTT is obtained by optically measuring the changes in the volume of blood over the fingertip, whereas the PPG signal is used to determine and register the variations in blood flow in the body, which occur at each heartbeat. The sensor generates a signal from the fingertip where the desired PPG signals are collected with higher quality. ESP8266 is used to send the data from the measuring device to the IoT device via a Wi-Fi connection. The measuring devices instrumentation is powered by a Li-Ion battery that can be recharged. The Blynk Apps is smartphone application that can be installed on any Android and iPhone device. The application purpose to display the output of the blood pressure reading (systolic and diastolic) on the smartphone. The calibration results are used to compare the accuracy of this Cuffless Blood Pressure with NIBP device that is commercially accessible.

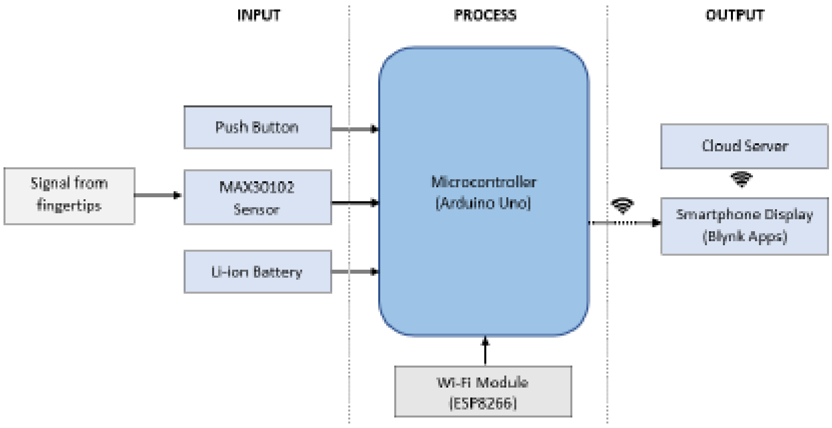


Figure 40: Block Diagram of Cuffless BP Monitoring

3.2 SBP and DBP Analysis

Through rigorous mathematical analysis of the PPG signals, a mathematical model was established at (Chowdhury et al., 2020) to estimate predicting SBP and DBP. Systolic and diastolic blood pressure levels were estimated using the pulse transit time (PTT) in (Sharma et al., 2017) (Chowdhury et al., 2020) and a combination of Pulse Arrival Time (PAT) and heart rate, with the combination outperforming PTT alone. The following equations provide the linear formulation of the model in the variables Time Delay (Delay) and HR:

$$SBP = A_S * Delay + B_S + HR + C_S \quad (1)$$

$$DBP = A_D * Delay + B_D + HR + C_D \quad (2)$$

These equations are used to produce SBP and DBP after calibration to preserve accuracy:

$$SBP = 184.3 - 1.329 * HR_{bpm} + 0.0848 * Td \quad (3)$$

$$DBP = 55.96 - 0.02912 * HR_{bpm} + 0.02302 * Td \quad (4)$$

$$Td = HR_{ms} - TimeDelay \quad (5)$$

3.3 Data Collection

The data collection is gained by taking the reading from the subject using the developed product and current medical product which is NIBP device. There are five subjects involved in this project. The process was repeated for systolic and diastolic blood pressure readings taken in the morning and evening. The flow chart shows that as soon as the subject places a finger on the device, blood pressure monitoring even begins with the operating system detecting and calculating the subject's parameters. After that, the smartphone display shows the SBP and DBP readings of the subject and then the data of these parameters are collected to be evaluated and analyzed. The data that has been analyzed is recorded and stored into the Cloud server.

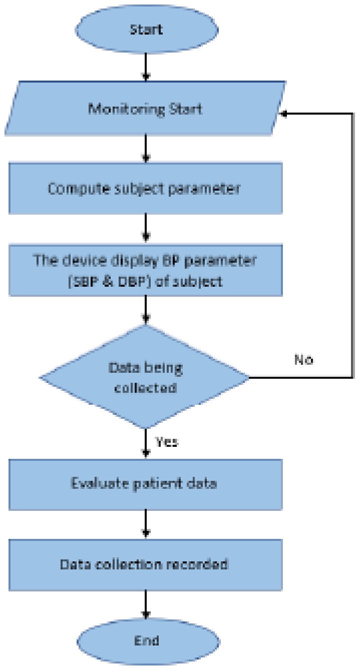


Figure 41: Data Collection Method

4.0 Result and Analysis

This section discussed on blood pressure obtained from the subject at morning and evening session by using Cuff-Less Continuous Blood Pressure and Non-Invasive Blood Pressure (NIBP).

4.1 Comparison Data Between Cuffless BP and Product in the Market (NIBP) for Blood Pressure Measurement

Table 1 tabulates the Cuff-Less Continuous Blood Pressure for systolic and diastolic in the morning session. There 30 readings from five subjects were taken in the morning which is 15 readings are cuffless BP and 15 readings are NIBP. It shows that the cuffless

BP reading is average from (110.33) to (128.78) and the NIBP reading (114.00) to (128.67), for systolic. It shows that the cuffless BP reading is average from (56.67) to (60.67) and the NIBP reading (63.00) to (70.00), for diastolic. It was found that for systolic Cuffless BP is reliable as the tolerance is within the different range 1.33 to 3.67, this per cent is acceptable. However, for diastolic, the difference is between 4.33 to 9.33. It is interesting to see that for subjects 2 and 4, the difference is between Cuff-less and NIBP, the value is great due to the systematic error.

Table 1: Cuff-Less Continuous Blood Pressure for systolic and diastolic in the morning session

		MORNING					
Subject	Number of readings	SYSTOLIC			DIASTOLIC		
		Cuffless BP	NIBP	Different	Cuffless BP	NIBP	Different
1	1	131.00	133.00	2.00	57.00	56.00	1.00
	2	125.00	125.00	0.00	56.00	64.00	8.00
	3	130.00	128.00	2.00	62.00	69.00	7.00
	Average	**128.78**	**128.67**	**1.33**	**58.33**	**63.00**	**5.33**
2	1	120.00	122.00	2.00	56.00	59.00	3.00
	2	122.00	125.00	3.00	58.00	64.00	6.00
	3	119.00	119.00	0.00	56.00	70.00	4.00
	Average	**120.33**	**122.00**	**1.67**	**56.67**	**64.33**	**4.33**
3	1	117.00	117.00	0.00	56.00	62.00	6.00
	2	125.00	127.00	2.00	60.00	68.00	8.00
	3	115.00	119.00	4.00	57.00	65.00	8.00
	Average	**119.00**	**121.00**	**2.00**	**57.67**	**65.00**	**7.33**
4	1	109.00	110.00	1.00	65.00	73.00	8.00
	2	112.00	114.00	2.00	58.00	69.00	11.00
	3	110.00	118.00	8.00	59.00	68.00	9.00
	Average	**110.33**	**114.00**	**3.67**	**60.67**	**70.00**	**9.33**
5	1	109.00	110.00	1.00	63.00	75.00	12.00
	2	117.00	119.00	2.00	61.00	69.00	8.00
	3	118.00	120.00	2.00	64.00	70.00	6.00
	Average	**114.67**	**116.33**	**1.67**	**62.67**	**71.33**	**8.67**

Table 2 tabulates the Cuff-Less Continuous Blood Pressure for systolic and diastolic in the morning session. There 30 readings from five subjects were taken in the morning which is 15 readings are cuffless BP and 15 readings are NIBP. It shows that the cuffless BP reading is average from (106.67) to (129.00) and the NIBP reading (104.33) to (134.00), for systolic. It shows that the cuffless BP reading is average from (56.67) to (65.67) and the NIBP reading (59.67) to (71.67), for diastolic. It was found that for systolic Cuff-less BP is reliable as the difference is within 1.00 to 4.00, this per cent is acceptable. However, for diastolic, the difference between cuffless and NIBP is 3.00 to 9.33. It is interesting to see that for subjects

2 and 5, the difference is between Cuff-less BP and NIBP, however, it is still within the accepted range and this device works well.

Table 2: Cuff-Less Continuous Blood Pressure for systolic and diastolic in the evening session

EVENING							
Subject	**number of readings**	**SYSTOLIC**			**DIASTOLIC**		
		Cuffless BP	**NIBP**	**difference**	**Cuffless BP**	**NIBP**	**difference**
1	1	128.00	129.00	1.00	69.00	75.00	6.00
	2	130.00	130.00	0.00	62.00	72.00	10.00
	3	122.00	125.00	3.00	59.00	68.00	9.00
	Average	**129.00**	**134.00**	**1.33**	**65.67**	**71.67**	**8.33**
2	1	119.00	117.00	2.00	60.00	69.00	9.00
	2	110.00	115.00	5.00	58.00	68.00	10.00
	3	117.00	115.00	2.00	56.00	65.00	9.00
	Average	**115.33**	**115.67**	**3.00**	**58.00**	**68.33**	**9.33**
3	1	109.00	112.00	3.00	60.00	69.00	9.00
	2	110.00	105.00	5.00	58.00	60.00	2.00
	3	107.00	103.00	4.00	60.00	68.00	8.00
	Average	**108.67**	**106.67**	**4.00**	**59.00**	**65.67**	**6.33**
4	1	110.00	109.00	1.00	58.00	60.00	2.00
	2	105.00	105.00	0.00	67.00	70.00	3.00
	3	115.00	112.00	2.00	65.00	71.00	6.00
	Average	**110.00**	**108.67**	**1.00**	**63.33**	**67.00**	**3.67**
5	1	108.00	102.00	6.00	56.00	56.00	0.00
	2	102.00	102.00	0.00	56.00	61.00	5.00
	3	110.00	109.00	1.00	58.00	62.00	4.00
	Average	**106.67**	**104.33**	**2.33**	**56.67**	**59.67**	**3.00**

From this observation, the different measurement value between two devices in term of two parameters which is systolic and diastolic have a significant difference. The systolic values produced are very satisfactory but the diastolic values show a fairly significant difference

5.0 Conclusions

There are various types of blood pressure devices on the market in this innovative world advancement, cuffless blood pressure is specially designed for all, especially if users have been diagnosed with high blood pressure or hypertension. The developed device produces a cuff-less blood pressure (BP) reading based on the pulse transit time (PTT), allowing the patient to utilise it at any time as long. Following that, the device comes with the design of a mobile application that can facilitate real-time blood pressure monitoring with IoT. Furthermore, this project can analyse blood pressure data (systolic and diastolic) by comparing readings from non-invasive blood pressure (NIBP) device with a cuffless blood pressure device. It is simpler without the use of a cuff. It will allow keeping track of any changes in blood pressure readings on a daily basis without having to visit the doctor. The developed device is important as it is beneficial to hypertension as well as the related field of patients' cardiac systems.

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