Measurement of Ankle Brachial Index with Oscillometric Method for Early Detection of Peripheral Artery Disease

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Abstract—**Peripheral Arterial Disease (PAD) is a blood vessel disease caused by blockage or accumulation of plaque around the artery walls. PAD is included in the category of diseases that are often diagnosed too late and affect more severe cases, such as the death of certain tissues or body parts. The Ankle Brachial Index (ABI) is an accurate non-invasive method for diagnosing PAD, in practice ABI is usually performed in certain hospitals and is still difficult to find due to limited tools. Therefore, a tool is made that can detect the condition of a person's PAD based on the ABI value. The tool is made using two MPX5050GP sensors to detect oscillometric pulses, a DC pump and solenoid valve as an actuator to pump and deflate the cuff, ADS1115 as an external ADC to increase the accuracy of sensor readings, as well as an LCD and buzzer as tool indicators. The output is displayed in the form of a print out from a thermal printer, with an emergency stop that functions as a safety system to power off the supply when a failure occurs in the measurement process. Oscillometric method is used to detect systolic and diastolic pressure. The accuracy of the tool is 95.5%. This accuracy result is obtained by comparing the readings of systolic and diastolic values using a sphygmomanometer which is commonly used.**

Keywords: *peripheral arterial disease, ankle brachial index, oscillometric*

Abstrak—***Peripheral Arterial Disease* (PAD) merupakan penyakit pembuluh darah yang disebabkan penyumbatan atau penumpukan plak di sekitar dinding arteri. PAD termasuk ke dalam kategori penyakit yang seringkali terlambat terdeteksi dan berimbas pada kasus yang lebih parah, seperti matinya jaringan atau bagian tubuh tertentu. *Ankle Brachial Index* (ABI) merupakan metode *non-invasive* yang akurat untuk mendiagnosa PAD. Dalam praktiknya, pengukuran ABI hanya dapat dilakukan di rumah sakit tertentu karena keterbatasan alat. Oleh karenanya dibuatlah alat yang dapat mendeteksi kondisi PAD seseorang berdasarkan nilai ABI. Alat yang dibuat menggunakan dua buah sensor MPX5050GP untuk mendeteksi pulsa osilometri, pompa DC dan *solenoid valve* sebagai aktuator untuk memompa dan mengempiskan manset, ADS1115 sebagai ADC eksternal untuk meningkatkan ketelitian pembacaan sensor, serta LCD dan *buzzer* sebagai indikator alat. Output ditampilkan dalam bentuk *print out* dari *thermal printer*, dengan *emergency stop* yang berfungsi sebagai sistem pengaman untuk memutus supply pada aktuator ketika terjadi kegagalan dalam proses pengukuran. Metode osilometri digunakan untuk mendeteksi tekanan sistol dan diastol. Akurasi alat yang dibuat adalah 95.5%. Hasil akurasi ini diperoleh dengan membandingkan pembacaan nilai sistol dan diastol menggunakan *sphygmomanometer* yang sudah umum dipasaran.**

Kata kunci: *peripheral arterial disease, ankle brachial index, osilometri*

I. Introduction

The cardiovascular system is a collection of organs that act as a transport function in the human body. The cardiovascular system consists of the heart and blood vessels, where the heart acts as a pump and the blood vessels act as the channel or pipe. Based on the direction of blood flow, blood vessels can be grouped into two. The first is the blood vessels that leave the heart (arteries) and the blood vessels that lead to the heart (veins). Arteries are a type of blood vessel that carries blood away from the heart and distributes oxygenated blood to various parts of the body.

Based on the cross-sectional size (diameter), arteries can be grouped into elastic arteries (large), muscular arteries (medium), and arterioles (small). Muscular arteries are responsible for delivering blood to several parts of the body, the walls of these arteries are composed of smooth muscle fibers that regulate blood flow, according to the body's needs. Examples of muscular arteries are the femoral and popliteal arteries [1]. The circulatory system can experience disorders or diseases that can be caused by internal factors or external factors. Diseases of the circulatory system that are often experienced and receive less medical attention are Peripheral Arterial Disease (PAD).

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Peripheral arterial disease can affect quality and life expectancy by increasing cardiovascular events. PAD is also often underdiagnosed, undertreated, and has received little attention from the medical community [2]. In 2011, an estimated 14,000 deaths occurred in the American population due to PAD [3].

PAD is generally a collection of disorders that block blood flow to the upper and lower extremities, however, clinically PAD is a disorder of the arteries of the lower extremities. The arteries most involved are the femoral and popliteal (80-90%) in the lower extremities, namely in the lower limbs and are rarely found in the fingers. Most occur due to atherosclerosis (buildup of fat on the walls of the arteries) which is triggered by an unhealthy diet and life. The most common complaint of PAD is the sensation of pain in the legs during exercise/physical activity, this is known as intermittent claudication. This pain, burning sensation, heaviness sensation, or tightness in the leg muscles usually begins after walking a certain distance, walking up a hill, or climbing stairs, and goes away after resting for a few minutes. The condition of PAD can be identified through examination of the Ankle Brachial Index (ABI) [2].

The ABI examination is a noninvasive test that is sufficiently accurate to detect the presence of PAD and to determine the degree of this disease. ABI is defined as the ratio between systolic blood pressure in the leg (ankle) and systolic blood pressure in the arm (brachial). If blood flow is normal in the lower extremities, the pressure at the ankles should be equal to or slightly higher than in the arms, then the ABI will be 1.0 or more. This ABI value is based on American Heart Association standards. In practice, this ABI examination is still done manually, and is carried out by competent medical personnel. This kind of inspection means that ABI testing cannot be carried out anywhere and anytime, and from an economic point of view, it becomes a problem for the underprivileged [3].

Based on this background, in this research, an Early Detection of Peripheral Arterial Disease with Oscillometric Method was created. With this tool, PAD level checks can be carried out automatically and independently without competent medical personnel and can be done anytime and anywhere.

II. Materials and Methods

A. Ankle Brachial Index

Ankle Brachial Index (ABI) is a non-invasive test method that is quite accurate to detect the presence of PAD and to determine the degree of this disease. The ABI value was obtained by comparing the systolic blood pressure in the legs (ankle) with the systolic blood pressure in the arm (brachial). The pressure value that can be compared can be with 2 sides of the body, the left or right, or only one side as seen in Figure 1 [4]. To calculate ABI, it is necessary to measure the brachial systolic pressure and the ankle systolic pressure which are measured simultaneously at

Figure 1. ABI measurement

the same time [5], [6]. The systolic point is obtained from the oscillometric method. The equation to get the ABI value can be seen in equation (1) [7].

$$ABI = \frac{ankle\ systolic}{brachial\ systolic} \tag{1}$$

If the blood flow in the arteries is normal, then the systolic blood pressure at the leg must be the same or slightly higher than the arm, then the ABI will be 1.0 or more. If the ABI value is 0.9, it indicates the presence of PAD. This ABI value is based on American Heart Association standards that are shown in Table 1

B. Oscillometric Method

The oscillometric method is based on the detection of pulses generated by pressure on the cuff. The oscillometric method is performed using a cuff that is placed around the area being measured. This cuff will detect oscillations in a large artery called the brachial artery. The cuff pressure in the pump reaches a state called super-systolic or about 180 mmHg. In this condition the blood flow to the branchial arteries stops. Then the cuff pressure will be lowered at a constant rate (deflation). It is during this deflation process that oscillations will be generated. During deflation, sensors are used to measure the pressure in the cuff and detect the magnitude of the oscillating pulse [8], [9]. The image of the oscillating pulse is shown in Figure 2.

In the Figure 2, the part that is delimited in the form of a dotted line is the moment where the systolic and diastolic pressures can be seen. If the signal is extracted using an active filter circuit, the results will be obtained as shown in Figure 3.

Figure 3 is an image of the output of the High Pass

Table 1. Standards ABI value

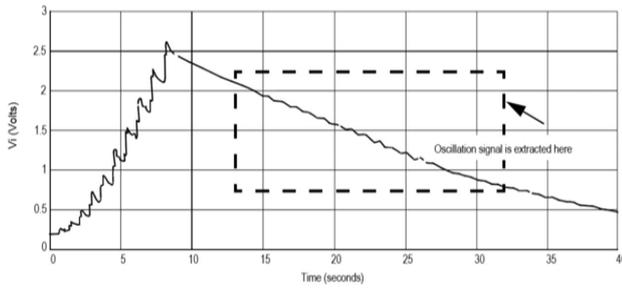| No	ABI	Interpretation
1	1.00 – 1.40	Normal
2	0.91 – 0.99	Borderline
3	< 0.90	PAD
4	>1.40	Noncompressible

Figure 2. Output signal pressurefrom sensors

Filter where the frequency filter has been carried out in the image, where the frequency taken is above 1 Hz, while the frequency is 0.04 Hz [10]. In the Figure 3, there are three parameters obtained, namely SBP (Systolic Blood Pressure) which means systolic pressure, MAP (Mean Arterial Pressure) which is the point where maximum oscillation occurs, and DBP (Diastolic Blood Pressure) which is diastolic blood pressure. Systolic and diastolic values were calculated using different mathematics for each medical measurement tool [11], [12]. The systolic pressure is set at 0.55 from the maximum oscillations, while the diastolic pressure is set at 0.85 from the maximum oscillations as in equations (2) and (3). Om is the point of maximum oscillation, Os is the systolic point, and Od is the diastolic point [13].

$$\frac{Os}{Om} = 0.55 \qquad (2)$$

$$\frac{Od}{Om} = 0.85 \qquad (3)$$

C. System Description

Peripheral Arterial Disease detection system using the Ankle Brachial Index measurement is a system that can detect PAD by knowing the value of the ABI. The ABI value can be determined by dividing the systolic pressure in the leg (ankle) by the systolic pressure in the arm (Brachial), the systolic value is obtained from the measurement results by the MPX5050GP sensor through a cuff wrapped around the arm and leg, the output of this sensor is analog signal which connected on a 16-bit ADC module. The ADC module used is ADS1115, it supports I2C communication with 4 adjustable address modes, so it can be combined with an LCD that also uses I2C. The
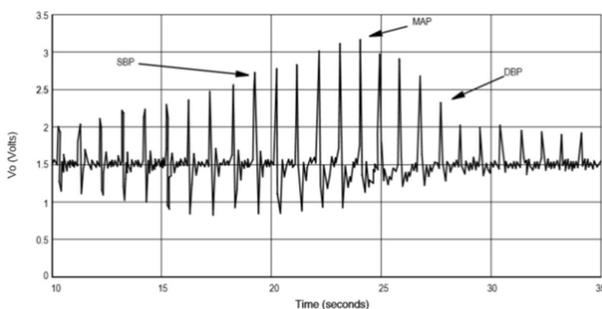

Figure 3. Extraction Signal

ADS1115 module has 4 16-bit ADC channels which are sufficient for sensor readings with 5V operating voltage from Arduino.

The signal generated by the ADC is in the form of binary, which is a number with base 2 (consisting of the numbers 0 and 1). This binary output will represent the received analog signal. The representation of the ADC is getting better when the ADC is more sensitive to changes in analog signals. For example, if the received signal is 0-15V and the ADC has a sensitivity of 1V, it means that the digital value obtained is in the form of 16 stages, namely from 0000 to 1111. These stages are obtained according to the number of bits owned by the ADC, in this case the ADC made is ADC 4 bits because the number of bits (n) represents 2^n which means 24 is 16 bits [14].

Besides resolution, ADC has sampling rate which is usually expressed in samples per second (SPS). Figure 4 shows the difference between ADC with low and high sampling [15].

Arduino UNO processing the signals to obtained systolic and diastolic pressure for the ABI calculation. Figure 5 is a block diagram of the system. This system is equipped with an emergency stops which will cut off the current to the relay coil, as a safety measure when system failure accur than causes the DC pump continue to pump pressure on the cuff and result in excessive pressure.

III. RESULT AND DISCUSSION

A. Oscillometric pulse

The wave in Figure 6 is the output of the pressure sensor. First the oscillometric pulse that occurs has to pass through the High Pass Filter (HPF), so that the unwanted frequency of the cuff pressure will be lost and only the frequency of the arteries will be left. Pulses with very
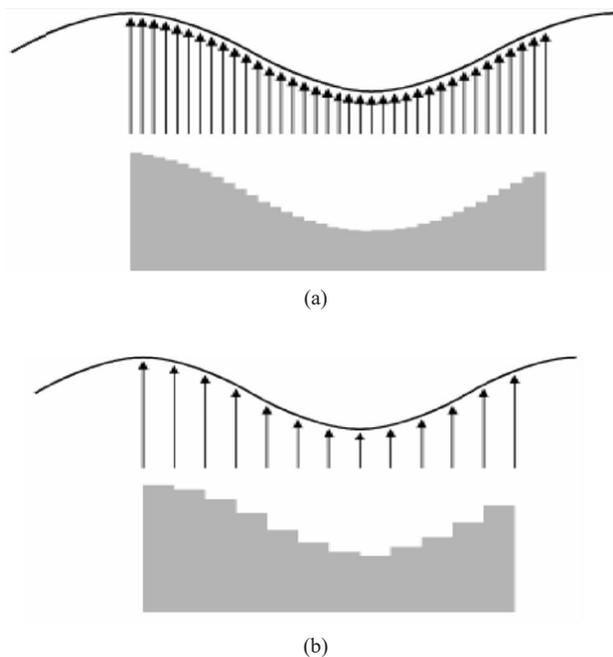

(a)

(b)

Figure 4. (a) High sampling rate, (b) Low sampling rate

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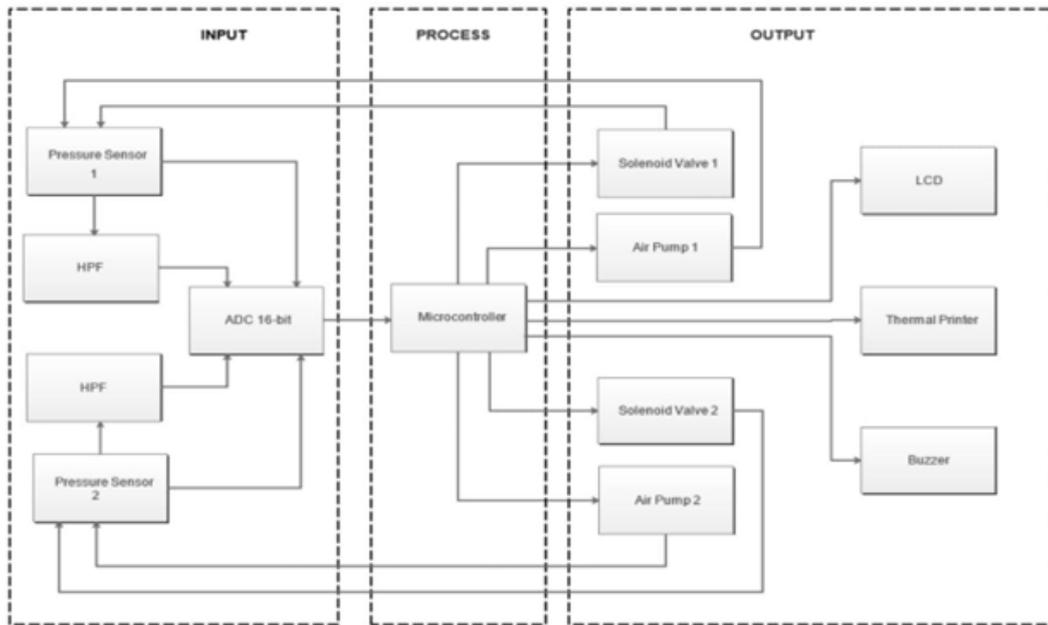
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Figure 5. Proposed ABI measurement by Oscillometric Method

small changes in voltage are amplified using an op-amp, so the HPF circuit used is an active HPF.

Figure 7 is the pressure signal after filtered. The comparison between the pulse after being filtered and before being filtered can be seen in Figure 8. Figure 8 has two graphs; the red curve is the pulse after being filtered and the blue curve is the pulse before it is filtered. The red curve contains the parameters needed to detect systolic blood pressure and diastolic blood pressure. The green box represents the MAP pressure, which is the highest pressure that will be used in equations (2) and (3) to get the systolic and diastolic pressures. The formation of a red curve indicates that the oscillometric method has been successful.
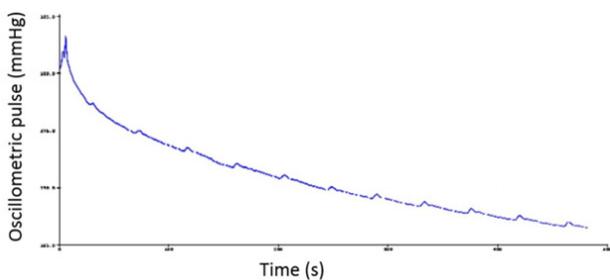
B. ABI measurement

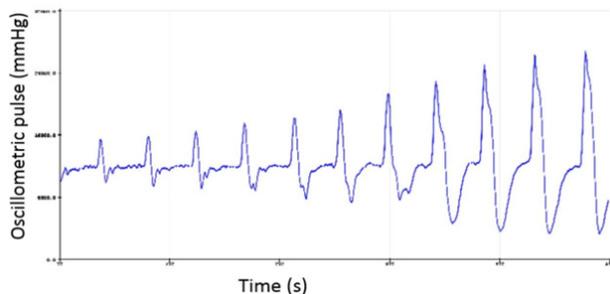System testing is done by taking data on 3 normal people as measuring objects. The test is carried out by taking ten samples of data for each person. Figure 9 shows the ABI measurement process. The sleeping object is supine so that the heart is in line with the hands and feet. The cuff is attached to the arm and ankle then the system will pump simultaneously in order to obtain arm and leg systolic values simultaneously for ABI calculation. From the overall measurement results, the system is able to classify the condition of PAD and the condition of a person's blood pressure. Figure 10 is the
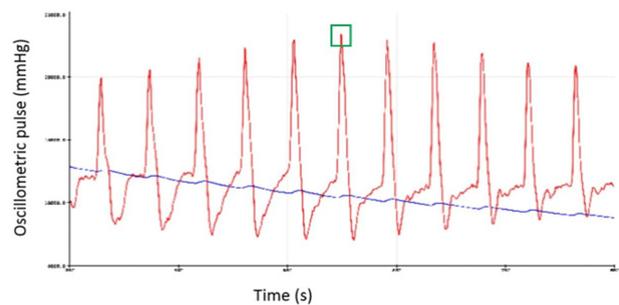

Figure 6. Output of the pressure sensor

Figure 8. Determination of MAP, Os and Od

Figure 7. Pressure signal after filtered
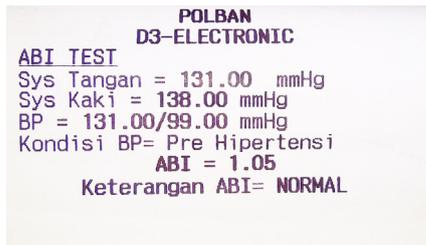

Figure 9. ABI measurement
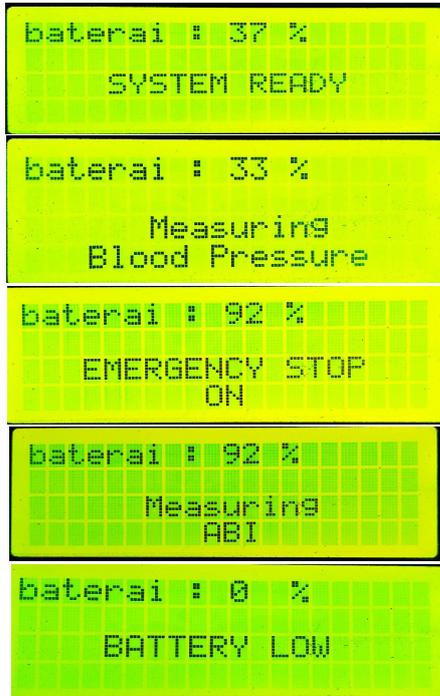
Figure 10. Print out of ABI measurement

Figure 11. LCD display

print out of the ABI measurement, then Figure 11 is the display on the LCD which contains information on the condition of the tool. The information is an indication of battery, equipment readiness, measurement process, and emergency conditions.

Validation is done by compiring measurements of systolic and diastolic pressure on the arm and leg by with a sphygmomanometer. The method of measurement is to

Table 2. Arm systolic pressure measurement

No	Proposed tool (mmHg)	Sphygmomanometer (mmHg)	Error (%)
1	125	123	1,63
2	127	123	3,25
3	120	123	2,44
4	124	123	0,81
5	124	123	0,81
6	130	123	5,69
7	135	123	9,76
8	120	123	2,44
9	117	123	4,88
10	120	123	2,44
Average			3,41

Table 3. Arm diastolic pressure measurement

No	Proposed tool (mmHg)	Sphygmomanometer (mmHg)	Error (%)
1	90	88	2,27
2	85	88	3,41
3	88	88	0,00
4	80	88	9,09
5	90	88	2,27
6	78	88	11,36
7	85	88	3,41
8	90	88	2,27
9	86	88	2,27
10	83	88	5,68
Average			4,20

measure the same person once a day for 10 days. There are 10 measurement data that can be seen in the Table 2 – 5. The average error for arm systole is 3.41%, for arm diastole 4.20%, for leg systole 5.33% and for leg diastole 5,36%. From the data, the tool accuracy is 95.5%. The successful detection of systole and diastole in the arm and leg shows that the ABI method can be used.

Table 4. Leg systolic pressure measurement

No	Proposed tool (mmHg)	Sphygmomanometer (mmHg)	Error (%)
1	140	135	3,70
2	145	135	7,41
3	143	135	5,93
4	140	135	3,70
5	137	135	1,48
6	140	135	3,70
7	150	135	11,11
8	147	135	8,89
9	130	135	3,70
10	140	135	3,70
Average			5,33

Table 5. Leg diastolic pressure measurement

No	Proposed tool (mmHg)	Sphygmomanometer (mmHg)	Error(%)
1	100	97	3,09
2	101	97	4,12
3	101	97	4,12
4	90	97	7,22
5	105	97	8,25
6	108	97	11,34
7	100	97	3,09
8	95	97	2,06
9	102	97	5,15
10	102	97	5,15
Average			5,36

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IV. Conclusion

The tool is able to read systolic and diastolic pressures with the oscillometric method. The system is able to classify PAD conditions based on the ABI value. Based on the comparison with the sphygmomanometer the accuracy of the tool is 95.5%.

In the future, a tool can be developed by adding two cuffs with the aim of measuring at four points, the right and left body parts. To monitor an ABI condition regularly, the system can be connected to a mobile application or the Internet of things (IoT).

Acknowledgement

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