ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika

ISSN(p): 2338-8323 | ISSN(e): 2459-9638 | Vol. 11 | No. 4 | Halaman 1032 - 1045
DOI: http://dx.doi.org/10.26760/elkomika.v11i4.1032 Oktober 2023

IoT-Based Early Detection of Cardiovascular Disease with Ankle Brachial Index Measurement for Right and Left Body Simultaneously

ERVIN MASITA DEWI[1], AWAN WAHYU SETIAWAN[2], SUGONDO HADIYOSO[3]

[1,2]Politeknik Negeri Bandung, Indonesia
[3]Fakultas Ilmu Terapan, Universitas Telkom, Indonesia
Email: ervinmasita@polban.ac.id

Received 27 Juli 2023 **|** *Revised* 20 Agustus 2023 **|** *Accepted* 20 September 2023

ABSTRAK

Deteksi dini penyakit kardiovaskular sangat diperlukan untuk mengurangi risiko kematian. Deteksi dini penyakit kardiovaskular dapat dilakukan dengan bermacam-macam metode, salah satunya adalah menggunakan metode Ankle Brachial Indeks (ABI). Metode ini membandingkan tekanan darah antara sistole pada bagian tangan dan kaki secara bersamaan. Pada penelitian ini dibuatlah alat pengukur ABI yang dapat mengukur secara serempak antara bagian tubuh kanan dan kiri, yaitu merupakan pengembangan dari penelitian sebelumnya yang hanya dapat melakukan pengukuran pada satu sisi tubuh saja. Dengan pengukuran secara serempak, diharapkan hasil yang diperoleh lebih akurat dan lebih efektif. Hasil validasi dari alat ini setelah dibandingkan dengan sphygmomanometer memiliki akurasi sebesar 96.6%. Selain itu data riwayat pemeriksaan dapat disimpan dan diakses oleh pasien dan dokter melalui teknologi IoT.

Kata kunci*: deteksi dini, kardiovaskular, Ankle Brachial Indeks, IoT*

ABSTRACT

Early detection of Cardiovascular Disease (CVD) is needed to reduce the risk of death. Early detection of cardiovascular disease can be done using various methods, one of which is the Ankle Brachial Index (ABI) method. This method compares blood pressure between systoles on the hands and feet simultaneously. In this study, the ABI measuring instrument was made that could simultaneously measure the right and left parts of the body, a development from previous research that could only take measurements on one side of the body. With simultaneous measurements, the results will be more accurate and effective. The validation results of this tool, when compared with the sphygmomanometer, have an accuracy of 96.6%. Besides, patients and doctors can store and access examination history data through IoT platform.

Keywords*: early detection, cardiovascular, Ankle Brachial Indeks, IoT*

1. INTRODUCTION

The heart and blood vessels are the parts of the human body's cardiovascular system that play a central role in the circulatory system **(Mahmoud et al., 2021)**. The heart's main function is to pump blood throughout the body, delivering oxygen and essential nutrients to all cells and tissues **(Verzicco, 2022)**. It's also removing waste products like carbon dioxide. Blood carries oxygen and nutrients to all cells, enabling them to perform their functions. It also carries waste products and carbon dioxide away from the cells, eventually eliminated from the body through respiration and other processes. The heart and blood vessels are closely related and form a complex network known as the cardiovascular, circulatory, or circulatory systems **(Wuche, 2022)**. The coordinated function of the heart and blood vessels is essential for maintaining homeostasis and supplying the body's organs and tissues with the necessary resources to function optimally. Problems with either the heart or blood vessels can lead to various Cardiovascular Diseases (CVD), underscoring the importance of maintaining a healthy lifestyle to support the proper functioning of this vital system. Regular exercise, a balanced diet, not smoking, and managing risk factors can help promote cardiovascular health and reduce the likelihood of heart-related issues.

Disorders of the heart and blood vessels or cardiovascular disease cause 17.6 million deaths each year according to data from the World Health Organization **(Tan et al., 2018)**. Preventive measures and early detection are essential in reducing the burden of cardiovascular diseases. Lifestyle modifications such as adopting a healthy diet, engaging in regular physical activity, not smoking, and managing stress can help lower the risk of Cardiovascular Disease CVD. Additionally, timely medical interventions, such as regular health check-ups and screenings are crucial for early diagnosis and effective management of cardiovascular conditions **(Alageel & Gulliford, 2019)(Vaduganathan et al., 2022).**

Several types of CVD that exist include Arrhythmia, which is a condition when the heart has an abnormal rhythm. This is because the electrical impulses that function as heart rate regulators work abnormally so that the rhythm of the heart becomes too fast, slow, or irregular. Next there is coronary heart disease which is caused by blockage or narrowing of the coronary arteries by plaque buildup. Coronary heart disease is the main cause of heart attacks if not treated immediately. The next cardiovascular disorder is cardiomyopathy or heart valve disorders caused by abnormalities in the heart muscle. Lastly is Peripheral Arterial Disease (PAD), which is when the blood flow to the legs is blocked due to plaque in the arteries **(Khoury & Ratchford, 2021)**. This makes the feet lack blood supply, causing pain when walking. PAD is associated with an increased risk of lower limb amputation and is also a marker of cardiovascular, cerebrovascular and renovascular atherothrombosis **(Maharani et al., 2019)(Powell-Wiley et al., 2021)**. Electrocardiography (ECG) is one of the primary methods used for diagnosing heart failure **(Grün et al., 2021)**. Many studies have proposed methods of automatic diagnosis of heart failure based on ECG signals **(Grün et al., 2021) (Hadiyoso & Rizal, 2017)(Kropf et al., 2017)**. But it is often used in conjunction with other diagnostic tests, patient history, and physical examinations to provide a comprehensive evaluation of the heart's electrical activity and overall health. It allows healthcare professionals to determine the appropriate treatment and management strategies for patients with arrhythmias.

PAD disease is arterial vascular disease due to plaque buildup that causes blockages in the arteries to the legs, specifically in the arteries of the abdomen, pelvis, and legs. In PAD patients where the blockage is outside the heart, the vascular system forms an alternative route of blood flow, called a collateral vessel, to replace the affected vessel. However, sometimes there is leg pain at rest and non-healing sores on the leg due to non-supportive collateral vessels that are formed. PAD disease is not life threatening, but if left unchecked it will cause more severe diseases such as heart attacks or strokes. Early detection of PAD can be done with the ABI test, which compares the systolic pressure at the ankle and brachial. If it is indicated by an abnormal ABI value, then further examination can be carried out, namely by Angiography.

Ankle Brachial Index (ABI) measurements using the oscillometric method for early detection of PAD have been carried out **(Dewi et al., 2022)**, but this study still used one side of the body. The PAD for early detection tool was created using the ABI calculation method. The ABI examination is a fairly accurate noninvasive test for detecting the presence of PAD and for determining the degree of this disease **(Rac-Albu et al., 2014)**. The ABI is defined as the ratio between the systolic blood pressure in the legs (ankle) and the systolic blood pressure in the arm (brachial) **(Aboyans et al., 2012)**. However, the Ankle Brachial Index (ABI) measurements using the oscillometric method for early detection of PAD tool can be used for one side of the body. To make it more accurate, an ABI detection tool has been developed for the all side of the body with simultaneous measurements **(Danieluk & Chlabicz, 2021).** Therefore, this study proposes a method for early detection of cardiovascular disease by measuring ABI for the right and left bodies simultaneously using the palpation method. The palpation method was used to replace the oscillometric method used in previous studies, because in ABI measurements only the systolic value is needed, so it will shorten the algorithm if you use the palpation method by only detecting the systolic value. As an added value, this system also supports online reporting using the internet of things (IoT) platform.

2. METHODS

2.1 Blood Pressure Standard Measurement

Arterial blood pressure is a process by which blood is pressed against the walls of the blood vessels. Blood pressure measurement using a shygmomanometer. Body position when checking blood pressure must also be considered. Two positions are commonly used when measuring blood pressure: sitting and supination. The two give different results on the diastolic measurement but do not significantly differ on the systolic. Measuring blood pressure in a sitting position is better for the back to be supported; sitting can also provide a greater diastolic result of about 5mmHg compared to the prone position. Meanwhile, the patient's arm must be given a pillow in the supine position. The position of the arms that are higher than the heart's position will cause lower examination results, and vice versa, the better the position of the arm parallel to the heart. Figure 1 shows the body's position when measuring blood pressure **(Myers et al., 2022)(Netea et al., 2002)**. When measuring blood pressure, a person should rest before the measurement is taken.

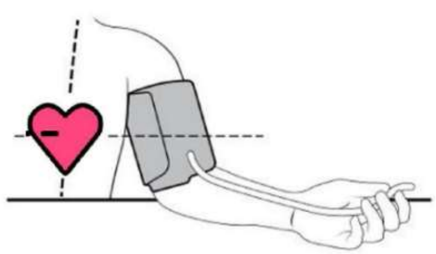

Figure 1. Position of The Body when Measuring Blood Pressure

2.2 Palpation Methods and ABI Measurement

Palpation is measuring blood pressure by directly touching the patient's pulse (Sadawarte et al., 2017). Measuring blood pressure this way can only measure systolic blood pressure by ignoring the diastolic. The way blood is measured by palpation technique is to press the radial artery pulse and inflate the cuff wrapped around the upper arm until the radial artery pulse disappears. Then the cuff pressure is reduced gradually until the radial pulse is felt for the first time. The first beat is interpreted as the systolic blood pressure.

Ankle Brachial Index is a non-invasive test method that is accurate enough to detect the risk or presence of PAD and determine this disease's condition. The ABI value is obtained by comparing the blood pressure in the systolic area of the leg (ankle) with the systolic blood pressure in the area of the arm (brachial). The pressure value can be compared on two sides of the body, left or right, or only one side, as shown in Figure 2. The equation for obtaining the ABI value can be seen in Equation 1 **(Miname et al., 2016)(Muntner et al., 2019)(Nead et al., 2013).**

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

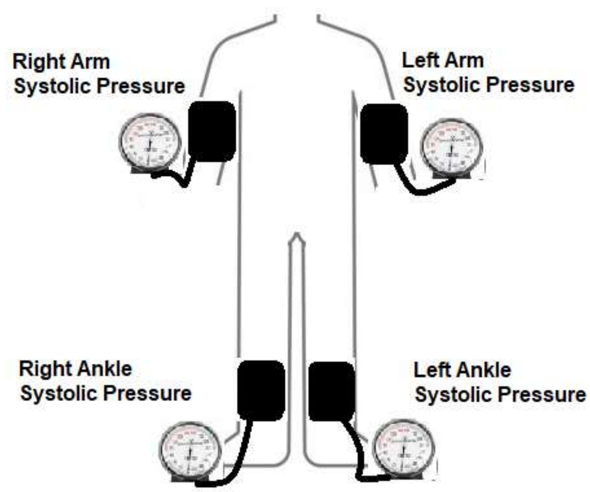

Figure 2. ABI measurement for PAD

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

2.3 Proposed Simultaneous ABI Measurement

The basic concept of the system which was made is that the system can know the condition of a person's PAD by using the Palpation method to get ABI value. The ABI value obtained will be a reference for the detection of PAD disease on someone. The basic principle of this system is to make 4 pieces digital sphygmomanometer attached to the arm area and leg area on the right side as well as the left side of a person's body. The measurement results of this system are displayed on the screen LCD and also sent to the patient's smartphone via email.

The Figure 3 is Proposed ABI measurement Simultaneously **(Arsianti et al., 2020)(Richart et al., 2009)(Said et al., 2021)**.

Table 1. The ABI Value Category

ABI	Interpretation	Recommendation
> 1.4	Vessel Hardening	Refer to vascular specialist
1.0 – 1.4	Normal	None
0.9 – 1.0	Acceptable	None
0.8 – 0.9	Some Arterial Disease	Treat risk factor
0.5 – 0.8	Moderate Arterial Disease	Refer to vascular specialist
< 0.5	Severe Arterial Disease	Refer to vascular specialist

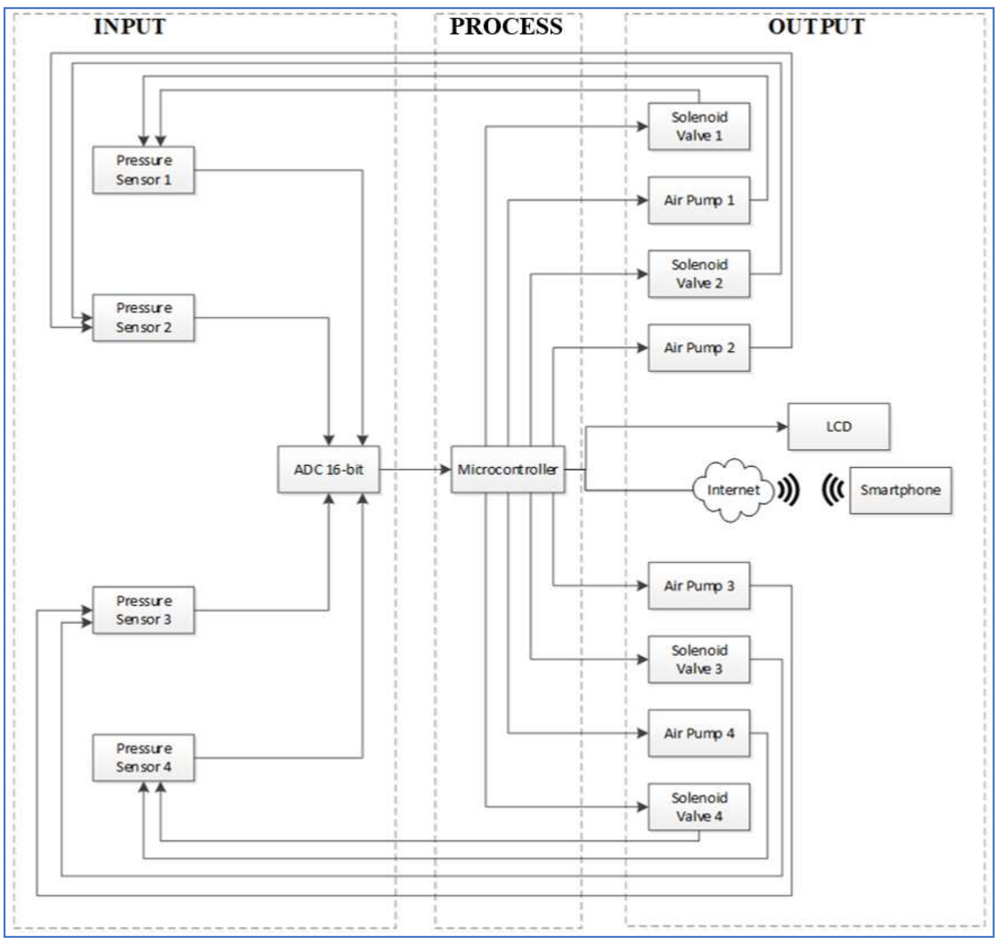

Figure 3. Proposed ABI Measurement Simultaneously with Palpation Method

The system has 4 digital blood pressure, 2 on the arm area and the others on leg area to find the ABI value. The ABI value can be known by dividing the systolic pressure in the leg (Ankle) by the systolic pressure in the arm (Brachial), the systolic value in the arm is obtained from the measurement results by the air pressure sensor through the intermediary of the cuff that is wrapped around the arm where the DC pump is on duty to fill the air in the cuff and solenoid the valve functions to deflate the cuff after the measurement is complete, the output of this sensor is in the form of analog data which will be connected to the 16-bit ADC and connected to the microcontroller to process the signal obtained and produce systolic and diastolic pressure. Figure 3 is the component of the system. The systolic value for the leg is obtained in the same way as for the arm. These parameters will be used to determine the ABI value. The measurement results from this system will be printed on the LCD screen and the output is in the form of data that can be sent to the doctor's and patient's smartphone.

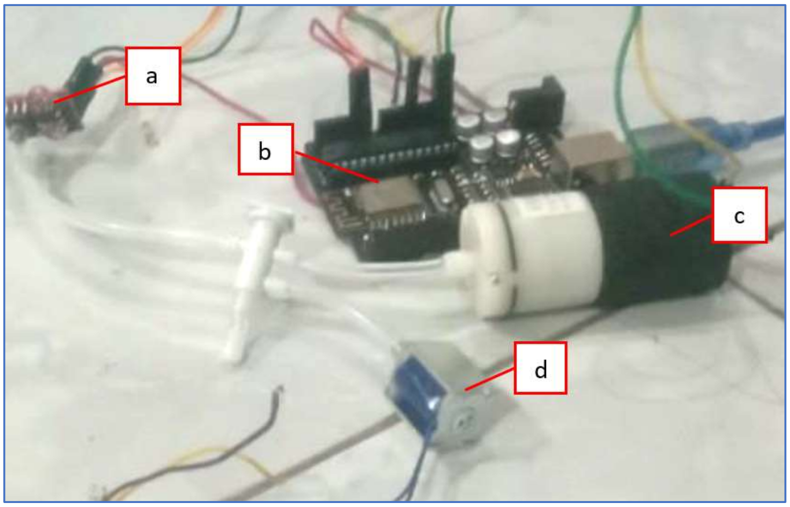

Figure 4. Proposed Digital Blood Pressure Meter used in ABI Measurement

Figure 4 is the component of the system. The systolic value for the leg is obtained in the same way as for the arm. These parameters will be used to determine the ABI value. The measurement results from this system are printed on the LCD screen and output in the form of data that is sent to the doctor's and patient's smartphone. The components used in this system are (a) Module 20N0040D Is an air pressure sensor using the Gauge Pressure principle. This type of sensor was chosen because it has a pressure value with a measurement range of 0 – 300mmHg. This sensor has an operational voltage of 5V and is also widely used as a digital sphygmomanometer in general. With the range that is owned, the pressure sensor of this model is very capable of meeting the system's needs. (b) Arduino Mega is a microcontroller unit that functions as a data processor. This component was chosen because it supports serial and I2C communication. Serial communication is used to interface with a PC or Arduino serial pins located on digital pins 0 and 1 as Rx and Tx, which are used for communication with the WiFi module, while I2C is used for communication with the LCD. This component has 16 Analog pins and more than 20 digital pins which are very sufficient for I/O needs in this system. The 8 channel relay module was chosen because a microcontroller can control it via digital pins and with an operational voltage of 5V, the number of channels on this relay is sufficient to control actuators in this system. ESP 32 is a microcontroller introduced by Espressif System, which is the successor of the ESP8266 microcontroller. This microcontroller already provides a WiFi module on the chip, so it is very supportive for creating Internet of Things application systems. This module is used to integrate the tool with the internet. (c) The 5V DC air pump is a device that can circulate air by being given a DC voltage input. This pump circulates air into the cuff from blood pressure so that the cuff can inflate. (d) Solenoid valve is a valve that works with DC voltage input. This Solenoid Valve is used because it has specifications that match the needs of the tool where this device can withstand pressures of up to 350 mmHg. LCD is a visual data display component in the form of characters, symbols, or numbers.

3. RESULTS AND DISCUSSION

3.1 Sensor Testing

A serial plotter is a tool for tracking data sent from a microcontroller. The pressure sensor sends systolic and diastolic data to the microcontroller. It is then displayed on the serial plotter, as shown in Figure 5. The systolic value is obtained (blue arrow) the first peak detected is the systolic peak and when the chart goes down, that's where the diastolic value (red arrow) detected by using the palpation method, as seen in Figure 6. The sensor calibration between the proposed tool and the aneroid manometer can be seen in Table 2. The pressure sensor reading is almost the same as the standard sphygmomanometer.

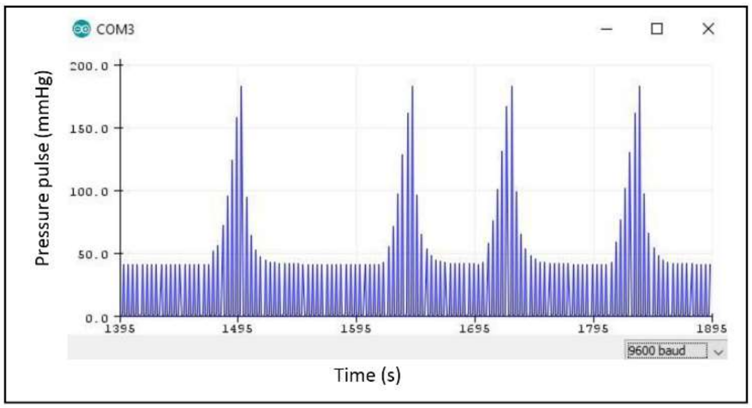

Figure 5. Serial Graph Plotter Sensor Testing

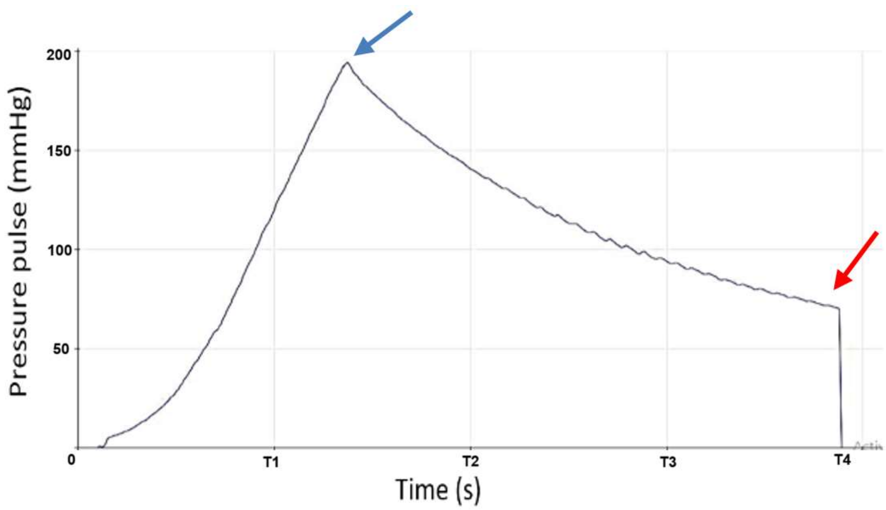

Figure 6. Systolic and Diastolic Detection by Palpation Method (blue arrow is systolic and red arrow is diastolic)

Table 2. Measurement Comparison between Sensor and Aneroid Manometer

Sensor Pressure (mmHg)	Aneroid Manometer Pressure (mmHg)
0	0
99.2	100
147.9	148
188.2	190

3.2 Measurement Result

The first step for ABI measurements is calibrating the sensor using a standard aneroid manometer. There is a 3.4% difference between the proposed tool and aneroid manometer, as shown in Table 3. Then ABI measurements were taken simultaneously from the right and left sides. Measurements are taken in a lying position so that the heart and body parts being measured are in a parallel position. Validated pressure sensors are placed non-exchangeably on the right and left arms, right and left leg, as shown in Figure 7. The ABI tool will work automatically to pump four pressure sensors. The output results on the ABI tool can be seen on the COM 3 serial port. The results of this ABI measurement are from sensor readings processed by the microcontroller using Equation 1.

Figure 7. Systolic Detection by Palpation Method from First Person

Table 3. Measurement Comparison between Sensor and Aneroid Manometer

No	Sensor Pressure (mmHg)	Aneroid Manometer Pressure (mmHg)	Systolic error
1	101/70	98/90	3%
2	109/79	106/87	2%
3	121/75	114/89	5%
4	126/85	119/40	5%
5	130/79	132/92	2%

For this study, measurements were taken on three people aged 20 years old who were in healthy condition without any history of CVD, measured in nine continuous days. Data is taken every 10 am every day so that the body condition is still fit. The recapitulation of measurements can be seen in Table 4, where the second and third columns are measurements of the first person. The second column is the right ABI, the third column is the left ABI, and so on for the second and third person. From the measurements of the three people, the ABI values were consistently within normal limits within 9 days. There is a tendency for the ABI value to be greater on the right side, possibly because these three people usually do more activities using the right side of the body, not left-handed people.

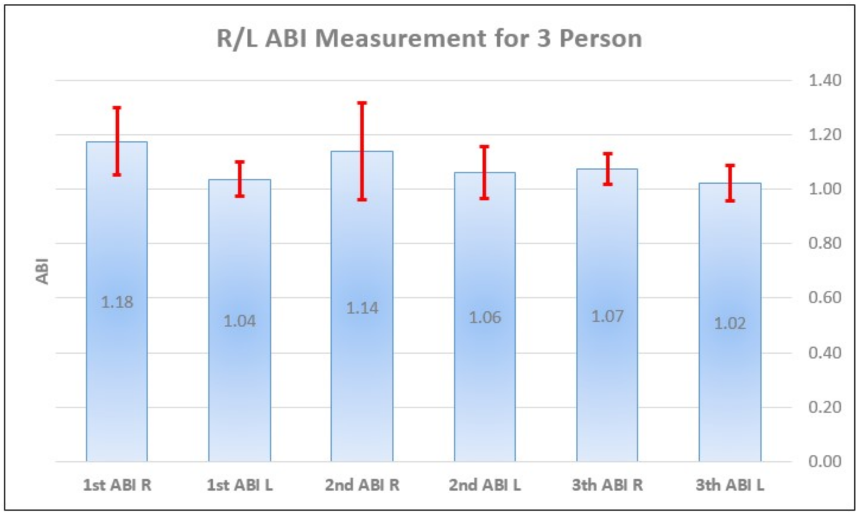

Figure 8. Graph of ABI Measurements on 3 Person

From Figure 8, can be seen that the results of the ABI measurements of 3 people for 9 days, it can be seen that the standard deviation of measurement ranges from 0.06 to 0.18. the ABI tool produces measurements with the largest deviation of 16%, this is because the pressure sensor has an error of 3.4%.

Table 4. ABI Measurement Simultaneously

No	First Person ABI		Second Person ABI		Third Person ABI	
	R	L	R	L	R	L
1	1.08	1.00	1.05	1.20	1.12	1.00
2	1.05	1.00	1.43	0.90	1.10	1.00
3	1.03	0.93	1.46	1.20	1.03	0.90
4	1.38	1.10	1.09	1.00	1.17	1.10
5	1.28	1.10	1.04	1.02	1.02	1.00
6	1.30	1.09	1.04	1.05	1.03	1.00
7	1.19	1.10	1.11	1.05	1.13	1.10
8	1.15	1.00	1.00	1.10	1.05	1.00
9	1.12	1.00	1.02	1.03	1.02	1.10
mean	**1.18**	**1.04**	**1.14**	**1.06**	**1.07**	**1.02**
std	**0.12**	**0.06**	**0.18**	**0.10**	**0.06**	**0.07**

3.3 IoT-Platform Test

When the button starts to be pressed and becomes "ON", the PAD detection system should start working until results are obtained. Meanwhile, when the reset button is pressed, it will reset the state of the device to the way it was before making the detection. After specifying the recipient's e-mail address for the PAD detection results, press the send email button until it becomes ON so that the PAD detection results can be sent.

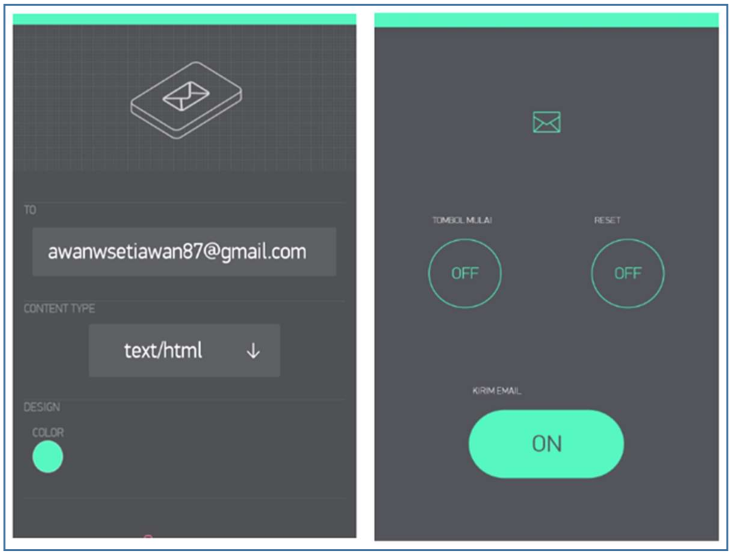

Figure 9. Display of the PAD Detection Application

Figure 10. Display of the PAD detection received in email

Display of the PAD detection application can be seen in Figure 9. Figure 10 present a display of the PAD detection received in email. The result of PAD detection that has been also received by the intended email account. The results obtained are in the form of blood pressure values and ABI values. Explanations of the variables above include:

- BP: Right arm blood pressure
- BP2: Right leg blood pressure
- BP3: Left arm blood pressure
- BP4: Left leg blood pressure
- ABI: ABI value of the right side of the body
- ABI2: ABI value of the left side of the body

4. CONCLUSION

Ankle Brachial Index is the ankle systolic pressure compared to the arm systolic pressure. This is a specific metric for diagnosing Peripheral Arterial Disease that must be measured simultaneously between the arms and legs so that the measured blood flow represents blood flow from the same heart over time. This research has succeeded in measuring ABI simultaneously on the right side of the body and the left side of the body with comparisons made on each side, the right ABI is between the right leg and right arm, whereas the left ABI is the comparison of the systole of the left leg and left arm. For further development and research, cross comparisons can be used, for example the right leg and left arm.

ACKNOWLEDGEMENT

This work was supported by the DIPA Politeknik Negeri Bandung B/98.51/PL1.R7/PG.00.03/2023.

REFERENCES

Aboyans, V., Criqui, M. H., Abraham, P., Allison, M. A., Creager, M. A., Diehm, C., Fowkes, F. G. R., Hiatt, W. R., Jönsson, B., Lacroix, P., Marin, B., McDermott, M. M., Norgren, L., Pande, R. L., Preux, P.-M., Stoffers, H. E. (Jelle), & Treat-Jacobson, D. (2012). Measurement and Interpretation of the Ankle-Brachial Index. Circulation, 126(24), 2890–2909. https://doi.org/10.1161/CIR.0b013e318276fbcb

Alageel, S., & Gulliford, M. C. (2019). Health checks and cardiovascular risk factor values over six years' follow-up: Matched cohort study using electronic health records in England. *PLoS Medicine*, *16*(7), 1–16. https://doi.org/10.1371/journal.pmed.1002863

Arsianti, R. W., Sardina, S., Fairul, F., Irfan, I., & Mulyadi, M. (2020). Rancang Bangun Alat Ukur Ankle Brachial Indeks Untuk Deteksi Peripheral Artery Disease. *Jurnal Rekayasa Elektrika*, *16*(3), 135–142. https://doi.org/10.17529/jre.v16i3.17877

Danieluk, A., & Chlabicz, S. (2021). Automated Measurements of Ankle-Brachial Index: A Narrative Review. Journal of Clinical Medicine, 10(21), 5161. https://doi.org/10.3390/jcm10215161

Dewi, E. M., Ramadhan, G., Parlindungan, R., Iryani, L., & Yuwono, T. (2022). Measurement of Ankle Brachial Index with Oscillometric Method for Early Detection of Peripheral Artery Disease. *Jurnal Rekayasa Elektrika*, *18*(2), 80–85. https://doi.org/10.17529/jre.v18i2.25758

Grün, D., Rudolph, F., Gumpfer, N., Hannig, J., Elsner, L. K., von Jeinsen, B., Hamm, C. W., Rieth, A., Guckert, M., & Keller, T. (2021). Identifying Heart Failure in ECG Data With Artificial Intelligence—A Meta-Analysis. *Frontiers in Digital Health*, *2*(February), 1–7. https://doi.org/10.3389/fdgth.2020.584555

Hadiyoso, S., & Rizal, A. (2017). Electrocardiogram signal classification using higher-order complexity of hjorth descriptor. *Advanced Science Letters*, *23*(5), 3972–3974. https://doi.org/10.1166/asl.2017.8251

Khoury, S. R., & Ratchford, E. V. (2021). Vascular Disease Patient Information Page: Subclavian artery stenosis. *Vascular Medicine (United Kingdom)*, *26*(4), 464–468. https://doi.org/10.1177/1358863X211021160

Kropf, M., Hayn, D., & Schreier, G. (2017). ECG classification based on time and frequency domain features using random forests. *Computing in Cardiology*, *44*, 1–4. https://doi.org/10.22489/CinC.2017.168-168

Maharani, A., Sujarwoto, Praveen, D., Oceandy, D., Tampubolon, G., & Patel, A. (2019). Cardiovascular disease risk factor prevalence and estimated 10-year cardiovascular risk scores in Indonesia: The SMARThealth Extend study. *PLoS ONE*, *14*(4), 1–13. https://doi.org/10.1371/journal.pone.0215219

Mahmoud, A., Alsalemi, A., Bensaali, F., Hssain, A. A., & Hassan, I. (2021). A review of human circulatory system simulation: Bridging the gap between engineering and medicine. *Membranes*, *11*(10), 1–24. https://doi.org/10.3390/membranes11100744

Miname, M., Bensenor, I. M., & Lotufo, P. A. (2016). Different methods of calculating ankle-brachial index in mid-elderly men and women: The Brazilian longitudinal study of adult health (ELSA-Brasil). *Brazilian Journal of Medical and Biological Research*, *49*(12), 1–7. https://doi.org/10.1590/1414-431X20165734

Muntner, P., Shimbo, D., Carey, R. M., Charleston, J. B., Gaillard, T., Misra, S., Myers, M. G., Ogedegbe, G., Schwartz, J. E., Townsend, R. R., Urbina, E. M., Viera, A. J., White, W. B., & Wright, J. T. (2019). Measurement of blood pressure in humans: A scientific statement from the american heart association. *Hypertension*, *73*(5), E35–E66. https://doi.org/10.1161/HYP.0000000000000087

Myers, M. C., Brandt, D. S., Prunty, A., Gilbertson-White, S., Sanborn, A., Santillan, M. K., & Santillan, D. A. (2022). Effect of positioning on blood pressure measurement in pregnancy. *Pregnancy Hypertension*, *27*, 110–114. https://doi.org/10.1016/j.preghy.2021.12.013

Nead, K. T., Cooke, J. P., Olin, J. W., & Leeper, N. J. (2013). Alternative ankle-brachial index method identifies additional at- risk individuals. *J Am Coll Cardiol.*, *62*(6), 1–17. https://doi.org/10.1016/j.jacc.2013.04.061.Alternative

Netea, R. T., Elving, L. D., Lutterman, J. A., & Thien, T. H. (2002). Body position and blood pressure measurement in patients with diabetes mellitus. *Journal of Internal Medicine*, *251*(5), 393–399. https://doi.org/10.1046/j.1365-2796.2002.00958.x

Powell-Wiley, T. M., Poirier, P., Burke, L. E., Després, J. P., Gordon-Larsen, P., Lavie, C. J., Lear, S. A., Ndumele, C. E., Neeland, I. J., Sanders, P., & St-Onge, M. P. (2021). Obesity and Cardiovascular Disease A Scientific Statement From the American Heart Association. *Circulation*, *143*(21), E984–E1010. https://doi.org/10.1161/CIR.0000000000000973

Rachmat, H. H. (2017). Comparison of radialis sphygmomanometer in evaluating the blood pressure of healthy volunteers. *Proceedings of 2016 1st International Conference on Biomedical Engineering: Empowering Biomedical Technology for Better Future, IBIOMED 2016*, (1–4). https://doi.org/10.1109/IBIOMED.2016.7869817

Rac-Albu, M., Iliuta, L., Guberna, S. M., & Sinescu, C. (2014). The role of ankle-brachial index for predicting peripheral arterial disease. Maedica, 9(3), 295–302. http://www.ncbi.nlm.nih.gov/pubmed/25705296

Richart, T., Kuznetsova, T., Wizner, B., Struijker-Boudier, H. A., & Staessen, J. A. (2009). Validation of automated oscillometric versus manual measurement of the ankle-brachial index. *Hypertension Research*, *32*(10), 884–888. https://doi.org/10.1038/hr.2009.125

Sadawarte, P., Bhure, A., Chauhan, S., & Gawande, R. (2017). Measurement of Diastolic Blood Pressure Without Stethoscope ... Is It Possible ?. *Scholars Journal of Applied Medical Sciences,* *5*(2E), 662–667. https://doi.org/10.36347/sjams.2017.v05i02.071

Said, Asbath, Novianti, Dwi, A., Fety, & Yulli. (2021). Early Detection of Peripheral Artery Disease through Ankle Brachial Index Examination in Prolanist Group at Puskesmas Poasia. *Health Information : Jurnal Penelitian*, *13*(1), 11–19.

Tan, J., Zhang, X., Wang, W., Yin, P., Guo, X., & Zhou, M. (2018). Smoking, blood pressure, and cardiovascular disease mortality in a large cohort of chinese men with 15 years follow-up. *International Journal of Environmental Research and Public Health*, *15*(5), 1–9. https://doi.org/10.3390/ijerph15051026

Vaduganathan, M., Mensah, G. A., Turco, J. V., Fuster, V., & Roth, G. A. (2022). The Global Burden of Cardiovascular Diseases and Risk: A Compass for Future Health. *Journal of the American College of Cardiology*, *80*(25), 2361–2371. https://doi.org/10.1016/j.jacc.2022.11.005

Verzicco, R. (2022). Electro-fluid-mechanics of the heart. *Journal of Fluid Mechanics*, *941*, 1–81. https://doi.org/10.1017/jfm.2022.272

Wuche, C. (2022). The cardiovascular system and associated disorders. *British Journal of Nursing*, *31*(17), 888–892. https://doi.org/10.1159/000412682