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Design of Ambulatory Blood Pressure Monitoring for IOT-Based Hypertension Patients

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ABSTRACT Ambulatory blood pressure monitoring or ABPM is a non-invasive method to determine the average blood pressure for at least 24 hours, not only when medical checkup. ABPM is often found in cardiac examinations and monitoring of catlab preoperative patients. This study aims to analyze the performance of the ABPM tool that can measure blood pressure continuously with a specified time interval connected to IoT so that can make it easier to get test results. The contribution of this research is a 24-hour monitoring system with delivery via IoT. The experiment was conducted 10 times with Prosim comparison at each point to assess the level of reading accuracy and effectiveness of IoT viewers. At 120/80 mmHg systole accuracy 98.42%, diastole 97.25%. While at 150/100 mmHg systole accuracy is 99.67%, Diastole is 98.1%. At 200/160 mmHg point Systole accuracy 98.35%, Diastole 98.25%. The SPSS test states that the reading data collection is acceptable and has an average commensurate with the test. The difference in viewer time on the TFT and IoT layers is 3.8 seconds and the test data value is 0% loss. The results from making this module, concluding by utilizing the sensor MPX5050 obtained sufficient accuracy, the use of ESP32 as a microcontroller processes the sensor readings which will be converted into systole-diastole values and displays on IoT so that it can slightly help analyze the patient's condition, and this module can read the simulator tool well at pressures of 120/80 mmHg, 150/100 mmHg, and 200/160 mmHg. The device showed good accuracy and reliability in measuring blood pressure at different levels compared to a vital signs simulator. The device can be used for 24-hour monitoring of hypertension patients and provide useful information for diagnosis and treatment.

INDEX TERMS ABPM, Hypertension, Blood Pressure, IoT, MPX5050

I. INTRODUCTION

Hypertension continues to be one of the major global health problems as a risk factor for stroke, cardiovascular disease, kidney failure and other serious diseases that have the potential to cause death and disability. Against this backdrop, finding appropriate strategies in the diagnosis and therapy of hypertension is imperative. The 2017 Indonesia May Measurement Month (MMM) activity report states that based on blood pressure (BP) data taken from all over Indonesia, hypertension was found in 34.5% of subjects. As many as 62.8% in the group that had received anti-hypertension therapy did not reach the target blood pressure [1][2]. Basic Health Research (Riskesdas) data from 2013 to 2018 reported that 25.8-34.1% of the adult population in Indonesia had high blood pressure [3][4]–[6]. The higher the blood pressure, the greater the disability, morbidity, and mortality caused by hypertension. Screening the right way is thought to be one of the solutions to achieve effective primary prevention, thereby reducing morbidity and mortality rates, and providing an appropriate basis for public policy making.

Blood pressure measurement accuracy is one of the key factors in the diagnosis and management of hypertension. Blood pressure measurement in the clinic (Office Blood Pressure Measurement/OBPM) has limitations in terms of variations in measurement conditions and individual vigilance responses to measurement procedures that often cause an increase in blood pressure. Currently, blood pressure measurements outside the clinic, namely ABPM (Ambulatory Blood Pressure Monitoring) and HBPM (Home Blood Pressure Monitoring) have been recommended in many hypertension guidelines to evaluate and measure blood pressure that is not only limited to one measurement time. ABPM is often found in cardiac examinations as well as monitoring of preoperative catlab patients where it is necessary based on the recommendation of a cardiologist so that it has been through thorough consideration of the patient's condition [3][4][9]. Some of the reasons underlying the use of these two methods are as follows:

1) Provides more stable and validated result information on blood pressure measurement.
2) The measured parameters are useful in assessing prognosis in patients,
3) Clinical blood pressure measurements have high variability and therefore do not always reflect the basal blood pressure profile and cardiovascular risk of patients,
4) Help differentiate the diagnosis of white coat hypertension and masked hypertension so that clinicians can determine the diagnosis of hypertension more precisely and lead to a reduction in the burden of health care costs for hypertensive patients [10].

Ambulatory blood pressure monitoring or ABPM is a non-invasive method to determine the average blood pressure for at least 24 hours [7][8][9][10][15]. This method allows doctors to measure blood pressure over a 24-hour period not only when sitting on the examination table. The monitoring even includes sleeping. By undergoing this monitoring, the doctor can decide whether a person needs to take hypertension medication or not. This monitoring uses a small, automatic digital blood pressure meter that is attached to a belt around the patient's body and connected to a cuff that is attached to the patient's upper arm. The device will measure blood pressure periodically during the patient's activities and during sleep. In 2018 ABPM was made by Ariman using the MPX5700 pressure sensor as a blood pressure and pulse detector, and using the Arduino microcontroller as a data processor with the lowest percentage of Systole measurement accuracy of 90.62% and the lowest Diastole measurement accuracy of 78.21% [12][13][18][19]. In 2020 APBM with Android application was made by Kurniawan where this digital blood pressure monitoring system uses the US9111 pressure sensor with the lowest percentage accuracy of Systole measurement is 93.33%, while Diastole is 76.90% [14][15]. In 2021, an Android-based ABPM with a printout was made by Waskito where this digital blood pressure monitoring system using an MPX2100 pressure sensor has obtained systole data has the largest error value of 1.2%, diastole data has the largest error value of 1.2%. Disadvantages of this tool cannot be used during activities [22][23][24]–[26]. In some of the above studies, not many have utilized the NodeMCU ESP32 for wireless networks which can send the latest information about the patient's blood pressure which will be sent to the doctor via Smartphone. Also, data collection can be used while resting and being active. From the results of the identification above, the authors plan to develop an Ambulatory Blood Pressure Monitor (ABPM) tool to detect early hypertension (adults) with Internet of Things technology.

The aim of this research is to analyze the performance of an ABPM device that can measure blood pressure continuously at certain time intervals connected to IoT and compare the accuracy and error of the device with a vital signs simulator at different blood pressure levels. The contributions of this research are:

- The authors developed a 24-hour monitoring system with data transmission via IoT cloud, which can provide more stable and validated results of blood pressure measurement.
- The authors utilized the MPX5050GP sensor, which has sufficient accuracy and sensitivity for blood pressure detection.
- The authors used the ESP32 microcontroller, which has a built-in Wi-Fi feature and can process the sensor readings and send them to the Arduino IoT Cloud server.

II. MATERIALS AND METHOD

This research has been completed. The author used a pressure gauge to determine the appropriate pressure inside the cuff. The next section will discuss the equipment and procedures.

I. DATA COLLECTION

The researchers compared the designs in this study. A Vital Signs Simulator was used as a comparison tool. This study uses MPX5050GP sensor as the voltage reader sensor. Using ESP32 Dev Module as a microcontroller and utilizing its Wi-Fi feature as a medium for sending data to IoT. Also using LCD and Arduino IoT Cloud as a viewer of this research reading. After being connected to a cuff attached to a dummy tube, a branch is made on the hose to go to a Vital Signs Simulator. (As shown in FIGURE 1).

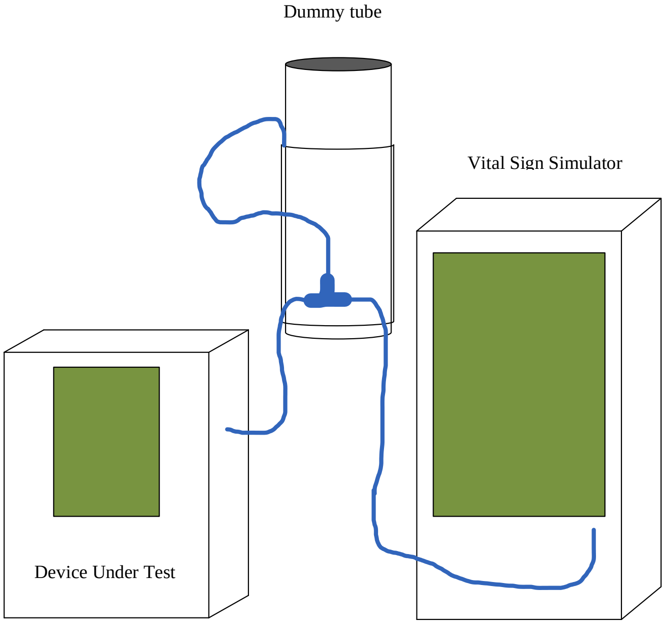

FIGURE 1. Simulation of installing a vital sign simulator with a cuff attached to a dummy tube

In Figure 2 it is explained that when the ABPM is turned on, the battery will provide voltage to the microcontroller and pressure sensor. The air pressure read by the sensor will be

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converted into digital data to be read on the microcontroller. When the tool is run, the pump will fill the cuff with air, then there is data that is read by the sensor and the results of this data reading are processed to get systolic and diastolic values which will be displayed via TFT, also uploaded to a database via the Internet. Upload results in the database can be opened in the IoT delivery application which can be accessed on a smartphone.

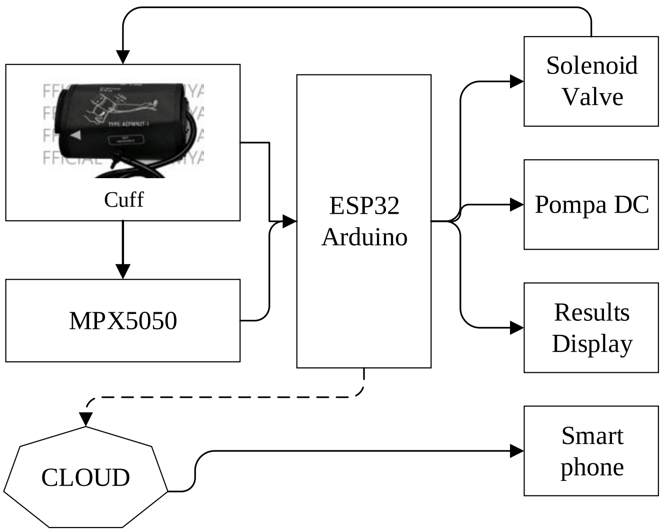

FIGURE 2. **ABPM block diagram system with MPX505 as an input sensor whose output results are programmed by a microcontroller which will then drive a motor that produces pressure values.**

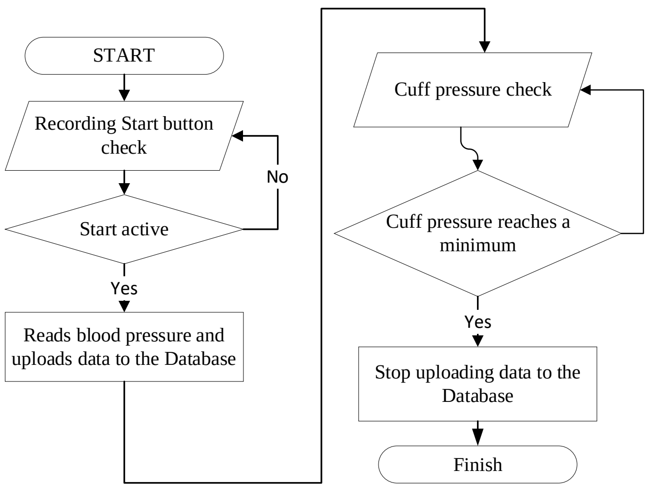

FIGURE 3. **The flowchart of the system detects the flatness of the surface, in this case, x-ray tube and bucky table.**

The Database transmission flowchart in Figure 3 explains that when the device is turned on in the initial condition, the Start button checking process occurs. If it starts, the device will read the air pressure in the cuff that is obtained and processed in the microcontroller, then the processing data obtained will be sent to the Database via the Internet. The reading and sending process will continue to run repeatedly until the air pressure in the cuff is successfully removed. This will end the process of sending to the database.

II. DATA ANALYSIS

Temperature, humidity, flow, and noise measurements were taken 20 times for each parameter. By applying Eq. (1), the mean or average is used to determine the mesurement's average value [21][22]:

$$\text{Average } (\overline{X}) = \frac{\sum Xi}{n} \quad (1)$$

where x represents the mean (average) value for the first n measurements, x1 represents the second, and xn represents the nth measurement. The standard deviation is a number that represents how much variance there is in a set of data or a standard deviation from the mean. Eq. (2) can be used to display the standard deviation (SD) formula :

$$X = \sqrt{\frac{\Sigma(Xi - X)^2}{n-1}} \quad (2)$$

where xi is the percentag of the intended values, x denotes the measurement results' average, and n denotes the total number of measurements. The system error is displayed by the % error. The lesser amount the difference between each data set's means is the error. The mistake might demonstrate how the model or design deviates from the norm. Equation (4) displays the error formula.

$$\%ERROR = \frac{(Xn - X)}{Xn}\, x\, 100\% \quad (3)$$

where Xn represents the value that the calibrator machine measured. The value determined from the design is the x.

FIGURE 4. **IoT Based Ambulatory Blood Pressure Monitoring Design. The results of the systole and diastole values are displayed on the display module.**

III. RESULT

The researchers compared the designs in this study. A Vital Signs Simulator was used as a comparison tool. This study uses

MPX5050GP sensor as the voltage reader sensor. Using ESP32 Dev Module as a microcontroller and utilizing its Wi-Fi feature as a medium for sending data to IoT. Also using LCD and Arduino IoT Cloud as a viewer of this research reading. FIGURE 4 is the result of the design of this research module. The data collection process was carried out on ABPM with measurements of 120/80 mmHg, 150/100 mmHg, 200/160 mmHg each for a total of 10 trials using the MPX5050GP pressure sensor. For measurements of 120/80 mmHg we found out that the error value is 1.58% for systole and 2.75% for diastole, and the accuracy is 98.42% systole, 97.25% diastole. Systole and diastole as shown in TABLE 1.

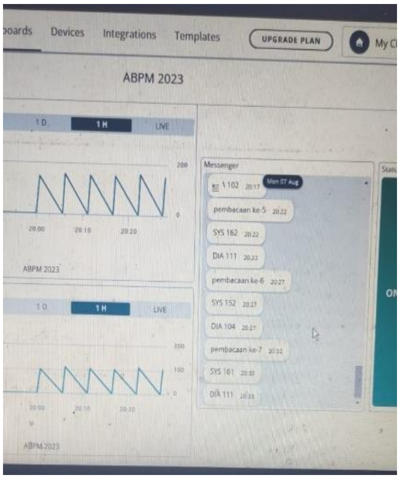

FIGURE 5. Results sent by IoT with display on Arduino Cloud and Mobile Web.

TABLE 1
Results of the average value of systole and diastole tests by taking data at each point 10 times.

Systole (mmHg)	NIBP ABPM			Diastole (mmHg)	NIBP ABPM		
	Average	Stdev	Error %		Average	Stdev	Error %
120	121.9	1.9	1.58	80	82.2	2.2	2.75
150	150.5	0.5	0.33	100	98.1	1.9	1.9
200	203.3	3.3	1.65	160	157.2	2.8	1.75

For measurements of 150/100 mmHg we found out that the error value is 0,33% for systole and 1,9% for diastole, and the accuracy is 99,67% systole, 98,1% diastole. For measurements of 200/160 mmHg we found out that the error value is 1,65% for systole and 1,75% for diastole, and the accuracy is 98,35% systole, 98,25% diastole. The data collection process on the module was carried out at the module production site. The data collection process was carried out on ABPM with measurements of 150/100 mmHg for a total of 24 trials with data collection intervals every 5 minutes using the MPX5050GP pressure sensor. as shown in TABLE 2 For measurements of 150/100 mmHg we found out that the average difference in appearance is 3.8 s. Table 2 shows the results of a comparison of display times between the module screen and the web viewer on the ABPM tool designed in this research. Table 7 consists of four columns, namely the blood pressure value that appears, the display time on the module screen, the display time on the web viewer, and the time difference between the two. Measurement of blood pressure 150/100 mmHg 24 times at intervals of every 5 minutes using the MPX5050GP pressure sensor.

Shows that the average difference in display time between the module screen and the web viewer is 3.8 seconds, which means the ABPM tool can send blood pressure data to IoT quickly and accurately.

TABLE 2
Comparison of display time on modules and web displays at each test value point

Emerging Value	Appearance Time		Time Difference
	Module Screen	Web Viewer	
148/100	20:00:28	20:00:24	4 s
154/105	20:06:33	20:06:29	4 s
155/105	20:11:43	20:11:40	3 s
154/102	20:17:08	20:17:04	4 s
152/101	20:22:14	20:22:10	4 s
	Average difference in appearance		3.8 s

IV. DISCUSSION

The researchers compared the designs in this study. A Vital Signs Simulator was used as a comparison tool. This study uses MPX5050GP sensor as the voltage reader sensor. Using ESP32 Dev Module as a microcontroller and utilizing its Wi-Fi feature as a medium for sending data to IoT. Also using LCD and Arduino IoT Cloud as a viewer of this research reading. After being connected to a cuff attached to a dummy tube, a branch is made on the hose to go to a Vital Signs Simulator. The data collection process was carried out 10 times using a comparison tool Calibrator settings 120/80 mmHg, 150/100 mmHg, and 200/160 mmHg. Of the 10 experiments data collected, the average value, error value, and accuracy are calculated with the results obtained in the 120/80 mmHg pressure mode obtained accuracy systole 98.42% diastole 97.25%, in the 150/100 mmHg pressure mode obtained accuracy systole 99.67% diastole 98.1%, and in the 200/160 mmHg pressure mode obtained accuracy systole 98.35% diastole 98.25%. From these three results, it can be seen that the value of 120/80 mmHg has a very large error value, especially in the diastole value. The resulting value tends to be unstable. This is due to the appearance of many extraneous pulses that affect the reading.

In accordance with what was done by Waskito, where the digital blood pressure monitoring system connected via Android via Bluetooth using the MPX5050 pressure sensor had a reading error of 2% [23]. In the module that has been created, an average reading error value of 1.88% is obtained. And by utilizing the IoT Cloud function, it makes it easier for doctors to carry out checks without having to be close to the module of this tool. In making the module, the author certainly does not escape the shortcomings, and the author really hopes that in the future the existing shortcomings can be improved and developed to be better. The shortcomings of this module include, among others, the circuit and program made have not been able to read low blood pressure on the calibrator. By utilizing the IoT Cloud function, doctors can monitor and analyze the patient's blood pressure from the data recorded and displayed on the graph panel that has been provided for 24-hour checking [18][19]. The weakness of this research is that the data used in this research is simulation data.

This of course limits the generalization of research results to real world conditions. The ABPM device designed in this study can only measure blood pressure in the arm. This of course cannot meet the needs of hypertensive patients who have certain medical conditions, such as pulmonary hypertension or orthostatic hypertension. The ABPM device designed in this study has not been clinically tested. Therefore, it remains unknown whether these devices can perform well in real-world conditions. Apart from the limitations above, the article also has several weaknesses, including: This research does not discuss in detail the security and privacy aspects of patient data. This is important to consider, considering that ABPM devices will collect sensitive data about patient health. This research does not discuss in detail the production and distribution costs of ABPM devices. This is important to consider so that ABPM devices can be accessed by more hypertensive patients.

V. CONCLUSION

Based on the results of the discussion and the purpose of making the module, like as the sensor uses an MPX5050 pressure sensor. The sensor can read pressure so that it can be used for systole-diastole blood pressure readings. Then ESP 32 functions as a microcontroller in this module in processing sensor readings that will be converted into systole-diastole values and send data to Arduino IoT Cloud server. When tested with the Prosim simulator at 120/80 mmHg pressure mode, the accuracy of systole is 98.42% diastole 97.25%, at 150/100 mmHg pressure mode, the accuracy of systole is 99.67% diastole 98.1%, and at 200/160 mmHg pressure mode, the accuracy of systole is 98.35% diastole 98.25%. From these three results, it can be seen that the value of 120/80 mmHg has a very large error value, especially in the unstable diastole value. This is due to the appearance of many extraneous pulses that affect the reading. All data has a test value of 0% loss. With this, it is said that the delivery system on the module is very good at sending measurement results.

From the research found a gap between expectations and reality at the time of data collection. For further research development can be done. first, minimizes extraneous pulse readings so that it can be used to read low blood pressure. Adding a program that can process test result data directly in excel so there is no need to manually fill in the test result sheet. Change the size and design of the tool to make it smaller.

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