Indonesian Journal of Electrical Engineering and Computer Science
Vol. 35, No. 1, July 2024, pp. 62~69
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v35.i1.pp62-69

Real-time monitoring system for blood pressure monitoring based on internet of things

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Article Info

Article history:

Received Feb 24, 2024
Revised Mar 3, 2024
Accepted Mar 15, 2024

Keywords:

Blood pressure
Internet of things
Microcontroller
Monitoring device
Monitoring system

ABSTRACT

Blood pressure is an important cardiovascular health indicator, with normal values set by the WHO at 140 mmHg for systole and 90 mmHg for diastole. Excess of these values indicates hypertension, which increases the risk of serious medical complications. This research developed an internet of things (IoT)-based blood pressure monitoring device, which facilitates digital blood pressure measurement and data transmission to widely accessible applications and websites. The device uses an MPX5050GP pressure sensor, Arduino Nano, and NodeMCU ESP32, as well as other components programmed using the Arduino IDE. Test results obtained from 10 subjects, the device showed an average difference in systole of 7.9 mmHg and diastole of 5.4 mmHg. This complies with recognized accuracy standards of a maximum error of 10 mmHg and indicates that the device operates effectively with the designed concept.

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1. INTRODUCTION

The internet of things (IoT) is a technology that allows various objects such as electronic devices and sensors to connect and communicate through internet-like networks, with each device having a unique identification [1]-[7]. In the medical context, IoT plays a role in the development of smart healthcare, where integrated sensors and communication devices collect patient health data. The technology facilitates easy and accessible blood pressure monitoring, with results that can be monitored online and analyzed by medical professionals via web or mobile applications [8]-[18].

High blood pressure is a critical indicator for many medical conditions [19], [20]-[27]. World health organization (WHO) sets the normal blood pressure limit at 140/90 mmHg. Higher numbers indicate hypertension, which poses risks to cardiovascular and renal health. Hypertensive patients should routinely monitor blood pressure to avoid dangerous fluctuations. Digital tensimeters, which are preferred for their practicality and high accuracy, are the tools of choice. The integration of digital tensimeters with IoT introduces an efficient health monitoring method, enabling regular blood pressure checks and remote monitoring [18], [28]-[34].

Monitoring blood pressure regularly is essential in detecting and preventing health complications such as hypertension [19], [20], [24], [27], [35]. For patients with hypertension, daily blood pressure measurements are key to monitoring the effectiveness of treatment, including drug dose adjustments. Unfortunately, the necessity for regular measurements imposes a considerable burden on medical staff, who must attend to patients consistently. Given the requirement for multiple readings in each session to ensure accuracy, there arises a critical need to streamline and simplify the monitoring process within the hospital environment. Neglecting regular measurements can reduce the effectiveness of treatment and increase the risk of serious complications such as stroke or blindness. Therefore, with the advancement of digitalization, independent blood pressure measurement at home is an alternative that can support patients independetly and offer efficiency in health monitoring. In this context, research has developed an IoT-based blood pressure monitoring tool that enables easy, low-cost, and user-friendly use, and facilitates effective blood pressure monitoring by reporting data directly to doctors using Telegram service as a real-time notification platform, while Google Sheets functions as a datalog for recording the previous readings of the blood pressure sensor. This tool encourages family participation in the health process and ensures that health data is easily accessible through mobile devices, which is can be view by both doctor and patience.

2. METHOD

In conducting research, the data collection methods used to formulate problems are divided into two methods, namely primary methods and secondary methods as shown in Figure 1. The method used to obtain primary data was carried out by interviews, while for data collection used secondary methods using the library method, namely sourced from a theoretical data collection method and obtained from studying books, internet sites related to the research carried out and scientific journals. These two methods play a very important role in this research activity.

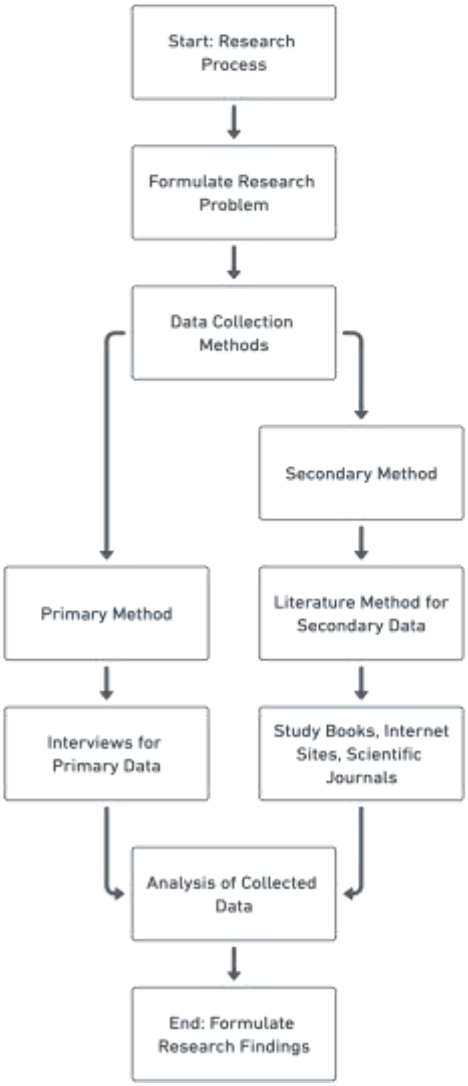

Figure 1. Method of collecting data

This system is designed to explain the operational process of the device in question. The uninterruptible power supply (UPS) module functions to convert the input voltage from the 18650 battery, which has a voltage of 3.7 V, to 12 V. This voltage is then used to supply the direct curren (DC) pump motor and solenoid valve. Furthermore, the 12 V voltage from the UPS module is converted back through a DC Step Down from 12 V to 5 V. This conversion aims to supply voltage for the MPX5050GP Sensor, 16x2 LCD, ULN 2803, Arduino Nano, and NodeMCU ESP32. The process is initiated by a push button that determines the start of the system operation. Once the process starts, the sensor will read the pressure obtained from the cuff. The pressure read is then processed by the Arduino Nano, which converts the analog data into Systole and diastole data. The data is then displayed on the 16x2 LCD and sent to the NodeMCU ESP32. The NodeMCU ESP32, which is connected to a Wi-Fi network, is responsible for sending the data to Google Spreadsheet and Telegram for further documentation and analysis.

The schematic and system architecture can be seen in Figure 2. The center of this circuit is the microcontroller, based on its layout and pin markings. This microcontroller is directly connected to an LCD display module that serves as the user interface, allowing visualization of the operational parameters and outputs of the system. Relays connected through transistors as signal amplifiers and diodes as flyback protection, indicate the system's ability to control external loads, such as motors or valves, by providing isolation between the microcontroller and high-power loads. Sensor integration, expressed by the symbolic representation in the schematic, indicates the functionality of collecting data from the operational environment. Meanwhile, resistors and auxiliary components play a role in bias configuration and circuit protection. The circuit is also equipped with connectors that facilitate external communication and system functionality expansion. The use of wiring configurations and component installation follow electronic design standards to ensure reliability and operational effectiveness. In a scientific context, this scheme reflects the design of a control and data acquisition system designed for automation applications in electronic engineering and informatics. The device is designed to enable accurate and efficient blood pressure monitoring, utilizing components such as a microcontroller that serves as the data processing center, a pressure sensor to detect blood pressure values, an air pump to control the pressure gauge cuff, and a solenoid valve for airflow regulation. The integration of these components facilitates the capture of blood pressure data and real-time transmission of information via the internet network.

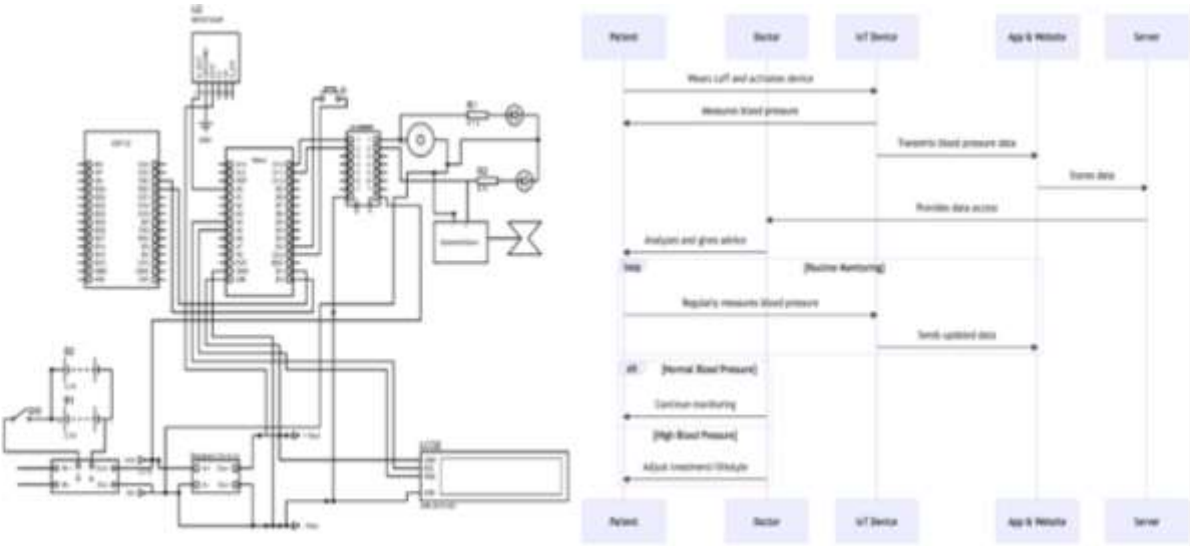

Figure 2. Schematic and architecture diagram of blood pressure monitoring based on IoT

In this system, the patient uses a cuff connected to an IoT device to measure blood pressure. The measurement results are then transmitted to an application or website and automatically stored on a server that serves as a data repository. This process allows doctors to access and analyze the measurement results, as well as provide medical recommendations based on the collected data. The system is also designed to perform routine blood pressure monitoring, where up-to-date data is sent back to the server at regular intervals. In this workflow model, there is a conditional mechanism (marked with "alt") that allows the system to respond based on the measurement results: if the blood pressure is within the normal range, the monitoring process will continue without change; conversely, if high blood pressure is detected, the system will recommend adjustments in the patient's medication or lifestyle in response to the condition.

2.1. Liniear regression

In this study, linear regression was used to find the relationship between sensor readings and blood pressure sensors. Because the sensor only able to output the voltage level of the blood pressure, we need to be able to interpreted those voltage level into the correct blood pressure value, using method such as Liner Regression we can find those value. Linear regression is a parametric statistical technique aimed at elucidating the linear relationship between a dependent variable and one or more independent variables within a given dataset. In the case found, a correlation was carried out between the sensor value and the blood pressure sensor. The fundamental premise revolves around postulating linear equations that capture the underlying dynamics of observed data, thereby facilitating predictive modeling and inferential analysis. In its basic form, a simple linear regression model is articulated with formula 1, while the main goal in linear regression involves optimization to minimize the residual sum of squares with formula 2. Linear regression models are typically estimated through methodologies such as ordinary least squares (OLS), a technique that seeks to minimize the sum of squared residuals. This analytical framework, while assuming linearity, facilitates a nuanced understanding of relationships between variables and holds broad applicability across diverse domains for predictive modeling and insights extraction.

$$Y = \beta_0 + \beta_1 X + \in \quad (1)$$

$$\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 \quad (2)$$

2.2. Oscillometric method

The oscillometric method is a non-invasive technique used in automatic blood pressure measurement. It begins with deployment of an inflatable cuff around the upper arm, with the cuff pressure exceeding the expected systolic blood pressure. Next, the cuff deflates gradually, allowing blood to flow to the brachial artery. As blood pulses through the arteries due to the heartbeat, fluctuations in arterial pressure occur. A pressure sensor inside the cuff detects these oscillations and converts them into electrical signals. The monitor identifies the point of maximum oscillation amplitude, corresponding to the mean arterial pressure.

To obtain systolic and diastolic values from mean arterial pressure, a sophisticated algorithm is needed that can detect these values. Each manufacturer has implemented its own unique way of finding systolic preasure (SP)/diastolic preasure(DP) values. In designing this tool, 0.55 maximum amplitude was used before maximum amplitude oscillations occurred for SP and 0.85 after maximum amplitude oscillations occurred for DP.

3. RESULTS AND DISCUSSION

Blood pressure sensor testing was conducted through the integration of the MPX5050GP sensor with a standard aneroid tensimeter and a DC pump motor as shown in Figure 3. The sensor was tested to determine the correlation between the resulting analog reading (in apparent diffusion coefficient (ADC) units) and the direct blood pressure reading (in mmHg) obtained from the aneroid tensimeter. The DC pump motor was used to adjust the pressure in the cuff, which allowed the mapping and calibration of the sensor value against an accurate reference value to establish a linear relationship between the two variables.

Figure 3. Blood pressure monitoring based on IoT

3.1. Getting the correct blood preasure reading

The graph in Figure 4 shows the relationship between ADC units and current blood pressure readings using linear regression. The 'y' axis will represent the ADC of the sensor, and the 'x' axis will represent the blood pressure reading. From the graph above we can get the represented linear function that can be used to calculate the correct blood pressure reading. From the results in this graph, errors found in the system can also be analyzed. The results of this calculation are using (3).

$$x = \frac{y - 1686.9}{1.7355} \quad (3)$$

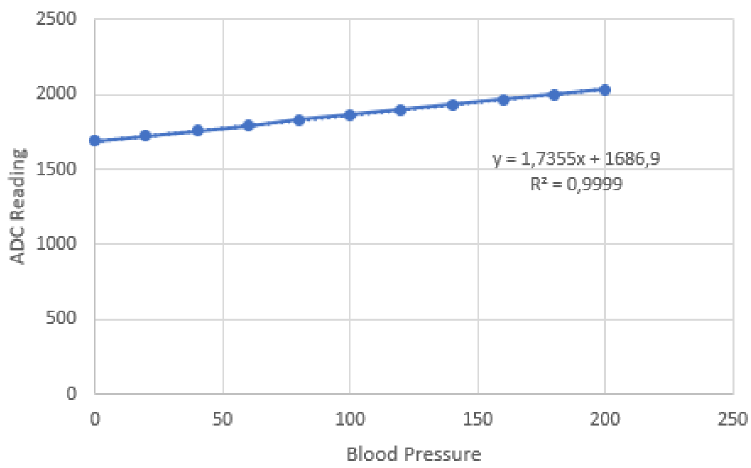

Figure 4. Relationship between ADC units and current blood pressure readings using linear regression

3.2. Testing the device

After the design and development process is complete, the device is tested to see whether the device meets the expected device requirements. In this section, the SP and DP values of the devices that have been made with commercial blood pressure devices will be compared. The results obtained came from 10 samples using the designed device and the Omron HEM-8712 as shown in Figure 5. Based on the tests that have been carried out, the device created has an error rate of 7.09% for the SP value and 6.88% for the DP value of the Omron HEM-8712 device. The results of this test can be seen in Table 1.

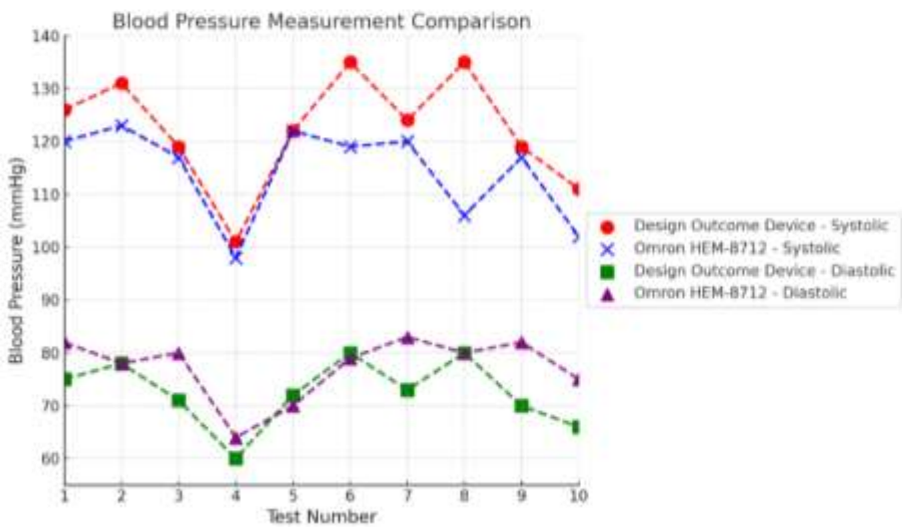

Figure 5. Graph of comparison results of blood pressure measuring devices

Table 1. Comparative results of testing blood pressure measuring devices

No	Gender	Blood pressure IoT		Omron HEM-8712		Difference		Error %	
		SYS	DYS	SYS	DYS	SYS	DYS	SYS	DYS
1	M	126	75	120	82	6	7	5.00	8.54
2	M	131	78	123	78	8	0	6.50	0.00
3	M	119	71	117	80	2	9	1.71	11.25
4	F	101	60	98	64	3	4	3.06	6.25
5	M	122	72	122	70	0	2	0.00	2.86
6	F	135	80	119	79	16	1	13.45	1.27
7	F	124	73	120	83	4	10	3.33	12.05
8	M	135	80	106	80	29	0	27.36	0.00
9	F	119	70	117	82	2	12	1.71	14.63
10	F	111	66	102	75	9	9	8.82	12.00
Average		122.3	72.5	114.4	77.3	7.9	5.4	7.09	6.88

3.3. Testing the IoT feature

In this section, testing is carried out to see whether the previously tested data is sent to the IoT feature. The results of sending data are sent to Telegram using the Telegram Bot and also to Google Sheets. By using the same sample as before, it can be seen that it can be sent and received well. From Figure 6 it can be seen that the data is recorded in Google Sheets and the Telegram bot will send messages to patients and doctors. Based on Table 2 it can also be concluded that the device has successfully sent sample data to Google Sheet and Telegram.

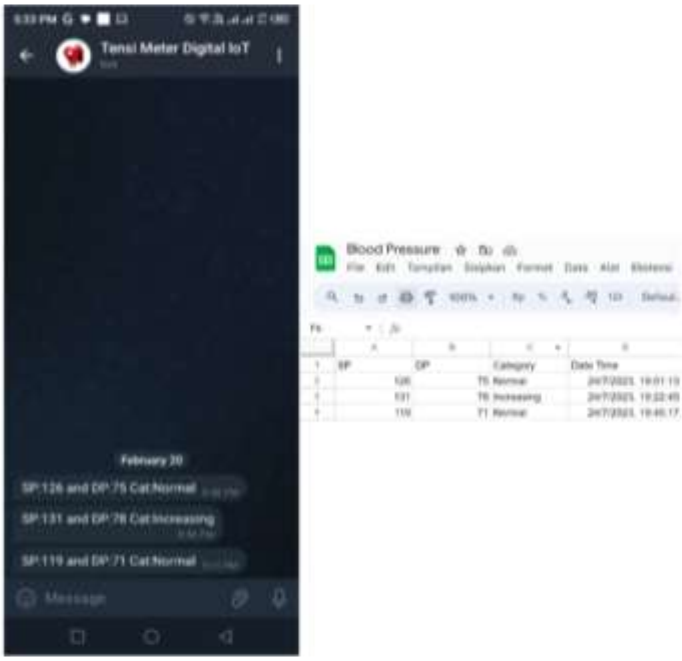

Figure 6. Test results of data sending to Telegram and Google Sheet

Table 2. The results of sending data to Telegram and Google Sheet from testing to respondents

Respondent	Data Sent Destination		Description
	Telegram	Google Sheet	
1	✓	✓	The data has been sent successfully
2	✓	✓	The data has been sent successfully
3	✓	✓	The data has been sent successfully
4	✓	✓	The data has been sent successfully
5	✓	✓	The data has been sent successfully
6	✓	✓	The data has been sent successfully
7	✓	✓	The data has been sent successfully
8	✓	✓	The data has been sent successfully
9	✓	✓	The data has been sent successfully
10	✓	✓	The data has been sent successfully

4. CONCLUSION

In conclusion, this study introduces an IoT-based blood pressure monitoring tool that integrates a digital blood pressure monitor and connectivity to enable convenient, efficient, and easy-to-use blood pressure checks with remote monitoring capabilities. This research uses a mixed methods approach involving primary methods such as interviews and secondary methods such as literature reviews, explaining the operational processes of the system, which includes UPS modules, digital tensimeters, and IoT components for data transmission and analysis. This study establishes a linear relationship between analog sensor readings and blood pressure values through graphical representation, thereby confirming the accuracy of the device. Additionally, the oscillometric method is described as a non-invasive technique for automated blood pressure measurement, with the device showing promising results compared to commercial blood pressure devices. The results show an error rate of 7.09% for systolic values and 6.88% for diastolic values. Apart from that, this device has also succeeded in sending data to Telegram and Google Sheets to store patient records to monitor their health. Overall, this research contributes to the scientific advancement of intelligent healthcare technologies by presenting a comprehensive IoT-based blood pressure monitoring system, offering practicality, accuracy, and accessibility to improve patient care and preventive health management.

ACKNOWLEDGEMENTS

Thanks are given to the Institute of Business and Technology Indonesia and Marine and Fisheries Polytechnic of Kupang for all their help and support in this research.

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