

Design and Construction of Multi-Parameter Health Testing and Monitoring Equipment

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ARTICLE INFO

Received: 09/01/2025
Revised: 09/03/2025
Accepted: 29/04/2025
Published: 28/11/2025

KEYWORDS

Vital signs;
Patient monitoring;
IoT in Healthcare;
Multi-Parameter Monitoring;
Home Healthcare.

ABSTRACT

Since the COVID-19 pandemic, the demand for home healthcare services has increased significantly. According to a report by Global Market Insights, the home medical devices market is projected to reach a value of USD 58 billion by 2030, growing at an annual rate of 6.5%. To meet the demand for home healthcare, particularly the use of multi-parameter monitoring devices, this project aims to design a home health monitoring and tracking device focusing on four important physiological indicators: blood pressure, heart rate, temperature, and blood oxygen saturation. These are essential metrics for assessing health status, especially for patients with hypertension, hypotension, cardiovascular conditions, or post-COVID-19 status. This device utilizes the Arduino Mega Wi-Fi R3 as the processing center. The DS18B20 sensor is used to measure body temperature, the MAX30100 sensor measures heart rate and blood oxygen saturation, and the MPS20N0040D sensor combined with the ADC HX710 is employed to design the blood pressure measurement circuit. All collected data will be stored on a server through the ESP8266 module and then displayed on an Android phone using Android Studio software. Test results indicate that the system achieves high accuracy in measurements and maintains stable communication between the device and the application. This device has significant potential for application in home healthcare.

Doi: <https://doi.org/10.54644/jte.2025.1761>

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1. Introduction

Multi-parameter health monitoring systems play a crucial role in overseeing physiological indicators, assisting users and doctors in promptly detecting abnormalities, and implementing effective interventions [1]. This is especially important for the elderly or individuals with chronic illnesses who require regular health monitoring. Relying solely on periodic hospital visits consumes time and risks overlooking early warning signs of health issues. Therefore, the demand for a multi-parameter monitoring device for home use is becoming popular. The remarkable advancement of technology following the COVID-19 pandemic has significantly boosted the home health monitoring device market. According to a report by Market Research Future, the multi-parameter patient monitoring device market is expected to reach USD 16.40 billion by 2029, growing from USD 11.44 billion in 2022 [2]. Additionally, Global Market Insights predicts that the home medical devices market will attain a value of USD 58 billion by 2030, with an average annual growth rate (CAGR) of 6.5% [3]. Another study by Grand View Research indicates that the multi-parameter patient monitoring device market reached USD 1.56 billion in 2022 and is projected to grow at a rate of 5.7% from 2023 to 2030 [4]. These figures demonstrate a strong and increasing trend in the demand for home healthcare, particularly in the field of physiological parameter monitoring. Physiological parameters such as blood pressure, body temperature, heart rate, and blood oxygen saturation are important factors in assessing overall health [5]. Regular monitoring of these parameters not only helps in the early detection of potential health issues but also assists doctors in making accurate diagnoses and treatment decisions. To meet this demand, this study proposes the design and development of a multi-parameter health monitoring system

that includes blood pressure, body temperature, heart rate, and blood oxygen saturation [5]. The system will monitor physiological indicators in real-time, store data on a server, and provide a display interface through an Android application. Additionally, the application allows users to set reminders and control the device remotely, providing convenience and effectiveness in daily health management.

2. Materials and Methods

2.1. Overview

Figure 1 below shows the system block diagram and materials used in this project. In this study, the system is designed with the Arduino Mega Wi-Fi R3 as the central microcontroller for processing [6]. The health parameters are measured using specialized sensors, specifically: the DS18B20 sensor to provide temperature data with high accuracy [7], [8], the MAX30100 sensor to measure blood oxygen saturation and heart rate [8], and the MPS20N0040D pressure sensor combined with the HX710 IC to amplify the signal and convert it from analog to digital with a 24-bit resolution [9]. To measure pressure, a pump and a drain valve are used to determine the fluctuations [10]. Each sensor is connected to an ATmega328P microcontroller, which performs preliminary processing tasks and sends the data via UART communication to the Arduino Mega Wi-Fi R3. The central microcontroller then aggregates the parameters and displays the results on a 3.5-inch TFT ILI9486 screen. The entire system is powered by a Lithium-Ion battery.

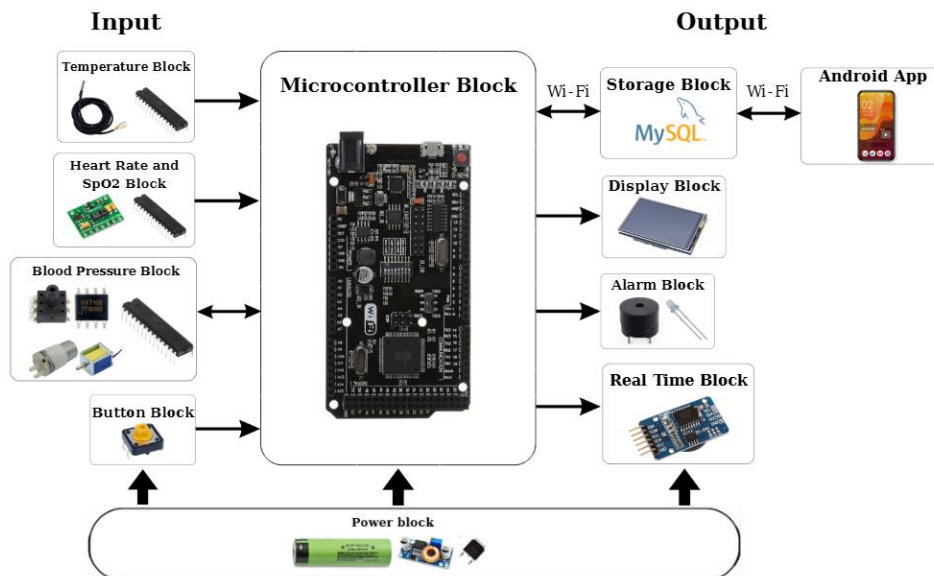


Figure 1. Block diagram of patient monitor

The hardware components will be connected according to the design illustrated in **Figure 1** using the aforementioned materials. Following this, during the software design phase, the Arduino IDE will be utilized to upload the program to the microcontroller, and Android Studio will be employed to create the display interface on the smartphone. The collected data will be stored on phpMyAdmin and monitored through the mobile application. Next, we will verify that the connected device is working correctly and performing as expected. During testing, we will calibrate and process the sensor data appropriately. The final results will be compared to medical measurement devices such as digital thermometers, pulse oximeters, digital blood pressure monitors, and patient monitors as shown in **Figure S1**. Finally, we will collect data and analyze the results to evaluate the overall performance of the system. The data will be calculated using the following equation:

$$\text{Relative Error} = \frac{|\text{Measured Value} - \text{Actual Value}|}{\text{Actual Value}} \times 100\% \quad (1)$$

Based on the relative error calculation, the accuracy value will be computed using the following equation:

$$\text{Accuracy} = 100\% - \text{Relative Error} \tag{2}$$

Additionally, to evaluate the degree of variability in the measured values, we need to calculate the standard deviation using the equation 3, where n is the number of test samples. The final results are compiled, analyzed, and conclusions regarding the system's performance are drawn. The measured values are compared with medical standards to ensure feasibility and reliability.

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^n (\text{Measured Value} - \text{Mean Value})^2}{n}} \tag{3}$$

2.2. Hardware Design

The patient monitoring device's circuit board is designed as shown in **Figure S2**. This is the printed circuit board (PCB) after assembly, designed to integrate comprehensive health measurement and monitoring functions. The bottom of the board is the Arduino Mega Wi-Fi R3 microcontroller, which is responsible for signal processing and controlling the entire system. The top layout of the board is logically designed, with specialized areas for each function to optimize performance and ensure stable signal transmission between components.

2.3. Software Design

In the software programming part, Arduino IDE will be used to upload the program to the microcontroller. The algorithm diagram (**Figure 2**) shows the operation process of the health measurement and monitoring system. After the process of displaying and sending data is completed, the system returns to the end state, waiting to perform the next cycle.

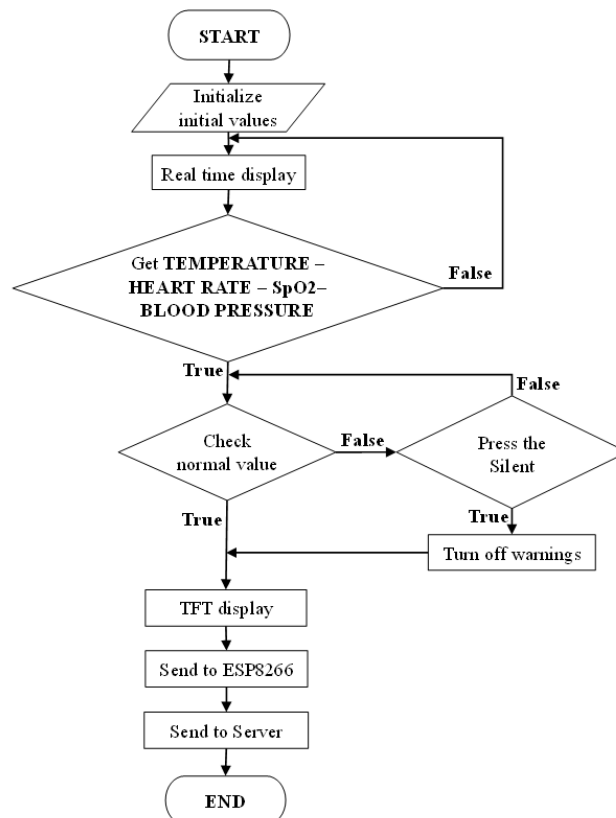


Figure 2. Flow chart of the main program

2.4. Android App Design

To create an application on the phone, we use Android Studio software with Java programming language. Diagram **Figure 3** describes the functions to be programmed.

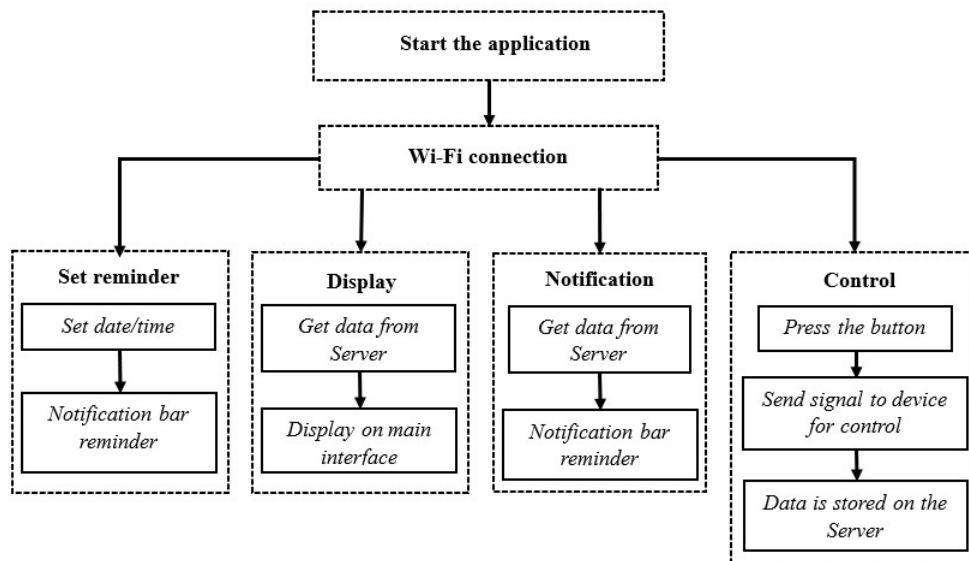


Figure 3. Summary diagram of the functions of the application on the phone

2.5. Local server

A server is a computer or a networked system that can run on one or more dedicated computers. It usually operates in a client-server model. In this system, the server acts as a local server because it runs on a personal computer through XAMPP. XAMPP includes:

Apache: This is a web server, handles HTTP requests and serves web content, such as the phpMyAdmin interface.

Database (MySQL/MariaDB): This is a database server, where data is stored and managed.

Localhost: Because this system operates on a computer, it is often called localhost.

The way the server works is described in **Figure 4**.

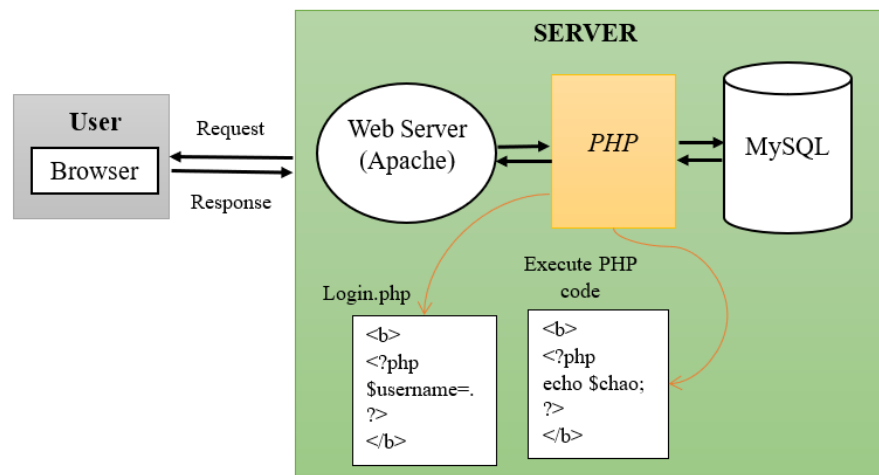


Figure 4. Principle of data transmission and reception

3. Results

In this section, we demonstrate the accuracy of the device through quantitative research. Data will be collected 600 times under different conditions and compared with data from commercial devices to determine the error of the device.

3.1. Blood pressure measurement results

For blood pressure measurements, data will be collected in a relaxed state and a state after chronic physical activity. Then, they will be compared with the results from the OMRON device (**Figure 5**).

Measurements will be taken on 10 individuals, each individual taking 5 measurements on the left arm and 5 times on the right arm, total of 200 test samples.



Figure 5. Compare blood pressure measurement results with OMRON machine

Table 1. Average blood pressure values of 10 students when measured by measuring device and OMRON in a relaxed state, resting both right and left arms

No.	Tester	Measuring Equipment		OMRON Machines	
		Left Hand (mmHg)	Right Hand (mmHg)	Left Hand (mmHg)	Right Hand (mmHg)
1	Student 1	95/58	95/59	96/55	95/56
2	Student 2	106/70	109/70	114/73	114/72
3	Student 3	107/68	108/68	108/62	111/66
4	Student 4	103/67	107/71	98/63	108/66
5	Student 5	100/67	105/67	99/60	101/62
6	Student 6	105/71	107/68	112/69	112/69
7	Student 7	106/68	107/68	107/68	110/72
8	Student 8	105/70	106/67	107/70	108/69
9	Student 9	104/64	104/68	106/64	106/65
10	Student 10	105/68	106/69	106/67	107/68

Table 1 illustrates that blood pressure measurements obtained from the OMRON blood pressure monitor tend to be slightly higher than those from the developed device, with discrepancies of approximately ± 8 mmHg for systolic pressure and ± 3 mmHg for diastolic pressure. Additionally, blood pressure in the left arm consistently tends to be lower than in the right arm, with variations ranging from 1 to 4 mmHg. The reason for this discrepancy is that the arterial system in the right arm originates from the brachial artery trunk, a position closer to the heart, compared to the arterial system on the left side. Consequently, the pulse pressure is higher in the right arm's arterial system during heart contractions. This leads to higher blood pressure readings in the right arm compared to the left arm. **Table S1** shows that after exercise, blood pressure tends to increase compared to **Table 1**. Systolic blood pressure values range from 99 to 125 mmHg, while diastolic blood pressure values fluctuate between 56 and 76 mmHg. From the experiment tests in section 3.1 and **Table S2**, when compared with the OMRON blood pressure monitor, the relative error ranges from 0.3 % to 3.07 % at rest and tends to increase during intense

exercise, ranging from 1.9 % to 3.64 %. The Omron device is optimized with an error range of ± 3 mmHg and a measurement time of about 40 seconds. Meanwhile, our device has an error range of ± 5 mmHg and a measurement time of about 50 seconds. In the publication by George Stergiou, “A Universal Standard for the Validation of Blood Pressure Measuring Devices,” the standards for blood pressure monitors are discussed [11]. Based on the ANSI/AAMI SP10 accuracy standards, which specify a standard error of ± 5 mmHg and a standard deviation of ± 8 mmHg, the results presented in the section are entirely consistent with these standards.

3.2. Temperature measurement results

For temperature measurements, we will compare the results with those from an OMRON thermometer. Data will be collected under three conditions: in a normal environment, in a 20-degree temperature environment, and after physical activity. Measurements will be conducted on 10 individuals, with each person taking 5 measurements, resulting in a total of 150 experimental samples (Figure 6). Table S3 illustrates that the temperature values measured by the device and the OMRON thermometer are quite similar. With a small discrepancy of only 0.1 – 0.2 °C, this indicates that the device operates very stably with negligible error.



Figure 6. Compare blood pressure measurement results with OMRON machine

Table 2. Average temperature values of 10 students when measured by group equipment and OMRON thermometer at 20°C environmental condition

No.	Tester	Measuring device (°C)	OMRON Thermometer (°C)
1	Student 1	36.0	36.0
2	Student 2	36.1	36.0
3	Student 3	36.5	36.5
4	Student 4	36.1	36.1
5	Student 5	36.3	36.2
6	Student 6	36.3	36.3
7	Student 7	36.4	36.3
8	Student 8	36.3	36.2
9	Student 9	36.2	36.2
10	Student 10	36.3	36.2

Table 2 shows that after measuring temperature in an air-conditioned room at 20 °C, the values were almost all reduced by 1–2 °C. However, the values still closely align with those from the OMRON thermometer, without significant discrepancies. Additionally, they remain within the normal temperature range for a healthy individual. **Table S4** describes that temperature values slightly increase after exercise compared to the normal state. This is because, during physical activity, muscles work to

generate movement, and the body expends energy. This energy is converted into heat, causing the body's temperature to rise when exercising. Overall, the temperatures of all subjects remain fairly uniform with minimal fluctuations, differing by only 0.1 – 0.2 °C. **Table S5** indicates that in a normal environment, the average temperature is 36.77 °C. When measuring in a 20 °C air-conditioned environment, body temperature slightly decreases to 36.25 °C. Conversely, during physical activity and heat generation, the temperature rises above the normal level. This indicates that body temperature changes appropriately according to the environment, while also confirming that the device's temperature sensor operates stably, ensuring accuracy under different measurement conditions. Additionally, the standard deviation tends to decrease when measuring in a 20 °C environment and decreases further during intense exercise. This is because, in a cold environment, the body must adjust to maintain a stable temperature, resulting in a more uniform temperature distribution and reduced standard deviation. After exercise, the body rapidly adjusts temperature by sweating and enhancing blood circulation, making body temperature more uniform and reducing variability, or standard deviation. When compared with the OMRON thermometer, the relative error is low, ranging from 0.08 % to 0.14 %. This demonstrates that the device's temperature sensor is highly accurate and reliable for measuring body temperature.

3.3. Heart rate and SpO₂ measurement results

For heart rate and SpO₂ measurements, we will compare our device with the OMNI II Monitor (**Figure 7**). Data will be collected under various conditions, including resting, deep breathing, talking, movement, and intense exercise. A total of 150 experiments will be conducted with 10 participants, with each participant taking 5 measurements.



Figure 7. Heart rate and SpO₂ results compared with OMNI II

Table 3. Average heart rate and SpO₂ values of 10 students measured by measuring device and OMNI II machine in a relaxed, resting state

No.	Tester	SpO ₂ (%)		Heart rate (bpm)	
		Measuring Device	OMNI II	Measuring Device	OMNI II
1	Student 1	99	99	89	88
2	Student 2	98	98	80	82
3	Student 3	98	98	93	94
4	Student 4	98	98	80	81
5	Student 5	98	98	93	94
6	Student 6	98	98	86	87
7	Student 7	98	98	71	70

8	Student 8	98	98	87	87
9	Student 9	98	98	80	80
10	Student 10	99	99	88	88

Table 3 shows that the SpO₂ measurements from both devices are similar, with values ranging from 98 % to 99 %. For heart rate, there is a slight discrepancy of approximately 1 – 3 bpm. Both SpO₂ and heart rate indicators for all 10 individuals remained within normal ranges. The error between the two devices is very small, being less than 1 % for SpO₂ and less than 3 bpm for heart rate. **Table S6** indicates that with slight fluctuations, the SpO₂ values have a small discrepancy of around 1 – 2 %, which falls within the acceptable error margin. Regarding heart rate results, the heart rate ranges from 62 bpm to 92 bpm, reflecting changes in heart rate depending on the state. **Table S7** describes that after intense exercise, the heart rate increases significantly, ranging from 84 bpm to 128 bpm. For the SpO₂ index, after exercise, the measurements slightly decrease to approximately 95 – 97%, but quickly recover to 98 – 99%, equivalent to the resting state. **Table S8** indicates that the SpO₂ values consistently remain within the normal range, regardless of the measurement conditions. In both the resting state and after exercise, the standard deviation is zero, indicating that the body quickly returns to its initial state with minimal fluctuations. However, when measurements are taken while moving or talking, the signal exhibits higher variability and slight noise, leading to an increased standard deviation. Compared to the OMNI II device, the error across all three conditions remains relatively low, demonstrating that the group's device achieves a certain level of accuracy. In **Table S9**, we can see that the average heart rate at rest falls within the normal range for a healthy adult. However, after intense exercise, the heart rate increases significantly, and the absolute error abruptly rises to 9.5 beats per minute (bpm), reflecting a noticeable deviation from the reference values obtained from the OMRON device. This discrepancy may be due to factors such as rapid heart rate changes, sweating, vigorous movement, or the device struggling to accurately detect the pulse during intense physical activity. The relative error after exercise also increases significantly, reaching 9.21%, indicating that the device does not maintain stability under these conditions. In contrast, during the resting state, the heart rate is measured with high accuracy and stability, exhibiting low error levels. When the user is moving or talking, the average heart rate slightly decreases, variability increases, and the error rises, though it remains within acceptable limits. After intense exercise, the heart rate is elevated, but the measurement accuracy decreases, with both absolute and relative errors increasing markedly.




3.4. Measurement results of 4 parameters

Table S10 presents the results of 10 measurements for four health parameters: blood pressure (in mmHg), heart rate (in bpm), SpO₂ (in %), and temperature (in °C). Each measurement order (from 1 to 10) shows variations across the parameters. Blood pressure values range from 88/71 mmHg to 116/71 mmHg, indicating minor fluctuations. Heart rate values are between 81 bpm and 92 bpm, while SpO₂ remains consistent at 98% or 99%. Temperature measurements range from 36.5°C to 36.9°C, demonstrating stable body temperature readings. These results provide a comprehensive overview of the subject's physiological condition across multiple trials.

3.5. Data Storage Result on Server

The data collected from the sensors will be sent to and stored in a database in real time and managed through phpMyAdmin, as shown in **Figure S3**. This database stores data on blood pressure, temperature, heart rate and blood oxygen saturation from the sensors and then sends it to the application developed using Android Studio software [5].

3.6. Android Application Deployment Result

After deploying on the phone, the application after programming will include 3 interface tabs: display , history  and utilities  as shown in **Figure 8**. In the display tab interface, the parameters are continuously updated in real-time. When clicking on each parameter, the application provides a conclusion about the measured results corresponding to a color scale based on the classification table at the bottom of the screen, as shown in **Figure S4**. This classification table helps users easily reference

and understand the significance of each level. In the Utilities tab interface, there will be three main functions: Profile, Reminders, and Measurements. Each function plays an important role in managing and monitoring personal health, as illustrated in **Figure S5**.



Figure 8. Main interface tabs of the phone App: (a) Display tab; (b) History tab; (c) Utilities tab

For the Profile function, users can enter personal information such as full name, date of birth, gender, weight and height. Next is the Reminders function, which helps users set up a schedule to measure health parameters periodically. This helps users maintain the habit of checking their health on time, ensuring that they do not miss necessary monitoring times. Finally, the Measurements function allows users to control and perform remote measurements, specifically blood pressure measurement. The simple interface, with function buttons labeled "START", "STOP" and "SILENT", allows users to operate the device quickly and easily. Additionally, the application includes a Notification feature that alerts users to any unusual health signs. Notifications are sent directly to the phone's notification bar, enabling users to recognize issues immediately and take prompt action, as shown in **Figure S6**.

3.7. Equipment performance evaluation results

Table S11 shows the test results and evaluation of the usage time and full charge time of the multifunctional health monitoring and testing device. We can see that the usage time and charging time between the calculated value and the actual value have a negligible difference. Specifically, the battery time verified after use is 6.5 hours, higher than the calculated time of 6.2 hours. That shows that the battery has good performance, optimizing the device's energy. Also during the testing, the device was measured 500 times. And now, my device can still measure and operate with constant performance.

4. Discussion

The device's measurement results demonstrate high accuracy compared to reference devices. Specifically, the temperature and SpO₂ parameters align closely with those of established commercial devices. However, blood pressure and heart rate measurements show larger errors during intense physical activity. This discrepancy likely stems from the fact that the system's programming has not yet been fully optimized, as insufficient data have been collected for calibration. Furthermore, the data collection process is subject to environmental factors, such as temperature, lighting, and human interference. In addition, the device's compatibility with various real-world usage scenarios such as continuous operation or measurements taken from individuals with diverse physiological conditions (adults, children) is another aspect requiring further study. Improving device accuracy in these

specialized situations will be necessary as development continues. Some commercial products in the same field include OMRON, CONTEC PM50, Berry PM6100, etc. Our device clearly achieves good accuracy and combines information in one device. This combination reduces complexity for the user. Health parameters are read and stored on the internet, making the content accessible to doctors and patients. The application (app) deployed on smartphones increases the mobility of the system to suit the requirements of today's dynamic life. Second, some existing studies have built similar systems. However, the cost is high for some specialized fields, and the system analysis is not detailed enough or has only been successful in the laboratory [12]-[13]. Our research has brought the intelligent healthcare system very close to an actual commercial product.

5. Conclusions

This study has developed a device capable of measuring four parameters: blood pressure, temperature, heart rate, and blood oxygen saturation. We have performed programming, data collection, and data processing using filters, followed by calculations based on appropriate formulas, achieving error margins of ± 5 mmHg, ± 0.05 °C, ± 8 bpm, and $\pm 0.1\%$, respectively. All measurement results from the device are stored on a server and displayed on an Android application. The mobile application not only provides a monitoring interface but also supports various utility features such as entering basic user information, reviewing measurement history, setting measurement reminders, sending alerts to the phone, and remote control.

Acknowledgments

This work was supported by Ho Chi Minh City University of Technology and Education, Vietnam.

Conflict of Interest

The authors declare no conflict of interest.


Data Availability Statement

Supporting data includes **Figures S1–S6** and **Tables S1–S11** in **Supporting Information** (https://docs.google.com/document/d/1BThzUmCd_CRWsdCR1B1loS8_Q1wlYK6a/edit?tab=t.0).


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