DEVELOPING A MEDICAL DEVICE STRUCTURES THAT SUPPORT REMOTE MONITORING FOR CARDIOVASCULAR PATIENTS

Tran Thi Hien*, Dao Thi Hang, Pham Van Phi

Nam Dinh University of Technology Education, Nam Dinh, Vietnam

ARTICLE INFORMATION

Journal: *Vinh University Journal of Science Natural Sciences, Engineering and Technology*
p-ISSN*: 3030-4563*
e-ISSN: *3030-4180*

Volume: 53
Issue: 2A
****Correspondence:***
tthiena.spktnd@moet.edu.vn
Received: *24 January 2024*
Accepted: *25 March 2024*
Published: *20 June 2024*

Citation:
Tran Thi Hien, Dao Thi Hang, Pham Van Phi (2024). Developing a medical device structures that support remote monitoring for cardiovascular patients. ***Vinh Uni. J. Sci.*** *Vol. 53 (2A), pp. 24-36*
doi: 10.56824/vujs.2024a013

ABSTRACT

This article focuses on researching and developing a medical support device with functions to monitor various health parameters of patients directly or remotely, such as body temperature, heart rate, and blood oxygen saturation. The implementation method includes designing algorithm diagrams, hardware circuit design, component selection, and building a display application on smartphones or a website interface that allows monitoring the parameters quickly and accurately. Actual testing initially showed that, the device essentially operates quite accurately according to the design and programming with many advantages such as: The system operates stably, meeting design requirements; Results can be monitored visually in a variety of ways and conveniently on LCD screen, App, Web; Each measurement data is saved with data security assurance; The system is evaluated to have minimal errors, low power consumption, and is cost-effective, along with the convenience of result monitoring, making it suitable for various user groups. Furthermore, the research results can serve as a practical model for students in the Biomedical Engineering field at educational institutions where there is currently a shortage of devices catering to learning needs.

Keywords: Medical device; body temperature; heart rate; blood oxygen saturation; IoT.

1. Introduction

In today's era, the demand for medical support devices is becoming increasingly crucial, especially as the healthcare industry faces growing pressure from societal and technological advancements. These devices play a vital role not only in monitoring patients' health but also in providing accurate and timely information to healthcare professionals. Parameters such as body temperature, heart rate, and blood oxygen saturation are essential for monitoring the overall health status of individuals. Regular self-health monitoring has also become imperative, aiding in the early detection of adverse health signals. Tracking one's own body temperature, heart rate, and blood oxygen saturation helps in promptly identifying potential health issues. Additionally, monitoring these indicators contributes to physical training, enhancing human health. Alongside other metrics such as blood pressure, respiratory rate, blood sugar levels, etc., body temperature, heart rate, and blood oxygen saturation represent crucial indicators reflecting human health. The integration with the Internet of Things (IoT) has introduced new possibilities, providing flexibility in remote monitoring and automating the healthcare data collection process [1-3]. These devices not only alleviate pressure on the healthcare system but also offer convenience for patients and caregivers. The increasing convenience, accuracy, and synchronization of medical support devices make them an integral part of modern healthcare.

In the following are some remote heart monitoring devices currently available on the market:

+ Smartwatches and fitness trackers: Apple watch, Samsung Galaxy watch, Fitbit: These devices not only measure heart rate but also offer features such as activity tracking, sleep monitoring, and comprehensive health monitoring applications.

+ Mobile ECG monitors: AliveCor KardiaMobile: This is a mobile ECG device that can connect to a smartphone and provide accurate ECG data.

+ Blood pressure monitors with heart rate monitoring: Withings BPM Core: Measuring blood pressure and remote ECG, it also provides information about heart rate, aiding in the monitoring of heart health.

+ Heart rate monitoring patches: BioSticker by BioIntelliSense: These are small patches directly attached to the skin, providing continuous heart rate monitoring data and the ability to send information to healthcare devices remotely.

+ Online heart rate monitoring applications: Cardiogram - An application designed to monitor heart rate and provide analysis of heart health data.

+ EKG smart cases for mobile phones: KardiaCase - Some phone cases are designed to measure EKG and remotely monitor heart rate.

From existing market products or published research works, this study develops a similar device with several enhanced features. Notably, the device is significantly more cost-effective, consumes less power, and is easily maintainable and replaceable when necessary. Despite these advancements, it continues to meet the specified technical requirements. Furthermore, the research aims to create a simple yet meaningful practical model for Biomedical Engineering students at institutions where practical experimentation equipment is scarce. With such objectives, the research product must ensure compliance with problem-solving requirements, such as designing a wireless monitoring system for body temperature, heart rate, and blood oxygen saturation. The system must address the following needs [4-10]:

• Measure and display the specified patient parameters.

• Wireless communication of measurement results for accessible recording conveniently and visually.

• Low-cost system design.

• Simple and understandable programming language with high expandability.

• Stable and accurate system operation.

• Flexibility in measurements for individual customization, considering age groups or general use for multiple individuals.

• Low power consumption.

• Ease of operation.

2. Some parameters to monitor the patient's overall health status

Common factors related to the health status of patients include:

2.1. Body temperature

Body temperature: is the temperature of the human body. Body temperature varies depending on different areas (Table 1) [2]. In normal individuals, body temperature remains stable at 37°C and does not fluctuate more than 0.5°C (37°C is the temperature measured orally, slightly lower in the armpit, and slightly higher in the rectum).

Table 1: *Normal body temperature at different measuring locations*

Temperature (°C)	0-2 years old	3-10 years old	11-65 years old	>65 years old
Oral measurement	36.4-38.0°C	35.5-37.5°C	36.4-37.5°C	35.7-36.9°C
Rectal measurement	36.6-38.0°C	36.6-38.0°C	37.0-38.1°C	36.2-37.3°C
Axillary measurement	34.7-37.3°C	35.8-36.7°C	35.2-36.8°C	35.5-36.3°C
Ear measurement	36.4-37.7°C	36.1-37.7°C	35.8-37.6°C	35.7-37.5°C
Core body temperature	36.4-37.7°C	36.4-37.7°C	36.8-37.8°C	35.8-37.1°C

2.2. Theoretical basis of heart rate signal

Heart rate is defined as the number of heartbeats per minute, significantly impacting human health. The body's heart rate provides valuable insights into a person's health status. Ideal heart rate standards for each age group are as follows [3]:

- Infants: 120-160 beats per minute.
- Children aged 1 month to 12 months: 80-140 beats per minute.
- Children aged 1 to 2 years: 80-130 beats per minute.
- Children aged 3 to 6 years: 75-120 beats per minute.
- Children aged 7 to 12 years: 75-110 beats per minute.
- Children aged 13 to 19 years: 60-100 beats per minute.
- Adults aged 20 and above: 60-100 beats per minute.
- Athletes: 40-60 beats per minute.

2.3. Blood oxygen saturation (SpO2)

SpO2 is the abbreviation for saturation of peripheral oxygen, also known as peripheral blood oxygen saturation. This index is measured through the skin using a SpO2 sensor clipped to the fingertip, toe, or earlobe. Specifically, it represents the percentage of oxygenated hemoglobin (Hemoglobin containing oxygen) compared to the total hemoglobin in the blood (both oxygenated and deoxygenated hemoglobin).

3. Implementation method

3.1. Block diagram construction and equipment selection

Through studying the actual situation, the following technological solutions have been proposed: The module that monitors the patient's body temperature, heart rate, and blood oxygen saturation is constructed with Arduino Nano control board, MAX30100 sensor (for heart rate measurement), and GY906 non-contact infrared temperature sensor (for body temperature measurement). The results are transmitted wirelessly using the

ESP8266 WiFi module and are simultaneously displayed on an LCD (Liquid crystal display) screen, a smartphone app, or a personal computer website. This measurement method does not affect blood circulation at the sensor placement, ensuring absolute safety in electrical measurements (using a non-contact measurement method) [4-9]. The monitoring device is visual, user-friendly, and accurate. The system consists of the following main components:

- Sensor device block*:* Includes sensors for measuring heart rate and blood oxygen saturation using the non-invasive Pulse Oxymeter method with the MAX30100 sensor. For temperature measurement, a non-contact infrared temperature sensor GY906 is chosen. This block's task is to collect body temperature, heart rate, and blood oxygen saturation signals from the patient and transfer them to the control unit.

- Central control block: This is a crucial part of the system responsible for processing signals received from the sensors and transmitting them to the display unit. The central control block used is the Arduino Nano control kit.

- Signal transmission block: Wireless communication technology has been used with the ESP8266 module. This block's task is to transmit measurement results to the user's app or website.

- Display block: Displays the measured values on the LCD screen and the user's app or website.

- Communication (Button) block: This block has the function of inputting information such as age, selecting measurement modes, etc., as per user requirements.

- Power block: Provides power for the entire system.

The block diagram of the system is shown in Figure 1.

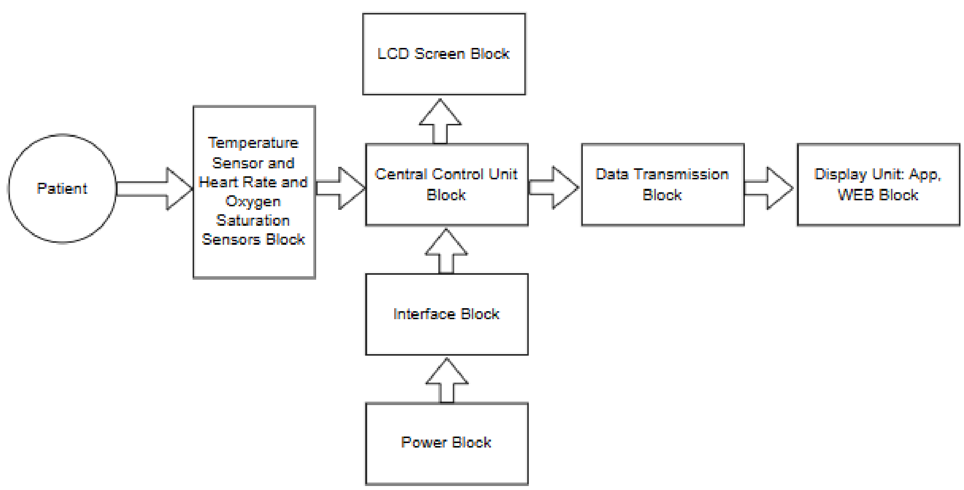

Figure 1: *Block diagram of the system*

As shown in Figure 1, the blocks are designed with logical and mutually supportive connections. The finished product will have a design and functionality similar to the created block diagram.

3.2. Construction of the hardware circuit diagram

The schematic diagram of the system is designed using the Proteus tool (a circuit design software developed by Labcenter Electronics) as illustrated in Figure 2.

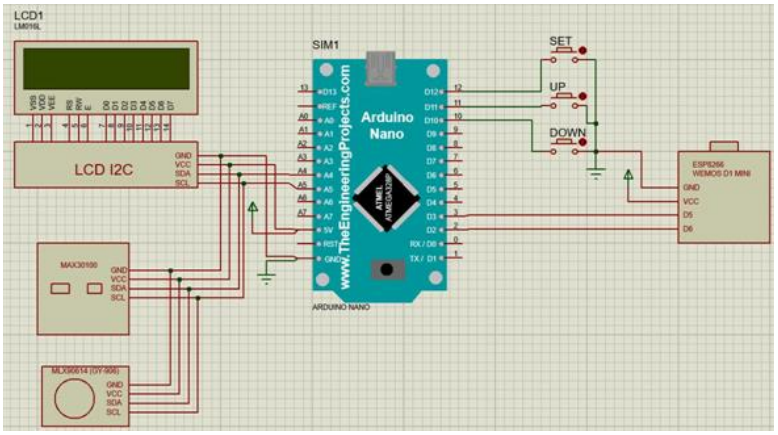

Figure 2: *System hardware circuit diagram*

3.3. System control program design

To operate the designed hardware circuit, a control program for the microcontroller needs to be built. The algorithm diagrams below, shown in Figures 3-6, are used in microcontroller programming [10-20]:

- Overall system algorithm flowchart:

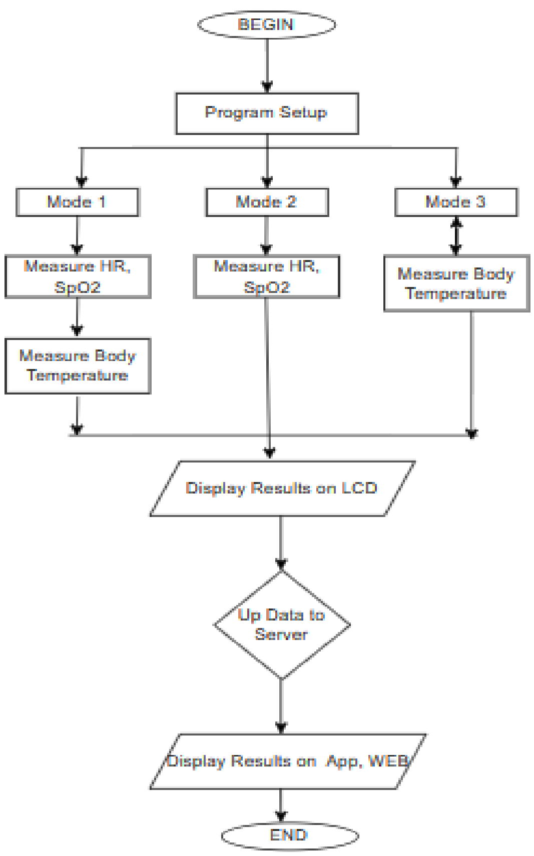

Figure 3: *Algorithm flowchart for heart rate measurement*

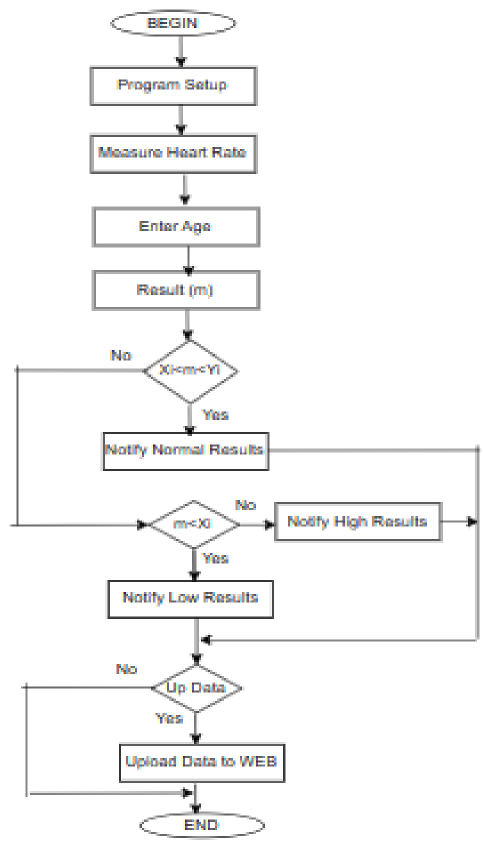

Figure 4: *Algorithm flowchart for blood oxygen saturation measurement*

- Other algorithm flowcharts:

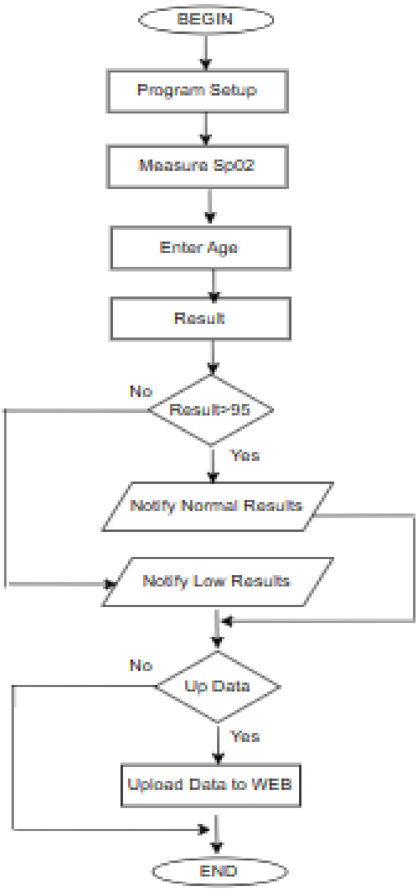

Figure 5: *Algorithm flowchart for temperature measurement*

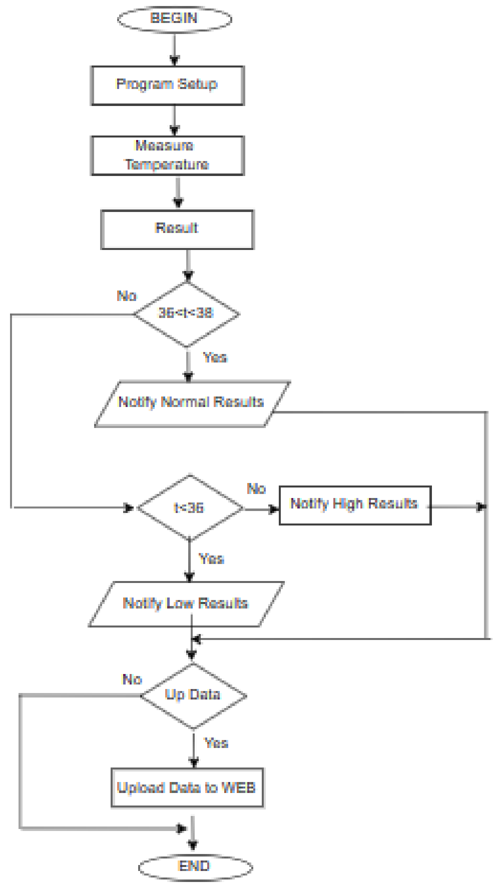

Figure 6: *Algorithm flowchart for temperature measurement*

The general algorithm flowchart provides a general overview of the device's operation. There are three set measurement modes: Mode 1 is used for measuring heart rate, SpO2, and temperature; Mode 2 is used for measuring heart rate and SpO2; Mode 3 is used for measuring temperature. These modes can be selected by using corresponding buttons on the device.

+ *Mode 1:* The device sequentially measures heart rate, SpO2 and then temperature. After receiving results from sensors and displaying them on the LCD, the user chooses to push data to the server or not by pressing the corresponding button (YES or NO). If the user chooses to push data to the server, the heart rate, SpO2, and temperature results are synchronized with the web, and the measurement program ends. If not, the program immediately terminates.

+ *Mode 2:* The device only measures heart rate and SpO2, with the operation process and steps similar to Mode 1.

+ *Mode 3:* The device only measures temperature, with the operation process and steps similar to Modes 1 and 2.

For the heart rate measurement algorithm flowchart, age-specific threshold limits were set for the sensor, so accurate age input is required for heart rate measurement. After receiving the returned heart rate result, the program compares it with the threshold limits set according to age (Xi - Yi). If the measured result falls within the normal range, the LCD displays a normal measurement result. If it is lower, it indicates a low heart rate, and vice versa for a high heart rate. The heart rate result is then either pushed to the server or not, based on the user's choice. The normal heart rate thresholds by age are presented in Table 2. Thus, for each age group, there will be a pair of threshold values for normal heart rate results. To accurately notify the device of the results, the correct age must be entered.

Table 2: *Normal heart rate thresholds by age*

i	Age	Heart rate threshold (beats per minute) (Xi-Yi)
1	<1	102-155
2	1	95-137
3	2-3	85-124
4	4-5	74-112
5	6-8	66-105
7	12-15	57-97
8	16-19	52-92
9	20-39	52-89
10	40-59	52-90
11	60-79	50-91
12	>80	51-94

For the SpO2 algorithm flowchart, a threshold was set for the sensor, and the normal SpO2 value is greater than 95%. Although the normal SpO2 value is independent of age, the algorithm still requires age input since SpO2 and heart rate are measured on the same sensor. After receiving the SpO2 value from the sensor, the program compares it with the 95% threshold. If the value is greater than or equal to 95%, the LCD will display a normal result; otherwise, it will indicate low blood oxygen saturation. The result is also sent to the server or not, depending on the user's choice by pressing a button.

For the temperature measurement algorithm flowchart, the temperature threshold for the sensor is set from 36^{o}C to 38^{o}C. After receiving the temperature value from the sensor, if it falls within the threshold, the LCD will display a normal result. If it is higher, it will indicate a fever, and if lower, it will indicate a low temperature. The temperature measurement algorithm is completely independent of age, so if the user selects mode 3 (only temperature measurement), age input is not required. After obtaining the temperature measurement result, it is also sent to the server if the user chooses to send data to the server.

When designing smartphone's application design, to meet practical needs, it is sufficient to build an application (App) that displays and stores results. In this study, the open-source platform Blynk is used. Figure 7 represents the interface of the monitoring software after construction. The three parameters at the latest measurement can be reviewed, historical data is tracked through graphs and the resulting file (Excel file) is extracted and sent to email.

Figure 7: *Monitoring app interface*

To monitor and store results via a website, ThingSpeak platform has been used to simplify the process while still meeting the project's requirements. The measurement results are monitored through visual charts, ensuring security. ThingSpeak is an open-source IoT application platform that uses APIs to store and access data uploaded from sensors using the HTTP protocol over the Internet or local networks (Figure 8).

Figure 8: *Simulating the result monitoring process using ThingSpeak*

All observable information from the sensors and connected devices will be collected by the microcontroller, then sent to the Internet via a wireless network (in this case, the ESP8266 module). This information sent will be stored on an available server (ThingSpeak), which can be accessed from anywhere by phones and computers to observe and monitor the parameters sent by the system. Figure 9 shows the monitoring results in this research.

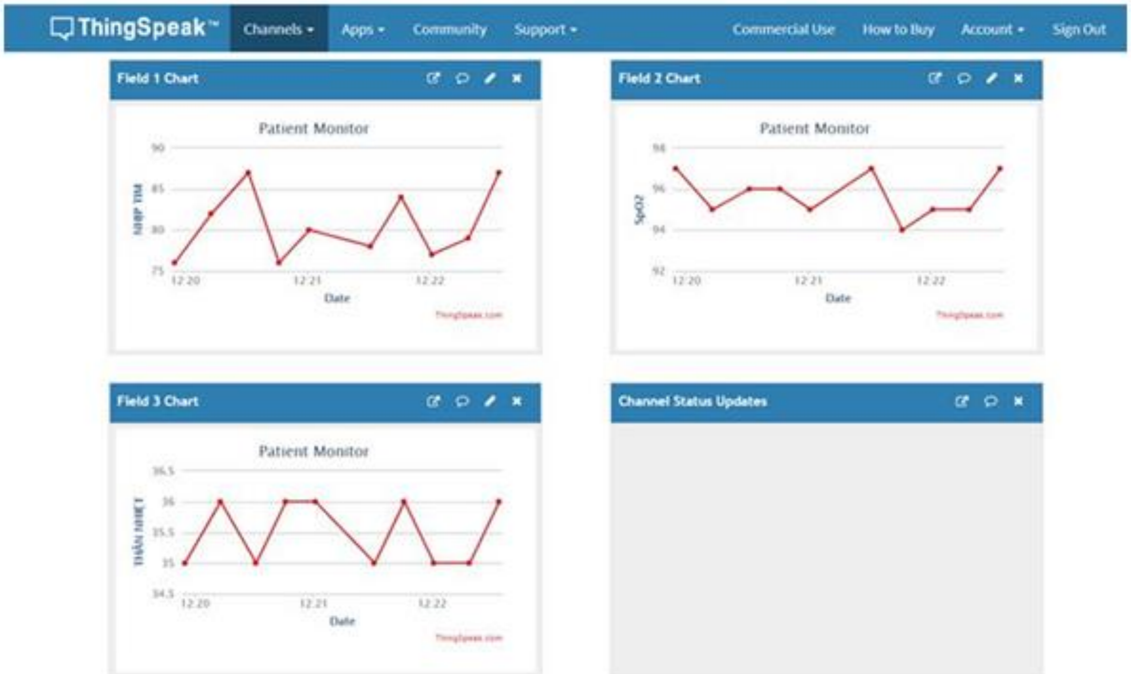

Figure 9: *Interface for monitoring the measurement results of body temperature, heart rate, and SpO2 via the web*

5. Results and discussions

In this study, a successful design of a wireless monitoring system for body temperature, heart rate, and blood oxygen saturation has been implemented. The system achieves the following functions:

● The device offers options to simultaneously measure body temperature, heart rate, and blood oxygen saturation or select a mode to measure each parameter individually.

● The device allows inputting the age of the subject to provide the most accurate result alerts based on different age groups.

● Results are visually displayed on the device's LCD screen, on a smartphone application, and on the web.

● Patients' measurement results can be monitored by doctors at any time with a computer or internet-connected phone.

● Although data is pushed to the web and the app, data security is ensured.

● Measurement results are stored in chart form, allowing for retrieval, analysis, evaluation of the measurement process, tracking the progress of treatment, or monitoring health trends reflected in the measurement history.

After powering on the device, the LCD will display the startup screen and prompt the user to choose measurement modes, including:

- Measurement Mode 1: This is the most comprehensive mode, measuring all parameters of heart rate, SpO2, and body temperature.

- Measurement Mode 2: Measures heart rate and SpO2.

- Measurement Mode 3: Measures body temperature.

Figure 10: *Notification screen for measurement mode selection*

Figure 11: *Placing finger on Max30100 sensor*

Figure 12: *Press 1 to choose mode 1*

Figure 13: *Measurement results of heart rate, SpO2*

To use the application on a smartphone or personal computer to monitor results on the website, users need to use the provided account and password to log in to the system. At that point, users can visually and easily view the parameters. After conducting experiments and calibrating the system, the initial results indicate that the device works stably and accurately. Factors that can cause errors, such as light interference, inaccurate measurements, environmental temperature, circuit board quality, sensor quality, and especially the body's conditions like movement or mental state, can affect heart rate, SpO2, and body temperature within a minute. These factors should be considered by users.

5. Conclusion

Based on the results obtained through multiple operational tests, the system's performance is assessed as follows: The system operates stably, meeting the requirements of the pre-designed and programmed functionalities. Visual and easy monitoring of results on the LCD screen, mobile app, and web interface is possible. Data is securely stored after each measurement. The system is evaluated to have minimal error, low power consumption, and acceptable cost. It is convenient for tracking results and suitable for a diverse user base. The completed device is simple, compact, aesthetically pleasing, user-friendly, easy to install, and equipped with all the necessary features. It competes effectively with other devices on the market. However, there is occasional measurement discrepancy due to objective factors. The manual, handcrafted assembly results in lower circuit quality. From these quantitative results, the product can be utilized as practical research models for students majoring in Biomedical Engineering and related fields in current educational institutions. Furthermore, for practical application, improvements or optimizations are needed to address the mentioned limitations.

REFERENCES

[1] R. Ahmad, "Development of Blood Oxygen Level, Heart Rate and Temperature Monitoring System by Using ESP32," *Conference: 2022 4th International Conference on Smart Sensors and Application (ICSSA)*, pp. 167-172, 2022. DOI: 10.1109/ICSSA54161.2022.9870943

[2] K. Boikanyo, "Remote patient monitoring systems: Applications, architecture, and challenges," *Information Technology and Engineering*, pp. 1-25, 2023. DOI: 10.1016/j.sciaf.2023.e01638

[3] M. Timothy, T. Sumegh, K. T. Pradeep et al., "Artificial Intel- ligence of Things-(AIoT-) based patient activity tracking sys- tem for remote patient monitoring," *Journal of Healthcare Engineering*, Article ID 8732213, pp. 15, 2022. DOI: 10.1155/2022/8732213

[4] K. Priyanka, K. T. Nitin, and K. Peerapong, "A real-time health monitoring system for remote cardiac patients using smart- phone and wearable sensors," *International Journal of Tele- medicine and Applications*, vol. 2015, Article ID 373474, pp. 1-11, 2015. DOI: 10.1155/2015/373474

[5] I. M. Sandeep and K. Sood, "Wearable IoT senssor based healthcare system for identifying and controlling chikungunya virus," *Science Direct: Computer in Industry*, vol. 91, pp. 33-44, 2017. DOI: 10.1016/j.compind.2017.05.006

[6] S. M. Sefa-Yeboah, K. Osei Annor, V. J. Koomson, F. K. Saalia, M. Steiner-Asiedu, and G. A. Mills, "Development of a mobile application platform for self-management of obesity using artificial intelligence techniques," *International Journal of Telemedicine and Applications*, vol. 2021, Article ID 6624057, pp. 1-16, 2021. DOI: 10.1155/2021/6624057

[7] K. K. H. Yamin and P. Indrajit, "Real-Time Remote Patient Monitoring and Alarming System for Noncommunicable Lifestyle Diseases," *International Journal of Telemedicine and Applications*, vol. 2023, Article ID 9965226, 1-13, 2023. DOI: 10.1155/2023/9965226

[8] C. P. Naveena and D. Rajappa, "Design and Development of Mobile Application for Wireless Patient Monitoring System," *Conference on Circuits and Systems in Digital*

Enterprise Technology (ICCSDET), pp. 1-5, 2018. DOI: 10.1109/ICCSDET.2018.8821089

[9] D. Yang and P. Zhu "SpO2 and Heart Rate Measurement with Wearable Watch Based on PPG," *IET International conference on image and signal processing (ICBISP2015*), 12(5) pp.14 - 19, 2015.

[10] A. Harbouche, "Model driven flexible design of a wireless body sensor network for health monitoring," *Computer Networks IEEE Transactions*, vol. 129, no. 5, pp. 548-571, 2017. DOI: 10.1016/j.comnet.2017.06.014

[11] D. Jarchi, Dario Salvi and D. A. Clifton, "Estimation of HRV and SpO2 from Wrist-Worn Commercial Sensors for Clinical Settings," *IEEE 15th International Conference on Wearable and Implantable Body Sensor Networks (BSN)*, vol. 15, no. 6, pp. 4-7, 2018. DOI: 10.1109/BSN.2018.8329679

[12] O. Y. Tham, "IoT Health Monitoring Device of Oxygen Saturation (SpO2) and Heart Rate Level," *Conference: 2020 1st International Conference on Information Technology, Advanced Mechanical and Electrical Engineering (ICITAMEE)*, pp. 128-133, 2020. DOI: 10.1109/ICITAMEE50454.2020.9398455

[13] M. Hassanalieragh and G. Mateos, "Health Monitoring and Management Using Internet-of-Things (IoT) Sensing with Cloud-based Processing: Opportunities and Challenges," *in 2015 IEEE International Conference on Services Computing*, pp. 285-292, 2015. DOI: 10.1109/SCC.2015.47

[14] M. S. Hossain and G. Muhammad, "Cloud-assisted Industrial Internet of Things (IIoT) - enabled framework for health monitoring," *Comput. Networks*, vol. 101, pp. 192-202, 2016. DOI: 10.1016/j.comnet.2016.01.009

[15] V. G. Bangera and V. Dhiman, "IOT based Smart Health Monitoring for Old Aged Patients," *Int. J. Recent Trends Eng. Res.*, vol. 3, no. 5, pp. 431-437, 2017. DOI: 10.23883/ijrter.2017.3246.uvyjc

[16]. L. H. Hiep and H. M. Viet, "Study to build a control and monitoring system of poultry incubator based on Internet of Things," *TNU Journal of Science and Technology*, vol. 227, no. 08, pp. 20-28, 2022.

[17] L. H. Hiep, "Research and building a voice-controlled environmental monitoring device using Internet of Things", *Vinh University Journal of Science (VUJS)*, vol 51, no. 2A, pp. 13-23, 2022. DOI: 10.56824/vujs.2022nt07

[18] L. H. Hiep, "Remote mobile patient's room control and monitoring system based on android platform," *TNU Journal of Science and Technology*, vol. 189, no. 13, pp. 15-21, 2018.

[19] L. H. Hiep, "Study to build a warning and monitoring system for smart home through mobile devices," *Vinh University Journal of Science (VUJS)*, vol 52, no. 2A/06-2023, pp. 34-45, 2023. DOI: 10.56824/vujs.2023a045

[20]. L. H. Hiep, "Study to build a goods arranging and classification system based on Internet of Things," *Vinh University Journal of Science (VUJS)*, vol 52, no. 3A/2023, pp. 72-83, 2023. DOI: 10.56824/vujs.2023a060

TÓM TẮT

NGHIÊN CỨU XÂY DỰNG THIẾT BỊ Y TẾ HỖ TRỢ THEO DÕI TỪ XA CHO BỆNH NHÂN TIM MẠCH

Trần Thị Hiền, Đào Thị Hằng, Phạm Văn Phi
Trường Đại học Sư phạm Kỹ thuật Nam Định, Việt Nam
Ngày nhận bài 24/01/2024, ngày nhận đăng 25/3/2024

Bài báo này tập trung nghiên cứu, xây dựng một thiết bị hỗ trợ y tế có các chức năng giúp theo dõi trực tiếp hoặc từ xa các thông số của người bệnh như thân nhiệt, nhịp tim, độ bão hòa Oxy trong máu. Phương pháp thực hiện bao gồm thiết kế sơ đồ thuật toán, thiết kế mạch phần cứng, lựa chọn linh kiện và xây dựng ứng dụng hiển thị trên điện thoại thông minh hoặc giao diện website cho phép người sử dụng có thể giám sát các thông số một cách nhanh chóng và chính xác. Sau khi tiến hành đo thử nghiệm trên thực tế bước đầu cho thấy về cơ bản thiết bị làm việc khá chính xác theo thiết kế và lập trình trước đó với nhiều ưu điểm: Hệ thống hoạt động ổn định đáp ứng theo yêu cầu thiết kế; Có thể theo dõi trực quan kết quả; Theo dõi kết quả đa dạng và thuận tiện trên màn hình LCD, App, Web; Dữ liệu mỗi lần đo được lưu và được bảo mật an toàn; Hệ thống được đánh giá là có sai số nhỏ, tiêu thụ ít điện năng; Với giá thành chấp nhận được cộng thêm tính thuận tiện của việc theo dõi kết quả, phù hợp với nhiều đối tượng sử dụng. Hơn nữa, kết quả của nghiên cứu có thể dùng làm mô hình thực hành cho sinh viên ngành Kỹ thuật Y sinh tại các đơn vị đang đào tạo lĩnh vực này, nơi hiện còn thiếu và rất ít thiết bị phục vụ cho nhu cầu học tập.

Từ khóa: Thiết bị y tế; thân nhiệt; nhịp tim; độ bão hòa Oxy trong máu; mạng kết nối vạn vật.