ICo SCIENCE: Journal Of Intelligent Computing And Advanced Data Science ***Origina Paper***
VOL 1 Issue 2 (2026)

Design of an IoT-Based Heart Rate and Room Temperature Monitoring System Using ESP32

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ABSTRACT

Introduction/Main Objectives: Continuous monitoring of heart rate and environmental conditions is essential for supporting remote healthcare services and real-time observation. This study aims to design and implement an Internet of Things (IoT)-based monitoring system using ESP32 for simultaneous monitoring of heart rate, room temperature, and humidity. **Background Problems:** Conventional monitoring systems generally require separate devices for physiological and environmental measurements and provide limited remote monitoring capabilities. Therefore, there is a need for an integrated, low-cost, and real-time IoT-based monitoring system. **Novelty:** The proposed system integrates a pulse heart rate sensor and a DHT11 temperature-humidity sensor into a single ESP32-based IoT platform. The system incorporates Wi-Fi communication, cloud-based visualization using the Blynk platform, and a finger-detection mechanism to minimize false heart rate readings caused by sensor noise. **Research Methods:** The system was developed using an ESP32 microcontroller, a pulse heart rate sensor, and a DHT11 sensor. Sensor data were acquired, processed, and transmitted through a Wi-Fi network to the Blynk cloud platform for real-time visualization. Experimental evaluation was conducted in a laboratory environment under three operating conditions: Danger, Normal, and Not Detected. **Finding/Results:** The experimental results demonstrate that the proposed system successfully monitored heart rate, room temperature, and humidity in real time. The system accurately classified monitoring conditions into Danger, Normal, and Not Detected states. Furthermore, the implemented finger-detection mechanism effectively prevented false heart rate measurements when no finger was placed on the sensor, while maintaining stable wireless communication and continuous cloud-based monitoring. **Conclusion:** The proposed ESP32-based IoT monitoring system provides a practical, low-cost, and reliable solution for integrated physiological and environmental monitoring. The successful implementation demonstrates the feasibility of using ESP32 as an IoT gateway for real-time health monitoring applications, particularly for educational purposes, laboratory experiments, remote monitoring, and prototype smart healthcare systems.

ARTICLE INFO

Keywords:
IoT, ESP32, Heart Rate Monitoring, Temperature Monitoring, Blynk

Histori:
Received: 26 June 2026
Accepted: 16 July 2026
Published: 25 July 2026

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1. INTRODUCTION

The Internet of Things (IoT) has emerged as one of the most influential technologies in modern healthcare systems. IoT enables physical devices equipped with sensors and communication modules to collect, process, and exchange data through the Internet. In healthcare applications, IoT technology facilitates continuous patient monitoring and supports healthcare providers in delivering more efficient medical services.

According to (Valsalan et al., 2020) , IoT-based healthcare systems can improve service quality by enabling accurate diagnosis, reducing unnecessary hospital visits, and providing continuous remote monitoring of patients. The integration of wearable devices and sensor networks allows healthcare professionals to monitor patients without requiring physical interaction.

Heart rate is one of the most important physiological parameters used to assess cardiovascular conditions. Abnormal heart rate patterns may indicate various health problems, including cardiac disorders and stress-related conditions. In addition, temperature is another critical health indicator that can be used to detect infections and other medical abnormalities.

(Wan et al., 2018) proposed the Wearable IoT-cloud-baSed hEalth monitoring system (WISE), which integrates wearable sensors, including heart rate, body temperature, and blood pressure sensors, for real-time health monitoring through cloud computing technology. Their study demonstrated the effectiveness of IoT-based wearable systems in supporting healthcare services.

Furthermore, (Woo et al., 2018) developed a reliable IoT architecture for Personal Healthcare Devices (PHDs) using the oneM2M standard. Their research focused on improving communication reliability and fault tolerance in healthcare monitoring systems.

Despite significant advancements in IoT healthcare applications, most existing studies focus on wearable healthcare devices and large-scale healthcare infrastructures. Limited studies have explored simple and low-cost healthcare monitoring systems based on ESP32 using heart rate and temperature sensors. Therefore, this study aims to design and implement a real-time heart rate and body temperature monitoring system using ESP32, Pulse Heart Rate Sensor, and DHT11 sensor.

The objective of this study is to develop and evaluate an IoT-based monitoring system capable of continuously measuring heart rate and body temperature while providing real-time data visualization through internet connectivity.

1. LITERATURE REVIEW

The rapid advancement of the Internet of Things (IoT) has significantly transformed healthcare services by enabling continuous monitoring of physiological and environmental parameters through interconnected smart devices. IoT-based healthcare systems facilitate remote patient monitoring, real-time data transmission, and early detection of health abnormalities, thereby improving healthcare accessibility and efficiency. According to (Valsalan et al., 2020), IoT-based monitoring systems enable continuous observation of heart rate, temperature, and environmental parameters while allowing remote access to patient information through internet-based platforms. Similarly, (Bhardwaj et al., 2022) demonstrated that IoT technology can support real-time monitoring of heart rate, temperature, blood pressure, and oxygen saturation with low measurement error and cloud-based storage capabilities.

Reliability and scalability remain important requirements for healthcare IoT systems. (Woo et al., 2018) proposed a oneM2M-based healthcare architecture capable of maintaining data reliability through fault-tolerant communication mechanisms. Likewise,(Krishnan et al., 2018) developed an IoT patient monitoring system that continuously tracks heart rate and temperature while generating alerts when abnormal conditions occur. These studies confirm that IoT technologies can improve healthcare monitoring by providing timely and accessible patient information.

The growing adoption of wearable technologies has further accelerated the development of healthcare IoT applications. (Wan et al., 2018) introduced the Wearable IoT-cloud-baSed hEalth monitoring system (WISE), integrating heartbeat, body temperature, and blood pressure sensors into a cloud-based architecture. Similarly,(Kajornkasirat et al., 2025) combined wearable devices, artificial intelligence, databases, and visualization platforms to enhance infectious disease monitoring and healthcare decision-making. These findings demonstrate that wearable sensing technologies play a significant role in supporting real-time healthcare monitoring.

Recent research has increasingly incorporated intelligent technologies to enhance IoT healthcare systems. (Singh, 2025) explored the integration of Artificial Intelligence (AI) and Machine Learning (ML) into wearable IoT systems for cardiovascular monitoring and anomaly detection. Likewise, (Kajornkasirat et al., 2025) employed Random Forest, Support Vector Machine, and Multilayer Perceptron algorithms to classify patient conditions based on collected sensor data. The importance of AI-driven healthcare is also emphasized by (Alsabah et al., 2025), who identified AI as a key enabling technology for future smart healthcare systems.

Security and privacy remain major concerns in healthcare applications involving sensitive patient information. To address these challenges, (Ali et al., 2025) proposed a Blockchain-Enabled Federated Learning framework that combines blockchain, homomorphic encryption, and federated learning to secure Electronic Health Records (EHRs). Similarly, (Malik & Parihar, 2026) reviewed Blockchain-IoT healthcare architectures and highlighted their potential in improving data integrity, privacy, and trust in healthcare monitoring systems. These studies indicate that secure data management will remain an important aspect of future healthcare IoT deployments.

Communication efficiency and energy management are also critical factors influencing IoT system performance. (Hudda & Haribabu, 2025) investigated secure and energy-efficient communication mechanisms for Wireless Sensor Network (WSN)-based IoT environments, while (Almudayni et al., 2025) identified key factors affecting IoT energy consumption and proposed optimization strategies using lightweight communication protocols such as MQTT and CoAP. These findings are particularly relevant for embedded IoT devices such as ESP32, which operate under limited power and computational resources.

The effectiveness of IoT systems is also influenced by supporting communication technologies and hardware infrastructure. (Jain et al., 2025) demonstrated how machine learning techniques can optimize antenna design for next-generation IoT communication systems, improving wireless connectivity and transmission performance. Meanwhile, (Washizaki et al., 2020) highlighted the importance of IoT architecture and design patterns in developing scalable, maintainable, and interoperable IoT solutions across various domains, including healthcare.

Several review studies have provided comprehensive perspectives on IoT-based healthcare monitoring systems. (Rahaman et al., 2019) reviewed numerous smart healthcare monitoring designs and concluded that real-time monitoring remains one of the most significant IoT applications in healthcare. Similarly, (Alsabah et al., 2025) discussed emerging technologies supporting smart healthcare, while (Al-Azzam & Alazzam, 2019) emphasized the growing role of mobile healthcare and smart city infrastructure in enabling ubiquitous healthcare services. Furthermore, (Shalini, 2021) demonstrated the effectiveness of IoT-based patient monitoring systems that combine physiological sensors, GSM communication, and GPS technologies to support emergency response and patient tracking.

Research specifically focused on heart rate monitoring has also shown promising results. (Ali et al., 2025; Purbadewi et al., 2013) developed a real-time heart pulse monitoring system that transmits heart rate data to smartphones and computers through internet-based communication. The study demonstrated that low-cost sensor platforms can provide reliable and user-friendly heart rate monitoring solutions. In addition, environmental monitoring technologies can complement healthcare applications by providing contextual information. (Budi & Pramudya, 2017) developed a DHT11-based temperature and humidity monitoring system connected to a web platform, demonstrating that low-cost environmental sensors can provide acceptable measurement accuracy and support real-time data visualization.

Although social and behavioral aspects are not directly related to physiological monitoring, user acceptance remains important in technology adoption. (Wu & Horng, 2022) highlighted how user interaction and perceived support influence technology utilization within online environments. These findings suggest that usability and accessibility should also be considered when designing IoT-based monitoring systems.

Based on the reviewed literature, previous studies have extensively explored IoT healthcare monitoring systems incorporating wearable sensors, cloud computing, artificial intelligence, blockchain technology, wireless communication, and smart healthcare infrastructures. However, most existing solutions focus on complex multi-parameter healthcare systems involving body temperature, blood pressure, oxygen saturation, AI analytics, or advanced security mechanisms. Limited research specifically investigates a simple and low-cost IoT platform that integrates heart rate monitoring and room temperature monitoring using ESP32 and DHT11 sensors while maintaining real-time internet connectivity.

2. METHOD, DATA, AND ANALYSIS

2.1. Research Design

This study employed an experimental and prototype-based research design to develop an Internet of Things (IoT)-based monitoring system capable of measuring heart rate and room temperature in real time. The proposed system integrates a heart rate sensor, a DHT11 temperature sensor, and an ESP32 microcontroller as the primary processing and communication unit. The system was designed to collect physiological and environmental data, process the acquired information, and transmit the results through a Wi-Fi network to an IoT monitoring platform.

The selection of ESP32 was motivated by its built-in Wi-Fi capability, low power consumption, low cost, and suitability for IoT applications. The DHT11 sensor was selected due to its simplicity and capability to measure room temperature in real time, while the heart rate sensor was utilized to monitor the user's pulse rate.

2.2. Sampling and Research Context

The research was conducted in a laboratory environment to evaluate the functionality and performance of the proposed monitoring system. The unit of analysis in this study consists of sensor-generated data, including:

- Heart Rate (beats per minute/BPM)
- Room Temperature (°C)

The monitoring system was tested using volunteer subjects for heart rate measurements, while room temperature data were collected directly from the surrounding environment through the DHT11 sensor.

2.3. System Architecture

The proposed IoT-based monitoring system consists of a pulse sensor, a DHT11 sensor, an ESP32 microcontroller, a Wi-Fi network, and a Blynk cloud platform, as illustrated in Figure 1. The pulse sensor is used to measure the user's heart rate, while the DHT11 sensor is utilized to acquire room temperature and humidity data. Both sensors are connected to the ESP32, which functions as the main processing and communication unit.

After acquiring data from the sensors, the ESP32 processes the measured values and transmits them through a Wi-Fi network to the Blynk Cloud platform. The transmitted data are then visualized in real time on a smartphone or computer dashboard, allowing users to monitor heart rate, room temperature, and humidity remotely. In addition, the system can generate notifications when abnormal conditions are detected, such as heart rate values outside the normal range.

Figure 1 presents the overall architecture of the proposed monitoring system, showing the flow of data from the sensing layer to the end-user monitoring application. To realize this architecture, a hardware configuration was developed by integrating the pulse sensor and DHT11 sensor with the ESP32 microcontroller, as shown in Figure 2. The detailed wiring configuration between the sensors and the ESP32 is summarized in Table 1.

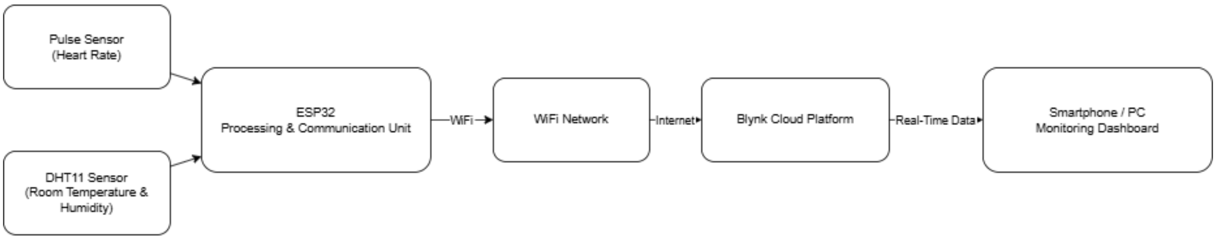

Figure 1. System Architecture of the Proposed IoT-Based Heart Rate and Room Temperature Monitoring System Using ESP32

Figure 2 illustrates the hardware implementation of the proposed system. The pulse sensor is connected to GPIO 34 of the ESP32 for heart rate measurement, while the DHT11 sensor is connected to GPIO 12 for room temperature and humidity monitoring. Both sensors are powered by the 3.3 V output of the ESP32 and share a common ground connection.

The ESP32 collects data from both sensors, processes the acquired measurements, and transmits the results to the Blynk cloud platform through its built-in Wi-Fi module. The monitoring data can then be accessed and visualized in real time through a smartphone or computer dashboard. This hardware configuration provides a simple, low-cost, and efficient solution for integrating physiological and environmental monitoring within a single IoT-based platform.

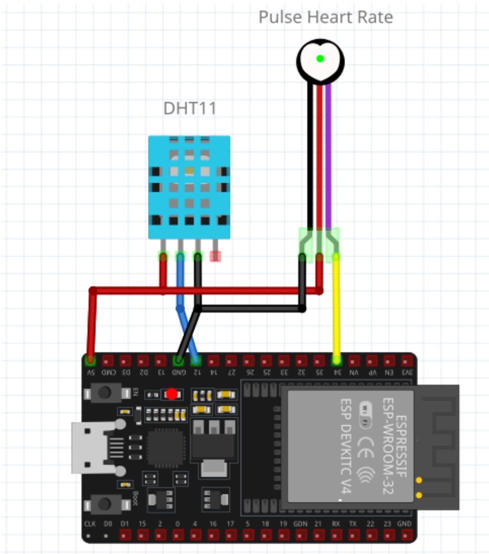

Figure 2. Hardware Circuit Design

Table 1. Hardware Wiring Configuration

No	Komponen	Pin Komponen	Pin ESP32	Keterangan
1	DHT11	VCC	3.3V	Catu daya sensor DHT11

2	DHT11	GND	GND	Ground
3	DHT11	DATA	GPIO 12	Input data suhu dan kelembapan
4	Pulse Sensor	VCC	3.3V	Catu daya sensor denyut jantung
5	Pulse Sensor	GND	GND	Ground
6	Pulse Sensor	SIGNAL	GPIO 34 (ADC)	Input sinyal analog denyut jantung
7	ESP32	Wi-Fi Internal	Router/Hotspot Wi-Fi	Komunikasi data ke Blynk Cloud
8	ESP32	USB Type-C/Micro USB	PC/Laptop	Pemrograman dan catu daya

The DHT11 sensor is connected to GPIO 12 of the ESP32 for temperature and humidity acquisition, whereas the pulse sensor output is connected to GPIO 34, which serves as an analog input pin for heart rate measurement. Both sensors are powered by the ESP32's 3.3V supply. The ESP32 utilizes its built-in Wi-Fi module to establish communication with the Blynk Cloud server, enabling real-time data transmission and monitoring.

The operational workflow of the system is illustrated in Figure 3. The process begins with the initialization of the ESP32, sensors, Wi-Fi connection, and Blynk platform. The system continuously acquires heart rate and environmental data, processes the sensor readings, transmits the data to the cloud platform, and displays the results on the monitoring dashboard. When abnormal heart rate or temperature conditions are detected, an alert notification is automatically generated and sent to the user.

Figure 3 illustrates the operational flow of the proposed IoT-based heart rate and room temperature monitoring system. The process begins with the initialization of the ESP32 microcontroller, DHT11 sensor, pulse sensor, Wi-Fi connection, and Blynk platform. Once the initialization process is completed, the system continuously reads data from the pulse sensor and DHT11 sensor.

The acquired sensor data are then processed by the ESP32 to calculate the heart rate value in beats per minute (BPM) and obtain room temperature and humidity measurements. After processing, the measured values are transmitted to the Blynk cloud platform through a Wi-Fi connection and displayed on the monitoring dashboard in real time.

The system subsequently evaluates whether the measured parameters are within the predefined normal range. If abnormal conditions are detected, such as a heart rate below 60 BPM or above 100 BPM, an alert notification is sent through the Blynk platform. Otherwise, the system continues normal monitoring operation.

Finally, the monitoring results are displayed on both the Blynk dashboard and the serial monitor. The entire process is repeated automatically every two seconds to ensure continuous real-time monitoring.

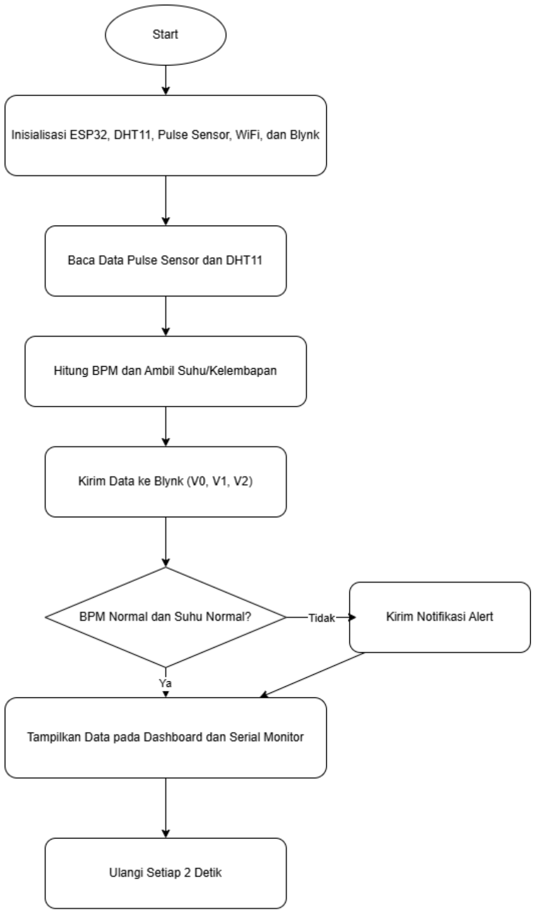

Figure 3. Flowchart of the Proposed Monitoring System

Figure 3 illustrates the operational flow of the proposed IoT-based heart rate and room temperature monitoring system. The process begins with the initialization of the ESP32 microcontroller, DHT11 sensor, pulse sensor, Wi-Fi connection, and Blynk platform. Once the initialization process is completed, the system continuously reads data from the pulse sensor and DHT11 sensor.

The acquired sensor data are then processed by the ESP32 to calculate the heart rate value in beats per minute (BPM) and obtain room temperature and humidity measurements. After processing, the measured values are transmitted to the Blynk cloud platform through a Wi-Fi connection and displayed on the monitoring dashboard in real time.

The system subsequently evaluates whether the measured parameters are within the predefined normal range. If abnormal conditions are detected, such as a heart rate below 60 BPM or above 100 BPM, an alert notification is sent through the Blynk platform. Otherwise, the system continues normal monitoring operation.

3. RESULT AND DISCUSSION

3.1. System Implementation

The proposed IoT-based monitoring system was successfully implemented using an ESP32 microcontroller integrated with a pulse heart rate sensor, a DHT11 temperature and humidity sensor, and the Blynk cloud platform. The ESP32 acts as the central processing unit responsible for acquiring sensor data, processing the measurements, and transmitting the information to the cloud through a Wi-Fi connection.

During the implementation stage, the pulse sensor continuously measured the user's heart rate, while the DHT11 sensor monitored the surrounding room temperature and humidity. The collected data were processed every two seconds and transmitted automatically to the Blynk cloud server for real-time visualization.

Figure 4 presents the monitoring dashboard displayed on a smartphone. The dashboard provides real-time visualization of heart rate, room temperature, and humidity, enabling users to remotely observe the monitored parameters. Furthermore, the system automatically generates notifications whenever abnormal heart rate values are detected.

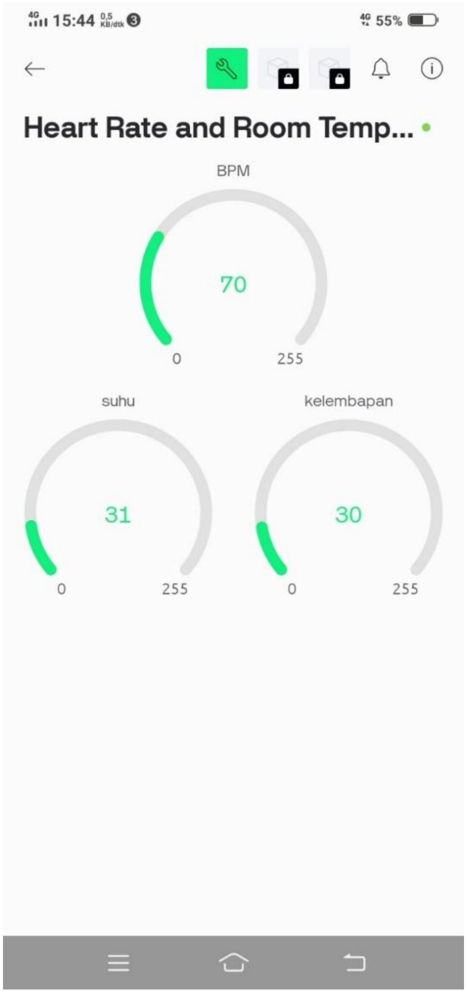

Figure 4. Real-Time Monitoring Results on the Blynk Dashboard

3.2. Experimental Results

To evaluate the proposed monitoring system, thirty experimental observations were conducted under three operating conditions: abnormal heart rate (Danger), normal heart rate (Normal), and no finger detection (Not Detected). The experimental results are summarized in Table 2.

Table 2. Experimental Results of the Pulse Heart Rate Sensor and Temperature-Humidity

Sample	Heart Rate (BPM)	Finger Detection	Room Temperature (°C)	Humidity (%)	System Status
1	156	Detected	31.9	33.9	Danger
2	179	Detected	31.9	33.7	Danger
3	174	Detected	31.9	33.4	Danger
4	163	Detected	31.9	33.1	Danger
5	159	Detected	32.0	32.6	Danger
6	192	Detected	31.9	32.3	Danger
7	227	Detected	31.9	32.0	Danger
8	209	Detected	32.0	31.6	Danger
9	222	Detected	31.9	31.5	Danger
10	197	Detected	32.0	31.1	Danger
11	86	Detected	32.0	31.7	Normal
12	74	Detected	31.9	32.0	Normal
13	66	Detected	31.9	32.2	Normal
14	72	Detected	32.0	32.2	Normal
15	96	Detected	31.9	32.4	Normal
16	82	Detected	31.9	32.1	Normal
17	78	Detected	32.0	32.0	Normal
18	75	Detected	31.9	32.2	Normal
19	88	Detected	32.0	32.3	Normal
20	91	Detected	31.9	32.1	Normal
21	--	Not Detected	32.0	32.3	Not Detected
22	--	Not Detected	31.9	32.3	Not Detected
23	--	Not Detected	31.9	32.2	Not Detected
24	--	Not Detected	32.0	32.1	Not Detected
25	--	Not Detected	31.9	32.2	Not Detected
26	--	Not Detected	32.0	32.1	Not Detected
27	--	Not Detected	31.9	32.2	Not Detected
28	--	Not Detected	31.9	32.3	Not Detected
29	--	Not Detected	32.0	32.2	Not Detected
30	--	Not Detected	31.9	32.3	Not Detected

Based on Table 2, the monitoring system successfully classified the acquired measurements into three operational states.

During the Danger condition (Samples 1–10), the measured heart rate ranged from 156 BPM to 227 BPM, exceeding the predefined normal threshold of 60–100 BPM. Consequently, the system generated warning notifications while continuing to transmit the environmental measurements.

For the Normal condition (Samples 11–20), the measured heart rate ranged from 66 BPM to 96 BPM, indicating that the user's physiological condition was within the normal range. The DHT11 sensor consistently recorded room temperatures between 31.9°C and 32.0°C and relative humidity between 31.7% and 32.4%.

During the Not Detected condition (Samples 21–30), the pulse sensor correctly identified the absence of finger contact and did not calculate a heart rate value. Instead, the system displayed "--" for the heart rate measurement while continuing to acquire and transmit room temperature and humidity data. This mechanism prevents false BPM values caused by electrical noise when the sensor is not being used.

3.3. Discussion

The experimental results demonstrate that the proposed IoT-based monitoring system is capable of simultaneously monitoring physiological and environmental parameters using a single ESP32 platform. The successful integration of the pulse sensor, DHT11 sensor, Wi-Fi communication, and the Blynk cloud platform enables continuous real-time monitoring through mobile devices.

The implementation of a finger-detection mechanism significantly improves measurement reliability by preventing invalid heart rate calculations when the sensor is not touched. This enhancement addresses one of the common limitations of low-cost optical pulse sensors, which are susceptible to ambient electrical noise. As a result, only valid measurements are transmitted to the cloud platform.

The room temperature and humidity measurements remained relatively stable throughout the experiment, indicating consistent performance of the DHT11 sensor under indoor laboratory conditions. Although the DHT11 sensor is not intended for medical body temperature measurement, it effectively provides environmental information that complements physiological monitoring.

Compared with previous IoT healthcare systems proposed by (Wan et al., 2018) and (Woo et al., 2018), which emphasize wearable and cloud-based healthcare architectures, the proposed system provides a simpler and lower-cost implementation suitable for educational purposes, laboratory experiments, and prototype healthcare monitoring. Similarly, the use of ESP32 with wireless communication supports the concept of remote patient monitoring discussed by (Rahaman et al., 2019) and (Valsalan et al., 2020)

The developed system also aligns with the smart healthcare concept described by (Al-Azzam & Alazzam, 2019)), where IoT technologies facilitate continuous monitoring and remote access to health information. In addition, the integration with the Blynk platform demonstrates the feasibility of cloud-based visualization, consistent with the findings reported by (Krishnan et al., 2018) and (Shalini, 2021) regarding real-time healthcare monitoring.

Although the prototype successfully demonstrates real-time monitoring capability, several limitations remain. The pulse sensor is sensitive to finger placement and motion artifacts, resulting in unstable readings during the initial acquisition period before stabilizing within the normal heart rate range. Furthermore, the DHT11 sensor measures room temperature rather than body temperature and provides lower accuracy compared with medical-grade temperature sensors. Future work may incorporate more accurate biomedical sensors, signal filtering techniques, and machine learning algorithms for anomaly detection, as suggested by recent studies in smart healthcare IoT systems.

4. CONCLUSION AND SUGGESTION

4.1. Conclussion

The proposed IoT-based monitoring system was successfully implemented using an ESP32 microcontroller, a pulse heart rate sensor, a DHT11 sensor, and the Blynk cloud platform. The system was evaluated in a laboratory environment to verify its ability to acquire physiological and environmental data, process the measurements, and transmit them wirelessly for real-time monitoring.

This study successfully designed and implemented an Internet of Things (IoT)-based monitoring system for heart rate and room temperature using an ESP32 microcontroller, a pulse heart rate sensor, a DHT11 sensor, and the Blynk cloud platform. The proposed system was capable of acquiring physiological and environmental data, processing the measurements, and transmitting them to the cloud via a Wi-Fi connection for real-time monitoring.

Experimental evaluation demonstrated that the system successfully classified monitoring conditions into three operational states: Danger, Normal, and Not Detected. The pulse sensor was able to detect heart rate values when a finger was properly placed on the sensor, while the implemented finger-detection mechanism effectively prevented false heart rate measurements caused by ambient electrical noise when no finger was detected. Meanwhile, the DHT11 sensor consistently measured room temperature and humidity, and the monitoring results were displayed in real time through both the ESP32 Serial Monitor and the Blynk mobile dashboard.

Overall, the proposed monitoring system provides a simple, low-cost, and practical IoT solution for integrating physiological and environmental monitoring into a single platform. The successful implementation demonstrates the feasibility of using ESP32 as an IoT gateway for real-time health monitoring applications, particularly for educational purposes, laboratory experiments, and prototype smart

4.2. Suggestion

Although the proposed system successfully demonstrates real-time monitoring capabilities, several improvements can be considered for future research.

First, the pulse sensor used in this study is susceptible to motion artifacts and electrical noise, which may affect measurement accuracy during the initial acquisition stage. Therefore, future studies should employ medical-grade heart rate sensors or pulse oximeter modules such as the MAX30102 to improve measurement precision.

Second, the DHT11 sensor measures room temperature rather than body temperature and has relatively limited accuracy. Replacing it with a contact or infrared body temperature sensor, such as the DS18B20 or MLX90614, would make the system more suitable for healthcare applications.

Third, signal processing techniques such as digital filtering and adaptive noise reduction can be incorporated to improve the stability of heart rate measurements. In addition, integrating machine learning algorithms for anomaly detection could enhance the system's capability to identify abnormal physiological conditions automatically.

Finally, future work may expand the proposed system by integrating additional biomedical sensors, such as blood oxygen saturation (SpO_2), electrocardiography (ECG), or blood pressure sensors, as well as implementing secure cloud communication using encryption or blockchain technologies to improve data privacy and support more comprehensive smart healthcare applications.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Department of Informatics, Universitas Satya Terra Bhinneka, for providing the facilities and support required to conduct this research. The authors also thank all volunteers who participated in the experimental testing and contributed to the evaluation of the proposed IoT-based monitoring system.

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