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Development and evaluation of an Iot-based wearable heart rate monitoring system

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Abstract

This study aims to develop and evaluate a cost-effective Internet of Things (IoT)-based heart rate monitoring armband that addresses the limitations of existing devices lacking wireless connectivity for real-time data transmission in dynamic and remote monitoring contexts. A mixed method approach was employed to assess device functionality, usability, and effectiveness. The armband utilized ESP32 NodeMCU microcontroller and Blynk mobile application platform for wireless transmission. Purposive sampling recruited volleyball players (n = 30) from Aklan Catholic College, Philippines. Following cardiologist validation, data were collected through structured surveys and semi-structured interviews across multiple activity levels (rest, walking, running). Quantitative analysis revealed excellent functionality (M = 3.41), usability (M = 3.43), and effectiveness (M = 3.43) on a 4-point Likert scale. The armband demonstrated reliable real-time heart rate detection across varying intensities: rest (M = 3.29), walking (M = 3.27), and running (M = 3.29). Qualitative feedback identified enhancement opportunities including strap comfort, battery longevity, sensor precision, and water resistance. The study was limited to a single institution and specific user demographic. The IoT-enabled armband represents a reliable, user-friendly, and economically viable solution for cardiovascular monitoring, with significant potential for remote patient monitoring systems and broader healthcare applications.

Keywords: *wearable technology, real-time monitoring, cardiovascular health, mobile health applications, ESP32 microcontroller*

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1. Introduction

Heart rate monitoring plays a crucial role in both medical and fitness contexts, as it is vital for gauging cardiovascular wellness. It is frequently used to evaluate a person's fitness level, track physical activity, and detect abnormalities in heart function (Hughes et al., 2023; Li et al., 2023). In clinical settings, heart rate monitoring assists in diagnosing certain medical conditions such as arrhythmias and other cardiac disorders (Bokhari et al., 2025; Staszak et al., 2023; Mastoi et al., 2024). In the fitness industry, trainers and athletes monitor heart rates to costumize training modalities, ensuring that individuals perform exercises at the target heart rate zones for optimal productivity (Gadja et al., 2023).

Athletes often exhibit a lower resting heart rate than the typical 60-100 beats per minute due to their superior cardiovascular fitness. However, during intense exercise, their heart rate can exceed 100 beats per minute, reflecting their body's ability to handle greater physical demands (D'Souza et al., 2014). This highlights the difference between average individuals and highly trained athletes. It is normal for an athlete's heart rate to increase above baseline as part of the body's natural response to exercise (Olshansky et al., 2022).

According to Al et al. (2023), heart rate is one of the various variables that the human body relies on to function effectively. Generally, measuring the heart rate through devices can offer valuable insights into a person's overall health condition. Cardiac arrests due to lack of access to essential medical devices are on the rise, especially in rural regions with severe lack of immediate medical attention. For residents in remote areas, the risk of suffering from advanced health problems increases because they are less likely to recognize the warning signs of a heart attack, given their limited access to healthcare technologies. Therefore, to reduce the occurrence of cardiac crises, regular education on heart monitoring is essential. There are existing heart rate-tracking tools, such as wrist-worn devices, which are also popular because of their real-time data feedback. However, these devices have drawbacks due to their limited functionality and inadequate data distribution (Li et al., 2023). These limitations highlight improvement solutions to enhance monitoring capabilities, guarantee data dependability and enable sharing of data easily with coaches, trainers, or healthcare providers.

Despite the growing number of studies on heart rate monitoring devices, the integration of real-time wireless data synchronization remains unexplored. The exploration of an IoT-based heart rate monitoring system using an armband addresses this gap by synchronizing real-time heart rate data via Wi-fi or mobile data. With the use of the suggested solution, this heart rate monitoring is made possible for coaches, trainers, and healthcare professionals to track health information without speaking with them directly (Alugubelli et al., 2024). Real-time transmission of heart rate data via the Blynk application provides faster responses to requests of users, improving overall efficiency, especially during workouts and other physical activity sessions (Jena et al., 2025; Amini Gougeh & Zilic, 2024). The use of Wi-Fi and mobile data enhances the prospects for future applications of the product, including remote consultation and continuous health monitoring, without the restrictions associated with wired or Bluetooth-only technologies.

This study aims to analyze and evaluate an IoT-based heart rate monitoring armband in terms of its functionality, usability, and overall effectiveness. It examines how well the device performs in monitoring heart rate, including its ease of use, ability to wirelessly transfer data to mobile devices, and capacity to provide real-time updates. The study also explores the wearability of the armband, the simplicity of its setup, and the user's interaction with its interface. In addition, the research determines the accuracy and reliability of the heart rate data collected, particularly during different physical activities. It investigates how quickly the device detects and registers changes in heart rate across various conditions such as resting, walking, and running, as well as how responsive it is to fluctuations during these activities. Furthermore, user feedback is gathered to better understand the perceived value, benefits, and overall user experience of the device.

2. Literature Review

2.1. Functionality of Heart Rate Monitoring Devices

Heart rate monitoring devices are tools designed to continuously track an individual's heart or pulse rate. Over time, these devices have become more compact, wearable, and precise, enabling individuals to monitor their cardiovascular health with ease. Their primary purpose is to provide real-time data on heart rate, serving as vital indicators of cardiovascular well-being and physical activity levels (Cleveland Clinic, 2022). In the medical field, these devices play an important role, particularly for patients requiring continuous cardiac observation (Chhabra & Sattar, 2023). To ensure accurate measurement, these devices often utilize electrocardiogram (ECG) sensors, which assist in detecting heart-related issues such as arrhythmias. In addition, recent developments have enabled remote monitoring of patients which is advantageous for the management of chronic illnesses as well as minimizing hospital attendance by facilitating proactive intervention through evaluations done remotely (Serrano et al., 2023).

Unlike traditional ways of monitoring heart rates, the modern methods of tracking one's physical activity have been revolutionized by wearable heart rate monitors. The overwhelming majority of these devices utilize the photoplethysmography (PPG) sensors that aid in tracking one's heart rate during the working out as well as during rest periods (Hughes et al., 2024). Wearable heart rate monitors became even more advanced with the integration of new technologies such as multi-sensor systems and machine learning (Gaoudam et al., 2025; Ghadi et al., 2025; Gu & Qian, 2025; Namazi et al., 2025). Many of these devices can now track sleep, detect stress, and even analyze variability in heart rates (Zambotti et al., 2020). While it is widely accepted that PPG-based wearables are not as accurate as sensors that are ECD-based, their affordability and ease of use makes them more accessible for daily activities. In spite of accuracy limitations, wearable heart rate monitors have truly changed when it comes to managing personal health.

Health-related wearable devices serve multiple functions. For instance, they can continuously monitor heart rates, physical activity levels, sleep cycles, and even blood oxygen levels. These features allow users to observe fluctuations in their health over time. The practicality of wearables lies in their ability to collect information continuously without requiring users to manually document it (Jafleh et al., 2024). Furthermore, many of these devices are integrated with visual feedback and goal setting functionalities that promote behavioral motivation and encourage healthier lifestyles. These user-friendly functions contribute significantly to the growing popularity of such devices.

Users have reported devices that track heart rates help them lower or rise to specific zones where heartbeats are best optimally to improve endurance as well as heart strength. Not all devices are effective because the amount of accuracy each device provides differs by how it is used and by what level of intensity is the activity. Strap type monitors for the chest provide a higher-level accuracy compared to those that are worn on the wrist (Marzano-Felisatti et al., 2024; Pasadyn et al., 2019). The wrist monitors tend to lose precision during activities that require a lot more physical movement. According to Worlanyo et al. (2023), the usability of wearable armband health devices, such as fitness trackers and smartwatches, for basic health tracking functions like heart rate monitoring and step counting is generally rated as good. However, factors such as accuracy, ergonomics, user-friendliness, battery longevity, and data display clarity may pose limitations depending on the users' skills and health conditions. Additionally, the use of wearable health devices positively influences the overall quality of success of healthcare service delivery (Moorthy et al., 2024).

Despite their clear benefits, there are still downsides to consider. For example, the accuracy of some metrics, particularly for blood pressure and glucose levels, remains questionable. Comfort and proper fit are major issues; as improper usage can render the devices ineffective. Some users find the technology too advanced and require some time to fully appreciate and understand its potential. Frequent charging is another inconvenience, and many users also struggle to interpret the health data provided by the device. While there are difficulties in usability, wearable health devices continue to have a significant positive impact on personal health (Kibuuka, 2024).

2.2. Effectiveness in Health Monitoring and Performance Tracking

Through personalization, real time updates, and holistic data insights, wearable devices offer diverse functionalities for health monitoring, especially within medical context. As stated by Luong (2024), wearable devices are crucial in health monitoring as they capture real-time heart rate and assist in the early detection of potential health issues. These devices can effectively monitor various bodily functions, such as heartbeats, blood pressure, and even glucose levels, making it easier to alert both users and medical professionals before a condition becomes critical. For instance, continuous glucose monitors (CGMS) have revolutionized diabetes management by providing real-time glucose level tracking, enabling users to administer insulin more accurately and manage their blood sugar levels more effectively. This approach not only enhances health outcomes of the patients but also reduces the risk of serious complications.

In addition to medical monitoring, wearable devices provide essential information into physical activity, sleep quality, and recovery. Users can work out within their target heart rate zones and monitor progress over time. These devices offer feedback on exercise intensity, recovery rate, and stress levels, allowing users to adjust their training regimens for better performance and reduced risk of injury (Shei et al., 2022). Thus, this approach promotes user engagement and motivation, thereby significantly improving their health.

2.3. Response Time Across Physical Activities (Resting, Walking, and Running)

The response time of wearable equipment greatly vary across different physical activities such as resting, walking and running due to different types of sensors, activity levels and external conditions. According to Damoun et al. (2024), wearable devices have been shown to have a high-level functionality and reliability when measuring physiological metrics such as heart rate and heart rate variability during resting states. Devices with electrocardiogram (ECG) sensors have up to milliseconds of delay, which can be sufficient for monitoring health (Hizem et al., 2025; Ehnesh et al., 2020; Bouzid et al., 2022). At the same time, those devices that use photoplethysmography (PPG) sensors may suffer some delays because of their signal processing algorithms. The rest period is characterized by stable conditions, and therefore, physiological tracking wearable devices have consistent and reliable readings, which renders them useful for following baseline health metrics.

In terms of response time for walking, the moderate movements associated with walking have a minimal effect on the response time of wearable sensors. Wearable devices have accelerometers and gyroscopes built within them, and these detect motion patterns and adapt measurements as appropriate. Research noted that wearables were reasonably precise in measuring walking pace, though there were some delays depending on the wearer's position, such as on the wrist or chest (Dunn et al., 2018; Sartor et al., 2018; Ho et al., 2022; Germini et al., 2022). Response time in recognition of arm or leg movements that occur though walking increases due to capturing movement noise resulting from external vibrations or vigorous arm motion while moving or walking in an upright position (Morouco, 2024).

Running increases the difficulties faced by wearable devices due to challenges such as high motion intensity and significant biomechanical variability (Van Hooren et al., 2020; Seifi et al., 2026; Kakhi et al., 2025; Giraldo-Pedroza et al., 2020; Chalitsios et al., 2024). Advanced wearables employing multi-sensor PPG systems. Response time in devices based on PPG sensors can be delayed due to motion from severe head or body movement (Baek & Kim, 2023). However, factors like variations in body movement and personal running styles continue to influence the precision of measurements such as heart rate and energy expenditure during high-intensity activities.

3. Methodology

3.1. Research Design

The study employed an experimental research design integrated with a mixed-methods approach to evaluate the efficiency of an IoT-based heart rate monitoring armband. According to Sirisilla (2022), an experimental research design is a framework of protocols and procedures developed to conduct scientific investigations using two sets of variables, the independent and the dependent variables. This approach allows researchers to manipulate the independent variable (the use of the IoT-based armband) and observe its effects on dependent variables such as heart rate reliability, response time, and user satisfaction.

This design was implemented by requiring participants to wear and use the device under controlled conditions involving different physical activities, specifically resting, walking, and running. This allowed the researchers to observe variations in heart rate detection and overall device performance across activity levels. During the experimentation phase, the device continuously recorded heart rate data, enabling the assessment of its real-time monitoring capability, responsiveness, and reliability. Standardized procedures were followed to ensure consistency in testing conditions and to maintain the validity of the results.

To ensure a comprehensive assessment, both quantitative and qualitative data were collected. Quantitative data included device-generated readings and participants' evaluations of functionality, usability, and effectiveness through structured survey questionnaires using a Likert scale. Qualitative data, on the other hand, were gathered through a structured interview guide with open-ended questions, allowing participants to describe their experiences in terms of convenience, comfort, and overall satisfaction after using the device. The integration of these methods enabled the researchers to triangulate findings, combining objective performance metrics with subjective user feedback, thereby providing a more in-depth evaluation of the device's technical performance and user acceptance.

3.2. Participants of the Study

The participants in this study were varsity volleyball players from Aklan Catholic College, particularly from the Basic Education Department. The sample consisted of 10 boys and 12 girls from Senior High School, and 8 players from Junior High School who participated during the intramurals (n = 30).

The study employed purposive sampling, a non-probability sampling technique in which participants are selected based on specific characteristics relevant to the research. These characteristics included being an active varsity or intramural volleyball player, being physically fit to engage in moderate- to high-intensity activities, having no known cardiovascular conditions, and being willing to wear and test the IoT-based heart rate monitoring armband during various physical activities.

According to Buchheit et al. (2010), sports that involve high-intensity exertion with recovery periods provide a valuable framework for monitoring and examining heart rate responses. Volleyball players are well-suited for this study, as the sport combines short bursts of high-intensity activity with intervals of rest throughout the game.

3.3. Device Development

The development of the heart rate monitoring armband required several essential hardware and software components that work together to ensure accurate data collection, processing, and display. The programming and firmware development were carried out using the Arduino IDE, which provided the environment for coding and uploading instructions to the ESP32 NodeMCU microcontroller. The ESP32 served as the main processing unit, responsible for receiving heart rate data from the MAX30102 pulse oximeter sensor, processing the information, displaying it on the OLED screen, and transmitting it wirelessly to an external device via Wi-Fi or mobile data.

To initially build and test the circuit, a breadboard was used along with male-to-male jumper wires, allowing flexible and solderless connections between components. Once the design was finalized, the components were assembled on a double-sided PCB prototype universal board to ensure a more stable and permanent configuration. The MAX30102 sensor, which operates using photoplethysmography (PPG), enabled the detection of heart rate by measuring light absorption through the skin, while the OLED display provided real-time visual feedback of the collected data.

For power management, the device utilized a 3.7V Li-ion battery housed in a battery holder, along with a Li-ion charger module to regulate and ensure safe charging. Charger wires and a power cord were used to facilitate the flow of electricity between components and allow external power input when necessary. A switch was also integrated to control the power supply, enabling the user to turn the device on or off conveniently.

Finally, the entire system was enclosed in an acrylic case to protect the internal components from physical damage and environmental exposure. To ensure usability and comfort, Velcro tape was attached, allowing the armband to be securely and adjustably fastened around the user's arm during use.

3.4. Setup Procedures

The development and setup of the IoT-based heart rate monitoring armband followed a systematic procedure to ensure proper functionality and reliability of the device. Initially, the Arduino IDE was prepared by configuring the ESP32 board through the Preferences menu and installing the necessary board package using the Boards Manager. Once configured, the ESP32 Dev Module was selected as the target board, and the microcontroller was connected to a computer via a USB cable to enable programming and data transfer.

To support the system's operation, the required libraries, such as Adafruit_GFX, Adafruit_SSD1306, Wire, MAX30105, heartRate, and BlynkSimpleEsp32, were installed to facilitate communication between the microcontroller, sensors, and display module. The MAX30102 pulse oximeter sensor was then connected to the ESP32 using a breadboard for initial prototyping, allowing the researchers to test and verify circuit connections without permanent assembly. Similarly, the OLED display was integrated to provide real-time visualization of the heart rate data.

Power components, including the Li-ion battery, charging module, and connecting wires, were assembled to ensure stable power supply throughout the system. After completing the circuit connections, the developed code was uploaded to the ESP32 NodeMCU to enable data acquisition, processing, and transmission. Once the system was confirmed to be functioning correctly, all components were soldered onto a universal prototype board to create a more durable and stable configuration.

Finally, the fully assembled device underwent functionality testing to evaluate its performance. A custom acrylic case was then fabricated to house and protect the internal components, and Velcro tape was attached to allow the armband to be securely and comfortably worn by the user during operation.

3.5. Instrumentation and Data Gathering Process

The study utilized a structured survey questionnaire and an interview guide as the primary instruments for data gathering. The survey questionnaire was designed to quantitatively assess the device in terms of functionality, usability, and effectiveness, using a Likert-scale format to capture participants' evaluations. In addition, a structured interview guide with open-ended questions was employed to gather qualitative insights, allowing participants to elaborate on their experiences, perceptions, and suggestions for improvement after using the IoT-based heart rate monitoring armband.

The data gathering process began with thorough preparation and title formulation, followed by the construction of the device prototype. Prior to field testing, the device underwent validation by a licensed cardiologist to ensure that it properly activated, functioned, and measured heart rate accurately. This validation confirmed the device's readiness for actual use, although it did not establish clinical-grade accuracy. Subsequently, the researchers secured the necessary approvals from the principal and sports coordinator of Aklan Catholic College, Basic Education Department.

Data collection was then conducted by distributing the survey questionnaires individually to the participants during their free time to avoid disruption of academic and training schedules. After using the device, participants completed the questionnaire to evaluate its performance. Furthermore, selected participants were engaged using the interview guide to provide more detailed feedback regarding their overall experience, perceived benefits, and recommendations, ensuring a comprehensive analysis of both quantitative and qualitative data.

A survey questionnaire was developed to assess three primary aspects: Functionality (15 questions), Usability (15 questions), and Effectiveness (10 questions). Additionally, sections focused on three activity states: Walking (5 questions), Running (4 questions), and Resting (5 questions). The survey used a 4-point Likert scale: 4 – Strongly Agree, 3 – Agree, 2 – Disagree, 1 – Strongly Disagree. Each activity state section included a question regarding detection time with response options: less than 5 seconds, 5-10 seconds, 11-20 seconds, and more than 20 seconds.

A structured interview guide was used to gather qualitative feedback about potential enhancements, recommendations and suggestions. Its primary role was to supplement the quantitative data by capturing participants' insights, experiences, and suggestions for improvement after using the IoT-based heart rate monitoring armband. The guide was administered after the testing phase, allowing respondents to reflect on their interaction with the device. The interview guide included an open-ended question which allows participants to elaborate on their ratings and discuss overall experience utilizing the product. Through this approach, the researchers were able to identify potential enhancements, user preferences, and practical recommendations, which contributed to a more comprehensive evaluation of the device's functionality, usability, and effectiveness.

3.6. Data Analysis

This study utilized a comprehensive range of statistical tools to gather the necessary data, allowing the researchers to assess the armband's functionality, usability, and effectiveness in real world applications.

Mean. Mean implies average, and it is the sum of set of data divided by the number of data points (Dudovskiyl, 2011). In this study, the mean was used to evaluate the levels of functionality, usability, and effectiveness of the IoT heart rate monitoring armband. To analyze the collected data, the researchers utilized the mean as a statistical measure of central tendency to compute the average rating for each criterion. Through this method, the researchers were able to interpret the participants' responses and assess the overall performance of the device across different physical activities.

Standard Deviation. A standard deviation is a measure of how dispersed the data is in relation to the mean. In this study, standard deviation was calculated to determine the consistency of the respondents' ratings for functionality, usability, effectiveness and detection activities from the mean. A lower standard deviation signified consistent performance, while a higher SD suggested variability in the device's readings.

Frequency. It refers to the number of times a particular value for a variable has been observed to occur. In this study, frequency was used to determine the number of users reporting specific detection times of the IoT-based heart rate monitoring armband during different activities. This measurement helped assess how quickly the device detected heart rate changes under varying conditions.

3.7. Research Ethics

Ethical consideration is an important part of the research process ensuring that the respondents are treated well and that their rights are reserved and protected (Mirza, 2023). The researchers provided a letter to the sports coordinator of the girls' and boys' volleyball teams at Aklan Catholic College, seeking formal consent for the athlete's participation.

A consent letter was given to the athletes, explaining the main purpose of the study and requesting their willingness to participate. Additionally, the letter expressed appreciation for their time and cooperation, as well as gratitude for their involvement in the research. This ensures respect for the athlete's decision to be part of the study.

As the study involved an IoT-based heart rate monitoring armband, which may be beneficial for athletes, their personal data will be protected under Republic Act No. 10173, also known as the Data Privacy Act of 2012. This law ensures that all responses and collected data will remain confidential and will not be shared with the public. Adhering to this regulation helps build trust between the researchers and the participants, with any misuse of information strictly prohibited. All collected information will be handled with full confidentiality in compliance with the Data Privacy Act.

4. Findings and Discussion

Table 1 displays the mean functionality level of the IoT-based heart rate monitoring armband (Mean = 3.41, SD = 0.38), which falls under the category of "excellent functionality."

Table 1

Functionality of the IoT-based heart rate monitoring armband

	Mean	**Standard Deviation**
Overall	3.41	0.38

This indicates that users generally found the IoT-based heart rate monitoring armband functional, with basic yet accessible features for heart rate tracking. This finding aligns with the study of Hughes et al. (2024), which discusses how wearable heart rate monitors using photoplethysmography (PPG) sensors contribute to heart rate monitoring. The research highlights that while these devices may not match the precision of medical-grade equipment, they remain functional for fitness tracking and health monitoring. Similarly, the IoT-based armband in this study provided users with a practical tool for monitoring heart rate.

Table 2 presents the mean usability level of the IoT-based armband for measuring the heart rate of the users (Mean = 3.43, SD = 0.33).

Table 2

Usability of the IoT-based heart rate monitoring armband

	Mean	Standard Deviation
Overall	3.43	0.33

The mean can be interpreted as "excellent usability," indicating that the armband is user-friendly. This means that users generally found the device easy to use and convenient for heart rate monitoring. This finding supports the study of Liang et al. (2018), which examined the usability of popular wearable fitness devices. This study showed that while different brands had varying usability scores, the overall user experience was a key factor in whether people continued using the devices. In the same way, the IoT-based armband in this study proved to be user-friendly, highlighting the importance of usability in encouraging people to adopt wearable health-monitoring technology.

The table 3 shows the mean effectiveness level of the IoT-based heart rate monitoring armband (Mean = 3.43, SD = 0.34).

Table 3

Effectiveness of the IoT-based heart rate monitoring armband

	Mean	Standard Deviation
Overall	3.43	0.34

This shows that the device is "highly effective" in evaluating the user's heart rates during various activities. As supported by the study of Kamati et al. (2024), which stated that the ESP32 NodeMCU and MAX30102 pulse oximeter sensor system successfully processed and displayed real-time heart rate data via the Terminal app on a smartphone. The proposed system reliably measures and transmits heart rate data, demonstrating strong performance in efficiency. The consistency of the displayed data, despite the absence of rigorous testing, suggests that the system is capable of providing reliable heart rate measurements under standard conditions.

Table 4

Detection Rates of IoT-based heart rate monitoring armband for various activities

	Mean	Standard Deviation
Overall	3.29	0.48

The physical activities in which the armband was used to evaluate the heart rate, as shown in Table 4, were walking, running, and resting. The mean detection rates for each of these various activities were measured. Running (Mean = 3.29, SD = 0.54) and resting (Mean = 3.29, SD = 0.48) had the highest mean detection rate, closely followed by walking (Mean = 3.27, SD = 0.57). Across all activities, the means can be interpreted as "very fast," that is, the IoT-based monitoring armband quickly detects the heart rate readings, updates smoothly, and remains stable during use. As supported by the study of Iqbal et al. (2020) physical activity is the movement of body produced by skeletal muscle contractions resulting in energy expenditure above the resting level.

Table 5 displays the frequency of responses from ACC male and female volleyball players regarding how quickly the IoT-based armband detects heart rate.

Table 5

Frequency of detection rate of the IoT-based heart rate monitoring armband for different activities

Variable	Less than 5 seconds	5 to 10 seconds	11 to 20 seconds	More than 20 seconds
Walking	6	12	0	4
Running	9	9	1	3
Resting	8	11	1	3

For all three activities, majority of the users reported that the armband monitored their heart within 5–10 seconds. Additionally, some users experienced a detection rate as quick as less than 5 seconds. Lastly, still for the three activities, around 15% - 20% of users reported that the detection time exceeded 20 seconds. As supported by the study of Qi et al., (2018), the sensor plays a key role in different activities, and the position only has only a limited influence on classification results. This suggests that the device performs consistently across different movements, providing timely feedback users. The overall performance demonstrates the armband's reliability and responsiveness for real-time heart rate monitoring.

Table 6 presents the summary of the interview responses according to the generated themes. Based from the responses of the participants, the generated themes include: (1) real-time heart rate monitoring; and (2) wireless connectivity and convenience. On the other hand, Table 7 presents the suggestions given by the participants to further improve the IoT-Based heart rate monitoring armband.

Table 6

Perceived benefits of the IoT-based heart rate monitoring armband

Themes	Descriptions	Illustrative Quotes
Real-time Heart Rate Monitoring	Respondents found the armband useful for tracking heart rate instantly during workouts through repeated measurements under controlled conditions.	*"Do pag monitor hay klaro pero dasig mag bag-o do resulta which ga pause imaw sa real-time sa aton nga heart-rate average." (The monitoring was clear, but the results change quickly, which causes our real-time heart rate average to pause.)* **Respondent 1**
Wireless Connectivity & Convenience	The Blynk app integration allows for remote monitoring, making it easier to track progress.	*"Astig ta nga pwede ma-check do akon nga heart-rate gamit sa daya nga app." (It's kind of cool that I can check my own heart rate using the application.)* **Respondent 3**

Table 7

Suggested improvements for the IoT-based heart rate monitoring armband

Themes	Descriptions	Illustrative Quotes
Real-time Heart Rate Monitoring	Respondents found the armband useful for tracking heart rate instantly during workouts through repeated measurements under controlled conditions.	*"Do pag monitor hay klaro pero dasig mag bag-o do resulta which ga pause imaw sa real-time sa aton nga heart-rate average." (The monitoring was clear, but the results change quickly, which causes our real-time heart rate average to pause.)* **Respondent 1**
Wireless Connectivity & Convenience	The Blynk app integration allows for remote monitoring, making it easier to track progress.	*"Astig ta nga pwede ma-check do akon nga heart-rate gamit sa daya nga app." (It's kind of cool that I can check my own heart rate using the application.)* **Respondent 3**
Fluctuations in Readings	Respondents noticed inconsistent heart rate readings, possibly due to sensor placement.	*"Kung amat pabago-bago pagbasa it heart rate, malisod man da pagkatiwalaan." (Sometimes the heart-rate ratings are inconsistent, it's hard to trust them.)* **Respondent 12**
Battery Life Concerns	Respondents suggested extending battery life for longer use.	*"Mas manami kung ga buhay do usage it baterya mga pila nga adlaw nga pag-exercise." (It would be better if the battery lasts for several days for exercise.)* **Respondent 9**
Resilience & Water Barrier	Respondents expressed a desire for the armband to be resistant to sweat and water, ensuring it remains durable and functional during exposure to moisture	*"Nahawag ako nga basi masamad pagkatapos it pila ka oras nga ginamit, lalo kung daya hay exposed sa hueas it aton nga eawas." (I am worried it might get damaged after a few hours of use, especially if it's exposed to sweat from our body.)* **Respondent 20**

5. Conclusion

This study successfully developed and evaluated an IoT-based heart rate monitoring armband, demonstrating high levels of functionality (M = 3.41), usability (M = 3.43), and effectiveness (M = 3.43). The device efficiently de tected heart rate changes across resting, walking, and running activities, with all conditions rated "very fast," confirming its responsiveness and adaptability to varying exercise intensities. These results validate the device's overall performance, as it effectively integrates the ESP32 NodeMCU, MAX30102 sensor, and Blynk platform to deliver reliable, real-time monitoring with wireless data transmission. User feedback further indicated strong acceptance, highlighting the device's practicality, accessibility, and value for fitness tracking and cardiovascular awareness, consistent with the Technology Acceptance Model. Consequently, the null hypothesis was rejected, establishing the device as efficient in terms of functionality, usability, and effectiveness.

The findings imply that the armband is a viable, low-cost solution for athletes, fitness enthusiasts, health-conscious individuals, and students, supporting real-time monitoring, remote coaching, and experiential learning in IoT-based health technologies. However, the study also identifies areas for refinement, including improving strap comfort, battery performance, sensor precision, and water resistance to enhance usability and durability. Future work should focus on validating accuracy against medical-grade devices, expanding participant diversity, examining environmental influences, and integrating additional sensors and intelligent features such as machine learning for personalized monitoring. Overall, the developed system provides a strong foundation for accessible, non-clinical health monitoring while offering clear directions for continuous improvement and broader application.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Institutional Review Board Statement

This study was conducted in accordance with the ethical guidelines established by Aklan Catholic College. Approval and clearance were obtained from Aklan Catholic College administration, the school principal, participating students (study respondents), and the faculty adviser prior to data collection.

AI Declaration

The author declares the use of Artificial Intelligence (AI) tools in the preparation of this paper. Specifically, Claude AI was used to assist with content development and clarification, Grammarly for grammar and style improvements, and QuillBot for paraphrasing and rephrasing. The author takes full responsibility for ensuring proper review and editing of all contents generated using AI.

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