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Bluetooth-Based Pulse Rate Detection and Monitoring System

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A B S T R A C T

Stethoscopes play an essential role in diagnosing various medical conditions, and hold a prominent place in the world of medical instruments. However, the chest piece and the connecting cable of the stethoscope are known to facilitate the transmission of pathogens from patient to patient and from patient to user. Healthcare-associated infections (HAIs) have proven to significantly cause mortality and morbidity in healthcare settings. The 2011 report by the Centres for Disease Control and Prevention (CDC) has estimated that 721,000 HAIs have occurred in acute care settings, with somewhere around 75,000 of these leading to mortality. With studies demonstrating that stethoscopes can be contaminated to a similar extent as hands, and a clear establishment of poor hand hygiene practices in both ICU (40-50%) and non-ICU (50-60%) settings, contamination and spread of pathogens has become unnoticeable and highly common and highlighted the suboptimal adherence to stethoscope hygiene protocols, thus demanding the need for a wireless form of the stethoscope. The digitisation of the pulse rate values could also be helpful in terms of detecting irregular abnormalities in patients that are only recognised for brief periods and at random intervals. A Bluetooth-based digital stethoscope would handle both of these issues, provide protection from contagious and/or dangerous pathogens, and quantify pulse rates. The Bluetooth-based pulse rate detection and monitoring system can be designed by integrating an ESP32 board with the uniquely written code such that a sensor can pick up the audio data from the pulse points of the human body and employ the necessary filtering techniques and display the final pulse rates on a device connected via Bluetooth.

Keywords: Stethoscope, Bluetooth, Pulse rate, Heartbeat rate, Wireless, Digital

1. Introduction

The emergence of technology has had a significant impact on the healthcare and personal well-being sector in recent years. The need for precise monitoring of vital signs in a timely manner has become essential for the detection of potential health issues, the prevention of them from occurring in the first place, and the provision of preventive healthcare services. One of the most important of these vital signs is pulse rate, which provides valuable information about the cardiovascular health and general well-being of an individual. Therefore, developing dependable and effective methods for detecting and monitoring pulse rate has become a major focus of research and development.

Manual palpation methods for the measurement of pulse rate are subjective, lengthy, and susceptible to errors. As a result, there is an increasing need for automated systems that are non-intrusive, user-friendly, and offer real-time monitoring of pulse rate. Additionally, the transmission and analysis of the collected data wirelessly is essential for the integration of the system into existing healthcare networks and remote monitoring systems.

In response to these challenges, this research paper presents a Bluetooth-based Pulse Rate Detection and Monitoring System that offers a convenient, non-invasive, and efficient approach for monitoring pulse rate in real-time. The system utilises an ESP32 development board, a piezoelectric sound sensor, and the Arduino IDE software to capture, process, and transmit the pulse rate data wirelessly.

The ESP32 board is equipped with a built-in Bluetooth capability and serves as the foundation for the development of the pulse rate monitoring solution. Its low power consumption, compatibility with a wide range of devices, and user-friendly programming via the Arduino IDE make it an ideal selection for this application. By positioning the piezoelectric sound sensor in the appropriate position to capture mechanical vibrations generated by the heartbeat, the non-invasive detection of pulse rate can be achieved without direct skin contact or the need for additional external devices.

The objective of the project is to develop a system that is not only capable of accurately measuring and monitoring pulse rate but also offers a smooth wireless data transmission using Bluetooth technology. Developing a portable and easy-to-use system will enable individuals to monitor their pulse rate over time, allowing them to make informed choices about their health and well-being. Healthcare professionals will be able to take advantage of the system's remote monitoring capabilities, data analysis capabilities, and the potential for early detection of abnormal or unusual pulse rate patterns.

By developing an innovative and reliable Bluetooth-based pulse rate monitoring system, this research aims to advance remote healthcare monitoring, enhance personal wellness practices, and facilitate early detection and intervention for improved cardiovascular health.

2. Basic Preliminaries

2.1 Pulse Rate Detection and Monitoring

Pulse rate, commonly referred to as the number of heart beats per minute, is a vital sign that provides valuable insights into an individual's cardiovascular health. It is an essential parameter for diagnosing various cardiovascular conditions, assessing physical fitness levels, and monitoring overall well-being. Accurate and timely measurement of pulse rate is crucial for effective healthcare management and preventive measures.

2.2 Bluetooth Technology

Bluetooth technology has emerged as a popular wireless communication protocol for short-range data transmission. With its low energy consumption, compatibility across various devices, and ease of implementation, Bluetooth has become an attractive solution for developing remote monitoring systems. Its ability to establish reliable and secure connections between different hardware components makes it well-suited for applications in healthcare and personal wellness.

2.3 ESP32 Board

The ESP32 development board is a versatile platform that integrates Wi-Fi and Bluetooth capabilities, making it suitable for a wide range of Internet of Things (IoT) applications. It offers robust processing power, ample memory, and a comprehensive set of peripherals, making it an ideal choice for developing the Bluetooth-based pulse rate detection and monitoring system. The ESP32 board's built-in Bluetooth functionality simplifies the integration process, allowing for seamless communication with other Bluetooth-enabled devices.

2.4 Piezoelectric Sound Sensor

The piezoelectric sound sensor is a key component of the pulse rate detection and monitoring system. This sensor converts mechanical vibrations, such as those produced by the heartbeat, into electrical signals. It offers a non-invasive and sensitive means of capturing the pulse signal, eliminating the need for direct skin contact or invasive methods. The piezoelectric sound sensor enables the system to accurately detect and analyse the subtle vibrations associated with each heartbeat.

2.5 Arduino IDE Software

The Arduino Integrated Development Environment (IDE) software provides a user-friendly platform for programming and developing firmware for the ESP32 board. Its intuitive interface, extensive library support, and community-driven development make it accessible even to individuals with limited programming experience. The Arduino IDE simplifies the implementation of pulse rate detection and monitoring algorithms, enabling efficient data processing and wireless transmission.

3. Related Works

3.1 Bluetooth-based Pulse Rate Monitoring Systems

Several studies and projects have explored the use of Bluetooth technology for pulse rate monitoring. Kumar et al. (2011) developed a Bluetooth-based wireless sensor system with a disposable sensor element and a reusable wearable wireless component which allowed pulse rate monitoring. Khan et al. (2020) presented a similar system using a Bluetooth board and heartbeat rate sensor unit for continuous pulse rate measurement. These works demonstrate the feasibility and potential of Bluetooth-based solutions for pulse rate monitoring applications.

3.2 ESP32 and Arduino-based Health Monitoring Devices

The ESP32 board and Arduino platform have been widely adopted for various health monitoring applications. For instance, Rahman et al. (2021) proposed an ESP32-based cloud server data transmission for remote electrocardiogram (ECG) and beats per minute (BPM) monitoring. Their system utilised Bluetooth for transmitting ECG and BPM data to Ubidots and Thingspeak platforms. Similarly, Mallick et al. (2016) developed an Arduino-based health monitoring system by incorporating the concept of photoplethysmography (PPG). These works highlight the versatility and effectiveness of ESP32 and Arduino platforms in health monitoring applications.

4. Literature Survey

4.1 Wireless Stethoscope

Malek et al. (2013) proposed a wireless stethoscope system with digital signal processing capabilities for heart sound analysis such that data logging was available. In their work, which dealt with the design and development of a wireless stethoscope by including a data logging function, they integrated wireless communication and advanced signal processing algorithms to identify abnormal heart sounds. Their system employed condenser microphones as sensors and a Zigbee Pro Series 1 wireless module, which sent the heartbeat wirelessly, contributing to the detection and monitoring of cardiovascular diseases.

4.2 Bluetooth Stethoscope

Lakhe et al. (2016) introduced a Bluetooth-enabled digital stethoscope that enabled the monitoring and analysis of heart sounds. Their study, which developed a digital stethoscope for telemedicine, involved integrating a Bluetooth condenser microphone into the stethoscope to transmit heart sound data wirelessly to a mobile device or computer for analysis. The system provided physicians with a convenient tool for auscultation in clinical settings, enhancing remote diagnosis and telemedicine capabilities.

4.3 ESP32 Pulse Rate Monitor

Divagar et al. (2022) proposed an ESP32-based pulse rate and ECG signal monitoring system. In their study, they were able to develop a way to remotely observe the pulse and ECG signal using ESP32. They depicted the development in the collection of heart rates based on the framework design of ESP32 and AD8232 modules. The heart rates were collected by utilising WiFi, Bluetooth, and Bluetooth minimum energy association.

4.4 Integration of ESP32 and Bluetooth Technology

Martínez-Suárez et al. (2022) proposed a long-term continuous ECG monitor with heart rate measurement in real-time using ESP32. This work presents an ambulatory ECG monitor for simultaneous acquisition and storage of DI, aVF, and V2 leads, and R wave detection using wavelet transform for heart rate measurement in real-time. The system has analog-to-digital converters and programmable gain amplifiers, ESP32 microcontroller, micro SD memory for data storage and thin-film transistor LCD. This system proves to be a huge advantage to the field of telemedicine and the analysis of the cardiovascular system is made accessible for long-term requirements.

5. Methodology

The Bluetooth-based pulse rate detection and monitoring system is designed to wirelessly monitor and analyse a person's pulse rate using an ESP32 microcontroller and a piezoelectric sensor. The system employs a high-sensitivity piezoelectric sensor that is placed in contact with the body, typically on a suitable arterial location such as the fingertip, the wrist, the earlobe or the heart. The piezoelectric sensor consists of a piezoelectric crystal that exhibits the piezoelectric effect, generating electrical charges in response to mechanical stress caused by the pulse. These electrical charges are then converted into analog voltage signals.

The analog signals from the piezoelectric sensor are connected to the input channels of the ESP32 microcontroller. The ESP32 microcontroller features a powerful processing unit and built-in analog-to-digital converters (ADCs) with configurable sampling rates. The ADCs convert the continuous analog signals into discrete digital values, enabling further digital signal processing.

To ensure accurate pulse rate detection, the acquired analog signals undergo a series of digital signal processing (DSP) techniques. The DSP algorithms include anti-aliasing filtering to remove high-frequency noise and artefacts, as well as low-pass filtering to extract the pulsatile components of the signal. Moreover, digital noise reduction techniques, such as adaptive filtering or wavelet denoising, are applied to mitigate unwanted interference and improve the signal-to-noise ratio.

Once the signal has been processed, pulse rate calculation is performed using specialised algorithms. One common approach is the peak detection algorithm, which measures the time intervals between successive peaks in the pulsatile signal. These time intervals correspond to the time between consecutive heartbeats and can be used to derive the pulse rate.

The ESP32 microcontroller integrates Bluetooth capabilities, allowing wireless communication with external devices. The pulse rate data, after being calculated, is transmitted over Bluetooth to a connected device, such as a smartphone or computer. The Bluetooth module on the ESP32 establishes a reliable and secure connection with the receiving device, facilitating data transfer with low latency. This entire process is represented diagrammatically in figure 1.

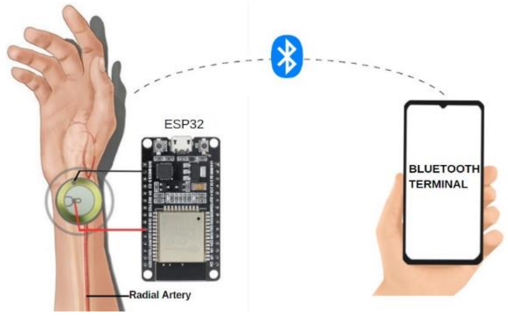

Fig. 1 - Bluetooth-enabled Pulse-Rate Transmission

The receiving device, equipped with a dedicated application or software, receives the pulse rate data and provides real-time visualisation and analysis. The application displays the pulse rate in beats per minute (BPM) on a graphical user interface (GUI), allowing users or healthcare professionals to monitor the pulse rate continuously.

6. Results and Discussion

The implemented Bluetooth-based pulse rate detection and monitoring system successfully measured and analysed the pulse rate wirelessly using an ESP32 microcontroller and a piezoelectric sensor. The system provided real-time readings of the pulse rate, which were displayed on the Serial Monitor and transmitted via Bluetooth to a connected device.

The Arduino IDE software and the provided code allowed for the integration of the hardware components and the development of the required functionalities. The system utilised the analog-to-digital converter (ADC) of the ESP32 microcontroller to convert the raw analog readings from the piezoelectric sensor into digital values. To improve the accuracy of pulse rate detection, the system implemented digital signal processing techniques, including filtering and noise reduction.

The pulse rate readings were captured and displayed in real-time on the Serial Monitor as shown in figure 2(a). Specifically, the system calculated the pulse rate value every 0.8 seconds, corresponding to the average time interval between consecutive heartbeats. This real-time monitoring feature allowed for immediate feedback on the user's pulse rate.

The Serial Plotter, a feature of the Arduino IDE, graphically represented the pulse rate readings over time and is shown in 2(b). This visual representation enabled a more intuitive understanding of pulse rate variations and trends.

a

b

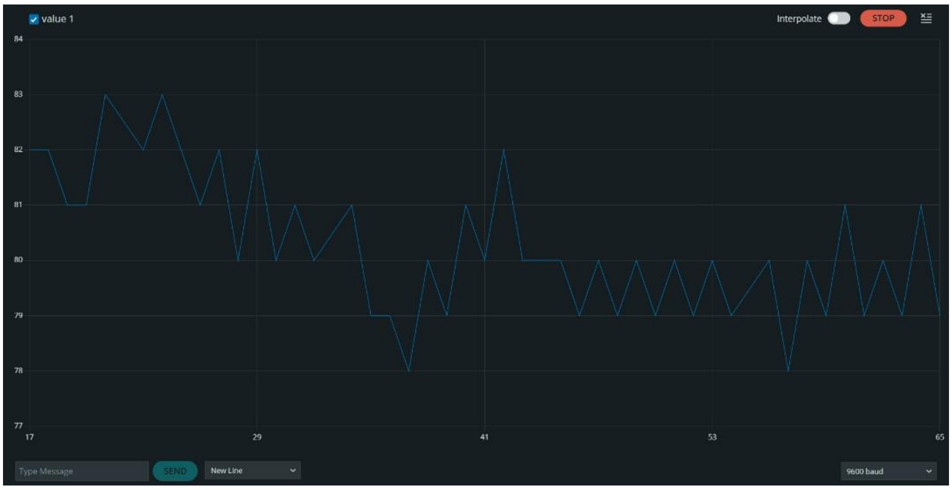

Fig. 2 – (a) Serial Monitor Output; (b) Serial Plotter Output

Figure 2 shows the outputs achieved through the establishment of a Bluetooth connection with the Bluetooth-enabled device and the designed stethoscope. These outputs specifically pertain to the software of the code and its features are used to display digitised and graphical readings in the code-containing device. The software Arduino IDE is used to make use of the Serial Monitor and Serial Plotter features. Figure 2(a) shows the output observed in the Serial Monitor of Arduino IDE Software when the code is uploaded to the ESP32 chip and the Bluetooth connection is established. Figure 2(b) shows the graphical representation of the readings gathered in the Serial Plotter of Arduino IDE Software.

Through the Bluetooth connectivity feature, the system wirelessly transmitted the specific pulse rate readings to a connected device, such as a smartphone or computer. This allowed for remote monitoring and analysis of the pulse rate data. This is conveyed in figure 3.

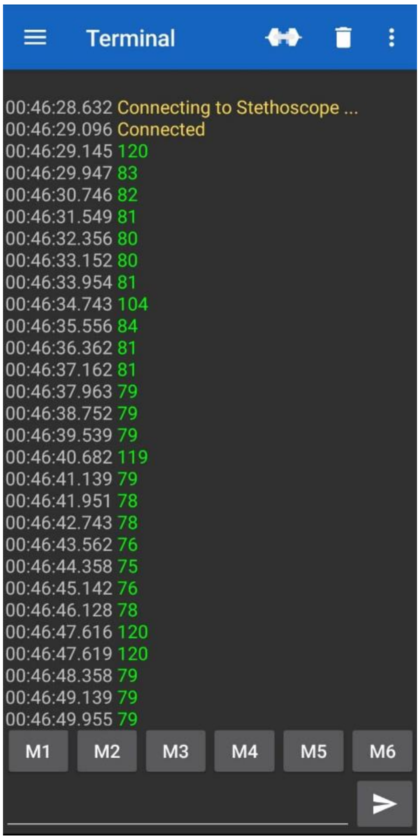

Fig. 3 – Bluetooth-equipped Device Output

Figure 3 is only available once an actual connection is made between a Bluetooth-enabled device and the device labelled ‘Stethoscope’ via the code. Ultimately, figure 2 is dependent on this connection as well, since based on the code, the stethoscope will only begin reading the heartbeats once there is a device selected to view the readings wirelessly.

The results of the study demonstrated the successful implementation and functionality of the Bluetooth-based pulse rate detection and monitoring system. The system accurately captured the mechanical vibrations caused by the pulse using the piezoelectric sensor. The ESP32 microcontroller processed the analog signals, applying digital signal processing techniques to enhance the accuracy and reliability of the pulse rate measurements.

The system's ability to wirelessly transmit the pulse rate data via Bluetooth offered flexibility and convenience. Users could access their pulse rate readings in real-time on their connected devices, enabling remote monitoring and analysis.

7. Conclusion

This project presented the design and implementation of a Bluetooth-based pulse rate detection and monitoring system using an ESP32 microcontroller and a piezoelectric sensor. The system successfully measured and analysed the pulse rate wirelessly, providing real-time readings and enabling remote monitoring and analysis.

The developed system showcased the capabilities of the Arduino IDE software in integrating hardware components and programming functionalities. The system achieved accurate and reliable pulse rate measurements by leveraging the ESP32 microcontroller's analog-to-digital converter and digital signal processing techniques.

The use of a piezoelectric sensor allowed the system to capture the mechanical vibrations caused by the pulse and convert them into electrical signals. These signals were then processed and analysed to determine the pulse rate. The system incorporated digital signal processing techniques, including filtering and noise reduction, to improve the accuracy of the measurements.

The real-time display of pulse rate readings on the Serial Monitor and the graphical representation on the Serial Plotter provided immediate feedback and a visual understanding of pulse rate variations over time. The wireless transmission capability via Bluetooth enabled the pulse rate data to be conveniently accessed and analysed on connected devices such as smartphones or computers.

The implemented system offers several potential applications in the field of healthcare. It provides a portable, wireless solution for monitoring pulse rate, allowing individuals to track their heart health and detect abnormalities. The remote monitoring feature enables healthcare professionals to remotely monitor patients' pulse rates and provide timely interventions if necessary. Additionally, the system can be utilised in fitness tracking and telemedicine applications, enabling users to track their pulse rate during physical activities and facilitating teleconsultations with healthcare providers. The main selling point of the system would be its ability to function in almost any location at any instance of time. The transmission capabilities provide a huge boost to the existing system of periodic physical check-ups.

However, it is essential to acknowledge some limitations of the system. Factors such as sensor placement, environmental noise, and signal interference can affect the accuracy of pulse rate measurements. Further validation studies and calibration procedures may be required to ensure the system's performance under various conditions and for different user populations.

Future research directions could involve enhancing the system's capabilities by incorporating advanced signal processing techniques, evaluating the system's performance in diverse settings and populations, and exploring additional features for comprehensive pulse rate analysis and interpretation. The system as a whole could be optimised more by developing aspects related to the portability and compactness of the device.

In conclusion, the implemented Bluetooth-based pulse rate detection and monitoring system utilising the ESP32 microcontroller, piezoelectric sensor, and Arduino IDE software has demonstrated its functionality in real-time pulse rate monitoring and transmission. The system's performance, ease of use, and wireless capabilities make it a promising tool for various applications, including healthcare, fitness tracking, and telemedicine. Further refinements and studies are warranted to optimise its accuracy, reliability, and usability in practical scenarios.

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