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An Efficient ECG Monitoring System using MQTT Protocol for Remote Patients in an IoT System

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Abstract: The healthcare domain has undergone a significant transformation to the Internet of Things (IoT), which has enabled the real-time monitoring of vital signs in patients. Among these vital signs, Electrocardiogram (ECG) monitoring is pivotal in the diagnosis of cardiac abnormalities. In this research article, we introduce an IoT-based ECG detection system that leverages the Pan-Tompkins algorithm to ensure precise and dependable processing of ECG signals. This system allows for the remote monitoring of ECG signals, facilitating the early identification of cardiac irregularities and timely intervention. This paper encompasses the conception, implementation, and assessment of the proposed IoT-based ECG detection system, emphasizing its efficacy and potential impact on healthcare through the utilization of MQTT (Message Queuing Telemetry Transport). The paper illustrates how IoT technology can be applied in the healthcare domain, presenting a system designed for monitoring a patient's ECG remotely. This system consists of components such as the ESP8266, ECG Sensor, and Ubidots Cloud for real-time storage and visualization of ECG data, enabling the precise measurement of a remote patient's heart rate.

Keywords: *Internet of Things, ECG Detection, Pan-Tompkins Algorithm, Remote Monitoring, Healthcare.*

1. Introduction

The healthcare sector has undergone a transformative change due to the extensive approval of the Internet of Things (IoT), and one notable area where IoT has through a important impact is in the realm of electrocardiogram (ECG) analysis, specifically in the detection of QRS complexes[1]. The QRS complex is a vital component of the ECG signal, reflecting the electrical movement of the heart during ventricular depolarization, and its accurate detection is pivotal for diagnosing a range of cardiac abnormalities. Through the incorporation of IoT (Internet of Things) technologies, the process of QRS complex detection has seen improvements in efficiency, precision, and accessibility, marking a significant advancement in healthcare. QRS detection systems based on IoT typically entail the utilization of wearable ECG devices that are equipped with sensors for the continuous capture and recording of a patient's heart activity.

These devices are commonly connected to the internet, enabling the seamless transmission of real-time data to either cloud-based platforms or local servers. Through the implementation of IoT, both patients and healthcare providers gain the ability to remotely monitor the electrical activity of the heart, facilitating the early detection of any irregularities and allowing for prompt medical intervention when necessary. Furthermore, QRS detection systems empowered by IoT have the capacity to elevate the quality of patient care by offering valuable insights into an individual's cardiac well-being. Through the continuous analysis of QRS complexes over an extended timeframe, these systems can discern subtle changes that might otherwise escape notice. Moreover, the amalgamation of IoT technology [2] with QRS detection plays a significant role in the burgeoning realm of telemedicine, expanding healthcare access to remote or underserved communities. As technology advances persist, the prospects of IoT-driven QRS [3] detection hold the potential for enhancing the management and diagnosis of cardiac conditions, ultimately resulting in improved patient outcomes and a healthier populace at large. Cardiovascular disorders stand as a leading cause of mortality worldwide, particularly among the elderly demographic. With the global population of individuals aged 65 and older projected to exceed the population of those aged 15 years in the near future, the importance of health monitoring for this age group is growing exponentially. Researchers and innovators have responded to this imperative by devising IoT-based [4] systems for remote ECG (Electrocardiogram) monitoring of patients.

In the past, ECG detection relied on sizable and immobile equipment primarily situated within healthcare facilities. These conventional devices typically employed a set of twelve electrodes for the acquisition of ECG data, ensuring precise but short-term measurements. Nonetheless, their lack of portability imposed limitations on patients' mobility during data gathering, and their substantial cost rendered

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them unsuitable for in-home application. Consequently, patients often found themselves compelled to make recurrent trips to hospitals, further adding to their healthcare-related burdens.

The primary contributions of this study can be summarized as follows:

I. Internet of Thongs-based ECG detection system that utilizes the Pan-Tompkins algorithm for accurate and reliable ECG signal processing.

II. The architecture comprises of key components, including the ESP8266, an ECG Sensor, and the utilization of the Ubidots Cloud for the real-time storage and visualization of ECG data. This arrangement empowers the accurate measurement of a remote patient's heart rate.

2. Related Work

Johnson et al [5] introduced a real-time QRS detection system tailored for wearable ECG devices, harnessing the power of the Pan-Tompkins algorithm. This innovative system incorporates IoT technologies to facilitate the remote monitoring of cardiac activity. To assess its efficacy, the algorithm's performance was scrutinized using a dataset of ECG recordings from individuals in good health, revealing precise QRS detection and minimal computational load, making it well-suited for deployment on IoT devices.

Patel et al. [6] proposed an IoT-based ECG monitoring system with real-time QRS detection using the Pan-Tompkins algorithm. The system consists of a wearable ECG device connected to a cloud platform. The algorithm's performance was evaluated on diverse ECG datasets, including patients with cardiac arrhythmias. The study demonstrates the system's ability to accurately detect QRS complexes and provides timely alerts to healthcare providers for potential abnormalities.

Wilson et al.[7] put forth an innovative strategy aimed at enhancing QRS detection within wearable ECG devices integrated with IoT capabilities. Their approach involves the integration of the Pan-Tompkins algorithm with machine learning methodologies, such as support vector and deep neural networks. This hybrid system attains a heightened level of precision in QRS detection when juxtaposed with conventional algorithms. The research underscores the promise inherent in the fusion of IoT and machine learning for the advancement of cardiac monitoring applications.

Chen et al [8] presented an IoT-driven QRS detection system tailored for environments with limited resources, such as rural or underserved areas. They optimized the Pan-Tompkins algorithm to operate efficiently on low-power devices, rendering it well-suited for deployment in remote regions. The system's effectiveness was assessed through field trials, affirming its capacity to deliver dependable QRS detection and transmit data to a central server for subsequent analysis.

Park et al. [9] proposed a wearable IoT ECG device that integrates an embedded Pan-Tompkins algorithm to enable uninterrupted QRS detection. This device is purposefully crafted for the at-home monitoring of cardiac patients, offering real-time data transmission to healthcare providers via IoT connectivity. The precision and real-time processing capabilities of the algorithm were put to the test in a clinical study encompassing patients with diverse heart conditions.

3. Ecg Signal Processing

3.1 ECG Basics and Significance

The ECG basics and significance section provides an overview of the electrocardiogram (ECG) and its importance in diagnosing cardiac abnormalities. It explains the electrical movement of the heart, which is represented by various components in the ECG waveform, including the P-wave, QRS complex, and T-wave. The section also highlights the clinical significance of these components, such as detecting arrhythmias, ischemia, and conduction abnormalities.

3.2 Pan-Tompkins Algorithm

The Pan-Tompkins algorithm is a broadly used technique for QRS complex detection in ECG signals [10]. The different steps involved in the algorithm is highlighted in the Figure 1.

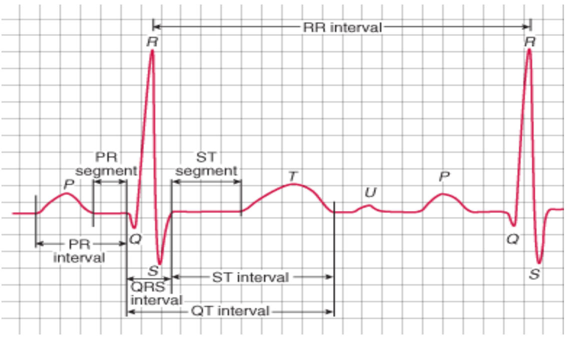

Fig 1. Flow diagram of Pan-Tompkins Algorithm.

3.2.1 ECG Signal Filtering

Signal filtering techniques [11] are applied to improve the quality of the acquired ECG signal. Baseline wander removal techniques, such as high-pass filtering and polynomial fitting, eliminate the low-frequency components that can distort the signal. Other preprocessing steps may include noise reduction techniques, such as adaptive filtering and median filtering, to suppress unwanted noise and artifacts.

3.2.2 QRS Detection

The QRS complex is a vital segment of the ECG waveform, representing ventricular depolarization. To achieve accurate

QRS complex detection, the Pan-Tompkins algorithm employs a range of techniques.

i).Derivative-based thresholding: This method identifies substantial alterations in the slope of the ECG signal, aiding in QRS complex detection.

ii).Adaptive thresholding: Adaptive thresholding [12] dynamically adjusts the detection threshold based on the specific features of the signal, enhancing the accuracy of QRS complex identification.

iii)Template matching: Template matching involves comparing the ECG signal with a predefined QRS template, aiding in the precise recognition of QRS complexes.

3.2.3 RR Interval Calculation

The RR interval, signifying the time duration among successive R-peaks, holds pivotal importance in heart rate variability analysis and the detection of irregular heart rhythms. The Pan-Tompkins algorithm employs this interval as depicted in Figure 2 by identifying the R-peaks within the QRS complex. This RR interval serves as a crucial metric for evaluating heart rate and identifying anomalous heart rhythms, including tachycardia or bradycardia.

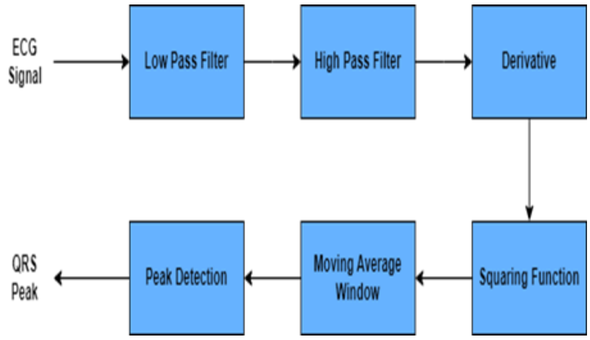

Fig 2. Illustration of PR, QRS and RR Interval to measure the heart rate.

Upon the successful finding of the R peaks, an individual's heart rate can be determined by analyzing the time intervals between consecutive R peaks. Heart rate can be computed as follows:

Heart Rate = 60 / RR Interval

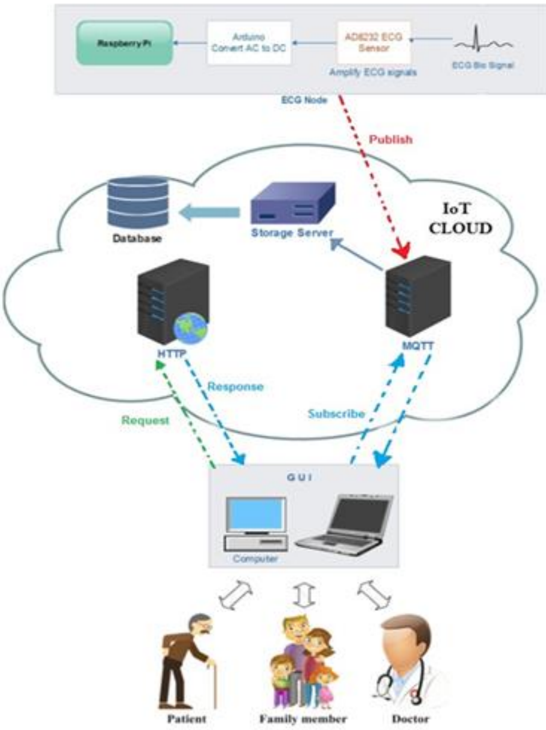

Fig 3: Proposed Architecture of IoT based ECG monitoring System.

4. IOT Based ECG Detection System Architecture

4.1 System Overview

The system overview section provides a high-level description of the IoT-based ECG monitoring system [13]. Figure 3 outlines the key components and their interactions, offering a comprehensive understanding of the system's architecture. The IoT-based ECG detection system [14] consists of interconnected components that enable remote monitoring and real-time processing of ECG signals. The core components typically include ECG sensors, microcontrollers or embedded systems, wireless communication modules, cloud infrastructure, and user interfaces.

4.2 Hardware Components

This subsection focuses on the hardware components of the IoT-based ECG detection system [15]. The following IoT devices discusses each component's role and functionality in the system architecture.

ECG Sensors: ECG sensors are responsible for acquiring the electrical signals generated by the heart. These sensors come in various forms, such as chest electrodes or wearable devices, and capture the ECG waveform accurately.

Microcontrollers or Embedded Systems: Microcontrollers [16] or Embedded Systems play a crucial role in processing the acquired ECG signals. They execute the Pan-Tompkins algorithm and other signal processing algorithms to detect QRS complexes, calculate RR intervals, and filter out noise and artifacts. These devices may also handle data preprocessing tasks and interface with other system components.

4.2.1 AD8232 ECG Sensor

An Electro-cardiogram (ECG) is a medicinal test that detects the heart's electrical pulse, capturing important bio-signals. These bio-signals are used to plot a graph of the heart rate and provide valuable insights into cardiac activity. The AD8232 Single Lead Heart Rate Monitor is an economical board created for the purpose of capturing the heart's electrical activity. It functions as an operational amplifier (op-amp) to acquire a precise ECG signal, focusing on the PR and QT intervals.

The AD8232 serves as an combined signal conditioning module specially designed for ECG and various other biopotential measurement tasks. Its primary function is to extract, intensify, and filter faint biopotential signals, even when faced with challenging conditions like motion interference or the positioning of distant electrodes.

4.3 IoT Data Communication Protocols

The data communication protocols are used for transmitting data between the IoT devices and the cloud infrastructure. Common IoT communication protocols such as MQTT [17] (Message Queuing Telemetry Transport), CoAP (Constrained Application Protocol), or HTTP (Hypertext Transfer Protocol) are utilized for efficient and secure data transfer. These protocols ensure reliable connectivity, low bandwidth consumption, and support for data encryption. These protocols offer a range of features to meet the diverse requirements of IoT communication.

MQTT is known for its lightweight and efficient publish-subscribe model and it uses the APIs such as publish, connect, disconnect, subscribe and unsubscribe in the client server development. CoAP provides a lightweight and RESTful approach such request response model, while HTTP is suitable for more traditional devices and web services.

While HTTP is a widely used protocol for web applications, it is also used in some IoT scenarios, especially when more traditional devices and web services are involved. However, HTTP is less efficient and may not be the best choice for resource-constrained IoT devices.The choice of protocol depends on factors like reliability, scalability, bandwidth efficiency, security, and interoperability, tailored to the specific needs of an IoT project. Many IoT solutions even employ a combination of these protocols to address different communication requirements within a single system.

5. System Implementation

The system implementation section provides a detailed explanation of the stages involved in implementing the IoT-based ECG detection system using Pan-Tompkins algorithm. It outlines the process of integrating the hardware and software components, configuring the system, and ensuring its proper functionality.

5.1 Sensor Integration

The sensor integration step involves attaching the ECG sensors to the patient's body to capture the electrical signals. The type of sensors used may vary depending on the system design and application. These sensors are typically placed on specific locations such as the chest to obtain accurate ECG waveforms as shown in Figure 4. The sensors should be properly calibrated and connected to the microcontrollers or embedded systems for signal acquisition.

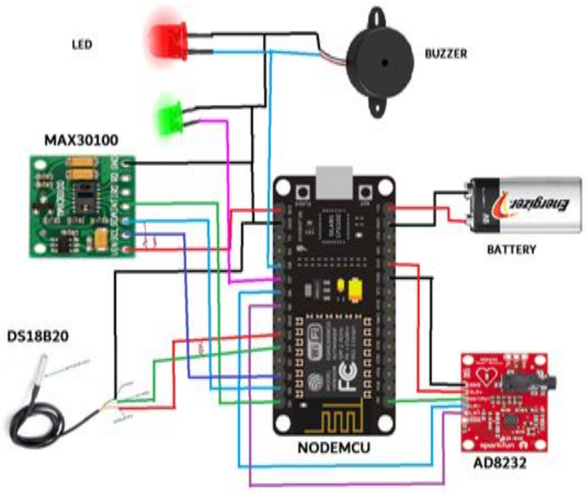

Fig 4. Circuit diagram of Interfacing of AD8232 with NodeMCU.

5.2 Signal Acquisition and Preprocessing

During this step, microcontrollers or embedded systems acquire analog ECG signals from the sensors. These signals undergo preprocessing techniques aimed at improving their quality and eliminating unwanted artifacts. Preprocessing involves a series of procedures, such as baseline wander removal, filtering, and normalization. Filtering techniques, such as high-pass, low-pass, or band-pass filters, are applied to suppress noise and interference in the ECG signals.

Additionally, normalization techniques may be employed to ensure consistent signal amplitudes.

Algorithm: Pan-Tompkins

```
Input ECG Signal
Function PAN TOMPKINS  (Noisy ECG)
    Stage-1 = High pass Filter(Noisy ECG). In this stage the noisy ECG signal is passed through a   high-pass filter to remove baseline wander and other low-frequency noise.
    Stage-2 = Low pass Filter(Stage 1). In this stage The output of the high-pass filter is further filtered using a low-pass filter to attenuate high-frequency noise and obtain a smoother waveform.
    Stage-3 = Differentiator(Stage 2). In this stage The filtered signal is then differentiated to accentuate the QRS complex's steep slopes.
    Stage-4 = Stage-3 * Stage-3. The differentiated signal is squared to emphasize the peaks and suppress any negative components.
    Stage-5 = Integrate(Stage-4). The squared signal is integrated over a specific window to smooth the waveform and enhance the R-peaks.
    Plot Signal.PQRST(Stage-5).The processed signal is plotted, visualizing the PQRST complexes.
    Calculate Signal.RR interval; The RR interval, which represents the time between consecutive R-peaks, is calculated from the processed signal to determine the heart rate.
end function
procedure DECISION MAKER(Extracted RR interval)
    If the "Extracted RR interval" is less than the "HardThreshold then
        Decides that the patient's heart rate is abnormal
        The data is then transmitted, and the samples are stored in local storage.
    Otherwise
    If the "Extracted RR interval" is greater than or equal to the "HardThreshold," then
        Decides that the patient's heart rate is normal
        The data is then transmitted, and the samples are stored in local storage.
    end if
end procedure
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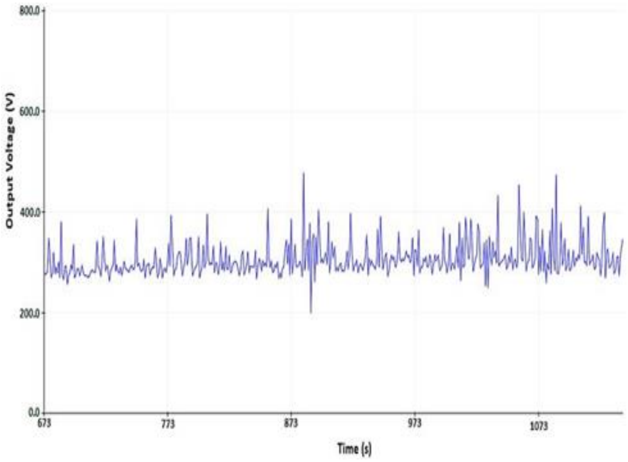

Fig 5. Output of ECG noised signal of Arduino Serial Port.

5.3 Pan-Tompkins Algorithm Implementation

The Pan-Tompkins algorithm, as given below, is integrated into microcontrollers or embedded systems to facilitate QRS complex detection, RR interval calculation, noise and artifact filtering. The algorithm's stages, comprising signal preprocessing, QRS detection, RR interval calculation, and filtering techniques, are executed sequentially.

The actual implementation details can vary based on the chosen programming language and hardware platform. The output of the de noised signal is as shown in the Figure 7.

5.4 Cloud Connectivity and Data Storage

After the ECG signals are processed, using Arduino Uno board and ESP8266 which establish wireless connectivity using modules such as Wi-Fi or Bluetooth to transmit the processed data to the cloud infrastructure using MQTT protocol. The data is securely transmitted to the Ubidots cloud servers as shown in the figure 6, where it is stored for further analysis and access by authorized healthcare providers. Data encryption techniques may be employed to ensure the confidentiality and integrity of the transmitted data.

Ubidots is a cloud platform for IoT that allows users to collect, analyze, and visualize data from connected devices, enabling data-driven decision-making and remote monitoring. Ubidots offers tools for real-time data visualization, device management, and integration with various IoT devices and services, making it a versatile solution for IoT applications and data management in the cloud.

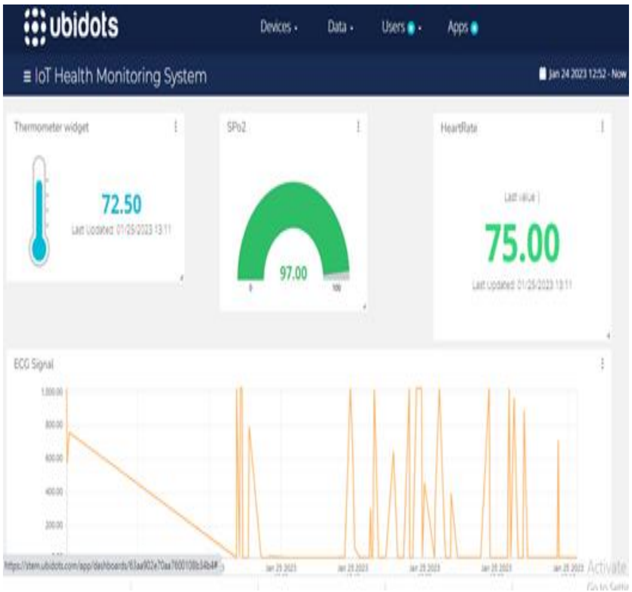

Fig 6: Output of the Ubidots Cloud Server

6. Results

6.1 MQTT Server

The MQTT server takes on the responsibility of managing the transfer of ECG values from the monitoring device to the web page. In contrast to the HTTP server, which mainly offers a visual interface for observing the ECG signal, MQTT adheres to a publish and subscribe protocol model, distinguishing it from the request/response structure employed in HTTP. Within MQTT, there are two central concepts:

i). Publisher: A device or node that publishes data to the MQTT broker. In the context of ECG monitoring, the monitoring node acts as the publisher, sending ECG data to the MQTT broker.

ii). Subscriber: A device or client that subscribes to specific topics on the MQTT broker to receive data. The web page that displays the ECG signal acts as a subscriber, subscribing to the relevant topics to receive the ECG data pushed by the broker.

The main distinction between MQTT and HTTP lies in the communication model. In MQTT, the broker pushes information to the subscribed clients (subscribers), allowing real-time updates without the need for the clients to continuously request data. On the other hand, in HTTP, the client (web page) makes requests to the server to retrieve information, and the server responds with the requested data.

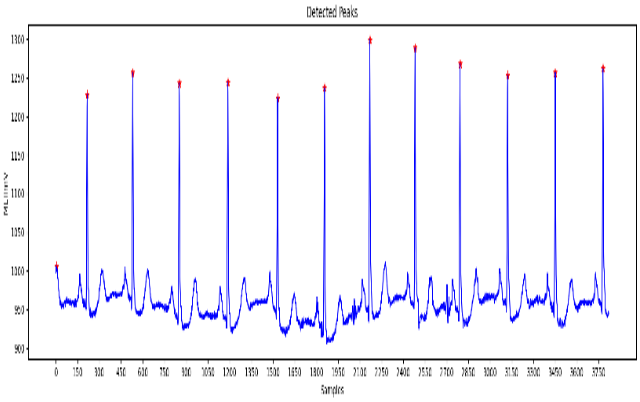

Fig 7. Output of the de-noised ECG signal using Pan Tompkins Algorithm and QRS Peaks.

6.2 Real-time Notification:

The notification service is designed to deliver real-time notifications in the event of specific abnormal situations that meet predefined criteria. These abnormal conditions are categorized into three groups, each with its own distinct set of conditions:

i) When the heart rate falls within the range of 85-95 beats per minute, or the QRS time interval is equal to or less than 0.1 seconds, and the QRS voltage is within the range of 0.5-0.7 mV.

ii) When the heart rate falls within the range of 95-105 beats per minute, or the QRS interval exceeds 0.1 seconds, and the QRS voltage is less than 0.4 mV.

iii) When the heart rate surpasses 105 beats per minute or deviates from the normal heart rate range.

6.3 Result and Analysis

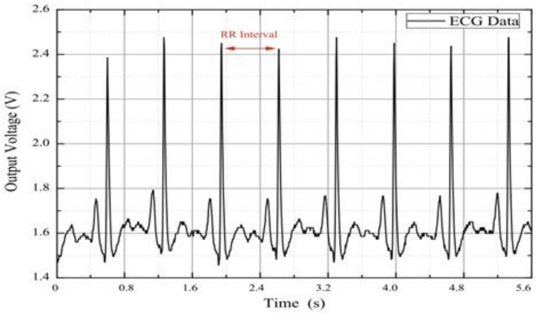

Fig 8: Output of the QRS detection and RR interval.

As shown in the figure 8 that adjacent R waves (RR interval) are nearly the same, which shows no risk of developing arrhythmia.

RR Interval: The RR interval, often identified by the prominent R wave, signifies the duration between two consecutive R waves within an ECG signal. This interval can exhibit irregularities in cases of certain heart conditions, such as arrhythmia.

PR Interval: The PR interval gauges the time from the initiation of the P wave to the initiation of the QRS complex. It reflects the duration required for the electrical impulse to travel from the sinus node to the ventricles.

QT Interval: The QT interval spans the time from the onset of the Q wave to the conclusion of the T wave and is associated with ventricular depolarization and repolarization. If the QT interval extends beyond the normal range, it elevates the risk of ventricular fibrillation or even sudden cardiac death.

7. Conclusion

The IoT-based ECG monitoring system presented in this study is an efficient and cost-effective solution for remote patient monitoring. The ECG monitoring sensor, AD8232, features three electrodes and enables the real-time acquisition of ECG signals with a high degree of accuracy. Subsequently, these signals are transmitted to the Ubidots cloud using Wi-Fi connectivity, facilitated by the ESP8266 module. The IoT cloud platform assumes the responsibility of visualizing the ECG data for users and securely storing it for subsequent analysis. This cloud-based implementation leverages three key servers: an HTTP server, an MQTT server, and a storage server, to efficiently manage the data. In comparison to existing systems documented in the literature, this IoT-based ECG monitoring system stands out for its cost-effectiveness while delivering performance that is on par with established alternatives. Additionally, the system's capability to provide real-time notifications in case of abnormal ECG signals enhances its value in timely medical interventions and patient care.In future work, we will incorporate various machine learning models to predict the heart disease.

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