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Design and Development of Cloud Based Real Time ECG Anomaly Detection

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ABSTRACT
The functionality of the heart is assessed by analysing the electrocardiogram (ECG) signal. Numerous methods were developed for the accurate detection of heart diseases utilising the recorded ECG signals. However, individuals with serious heart diseases must be constantly observed, especially if there are few indicating bio-signal patterns. Real-time data collection and processing enables early detection of heart diseases and prevent complications. The AD8232 sensor is used in the project along with its interface with the Node MCU for real time acquisition of ECG signal. The intervals of the PQRST wave are thoroughly investigated utilizing a novel windowing approach based on Wavelet Transform. To increase the QoS in the healthcare system, the final findings are displayed on both the system and the cloud interface. In this work, we compared the ECG parameters with those from well-known smartwatches. The outcomes demonstrated a striking match between the ECG parameters acquired using our method and those obtained using smartwatches. This verifies the precision and dependability of our system in monitoring the ECG parameters from ECG signal. Our methodology has the potential to be a dependable and practical solution for heart rate monitoring in real-time and distant healthcare applications because our algorithm and smartwatches consistently report heart rate rates in the same range.
Keywords—ECG monitoring, Cloud computing, wavelet transform, Anomaly detection.

1. INTRODUCTION

An electrocardiogram (ECG or EKG) is a test that measures the electrical activity of the heart. It is a commonly used tool to diagnose various heart diseases such as arrhythmias, myocardial infarction (heart attack), and heart failure. During an ECG, electrodes are placed on the skin of the chest, arms, and legs. These electrodes detect the electrical signals produced by the heart and transmit them to a machine that records the data. The ECG waveform shows the electrical activity of the heart over time, and can provide information about the heart rate, rhythm, and any abnormalities in the heart's electrical activity. Doctors use ECG results to diagnose and monitor heart conditions, as well as to evaluate the effectiveness of treatments. ECG is a non-invasive, painless and low-risk test, making it a valuable tool for detecting and managing heart diseases.

Heart disease is one of the leading causes of death worldwide, accounting for millions of deaths each year. Heart disease can affect people of all ages, but it is more common in older adults.There are many different types of heart diseases, including: Coronary artery disease: This occurs when the arteries that supply blood to the heart become narrow or blocked, reducing blood flow and oxygen to the heart, Heart attack: A heart attack occurs when blood flow to a part of the heart is blocked, usually by a blood clot. This can cause permanent damage to the heart muscle, Arrhythmia: An arrhythmia is an abnormal heart rhythm that can cause the heart to beat too fast, too slow, or irregularly.

Heart failure occurs when the heart is unable to pump blood effectively, often due to damage from another heart condition.Valve disease occurs when the heart's valves do not function properly,

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either due to narrowing (stenosis) or leakage (regurgitation). Risk factors for heart disease include smoking, high blood pressure, high cholesterol, diabetes, obesity, and a family history of heart disease. Lifestyle changes such as quitting smoking, eating a healthy diet, and getting regular exercise can help reduce the risk of developing heart disease.
Cardiovascular disease (CVD) is a major global health problem and a leading cause of morbidity and mortality worldwide. According to the World Health Organization (WHO), CVD is responsible for an estimated 17.9 million deaths per year, accounting for 31% of all global deaths. CVD includes a range of conditions that affect the heart and blood vessels, including coronary artery disease, stroke, and heart failure.
The burden of CVD varies by region and country, with low- and middle-income countries being disproportionately affected. In these countries, CVD is often associated with poverty, lack of access to healthcare, and unhealthy lifestyle choices such as tobacco use and unhealthy diets. In the United States, CVD is also a major public health problem. According to the Centers for Disease Control and Prevention (CDC), CVD is the leading cause of death in the US, responsible for approximately 1 in every 3 deaths. In 2020, CVD was responsible for 690,000 deaths in the US alone.
In India CVDs account for the largest cause of mortality, accounting for around 28% of all deaths, According to a study published in The Lancet, the age-standardized prevalence of coronary heart disease in India increased from 3.0% in 1990 to 3.7% in 2016, The same study found that the age-standardized prevalence of stroke in India increased from 1.6% in 1990 to 2.7% in 2016., Risk factors for heart disease in India include high blood pressure, diabetes, smoking, and a diet high in salt and saturated fats, The Indian government has implemented various initiatives to address the burden of heart disease, including the National Programme for Prevention and Control of Cancer, Diabetes, Cardiovascular Diseases and Stroke (NPCDCS).

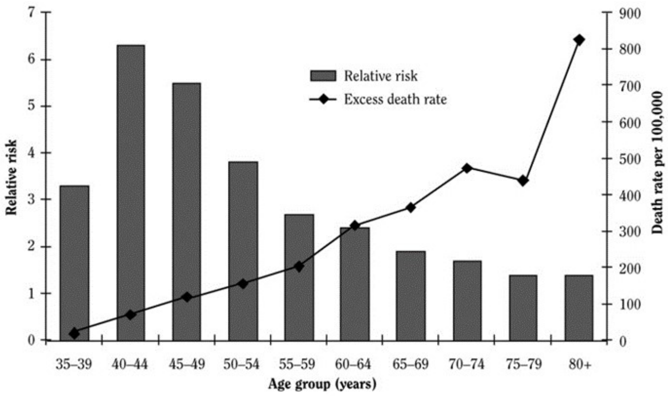

Fig. 1 Relative risk and excess death rate for coronary heart disease among people, by age group

Heart disease is a major cause of mortality worldwide, and individuals with weakened hearts who have undergone heart surgeries require ongoing monitoring to manage their condition. However, traditional methods of ECG monitoring are often inconvenient and do not allow for instant detection of abnormal heart rhythms. Therefore, there is a need for wireless ECG monitoring that can provide remote and instant monitoring of the patient's heart condition, as well as a secure method for physicians to access the patient's ECG data and anomaly information.

2. MATERIALS AND METHODS

The first step is to acquire the ECG signals using Ag-Al ECG electrodes attached to the patient's chest. The ECG Acquisition sensor (AD8232) is used to acquire the ECG signals from the patient. The ECG signals are then amplified and filtered to remove the noise. The processed ECG signals are then passed through an Analog-to-Digital Converter (ADC) to convert the analog signals into digital form. The ECG sensor generates analog signals, which are connected to the NodeMCU's analog input pins. The NodeMCU is an embedded device with integrated Wifi which reads the

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analog signals from the ECG sensor using an analog-to-digital converter (ADC). A software library, such as the Arduino ECG library is used to read the analog signal from the sensor and convert it into a digital signal that can be sent over WiFi. The NodeMCU processes the digital ECG signals and performs various operations such as filtering, normalization, and feature extraction.
The processed digital ECG signal is then transmitted wirelessly via WiFi using MQTT to the cloud for storage, further analysis, and instant warnings. On the computer, a software application or cloud (Thingspeak) receives the ECG data over WiFi and can visualize or analyze it as needed. Once the data has been uploaded to Thingspeak, it can be downloaded from Thingspeak in CSV or TXT file format.
The file contains the time series data of the ECG signal with each row representing a single data point. After receiving the data points of the ECG signal, Matlab is used to perform the signal processing for the ECG anomaly detection. The data is preprocessed to remove the noise and artifacts using filters such as a low-pass filter to remove high-frequency noise, or a median filter to remove baseline wander. In this work, a derivative-based algorithm is used for detecting PQ, QR, RS, and ST intervals of ECG signal. By taking the time difference between successive R-peaks, the RR intervals are computed, which can be used to detect any abnormalities that may indicate a disease or condition. The ECG data can also be stored on a remote server or device for later analysis and interpretation by a healthcare professional.

Diseases	**Parameters**	**Values in the Literature**	**Average Values Obtained in our Study**	**Normal Values in Healthy Adults**
Bradycardia	Heart rate	< 60 bpm	N / A	>60 bpm < 92 bpm
Tachycardia	Heart rate	> 100 bpm	N / A	> 60 bpm < 92 bpm
Premature ventricular contraction	Duration of QRS interval	> 120 ms	N / A	> 75.5 ms < 108.0 ms
Premature atrial contraction	Heart rate	> 60 bpm < 100 bpm	N / A	> 60 bpm < 92 bpm
Atrial fibrillation	Duration of P – wave Heart rate	N / D Irregular	N / A N / A	> 80 ms < 120 ms > 60 bpm < 92 bpm
Arrhythmia	Heart rate variability	N / D	> 100 %	N / A
Heart rate failure	Heart rate variability	N / A	> 100 %	N / A

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Arterial hypertension	Duration of QRS interval	N / A	< 700 ms	> 75.5 ms < 108.0 ms
Parkinson's disease	Duration of R - R interval	N / A	> 2000 ms	> 600 ms < 1200 ms
Bilateral Gonarthrosis	Duration of QRS interval	N / A	> 700 ms	> 75.5 ms < 108.0 ms

Table 1 : Parameter for Disease detection

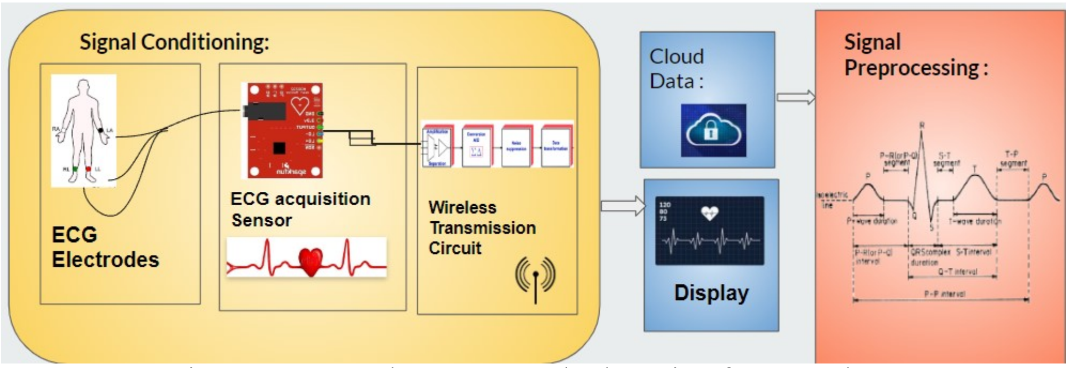

Fig. 6 : Proposed ECG anomaly detection framework

2.1 Components Of ECG Acquisition System

The major components of the ECG acquisition system includes ECG electrodes, a signal conditioning unit, wireless transmission and a display unit.

2.1.1 Ag-Al Electrodes

ECG electrodes are small, flat, adhesive patches that are placed on the skin to record the electrical activity of the heart. Typically, ECG electrodes are made of a conductive material, such as silver/silver chloride or stainless steel, which allows for the transmission of electrical signals from the body to the ECG machine. They are designed to adhere to the skin firmly and without causing discomfort to the patient. ECG electrodes are placed on specific locations of the chest, arms, and legs, depending on the type of ECG test being performed. The placement of the electrodes is critical to ensure accurate recording of the heart's electrical activity. The standard 12-lead ECG requires the placement of ten electrodes on the chest, arms, and legs, while a single-lead ECG may only require two electrodes on the chest.

2.1.2 Signal Conditioning unit

The ADC8232 is an Analog-to-Digital Converter (ADC) integrated circuit that is specifically designed for ECG monitoring applications. It is used to convert the analog electrical signals generated by the heart into a digital signal that can be processed and analyzed by a microcontroller. The ADC8232 has a high resolution of 24 bits and a high accuracy, which allows it to accurately capture and digitize the subtle electrical signals generated by the heart. It also has low noise, which reduces the amount of interference in the ECG signal and improves the overall accuracy of the system.The ADC8232 typically interfaces with a microcontroller, such as an Arduino, through an SPI or I2C interface. This allows for easy integration into a larger system and enables the microcontroller to control the ADC and retrieve the converted digital ECG data.

2.1.3 Wireless transmission

NodeMCU ESP8266 is an embedded device with integrated WiFi. This is essential for the proposed small compact system since there is no need for a separate WiFi module. The architecture of

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NodeMCU ESP8266 has the capabilities of GPIO connection to the Internet and data transmission via the Internet. NodeMCU ESP8266 utilizes the standard Lua Programming Framework script [29]. The main reason for Figure 5: Actual system hardware Algorithm 1 (continued) IASC, 2022, vol.33, no.1 59 this is to allow programming in a simple way. The memory of NodeMCU ESP8266 has a capacity of 4 MB [30]. Another powerful feature of this embedded device is the use of Arduino IDE, which is currently compatible with many popular operating systems, such as Windows, Mac OS, and Linux.

2.1.4 Display unit

Adafruit SSD1306 is a monochrome OLED display module that can be used with microcontrollers to display text, images, and graphics. The module features a 128x64-pixel resolution display with a white or blue OLED and is controlled through an I2C interface. The SSD1306 module is compatible with a variety of microcontrollers, including Arduino, Raspberry Pi, and ESP8266. The Adafruit SSD1306 library provides an easy-to-use interface for controlling the module, with functions for drawing text, lines, shapes, and images on the display. The library also includes built-in fonts and graphics that can be used to create custom displays. The module is a popular choice for small-scale projects that require a simple and low-power display. Its compact size, low power consumption, and easy-to-use interface make it ideal for use in wearable electronics, portable devices, and embedded systems.

2.2 Signal Processing System

2.2.1 Artifact removal

The first step is to load the ECG signal. The signal is stored and the time vector is created using the sampling rate of 200 Hz. The ECG signal is contaminated with noise and other high frequency artifacts. Hence, a low-pass filter is applied to the signal to remove high-frequency noise. The filter coefficients are defined using a 13-tap FIR filter with a cutoff frequency of 15 Hz. After removing high-frequency noise using the low-pass filter, a high-pass filter is applied to the signal to remove low-frequency noise. The filter coefficients are defined using a 32-tap FIR filter with a cutoff frequency of 5 Hz. The derivative filter is used to enhance the QRS complex by emphasizing its steep slope. The filter coefficients are defined using a 5-tap FIR filter. The filtered signal is squared and then normalized to produce a new signal with values between 0 and 1. A moving average filter is applied to the normalized signal to smooth the signal and remove high-frequency noise. The filter coefficients are defined using a 31-tap FIR filter. A threshold value is computed based on the mean of the smoothed signal, and the threshold signal is generated by setting any value in the smoothed signal that exceeds the threshold to 1 and the rest to 0. The PQRST complexes are detected by locating the R, Q, S, P, and T points in the ECG signal. This is done by finding the maximum and minimum values in the signal within certain intervals defined by the QRS complex. Finally, the Heart Rate Variability (HRV) is computed by subtracting the location of the P wave from the location of the next P wave in the ECG signal.

2.2.2 QRS detection

The algorithm uses a particular type of wavelet transform called the Maximal Overlap Discrete Wavelet Transform (MODWT) with the 'sym4' wavelet and 4 decomposition levels. The 'sym4' wavelet is a type of Daubechies wavelet that has good properties for detecting QRS complexes in ECG signals. It also applies a threshold to the wavelet coefficients using the universal threshold method. The findpeaks function is used to detect the R-peaks, with a minimum peak height of 8 times the average value of the signal and a minimum peak distance of 50 samples. Finally, the heart rate is calculated by counting the number of R-peaks detected and dividing by the duration of the signal in minutes. The wavelet transform is a convolution of the wavelet function $\psi(t)$ with the signal $x(t)$. Orthonormal dyadic discrete wavelets are associated with scaling functions $\varphi(t)$. The scaling function can be convolved with the signal to produce approximation coefficients S.

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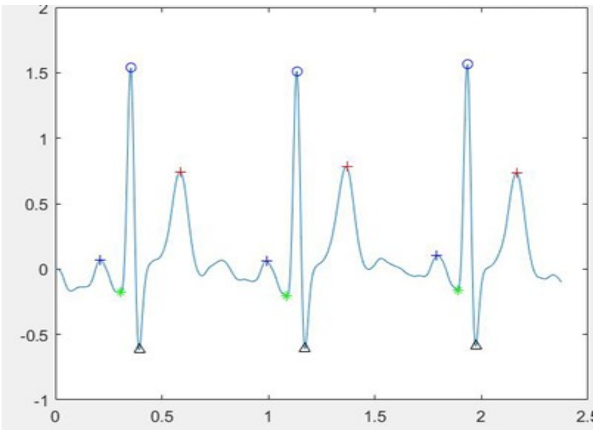
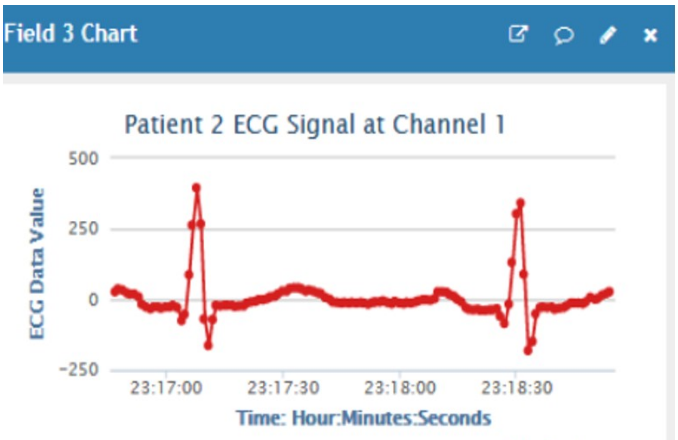


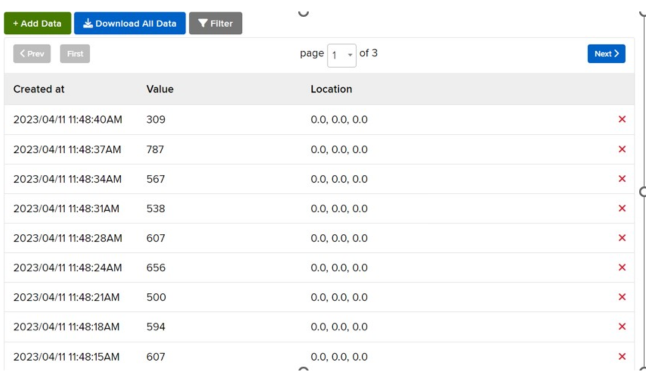
Fig. 4 : PQRST Detection from ECG Data

2.3 Cloud Interfacing

On the other hand, we have built a cloud database using AdafruitIO. Adafruit IO is a platform designed to display, respond, and interact with the project's data. Made an attempt to transfer and store ECG data on this IOT cloud platform. The major advantage of the platform - the data loss has been reduced to a major extent when compared to the previous to the previous cloud service. The data points gets uploaded for every 2 seconds, thus enhancing the PQRS acquisition and values can be finally downloaded as a csv. Since the matlab is not integrated with this platform-data is taken back to thingspeak platform in the form of CSV file, to be processed within the Cloud premises.



(a)



Created at	Value	Location
2023/04/11 11:48:40AM	309	0.0, 0.0, 0.0
2023/04/11 11:48:37AM	787	0.0, 0.0, 0.0
2023/04/11 11:48:34AM	567	0.0, 0.0, 0.0
2023/04/11 11:48:31AM	538	0.0, 0.0, 0.0
2023/04/11 11:48:28AM	607	0.0, 0.0, 0.0
2023/04/11 11:48:24AM	656	0.0, 0.0, 0.0
2023/04/11 11:48:21AM	500	0.0, 0.0, 0.0
2023/04/11 11:48:18AM	594	0.0, 0.0, 0.0
2023/04/11 11:48:15AM	607	0.0, 0.0, 0.0

(b)

Fig. 5 : (a) Output Obtained from Thingspeak (b)Data Points Displayed on Adafruit

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2.4 Oled Interfacing :

Once the peak is detected, the algorithm calculates the heart rate and displays it on the OLED screen. The anomaly detection algorithm is designed to identify abnormal ECG patterns, such as arrhythmia or abnormal heart rhythms which can be difficult for physicians to identify manually. If any abnormal pattern is detected, the algorithm alerts the physician with detailed patient condition information. The use of the NodeMCU board and Wi-Fi technology enables wireless transmission of the ECG data, eliminating the need for cumbersome and inconvenient wires. Thirdly, the use of the AD8232 ECG sensor, NodeMCU board, and OLED screen provides an affordable and portable solution for ECG monitoring, which can be particularly beneficial for patients in remote or rural areas who do not have access to specialized medical facilities.

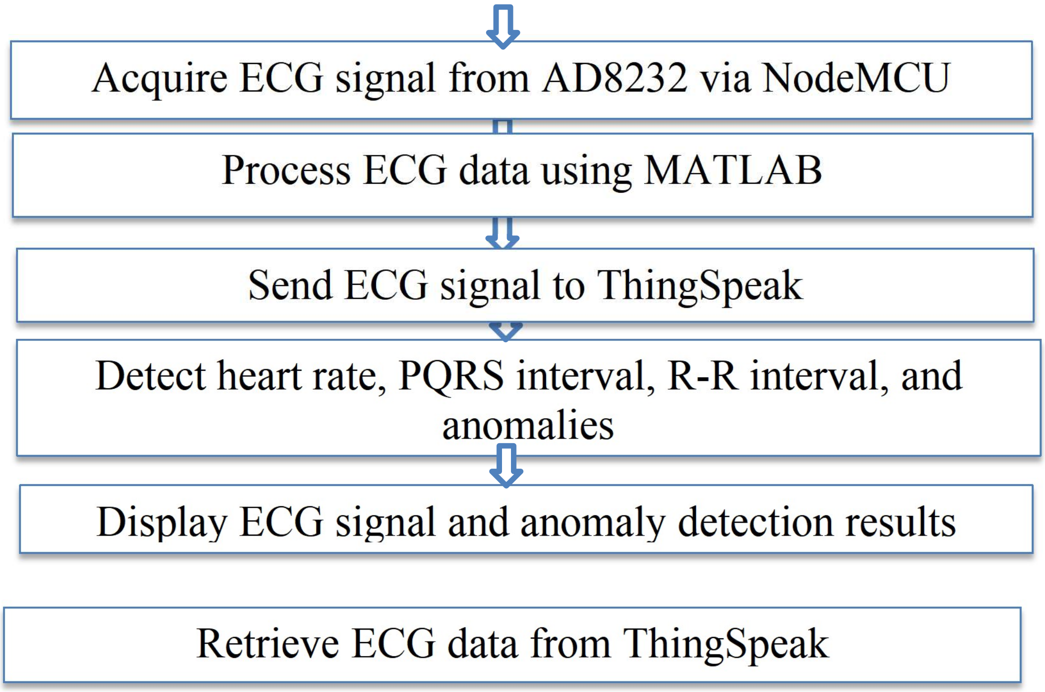

Fig. 3 : Flow chart of Real-time basis ECG Anomaly Detection

3.Results and Discussion

Signal processing and analysis are essential techniques used in electrocardiogram (ECG) analysis to extract meaningful information from the raw ECG data. In this study, Matlab software was utilized to process and analyze ECG data obtained from the AD8232 device. The processed ECG data underwent a series of filtering and feature extraction stages, including low pass filtering, high pass filtering, derivative filtering, moving average filtering, and thresholding, followed by PQRST complex detection. Each of these processing steps plays a crucial role in enhancing the ECG signal, removing noise, and detecting relevant features associated with the cardiac cycle. In this section, we provide a detailed explanation of each processing step and its significance in the analysis pipeline, which contributes to the accurate detection of impending heart attacks or other relevant medical conditions. Original ECG This represents the raw ECG data obtained from the AD8232. It typically consists of the electrical activity of the heart recorded over time, and it serves as the input for subsequent processing stages.

In ECG analysis, various filters are employed to enhance signal quality. A low-pass filter permits low-frequency cardiac activity while eliminating high-frequency noise. Conversely, a high-pass filter removes slow variations, focusing on rapid cardiac changes. A derivative filter gauges signal slope, highlighting features like the QRS complex. Subsequently, a moving average filter smooths and refines the waveform. The next step involves identifying PQRST phases using algorithms like

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peak detection. These phases signify distinct cardiac events. Furthermore, interval values (e.g., PR, QRS, QT) provide essential timing data.

Findings

In our study, we compared the heart rate values obtained from our algorithm with those obtained from popular smartwatches. The results showed a remarkable similarity between the heart rate values obtained from our algorithm and those recorded by the smartwatches. This validates the accuracy and reliability of our algorithm in detecting and analyzing heart rate from ECG data. The consistency in heart rate values between our algorithm and smartwatches highlights the potential of our approach as a reliable and convenient method for heart rate monitoring in realtime and remote healthcare applications.

4. CONCLUSION

In conclusion, our project offers a more convenient and efficient method of ECG monitoring that can improve the quality of care for patients with weakened hearts who have undergone heart surgeries. Our study showed that our project was effective in detecting abnormal ECG patterns and alerting the physician if necessary. Future work can include testing our project with a larger sample size and conducting a cost-benefit analysis to determine the economic feasibility of our project.

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