An Advanced Embedded System Based Diagnostic Technique For Coronary Artery Disease (CAD) Using Insightful Assessment Of Electrocardiogram With Internet Of Things (IoT)

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Abstract: Coronary Arterial Disease (CAD) is the most commonly known heart disease and this disease is one of the prevalent reasons for the high mortality rate. The most obvious way of analysing the different types of heart block is still done on the basis of the graphical assessment of the Electrocardiogram (ECG) graph. Using an analog graph plotted on the existing ECG machine, it is very difficult to perform system-based analysis without live digital data. In this research paper, an instrument was designed for live ECG monitoring in order to create a database for different types of blockage in the heart. Different kinds of an atrioventricular block (AVB) are determined with the aid of ECG graphs delay. So, all such possible cases are determined using a newly developed CAD algorithm for feature extraction, event detection and temporal localization using free open source software Scilab. This paper has also proposed a novel method for consistently monitoring the heart block with the help of MQTT using the Internet of Things. The data retrieved from the ECG graph is collected via the sensor (AD8232) developed by Texas Instruments and known for its high sensitivity. Further, the data are transmitted through 16-bit analog to digital converter (ADS1115) and by using I2C protocol, it is interfaced with Raspberry Pi 3. With the support of IEEE 802.11 (WLAN) and an in-built Raspberry Pi 3 module, MQTT mosquito client was developed which publishes the data received by the ADC to Cloud MQTT. The main purpose of using the MQTT subscribe is to accurately assess the ECG data for detecting the delay and finally correlating with the specific type of heart block and finally using Graphic User Interface (GUI) yet another advantage is that the data can be remotely assessed from any part of the world.

Index Terms: Atrioventricular Block (AVB), Coronary Arterial Disease, Graphic User Interface, IoT, MQTT mosquito, Raspberry Pi 3, SoC;

1. INTRODUCTION

Kollicker and Muller both discovered that electrical impulses were present in the heart for the first time in the year 1856. Following the discovery, Muirhead also recorded the first ECG signal from a self-developed instrument known as siphon in the years 1869 and 1870 [1]. String Galvanometer invented by Einthoven was a breakthrough for development in ECG technology in 1901. It helped in measuring ECG accurately. He was the first person to correlate the ECG signal pattern to that of arrhythmias. He also developed a three-lead system for the measurement of ECG and created uniformity in recording the signal which helped him confer Noble Prize in 1924 [2]. In the year 1930, an experiment conducted by Parkinson and White involved eleven young patients who volunteered themselves with disorders in rhythm pattern that had an abnormality in short PR interval and also bundle branch block which was analyzed from ECG. Later in the year 1955, Auricular Fibrillation (AF) caused a cardiac failure in middle-aged person and ventricular hypertrophy and coronary atheroma an elderly person. Fraser declared that AF is a common arrhythmia [4]. In 1957, nearly four cases who were deaf-dumb from the same family were studied, two children and parents were normal.

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The ECG pattern observed from the children who died due to Adams Stoke suffered longer Q-T interval and heart was still enough [5]. In 1959, Classic Angina Pectoris is a heart disorder that was observed from the depression of the S-T segment from the recorded ECG pattern. It was observed that another kind of angina pectoris results in a remarkable elevation of the ST transiently [6]. In 1960, eighty patients suffering from a myocardial syndrome which blocks the flow of blood to the heart were studied. It was observed that these subject's ECG pattern exhibits interruptions of T waves by premature QRS. The R on T phenomena helps in determining disorders like myocardial infarction (MI), ischemic heart disease, hypertensive heart disease, and several other myocardiopathy [7]. In 1961, a preamplifier was designed for an ECG circuit. The interference in the graph was analyzed and the reduction of the interference was done with the help of transformer coupling. The prototype was constructed and the operational characteristics were studied [8]. In 1967, Lown proposed an interpretation of ECG patterns with missing P wave for more than 3 seconds as Sick Sinus Syndrome (SSS) and the sinus rates are comparatively slow [9]. In 1989, Brugada syndrome which is caused due to the irregular heartbeat of the patient. It was observed from the ECG pattern of 6 cardiac patients. Out of which 5 patients survived the cardiac arrest [10]. Brugada brothers continued their research further and then in 1992 found that a common pattern of ECG could define a distinct syndrome in the group of patients [11]. In 1996, 148 men from the rural side were analyzed and their cardiovascular system and resting ECG were observed. It can be concluded that coronary heart disease, risk factors, and cardiovascular disease could be determined using the patterns of resting ECG [12]. In 1999, a medical condition that has short QT syndrome also affects the electrical functionality in the heart and so the QT interval was observed to be less than 300 ms. The shortening of effective refractory period due to the presence of the syndrome can be a life-threatening situation [13]. In 2013, a wearable ECG measurement system was developed with a smart shirt that can be used by patients inside hospitals and at home for a consistent assessment. It was further extended to develop an on-site bed monitoring system for elderly people. Moreover, the wireless data transmission system is incorporated with the design to help healthcare professionals [14]. In 2018, ECG pattern feature extraction and analysis were done for MI. For early diagnosis of heart attack with end-user notification in case of emergency was implemented. Algorithms, filtering techniques were used to detect and denoise the waveform and analyses the peaks and intervals from the observed ECG graph. It was observed that the ST segment when compared with the threshold concerning normal sinus rhythm present in the healthy patient ECG graph was having a minimum difference [15]. ECG assessment requires a lot of tools to analyze the pattern and intervals of the segments which in turn helps in explaining the type of blocks and state of patients without any time delay used for manual analysis. The research focuses on the feature extraction of the ECG pattern in order to determine the cardiac condition for early diagnosis as well as for data storage using cloud computing. As a result, it helps the physicians to track the record of the patient and also execute treatment without spending much time for analysis.

2 METHODOLOGY

2.1 Hardware Implementation

Hardware implementation includes disposable electrodes, ECG sensing unit and processing board for determining the ECG signal as shown in Fig. 1(a) and 1(b) which is explained in the following section.

***Fig. 1**. (a) Hardware setup with Ubidots*

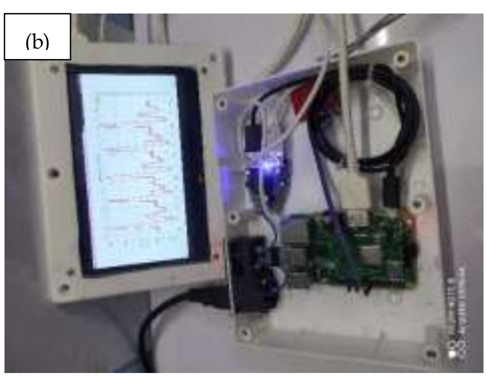

***Fig. 1**. (b) Hardware setup with Python IDE*

2.1.1 Electrodes

The idea is to implement hardware for both commercial and domestic applications. For commercial applications, disposable electrodes were used in order to avoid infection as shown in Fig. 2. For domestic applications, conductive metal can be used as a reusable electrode.

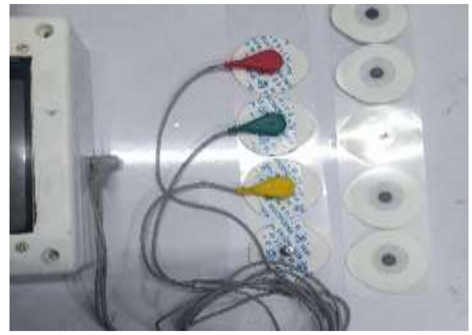

***Fig. 2**. Disposable Electronics*

2.1.2 Attenuation of noises from ECG signal

AD8232 is low power device with inbuilt integrated circuit in a single chip. The main purpose of this device is amplifying the given signal as ECG signal is a weak bio-signal. It becomes essential to eradicate the noise from the ECG signal. The signal from the electrical activity of heart is basically an analog signal. It consists of an operational amplifier for filtering the signal. It works at 3.3 V which is supplied from the processor. The gain of the op-amp is around 100. Following that a normal op-amp is placed for further filtration.

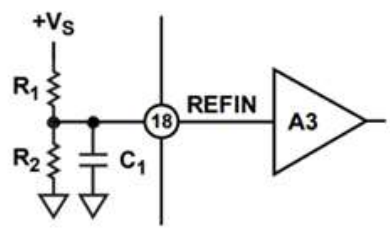

***Fig. 3**. Circuit diagram for internal reference*

The input reference voltage is expressed as REFIN which is shown in figure 3. In order to obtain the recommended reference voltage, both the resistors are of 10 MΩ. C1 capacitor is used for filtering the signal but takes time to settle to the exact supply voltage. the settling time can be estimated approximately from the given equation (1).

$$T_{set}=5(R_1R_2)C_1/R_1+R_2 \quad (1)$$

2.1.3 Sallen-Key Topology based High Pass Filter Design

The filter design had a unique combination of resistor and capacitor can be observed from the fig. 4. C2 capacitor is placed across the switch resistance in order to reduce the recovery time along with 10KΩ resistance. Since this circuit comprises of passive components across the output, it provides higher output impedance.

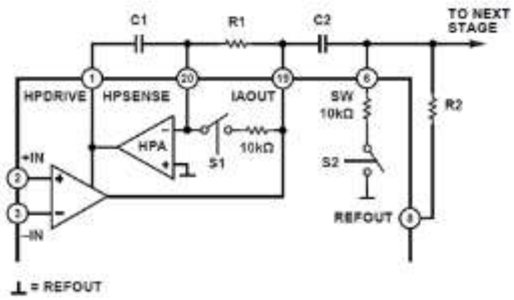

***Fig. 4**. High Pass Filter with Sallen-Key Topology*

2.1.4 High Pass Filter Design with DC blocking circuit

It becomes necessary to design an additional block circuit for the DC signal or the low frequency noise and also to improve the signal-to-noise rejection ratio as shown in fig. 5. Lower cut-off frequencies for determining the heart rate detection and for better filtration depends on R and C values that are appropriately chosen as given in equation (2) and (3).

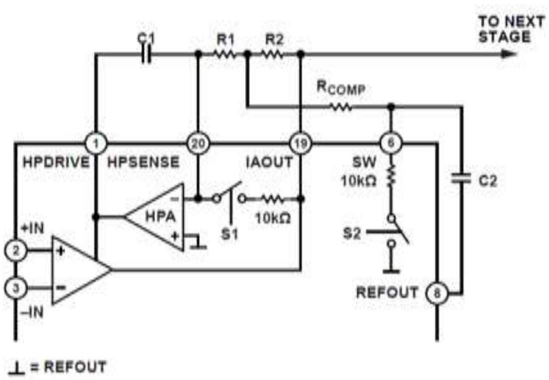

***Fig. 5**. High pass filter design with DC blocking circuit*

$$R_1=R_2 \geq 100\ K\Omega\ \&\ C_1=C_2 \quad (2)$$

$$R_{com} = 0.14.R_1 \quad (3)$$

Cut-off frequency is determined by the equation (4).

$$f_C=10/\ (2\pi\sqrt{(R_1\ C_1\ R_2\ C_2\ )}) \quad (4)$$

2.1.5 Design of Band Pass Filter

The equation (5-7) describes the cut-off frequency, gain and quality factor respectively of the bandpass filter. As value of Q affects the gain and hence for effective filtering the value of Q is maintained between 0.5-0.7.

$$f_C = \frac{10}{2\pi\sqrt{R_1C_1R_2C_2}} \quad (5)$$

$$Gain = 1 + \frac{R_3}{R_4} \quad (6)$$

$$Q = \frac{\sqrt{R_1C_1R_2C_2}}{R_1C_2+R_2C_2+R_1C_1(1-Gain)} \quad (7)$$

2.1.6 Coronary Artery Disease (CAD) Monitoring Circuit

CAD monitoring circuit analyses the shape, interval and peaks in the ECG graph. In order to minimize the ECG wave distortion, AD8232 is interfaced with circuit as shown in figure 6, the ECG signal lies between 0.5 Hz to 50 Hz, so a bandpass filter with these cut-off frequencies was designed. Since the ECG signal between this range will not be identified by the 16-bit ADC ADS1115, the operational amplifier is configured with the gain of 12, resulting in 1200 total system gain. Increased gain resulting in proper ADC conversion which will be interfaced with Raspberry Pi 3 through Inter-Integrated circuit.

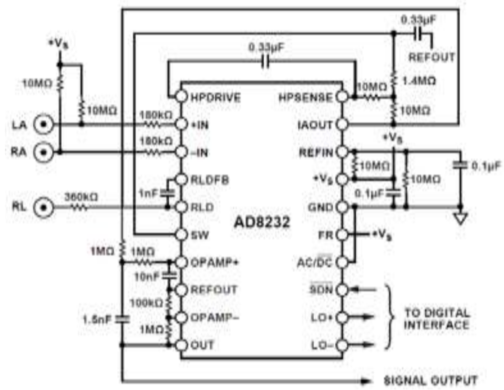

***Fig. 6**. CAD Monitoring Circuit*

2.1.7 Analog-to-digital conversion

The external ADC was connected to Raspberry Pi 3 to measure the analog data. It has high precision as it is a 16 bit, the minimum and maximum range of the values are 2^0-2^{16}. The analog value is scaled between 1-65536, the communication protocol used for this ADC is I2C. It has four addresses, which are chosen accordingly by connecting to the address pin. Even negative voltage ca also be scaled. The ECG circuit comprising of AD8232 is connected to the ADC which converts the analog continuous data to digital discrete data with a constant sampling time as only digital data can be fed to the Raspberry Pi 3.

2.1.8 Selection of processor

It is a 64-bit ARM board and has a 64-bit CPU. (CM2711) which is a Quad-core Cortex A72 on a SoC. It works about an operating frequency of 1.5 GHz and has a RAM of about 4 GB. It also has an in-built Wi-Fi module operating at 5 GHz. Two separate USB port is provided for data communication. I2C communication is the common protocol based on the chip to chip communication. Multiple devices can be connected with the Raspberry Pi 3 board with a unique address. ADCS115 is connected to it for digital signal transformations the ECG circuit output is in the form of analog data. The internal processing of data is done on the digital data. The reference model created using the CAD algorithm is fed to the processor. And real-time data is stored in the internal storage and compared with that of the reference model. In case of any kind of abnormality, an alert message is triggered and sent to the doctor especially in case of domestic application. Whereas in the case of commercial application, ECG data from the instrument is recorded and stored for future purposes in case of emergency.

2.2 Software Implementation

Software implementation deals with the development of an algorithm that is used to compute the reference model for normal as well as different blocks in the heart. So once when the data from the ECG signal are extracted it will be easy to compare it with the reference model created. And in case of any abnormality, the processor takes the necessary action.

2.2.1 Development of CAD algorithm

An algorithm was developed to identify the ECG signal and extract the feature via Fourier Series. The time the function 'u(t)' represents a signal in variation with time 't' is a of fourth-order given in the equation (8-9).

Time period T=1000ms & L=T/2=1000/2=500 (8)

$u(t)=-0.0001(t-10)^4+2.5$ (9)

The signal 'u(t)' is represented as the Fourier series expansion in the equation (10-15),

$$A_0 = \frac{1}{L}\int_{-L}^{L} u(t)dt = 0.15 \quad (10)$$

$$A_n = \frac{1}{L}\int_{-L}^{L} u(t)\cos\left(\frac{n\pi t}{500}\right)dt \quad (11)$$

$$A_n = -4 * 10^{-10}(5.6 * 10^8 n^4 sin0.25n + 8.1 * 10^{10}n^3 cos2.51 - 1.8 * 10^{11}n^2 sin0.2n + 2.55 * 10^{12} sin0.35n - 3.10 * 10^{13} ncos0.25n + 9.11 * 10^{11}n^2 - 4.08 * 10^{12}n)/n^4 \quad (12)$$

$$B_n = \frac{1}{L}\int_{-L}^{L} u(t).\sin\left(\frac{n\pi t}{L}\right)dt \quad (13)$$

$$B_n = 4 * 10^{10}(5.6 * 10^8 n^4 cos0.25n + 8.1 * 10^{10}n^3 sin2.51 - 1.9 * 10^{12}n^2 cos0.251n + 2.45 * 10^{14} cos0.25n - 3.08 * 10^{13} nsin0.25n - 6 *$$

$$u(t) = \frac{0.15}{2} - 4 * 10^{-10}(5.6 * 10^8 n^4 sin0.25n + 8.1 * 10^{10}n^3 cos2.51 - 1.8 * 10^{11}n^2 sin0.3n + 2.49 * 10^{11} sin0.25n - 4.08 * 10^{13} ncos0.25n + 8.31 * 10^{11}n^2 - 4.08 * 10^{12}n)/n^4 + 4 * 10^{10}(5.6 * 10^8 n^4 cos0.25n + 8.1 * 10^{10}n^3 sin2.51 - 1.9 * 10^{12}n^2 cos0.251n + 2.45 * 10^{14} cos0.25n - 3.08 * 10^{13} nsin0.25n - 6 * 10^8 n^4 + 1.94 * 10^{12} * n^2)/n^5 \quad (16)$$

The first 20 terms of the expansion are considered from the u(t) which actually represents the QRS portion of the ECG signal.

2.2.2 Extended CAD algorithm

The time period remains the same but the function u(t) used is slightly changed accordingly. The u(t) is represented as,

$$u(t) = \begin{cases} -0.0001(t-10)^4 + 2.5 \\ -9.4 * 10^{-5}(t-300)^2 + 0.6 \end{cases} \quad (17)$$

After estimating the coefficients A0, An and Bn from the Fourier Series, the resultant waveform generated as shown in the equation is used as the reference to compare with the data available from the cloud. Finally, a reference model is created and compared with the data and then accordingly different types of block are determined.

2.2.3 Implementation of Graphic User Interface (GUI)

Tk GUI toolkit is a graphical user interface developed in the Python platform. It is the most commonly used platform for various applications. Here it is used to develop an application related to study the ECG signal. It comprises an ID field and password for authenticated users. Python with tkinter output is easy and fast enough to develop GUI interface. The data from the instrument is stored and can be accessed anytime. Live streaming of digital data can be accessed and used in commercial mode as shown in Fig. 7 (a) & (b).

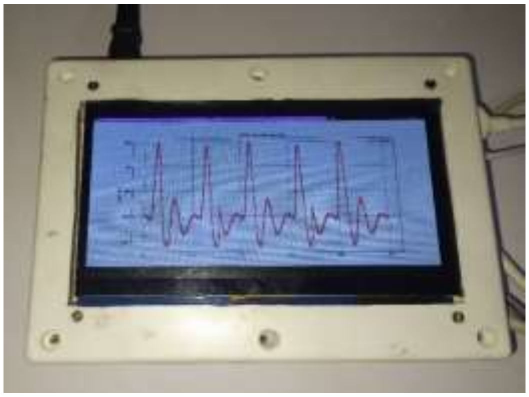

Fig.7. *(a) Software implementation using Python IDE*

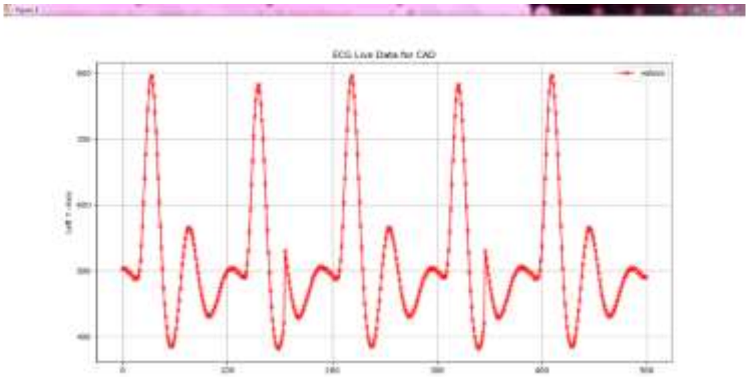

Fig.7. *(b) ECG screenshot using Python IDE*

2.2.4 Ubidots-IoT based ECG monitoring

Ubidots is a software platform to develop IoT and is a user self-design application. This app consists of features like Dashboard which displays the sensor data, alert on event, analytics that involves mathematical and statistical analysis of the data and it can be easily converted o CSV files. The ECG data is stored in the dashboard, the digital data from the analog graph is compared with that of the reference developed from the CAD algorithm. This application is designed for the domestic application where the physicians may not be available with the patients all the time. So, the data is stored in the cloud and accessed anytime by the technicians. During any kind of abnormality, an alert message is sent to the doctor's concerned as shown in Fig. 8 (a) & (b).

Fig. 8. *(a) Software implementation using Ubidots (IoT)*

Fig. 8*. (b) ECG Screenshot using Ubidots (IoT)*

3 RESULT AND DISCUSSIONS

Different types of blocks are classified using Table. 1 (a) & (b). So, this analysis is done on the obtained ECG results of the subjects through the Scilab software package. The different conditions and their graphical representation through Scilab are as follows:

Table. 1*. (a) Different types of Block and its parametric values*

S.NO.	Heart Abnormality Condition	Rhythm Pattern	Heart Beat per min	Duration of PR interval (s)
1	First Degree AV block	Regular	60-100	0.12-0.2
2	Second degree type I	Regular	60-70	0.25
3	Second Degree Type 2	Regular	60-70	0.12
4	Left bundle branch block (right)	Regular	60-70	0.12
5	Left bundle branch block	Regular	60-70	0.12
6	Third degree AV block	Regular	60-70	0.12

Table. 1*. (b) Different types of Block and its parametric values*

S.NO.	Heart Abnormality Condition	The time duration of the QRS complex (s)	Amplitude of P-wave (mV)	R height magnitude (mV)	ST-Segment with x-axis
1	First Degree AV block	0.10	0.10	2.5	Normal
2	Second degree type I	0.10	<0.25	2.5	Normal in baseline
3	Second Degree Type 2	0.13	0.25	2.5	Normal in baseline
4	Left bundle branch block (right)	0.14	0.25	2.5	Normal in baseline
5	Left bundle branch block	-0.14	0.25	2.5	Normal in baseline
6	Third degree AV block	0.12	0	2.5	Normal in baseline

3.1 Determination of First-Degree Atrioventricular Block (FD-AVB)

This is a kind of medical condition in which the atrioventricular node the electrical conduction is slowed down thereby increasing the total time taken by the action potential for transmission. The total time duration of the PR interval for a healthy person was observed around 0.13-0.21 sec. If the interval is quite longer than that of 0.21 sec then the condition is termed as First Degree AVB which is shown in Fig. 9. Initially, the sinoatrial node is fired which results in atrial depolarization as a result P wave is generated. Gradually it spreads across the AV node due to which there is a small delay in conduction to the ventricles. The impulses would sufficiently take a longer time to reach the ventricles due to this delay thereby increasing the interval of the P wave.

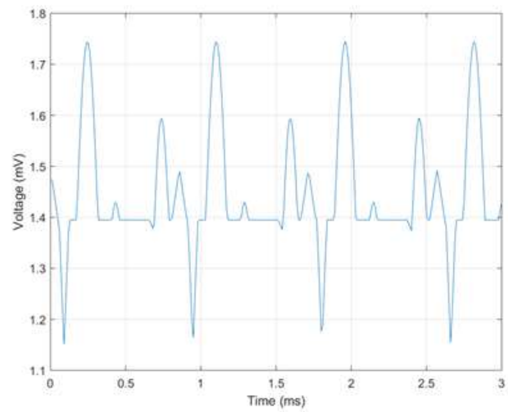

Fig. 9*. Scilab ECG graph with First Degree AVB*

3.2 Determination of Second-degree block (SD-AVB)

There are two subcategories of second-degree AVB. Type 1 kind of medical condition is benign in nature but the type 2 kind of condition may need a biventricular pacemaker for the patients. For SD-AVB Type 1, the QRS complex width is small in relation to the length and the interval between PR wave is quite long, this medical condition is also known as Wenkebach as shown in fig. 10(a). For SD-AVB type 2 condition the duration of the QRS complex is extended but not many changes observed in PR interval which is shown in fig. 10(b). In both cases of Type 1 and Type 2, the rhythm pattern is normal

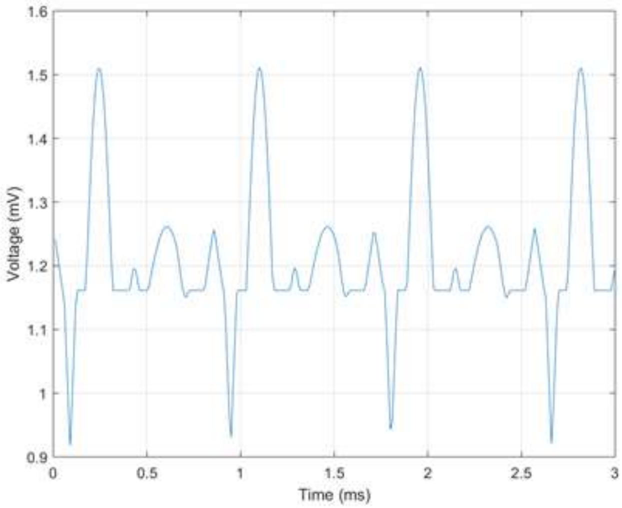

***Fig. 10**. (a) Scilab ECG graph of Second-degree AV block type 1*

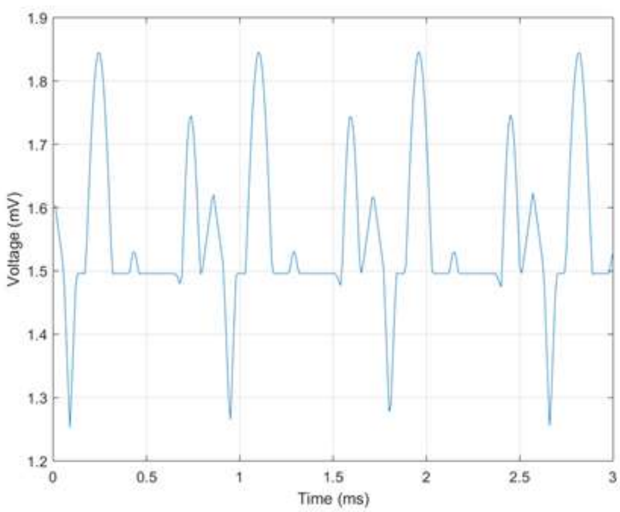

***Fig. 10**. (b) Scilab ECG graph with Second-degree AV block type 2*

3.3 Determination of Right/ Left bundle branch block (R/L BBB)

There are certain important features of the RBBB and LBBB which is discussed below,

•Around 120.5 ms time for the existence of the QRS complex.

•Q wave is not present in lead 1,5 and 6.

•In the QRS complex, the R wave doesn't change the shape in lead 1,5, and 6.

•T wave gets displaced from the ST segment and completely distorts the QRS complex.

The QRS complex in the case of LBBB is quite wide which is greater than 120.5 ms especially found at the lead 1 and the also the complex is directed downward as shown in fig. 11(a). In the case of RBBB, in the lead 1, the QRS complex remains wide but this time the complex directed upward unlike in the case of LBBB as shown in fig. 11 (b).

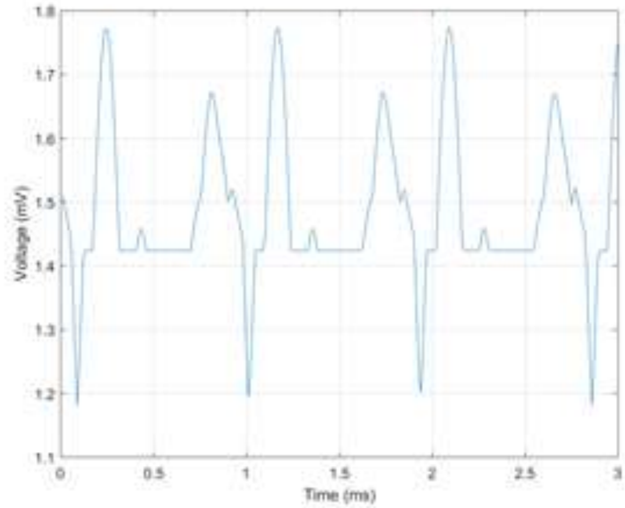

***Fig. 11**. (a) Scilab ECG graph with Right bundle branch block*

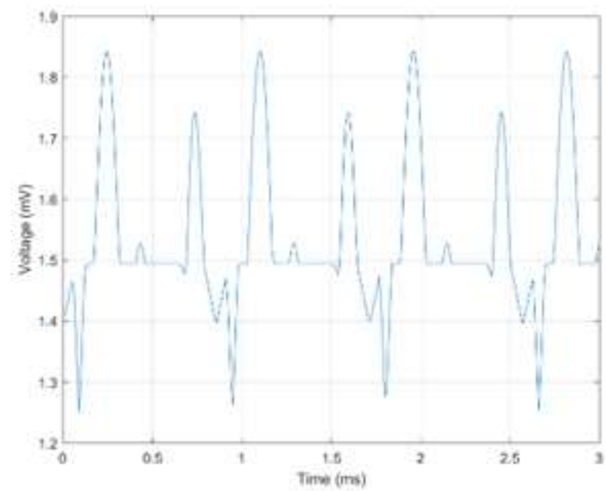

***Fig. 11**. (b) Scilab ECG graph with Left bundle branch block*

3.4 Determination of Third-degree AV block (TD-AVB)

TD-AVB is also known as a complete block. In the AV node, no conduction occurs as there is no action potential to conduct. Atrial depolarization has no relation to that of ventricular depolarization or else the P wave and QRS complex are not synced with each other. The rate of occurrences of these segments was different which is shown in figure 12. Ventricles don't have the capability to produce a faster rate of action potential. As this action potential doesn't develop from atria. This is why the QRS complexes become very slow and the heartbeat is also reduced but the atrial rate is around 100 bpm when compared to that of ventricular rate.

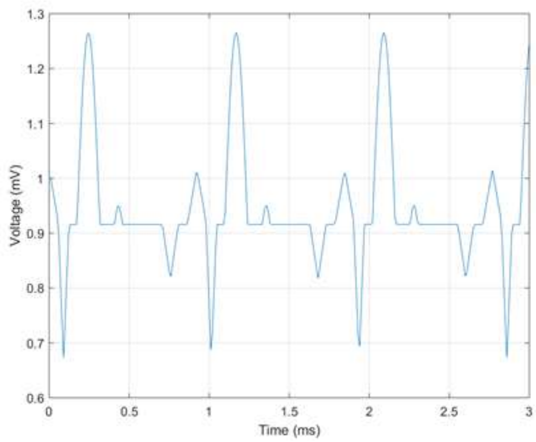

Fig. 12. *Third-degree AV block.*

4 CONCLUSION AND FUTURE SCOPE

The proposed system has been developed on the basis processor Raspberry Pi 3. The mosquitto MQTT client program is used to capture the ECG sensor data from the AD8232 module through 16-bits ADC ADS1115 and publish the data to the cloud. An algorithm was developed for feature extraction from the ECG data. The end-user in this case a physician needs not to visualize any kind of data. Directly the status of the block is updated in the server and anytime anywhere this data can be accessed for further treatment. The extension of the work can be achieved by developing a higher-end software platform for detecting the pattern of heart block much before its onset. The health condition was sent to the health departments concerned via message or email alert or any other kind of notification at the critical stage.

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