

# Signal Processing and Data Analysis of IoMT based 12 lead Electrocardiogram Signal

Shreya Chandrasekhar<sup>1</sup>, Gargee Vaidya<sup>1</sup>, Sandeep Vaidya<sup>2</sup>

<sup>1</sup>Student, Institute of Technology, Nirma University, Gujarat, India

<sup>2</sup>Director, Dazzle Robotics Pvt. Ltd., Ahmedabad, Gujarat, India

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**Abstract** - The electrocardiogram (ECG) has always been a popular measurement scheme to assess and diagnose cardiovascular diseases (CVDs). These electrical activities of the heart are visualized in the form of a waveform and its analysis can turn out to provide valuable insights about the functioning and normalcy of a healthy heart or detect a wide range of possible heart risks. This study deals with the Internet of Medical Technologies (IoMT) based healthcare monitoring system which diagnoses the ECG signals and hence manifests essential heart conditions. An electrocardiograph machine captures medical-grade patient heart data. The usage of the medical device is highly convenient, easily accessible and most importantly very accurate. The outcome of the project includes detecting the heart rate, the various interval and segment analysis of the signal, cardiac axis detection as well as prompting the various possible conditions in case of anomalies in the heart activities. In such cases, the system can send an automatic ECG report of the patient to the doctor. It can be further modified to generate a call in case of critical condition and provide urgent medical assistance.

services. In such situations the possibility of regular health checkups is a challenge as well.

In order to combat such issues, we can utilize the concept of IoMT (Internet of medical things) and develop a portable ECG healthcare device. The portable device can be made to be associated with a mobile app to make the process user friendly as well as faster and more accessible.

The Electrocardiogram also known as ECG or EKG depicts the measure of the electrical activity of the heart. The ECG consists of P, QRS and T waves and various intervals which can be analyzed to leverage prime requirements like the heart rate as well as the conditions and risks in the functioning of the heart. The amplitude (in millivolts) and the intervals (in milliseconds), are essential values to classify the signal as being in the normal range or not. Cardiac Arrhythmia shows a condition of abnormal heart activity which is a threat to humans. For cardiac patients, the timely detection of arrhythmia is very crucial. By examining any anomalies in the ECG signals, clinicians can identify a multitude of cardiac disease conditions.

**Keywords:** Electrocardiogram, Cardiovascular Diseases, Internet of Medical Technologies, Feature Extraction, Cardiac Axis.

## 1.1 12 Lead ECG machine

## 1. INTRODUCTION

Cardiovascular diseases have consistently been the leading cause of death and disability in the world till date. In 2019 World Health Organization, quoted it to be world's number one killer, causing over 17.9 million deaths per year. 80% of these deaths are caused by coronary heart diseases like heart attack and cerebrovascular diseases like stroke. Middle aged and elderly people are usually the prime targets. [1]

A picture of the electrical activity of the heart is provided by the 12-lead ECG machine. Ten different leads are used which give a visualization of the heart activity from twelve different views. These leads are placed on the limbs and chest of the body. They capture the electrical signals from different angles. The 12 leads are namely: lead1, lead2, lead3, V1, V2, V3, V4, V5, V6, aVR, aVL and aVF. The electrodes are placed on the chest, wrists, and ankles [2]. The spatial information about the heart's electrical activity in three orthogonal directions, namely, right and left, superior and inferior, anterior and posterior can be obtained using a 12 lead ECG machine. Fig -1 clearly elucidates the 12 views offered by the 12 leads.

Healthcare systems and especially health monitoring and its related technologies is one of the evergreen and most advancing applications. It is the need of the hour to leverage the advances in the technology in the healthcare sector and develop an efficient heart monitoring system. The unavailability of doctors or medical equipment as well the distance between the doctors and the patients turn out to be major obstacles in up-scaling the quality of medical

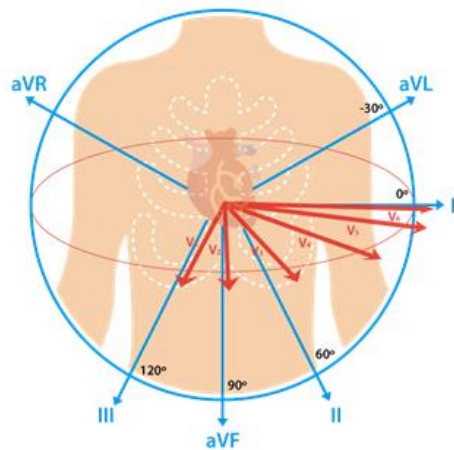


Fig -1: Vector representation of Lead 1, 2, 3, aVR, aVL and aVF [3]

### 1.1.1 Transverse Leads

The transverse leads are responsible for providing a horizontal plane view of the heart activities. V1, V2, V3, V4, V5, and V6 are the 6 chest electrodes used for this purpose [4]. The placement of these six electrodes on the human body is as follows:

- V1 - Right sternum's 4<sup>th</sup> intercostal space
- V2 - Left sternum's 4<sup>th</sup> intercostal space
- V3 - Midpoint of V2 and V4
- V4 - Midclavicular line's 5<sup>th</sup> intercostal space
- V5 - Anterior axillary line (at a horizontal level as V4)
- V6 - Mid-axillary line (at the same horizontal level as V4 and V5)

Fig -2 illustrates the placements of all the six leads. Being unipolar, the transverse leads require only a positive electrode. They have a common negative pole which is at the center of the heart.

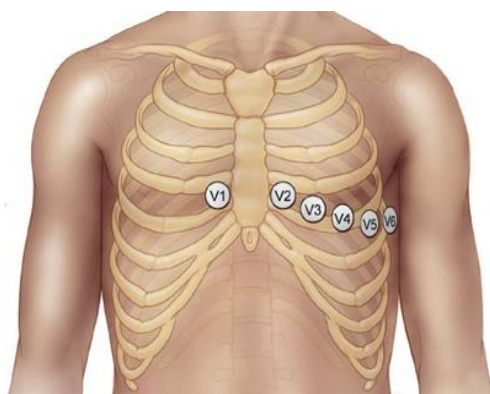


Fig -2: Placement of 6 chest leads [4]

### 1.1.2 Frontal Leads

Frontal leads, enable the view of the heart as projected on a vertical plane. It uses 4 four electrodes which are placed on the limb. Information can be obtained from the six frontal leads. The six frontal leads are - Lead I, Lead II, Lead III, Augmented Vector Right (aVR), Augmented Vector Left (aVL), Augmented vector foot (aVF) [5]. The augmented leads are unipolar whereas the other three are bipolar and hence require a positive as well as a negative electrode for analysis. The polarity of the six leads can be understood visually through Fig -3.

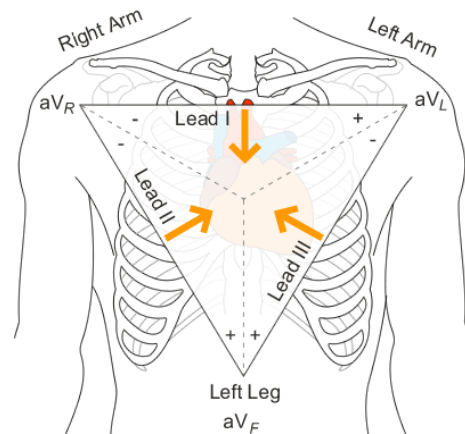


Fig -3: Polarity of limb electrodes [5]

### 1.2 Understanding the ECG signal

The ECG signal can be divided into P wave, QRS wave and T wave. Important information related to the heart functioning can be analyzed by interpreting these waves and other intervals and segments. Fig -4 illustrates the various intervals and segments in the ECG signal. [6]

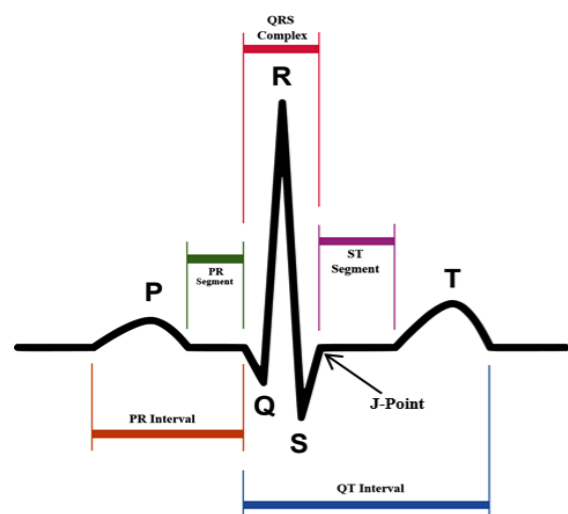


Fig -4: Various intervals and segments in the ECG signal [6]

- **P Wave**

With respect to the functioning of the heart, the left and right atrium's depolarization as well as the atrial contraction can be indicated by the P wave. The atrial contraction takes place a split second after the P wave begins.

- **QRS Complex**

The Q wave, R wave and S wave together make up the QRS complex. It represents the ventricular depolarization and hence depicts the electrical impulse spreading through the ventricles. Conventionally, the Q wave is always negative and the R wave is the first positive wave of the complex followed by the S wave which is the first negative deflection after an R wave.

- **T Wave**

T wave shows ventricular repolarization. It is asymmetrical and its peak is slightly closer to its end than to its beginning.

### 1.3 Cardiac Axis

The axis of the ECG is one of the important parameters which denotes the direction of the cardiac activity. It can be normal, leftward, rightward or indeterminable. A leftward axis indicates left axis deviation, or LAD. A rightward axis indicates right axis deviation, or RAD. The limb leads or the frontal leads are used for determining the cardiac axis [7]. Fig -5 indicates the various limb leads and their corresponding cardiac axis angles.

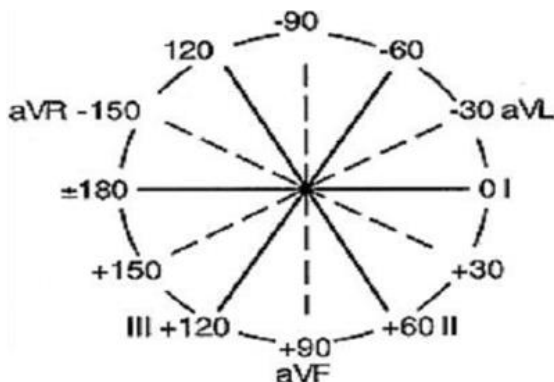


Fig -5: Axes of the leads [7]

The entire study has been organized as follows. Section 2 consists of the literature review. Section 2.1 gives an account of the traditional approaches which were adopted so far for analyzing ECG signals. Section 2.2 further gives a description of the various methods and approaches adopted by other fellow researchers. Finally, 2.3 elaborates on the tools and technologies involved in the proposed system. Section 3 gives a detailed description of the work done. Section 3.1 describes the complete flow of the project followed by section 3.2 where the conversion of raw data to processable format is discussed. Section 3.3 deals with the filtering of the received raw signal and section 3.4 is about

the feature extraction. Section 3.4 is further divided into 2 sub sections in which the Features like heart rate, peak detection and axis detection are highlighted. Section 4 is a detailed description of the results obtained and its discussion followed by chapter 5 which summarizes the study and provides the conclusion.

## 2. LITERATURE REVIEW

### 2.1 Traditional ECG Analysis Approach

ECG strips are commonly used to record the ECG signals. They are a kind of a graph paper which has grid like boxes. The boxes are 1 mm<sup>2</sup> in dimension. 25 mm/sec is usually the speed of the paper. Hence 0.04 seconds is the time interval of each 1mm horizontal box. 10 mm is equivalent to 1mV as per the standard calibration. The required information of the speed and calibration can be found at the bottom of the paper. [8]

P, QRS and T waves and their amplitude, deflection, and their duration are measured using this ECG strip and, ECG interpretation is done [9]. The vertical squares in the graph are used to measure the amplitude in terms of the voltage of the heartbeat. Based on the lead under consideration, the deflection will vary. Figure 6 shows a typical ECG strip with the 12 lead reading

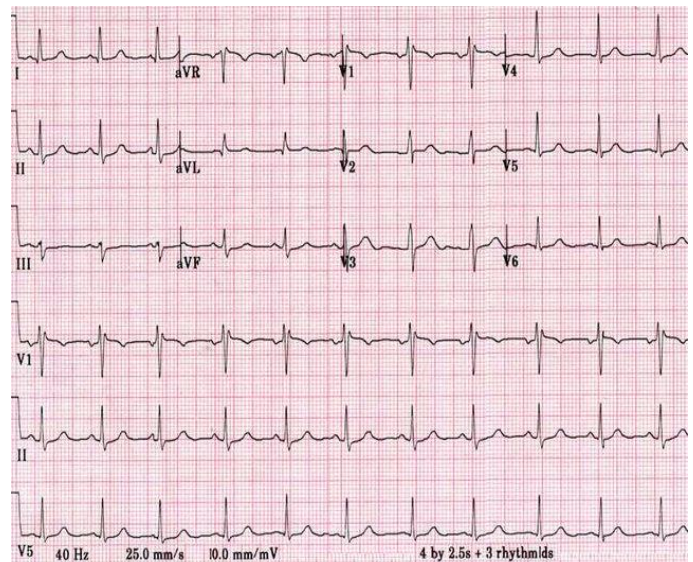


Fig -6: ECG strip with readings of 12 leads [10]

Such ECG strips are manually analyzed to interpret information about the heart rate, P, QRS, T waves, intervals, segments duration, wave amplitude, deflection and cardiac axis. The latest technology can be effectively used to rule out the manual and tedious process of counting and measuring the squares which is error prone. It could be made more time efficient along with improved accuracy in results.



## 2.2 Approaches by other researchers

Several approaches have been adopted to apply the technological advancements in the welfare of healthcare. In the paper “ECG beat classification based on PNN and wavelet transformation”, wavelet transformation technique and Probabilistic Neural Network(PNN) has been used for feature extraction. The PNN classifier was used to separate 6 kinds of ECG beats. The accuracy achieved was 99.65% [11]. Another such approach was adopted using Wavelet transform analysis technique for QRS complex detection and Peak detection on MATLAB in the paper, “Analysis of Electrocardiogram using WT”. The accuracy obtained was 99.8% and various abnormalities and their features were compared as well [12]. In “Acquisition, Filtering and analysis of Electrocardiogram using MATLAB”, similar detection of QRS interval, amplitude and other intervals was done using MATLAB Toolbox and a comparison of the extracted features of QRS complex were compared with that of the normal waves. [13]

Wavelet transform and non - adaptive filter approach was proved to be easier and convenient in the paper “Study & analysis of Electrocardiogram signal using MATLAB & LabVIEW as effective tools”. The QRS complex, heart rate as well as various abnormalities were detected using wavelet transform digital filter [14]. To make the monitoring more convenient, GUI based approach was adopted in “Monitoring of Heart rate and detection of PQRS based on GUI, MATLAB”. The system could identify P, Q, R, S, T waves and the heart rate. [15]

## 2.3 Details of tools and technologies used

The ECG data was procured from a portable electrocardiograph machine, that captures medical-grade patient heart data. With a responsive 500 Hz refresh rate, the ECG capturing instrument is simultaneous, smooth, and incredibly accurate. The specifications of the ECG machine used are:

- ARM@Cortex@-32-bit RISC core operating at a frequency of 48 MHz
- High speed 1 MSPS (Million samples per second) accurate 12bit ADC with high gain amplifiers
- BLE 4.0 with 1MB data buffer
- Low power standby for long battery life
- Total time to take reading and analysis of data is less than 20 seconds
- Data transfer with server uses AES-256 encryption and authentication is done using 4096-bit key pair

The entire backend was developed in Python and the testing of the code was done on the Ubuntu 20.04 LTS test server.

## 3. METHODOLOGY

### 3.1 Project Flow

The signals captured by the instrument are sent to a mobile application. The received signals are encrypted in the binary format and this data is sent to the server to run the backend code through an API call. The code decrypts the signal, extracts the readings of all leads and graphs of all these leads are plotted. These signals are passed through some filters for performing denoising of the signal. Clinically important features such as peaks, intervals, amplitudes and axes are extracted from the filtered ECG signal data using signal processing techniques. These features are significant in determining various heart diseases, based on their values. Fig -7 depicts the entire project flow from capturing the ECG signals to sending the report to the mobile application.

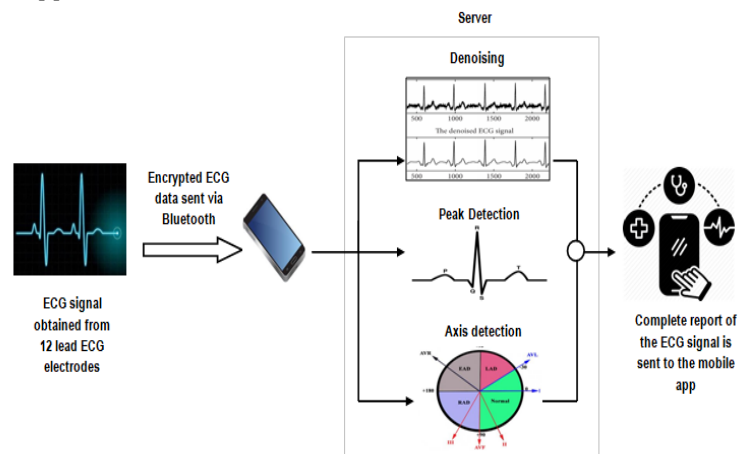


Fig -7: Complete project flow

### 3.2 Conversion of raw data into processable format

The raw data coming from the mobile application is in the binary format and is 80,000 bytes long. The data is further reshaped such that there are 5000 samples. In order to process the data and extract various features from it, the data is converted into a processable format by implementing an algorithm. The final data is obtained in an integer format with the values corresponding to all 12 leads. Fig -8 shows the graph of all the leads of an ECG of a healthy patient.

### 3.3 Filtering

Due to noise, the signal gets distorted and this makes the process of feature extraction less accurate. Pre-processing involves removing noise from the input ECG signal. This project involves making use of Butterworth filters to reduce the noise. The filter is designed using the following: [16]

$$[B, A] = \text{butter}(n, w_n)$$

Here,  $n$  is the order of the filter and  $w_n$  is the cut off frequency. B (numerator) and A (denominator) are the filter coefficients Fig -9 and Fig -10 show the original and the filtered signal of lead 2 of an ECG signal, respectively. It consists of 5000 samples.

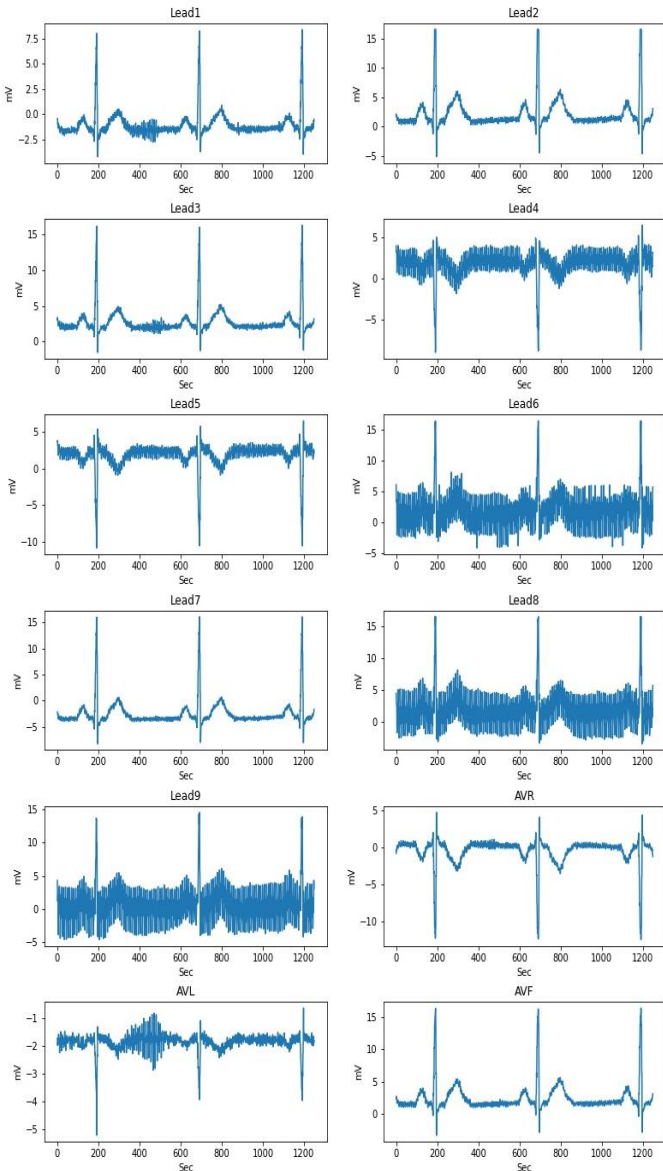


Fig -8: Graphs of all 12 leads of a healthy patient

### 3.4 Feature Extraction

For a proper disease diagnosis, it is essential that the clinically important features of an ECG signal must be detected accurately. These features are extracted using Python programming and the disease is predicted according to the range of the values of features such as amplitude, intervals and axis.

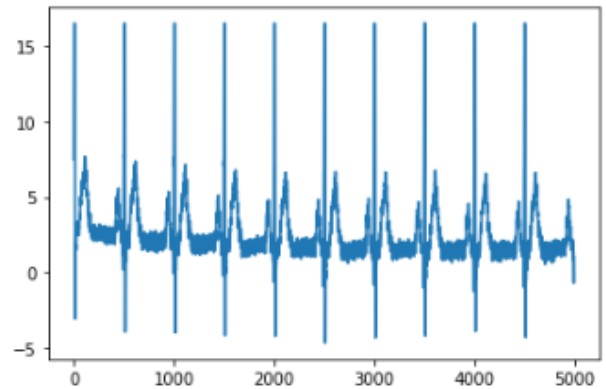


Fig -9: Original Signal

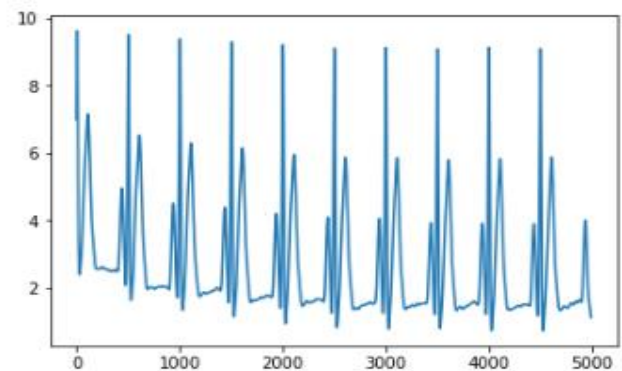


Fig -10: Filtered Signal

#### 3.4.1 Heart rate and Peak Detection

The P, Q, R, S, T waves are electrical illustrations of the contractile activity of the heart. Detecting the main characteristic features in an ECG is one of the most important tasks, and the performance of a cardiovascular analysis method depends on the accurate detection of these features. The R peak in the QRS complex is the most prominent feature for analyzing the ECG data and hence, it is detected first. The R peaks can be extracted from the ECG signal by using various algorithms such as PanTompkins, Hamilton, Christov, etc. The Lead 2 is mainly used for peak detection purpose since it provides a good view of the waves. Fig -11 shows the detected R peaks of Lead 2.

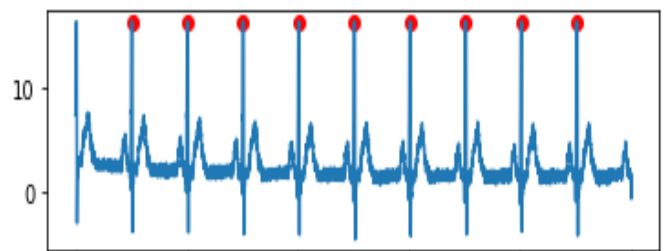


Fig -11: Detected R peaks (Lead 2)

The heart rate (in beats per minute) is measured with the help of the detected R peaks. A condition is set for determining if the heart rate of a patient is in the normal range or not. The following conditions specify the normal range of heart rate and the diseases corresponding to the values lying out of this range.

- Normal range: 60 - 100 bpm
- Tachycardia: heart rate > 100 bpm
- Bradycardia: heart rate < 60 bpm

The remaining peaks as well as the peak onsets and offsets are detected using discrete wavelet transform method. Some important intervals and segments are calculated with the help of these peaks. Based on the standard range of these intervals, various heart risks can be predicted. Table 1 suggests the recorded values of these features in a healthy person.

**Table -1:** Standard conditions for significant cardiovascular features

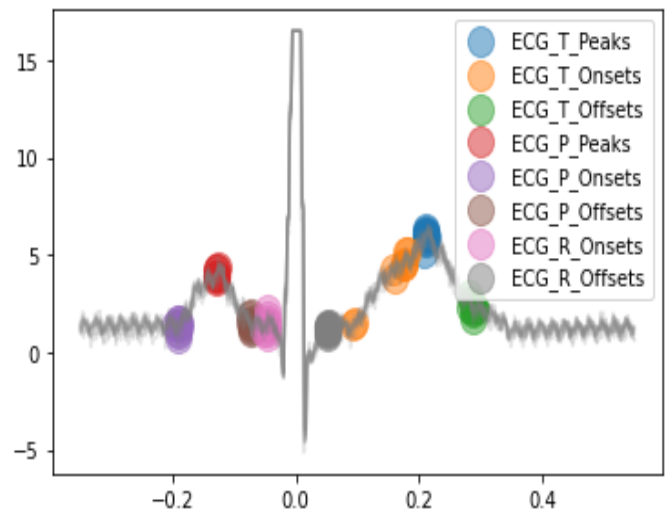
Features	Standard Conditions
PR Interval	120 - 220 ms
QRS Width	> 120 ms
QT Interval	>= 400 ms (for males) >= 440 ms (for females)
P wave Amplitude	< 3 mV
P wave terminal negative deflection	< 1 mV

It is necessary that the conditions mentioned in Table 1 must be fulfilled in order to ensure a healthy cardiovascular system. Fig -12 and Fig -13 show an individual heartbeat extracted from a recorded ECG signal (Lead 2) of a healthy patient and its corresponding features such as peaks, onsets and offsets. These will be further used for calculating various intervals.

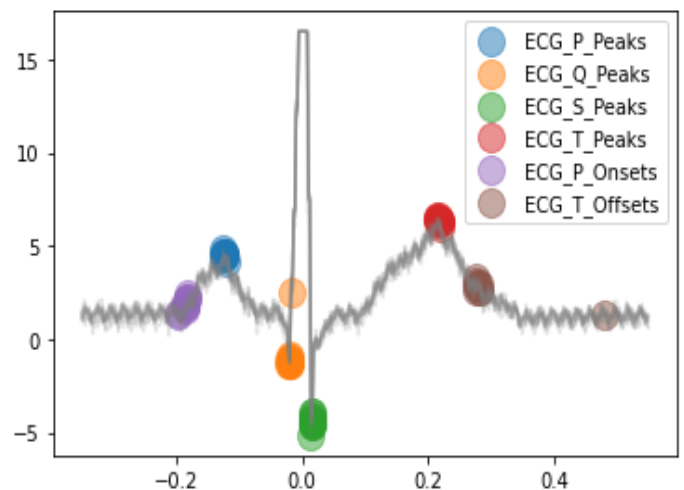
### 3.4.2 Axis Detection

Cardiac axis is the net direction of the electricity at the time of ventricular depolarization. Cardiac axis helps to confirm diagnosis or provide additional evidence of the presence of certain conditions [17]. Several methods are used to calculate the cardiac axis. One of the most clinically accurate methods has been implemented in the project.

This method takes into account the lead 1, aVF and lead 2. It is referred to as the three lead method [18]. The various axis conditions can be summarised as per Table 2. The leads are said to be positive when the R wave amplitude is greater than the S wave amplitude, equiphasic when both amplitudes are equal and negative when the R wave amplitude is lesser than that of the S wave.



**Fig -12:** Detected peaks, onsets and offsets - I



**Fig -13:** Detected peaks, onsets and offsets - II

**Table -2: Conditions for axis detection**

Axis type and its angle (in degrees)	Lead I	Lead II	aVF
Normal Axis (0 to +90)	Positive	Positive	Positive
LAD Physiological (0 to -30)	Positive	Equiphasic	Negative
LAD Pathological (-30 to -90)	Positive	Negative	Negative
RAD (90 to 180)	Negative	Positive	Positive
Extreme Axis (-90 to -180)	Negative	Negative	Negative
Indeterminate	Equiphasic	Equiphasic	Equiphasic

**Table -3: Characteristic features of some abnormalities [19]**

Name of Abnormality and its range	Characteristic Features
Prolonged PR interval (>200 ms)	Atrioventricular Delay
Prolonged PR interval (>220 ms)	1st degree AV block
Short PR interval (<120ms)	Pre-excitation syndromes
Width of QRS (>120 ms)	Wide QRS Tachycardia/Slow Ventricular Depolarization
High P amplitude (> 3mV)	P- Pulmonale
Left axis deviation	Left Ventricular Hypertrophy
Right Axis Deviation	Right Ventricular Hypertrophy
Extreme axis deviation	Misplaced limb electrodes/ Ventricular Tachycardia (if QRS complex wide also)

**Table -4: Results**

Patient	PR Interval (ms)	QRS width (ms)	P amplitude (mV)	Axis (degrees)	Diagnosis
Subject 1	145	98	2.84	0 to 90 (Normal axis)	Healthy
Subject 2	143	99	2.71	0 to 90 (Normal axis)	Healthy
Subject 3	117	101	1.62	0 to 90 (Normal axis)	Possibility of Pre-excitation syndromes
Subject 4	111	109	1.83	90 to 180 (Right Axis Deviation)	Possibility of Pre-excitation syndromes, Possibility of Right Ventricular Hypertrophy
Subject 5	124	95	1.61	0 to 90 (Normal axis)	Healthy



## 4. RESULTS AND DISCUSSION

An ECG signal contains important pointers indicating diseases afflicting the heart. Some heart risks corresponding to the values which lie out of the normal range of features are presented in Table 3. It states some of the main characteristic features corresponding to the abnormal values of the cardiological features. The Table 3 has been used as a reference for predicting the possibility of a certain heart disease according to the values of the different parameters of an ECG signal.

Based on the conditions mentioned in Table 3, for determining heart diseases, a report was generated for different patients. The Table 4 indicates the diagnosis done by the model based on the results obtained.

The Table 4 indicates various possible heart risks diagnosed with the help of the main characteristic features. The model takes into account all the conditions which are set, and accordingly predicts the possible cardiovascular conditions accurately. This provides a quick review of the patient's health status to the doctor and thus the diagnosis is accelerated. A solution can be provided by the doctor, on an urgent basis, in case of critical conditions.

## 5. CONCLUSIONS

This software provides an end to end platform, right from capturing the ECG data from the hardware device to providing the results on the mobile application. The entire process of analyzing the ECG signals to generate a report, is completely automated, and requires no manual support. It is easy to use and provides accurate results because of the use of highly efficient signal processing algorithms. The filter effectively eliminates noise from the distorted ECG signal. After testing on various patients, it can be concluded that the method is implementable on all kinds of ECG waveforms. A proper diagnosis can be carried out by finding out all the features and comparing it with the standard values, to find out if the patient is cardiologically healthy.

## ACKNOWLEDGEMENT

We would like to thank Dr. Ruchi Gajjar ma'am for her unceasing ideas and constant encouragement.

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