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# Detection and Processing of the R Peak

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**Abstract**: Electrocardiogram (ECG) is a commonly recorded bio-signal that captures the electrical activity of the heart. Identifying various features and traits could help us detect the normal and pathological physiology of the heart, thus providing valuable information about the activity of the human heart which is a very important step in ECG signal analysis. Computer processing of ECG has evolved as an emerging tool in medical diagnosis for effective treatments. The work proposed in this paper deals with the detection of the R peak and its feature evaluation and reviews and summarizes the various techniques used by researchers in order to detect the same. ECG signals in this work are collected from several places and it has been implemented using MATLAB routine consisting of four different databases formats. The processing of the data was done on the Lead-II ECG signals.

**Keywords**: Electrocardiogram (ECG), R Peak, Lead-II Configuration, Pan Tompkins Algorithm, Matlab

## I. INTRODUCTION

Heart being the most imperative organ of the human body, pumps oxygenated blood throughout the body [1]. The electrical manifestation of the contractile activity of the heart's myocardium is termed as Electrocardiogram (ECG). It is a realistic record of the direction and magnitude of the electrical commotion generated due to depolarization and repolarization of the atria and ventricles [2]. Willem Einthoven invented the ECG in 1901 which today, is recorded in an image consisting of all 12 channels or lead recordings interlaced 3 second intervals from combinations of leads per row. They often occur in the same order, all occurring aligned in columns:

First row: I, AVR, V1, V4; Second row: II, AVL, V2, V5; Third row: III, AVF, V3, V6

Since distinct diseases manifest differently in each of the leads, it is important to isolate the different leads. The ECG noises due to interferences like electrode contact, motion artifacts, base-line drift and instrumentation noise generated by electronic devices, electrosurgical noise, and muscle contraction sometimes hamper the signal [3]. Accurate measurements of ECG parameters are an important requirement for ECG analysis and this could be done using signal processing.

## II. THE CARDIAC MORPHOLOGY

The ECG is represented by a recurrent wave sequence of P, QRS, T and U wave and also segments, intervals and joint associated with each human heartbeat as shown in Fig 2. Various features of an ECG are described in the table below in table 1.

Table 1: ECG Features and their Description

| FEATURE | DESCRIPTION |
|---|---|
| **P WAVE** | P-waves represent atrial depolarization. |
| **Q WAVE** | The normal Q wave represents septal depolarization and is any initial downward deflection after the P wave. |
| **R WAVE** | The R wave represents early ventricular depolarisation and is normally the easiest waveform to identify on the ECG. |
| **S WAVE** | The first negative deflection after the R wave represents the S wave indicating the late ventricular depolarization. |
| **T WAVE** | The T-wave represents ventricular repolarization. |
| **U WAVE** | U waves represent re-polarization of the Purkinje fibers that indicates the last remnants of the ventricular repolarization. |
| **P-R SEGMENT OR PQ SEGMENT** | The PR or PQ segment is the flat, usually isoelectric segment between the end of the P wave and the start of the QRS complex. This segment represents the time the impulse takes to reach the ventricles from the sinus node. |

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| | |
|---|---|
| **P-R INTERVAL OR PQ INTERVAL** | The time taken for electrical activity to move between the atria and ventricles is represented by this interval. |
| **R-R INTERVAL** | The RR-interval begins at the peak of one R wave and ends at the peak of the next R wave and represents the time between two QRS complexes. |
| **P-P INTERVAL** | It indicates the duration of atrial cycle (atrial rate). |
| **QRS COMPLEX** | The depolarization of the ventricles is represented by the QRS Complex. |
| **QT INTERVAL** | It represents the time taken for the ventricles to depolarize and then repolarize. |
| **ST SEGMENT** | The isoelectric line that represents the time between depolarization and repolarization of the ventricles (i.e. contraction) represents the ST segment. |
| **J-POINT** | The J point is the junction between the termination of the QRS complex and the beginning of the ST segment. |
| **T-P INTERVAL** | The isoelectric interval on the electrocardiogram (ECG) is TP segment that represents the time when the heart muscle cells are electrically silent. |
| **T-Q INTERVAL** | Termed as the diastolic interval through the ECG. |
| **Q-U INTERVAL** | The QU interval is a measure of the time between the start of the Q wave and the end of the U wave in the heart's electrical cycle. |

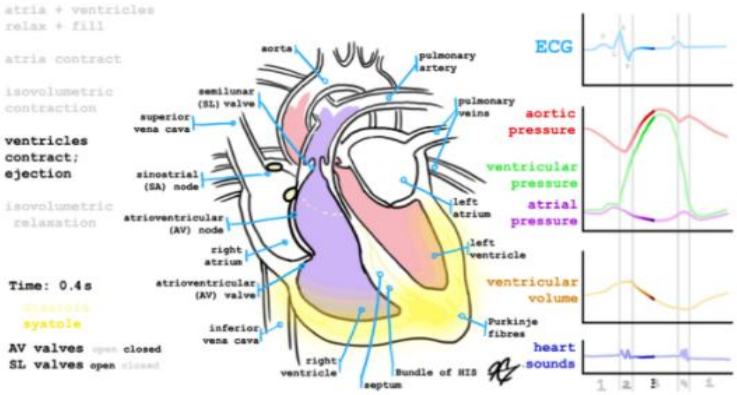


Fig. 1. The Cardiac Conduction Pathway

In the morphology of ECG signal where the normal rhythm of the heart represents no disease or disorder is called Normal sinus rhythm (NSR). For a normal heart at rest, it is considered to be from 60-100 BPM. Cardiac Arrhythmia could be defined as a disorder or disturbance or any abnormality resulting in the normal activation sequence of the myocardium giving rise to irregular heartbeat or abnormal rhythm of the heart that may cause permanent injury to the heart. Although cardiac arrhythmia is one of the leading causes of death, it can be treated if detected on time [4, 5 and 6]. Under the expert guidance of the doctors and after lots of literature review, it was seen that Lead II is the most preferred monitoring lead of choice for continuous ECG monitoring. Nowadays, ECG has become a golden medium for detecting Arrhythmia and Cardiovascular diseases and also could detect bifid P wave in lead II (P Mitrale).

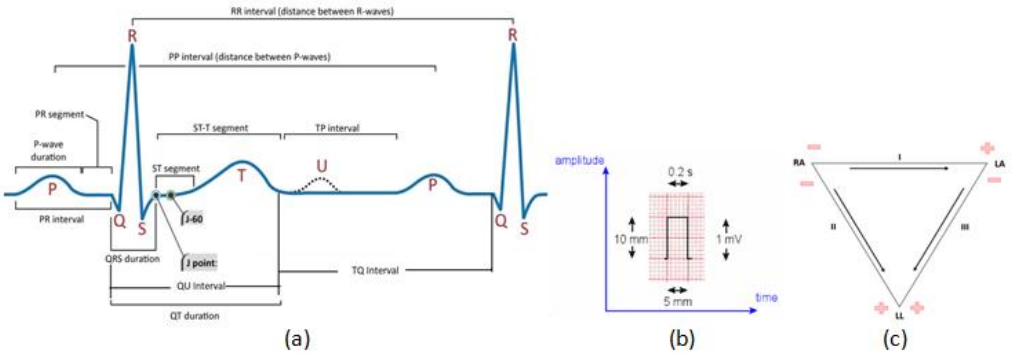


Fig. 2. The ECG (a), the Graphic Scale of an ECG (b) and the Lead-II Configuration (c)

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## III. THE IMPORTANCE OF THE R PEAK

An ECG is said to be in rhythm if it follows the sequence of waves in the order of P-QRS-T-U. Any signal disobeying the rhythm could indicate some serious peculiarities. Now, of the various morphological markers of ECG, the R Peak is considered to be the most important fiducial point in the signal due to its larger amplitude. Being the sharpest component with respect to all the other peaks in a Normal Lead-II ECG, it is considered to be a good parameter for easier evaluation. The R wave represents the electrical stimulus as it passes through the main portion of the ventricular walls. Proper detection of the R-Peak is said to have a major contribution in determining a fundamental called as the inter-beat interval (IBI) or the beat-to-beat interval, the RR interval, which is one of the intense driving factor for analyzing an ECG signal. The number of R peaks in a specific time interval translates to the heart rate (in beats per minute). The R-R interval begins at the peak of one R wave and ends at the peak of the next R wave and represents the time between two QRS complexes.

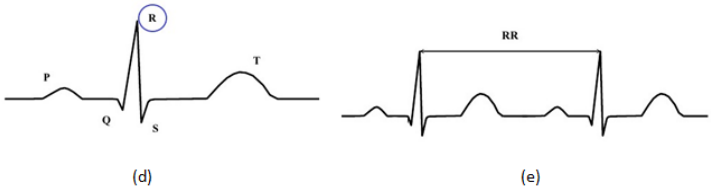


Fig.3. The R Wave (d) and the R-R Interval (e)

It plays a vital role in diagnosing heart rhythm irregularities, heart rate and can help us learn the irregularities in the various facets of the heart. This interval is one of the most significant duration as it also helps in estimating heart rate variability (HRV), which is the variation in the time interval between heartbeats and is one of the most crucial markers of autonomic activity proven to be predictive of future health related events and is also beneficial in obtaining reliable stress diagnosis.

## IV. SURVEY BACKGROUND

In a paper proposed by Kritika Bawa et al, R peaks were detected using modified Pan Tompkins Algorithm followed by calculation of R-R Interval for heart rate. Total Error Detection Rate and Sensitivity for different ECG signals were also calculated [9].

Tanushree Sharma et al, proposed a paper where QRS Complex was detected using the synchrosqueezed wavelet transform (SSWT) which consisted of synchrosqueezing to the continuous wavelet transform. Nonlinear Mapping technique was applied to detect the R peaks [10].

In a paper tackled by Sonia Rezk et al, the inter-beat intervals analysis was done using a new tool of estimation based on algebraic approach. Their idea focuses on the fact that the estimation of the R wave occurrence is considered as a Time Delay Estimation (TDE) problem. The technique detected the peaks by ignoring the peaks that preceded or followed larger peaks by less than a waiting time equal refractory period. The peaks higher than the detection threshold were termed as the R peak else noise. Also if there were no R peaks detected within 1.5 R-to-R intervals then back search was applied where if a peak higher than half the detection threshold followed the preceding detection by at least 360ms was termed as R peak [11 and 12].

Swetha Bellari et al proposed a paper of detecting R peaks using various methods and also compared the accurate method for the same. Methods like Wavelet transform, Hilbert transform, Pan Tompkins, Combination of Wavelet and Hilbert and Hilbert and Wavelet [13].

In a paper proposed by Harjeet Kaur et al, ECG was analyzed using the R-peak parameters. First the signal was processed and denoised using the hybrid linearization method, which was an arrangement of the extended Kalman filter along with discrete wavelet transform followed by detecting the R peaks using Principal Component Analysis (PCA). In PCA, first the mean of the original ECG signal is calculated, and then mean is subtracted from the original ECG signal followed by calculation of the covariance matrix, computation of the eigenvectors and formation of a feature vector by selecting components. After this, eigenvalues are squared for minimizing smaller values and maximizing larger values and then thresholding is done to retain R-peaks (larger eigenvalues) [14].

Awadhesh Pachauri et al devised a paper where detection of R wave was done using a Wavelet transform. The wavelets used for detection were Daubechies and Symmetric. The ECG signal under test had been decomposed to the required level using the selected wavelet and the selection of detail coefficient d4 had been done based on energy, frequency and cross-correlation analysis of decomposition structure of ECG signal. In wavelet transform, a linear operation transforms the signal to decompose it at different scales. In case of discrete wavelet transform (DWT), filters of different cutoff frequencies are used for analyzing the signal at different scales. The selected detail coefficient d4 is used to perform the detection of R-wave [15].

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In a paper proposed by G Vijaya et al, the detection of QRS complex or R peak is been done by using Artificial Neural Networks using Back Propagation. Also in another paper proposed by them, detection of QRS Complex was done using a Predictive Neural Network (PNN) based technique. The PNN was trained, using the back propagation algorithm, on non-QRS portions of the ECG to predict the signal one-step ahead. High prediction error was then taken as an indication of the occurrence of a QRS complex. Simple peak detection logic was then invoked to mark the exact location and magnitude of either a Q- or an R- or an S- peak within the QRS complex [16 and 17].

## V. FLOW CHART

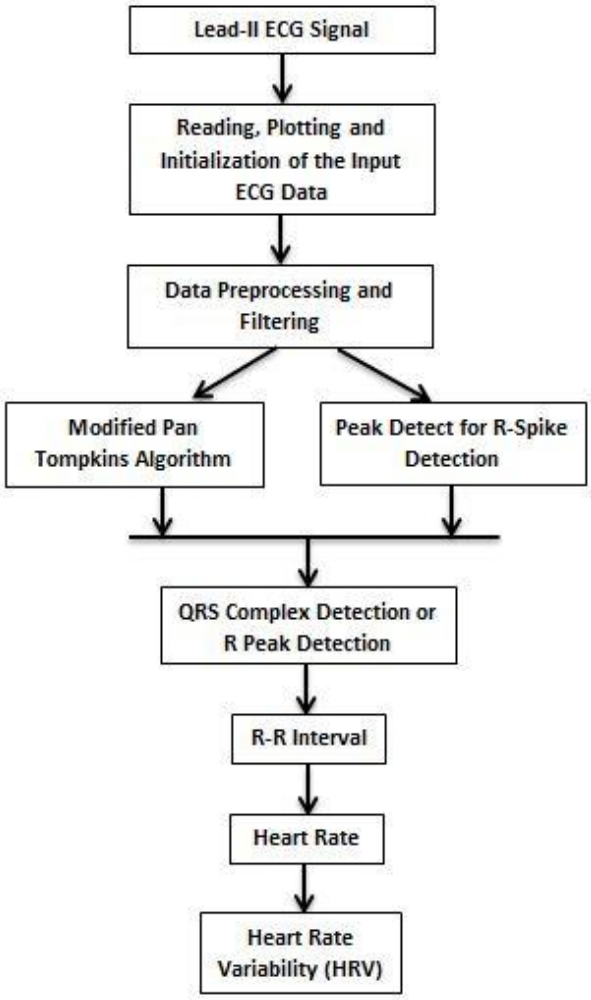


Fig.4. The Flow Diagram

## VI. THE METHODOLOGY OF THE WORK PROPOSED

**Step 1: ECG Database Collection**

ECG signals were collected from databases like:

- PhysioNet Bank
- MIT-BIH (The Massachusetts Institute of Technology– Beth Israel Hospital Arrhythmia Database)
- AHA (The American Heart Association ECG Database)
- ESC (The European Society of Cardiology ST-T Database)
- UCI (Machine Learning Repository)

The database consisted of several ECG format waveforms like .mat, .csv, .xml, .dat or .txt. Also, the databases were collected from the database banks, ECG Simulators, ECG Machines along with an ECG Amplifier in practical laboratories and Electrocardiographs from the hospitals and the preferred configuration for the ECG database was Lead-II Configuration.

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**Step 2: ECG Signal Initialization**

In order to process an ECG signal, we first need to read and plot the signal. Our Project has been implemented using the multipurpose tool i.e. the MATLAB Environment. If the signal is raw, which usually is unless it's taken from a filtered database, we need to perform initialization and remove the base and gain by using the following formula:

$$\mathbf{Xi} = \frac{\mathbf{Xi - Base}}{\mathbf{Gain}} \qquad \mathbf{(1)}$$

Where Xi= ECG Sample
Base= Baseline Value
Gain= Gain Factor

Once done, we can proceed to reading and plotting of the signal on Matlab. Depending upon the various formats, some signals could be plotted directly (.mat) and some required conversion from one format to the required format ((.csv, .xml, .dat or .txt) to .mat) by choosing the appropriate frequency and threshold along with re-dimensioning of the variable matrix.

**Step 3: The Preprocessing Phase**

In the preprocessing stage, the noise is removed or suppressed using specific filters in order to extract the required information from the signal and for noise reduction.

This could be done either by performing Amplitude Normalization where in each sample of signal is divided from max of absolute value of signal in order to limit signal dynamic range from -1 to 1, i.e.

$$\mathbf{Variable} = \frac{\mathbf{xi}}{\mathbf{max}(|\mathbf{x}|)} \qquad \mathbf{(2)}$$

Where xi= ECG Sample at a point
x= ECG Sample

The .mat format signal could be directly plotted in Matlab using a specific command. Considering the .csv and .dat format signals, Conversion and Zero Phase Filtering were done in order to plot it. In case of the .xml format signal, the same procedure was carried out in order to plot the signal which represented all the 12 Lead Configurations followed by extracting the required signal configuration needed to work on (Lead-II).

**Step 4: Feature Extraction Using Method 1**

The feature extraction stage is used to extract diagnostic information from the ECG signal.

Feature extraction and evaluation can be either done to find out:

- Morphological Features
- Dynamic Features

Morphological Features would mean determining the size, shape and structure of the ECG signal including the fiducial points like the peak points, onset and offset (wave boundaries), segments and interval durations. Dynamic features would mean extracting RR interval, Heart rate and HRV.

In this paper, what we present to propose is to extract R and its features in order to evaluate an ECG properly.

i. So in order to begin with this we first identified the QRS Complex which would help us identify the R peak using the Pan Tompkins Algorithm.
ii. In the Pan Tompkins Algorithm, ECG was first filtered using a Band Pass Filter.
iii. This was followed by differentiating the signal in order to get the slope information of the QRS Complex.
iv. This was then followed by squaring the signal which made the entire signal values positive and amplifies the output of the derivative process nonlinearly. It also emphasizes the higher frequencies in the signal that are mainly due to the QRS Complex.

$$\mathbf{y(nT)} = \mathbf{[x(nT)]^2} \qquad \mathbf{(3)}$$

v. This was concluded with the moving window average integration which was done to obtain the waveform feature information.
vi. After moving window integration, thresholding of the obtained signal was done.
vii. If a peak exceeded the threshold during the first step of analysis, it was classified as a QRS peak (Complex) or the R Peak having the highest amplitude in the array.

**Step 5: Feature Extraction Using Method 2**

i. The second method adapted to detect the R peak was a command based method.
ii. Infact, two different could be used to detect the R peaks in the signal, out of which one was:
   - Function PeakDetect (); peakdet()
   - Function FindPeaks (); findpeaks()
iii. The function peakdet () is used to detect peaks in a wave data or vector. It defines a peak detection utility that looks for local maxima and minima. It automatically detects peaks by searching high density points with anomalous large distance to higher density peaks.

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iv. The syntax used was:

function [maxtab, mintab]=peakdet(v, delta, x) (4)

v- Vector: delta- A vector of distance to closest observation of higher density

x- Corresponding Value: [maxtab, mintab] = peakdet(v, delta) finds the local maxima and minima ("peaks") in the vector v.

MAXTAB and MINTAB consist of two columns. Column 1 contains indices in v

Column 2 contains the found values

With [maxtab, mintab] = peakdet(v, delta, x) the indices in maxtab and mintab are replaced with the corresponding X-values.

A point is considered a maximum peak if it has the maximal value, and was preceded (to the left) by a value lower by delta.

v. The function findpeaks() is used to find values and locations of local maxima in a set of data. It gives positions and values of the detected peaks in data. This is a simple and fast command-line function to locate and count the positive peaks in the noisy data sets.

vi. The syntax used was:

[pks, locs] = findpeaks(data) (5)

pks- peaks, highest amplitude detected

locs- location of the peak value detected

data- Here, it additionally returns the indices at which the peaks occur of the input signal vector, data

**Step 6: Calculating the Attributes**

i. Now since the R peaks were detected, the R-R Interval which is basically calculating the interval between one R-Spike and the next R-Spike (successive R's) was found.

ii. This was then followed by calculating the heart rate. Initially the mean value of the R-R Interval is calculated and then this duration is then divided into 60. The resulting equation would be:

$$\textbf{Rate} = \frac{\textbf{60}}{\textbf{R}-\textbf{R Interval (Avg)}} \qquad \textbf{(6)}$$

iii. Then, Heart Rate Variability was found. In order to find out the HRV, the following steps were followed: First the maximum and the minimum value from the R-R Interval vector were detected. Then the mean value (average) of the R-R Interval was calculated.

iv. Then calculation of the HRVmax by subtracting the mean value of R-R Interval from the HRVmax and then dividing the entire value by the R-R interval (average) was found.

v. After that, calculation of the HRVmin by subtracting the mean value of R-R Interval from the HRVmin and then dividing the entire value by the R-R interval (average) was done. Then we calculated the HRV using the equation,

$$\textbf{HRV} = (\textbf{HRVmax} - \textbf{HRVmin}) * \textbf{100} \qquad \textbf{(7)}$$

## VII. RESULTS

The table displayed below gives the value of the average of more than 80 samples taken and analyzed in Matlab and that could be considered as Normal ECG, based on the characteristics observed.

- *These obtained values in the table are calculated manually as well as using specific algorithms through computer processing in Matlab by analyzing more than 80 samples and is verified by doing a lot of literature review and is approved by the doctors.
- The entered values in the table above are the average values of more than 80 samples after processing.
- Any value or feature that does not fall into the criteria and has a haphazard shape that does not have regularity and rhythm as defined in table 2 would be considered as an abnormal ECG.

Table 2: ECG Signal Features and their Respective Values (Normal)

| **FEATURES** | **VALUES** | |
|---|---|---|
| **General Factors** | **Values** | |
| Heart Rate | 60-100 bpm* | |
| R-R Interval | 0.6*s to 1.2*s | |
| Heart Rate Variability | +/-10%* to +/-30%* | |
| **Waves** | **Amplitude(mV)** | **Duration(s)** |
| R Wave | 0.8*-1.5* | 0.035*-0.09* |
| **Segments/Intervals** | **Duration(s)** | |
| QRS Complex | 0.06*-0.12* | |

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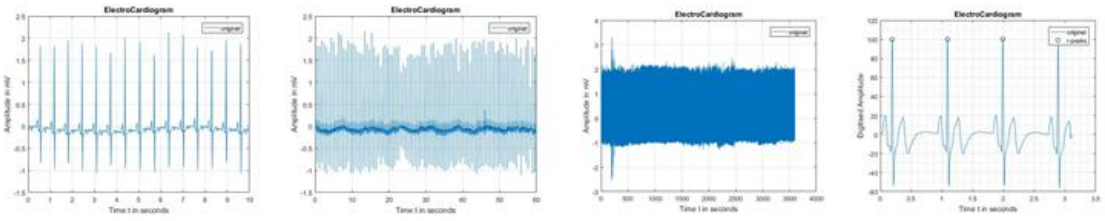
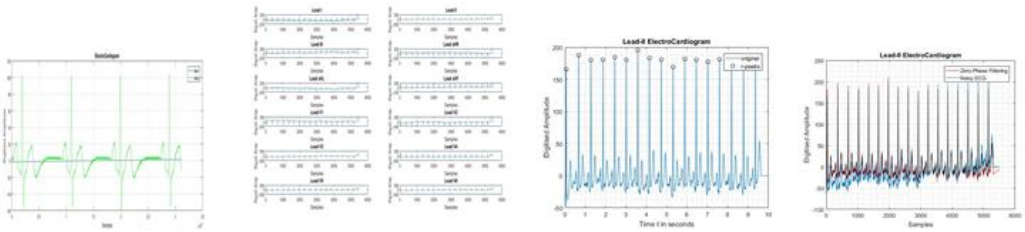


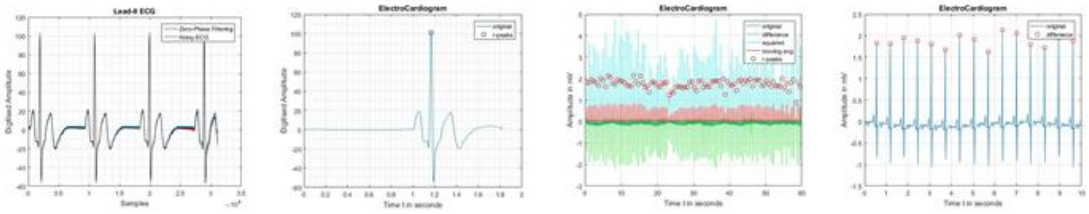
(a) (b) (c) (d)

Fig. 5. An Original ECG Signal (10, 60, 3600 sec) (Normal) Plotted (a,b,c) and Plotting of the .csv signal in Matlab (d)



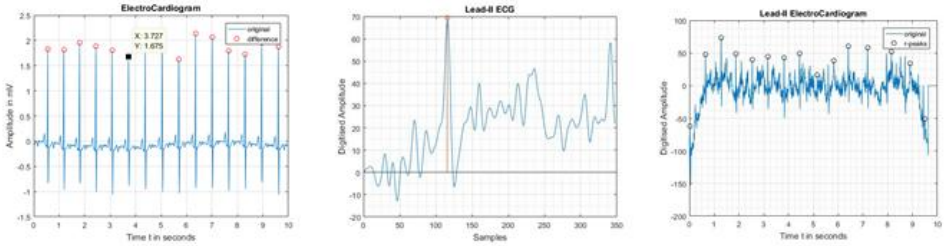
(e) (f) (g) (h)

Fig.6. Plotting of the.dat signal (e), 12 Lead Configuration ECG Signal from the .xml format to .mat signal (f), A Lead-II ECG Configuration extracted from 12 Lead Configuration ECG signal (g), Zero Phase Filtering of Extracted Lead-II ECG Signal (h)



(i) (j) (k) (l)

Fig. 7. Zero Phase Filtering of Extracted Lead-II ECG Signal (i), Detection of R Peak (j and k), Evaluating the R-R interval and the Heart Rate along with HRV (l)



(m) (n) (o)

Fig.8. An ECG Rhythm (m), Chaotic Plotted Waveforms (n and o)

After processing 10 such similar signals, it was seen that these signal tracings followed the particular sequence, a P wave with a round shape followed by a regular QRS Complex followed by T wave. Also signal in Fig. 8. (m) maintains a heart rate within 60 to 100 BPM at rest along with the specific values of the features as obtained in the table. After a lot of literature review and processing, it could be learnt that the following traits correlate to a normal sinus rhythm criteria and therefore, it could be said that the subject could be in Normal Sinus Rhythm. After processing 10 such similar signals, it could be seen that this signal lacks the necessary sequence and therefore, could be stated that this subject does not have a Regular Rhythm and the Waves, Segments and Intervals are either absent or immeasurable. The Rates observed in Fig. 8. (n and o) are above 100 BPM. This represents an Abnormal ECG Signal.

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## CONCLUSION

The R peak locations are detected using the proposed algorithm using two methods with an accuracy of 99%. The error in the location using the technique is within the permissible limit. Hence, this factor was used to calculate the IBI and then the HRV of the signal which is one of the biggest entities of cardiac diagnosis. Biomedical signals are non-stationary signals whose analyses require better time and frequency resolution. Such analysis include de-noising, filtering, normalizing, squaring, averaging, encoding, decoding, compressing, decompressing, deinterleaving, constructing, reconstructing and comparing of the data. The processing of ECG plays a major role in detection of many cardiac abnormalities. Future research heading in this direction is necessary with a larger sample size in order to accurately pinpoint the various heart defects individually.

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