

ECG Enhancement and Heart Beat Measurement

Sanchit Ailani¹, Sakshi Sethi²

B.Tech Student, Department of Biomedical Engineering, Amity University, Gurgaon, Haryana, India¹

Assistant Professor, Department of Biomedical Engineering, Amity University, Gurgaon, Haryana, India²

ABSTRACT: The following paper deals with the detailed study and analysis of ECG signal enhancement by the means of MATLAB tool effectively. Study of ECG signal includes generation & simulation of ECG signal, acquisition of real time ECG data, ECG signal filtering and pre-processing, feature extraction, analyzing different ECG signal analysis algorithms & techniques (i.e. Wavelet transform or so), detection of any abnormalities in ECG by calculating beat rate and using the most familiar and multipurpose MATLAB software. This project has been inspired by the need to find an efficient method for ECG Signal Analysis which is simple and has good accuracy and less computation time. The initial task for efficient analysis and enhancement is the removal of noise. It actually involves the extraction of the required cardiac components by eliminating the background noise. Enhancement of signal is achieved by the use of smooth function. The other task to detect R-peak of ECG waveform is achieved by using Discrete Wavelet Transform. And an extensive algorithm is required for the measurement of heart rate (beats per minute). The simulation is done in MATLAB environment and making a graphical user interface for it.

KEYWORDS: Electrocardiogram, Matlab, simulation, Biomedical Device, Arrhythmia, Wavelet, Transforms.

I. INTRODUCTION

Electrocardiogram (ECG or EKG) is a diagnostic tool that measures and records each and every electrical activity of the heart in detail. Correct interpretation of these details allows diagnosis of a wide range of heart conditions. These conditions may vary from minor to life threatening on the basis of problem. [1], [2]. Electrocardiography is a procedure that measures the electrical activity of the heart by placing the surface electrodes on the chest. The activity of the heart starts from the sino-atrial (SA) node that produces the heart frequency, at about 70 cycles per minute. The activation of SA-Node propagates to the right and left atrium muscle tissues. At the atrioventricular (AV) node, there is a delay to allow the ventricles to fill with blood from atrial contraction. The depolarization cycle then propagates to the ventricles through the Bundle of His and spreads along the Purkinje fibers in the heart. This activates the ventricles to contract and pump the blood to the aorta and to the rest of the body. Finally, depolarization takes place and the whole cycle is repeated. The trans-membrane potential, which is the voltage difference between the internal and external spaces of the cell membrane, changes at each stage as the cycle occurs. Surface electrodes are used to measure these voltage differences. At each stage different peaks viz., P, Q, R, S, T, and U are noticeable, as observed in Fig.1.

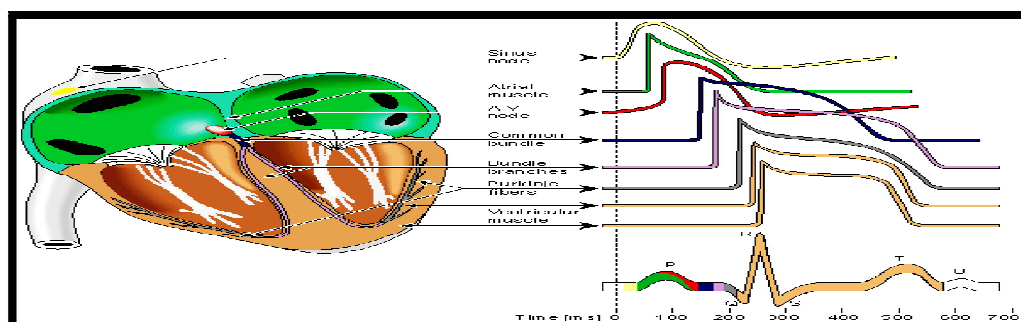


Figure 1: General ECG Waveform arising as a result of contraction and relaxation of heart. [3]

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II. ECG ENHANCEMENT METHODS

Since Einthoven had discovered ECG, a lot of work has been done in the field of ECG signal processing using certain approaches and methods. The basic principle of all the methods usually involves transformation of ECG signal using different transformation techniques including Fourier Transform, Hilbert Transform, Wavelet transform etc. ECG signals being physiological are considered to be quasi-periodic in nature. Their duration is finite and are non-stationary in nature. Hence, a technique like Fourier series that is based on sinusoids of infinite long duration is inefficient to be implemented on ECG. On the other hand, wavelet transformation, which is a very recent addition in this field of research, provides a powerful tool for extracting information from signals. Both Continuous Wavelet Transform (CWT) as well as Discrete Wavelet Transform (DWT) has been used for extracting information. CWT has some inherent advantages over DWT because in DWT, there is no dyadic frequency jump in CWT. Moreover, in time-frequency domain high resolution is achieved in CWT [4].

Transmission of ECG often results in the disruption of signal due to intervention of noise [5]. Various factors that are responsible for introduction of noise may include Baseline wander that is caused by respiration, poor channel selection, power line interference etc. Analyzing such disruptive signal is bound to give catastrophic results. Thus the signal is first made free of noise, a process called denoising or rather we may call it enhancement. A number of methods have been incorporated for enhancement ECG signal [6]. All of these studies or techniques and algorithms which have been proposed since the last decade are, Artificial Neural Network, Fuzzy Logic methods, Genetic Algorithm, Support Vector Machines, Digital Signal Analysis, Discrete Wavelet Transform (DWT), Bayesian, Hidden Markov Model Self-Organizing Map, Slope Vector Waveform (SVW), and Difference Operation Method (DOM) [7] [8] [9] [10] [11]. All of these methods have been dealing with the PQRST complex detection for ECG signals. Starting from, Slope Vector Waveform (SVW), which is basically proposed to detect ECG QRS complex and analyze R-R interval. This technique rapidly and accurately searches for the R location, R-R interval and QRS complex duration, and gives results of ECG feature extraction [12]. Secondly the Discrete Wavelet Transform (DWT) method states to extract the relevant information from the ECG signal in order to perform the classification task. The algorithm includes number of processing modules which includes data acquisition, Pre-processing beat detection, feature extraction, and classification of the ECG signal. The feature extraction module comprises the Wavelet Transform was derived from a single generating function termed as the mother wavelet by dilation and translation processes and is basically designed to address the problem of non-stationary ECG signals. The biggest advantage of this technique in feature extraction is that it has a varying window size, broad at lower frequencies and narrow at higher frequencies, which leads to an optimal time-frequency resolution in all frequency ranges [13]. Difference Operation Method (DOM) is another method used for detecting the QRS complex of an ECG signal. This technique includes the difference operation process (DOP) and the wave detection process. In the first process the R peak is found by applying the difference equation operation to the ECG signal. The second process looks for the points Q and S according to the point R to find the QRS complex [14]. A neural network is another different system to determine the features of ECG signal. It is a hybrid system which consists of cepstrum coefficient method for feature extraction from long-term ECG signals and artificial neural network (ANN) models for the classification. These methods are used to recognize features present inside an ECG signal and then classify the signal in addition to diagnose the abnormalities [15]. While a new technique has been evolved for extracting ECG features using neural networks and wavelet transformation. Features are extracted from wavelet decomposition of the ECG signal and then further processed by using artificial neural networks. The features are: mean, median, maximum, minimum, range, standard deviation, variance, and mean absolute deviation [16]. Another method is by using Artificial Neural Networks for detecting PQRST through use of the derivative where the minimum and maximum of the derivative of a wave is searched. The R peak wave should be the zero crossing lying between the maximum and minimum of the derivative. Therefore, the Q point should be at the zero crossing before the maximum and the S point should be at the zero crossing after the minimum. Similarly, the P and T waves are done by looking for local maximums in the original waveform and then using the derivative to identify peak and end points [17]. Work proposed in this paper shows a simple and reliable method to detect the R and S peaks of an electrocardiogram (ECG) signal. This method is based on finding a relationship between the highest values (peaks and valleys) of the ECG waveform in time domain. This method is implemented by designing a graphical user Interface (GUI) on MATLAB

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toolkit to detect QRS by using simple mathematical algorithm and calculating the heart beats per minute from the same sample.

III. THEORETICAL ASPECTS OF ECG

A. Heart: The heart, located in the mediastinum, is the central structure of the cardiovascular system. It is protected by the bony structures of the sternum anteriorly, the spinal column posteriorly, and the rib cage.

Sinoatrial (SA) node is the dominant pacemaker of the heart, located in upper portion of right atrium. It has an intrinsic rate of 60–100 bpm.

Atrioventricular(AV) node is a part of AV junctional tissue. It slows conduction, creating a slight delay before impulses reach ventricles. It has an intrinsic rate of 40–60 bpm.

Table 1: Electrophysiology

Action	Effect
Depolarization	Shifting of electrolytes across the cell membrane causes change in electric charge of the cell. It results in contraction.
Repolarization	Internal negative charge is restored and the cells return to their resting state.

Table 2: Conduction System Structure and Functions

Structure	Function and Location
Sinoatrial (SA) Node	Dominant pacemaker of the heart, located in upper portion of right atrium. Intrinsic rate 60–100 bpm.
Internodal Pathways	Direct electrical impulses between SA and AV nodes.
Atrioventricular (AV) node	Part of AV junctional tissue. Slows conduction, creating a slight delay before impulses reach ventricles. Intrinsic rate 40–60 bpm.
Bundle of His	Transmits impulses to bundle branches. Located below AV node.
Left bundle Branch	Conducts impulses that lead to left ventricle.
Right bundle Branch	Conducts impulses that lead to right ventricle.
Purkinje system	Network of fibers that spreads impulses rapidly throughout ventricular walls. Located at terminals of bundle branches.

B. Heart Phases: There are two phases of the cardiac cycle.

Systole: The ventricles are full of blood and begin to contract. The mitral and tricuspid valves close (between atria and ventricles). Blood is ejected through the pulmonic and aortic valves.

Diastole: Blood flows into the atria and through the open mitral and tricuspid valves into the ventricles.

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An ECG is a series of waves and deflections recording the heart’s electrical activity from a certain “view”. Many views, each called a lead, monitor voltage changes between electrodes placed in different positions on the body. Each cardiac cell is surrounded by and filled with solutions of Sodium (Na⁺), Potassium (K⁺), and Calcium (Ca⁺⁺). The interior of the cell membrane is considered to be negative with respect to outside during resting conditions. When an electric impulse is generated in the heart, the interior part becomes positive with respect to the exterior. This change of polarity is called depolarization. After depolarization the cell comes back to its original state. This phenomenon is called repolarization. The ECG records the electrical signal of the heart as the muscle cells depolarize (contract) and repolarize.

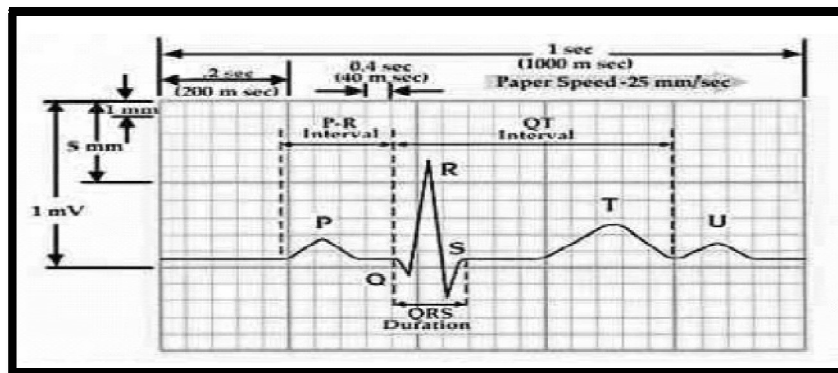


Figure 2 Typical ECG wave

The impulses of the heart are recorded as waves called P-QRS-T deflections and are shown in figure2.

The following is the description and significance of each deflection and segment.

P wave indicates atrial depolarization (and contraction).

PR Interval measures time during which a depolarization wave travels from the atria to the ventricles.

QRS Interval includes three deflections following P wave which indicates ventricular depolarization (and contraction).

Q wave is the first negative deflection while R wave is the first positive deflection. S wave indicates the first negative deflection after R wave.

ST Segment measures the time between ventricular depolarization and beginning of repolarization.

T wave represents ventricular repolarization.

QT Interval represents total ventricular activity.

C. Arrhythmia: Normally, the SA Node generates the initial electrical impulse and begins the cascade of events that result in a heart-beat. For a normal healthy person the ECG comes off as a nearly periodic signal with depolarization followed by repolarization at equal intervals. However, sometimes this rhythm becomes irregular.

Cardiac arrhythmia (also **dysrhythmia**) is a term for any of a large and heterogeneous group of conditions in which there is abnormal electrical activity in the heart. The heart beat may be too fast or too slow, and may be regular or irregular. Arrhythmia comes in varieties. It may be described as a flutter in chest or sometimes “racing heart”. The diagnosis of Arrhythmia requires Electrocardiogram. By studying ECG, Doctors can diagnose the disease and prescribe the required medications.

Table 3: Abnormalities

Sr. No	Name of abnormality	Characteristic features
1.	Tachycardia	Heart rate > 100 bpm
2	Bradycardia	Heart rate < 60 bpm
3	First degree heart block	Long PR interval

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4	Second degree AV block	QRS dropped
5	Sinoatrial block, asystole	drop out of a cardiac cycle

IV. METHODOLOGY AND RESULTS

The result of this work is a Matlab program which analyzes of ECG recordings to get Q R S complex as well as detect heart rate. The graphical user interface is very easy to use and enables to get R-R interval values from analysis of ECG signal. It is necessary for anyone who works on this program should select the numbers of samples for one cardiac cycle in an ECG signal of the P-QRS-T waves is equal to 1500 samples. The software tool provides the following main features for ECG processing and analysis:

- Loading ECG recordings from any source of data as text or binary files and excel files.
- Plotting the loaded ECG recordings.
- QRS detection as individual values and also appears on the graph.
- Detecting R peaks and measuring the heart rate, the diagram (Fig. 3) introduces the steps of heart rate detection.

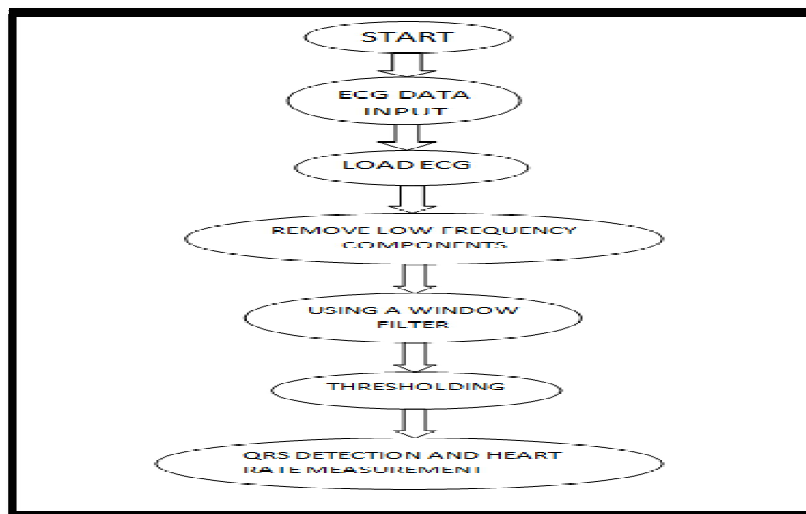


Figure 3 STEPS FOR QRS DETECTION AND HEART RATE MEASUREMENT

Convolution of the wavelet function $\psi(t)$ with the signal $x(t)$ gives the wavelets transform. The dyadic discrete wavelets are associated with scaling functions $\phi(t)$. The scaling function can be convolved with the signal itself to produce approximation coefficients S. The discrete wavelet transform (DWT) can be written as

$$T_{m,n} = \int_{-\infty}^{\infty} x(t) \psi_{m,n}(t) dt \dots \dots \dots (1)$$

By choosing an orthonormal wavelet basis $\psi_{m,n}(t)$ we can reconstruct the original [17]. The approximation coefficient of the signal at the scale m and location n can be written as

$$S_{m,n} = \int_{-\infty}^{\infty} x(t) \phi_{m,n}(t) dt \dots \dots \dots (2)$$

But the discrete input signal is of finite length N . So the range of scales that can be investigated is $0 < m < M$. Hence a discrete approximation of the signal can be written as

$$x_0(t) = x_M(t) + \sum_{m=1}^M d_m(t) \dots \dots \dots (3)$$

Where the mean signal approximation at scale M is $x_M(t) = S_{M,n} \phi_{M,n}(t)$ and detail signal approximation corresponding to scale m , for finite length signal is given by

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$$dm(t) = \sum_{n=0}^{M-m} Tm, n \psi m, n(t) \dots \dots \dots (4)$$

The signal approximation at a specific scale is a combination of the approximation and detail at the next lower scale.

$$xm(t) = x_{m-1}(t) - d_m(t) \dots \dots \dots (5)$$

In this work Daubechies [6] wavelet is chosen. Although the algorithm for Daubechies is conceptually more complex and has slightly complicated computations, yet this algorithm is capable of searching the minute detail that is missed by other wavelet algorithms like Haar wavelet algorithm. Always, there might be a good substitute to efficiently represent a signal if a signal is not represented well by one member of the Daubechies family.

The wavelet processing of ECG signal is performed using MATLAB software. MATLAB is a high performance and interactive system software which can solve many technical computing problems. The MATLAB software kit has inbuilt wavelet tool box. There are so many functions built on the MATLAB technical computing environment that provides tools for the analysis and synthesis of signals using wavelets and wavelet packets within the MATLAB domain.

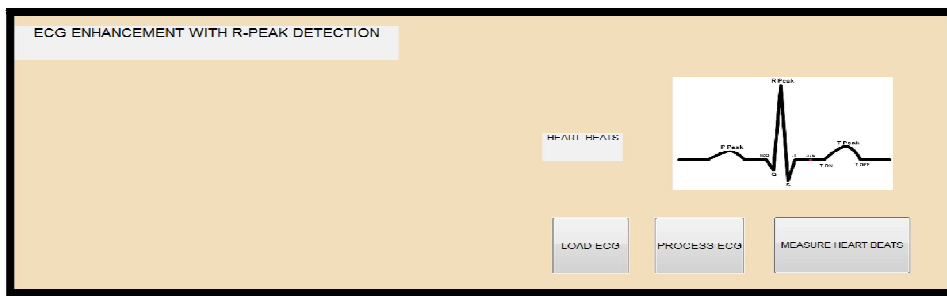


Figure 4 Prototype of GUI

The above figure 4 is the prototype of the simple GUI formed by us. The buttons clearly define to load the data input signal and process the signal by detecting the QRS complex. The centre button is used for measuring heart beats in just one click.

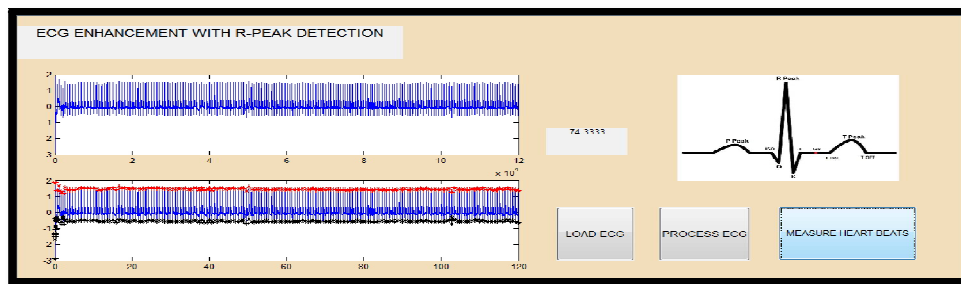


Figure 5 Fully Functional GUI

Figure 5 shows the fully functional and working GUI showing the smooth signal in first graph and detected peaks in second graph.

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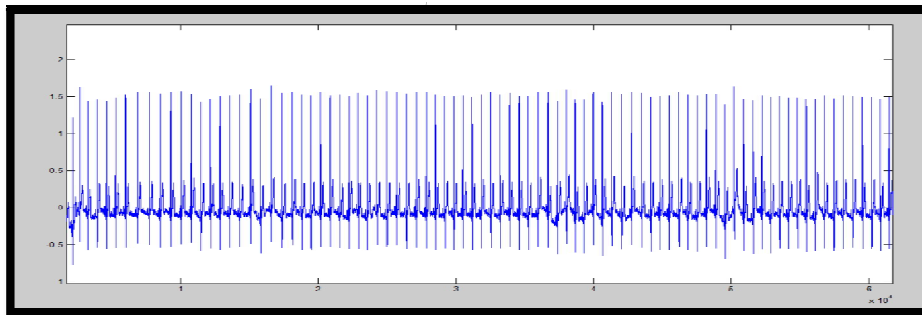


Figure 6 Smooth signal obtained after enhancement

Figure 6 shows the smooth signal after applying the wavelet transform along with notch filter (cascaded high pass and low pass filter).

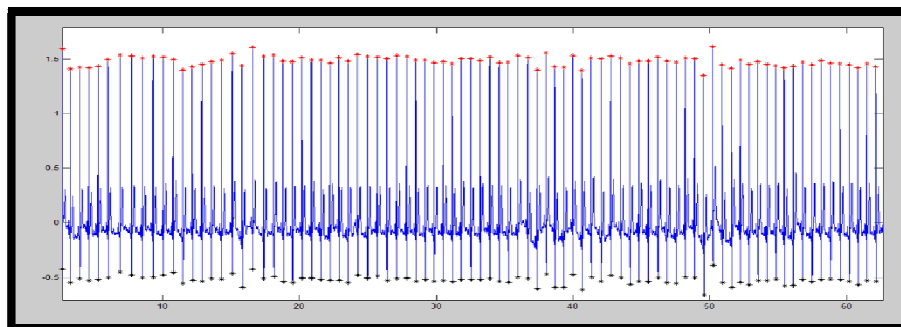


Figure 7 Detected QRS complex

Figure 7 shows the final detected QRS complex with R peaks and S valleys after applying the simple thresholding technique.

V. CONCLUSION AND FUTURE WORK

MATLAB has been proved a powerful tool for ECG signal processing since last decade. It is so useful and easy that anybody can monitor the heart condition simply by utilizing the power of MATLAB. The technique used in this paper can be utilized for virtual time experimental/lab purpose. One of the crucial steps in the ECG enhancement is to precisely detect the different waves namely P, Q, R and S depicting the entire heart cycle. The methodology is definitely a new approach using Pan Tompkins Algorithm with certain changes to detect peaks and nonstandard shapes present in the ECG signals. This proposed work could be continued to further improvements in the algorithm to detect certain heart abnormalities and can be implemented to diagnose diseases like arrhythmia in the heart by using calculations of intervals between impulses of two different signals in real time. For processing, enhancement and detection algorithms, MATLAB is used, in which they were implemented as signal processing operations and statistical results of signals were demonstrated.

Wavelet Transform is collaborating with Empirical Mode Transform and is a very recent technique. But a lot of research needs to be done on the properties of this very new hybrid method so that we can come up with still simpler methods for ECG signal Analysis.

Feature extraction and classification of Arrhythmia is another field in ECG signal Analysis that is untouched by us. Hence our future work will be dedicated to feature extraction and easy classification of the signal.

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The process of enhancement can be modified using more evolving techniques. Research needs to be done for finding more efficient and approximate methods for signal enhancement in real time.

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