



# PC Based Digital Signal Processing of ECG Signals

S. Thulasi Prasad<sup>1</sup>, S. Varadarajan<sup>2</sup>

Associate Professor, Dept. of ECE, CVSE, Tirupati, India<sup>1</sup>

Professor, Dept. of ECE, SVUCE, Tirupati, India<sup>2</sup>

**Abstract:** Due to fast advancement in the technology, scientists and engineers are facing several challenges in solving biomedical problem; Digital Signal Processing has become an essential and effective pedagogical approach to solve a problem of detecting selected arrhythmia conditions from a patient's electrocardiograph (ECG) signals. Finding arrhythmia characteristics corresponding to Atrial Fibrillation (AF), heart rate variability (HRV), etc., from ECG recording have received considerable attention in recent years. Several advanced signal processing techniques have been applied for cardiac arrhythmia detection using Fourier Transforms, Wavelets, Artificial Neural Networks, Independent Component Analysis, etc. Introducing a simple algorithm for arrhythmia detection can be very useful for better conceptual understanding of signal processing. In this paper, simple methods have been discussed to clean ECG signal corrupted by noise and to extract required parameters for detecting arrhythmia condition. These simple procedures involve using filter techniques, wavelet techniques, algorithms of finding peaks & valleys, local maxima & minima etc, for determining R peaks, R-R intervals and QRS amplitude.

**Keywords:** ECG, HRV, filter, QRS, lead, MATLAB

## I. INTRODUCTION

The recording of bioelectrical potentials generated on the surface of the body by the heart is called ECG (Electro-Cardio-Gram). An initial breakthrough came when Willem Einthoven, working in Leiden, the Netherlands, used the string galvanometer 1901. This device was much more sensitive than both the capillary electrometer Waller used and the string galvanometer that had been invented separately in 1897 by the French engineer Clément Ader. Einthoven assigned the letters P, Q, R, S and T to the various deflections, and described the electrocardiographic features of a number of cardiovascular disorders. In 1924, he was awarded the Nobel Prize in Medicine for his discovery.

A typical ECG tracing of the cardiac cycle (heartbeat) consists of a P wave, a QRS complex, a T wave, and a U wave, which is normally invisible in 50 to 75 % of ECGs because it is hidden by the T wave and upcoming new P wave [1]. The baseline of the electrocardiogram (the flat horizontal segments) is measured as the portion of the tracing following the T wave and preceding the next P wave and the segment between the P wave and the following QRS complex (PR segment). In a normal healthy heart, the baseline is equivalent to the isoelectric line (0mV) and represents the periods in the cardiac cycle when there are no currents flowing towards either the positive or negative ends of the ECG leads. However, in a diseased heart the baseline may be elevated (e.g. cardiac ischaemia) or depressed (e.g. myocardial infarction)

relative to the isoelectric line due to injury currents flowing during the TP and PR intervals when the ventricles are at rest. The ST segment typically remains close to the isoelectric line as this is the period when the ventricles are fully depolarised and thus no currents can flow in the ECG leads. Since most ECG recordings do not indicate where the 0 mV line is, baseline depression often gives the appearance of an elevation of the ST segment and conversely baseline elevation gives the appearance of depression of the ST segment. The features of the ECG signal are labeled as

- P-wave : due to depolarization of the atria
- Q-wave : due to activation of the anterioseptal region of the ventricular myocardium
- R-wave : due to depolarization of the ventricular myocardium
- S-wave : due to activation of the posterio basal portion of the ventricles
- T-wave : due to rapid ventricular repolarization

Originally, four deflections were noted, but after the mathematical correction for artifacts introduced by early amplifiers, a fifth deflection was discovered. Einthoven chose the letters P, Q, R, S, and T to identify the tracing as shown in the Fig. 1

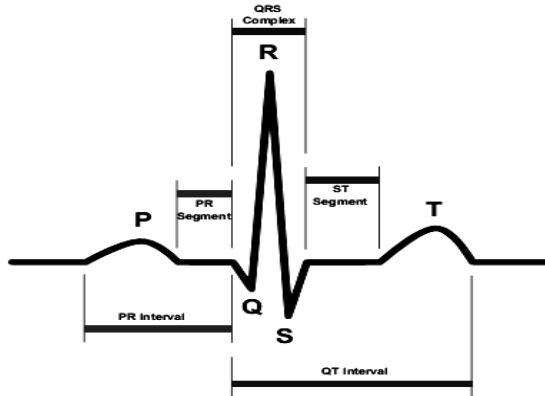


Fig. 1 ECG Signal

In intracardiac electrocardiograms, such as can be acquired from pacemaker sensors, an additional wave can be seen. This is called H deflection, which reflects the depolarization of the bundle of His. The H-V interval, in turn, is the duration from the beginning of the H deflection to the earliest onset of ventricular depolarization recorded in any lead. In both the 5- and 12-lead configurations, leads I, II and III are called limb leads [2]. The electrodes that form these signals are located on the limbs one on each arm and one on the left leg. The limb leads form the points of what is known as Einthoven's triangle. Lead I is the voltage between the (positive) left arm (LA) electrode and right arm (RA) electrode:  $I = LA - RA$ . Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode:  $II = LL - RA$ . Lead III is the voltage between the (positive) left leg (LL) electrode and the left arm (LA) electrode:  $III = LL - LA$

There are two types of leads known unipolar and bipolar. Bipolar leads have one positive and one negative pole. In a 12-lead ECG, the limb leads (I, II and III) are bipolar leads. Unipolar leads also have two poles, as a voltage is measured; however, the negative pole is a composite pole (Wilson's central terminal, or WCT) made up of signals from multiple other electrodes. In a 12-lead ECG, all leads except the limb leads are unipolar (aVR, aVL, aVF, V1, V2, V3, V4, V5, and V6). Wilson's central terminal  $V_w$  is produced by connecting the electrodes RA, LA, and LL together, via a simple resistive network, to give an average potential across the body, which approximates the potential at infinity (i.e. zero):  $V_w = (RA + LA + LL) / 3$ .

Leads aVR, aVL, and aVF are augmented limb leads (after their inventor Dr. Emanuel Goldberger known collectively as the Goldberger's leads). They are derived from the same three electrodes as leads I, II, and III. However, they view the heart from different angles (or vectors) because the negative electrode for these leads is a modification of Wilson's central terminal. This zeroes out the negative electrode and allows the positive electrode to become the "exploring electrode". This is possible because Einthoven's

Law states that  $I + II + III = 0$ . Wilson's central terminal paved the way for the development of the augmented limb leads aVR, aVL, aVF and the precordial leads V1, V2, V3, V4, V5 and V6. The aVR, aVL, and aVF leads can be represented using the I and II limb leads:  $aVR = -(I + II) / 2$ ,  $aVL = I - II / 2$ ,  $aVF = II - I / 2$ .

## II. PHYSIOLOGY

The human heart is a cone-shaped muscular pump located in the mediastinal cavity of the thorax between the lungs and beneath the sternum [3]. The cone-shaped heart lies on its side on the diaphragm, with its base (the widest part) upward and leaning toward the right shoulder, and its apex pointing down and to the left. In this biological pump, the muscles of the chamber walls provide the motive force, the valves direct the flow, and the great vessels convey blood to and from body tissues. Most of the great vessels (pulmonary trunk, aorta, and superior vena cava) emerge upward from the base of the heart. The chambers of the heart alternately contract and relax in a rhythmic cycle. During the period of contraction (systole), the heart pumps blood out through the arteries; during the period of relaxation (diastole), the heart fills with blood. One complete sequence of filling and pumping blood is called a cardiac cycle, or heartbeat. The heart's rhythm of contraction is controlled by the sinoatrial node (SA node), often called the pacemaker. This node is part of the heart's intrinsic conduction system, which is made up of specialized myocardial cells called nodal cells. Physiology of heart is shown in the Fig. 2

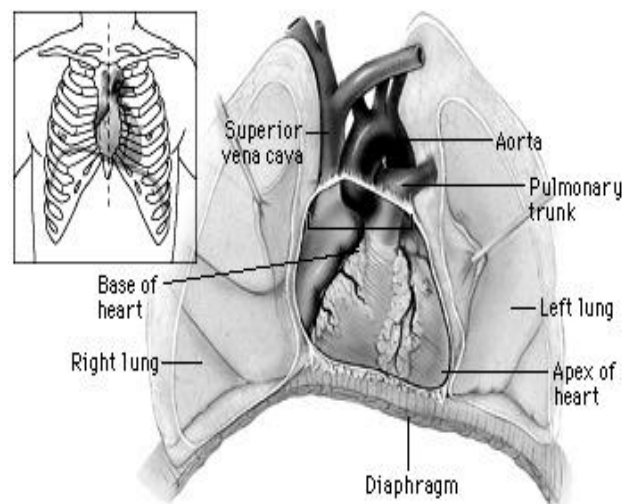


Fig. 2 Physiological features of human heart

The heart will beat without input from the nervous system and will continue to beat, even outside the body, as long as its cells are alive. The automatic nature of the heartbeat is referred to as automaticity. Automaticity is due to the spontaneous electrical activity of the SA node. Electrical impulses generated from the SA node spread through the



heart via a nodal tissue pathway that coordinates the events of the cardiac cycle. The activity of the conduction system, muscles, and valves of the heart are synchronized so that the heart can operate as a pump. The conduction system initiates and coordinates the muscular activity of the heart. Pressure differentials that result from muscle activity actuate the opening and closing of valves. The opening and closing of valves directs the flow of blood through the heart.

Each electrical signal begins in a group of cells called the sinus node or sinoatrial (SA) node [4]. The SA node is located in the right atrium, which is the upper right chamber of the heart. In a healthy adult heart at rest, the SA node sends an electrical signal to begin a new heartbeat 60 to 100 times a minute. From the SA node, the signal travels through the right and left atria. This causes the atria to contract, which helps move blood into the heart's lower chambers, the ventricles [5]. The electrical signal moving through the atria is recorded as the P wave on the ECG. The electrical signal passes between the atria and ventricles through a group of cells called the atrioventricular (AV) node. The signal slows down as it passes through the AV node. This slowing allows the ventricles enough time to finish filling with blood. On the ECG, this part of the process is the flat line between the end of the P wave and the beginning of the Q wave. The electrical signal then leaves the AV node and travels along a pathway called the bundle of His. From there, the signal travels into the right and left bundle branches.

The signal spreads quickly across your heart's ventricles, causing them to contract and pump blood to your lungs and the rest of your body. This process is recorded as the QRS waves on the ECG. The ventricles then recover their normal electrical state (shown as the T wave on the ECG). The muscle stops contracting to allow the heart to refill with blood. This entire process continues over and over with each new heartbeat. From this is clear that a PC based monitoring and analyzing system is required.

### III. METHODOLOGY

Normally ECG signal processing is performed in two stages: preprocessing and feature extraction [6]. In preprocessing stage the noise from the raw ECG signal is removed and in the feature extraction stage diagnostic information from the ECG signal is extracted. Fig. 3 shows the simple block diagram of methodology of analysis of ECG signal

#### A. Preprocessing

The ECG signal is corrupted by power line interference, electrode pop or contact noise, patient-electrode motion artifacts, electromyographic (EMG) noise and baseline wandering. All these types of noises can be removed by the preprocessing of ECG signals.

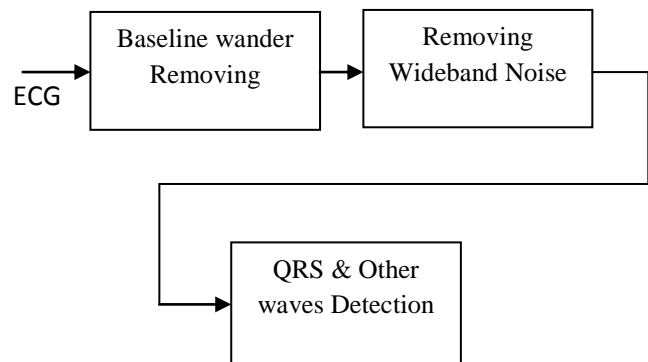


Fig. 3 Block diagram of methodology of analysis of ECG

Among these noises, the power line interference and the baseline wandering are the most significant and can strongly affect ECG signal analysis. Except for these two noises, other noises may be wideband and usually a complex stochastic process which also distort the ECG signal. The power line interference is narrow-band noise centered at 60 Hz (or 50 Hz) with a bandwidth of less than 1 Hz. Usually the power line interference can be eliminated by the hardware whereas baseline wandering, and other wideband noises cannot be easily suppressed by hardware equipments. However, the software scheme is more powerful and feasible for offline ECG signal processing. The following methods can be used to remove baseline wandering and the other wideband noise [7].

Normally the respiration at frequencies wandering between 0.15 Hz and 0.3 Hz cause the baseline wandering. This baseline wander can be suppressed by a high-pass digital filter. In Filter Approach, either LabVIEW or MATLAB is used to design lowpass and highpass filters to remove the baseline wandering. In our MATLAB implementation for filter method, algorithm is carried out through the following steps [8]

1. ECG is generated using `ecg(512)` matlab function
2. Random noise and a sinusoidal noise with frequency of 50 Hz are generated by using `randn(n)` and `sin(2*pi*f*t)` functions and added to give noisy ECG signal
3. Frequency spectrum is calculated using FFT
3. Notch filter is designed for 50 Hz and used to remove 50 Hz powerline interference
4. Lowpass filter is designed using its transfer function and operated on ECG signal
5. Highpass filter is designed using its transfer function and operated on ECG signal

In Wavelet Transform Approach, the wavelet transform is used to remove noises from ECG signals within specific



subbands. The LabVIEW or MATLAB can be used to remove the baseline wander from the ECG signal. In our MATLAB implementation for Wavelet Transform method, algorithm is carried out through the following steps [9]

1. ECG is generated using `ecg(512)` matlab function
2. Random noise and a sinusoidal noise with frequency of 50 Hz are generated by using `randn(n)` and `sin(2*pi*f*t)` functions and added to give noisy ECG signal
2. Frequency spectrum is calculated using FFT
3. Notch filter is designed for 50 Hz and used to remove 50 Hz powerline interference
4. Wavelet coefficients are obtained using `daubcwf(6)` Function
5. Denoising function is created using `daubcwf(6)` and applied on noisy ECG signal to remove noise

**B. Feature Extraction**

Various features from the preprocessed ECG signal which includes QRS intervals, QRS amplitudes, PR intervals and QT intervals are extracted for the purpose of diagnosis. This provides information about the heart rate, the conduction velocity, the condition of tissues within the heart as well as various abnormalities with which diagnosing cardiac diseases becomes more accurate and easy. For this reason, it has drawn considerable attention in the ECG signal. In this process first all beats (R waves) in the signal are detected and then other features are extracted for every beat and heart rate can be easily calculated from the difference between R-peaks [10]. Hence the accuracy of detecting R waves is very important. For normal ECG signals, they can be easily detected. While abnormal morphology makes the detection difficult for ECG from patients with some specific heart diseases. Thus sometimes you need to perform some signal enhancement (preprocessing) before feature extraction. The preprocessed ECG signal is used to detect position of R waves. After that, all other features will be extracted using original signal, because the signal enhancement may change these features. Signal enhancement usually contains two steps: filtering and rectification. R waves of human ECG usually have a frequency between 10-25 Hz. Thus R waves can be more obvious and easily for detection after filtering using a bandpass filter. Rectification sometimes can further enhance the R waves to make them easier to detect. Absolute and square are two common used rectification methods and after enhancement, all beats can be easily detected. Here MATLAB is used to extract features from ECG signal. In our MATLAB implementation for feature

extraction, algorithm is carried out through the following steps [11].

1. Derivative filter is designed using its transfer function and ECG signal is filtered with it
2. Moving average filter is designed and used on squared signal from derivative filter.
3. Signal is integrated and set a threshold
4. R-Peak is detected using threshold set in the previous step [12]
5. QRS complex is detected with the help of R-Peaks

**IV. RESULTS**

This paper demonstrates how to use a robust and efficient environment and powerful tools such as MATLAB, LabVIEW and the other signal processing-related toolkits to solve the problems that occur in processing ECG signals. This paper also demonstrates how to use these powerful tools in denoising, analyzing, and extracting features from ECG signals easily and conveniently not only in heart illness diagnosis but also in ECG signal processing research. The procedure explained in this paper will be useful to resolve problems in other biomedical signal processing applications such as Magnetic Resonance Imaging (MRI) and Electroencephalography (EEG). Fig. 4, Fig. 5 and Fig. 6 show the magnitude response of notch filter, lowpass and highpass filters respectively

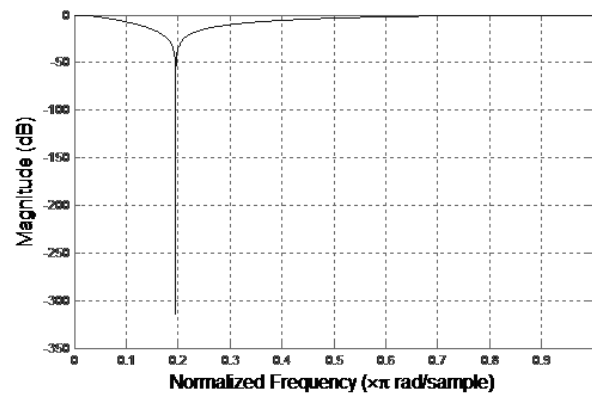


Fig. 4 Magnitude response of Notch Filter

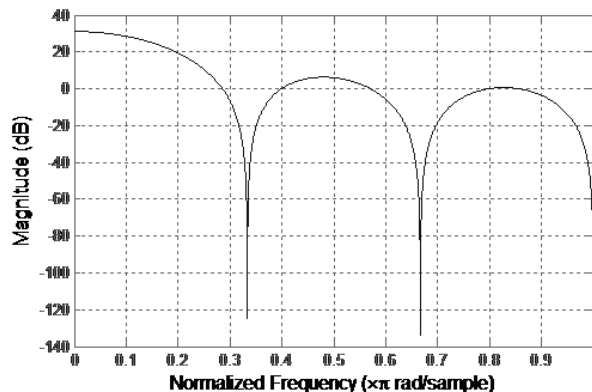


Fig. 5 Magnitude response of Lowpass Filter

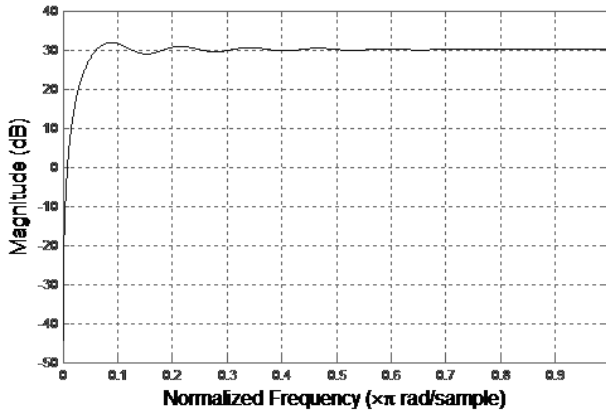


Fig. 6 Magnitude response of Highpass Filter

Fig. 7 shows the spectrum of Noisy ECG with 50 Hz powerline interference before and after notch filtering. Fig. 8 shows the Noisy ECG signal, highpass filtered and lowpass filtered ECG signal.

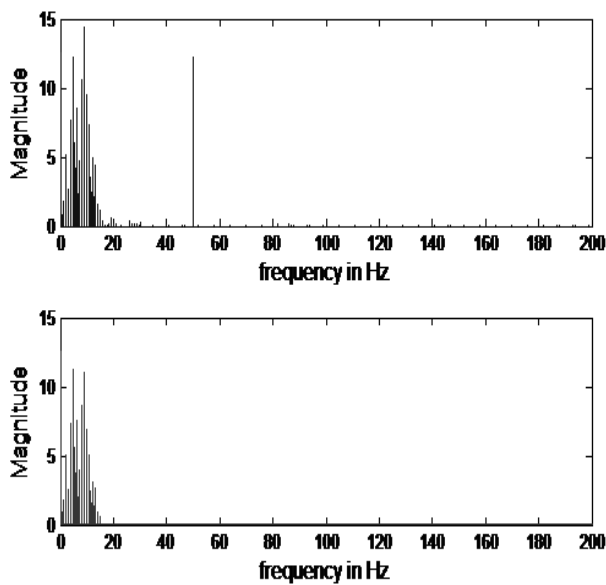


Fig. 7 Spectrum of Noisy ECG with 50 Hz powerline interference before and after notch filtering

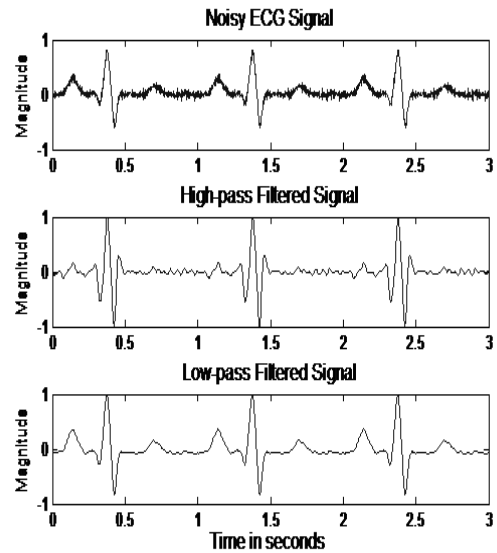


Fig. 8 Noisy ECG signal, highpass filtered and lowpass filtered ECG signal

Fig. 9 shows the derivative, squared and moving averaged ECG signal after filtering with lowpass and highpass filters.

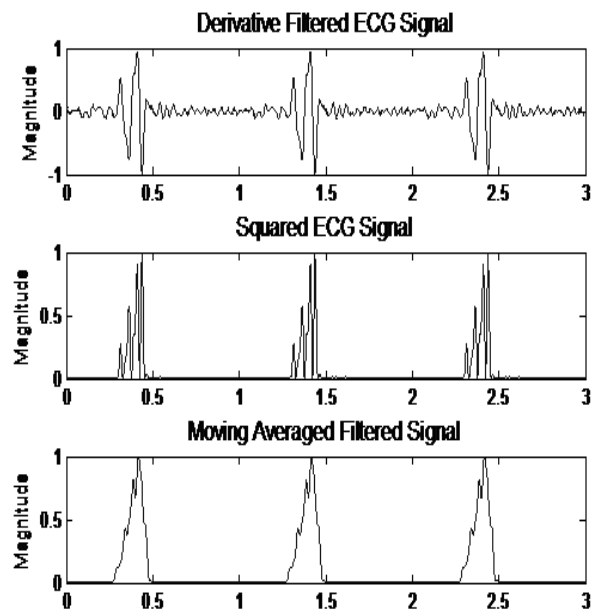


Fig. 9 Derivative, squared and moving averaged ECG signal after filtering with lowpass and highpass filters.

Fig. 10 shows the Noisy ECG and cleaned ECG signal with detected QRS points in filter method. Fig. 11 shows the Noisy ECG and cleaned ECG signal with detected QRS points in wavelet approach.

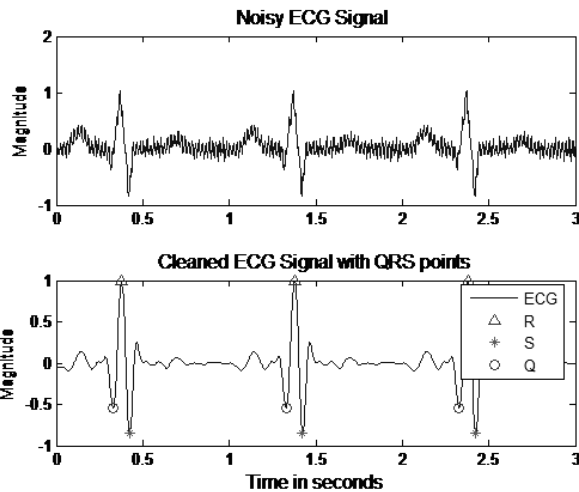


Fig. 10 Noisy ECG and cleaned ECG signal with detected QRS points in filter method

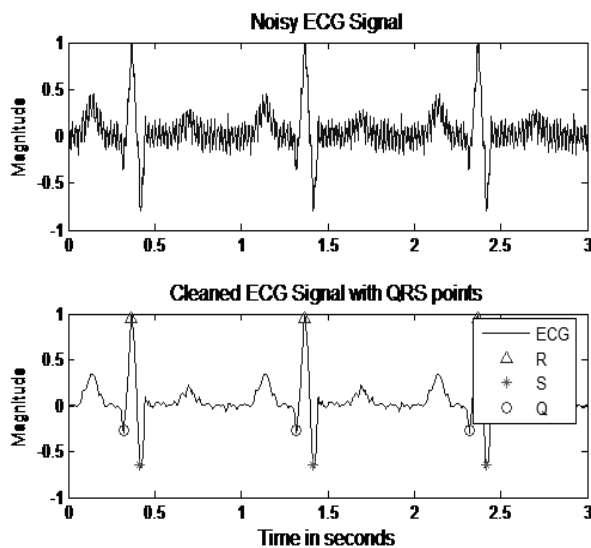


Fig. 11 Noisy ECG and cleaned ECG signal with detected QRS points in wallet approach

### V. CONCLUSION

The theoretical aspects of signal processing can be realized in practice with an application to solve a real-life practical problem in the laboratory. The study of advances in medical technology can be utilized for early diagnosis of heart diseases and preventing cardiac arrests. The PC based analysis of ECG signals helps to design portable instruments or products with low cost components and user friendly techniques such as we discussed, the product would reach a common and an untrained man. The variations in the characteristic parameter in ECG waveform are rather large. Thus, applying signal processing techniques yields reasonably encouraging results. However, they also emphasize the need for comprehensive feature extraction techniques and advanced

signal processing. It is to be noted that other arrhythmic conditions such as Tachycardia, Bradycardia are easily detected with acceptable results. However, discriminating Atrial Tachycardia, Atrial Flutter and Atrial Fibrillation and HRV pose difficulties with simple approaches. Developing suitable methods and obtaining appropriate data sets may be applicable for research in biomedical filed.

### ACKNOWLEDGMENT

We gratefully acknowledge the support of all our faculty and staff in providing lab and library facilities. We also extend our sincere thanks to KDC and Sneha hospitals, Tirupati for providing basic clinical information regarding ECG.

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## BIOGRAPHIES



**S. Thulasi Prasad** received the M. Tech degree in Electronics and Communication Engineering from S. V. University College of Engineering, Tirupati. He has 15 years of teaching experience and 2 years of industrial experience. He is presently working in

CVSE, Tirupati as Associate Professor and Head of the Department.



**Dr. S. Varadarajan** received the M. Tech degree in Electronics and Communication Engineering from NIT, Warangal and Ph.D degree from S. V. University College of Engineering, Tirupati. He is presently working as Professor in the Dept. of ECE in S. V.

University College of Engineering, Tirupati.