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Representation and Denoising of ECG Signal Using Hybrid Filtering Approach

Neeraj Venkat[1], Roopa S. R[2], Vamshi Tejas[3], Vishnupriya A[4]
[1, 2, 3, 4]*Electronic and Communication Engineering, Nagarjuna College of Engineering and Technology, Bangalore, Karnataka, India*

Abstract: Electrocardiogram (ECG) signal plays an imperative role in monitoring and examining the health condition of the heart. ECG signal represents the electrical activity of the heat. The most consequential noises that degrade important features in ECG signal are powerline interference noise, external electromagnetic field interference noise, baseline wandering and electroencephalogram noise. The features of ECG signal obtained in time domain is not sufficient for analyzing the ECG signal. As the signal is non-stationary, the time-frequency representation can be used for feature extraction. The Short Time Fourier Transform can be used but its time frequency precision is not optimal. In this current project, we will be able to implement the ideology proposed to overcome the problem among various time frequency transformation. The discrete wavelet transform (DWT) is used which gives effective results for non-stationary signals like ECG signal which may be often contaminated. The combination of Savitzky-Golay filtering and DWT can be used for ECG denoising and feature extraction which has the advantage of preserving the important feature by elimination the noise components. The method is applied for the database which is taken from MIT- BIH arrhythmia and the algorithm is implemented in MATLAB platform.
Keywords: ECG, QRS Complex, Discrete Wavelet Transform, Powerline Interference, Baseline Wander, R-peak, QRS-Complex, T-peak, Denoising and feature extraction

I. INTRODUCTION

ECG signals are generated from the electrical activity produced due to the stimulation in heart muscles. Each heart beat will produce a series of deflections from the baseline in ECG signal. These deflections occur due to the contraction and relaxation process in the heart muscle. There are some important peaks in each cycle of ECG signal they are sequentially represented as P, Q, R, S and T peaks.

The combination of signal information and the noises constitute raw ECG signal. The noise produced due to the muscle activity is called electromyographic (EMG) noise. This is one of the complex types of noise where linear filtering cannot be used, because it leads to cropping some of the significant peaks present in the signal i.e., QRS complex and also leads to widening of peaks.

In wavelet-based filtering approach it preserves some of the additive components of the QRS complexes in highest bands of decomposition, this is one of the important features of the wavelet transform. In nonlinear filtering approach reversible WT is used to estimate the level of noise present in particular decomposition bands.

It is important to select the decomposition and reconstruction filter banks and it is also very important to choose the level of decomposition and proper adjustment of wavelet co- efficient.

Discrete wavelet transform consists of both high pass filter and low pass filter. It is performed by repeatedly filtering the input signal using these digital filters. The high pass filtered output contains detailed coefficients and output from the low pass filter contain approximation coefficients.

The approximation coefficients are considered for further decomposition by considering the suitable mother wavelet. In this work Butterworth and Chebyshev filter are used for ECG signal performance analysis, where it removes50Hz powerline interference and fails to remove baseline wandering.

The resulting output still affected by ringing effect and some of the important features are suppressed. In order to overcome this problem Savitzky-Golay filtering and discrete wavelet transform techniques are used. The wavelet transform performs well for non-stationary signals and Savitzky-Golay filtering give best approximation and smoothing of the noisy data. In performance analysis this method gives us a good SNR (Signal to Noise Ratio) compared to n Butterworth and Chebyshev filter.

II. METHODOLOGY

In general ECG denoising system can be divided into two stages. First is preprocessing and then feature extraction. The preprocessing stage is used to suppress the unwanted noise present in the raw ECG signal and feature extraction stage extracts important diagnostic features from the ECG signal

A. Methods Used For Denoising And Feature Extraction

1) *Savitzky Golay Filter:* This filter is used to perform a local polynomial regression of degree k on a series of values which is of length (k + l) equally spaced to determine the smoothed value at each point. It tends to preserve features of the distribution such as relative maxima, minima and width, which are usually flattened by other adjacent averaging techniques. This is the main advantage of this approach.

Savitzky-Golay filters smooths the noisy data by using the method of least square fitting frame. In this method frame of noisy data is fitted onto a polynomial of given degree k. The coefficients of polynomial is given by the equation

$$P(n) = \sum_{\square=0}^{N} a_k n^k$$

The degree is the order of the polynomial and the frame size indicate the number of samples used to perform the smoothing for each data point. These coefficients minimize the mean squared error approximation for the group of input ECG signal centered at n=0. This filter is used retain the important characteristics of the signal which is corrupted by noise, this filter preserves the peak property and width of the signal and it is used to enhance the accuracy of the signal. The Savitzky-Golay filters have an important property of peak preservation that is very useful in ECG processing.

2) *Discrete Wavelet Transform:* In wavelet filtering the important methodologies are used for operating the non-stationary signals, they are mainly thresholding method in wavelet domain, the level of decomposition, selecting the suitable parameter for threshold multiplier, and filter banks used in SWT1 and SWT2 transforms. It is generally carried out by adjusting the appropriate wavelet coefficients in wavelet domain. In the case of biomedical signal processing it is very important to extract only the signal with useful information by eliminating the interference via thresholding technique. In wavelet wiener filtering many parameters are used, those parameter values play a great effect on filtering result. Unfortunately, it is not known that which parameters should be used for ECG signal denoising. The transform decomposes the signal manually in to orthogonal set of wavelets. The discrete wavelet transform (DWT) is an implementation of the wavelet transform using a discrete set of the wavelet scales and translations by considering some well-defined rules. In other words, here j represents the visibility and k is the position parameter which is used to represent each position of the signal. The scaling function used ϕj,k(n) and the mother wavelet function ψj,k(n) in discrete wavelet domain are

ϕj,k(n) = 2j/2ϕ2 jn − k

ψj,k(n) = 2j/2ψ2 jn − k

The DWT of an input ECG signal of length M-1 is calculated from this equation,

x(n) = X k Wϕ(j0, k)φj0,k(n) + X∞ j=j0 X k Wψ(j0, k)ψj,k(n)

here Wϕ(j0, k) and Wψ(j0, k) are called the wavelet coefficients of the input signal. ϕj,k(n) and ψj,k(n) are orthogonal to each other.

Wϕ[j0, k] = 1 √ M X n x(n)ϕj0,k[n]

Wψϕ[j, k] = 1 √ M X n x(n)ψϕj0,k[n], jj0

The coefficients Wϕ(j0, k) are called the approximation coefficients and Wψ(j0, k) called the detail coefficients which are obtained after passing through high pass and low pass filters. Again, the DWT is carried out by using high pass and low pass filters or digital filters. The relation to wavelets and the approximation properties of filter banks. The low pass filter output gives the approximation coefficients and the high pass filter output gives the detail coefficients. In order to get Wϕ(j0, k) filter coefficients and Wψ(j0, k) one can be written in the form of

Wϕ(j, k) = X n hϕ(n − 2k)Wϕ(j + 1, m)

Wψ(j, k) = X m hψ(m − 2k)Wψ(j + 1, m)

hϕ and hψ are the filter coefficients of the low pass filter and high pass filter and m represents number of samples respectively. The position and the subset scale selection is based on powers of two which results in more efficient and accurate results for analysis.

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3) *Wavelet Reconstruction:* Original signal reconstruction without losing the important features present in the signal. This is called synthesis; in other words, it is also called as reconstruction. Mathematically the term reconstruction is done by performing inverse discrete wavelet transform (IDWT). In the analysis of wavelet filtering, filtering is performed by down sampling and the wavelet reconstruction is performed and filtering is done by up sampling. Up sampling is the process which is used for lengthening a signal component by inserting zeros in between samples

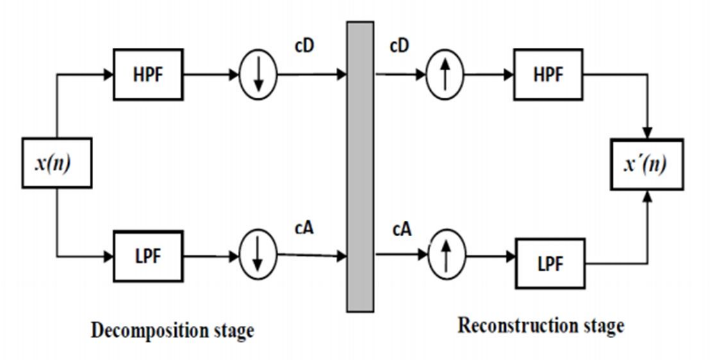

Figure 1: Decomposition and reconstruction for single stage

Here approximation coefficients (cA) and detailed coefficients (cD) are combined by IDWT in order to get back the reconstructed original signal. The single stage reconstruction technique is performed repeatedly for multiple level reconstruction to get back the original signal.

4) *Wavelet Transform Used For Feature Extraction:* The ECG signal decomposition is done using Doubechies (db4) wavelet which is similar to ECG signal. After decomposition the detail coefficients at particular level i.e., is 3rd, 4th and 5th coefficients are combined for reconstructing the original signal, in most of the signal the QRS complex contains more energy and it is concentrated in these coefficients. In order to reduce the oscillatory nature of the signal using the function i.e.,

$$D2 = d4 * (d3 + d5)/2n$$

Where d3, d4, d5 are high pass filter outputs considered as detail coefficients and represents the decomposition level [10]. In order to get the QRS wave segment information the ECG signal derivation is done. This derivation is done up to level 5 using transfer function. In order to avoid the merging of QRS complex with T wave the window should be wide enough because in the case of narrow window several QRS complex peaks generated will increase the complexity of analyzing the biomedical signal. Hence, the moving window concept is used in this algorithm to familiar with different samples for analysis.

B. Preprocessing

1) *Process of Eliminating Baseline Wander Noise:* Baseline wandering usually comes from respiration at frequencies wandering between 0.15 and 0.3 Hz, and it can also be removed by passing through a high pass digital filter. Wavelet transform can also be used to remove baseline wandering by eliminating the trend of the ECG signal. Removal of baseline wandering is very essential because due to the effect of this noise the origin of the whole signal is drifted due to this each peak in the signal has different origin. Hence, this is very essential to remove because a very small changes in the low frequency component may affect the proper analysis and diagnosis process, especially in the case of ischemia, which is usually observed during stress test.
2) *Process of Eliminating Powerline Interference:* Electromagnetic fields caused by a powerline represent a common noise source in the ECG that is characterized by 50 or 60 Hz sinusoidal interference, possibly accompanied by a number of harmonics. Such narrow band noise renders the analysis and interpretation of the ECG more difficult. It is essential to reduce these disturbances at the low frequency component in ECG signal to improve accuracy and reliability. The ECG signal becomes more stationary after removing baseline wander noise and explicit than the original signal. However, powerline interference and electromyographic noises might still affect the feature extraction of ECG signal. The noise may be complex stochastic processes within a wide band; it is not possible to remove using traditional digital filters such as notch filters, low pass and high pass filters. To remove the wideband noises using Wavelet Denoising technique.In this process the ECG signal is loaded from the database or it is recorded from the patients. Different data samples of different patients are taken for the experiment. ECG

denoising algorithm will be developed in the perspective of analysis of ECG signal in diagnosis of heart diseases, using wavelet transform. It is based on the wavelet basis function. Further, algorithms to enhance the robustness to cater noises caused due to power supplies. High frequency interference and random body voltages. The preprocessing of an ECG signal is performed for the removal of noise associated with the ECG signal. While acquisition of ECG, it gets corrupted due to powerline interferences, baseline wander noise, motion artifacts and because of some electronic devices nearby patients, electrosurgical noises will appear. Detrending is done by subtracting the mean or to best fit the line using least squares technique from the original data, removing the trend from the data enables to focus on the fluctuations in the data. The detrend signal which is also called a baseline wander removal which is done in order to effectively identify the major peaks in the signal. This noise in various degrees causes elimination of significant features for the ECG feature extraction and reduces the performance of diagnostic accuracy. Therefore, ECG signal denoising preprocessing is done by decomposing signal in to multiple basis functions using Daubechies wavelet transform which is similar to ECG signal. The primary processing is done to remove power supply interference and all the high frequency components from the ECG signal. Researchers have made several researches on wavelet basis functions such as coiflets, Haar, mortlet etc in order to check how well it performs on biomedical signals. From the obtained results it is proved that the Daubechies (Db4) wavelet basis function gives excellent performance when compared with other wavelet basis functions.

C. Feature Extraction

1) *R-peak Detection:* In QRS complex, detection of R peak plays a vital role in analyzing ECG signal. In order to determine the irregularities in heart beat and the number of beats per unit (minute). For peak detection and specific details extraction, at first signal should be selected. In electrocardiogram signal R-peak is very important peak which is having the largest amplitude among other peaks such as P, Q, S and T peaks. The specific detail components of low frequency components are removed to detect the R-peak.

2) *Algorithm for QRS complex extraction*

a) At first, the location of the R peak (fiducial point) is determined from the signal which is contaminated by noise.
b) The R-peak (fiducial point) is computed, along with this location of the peak is determined using wavelet transform.
c) After obtaining the R peak, the two nearest local minima are calculated, which are located both sides of the R-peak in a noisy ECG signal.
d) Two zero crossing points are detected; one is at left hand side of the left minima and another is at right hand side of the right minima from the obtained fiducial point.

The Q wave, R wave and S wave together constitute the QRS complex, where R wave is having largest amplitude among all other waves. The first negative peak obtained after the p wave is called Q wave which is induced due to ventricular depolarization. In some cases, it is absent due to abnormalities in heart. The amplitude of Q wave is normally less than R wave, which is the largest peak present in the ECG signal. The S wave is the second negative deflection obtained after R wave that may extend below baseline. The R wave is the first positive triangular deflection followed by Q wave.

3) *Beat Rate Detection:* The frequency measurement is mainly used in medical field in order to perform some critical tests such as stress tests, this test is usually done in sports application during some critical condition or life-threatening situation. In this case ECG signal plays a important role in computing the frequency of heart rate, To find out the rate of beats per minute. Hence, the detection of QRS complex and R peak is very essential. The QRS enhancement stage is used to enlarge the QRS complex compared to the other ECG features (P, T and noise). The QRS enhancement stage is occasionally called preprocessing or feature extraction, which we have done already under preprocessing section. If the R-Peak is required to be detected, an extra step is needed to determine the maximum amplitude value within the detected QRS complex. Since R-wave is positive peak and having highest amplitude in ECG signal, the time interval between two successive R-wave peaks is used to calculate beat rate (beats/minute) as follows

$$\textit{Heart Rate} = \frac{60}{\textit{RR-INTERVAL}} \text{ beats/minute}$$

III. PERFORMANCE ANALYSIS

The SNR performance is analyzed for the results obtained using notch filter and the proposed method after applying to an ECG signal, here 12 different ECG signals are taken from PTB and MIT-BIH diagnostic center and the comparative analysis prove that, the results obtained using the proposed method gives better SNR when compared to Butterworth and Chebyshev filter. The signal to noise ratio (SNR) is given by

$$SNR_{Out} = 10.log_{10}\left(\frac{\sum_{n=0}^{N-1} s[n]^2}{\sum_{n=0}^{N-1}[z[n]-s[n]]^2}\right).$$

Where s[n] is original noisy signal and z[n] represents the denoised signal. Table 3.1 shows the SNR performance comparison.

Database_Name	Butterworth	Chebyshev	Savitzky Golay
S0020arem	16.3289	16.3769	16.7426
S0021arem	26.1525	26.2126	26.9255
S0021brem	12.1482	12.2206	12.8325
S0022lrem	8.3881	8.4223	8.6447
S0025lrem	-5.9104	-4.9874	-5.0227
S0026lrem	0.2700	0.3817	1.0900
S0028lrem	16.5629	16.6105	17.0379
S0031lrem	17.2015	17.2561	17.6645
S0038lrem	8.4238	8.5058	8.6266
S0078lrem	-3.8045	-3.6612	-3.2711
S00101lrem	19.7633	19.8413	20.5255

IV. CONCLUSIONS

The morphology of electrocardiogram are elaborately discussed. Different types of noises that affect the ECG and their origins are described. For the simulation the ECG signals are taken from MIT-BIH database. ECG denoising consists of preprocessing and feature extraction is developed and tested using simulation tool MATLAB, the processing consists of removing wideband noise, baseline wander noise and powerline interference noise which are the major artifacts that affect the morphology of the ECG waveform using discrete wavelet transform. Feature extraction includes extracting some important feature such as P-peak, Q-peak, R-peak, S-peak, T-peak and number of beats per minute for analysis of ECG signal using wavelet thresholding. This system intend to help cardiologist to judge the status of a patient. Therefore, the recognition and analysis of the ECG signals is a very important task. The resulting advantage by effectively filtering the ECG signals is to determine in a clear and simple way to determine the PQRST complex, that helps to identify different types of arrhythmia's, like the tachycardia or the bradycardia and variations in the heart rate; as well as 39 ECG denoising and parameter extraction for diagnosis using wavelet transform determine other types of abnormalities in the cardiogram.

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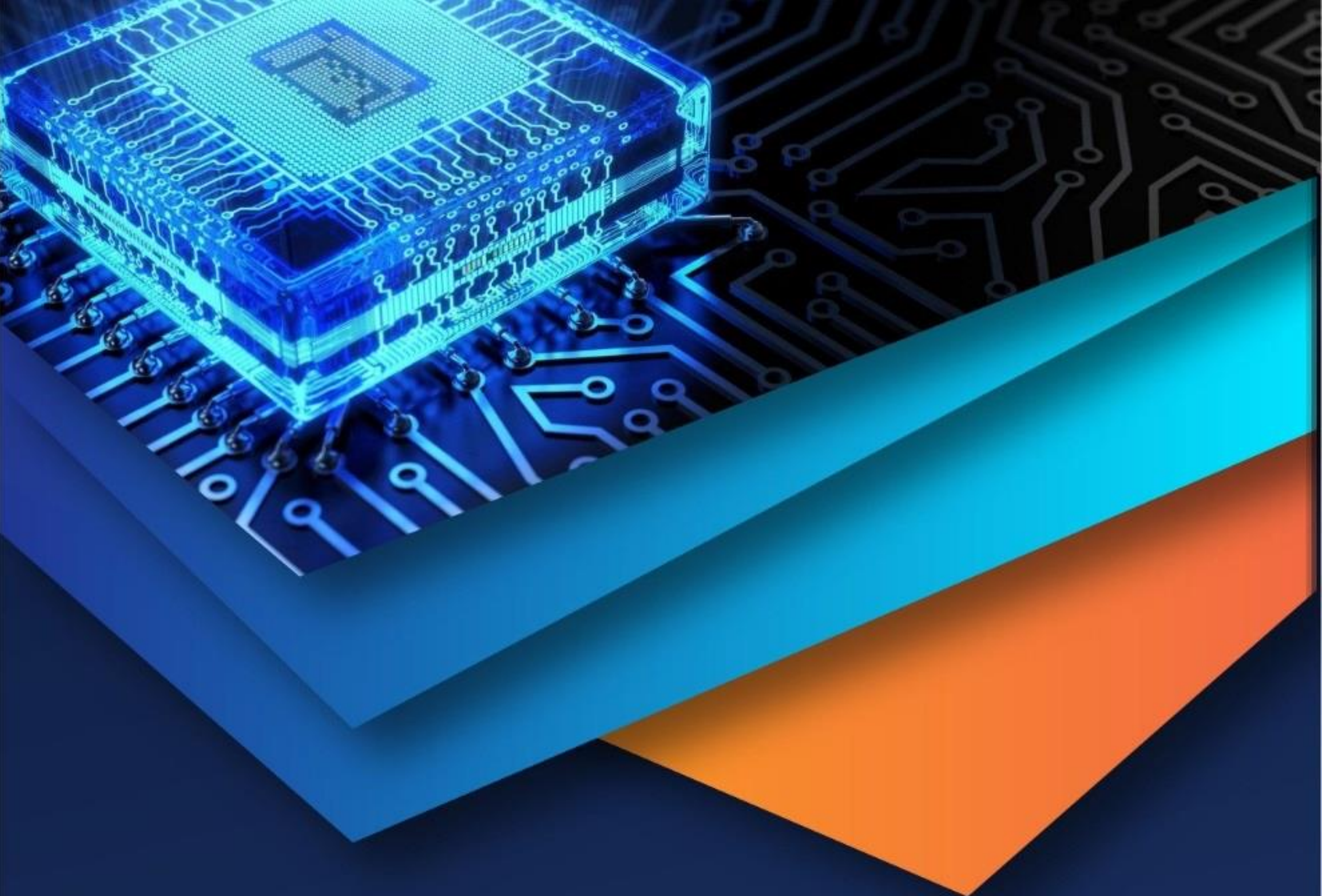

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