QRS Complex Detection of ECG Signal Using Wavelet Transform

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Abstract:
The electrocardiogram (ECG) is widely used for diagnosis of heart diseases. Generally, the recorded ECG signal is often contaminated by noise. In order to extract useful information from the noisy ECG signals, the raw ECG signals has to be processed. The baseline wandering is significant and can strongly affect ECG signal analysis. The detection of QRS complexes in an ECG signal provides information about the heart rate, the conduction velocity, the condition of tissues within the heart as well as various abnormalities. It supplies evidence for the diagnosis of cardiac diseases. An algorithm based on wavelet transforms (WT’s) has been developed for detecting ECG characteristic points. Discrete Wavelet Transform (DWT) has been used to extract relevant information from the ECG signal in order to perform classification. The QRS complex can be distinguished from high P or T waves, noise, baseline drift, and artifacts. By using this method, the detection rate of QRS complexes is above 99.8% for the MIT/BIH database and the P and T waves can also be detected, even with serious base line drift and noise.

Keywords- Electrocardiogram, Wavelet Transform, QRS Complex, Filters, Threshold.

I. INTRODUCTION

The electrocardiogram (ECG) signal is a recording of the heart’s electrical activity and provides valuable clinical information about the heart’s performance. The Electrocardiogram is the electrical activity of the heart. It is a graphical representation of the direction and magnitude of the electrical activity that is generated by depolarization and repolarization of the atria and ventricles. It provides information about the heart rate, rhythm, and morphology. ECG varies from person to person due to the difference in position, size, anatomy of the heart, age, relatively body weight, chest configuration and various other factors. There is strong evidence that heart’s electrical activity embeds highly distinctive characteristics, suitable for various applications and diagnosis. The electrical activity during the cardiac cycle is characterized by five separate waves of deflections designated as P, Q, R, S and T. The QRS complex is generally chosen for the detection of Cardiac arrhythmias, such as an irregular heart rate. The detection of QRS complex, specifically, the detection of the peak of the QRS complex, or R wave, in an ECG signal is a difficult problem since it has a time-varying morphology and is subject to physiological variations due to the patient and to corruption due to noise.

Direct visual monitoring of ECGs by human being is a tough task whose monotony increases the loss of clinical information. To this poser great efforts have been made to develop analog and digital systems for ECG analysis. Computer based ECG analysis system have proved to be more efficient, having made possible rapid retrieval of data for storage and techniques of data presentation whose clinical utility is evident. In the last decade many approaches to QRS detection have been proposed, involving artificial neural networks, real time approaches, genetic algorithms, and heuristic methods based on nonlinear transforms and filter banks. As noted in, most of the current QRS detectors can be divided into two stages: a preprocessor stage to emphasize the QRS complex and a decision stage to threshold the QRS enhanced signal. Typically, the preprocessor stage consists of both linear and nonlinear filtering of the ECG. Recognition of ECG wave starts with the R identification; with the help of Wavelet transform. The wavelet transform, which has been used in biomedical signal processing also, has its role in ECG characterization and QRS detection. To overcome the limitations imposed by fixed duration windowing techniques in detecting time-varying transients, a general, adaptive technique that captures the spectral/temporal variations in QRS morphology is needed.

QRS detection is one of the fundamental issue in the analysis of Electrocardiographic signal. The QRS complex consists of three characteristic points within one cardiac cycle denoted as Q, R and S. The QRS complex is considered as the most striking waveform of the electrocardiogram and hence used as a starting point for further analysis or compression schemes. The detection of a QRS complex seems not to be a very difficult problem. However, in case of noisy or pathological signals or in case of strong amplitude level variations, the detection quality and accuracy may decrease significantly.
Once the position of the QRS complex is obtained, the location of other components of ECG like P, T waves and ST segment etc. are found relative to the position of QRS, in order to analyze the complete cardiac period.

Recently Wavelet Transform has been proven to be a useful tool for non-stationary signal analysis. Among the existing wavelet approaches, (continuous, dyadic, orthogonal, biorthogonal), we use real dyadic wavelet transform because of its good temporal localization properties and its fast calculations. Discrete Wavelet Transform can be used as a good tool for non-stationary ECG signal detection.

II. WAVELET TRANSFORM

The Wavelet Transform is a time-scale representation that has been used successfully in a broad range of applications, in particular signal compression. Recently, Wavelets have been applied to several problems in Electrocardiology, including data compression, analysis of ventricular late potentials, and the detection of ECG characteristic points. The Wavelet transformation is a linear operation that decomposes the signal into a number of scales related to frequency components and analyses each scale with a certain resolution. The WT uses a short time interval for evaluating higher frequencies and a long time interval for lower frequencies. Due to this property, high frequency components of short duration can be observed successfully by Wavelet Transform. One of the advantages of the Wavelet Transform is that it is able to decompose signals at various resolutions, which allows accurate feature extraction from non-stationary signals like ECG. A family of analyzing wavelets in the time frequency domain is obtained by applying a scaling factor and a translation factor to the basic mother wavelet.

Wavelet Transform of a signal \( f(t) \) is defined as the sum of over all time of the signal multiplied by scaled, shifted versions of the wavelet function \( \psi \) and is given by,

\[
W(a,b) = \int_{-\infty}^{\infty} f(t) \psi_a(bt) dt
\]

where \( \psi_a(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \)

The DWT is sufficient for most practical applications and for the reconstruction of the signal. The DWT provides enough information, and offers a significant reduction in the computation time. Here, we have discrete function \( f(n) \) and the definition of DWT is given by:

\[
W(a,b) = c(y,k) = \sum_{n=2}^{\infty} f(n) \psi_j, k(n)
\]

Where \( \psi_j(n) \) is a discrete wavelet defined as

\[
\psi_j, k(n) = 2^{j/2} \psi(j2^n - k)
\]

In the DWT analyses, the signal at different frequency bands and at different resolutions is decomposed into a ‘coarse approximation’ and ‘detailed information’. Two sets of functions are employed by the DWT, the scaling functions (associated with the low pass filter) and the wavelet functions (associated with the high pass filter). The signal is filtered by passing it through successive high pass and low pass filters to obtain versions of the signal in different frequency bands. The fundamental idea behind wavelets is to analyze according to scale. Wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other functions. Wavelet algorithms process data at different scales or resolutions. If we look at a signal with a large window, we would notice gross features. Similarly, if we look at a signal with a small window, we would notice small features. The result in wavelet analysis is to see both the forest and the trees, so to speak.

Heart rate is calculated using the peak detection technique. R-wave is determined by analyzing the slopes of the ECG samples. The iso-electric baseline of a heart signal can be shifted for various abnormalities. Hence the ECG components may also be shifted. This may be a problem in detecting the R-waves. So a threshold level is taken into account. Peaks exceeded the threshold level are counted as R-waves by determining the slopes of the rising and falling edges. At first, we characterize the ECG signal, that is, we detect and locate the different waves and segments of the ECG signal. The onsets of P-wave, QRS complex, T-wave and the P-R segment, S-T segment, the average duration of QRS complexes are detected. To avoid the problem of baseline shifting of the ECG signal, the signal is de-trended. The baseline shifting is due to a very low frequency signal. This very low frequency component is filtered out by discrete wavelet transform method. The filtering is done in the following way.

We decompose the ECG signal into 5 levels by using DWT and reconstruct the approximation (A5) and detail (D5) signals at level 5 as shown below. Then the summation of A5 and D5 will be the low frequency signal in ECG that causes the baseline shifting. This low frequency signal is deducted from the original ECG signal to get the one without baseline shifting and thus the problem of baseline shifting is solved.
Now, the de-trended signal still contains some high frequency noise. Since, in calculation of heart rate we need only the R-waves, so any fluctuations in the signal except the R-waves are extraneous. These noises are removed using wavelet technique in the same way.

**Wavelet Selection**

The use of the Wavelet Transform has gained popularity in time-frequency analysis because of the flexibility it offers in analyzing basis functions. The selection of relevant wavelet is an important task before starting the detection procedure. The choice of wavelet depends upon the type of signal to be analyzed. The wavelet similar to the signal is usually selected. There are several wavelet families like Harr, Daubechies, Biorthogonal, Coiflets, Symlets, Morlet, Mexican Hat, Meyer etc. and several other Real and Complex wavelets. However, Daubechies (Db4) Wavelet has been found to give details more accurately than others. Moreover, this Wavelet shows similarity with QRS complexes and energy spectrum is concentrated around low frequencies. Therefore, we have chosen Daubechies (Db4) Wavelet for extracting ECG features in our application. The Daubechies Wavelet is shown in Fig 3.

III. DATA

ECG signals required for analysis are collected from Physionet MIT-BIH arrhythmia database where annotated ECG signals are described by a text header file (.hea), a binary file (.dat) and a binary annotation file (.atr). The database contains 48 records, each containing two-channel ECG signals for 30 min duration selected from 24-hr recordings of 47 different individuals. Header file consists of detailed information such as number of samples, sampling frequency, format of ECG signal, type of ECG leads and number of ECG leads, patient’s history and the detailed clinical information. In binary data signal file, the signal is stored in 212 format which means each sample requires number of leads times 12 bits to be stored and the binary annotation file consists of beat annotations. Signals were sampled using a 12-bit analog-to-digital converter board (National Instruments, PCI-6071E). Matlab and its wavelet toolbox were used for ECG Signal processing and Analysis. Analysis was performed on the PQRST waveform.

IV. METHODOLOGY

In order to extract useful information from the ECG signal, the raw ECG signal should be processed. ECG signal processing can be roughly divided into two stages by functionality: Preprocessing and Feature Extraction as shown in Figure 4.

![Fig. 4 Structure of ECG Signal Processing](image_url)

Feature Extraction is performed to form distinctive personalized signatures for every subject. The purpose of the feature extraction process is to select and retain relevant information from original signal. The Feature Extraction stage extracts diagnostic information from the ECG signal. The preprocessing stage removes or suppresses noise from the raw ECG signal. A Feature Extraction method using Discrete Wavelet Transform.

A. Preprocessing

ECG signal mainly contains noises of different types, namely frequency interference, baseline drift, electrode contact noise, polarization noise, muscle noise, the internal amplifier noise and motor artifacts. Artifacts are the noise induced to ECG signals that result from movements of electrodes. One of the common problems in ECG signal processing is baseline wander removal and noise suppression.
1) Removal of the baseline drift: Baseline wandering is one of the noise artifacts that affect ECG signals. Removal of baseline wander is therefore required in the analysis of the ECG signal to minimize the changes in beat morphology with no physiological counterpart. Respiration and electrode impedance changes due to perspiration are important sources of baseline wander in most types of ECG recordings. The frequency content of the baseline wander is usually in a range well below 0.5Hz. This baseline drift can be eliminated without changing or disturbing the characteristics of the waveform. We use the median filters (200-ms and 600-ms) to eliminate baseline drift of ECG signal. The process is as follows

a) The original ECG signal is processed with a median filter of 200-ms width to remove QRS complexes and P waves.

b) The resulting signal is then processed with a median filter of 600-ms width to remove T waves. The signal resulting from the second filter operation contains the baseline of the ECG signal.

c) By subtracting the filtered signal from the original signal, a signal with baseline drift elimination can be obtained.

2) Removal of the NOISE: After removing baseline wander, the resulting ECG signal is more stationary and explicit than the original signal. However, some other types of noise might still affect feature extraction of the ECG signal. In order to reduce the noise many techniques are available like Digital filters, Adaptive method and Wavelet Transform thresholding methods. Digital filters and Adaptive methods can be applied to signal whose statistical characteristics are stationary in many cases. However, for nonstationary signals it is not adequate to use Digital filters or Adaptive method because of loss of information. To remove the noise, we use Discrete Wavelet transform.

This first decomposes the ECG signal into several sub bands by applying the Wavelet Transform, and then modifies each wavelet coefficient by applying a threshold function, and finally reconstructs the denoised signal. The high frequency components of the ECG signal decreases as lower details are removed from the original signal. As the lower details are removed, the signal becomes smoother and the noise disappears since noises are marked by high frequency components picked up along the ways of transmission. This is the contribution of the discrete Wavelet Transform where noise filtration is performed implicitly. The preprocessed signal using DWT is shown in Fig 5.

B. Detection of R peak and QRS

In order to detect the peaks, specific details of the signal are selected. The detection of R peak is the first step of feature extraction. The R peak in the signal from the Modified Lead II (MLII) lead has the largest amplitude among all the waves compared to other leads. The QRS complex detection consists of determining the R point of the heartbeat, which is in general the point where the heartbeat has the highest amplitude. A normal QRS complex indicates that the electrical impulse has progressed normally from the bundle of His to the Purkinje network through the right and left bundle branches and that normal depolarization of the right and left ventricles has occurred. Most of the energy of the QRS complex lies between 3 Hz and 40 Hz. The 3-dB frequencies of the Fourier Transform of the wavelets indicate that most of the energy of the QRS complex lies between scales of 2^3 and 2^4, with the largest at 2^4. The energy decreases if the scale is larger then 2^4. The energy of motion artifacts and baseline wander (i.e., noise) increases for scales greater than 2^4. Therefore, we choose to use characteristic scales of 2^3 to 2^4 for the wavelet. The detection of the QRS complex is based on modulus maxima of the Wavelet Transform. This is because modulus maxima and zero crossings of the Wavelet Transform correspond to the sharp edges in the signal. Therefore, detection rules (thresholds) are applied to the Wavelet Transform of the ECG signal. The Q and S point occurs about 0.1 second from the R peak. The left point denoted the Q point and the right one denotes the S point. Calculating the distance from zero point or close to zero of left side of R Peak within the threshold limit denotes Q point. Similarly the right side denotes the S point.
QRS width is calculated from the onset and the offset of the QRS complex. The onset is the beginning of the Q wave and the offset is the ending of the S wave. Normally, the onset of the QRS complex contains the high-frequency components, which are detected at finer scales. To identify the onset and offset of the wave, the wave is made to zero base. The onset is the beginning and the offset is the ending of the first modulus maxima pair. Once this QRS complex is located the next step is to determine the onset and offset points for each QRS complex and to identify the component waves of the QRS complex.

V. CONCLUSION
An algorithm for R Peak and QRS complex detection using Wavelet Transform technique has been developed. The information about the R Peak and QRS complex obtained is very useful for ECG Classification, Analysis, Diagnosis, Authentication and Identification performance. The QRS complex is also used for beat detection and the determination of heart rate through R-R interval estimation. This information can also serve as an input to a system that allows automatic cardiac diagnosis. The overall sensitivity of the detector improves. The main advantage of this kind of detection is less time consuming for long time ECG signal.

Further, ECG signal is used as a tool for liveness detection. The physiological and geometrical differences of the heart in different individuals display certain uniqueness in their ECG signals. Hence ECG can be used as a Biometric tool for Identification and Verification of Individuals. The advantage of ECG in biometric systems is their robust nature against the application of falsified credentials. Amplitude of P wave remains constant throughout the life and other amplitude features are changes on small scale. Future work is to calculate the amplitude distance between ECG features and comparison will be made for Identification. Further verification of individuals can be done by using statistical theory of Sequential Probability procedures.

VI. REFERENCES


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