ECG PEAK DETECTION USING WAVELET TRANSFORM

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ABSTRACT

A wavelet-based algorithm is developed to calculate Instantaneous Heart Rate (IHR) and associated parameters of electrocardiogram (ECG). The base-line shift and other artifacts of ECG are eliminated using Discrete Wavelet Transform (DWT). The R-waves of ECG are detected using slope detection technique and proper thresholding. IHR time series is constructed from the R-peaks. Application of this technique to the 18 sets of ECG data of MIT-BIH database shows that the average successful peak detection rate is around 98.97%. From the IHR time series the Heart Rate Variability (HRV) is calculated and HRV data is analyzed with DWT. Finally, the time-frequency energy distribution is analyzed which helps to have a better understanding of the control of Autonomic Nervous System (ANS) on HRV.

1. INTRODUCTION

As the Autonomic Nervous System (ANS) modulates the cardiac pacemaker and provides beat-by-beat regulation of the cardiovascular system [1], the analysis of Heart Rate Variability (HRV) can be used clinically to assess the ANS providing separate measures of the sympathetic and parasympathetic nervous systems.

A disturbance in the conduction of excitation from the atria to the ventricles is revealed by the prolongation of the P-R intervals. Any electrocardiographic lead, which shows a P and QRS wave can be used to diagnose atrioventricular conduction defects. The electrocardiogram can reflect many types of conduction defects. One of these is the atrial arrhythmias which may be compatible with life but the severe and dangerous one is the ventricular fibrillation where death is ensued if proper step against fibrillation, i.e., ventricular defibrillation is not taken.

Analysis of HRV data from patients with congestive heart failure shows a decrease in spectral power at all frequency ranges [2]. This finding provides very important evidence that cardiac parasympathetic function is depressed in patients prone to sudden cardiac death. The purpose of this study is to characterize the HRV signals in time domain as well as in frequency domain. R-waves are detected by slope detection technique. Prior to the calculation of Instantaneous Heart Rate (IHR) we apply de-trending and de-noising to the ECG signal using discrete wavelet transform technique [3]. This study is based on statistical and discrete wavelet transform analysis. We analyze 30-minute duration recording of ECG of MIT-BIH database [4], to determine IHR, Mean Heart Rate (MHR), Standard Deviation (SD) and Coefficient of Variation (CV). We also perform a quantitative analysis of HRV in time-frequency (scale) domain.

Wavelet transform is used here to analyze the heart-rate fluctuations. This method is chosen because the components in the signals can be analyzed and quantified at different scales, i.e., long-time windows can be used for the low frequency components while short-time windows can be used for high frequency components [4].

2. METHOD

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 [1]. 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.

The wavelet transform depends upon two parameters, scale \( a \) and position \( \tau \), which vary continuously over the real numbers [6]. If the scale parameter is the set of integral powers of 2, i.e., \( a = 2^j \) ( \( j \in \mathbb{Z} \), \( \mathbb{Z} \) is an integer set), then the wavelet is
called a dyadic wavelet. And the corresponding transform is called Discrete Wavelet Transform (DWT). The DWT at scale $2^j$ is given by:

$$W_j(f) = \left\{ \frac{1}{\sqrt{2}} \int \psi_{2^j}((t - \tau)/2^j) \, dt \right\}$$

To cover the whole frequency domain the Fourier transform of $\psi_{2^j}(t)$ must satisfy the relation:

$$\sum_{j=-\infty}^{\infty} |\hat{\psi}(2^j \omega)|^2 = 1$$

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 [5]. 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 [Fig. 1].

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.

Using wavelets to remove noise from a signal requires identifying which component or components contain the noise [5] and then reconstructing the signal without those components. When we decompose a signal by DWT, we note that successive approximations become less and less noisy as more and more high frequency information is filtered out of the signal. Of course, in discarding all the high frequency information, we also lose many of the original signal’s sharpest features. Optimal de-noising requires a more subtle approach called “thresholding”. This involves discarding only the portions of the details that exceed a certain limit. We use here global thresholding option, which is derived from Donoho-Johnstone [3] fixed form threshold strategy for an un-scaled white noise.

![Fig. 1 ECG signal, its de-trended and de-noised version to calculate IHR by the proposed algorithm.](image-url)
The final signal (de-trended and de-noised) [Fig. 1] now contains only high amplitude spikes that denote the onset of R-waves. Then by observing the average amplitudes of the R-waves, a threshold voltage level (TP) is set up. The data sets, we characterized, show that some noisy spikes come just after the R-waves, which are approximately of same amplitudes as R-waves. These may be due to noises from supply lines and some other kinds of interferences. Generally, IHR for a normal adult varies within the range 60-120 beats/min. So any noisy spikes that appear within 180 samples after the R-waves are ignored and assumed as noise.

Before the occurrence of a R-wave, the slope of the signal is positive and after the R-wave, the slope is negative. Again, any upward excursion that exceeds the TP is taken as an R-wave. Thus, by calculating two slope values, one upward & one downward, an R-wave can be detected. Consecutive R-waves are detected using the same technique. Thus, the IHR is calculated continuously as long as R-waves are encountered. If R-wave is missing somewhere, the corresponding slope values can’t be found. As a result, the IHR may fall and hence the MHR.

So, cardiac abnormalities can be detected by this method. When an R-wave is missing, two cases may arise. First, the ventricles do not generate the R-wave. Second, the peak of the R-wave is not sufficient enough, i.e., peak is not capable to exceed TP. The first case may be due to ventricular fibrillation where ECG shows no R-waves. It is a much more severe cardiac abnormality and in this situation an electric current pulse is applied through defibrillator towards the heart in order to initiate the ventricular actions. The second case may arise because of improper ventricular conduction, which is a cause of lack of oxygenated blood supply to the ventricular muscles indicating that the ventricles do not contract forcefully enough to generate a normal R-wave. Sometimes R-wave missing is a quite normal case if it occurs rarely. But if R-wave is seen to be missing very frequently, then it may be an indication of cardiac abnormality. And if it is missed for a long duration, then it is evident that no ventricular pumping is taking place in the heart.

3. HRV ANALYSIS BY DWT

Analysis of the HRV signal at various resolutions is accomplished by decomposition into elementary functions that well localized both in time and frequency domains. These elementary functions are called wavelets. We performed multilevel decomposition of IHR signal by DWT using Symlet2 wavelet.

Although the lowest frequency components of the IHR signal are useful for studies of long-term modulation of ANS [1], they may affect the power spectra of HRV signals. We used wavelet transform method to de-trend IHR signal. The de-trended and hence de-noised IHR signal along with the trend (low frequency component) is shown in fig 2.

![Fig. 2 IHR signal, it’s low frequency component and de-trended IHR signal to analyze HRV by the proposed algorithm.](image)

The time-frequency energy distribution of the HRV signal was also investigated [Fig. 3]. The color intensity reflects time-scale energy distribution of the signal.

![Fig. 3 The DWT (above) and the CWT (below) approach of time-scale representation of the HRV signal.](image)
4. RESULTS

We analyzed 30-minute duration ECG data of MIT-BIH databases [6] and calculated IHR by slope detection technique. We also determined MHR, SD, CV and found that except some few cases, the results were correlated. Some of the data sets analyzed are given in table 1.

Table 1: Analysis of 30 minutes duration data sets

<table>
<thead>
<tr>
<th>DATA</th>
<th>Actual Beats (N1)</th>
<th>Detected Beats (N2)</th>
<th>Rate of detection (N2/N1)x100%</th>
<th>MHR (Beats/min)</th>
<th>SD</th>
<th>CV (SD/MHR)x100%</th>
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5. CONCLUSION

The proposed algorithm for the calculation of IHR is very flexible. It is easy to understand and can be implemented in practice. It is a faster method. It can process 30-minute duration data, which contains 648000 samples in less than 24 seconds with Matlab program in a Pentium-III processor. The process is supposed to be generalized for calculation of HRV of any kind.

The DWT algorithms can be used to characterize ANS modulation of cardiovascular activity in order to better understanding of short-term cardiovascular regulation. The wavelet method is chosen because they have the ability to localize the changes in characteristics of non-stationary HRV signal without loosing time and frequency information [7]. For example, if a patient is taken under continuous monitoring in Intensive Care Unit (ICU), then the clinician/doctor can determine his/her range of normal heart rate variations. Now an alarming arrangement can be established to alert the doctor or nurse to take immediate actions if IHR goes beyond the range.

The method proposed here can detect transients and artifacts in the signal. Actually it provides a multi-resolution analysis. Since the behavior of the ANS can be tracked using DWT, we believe that this technique will further improve our understanding of the interactions of the autonomic control systems with the cardiovascular activity. Since wavelet technique gives better time-frequency resolution, we can also apply it to pattern recognition of ECG. The method can be further enhanced so that it can be used in ECG data compression and on-line signal processing of ECG.

REFERENCES