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Hilbert Transform Based Adaptive ECG R-Peak Detection Technique

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ABSTRACT

In this paper we introduce a R-peak detection algorithm using the Hilbert transform for electrocardiogram processing. This algorithm uses the envelope obtained from Hilbert transform to detect the R-peaks in the ECG signal. The algorithm adaptively determines the threshold for peak determination. This technique minimizes the unwanted effects of large peaked T and P waves. Main advantage of this algorithm is that it performs extremely well in the pragmatic presence of noise.

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1. INTRODUCTION

Electrocardiogram (ECG) is considered to be the backbone of cardiology. The graphical tracing of depolarization and repolarization activities generated by the heart gives rise an Electrocardiogram (ECG) that can be measured by placing an array of 12 different electrodes referred as ECG leads on the body surface of a patient [1, 2]. Long term ECG recordings are performed by monitoring ECG signals from one or two leads in order to monitor any abnormal cardiac rhythm that cannot be observed during normal ECG test [3]. This typical tracing consists of a series of repetitive waves namely P-QRS-T as shown in Fig.1 and sometimes U waves that arises from isoelectric line, this indicates electrical activity [1]. Each of these waves has an important relation with the heart, with P-wave representing depolarization of atria, QRS complex representing ventricular depolarization and T-wave is associated with ventricular repolarisation [4].Cardiologists look for life threatening disturbances in the intervals, amplitudes and areas of these waves recorded from the surface electrocardiogram [2].

QRS complex is the most prominent feature in electrocardiogram because of its specific shape; therefore it is taken as a reference in ECG feature extraction. R peak detectors are very useful tools in analyzing ECG features thus form the basis of ECG feature extraction [1].

ECG is a nearly periodic signal that reflects the activity of the heart. A lot of information on the normal and pathological physiology of heart can be obtained from ECG. However, the ECG signals being non-stationary in nature, it is very difficult to visually analyze them. Thus the need is there for computer based methods for ECG signal analysis [5].

A lot of work has been done in the field of ECG signal analysis using various approaches and methods. The basic principle of all the methods however involves transformation of ECG signal using different transformation techniques including Fourier Transform, Hilbert Transform, Wavelet transform etc.

Physiological signals like ECG are considered to be quasi-periodic in nature [4]. They are of finite duration and non stationary. Hence, a technique like Fourier series (based on sinusoids of infinite duration) is inefficient for ECG. Apart from this, transmission of ECG often results in the corruption of signal due to introduction of noise [2]. Various factors responsible for introduction of noise include poor channel conditions, Baseline wander (caused by respiration), 50 or 60 Hz power line interference etc. Analyzing such a noisy signal is bound to give erroneous results [5].

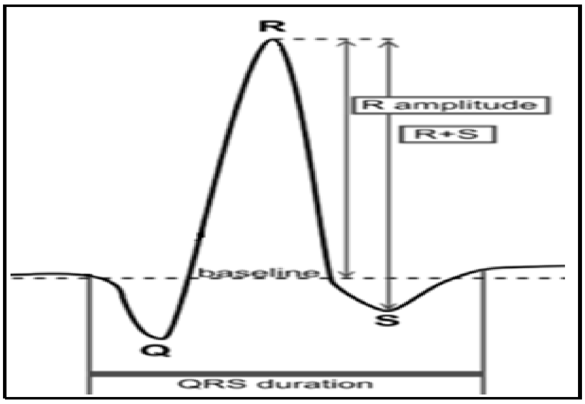

Figure 1. Peaks and waves in ECG signal

2. METHODOLOGY

Heart beat detection is a two step approach. The first step involves preprocessing the data using appropriate filtering to remove the unwanted noise. A well designed first step greatly improves the signal to noise ratio and provides a reliable baseline for the next step which is essential to obtain noise free results [1]. The second step involves a threshold detection scheme to distinguish and identify the R-wave from other components of the cardiogram. The threshold requires considerable attention as the threshold value cannot be static for all ECG signals. It should be defined with apropos to the ECG signal whose R peaks are to be detected [5].

The ECG signal must be filtered and represented in such way so that the peak detection process yields efficient results even in the presence of noise within certain tolerable limits [4]. We propose to use Hilbert Transform for this purpose. For a real-time function x(t), the Hilbert transform is defined as [1]:

$$X(t) = H[x(t)] = \frac{1}{\pi}\int_{-\infty}^{+\infty} \frac{x(\tau)}{t-\tau} d\tau \quad (1)$$

It can be seen from (1) that the independent variable is not changed a result of this transformation. So the output F(t) is also a function of t. Moreover F(t) is a linear function of f(t). It is obtained from f(t) by applying convolution with $(\pi t)^{-1}$

$$X(t) = \left(\frac{1}{\pi t}\right) * x(t) \quad (2)$$

X(t) and x(t) are related to each other in such a way that they together create a strong analytic signal. The strong analytic signal can be written with amplitude and phase where the derivative of phase can be identified as the instantaneous frequency [4]. The Fourier transform of the strong analytic signal gives us a one sided spectrum in frequency domain. The analytic signal is expressed as [1]

$$y(t) = x(t) + jX(t) \quad (3)$$

The envelope B(t) of y(t) is

$$B(t) = \sqrt{X(t)^2 + x(t)^2} \quad (4)$$

And its instantaneous phase angle in the complex plane can be defined by

$$\emptyset(t) = \arctan\left(\frac{X(t)}{x(t)}\right) \quad (5)$$

Applying the Fourier Transform we have

$$\{x(t)\} = \frac{1}{\pi} * F\left\{\frac{1}{t}\right\} F\{x(t)\}$$

$$F\{x(t)\} = -jsgnfF\{x(t)\} \quad (6)$$

$$asF\left\{\frac{1}{t}\right\} = -jsgnf$$

Thus it is found that a function and its Hilbert transform are orthogonal. Hilbert transform of the original function x(t) represents its harmonic conjugate. This relation helps enhance the signal and provides an improved signal for the detection stage [1].

The proposed R peak detection algorithm consists of two stages: first filtering the ECG signal to remove noise and second stage involves deciding threshold adaptively followed by the R-peak detection procedure. This algorithm has been proposed for analysis in discrete time domain [4].

A. First Stage: Filtering

ECG signal contains noise at all frequency but the data is primarily located up to 60Hz. This knowledge can be used to filter the ECG signal without affecting the data present in the signal. Hence, the data is band-pass filtered up to 60 Hz using a 4th order Butterworth digital filter with zero phase distortion. This filtered signal is then operated with the Hilbert Transform to obtain a complex signal as shown in equation (3). The envelope of this signal represented by equation (4) thus represents the enhanced signal. Such an enhanced signal can be used of efficient peak detection [3] [4].

B. Second Stage: Decision Thresholding

his stage determines the signal values above threshold and then determines the R peaks in the signal. The proposed stage adaptively reckons the threshold for a given signal and thereby determines the R peaks in the signal by implementing the steps stated below [2].

Step 1: Decision algorithm:

Step 1.1: Set the initial value of threshold to a suitably high value slightly less than the maximum value of Enhanced Hilbert signal.

Step 1.2: Calculate the step size to decrement the threshold in subsequent iteration. If M1 is the maximum value of the signal and M2 is the minimum value of the signal, then the step size can be expressed as in equation (7).

$$\emptyset = \frac{\text{mantissa}(M1 - M2)}{100} \text{ x } M1 \quad (7)$$

Step 1.3: Determine the peaks in the signal which are above tne threshold value. Calculate the number of peaks in the Hilbert signal.

Step 1.4: Repeat the above steps with threshold decremented by one step size and calculate the number of peaks.

Step 1.5: If the new peak count exceeds the earlier count then repeat the peak detection steps again until the new peak count does not exceed or is equal to the earlier peak count.

tep2: R peak detection algorithm [1]:

Step 2.1: Determine the instants in the signal where the amplitude equals or exceeds the threshold.

Step 2.2: The points above threshold, in the signal, will appear in groups. Each group will have one point with highest amplitude. Determine the sample with highest amplitude in each group. This detected peak does not indicate the actual R peak in the signal.

Step 2.3: Now consider each detected peak and search for a sample around the peak, on either side with some suitable and appropriate leeway, with amplitude greater than that of the detected peak. This search will provide not only the actual R peak but also the missing and extra R peaks which were not detected in the previous steps.

Step 2.4: Construct a signal by combining the peaks detected in step 2.3. This signal represents the R peaks of the given ECG signal.

3. SIMULATION AND RESULT

The ECG signal depicted in Figure 2 obtained from source at [6] was used to implement the algorithm described in methodology above.

The simulation was performed using Signal Processing Toolbox in MATLAB. The Threshold parameter in the simulation was initialized 0.95 times the maximum value of the signal.
The ECG signal is subjected to filtering using FIR filter as stated in first stage. The filtered signal shown in Figure 3. contains signal frequencies only up to 60 Hz as required. Filtered signal is transformed using equation (2) to obtain the Hilbert transform signal shown in Figure 4.

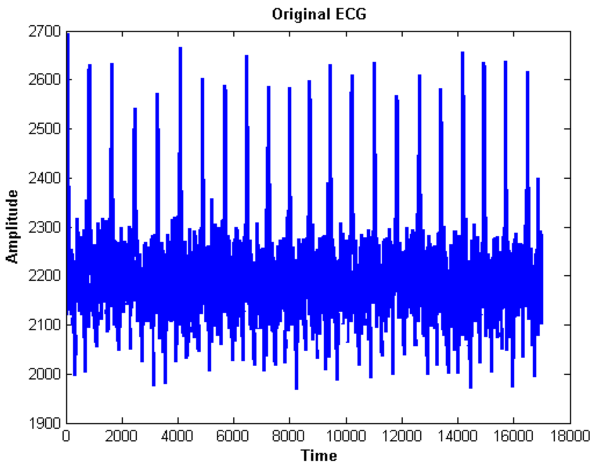

Figure 2 Original ECG Signal

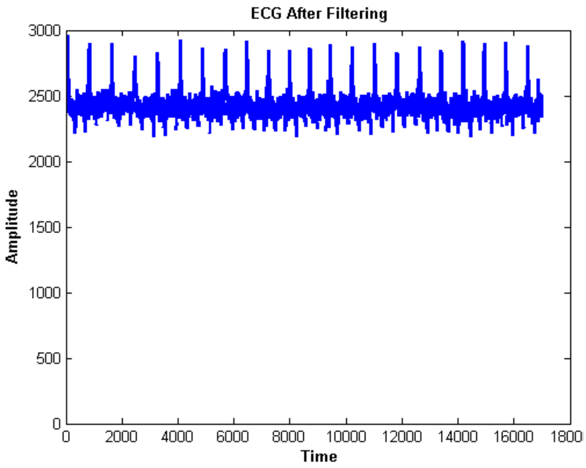

Figure 3 ECG signal after filtering

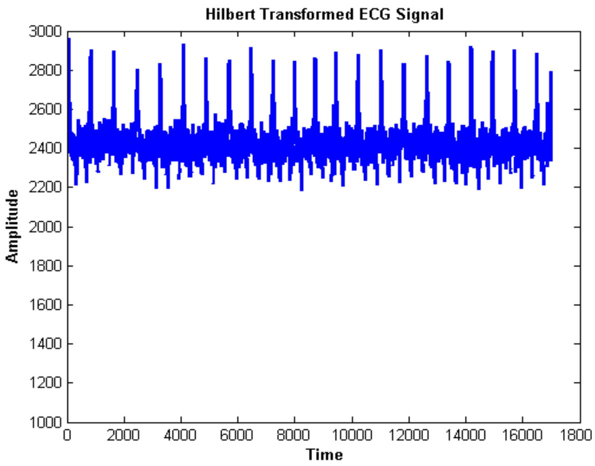

Figure 4 Hilbert Transformed ECG signal

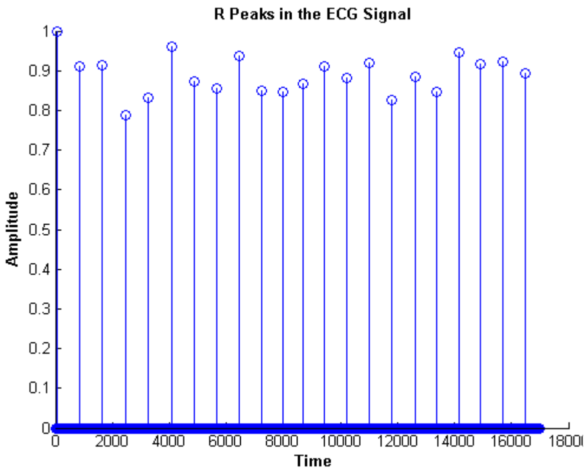

Figure 5 R-peaks in the ECG signal

As expected the transformed signal represents the enhanced version of the original signal which facilitates further processing. The R peaks are detected by using algorithm described in second stage as shown in Figure 5. The final signal with R-peaks is portrayed in Figure 6.

The final threshold after adaptive loops and hence the optimum threshold for the signal was 0.91 times the maximum signal with the step size being 0.02 times the maximum signal.

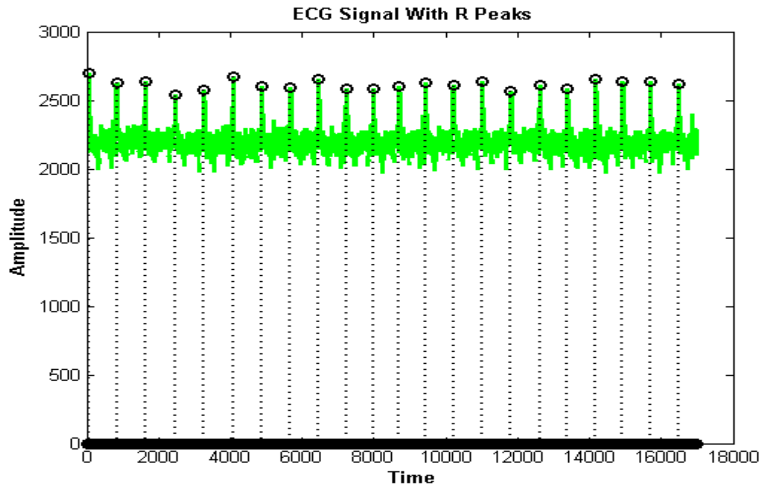

Figure 6 ECG Signal with R-peaks

4. CONCLUSION

An algorithm for R peak detection using Hilbert transforms has been developed. The R peak detection algorithm shows significant performance and has established a good Signal to Noise Ratio. The proposed algorithm provides 100 percent efficiency in absence of noise and notably high computation speed compared to other contemporary R peak detection methods. The algorithm performs extremely well in the presence of noise.

In addition to its proven performance in cardiac analysis, the algorithm can be used for fetal cardiac signal analysis that could be implemented for fetal health monitoring. Fetal movements during the recordings may induce amplitude and morphology change for the ECG signals. The Hilbert amplitude is insensitive to morphological changes such as mono polar to bipolar cardiac signals. Empirical results indicate that cardiac signals obtained by using sensors in the vicinity of the fetal heart have higher signal to noise ratio. Incorporating a fetal heart tracking based sensor selection algorithm for the Hilbert amplitude calculation may improve the detection rate.

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