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RESEARCH ARTICLE

QRS Detection in ECG Signal and De-noising using Biorthogonal DWT Technique

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Abstract

Noise is the most deterrent in signal transmission and processing. It results in faulty information after processing the signals, henceforth reducing its usability. In our work, Biorthogonal Wavelet was used to filter out the noise by implementing a cascade of low pass and high pass filter. The motivation of this research work was derived from the quest to develop wavelet based filters for ECG signal filtering with better results as compared to FIR filters. Electrocardiogram (ECG) signal has been widely used for heart diagnosis. This algorithm and architectural level approach has been implemented on the Field Programmable Gate Array (FPGA). The main focus of the work is to filter and detect the QRS complex in ECG signal and to identify the time and frequency variations. By comparing these variations with that of the variations in the normal ECG waveform one may reach to the conclusion if the patient is suffering from Arrhythmia or not.

1. INTRODUCTION

The aim of the paper is to implement an ECG analysis system for the detection of the QRS Complex. For such systems, it is first necessary to remove the noise in the ECG signal that is caused due to the disturbances during the ECG measurement using the electrodes. Some types of noises in ECG signal are electrode contact noise, baseline drift, motion artifacts, EMG from the chest wall, instrumentation noise and electrosurgical noise, etc.

So, the initial process involved in processing the ECG signal is to remove such variations using appropriate filtering methods. Once the signal is devoid of such variations, it is subjected to a 4 level decomposition using the DWT that is responsible for extracting the details in the ECG signal. After extracting such information embedded in the signal, i.e. the timing and frequency details of the waveforms it is compared with the actual signal to identify if there are conditions of Arrhythmia.

Signals may have some noise associated with them. Such signals cannot be used directly to extract information. Noise can result in an output which may not be intended, giving rise to faults in the system of which the signal is a component. It can also cause judgmental errors if the signal is being directly observed and the impact can range from being minute in some cases to destructive in certain critical systems like ECG machines.

Hence, it is important that signals should comprise of components that are relevant to the system and be free from unwanted, random values so that errors caused due to faulty representation of the original signal can be minimized. Most of the times the noise found in the signals are of higher frequency as compared to the signal produced by the quantity being measured. It is, therefore, of utmost importance that the noise from the signal is removed to the optimal extent.

According to Medical Researches, major causes of threat to life are the diseases associated with heart. Arrhythmia is one such heart disorder which is an irregularity in heart beat. Heart Arrhythmias occur when the electrical impulses in heart that coordinates the heartbeats don't work properly, causing the heart to beat too fast, too slow or irregularly. Arrhythmias can take place in a healthy heart and be of minimal consequence but they may also indicate a serious problem that may lead to stroke or sudden cardiac death. Heart Arrhythmia treatment can often control or eliminate irregular heartbeats. Electrocardiogram (ECG) is a diagnosis tool that reports the electrical activity of heart recorded by skin electrode. Any disorder of heart rate change in the morphological pattern is a reading of cardiac Arrhythmia, after measure could be detected by analysis of ECG waveform. It is very difficult to identify the symptoms of Arrhythmia from the lengthy ECG record. Information regarding this disorder can be obtained from the variations in the length and width of the QRS complex.

2. WAVELETS

Wavelets are mathematical functions with oscillatory nature similar to sinusoidal waves with the difference being that they are of “finite oscillatory nature”. Essentially a finite length, decaying waveform, when scaled and translated results in what is called a “daughter wavelet” of the original “mother wavelet”.

Wavelet transforms are classified as Continuous wavelet transforms (CWT) and Discrete Wavelet Transforms (DWT). The finite oscillatory nature of the wavelets makes them extremely useful in real life situations in which signals are not stationary. While Fourier transform of a signal only offers frequency resolution, wavelet transforms offer “variable time-frequency” resolution which is the hallmark of wavelet transforms.

A wavelet transform decomposes a signal into basic functions which are known as wavelets. Wavelet transform is calculated separately for different segments of the time-domain signal at different frequencies resulting in Multi-resolution analysis or MRA. It is designed in such a way that the product of time resolution and frequency resolution is constant. Therefore it gives good time resolution and poor frequency resolution at high frequency whereas good frequency resolution and poor time resolution at low frequency. This feature of MRA makes it excellent for signals having high frequency components for short durations and low frequency components for long durations, e.g. noise in signals, images, video frames, etc.

2.1 Discrete Wavelet Transform

A wavelet transform in which the wavelets are discretely sampled are known as discrete wavelet transform. The DWT gives a multi-resolution description of a signal which is very useful in analyzing “real-world” signals. Essentially, a discrete multi-resolution description of a continuous-time signal is obtained by a DWT.

Some examples of discrete wavelets are the Haar wavelets, Daubechies Wavelets, Biorthogonal wavelets, Symmlets etc.

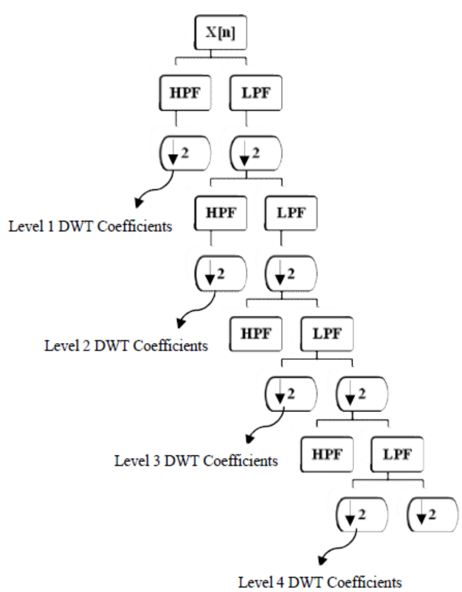

Figure 1: DWT Architecture

For any input comprising of 2^n number, the Haar wavelet transform simply pairs up input values, storing the difference and passing the sum. This process is recursive, pairing up the sums to provide the next scale: finally resulting in 2^{n-1} differences and one final sum and this is done in O (n) time, i.e. linear time.
The function is not continuous and hence not differentiable. Biorthogonal wavelets are families of wavelets where the associated wavelet transform is invertible but not necessarily orthogonal. Its design allows more degrees of freedom than orthogonal wavelets. Here, there are two scaling functions ø,ǿ, which may generate different multi-resolution analyses, and accordingly two different wavelet functions ψ, ψ.

3. SIGNAL FILTERING

As is the case with most of the signals in real life, they are always accompanied with noise which may be random, Gaussian noise etc. Till this noise is present with the signal, the received signal may be of very little use. Noise makes the process of information extraction from the signal a difficult task and results to incorrect output. Signal filtering is a process which can be thought as a "pre-processing step" for information extraction from the signal. Generally noise is a low amplitude high frequency signal imposed on the higher amplitude lower frequency signal.
Let S(n) be the original signal with no noise, V(n) be the high frequency noise added to the signal before it is received for analysis or information extraction.
The signal received is represented by VS(n) as follows:

$$VS(n) = S(n) + V(n)$$

The purpose of the procedure of de-noising is to extract S(n) from VS(n) so that it can be used for intended purposes. Noise added to the signal is higher in frequency as compared to the original signal. Hence, if we can remove the high frequency components of the signal, we would be able to separate the noise. This can be achieved by passing VS(n) through a low pass filter which will filter out the high frequency components and give the output which would be approximately close to S(n).

3.1 FIR Filter

We designed a filter based HDL design, using FIR window technique namely, Hamming window. The response of the Hamming window was studied and it was found to be better when compared to other filters due to the Zero Side Lobes present in its structure. In the complete work, two filters namely, BSF (Band Stop Filter) and LPF (Low Pass Filter) are used with different cut off frequencies.

3.2 DWT Based Filter

Next, we implemented the Biorthogonal Wavelet Transform based filter. The ECG signal was passed through a series of LPF (Low Pass Filter) and HPF (High Pass Filter) and hence was used for decomposing the ECG so that relevant features necessary could be extracted. The response of this filter was studied and it was found to be better when compared to FIR filter with an improved SNR (Signal to Noise) Ratio.

4. QRS COMPLEX

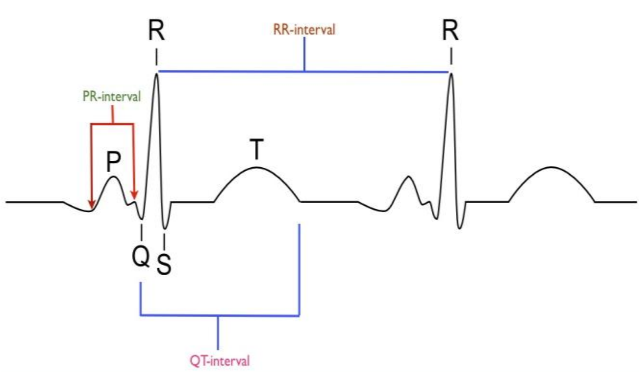

Figure 2: QRS Complex

The QRS complex is the largest deflection voltage of about 10-20 mV but may vary in size depending on age and sex of the human. The amplitude of the voltage of the QRS complex may also give information on heart disease. Duration of the QRS complex indicates the time for the ventricles to depolarize and can provide information on problems conduction in the ventricles as the bundle branch block.

5. ECG ANALYSIS SYSTEM

In order to extract the information hidden in the ECG signal many types of transformations can be adopted. Since the non stationary ECG signal is of the quasi periodic nature, transformation is done using the DWT. The ECG signal has P, QRS complex and T waves. The duration of each of the waves signifies the electrical activity of the heart. Among all the waves in the signal the QRS complex has higher amplitude. Here the ECG signal is captured from the MIT-BIH database. Basic principle behind the ECG signal analysis system is to find the QRS complex. Easier method for detecting the QRS complex is to find out the R peak.

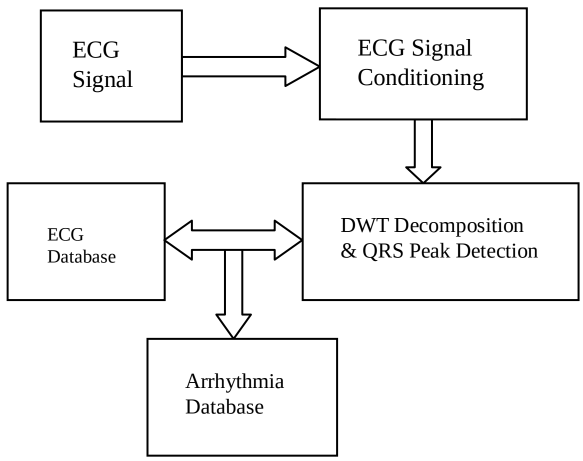

Figure 3: ECG Signal Analysis System

6. SIMULATION PROCEDURE

1) Firstly, input signal is taken from MIT-BIH arrhythmia database for the processing.
2) Some noises are also added to this signal for the worst case processing.
3) After that we process this signal in discrete form using MATLAB R2013b.
4) Wavelet filter bank is used for the de-noising purpose because wavelet has the greater than 99% performance and medium complexity with comparison to other techniques.
5) There are different wavelet transforms (Haar, Daubechies, Symmlets, and Biorthogonal etc.) which are used for different purposes. From all these wavelets, Biorthogonal 3.1 discrete wavelet transform is chosen for the ECG signal in accordance with the SNR and de-noising.
6) Then Mallat algorithm is used to implement this wavelet transform.
7) After de-noising, decomposition signals are multiplied to get regenerated ECG signal.
8) Here, we get the signal with R peaks after multiplication that will be detected using QRS detector.
9) According to the R peak heights, a threshold (mean and standard deviation of input signal) is setup to detect R peaks.
10) A comparator is used to compare the input signal with threshold. If the signal has value greater than threshold, then comparator output is high.
11) A counter is used to count the no. of R peaks.
12) According to the no. of peaks in 1 minute, we estimate the arrhythmia diseases (Bradycardia and tachycardia).
13) After this, algorithm is implemented on hardware using Verilog (Hardware description language). And this algorithm is successfully implemented.

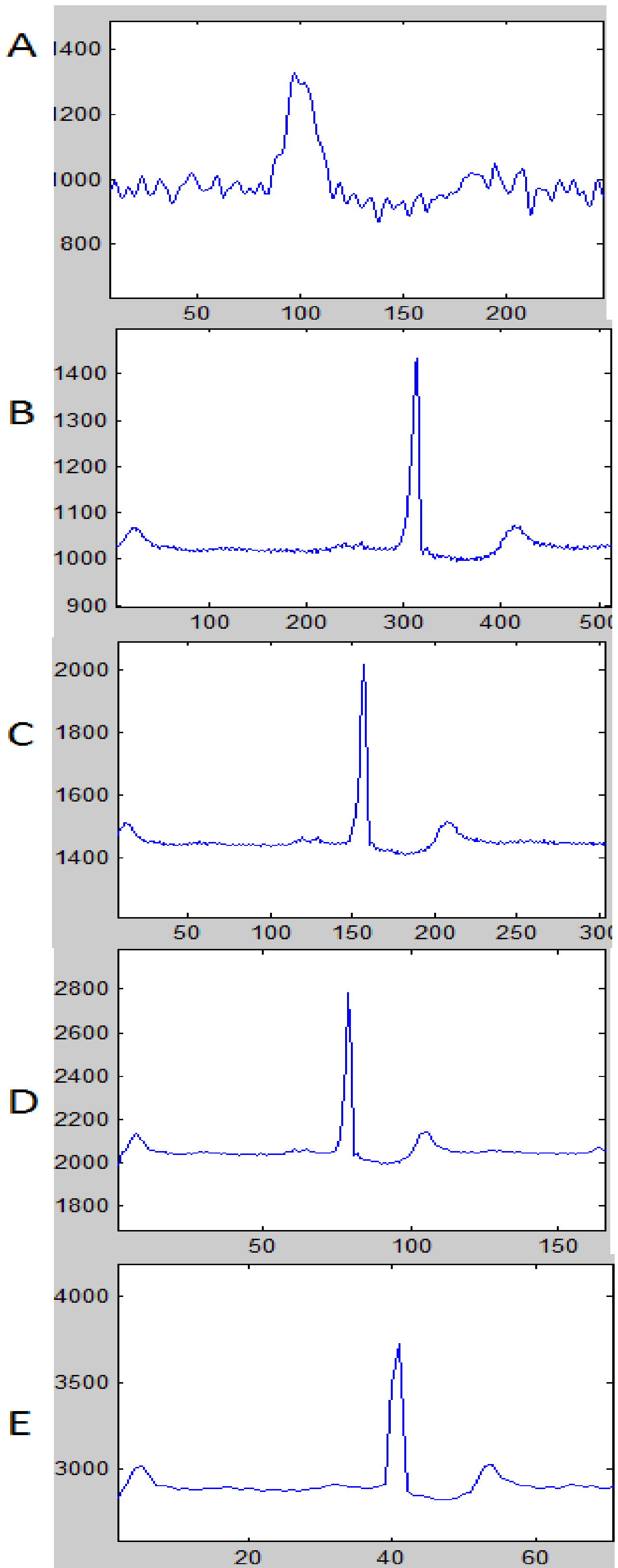

Figure 4: DWT Filtering of ECG Signal. (A) Original ECG Signal. (B) Output of Level 1 DWT. (C) Output of Level 2 DWT. (D) Output of Level 3 DWT. (E) Output of Level 4 DWT (Conditioned/Denoised ECG Signal)

7. CONCLUSION

Wavelets with their "variable time frequency resolution" and properties such as MRA provide an effective way to analyze a signal. The process of signal filtering can be performed quickly following this approach. The simulations that had been performed reveal that wavelets can be used to separate different frequency components of the signal efficiently with improved Signal to Noise Ratio when compared to FIR Filter based designs. Unwanted signal component can be removed easily. It was observed that there is a close similarity between original signal without noise and the signal obtained after the filtering procedure. This process, as shown in our research, can be used to filter out noise from ECG signal and the algorithm can easily be burnt on FPGA resulting in hardware based implementations to provide low cost and faster speed.

The proposed design using Biorthogonal Wavelet requires 39.5% less LUTs, 69.5% less IOBs and 59% less DSPs than the 1D Architecture, whereas 45% less IOBs and 30% less DSPs as compared to pipelined DF Filters. This is a significant reduction since there are limited numbers of DSP48 slices on an FPGA and should be prudently used. The proposed design reduces the critical path to 90% on an average but requires more number of slice registers and LUTs. If we require high speed then we have to compromise to slightly more area. Previously, works have been carried out using Haar and Daubechies wavelets in software based but the intention of this paper is to propose a hardware design for the QRS detector using Biorthogonal wavelet technique.

7. FUTURE SCOPE

In this work QRS detection is done using MATLAB tool which cannot be used for real time systems. For real time systems, HDL model of QRS detection is required. The Stationary Wavelet Transform (SWT) is an inherently redundant scheme as the output of each level of SWT contains the same number of samples as the input. So, for a decomposition of N level there is a redundancy of N in the wavelet coefficients. The Stationary Wavelet Transform (SWT) may yield better results than BWT.

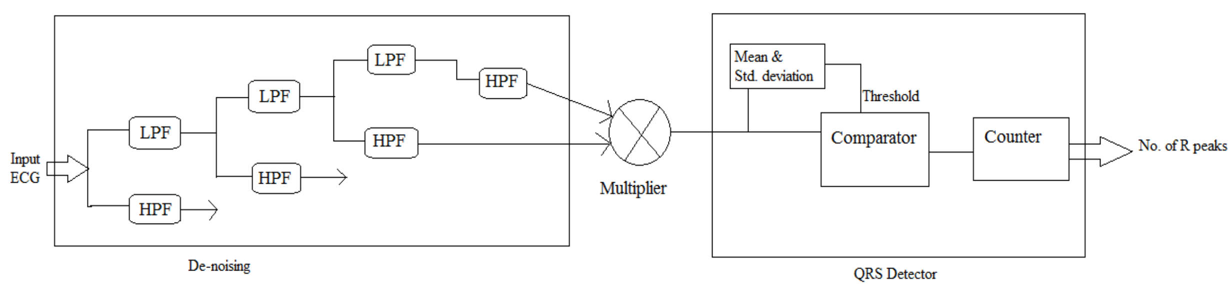

Figure 5: Complete QRS detector system with De-noising and Detection

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