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ECG Signal Analysis with DB6 Wavelet using Verilog HDL

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Abstract-The abnormal condition of electrical activity of the heart is given by ECG (Electrocardiogram). The peaks and the valleys of the ECG signal depict the useful information about the nature of disease affecting the heart.ECG signals are very low frequency signals, of about 0.5 Hz-100 Hz.

Discrete Wavelet Transform (DWT) has been used in last few years in many applications. In this paper, it has been used as a tool for noise removal and extraction of QRS complex. Db6 using FIR filter has been designed using Verilog Hardware Description Language (HDL). ModelSim Altera 6.4a is used as simulator.

Keywords- *Discrete Wavelet Transform, ECG (Electrocardiography), FIR Digital filter, STFT (Short time Fourier transform), Wavelet*

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1. INTRODUCTION

1.1 HEART

The heart is a muscular pump made up of four chambers. The two upper chambers are called atria, and the two lower chambers are called ventricles. The electrical activity that takes place causes the heart muscle to contract and pump blood through the heart to the lungs and rest of the body. [8]

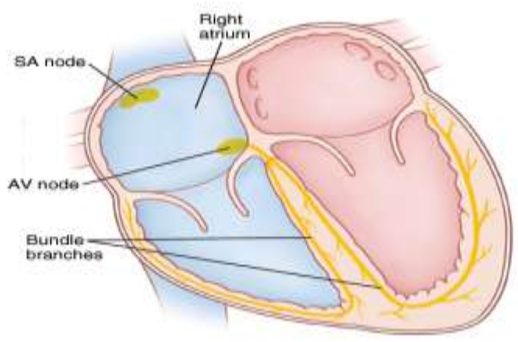

Figure 1: Electrical activity of Heart

Each action potential, in other words, electrical activity in heart originates near the top of the right atrium at a point called the pacemaker or Sinoatrial(SA) node. The wave generated terminates at a point near center of heart called as Atrioventricular (AV) node. The deviations in normal electrical patterns indicate various cardiac disorders.

Cardiac cells, in normal state are electrically polarized. Their inner sides are negatively charged relative to their outer sides. These cardiac cells lose their normal negativity in a process called depolarization, which is fundamental electrical activity of the heart. This depolarization is propagated from cell to cell, producing a wave of depolarization that can be transmitted across the entire heart. This wave of depolarization produces a flow of electric current and can be detected by placing electrodes on the surface of the body. Once depolarization is complete, the cardiac cells are able to restore their normal polarity by process called repolarization, sensed by electrodes. [1]

1.2 ELECTROCARDIOGRAM (ECG)

The Dutch Physician Willem Einthoven, in 1903 marked the beginning of new era in medical diagnostic techniques for establishment of clinical ECG. It is the tool that records and measures the activity of the heart. [9]

Description Of ECG Waveform:

The ECG signal is characterized by five peaks and valleys labeled by the letters P, Q, R, S, T. In some cases we also use another peak called U. A typical ECG tracing of electrocardiogram baseline voltage is known as the isoelectric line.

Features:

- P wave: It corresponds to the period of atrial depolarization in the heart.
- QRS complex: It is usually the most relevant (recognizable) feature of an ECG waveform. It is combined result of repolarization of atria and depolarization of ventricles; however atrial repolarization gets obscure due to large QRS complex.
- T wave: It represents the end of the cardiac cycle.

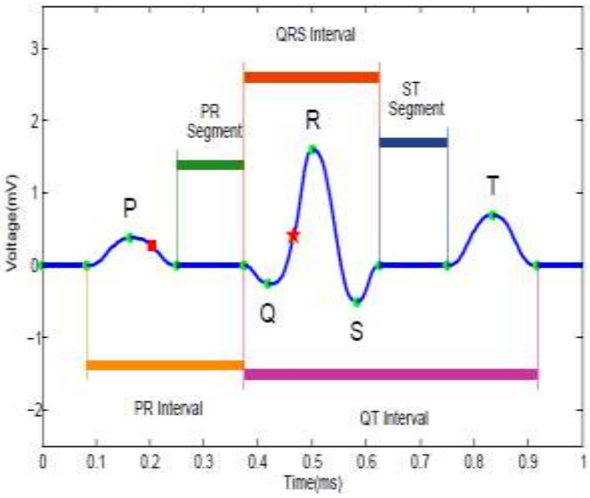

Figure 2: A typical Electrocardiogram Signal

There are various intervals in the ECG signal, each convey different information. Table no. 1 depicts it below.

Table No. 1: The various intervals in ECG signal

INTERVALS	REPRESENTATION
R-R interval	Represents the period from R peak of one beat of ECG signal to the next R peak.
P-R interval	Represents the period from the start of P wave to the beginning of QRS complex.
QRS duration	Measured from the first deflection of the QRS complex to end of QRS complex at isoelectric line.
Q-T interval	Represents the period from beginning of QRS complex to the end of the T wave.

2. EARLIER METHOD

Previous methods were based on time domain methods. These methods are not always perfect to study ECG signal. To overcome this issue, Fast Fourier Transform was introduced to study frequency spectrum of ECG signal. However, FFT does not determine the location of frequency components with respect to time. As the frequency content of ECG varies in time, the need for accurate description of ECG frequency contents according to their location is essential. This justifies the use of time frequency representation. Short Time Fourier Transform (STFT) overcomes the issues of FFT, but the major drawback of STFT is its non-optimum time frequency precision. [3], [5]

3. PROPOSED METHOD: WAVELET TRANSFORM

Wavelet technique solves the above issue. It is a set of analyzing wavelets allowing the decomposition of ECG signal into a set of coefficients. Each analyzing wavelet has its own time duration and frequency band. The wavelet coefficients resulting from decomposition correspond to measurement of ECG.

The fundamental idea behind wavelets is to analyze signal according to scale (stretching or shrinking the wavelet in time). Wavelets are mathematical functions that cut data into different frequency components, and then study each component with a resolution matched to its scale.

In wavelet analysis, the *scale* that we use to look at data plays a special role. 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. This makes wavelets interesting and useful. The wavelet analysis procedure is to adopt a wavelet prototype function, called an *analyzing wavelet* or *mother wavelet.*

Why do we need the frequency information?

Often times, the information that cannot be readily seen in the time-domain can be seen in the frequency domain. The frequency content of the biomedical signal varies in time, so there is a need for tool that can accurately describe the time location and frequency content is essential. STFT (Short time Fourier transform) can also be used to determine the frequency components over a small period of time (depending on the window size).However it does not give optimal time-frequency information. This is the reason of moving towards Wavelet Transform. [9], [11]

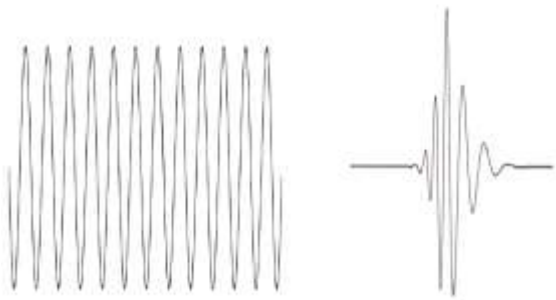

Figure 3: Wave and Wavelet

3.1 Discrete Wavelet Transform (DWT)

A discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution: it captures both frequency and location information (location in time). It is easy to implement and reduces the Computation time and resources required.

The DWT is computed by successive low pass and high pass filtering of the discrete time-domain signal. Sub sampling

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(down sampling) a signal corresponds to reducing the sampling rate, or removing some of the samples of the signal.

3.1.1 Mathematical Aspect

The procedure starts with passing the signal *x[n]* through a digital low pass filter with impulse response *h[n]*. Filtering a signal corresponds to the mathematical operation of convolution of the signal with the impulse response of the filter. The convolution operation in discrete time is defined as follows:

$$x[n] * h[n] = \sum_{k=-\infty}^{\infty} x[k].h[n-k]$$

The original signal x[n] is first passed through a high pass filter g[n] and a low pass filter h[n]. After the filtering, half of the samples can be eliminated according to the Nyquist's rule. The signal can therefore be sub sampled by 2, simply by discarding every other sample. This constitutes one level of decomposition and can mathematically be expressed as follows:

$$y\,high\,[k] = \sum_{n} x[n].g[2k-n]$$

$$y\,low\,[k] = \sum_{n} x[n].h\,[2k-n]$$

where y high [k] and y low [k] are the outputs of the highpass and low pass filters, respectively, after subsampling by 2. The decomposition process can be iterated. This is called the wavelet decomposition tree.

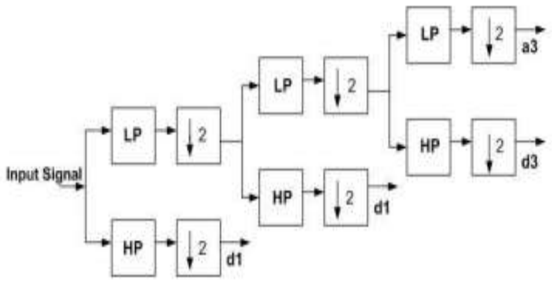
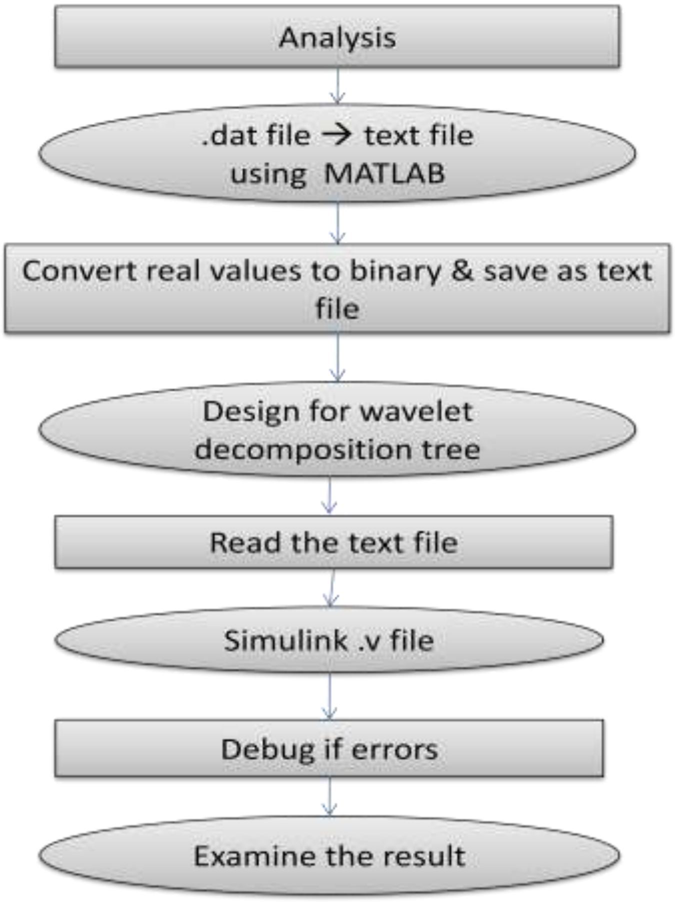


Figure 4: Wavelet Decomposition Tree

4. DESIGN FLOW

The flow chart below describes the design flow of the ECG signal analysis.



ALGORITHM: *for designing of wavelet decomposition tree is described below,*

Step 1: Lowpass filter is designed using direct form.

Step 2: Highpass filter is designed using direct form.

Step 3: Downsampling module is designed.

Step 4: All the above modules are instantiated in a single top module depending upon the decomposition level chosen

5. SIMULATION RESULTS

Lowpass FIR filter and highpass FIR filter has been designed for wavelet db6. The required number of coefficients for db6 is twelve. .

5.1 LOWPASS FIR FILTER: The lowpass filter coefficients are called as scaling functions.
In the top module, LPF filter is instantiated 4 times, as the decomposition level chosen is 4.

In figures below, purple color waveform is the input ECG signal and green color waveform is the approximate waveform of the input ECG signal.

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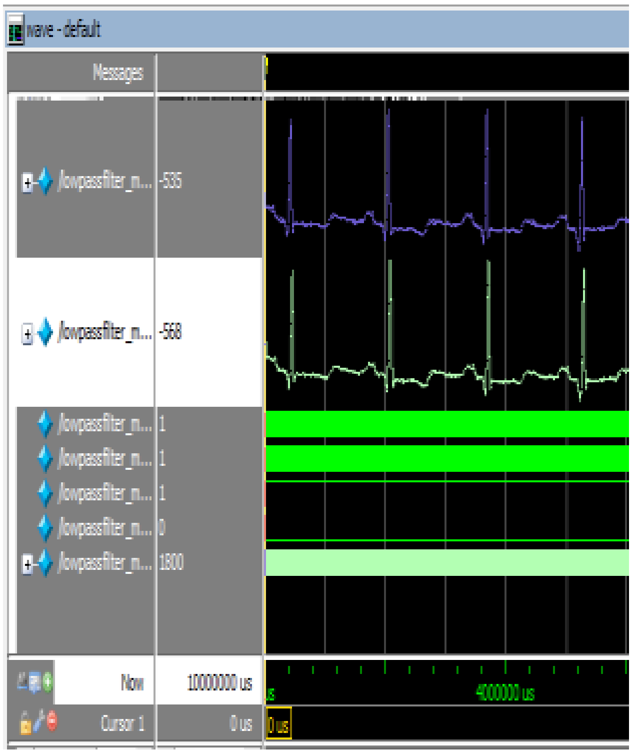

Figure 5: Simulation of Low-pass Filter

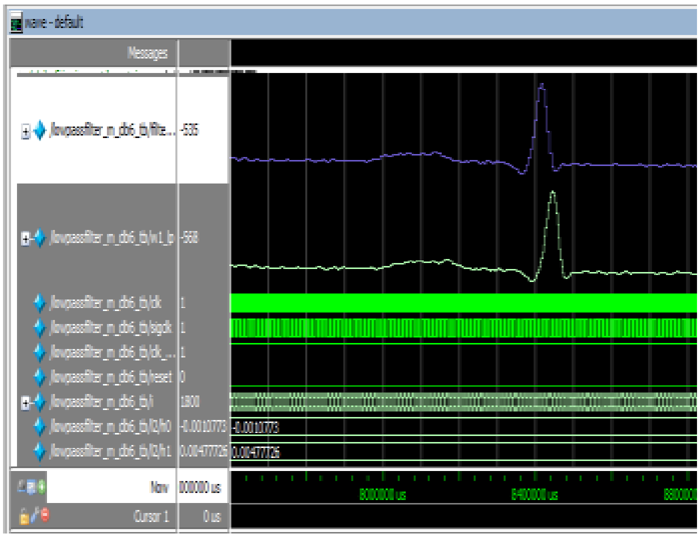

Figure 6: Closer View of Simulation Of The Lowpass Filter

5.2 HIGHPASS FIR FILTER: The highpass filter coefficients are called as wavelet functions.

In the top module, HPF filter is instantiated 4 times, as the decomposition level chosen is 4.

In the figures below, signal in purple is the input signal while signal in yellow is the output of highpass filter. The yellow signal depicts the noise contained in the ECG signal.

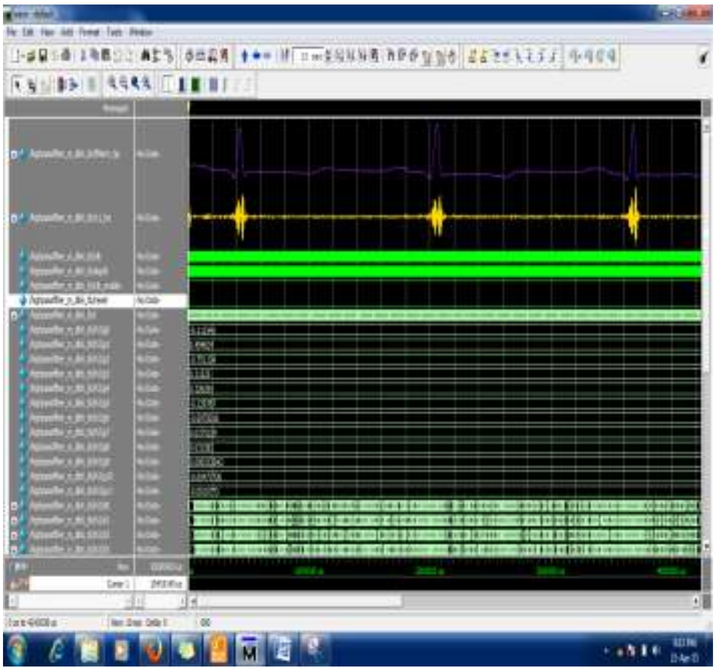

Figure 7: High-pass Filter Module Simulation

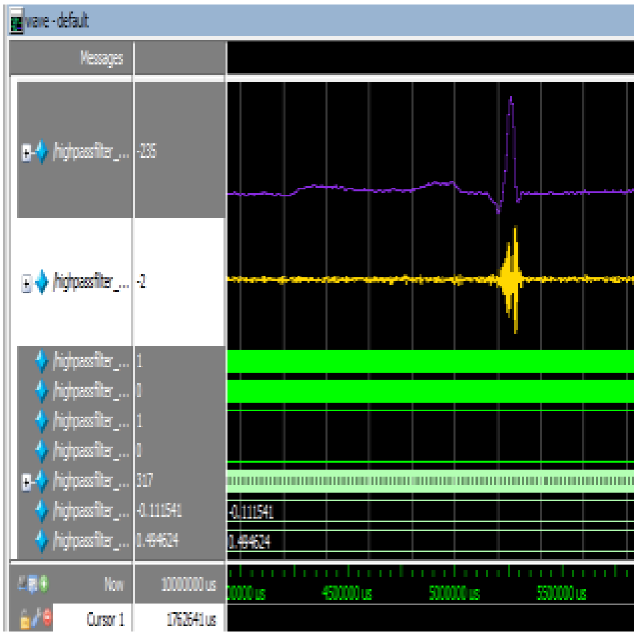

Figure 8: Removal Of Noise By High-pass Filter From ECG Signal

5.3 TOP MODULE SIMULATION: ECG

In the top module, all the modules are instantiated, the number of times it is required.

In figure 9 below, the signal in maroon is the input signal and the signal in purple is the output filtered signal.

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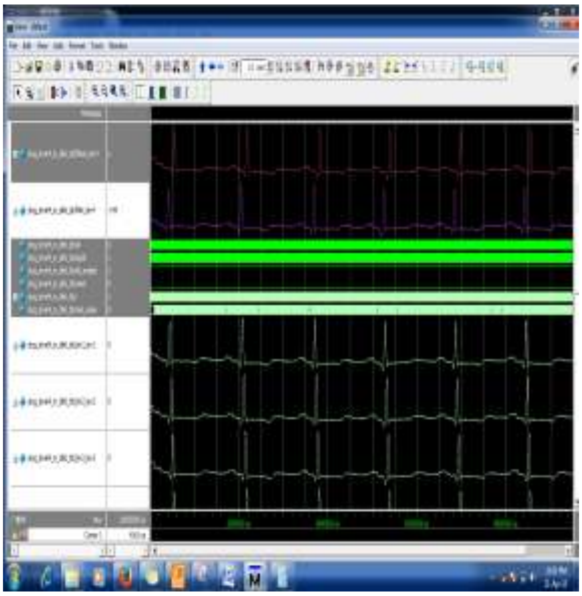

Figure 9: Complete Design Simulation

Figure 10: Outputs From LPF, Instantiated Four Times

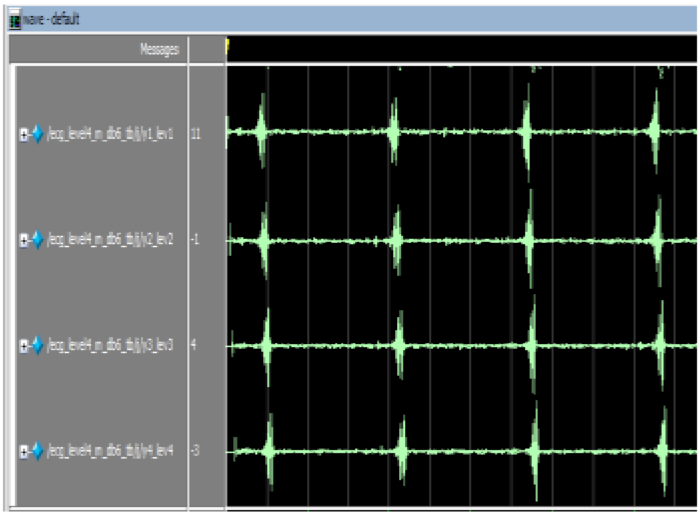

Figure 11: Removal of noise using HPF, instantiated four times

6. PERFORMANCE

The simulation is achieved with Modelsim simulator. The precision of time is set in microseconds. The first output is achieved with the delay of 1691 us.

7. CONCLUSION & FUTURE SCOPE

The benefit of wavelet transformation lies in its capacity to highlight the details of ECG signal with optimal frequency resolutions. For implementing the filter on hardware is the biggest challenge in order to achieve specified or maximum speed of data processing at minimum hardware cost.
The wavelet transformation in electro-cardiology is relatively new field of research, many aspects of wavelet technique such as choice of mother wavelet, values of scale parameters, etc. need further investigation inorder to improve the clinical usefulness of this technique.

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