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ECG Signal De-nosing using Wavelet Transform from MIT-BIH Database

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***Abstract* – In recent years, there is a trend of automated analysis of biomedical signals. Analysis of real time patient's data, picked up by various transducers or sensors is very important. Electrocardiographic (ECG) signals may be corrupted by various kinds of noise. Its processing has most demanding application in digital design concepts and practices. Signal processing is most important technology domain where the demand for enhanced performance and reduced resource application has increased exponentially over the years. Recently advances in FPGA design becomes the preferred platform for evaluating and implementing the signal processing algorithms and its utilization in real world problems. There are different methods to remove this noise like digital filters, adaptive filters. The paper presents the design and implementation of digital notch filter. The filter is implemented on ECG signal which is corrupted by the power line interference. The simulation results are presented in tabular form. But by considering the advantages of wavelet transform, this paper presents a wavelet based de-noising technique to remove power line interference from ECG signal. The wavelet transform is applied to the ECG signal so that wavelet coefficients are formed. Soft thresholding is applied to these coefficients which can remove noise due to power line interference. The proposed architecture can remove efficiently the power line interference from ECG signal.**

***Keywords* – ECG Signal, Thresholding, Wavelet Transform, Wavelet De-noising, Xilinx System Generator.**

I. Introduction

In this century, heart diseases are one of the death reasons of men/ women. The ways to diagnose heart diseases is to use electrocardiogram (ECG) signals. The ECG is a graphic record of the electrical activity that is generated by depolarization and repolarization of the atria and ventricles. The cardiac cycle in an ECG signal consists of the P-QRS-T waves. The changes in these parameters indicate an illness of the heart that may occur by any reason.

The ECG signal gets corrupted due to different types of artifacts and interferences such as Power line interference, Electrode contact noise, Muscle contraction, Base line drift, Instrumentation noise generated by electronic devices and Electrosurgical noise. The noise degrades the accuracy and precision of an analysis. Therefore the de-noising of the signal is highly desirable.

ECG signal is one of the biological signals which are non-stationary and to de-noise these types of signals hard work is required. For non-stationary signal processing wavelet transform is an efficient technique. The wavelet transform uses the signal in time frequency scale plane to decompose. But for removal of the noise from ECG signal there are different techniques available like digital filters (FIR or IIR), adaptive method and wavelet transform thresholding method. Digital filters and adaptive filters are useful for stationary signals and for non-stationary signals wavelet transform is useful.

II. ECG Signal

A typical ECG tracing of the cardiac cycle (heartbeat) consists of a P wave, a QRS complex, a T wave, and a U wave as in figure 1 which is normally visible in 50 to 75% of ECGs. The electric activity components of the ECG can be described as follows:

1. The P wave represents electrical activity associated with the original impulse from the senatorial node and its subsequent spread through the atria
2. The P-R interval represents a period from the start of the p wave to the beginning of the QRS complex.

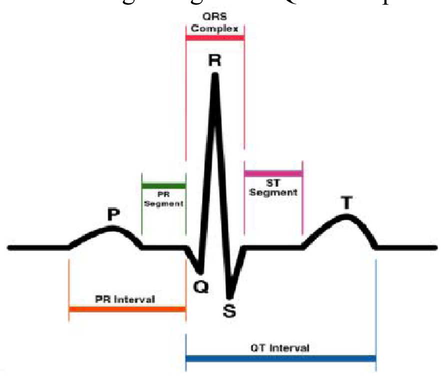

Fig.1. Typical normal ECG

This represents the time taken for the original impulse to reach the ventricles and initial ventricular depolarization. The impulse has traversed the atria and atrio- ventricular node.
3. The QRS complex represents the depolarization of ventricular muscle. Together this complex reflects the time necessary for the impulse to spread through the bundle of his and its branches to complete ventricular activation.

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4. The S-T segment describes the period between completion of depolarization and repolarization of ventricular muscle
5. The T wave represents the recovery phase or contraction.

III. Wavelet Transform

The powerful tool of signal processing is wavelet transform (WT) for its multi-resolution possibilities. The Fourier transform is useful for stationary signals; whereas the WT is suitable for application to non-stationary signals, whose frequency response varies in time. The measure of similarity in the frequency content between a signal and a chosen wavelet function is given by wavelet coefficients. The convolution of the signal and the scaled wavelet function gives the coefficients. The scale is inversely proportional to radian frequency. The high scale gives low wavelet frequencies i.e dilated wavelet function. By analysis at high scales, the global information is extracted called as approximations. Whereas the low scale gives high frequencies which extract fine information from a signal called details.

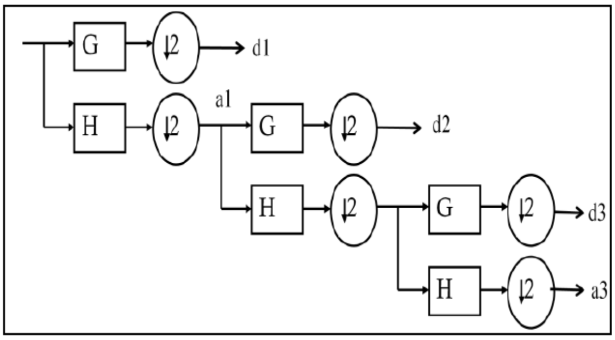

Fig.2. Decomposition in WT

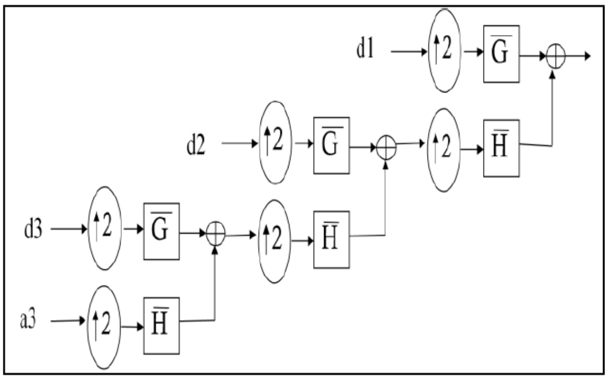

Fig.3. Reconstruction in WT

The DWT decomposes the signal by successively passing through a high-pass and a lowpass filter. Fig 2 shows the decomposition and Fig 3 shows reconstruction in WT. For each decomposition level, the high-pass filters hd produces the approximations A. The complementary low-pass filter ld produces the details D. This method of decomposition is called as the sub-band coding. The change in resolution is possible by the filtering process, and the change in scale is done by either up-sampling or down sampling by 2. This is described by relations in equation 1 and 2.

$$D_1[n] = \sum_{k=-\infty}^{\infty} hd[k]\, x[2n-k] \qquad (1)$$

$$A_1[n] = \sum_{k=-\infty}^{\infty} ld[k] x[2n-k] \qquad (2)$$

where n and k denote discrete time coefficients, l represents level of decomposition and x stands for the given signal. The synthesis consists of up-sampling by 2 and filtering

$$x[n]=\sum_{k=-\infty}^{\infty}(D1[k]\, hr[2k-n] + A1[k]\, lr[2k-n]) \qquad (3)$$

The reconstruction of filter is possible by using reconstruction filters lr and hr which are identical with the decomposition filters ld and hd, respectively, except the reverse time course. These filters produce perfect signal reconstruction from the DWT coefficients as in equation 3.

IV. Methodology

The presented method based on decomposing the signal into three levels of decomposition of wavelet transform by using Daubechies wavelet (db5). The threshold can be measured by using Donoho's method in such a way that the error between the detailed coefficients of threshold noisy signal and the original signal can be minimized. The method can be divided into the following steps:

A. Generation of Noisy ECG signal:

A power line interference of 50Hz is generated and added to the original signal. Mathematically defined:

$$S(n) + V(n) = Vs(n) \qquad (4)$$

where S(n) is the 50 Hz noise, V(n) is original ECG signal and Vs(n) is the ECG signal with noise.

B. Decomposition of the signals using wavelet transforms:

The noisy and original signals are decomposed into 3 levels by discrete wavelet transform using the Daubechies-5 wavelet.

C. Thresholding of the wavelet coefficients:

A threshold is applied to wavelet coefficients of each level of the decomposition of the detailed coefficients of the noisy signal. The two different types of thresholding which are applied to de-noise are (1) Hard thresholding and (2) Soft thresholding. In hard thresholding method the all wavelet coefficients below a given threshold value set equal to zero. The equation 5 is used for hard thresholding method.

$$T(w_k) = \begin{cases} w_k & \text{if } |w_k| \ge \lambda \\ 0 & \text{if } |w_k| < \lambda \end{cases} \qquad (5)$$

While in soft thresholding the wavelet coefficients are reduced by a quantity equal to the threshold value.

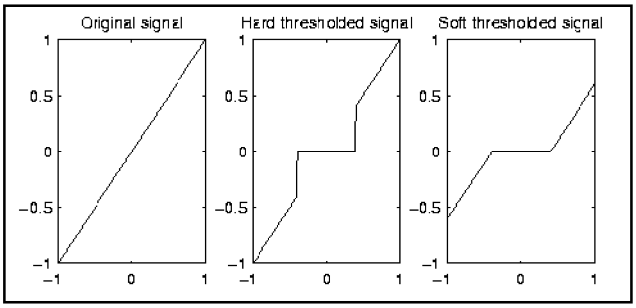

Fig.4. Soft and hard thresholding

A soft thresholding is used to shrinkage the wavelet detailed coefficients of the noisy signal such that:

$$T_\lambda^S(w_k) = \begin{cases} w_k - \lambda & \text{if } w_k > \lambda \\ w_k + \lambda & \text{if } w_k < -\lambda \\ 0 & \text{if } |w_k| \le \lambda \end{cases} \quad (6)$$

where, wk - is the wavelet transform coefficients to be threshold and λ is the Donoho's threshold value. The presented method is based on decomposing the signal into three levels of decomposition of wavelet transform by using Daubechies wavelet (db5). The threshold can be measured by using Donoho's method in such a way that the error can be minimized.

They proposed a universal threshold λ for the WT:

$$\lambda = \sigma\sqrt{2\log(n)}$$

with λ = threshold, where n is the length of the analyzed signal y(n) and σ is the noise level. A loop is applied to each level to find the threshold value that gives the minimum error between the detailed coefficients of the noisy signal and those of original signal.

D. Reconstruction of the signal:

The original signal is reconstructed using Inverse Discrete Wavelet Transform IDWR. Threshold plays the important role in determining the quality of reconstructed ECG signal. If thresholding is done very properly, the reconstructed signal will be approximately same as original signal. If due to thresholding of approximation coefficients some important coefficients lost, reconstruction will not be proper. The approximation coefficients contain the low frequency of the original signal where most energy exists. The block diagram for proposed algorithm is as shown in figure 5.

V. Experimental Results

In order to compare the performance of DWT and SWT, the experiments are conducted on algorithm explained above with different ECG signals from MIT-BIH database. Therefore to compare the results we have considered the SNR of noisy signal and de-noised signal after experiment. The DWT and SWT transform employs dB5 wavelets with 3 levels of decomposition. After this decomposition, the output signal is then pass through threshold estimator. This threshold estimator finds the value of universal threshold λ. On the basis of these wavelet coefficients and universal threshold λ, different thresholding techniques are used like soft thresholding, hard thresholding. After this thresholding, reconstruction of the signal is done. This gives output signal.

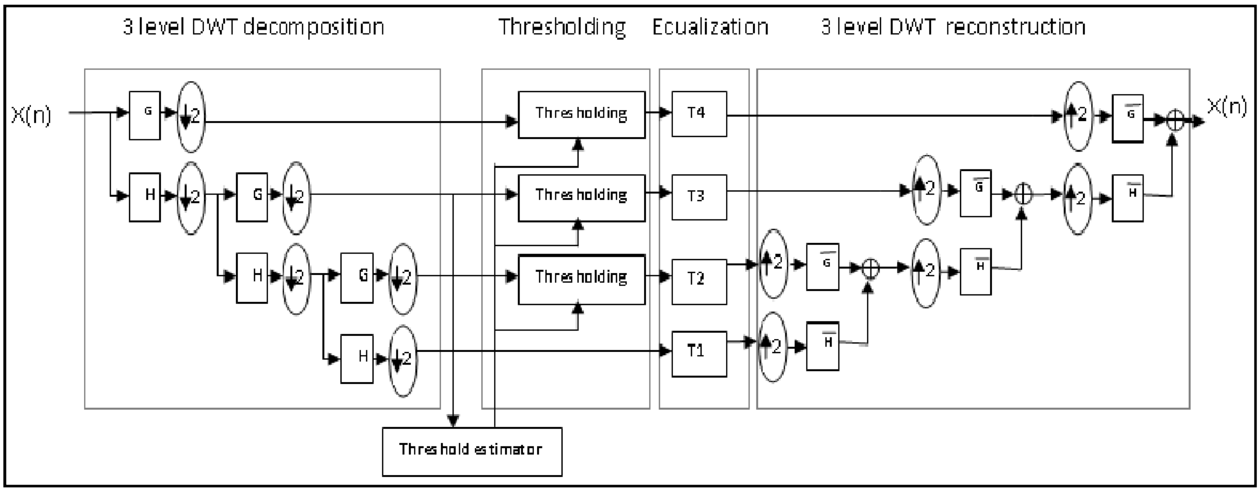

Fig.5. Flow chart for proposed de-noising algorithm using WT.

The simulation results for MIT-BIH database record number 102 are shown in Figure 6 below:

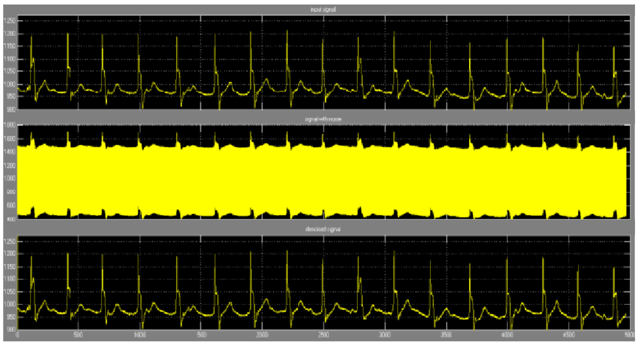

Fig.6. Results of the de-noising of ECG signal from MIT-BIH database of number 102
(a) Original ECG signal (b) Noisy ECG signal (c) De-noised ECG signal

In order to investigate the performance of wavelet transform and to compare it with soft and hard thresholding methods, the wavelet transform with 3 levels is implemented. Typical values of the SNR for ECG records are provided in table 1.

Table 1: Results of the De-Noising Of ECG Signal from Mit-Bih Database

ECG Data (MIT-BIH Database)	SNR With Soft Thresholding	SNR With Hard Thresholding
Record Number 101	28.32	30.92
Record Number 102	33.98	33.53
Record Number 103	25.49	27.33
Record Number 104	30.11	31.79
Record Number 105	22.2	26.375
Record Number 106	29.92	32.05

VI. Conclusion

The wavelet transform allows processing of non-stationary signals such as ECG signal. The steps used in the process are decomposition, the thresholding is done by using Donoho's method and reconstruction of the signal. For thresholding the threshold used in this paper is Donoho's universal threshold. The methods for thresholding used are soft thresholding and hard thresholding. From this table it is clear that hard thresholding technique gives the better results as compare to that of soft thresholding technique in terms of SNR for removal of power line interference.

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