Application of Wavelet Based Denoising for Stress ECG

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Abstract— Wavelet transform is a recently developed technique which has started gaining popularity in many fields including medical research. Many researchers' working towards obtaining a noise free clean ECG from patient that is not contaminated by noises. Techniques like adaptive filtering, EMD, etc. has been applied by the researchers to reproduce clean ECG signal. As stress testing requires the patient to walk on a treadmill, noises are more apparent than normal ECG testing. This paper describes Wavelet-based ECG denoising technique to remove noises which occur during stress ECG tests. The filter designed using this technique was tested for four major noises, that is, baseline wandering, electrical noise, muscle noise and respiratory noise. The description of the implemented software is briefly described in this paper.

Keywords— Adaptive filtering, Empirical Mode Decomposition (EMD), Stress ECG, Wavelet Transform

I. INTRODUCTION

Electrocardiogram or ECG is a measure of electrical activity of heart, which is responsible for pumping blood all over the body. Many times, diseases related to heart, so called cardiovascular diseases, may remain unnoticed when a person is at rest. This is because, at rest, there is no physical stress on the heart. But when the heart is made to perform during increased workloads, cardiac abnormalities may become apparent. When the heart has to perform harder during exercise, there is more necessity of blood and oxygen. Blocked arteries or narrow arteries cannot supply sufficient amount of blood during exercise. Therefore, signs and symptoms of heart disease are easily detected during exercise. Stress testing requires the patient to walk on a treadmill or pedal a stationary bicycle with varying workloads. Various parameters like blood pressure, oxygen consumption, ECG, etc. are measured continuously while the patient is exercising. During a resting ECG, patient movement is negligible which results in limited artifacts in the acquired ECG signal. But during cardiac stress testing, the patient is required to move. This result in incorporating more noise signals which tend to make the acquired signal unreliable for clinical decision making. In order to make accurate diagnosis, it is important to get the parameters of ECG signal clear without noises or artifacts.

A. *Corruption of ECG signal*

Generally, noises are unwanted signals that corrupt the original signal. Basically, there are two categories of noises which corrupt the ECG signal:

i. High frequency noise:

This includes power line interference noise and noise due to muscular activity. Power line interference is due to stray electric currents in the cables or due to differences in electrode impedances. These noises are typically of the 60Hz or 50Hz frequency and can be easily removed by using a notch filter. Noise due to muscular activity is because of the patient movement while walking or pedaling. This noise is also known as EMG noise and it is difficult to separate because the frequency spectrum of ECG signal overlaps the frequency spectrum of EMG signal. EMG signal frequency ranges from 0.5Hz to 350Hz whereas the frequency range of ECG signal is between 0.5Hz to 150Hz. Thus, it is very difficult to separate the EMG noise from ECG signal.

ii. Low frequency noise:

This category includes baseline wander noise and respiratory noise. Baseline wander noise is typically of 0.5Hz during resting ECG acquisition, but during stress ECG, this frequency increases beyond 0.5Hz. Also, due to exercising, the oxygen intake increases which results in incorporation of respiratory noise, which is also a low frequency noise.

II. NOISE REMOVAL TECHNIQUES

In order to suppress a specific range of signal, frequency selective filters are used which has fixed coefficients. Many times, the frequency spectrum of the required signal overlaps with the interference signal or the interference signal is either time-dependent or its characteristics are not exactly known. If frequency selective filters are used, it might be possible that the spectrals of ECG signal containing important information and which fall under the cut off region of the selected filter may be lost [1,2]. To enhance ECG signals, there are many recent contributions which use decimated filter banks [3], non-linear filter banks [4], independent component analysis (ICA) [5], etc. A recently introduced technique is empirical mode decomposition (EMD) [6] which processes non-linear and non-stationary signals.

A. Adaptive Filtering Technique

If the frequency spectrum of signal and interference signal overlap or the characteristic of interference signal is time-dependent or not exactly known, filters with fixed coefficients can hardly meet the demands. These difficulties can be handled using an adaptive filtering technique which has variable coefficients instead of fixed coefficients [1]. This filter can adapt its coefficients according to the signal characteristics. The most widely used algorithm in adaptive filtering is the LMS adaptive algorithm.

B. Empirical Mode Decomposition

EMD technique decomposes a signal into a collection of components called Intrinsic Mode Functions (IMF). Fourier based methods require some pre-defined basis functions to represent a signal. EMD method relies on a fully data-driven method that does not require any a priori basis [6]. Without distorting the original signal, both categories of noises are removed by using this technique.

III. IMPLEMENTATION OF PROPOSED SYSTEM

This paper intends to use wavelet-based technique to remove the artifacts arising during cardiac stress testing. For accurate diagnosis, it is important to retain the time as well as frequency information. Fourier transform retains only frequency information or time information but not both. A newer technique developed by Dennis Gabor, known as Short Time Fourier Transform (STFT), assumes a part of the signal to be stationary and the signal is divided into time and frequency domain. Thus, both time and frequency information of the signal can be obtained using STFT. The major disadvantage in this technique is that, it uses a "window" which is fixed along the length of the signal. But biomedical signals require a flexible approach by which it can be more accurately determined in either time or frequency domain and the important information is retained. To overcome this disadvantage, wavelet-based signal denoising technique is used here the width of window can be changed according to the spectral components of the signal. This technique was developed in 1982 by Jean Morlet.

Wavelet transform decomposes the original signal into two segments viz., high frequency decomposition & low frequency decomposition. Thus it can be thought of as a pair of high pass filter and low pass filter where high pass filtered signal is known as *details* and the low pass filtered signal is known as *approximations* of the signal. These coefficients actually represent the same signal but each corresponding to different frequency spectrum. The signal is decomposed with the help of a mother wavelet or a prototype wavelet which is translated and scaled along the length of the original signal. These translations and scaling of the mother wavelet over the signal produces coefficients which are known as wavelet coefficients, in general whereas approximate coefficients and detail coefficients for approximations and details respectively. The decomposition process is repeated up to certain levels. Some of the coefficients obtained in this process are retained while some are discarded and using these coefficients', the signal is reconstructed, which is a clean signal.

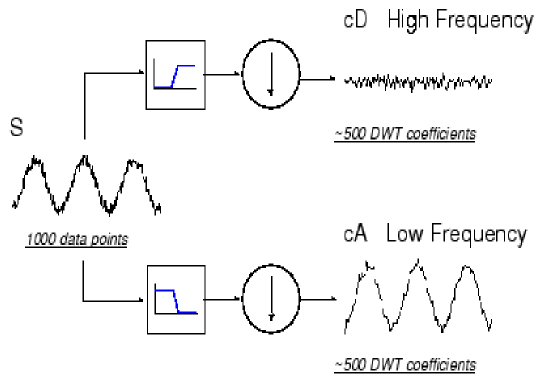

Figure 1: Wavelet Decomposition [7]

A. Implementation

The noisy ECG signal is acquired from *PS420 Multiparameter Simulator* from Fluke Biomedical which includes 12-channel ECG with different types of artifacts along with other features like blood pressure simulation and so on. It supports four different types of ECG artifacts which are 50/60Hz electrical noise, baseline wander, muscle noise and respiratory artifact. These signals are transmitted to PC through a tele-ECG system which is developed by B.A.R.C. This tele-ECG system supports Bluetooth communication with PC. Therefore, the signals are transmitted wirelessly which helps to minimize artifacts due to cables during signal transmission.

The signal obtained through the tele-ECG system is decomposed up to 10^{th} level using 'Coiflet' wavelet. The close resemblance of Coiflet wavelet with the ECG signal makes it suitable to use it as a prototype wavelet. The 10^{th} level approximation of the signal corresponds to the low frequency noises which are baseline wander noise and respiratory noise. Therefore, the 10^{th} level approximation is removed along with the removal of details which corresponds to high frequency noises. For reconstructing the signal, 5^{th} level approximation was used. A *'minimax'* threshold rule was used to remove the unwanted components from the signal. This implementation of wavelet filter was done using MATLAB. The flowchart of the implemented software is given below:

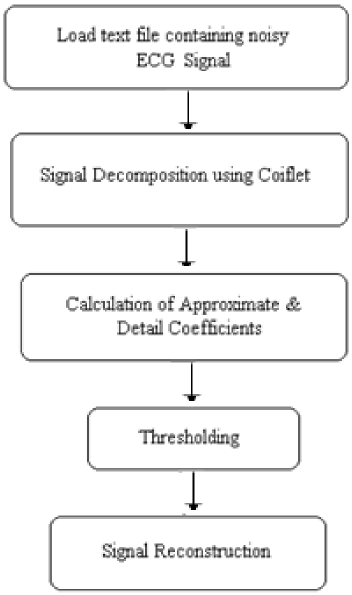

Figure 2: Flowchart of Wavelet-based ECG denoising

IV. EXPERIMENTAL RESULTS

The wavelet filtering technique was applied to all the four types of noises. The experimental results of noise removal using this technique are shown below:

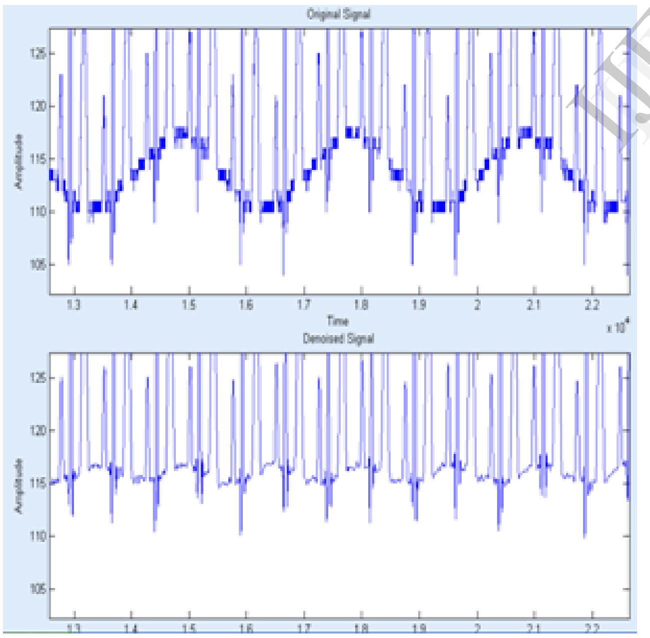

Figure 3: Respiratory Noise Removed

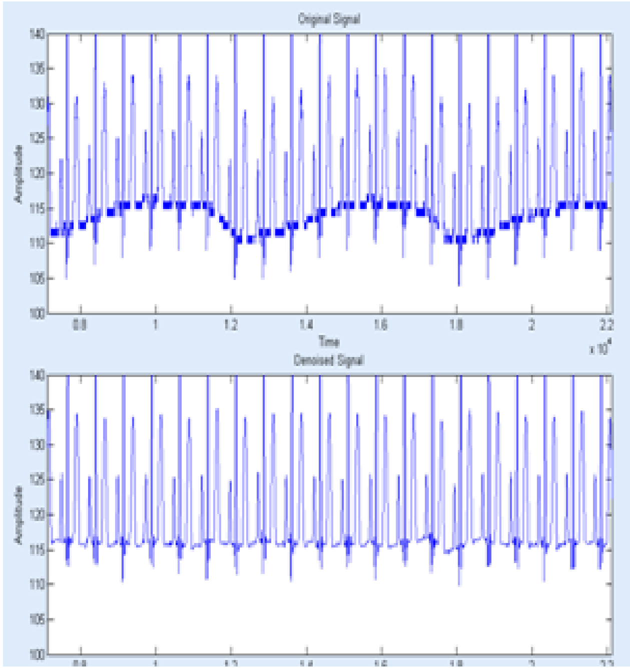

Figure 4: Baseline Wander Removed

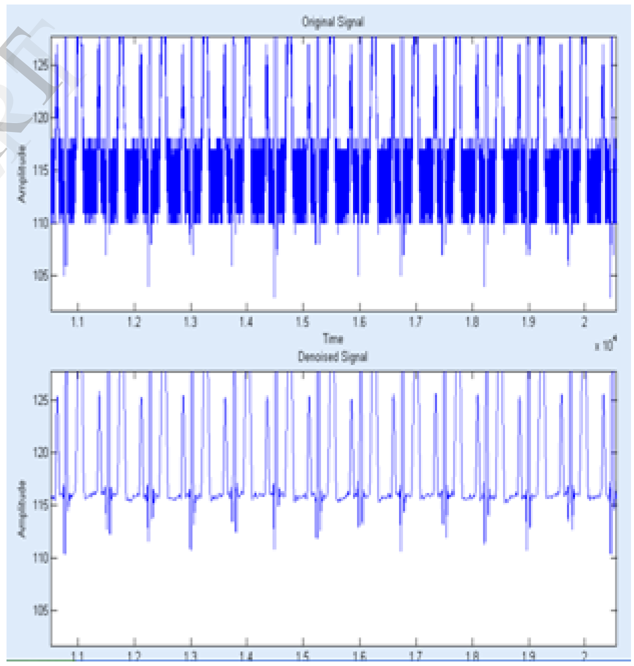

Figure 5: Electrical Noise Removed

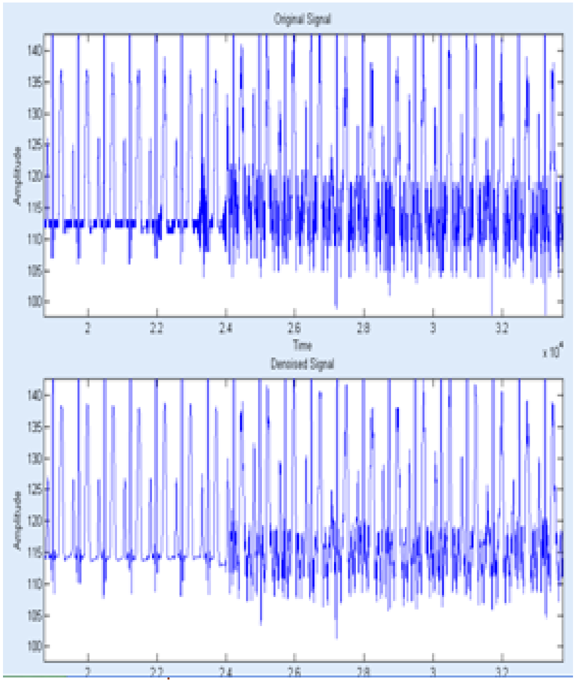

Figure 6: Muscle Artifact Removal

V. CONCLUSION

Wavelet-based denoising technique is a recently developed technique which is easy to implement and removes noise from the signal satisfactorily. It can be used for processing all types of biomedical signals as well as processing of images. The points to consider while applying this technique in signal processing are mainly the number of decomposition levels to be selected, the selection of prototype wavelet and selecting the coefficients to retain or discard, for faithful reproduction. Although this technique is successful in removing almost all kinds of artifacts successfully and retaining the important parameters of the signal; but cannot remove muscle artifact up to desired level. This technique can be further developed to reduce those artifacts by defining a new wavelet which is similar to the ECG signal, rather than using any pre-defined wavelet functions. Also, the future scope of this technique extends to implementation in real-time using MATLAB or Lab Windows Software, which is to be implemented.

REFERENCES

1. Baraniak, J., Leugering, G., Schuhmann, N., & Hauer, J. (2007, July). "Implementation of adaptive filters for biomedical applications", 3rd. Russian-Bavarian Conference on Biomedical Engineering (Vol. 2, No. 3).
2. Farhang-Boroujeny, B., "Adaptive Filters, Theory and Application" (Wiley England: Wiley-Verlag, 1998).
3. V.X. Afonso, W.J. Tompkins, T.Q. Nguyen, K. Michler, S. Luo, "Comparing stress ECG enhancement algorithms", IEEE Eng. Med. Biol. Mag. 15 (3), 1996, 37–44.
4. J.M. Leski, N. Henzel, "ECG baseline wander and power line interference reduction using nonlinear filter bank", Signal Process. 35 (4), 2004, 781–793.
5. A.K. Barros, A. Mansour, N. Ohnishi, "Removing artifacts from electrocardiographic signals using independent components analysis", Neurocomputing 22, 1998, 173–186.
6. Manuel Blanco-Velasco, BinweiWeng, Kenneth E. Barner, "ECG signal denoising and baseline wander correction based on the empirical mode decomposition", Computers in Biology and Medicine 38, 2008, 1 – 13
7. Website: http://www.mathworks.in/help/wavelet/gs/discrete-wavelet-transform.html