ELECTROCARDIOGRAM NOISE CANCELLATION USING WAVELET TRANSFORM

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ABSTRACT

This paper presenting a new electrocardiogram (ECG) noise removal based on wavelet transform technique. The system involves two stages filtration, which denoising process starts with ECG thresholds with several threshold methods. The residual signal will feed to the second stage filtration using the high/low wavelet based filter. Wavelet transform methods capable to counter the unpredictability of motion artifact noise which produce by physical movement. Wavelets may reduce the motion artifact effects since it has the capability to filter both high and low frequency signals and produce good results for both stationary and non-stationary signals. The performance of the wavelet arrangement is shown by using ECG signals taken from the MIT-BIH ECG database.

Keywords: wavelet; electrocardiogram (ECG); motion artifact.

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1. INTRODUCTION

Research based on the noise removal in the electrocardiogram (ECG) signals have been done by many researches. In [12] stated that the most common sources of noise contaminating the ECG signal includes Baseline Wander (BW), Powerline Interference (PLI), Electromyogram (EMG) [15] and Motion Artifact (MA). Motion artifact is the most difficult noise to be removed since frequencies of the ECG signal and the noise are overlaps. In [3] designed a new technique in order to detect the P, QRS and T peaks. They used Haar mother wavelet for QRS wave detection, while the rest P and T peak detection were done by using Daubachies mother wavelet. In [6-7] in their research used discrete wavelet transform (DWT) technique to reduce the MA noise. They used high-pass/low-pass filter to reduce the high frequency effects and the low frequency effects form ECG signal.

In [11] came with a new method, which used transform based with hybrid stage. By using the method, the ECG signal is compressed by using Discrete Cosine Transform (DCT) and combined with 1D or 2D DWT. These method is suitable for ECG compressing as well as QRS complex. In the research, QRS complex detection shows better result than the P and T peaks. The QRS complex increase in compression ratio and lower in percent root mean square difference for 1D and 2D hybrid technique respectively. In [1] in his study used a method based on stationary wavelet approximation in reducing the BW noise effect. In their study, the method used is non-supervised which is the main advantage compared to other techniques by allowing an automatic analysis of ECG. By using the proposed method, an accurate result is given in eliminating BW noise. They used the SWT approach based on Daubechies type 2 at level 8. The selection of Daubechies as the mother wavelet is capable to provide good results. In the work, Daubechies type 2 approaches used, but the use of Daubechies type 4 were seen to be more similar with the ECG signal shape.

The similarity between mother wavelet and ECG signal allows maintaining the originality of signals during the noise filtering process. In [2, 13] have been using a combination of wavelet denoising, a FFT bandpass filter and a Bayesian filter in filtering the BW and the results are compared with conventional ECG denoising approaches. In this study, they used Coiflet type 5 as the mother wavelet but this is no better than Duabechies mother wavelet. Here, the

similarity between mother wavelet and ECG signal plays a big role to maintain the initial signal. ECG signals corrupted with noise from subjects with Atrial Fibrillation (AF) and Left Ventricle Event (LVE) condition from the MIT-BIH library are used in this research.

2. METHODOLOGY

Signals from subjects with AF and LVE condition have been corrupted with motion artifact noise. The signals used were recorded using a 3-lead Holter monitor, which were augmented vector foot (aVF), augmented vector left (aVL) and augmented vector right (aVR) attached to a human body shown in Fig. 1. Several wavelet threshold methods can be used in removing the noise from signal based on two major threshold scheme, which are hard thresholding and soft thresholding. The hard threshold can be illustrated as the process of setting to zero the elements whose absolute values are lower than the threshold. The soft threshold is an extension of hard threshold, first setting to zero the elements whose absolute values are lower than the threshold and then shrinking the nonzero coefficients toward zero [10].
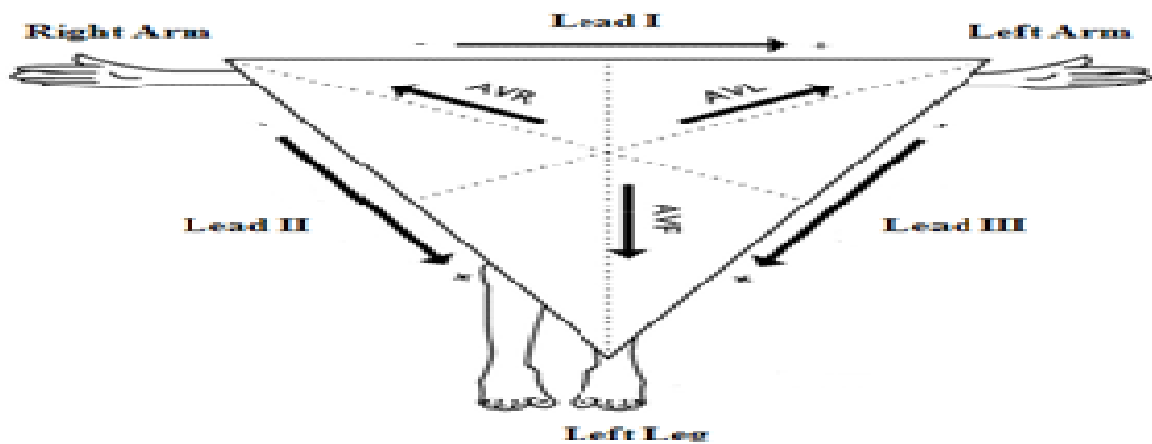
Fig.1. Leads placed on the patient's body

In signal denoising wavelet based threshold method often be used such as adaptive threshold selection using the principle of Stein's Unbiased Risk Estimate (Rigrsure), fixed threshold methods $\sqrt{(2\log(x))}$, (Stwolog), fixed threshold heuristic variant of the first option (Heursure) and fixed threshold minimax (minimax) [9, 14].

The minimax method uses a selected fixed threshold that can produce minimax performance of the mean squared error compared to the ideal procedure. Therefore, this minimax principle can be used to design estimators for statistical applications. The minimax estimator is being

used since it is able to obtain the minimum and maximum mean square error (MSE). The technique used in Rigrsure is using a soft threshold estimator as threshold selection for the rules, which are made on the basis of Stein's Unbiased Risk Estimate. The technique is able to estimate the risk and simultaneously minimize the risk in setting the threshold. The Sqtwolog estimator applies a fixed-form threshold technique in order to deliver minimax results and has been multiplied with a small factor proportional to log (length (signal)). The Heursure estimator is a combination between the Sqtwolog and Rigrsure estimators. Heursure depends on the value of the SNR, where very small SNR indicates the occurrence of the very noisy condition. If this situation is detected, a fixed form threshold is used to remove the noise [4-5, 8].
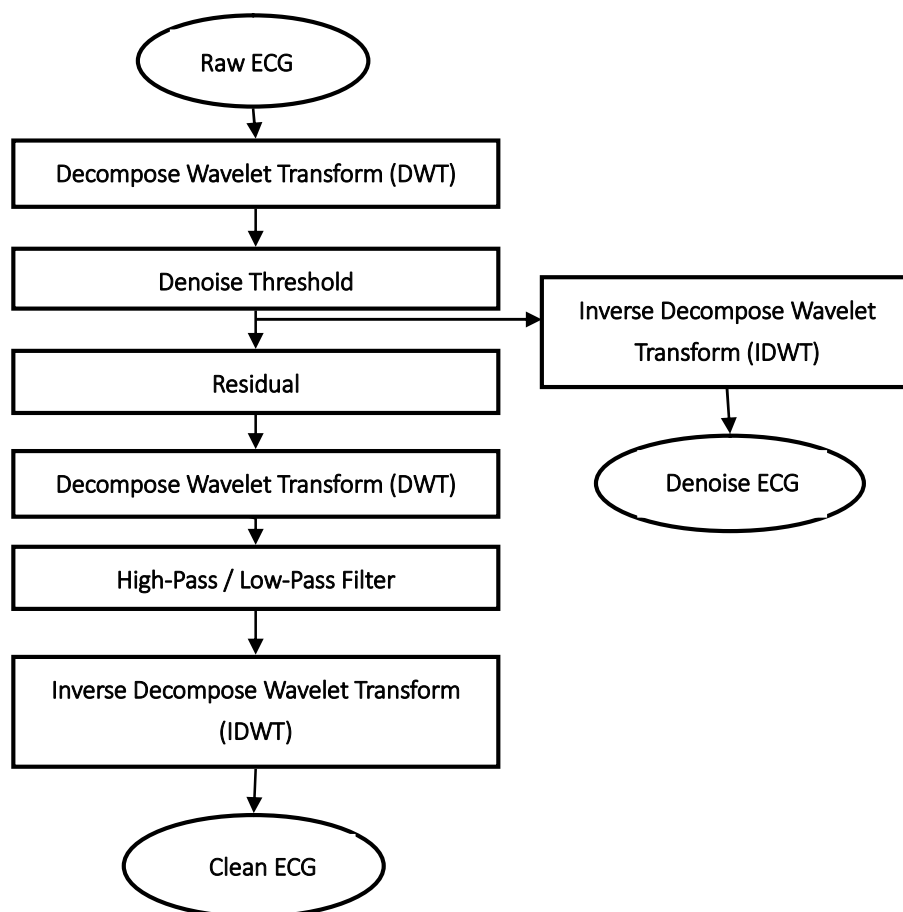

Fig.2. Block diagram for motion artifact noise removal

3. RESULTS AND DISCUSSION

Several methods were tested on the subjects with AF and LVE conditions. The approach involved wavelet based denoising methods (Sqtwolog, Rigrsure, Heursure and Minimax).

Since the noise occurring in the ECG signal was unpredictable, then the wavelet based denoising is followed by the high-pass/low-pass wavelet based filtering process. The combination of these filters is successful to cancel both the low and high frequency noise. The combinations of Sqtwolog, Rigrsure, Heursure and Minimax techniques with high-pass/low-pass filter are known as Sqtwolog-HL, Rigrsure-HL, Heursure-HL and Minimax-HL respectively. The results of all methods used are shown in Table 1 for AF and Table 2 for LVE condition based on Lead aVR-aVF.

Table 1. Noise removal from normal signals based on Lead aVR-aVF

Filtering Technique	SNR of Leads Placed (Db)
Corrupted signal	-0.91
Sqtwolog	18.75
Rigrsure	17.57
Heursure	17.56
Minimax	16.98
Sqtwolog-HL	8.12
Rigrsure-HL	7.85
Heursure-HL	7.83
Minimax-HL	6.98

Table 1 shows the performance of the wavelet based filters in order to reduce the noise effect in normal ECG condition. The Sqtwolog-HL method show the best results to be compared with other wavelet based filter techniques. The results show that the wavelet denoise technique gives better result than the corrupted signal, however by combining with the wavelet based high-pass/low-pass filters have increase the filtration performance.

Based on the Table 1, the wavelet based denoising techniques (Sqtwolog, Rigrsure, Heursure and Minimax) capable to produce better results compared to the corrupted signal. However, better results are given by combining the filtration technique with wavelet based high-pass/low-pass filter. Significant improvement has been shown compared to the corrupted signals and the results obtained by using wavelet based denoising method itself. Nevertheless, the Sqtwolog-HL method shows the best performance compared to Rigrsure-HL,

Heursure-HL and Minimax-HL in removing the noise from ECG signals as tabled in Table 1. Based on the Table 1, small improvement has been shows by Sqtwolog, Rigrsure, Heursure and Minimax denoise techniques. The improvement range between 0.6 to 1.4 dB. However, huge improvement has been shows after the residual signal from denoise technique been filtered with waelet based high pass/low pass filter. The improvement has been shows is up to 13 dB.

**Table 2.** Noise removal from LVE signals based on Lead aVR-aVF

Filtering Technique	SNR of Leads Placed (Db)
Corrupted signal	-0.50
Sqtwolog	0.09
Rigrsure	-0.33
Heursure	-0.32
Minimax	-0.07
Sqtwolog-HL	12.98
Rigrsure-HL	11.97
Heursure-HL	11.95
Minimax-HL	12.52

Table 2 exhibit the LVE signal filtering, but using wavelet based denoise threshold and high pass/low pass filter. The best results by using the Sqtwolog-HL method is used to compared with filtering result/technique with other methods. The results show that the combination of wavelet based denoising with the wavelet based high-pass/low-pass filters gives better performance compared to denoising approach alone. Based on the Table 2, the wavelet based denoising techniques (Sqtwolog, Rigrsure, Heursure and Minimax) capable to produce better results compared to the corrupted signal. However, more significant results are shows from the combining of the wavelet based denosing with wavelet based high-pass/low-pass filter. Significant improvement has been shown compared to the corrupted signals and the results obtained by using wavelet based denoising method itself. Nevertheless, the Sqtwolog-HL method shows the best performance compared to Rigrsure-HL, Heursure-HL and Minimax-HL in removing the noise from ECG signals as tabled in Table 1.

Although using the denoising techniques alone can obtain better performance compared to corrupted signal, but the filtered signal contains with both high and low frequency noises. In order to overcome this problem, the Sqtwolog-HL method has been used since it attempts to remove both low and high frequency noise whilst simultaneously retaining the important information from the ECG signal. Fig. 3 shows the comparison between the two phases denoising process and the performance. Fig. 3(a) shows the ECG signal corrupted with noises which contains low and high frequency noise. The wavelet based denoise method (Sqtwolog) was applied to the signal and it the high frequency noise has significantly removed from the signal and leaves the low frequency noise (and some high frequency noise). As shown in Fig. 2(b). Fig. 2(c), it shows the result with the combination of wavelet based denoise method with the wavelet based high-pass/low-pass filter (Sqtwolog-HL) in removing both low and high frequency noise, leaving the clean ECG signal behind.

Nevertheless, the processed clean ECG signal is not totally clean because there is still some noise in the signal with most of the important information of the signal yet to be processed. Since the MA noise is an unpredictable signal, it is difficult to be removed. Moreover, the MA might have overlapped with ECG signal. The removal of the MA may remove the important information of ECG simultaneously.

(a)   (b)

(c)
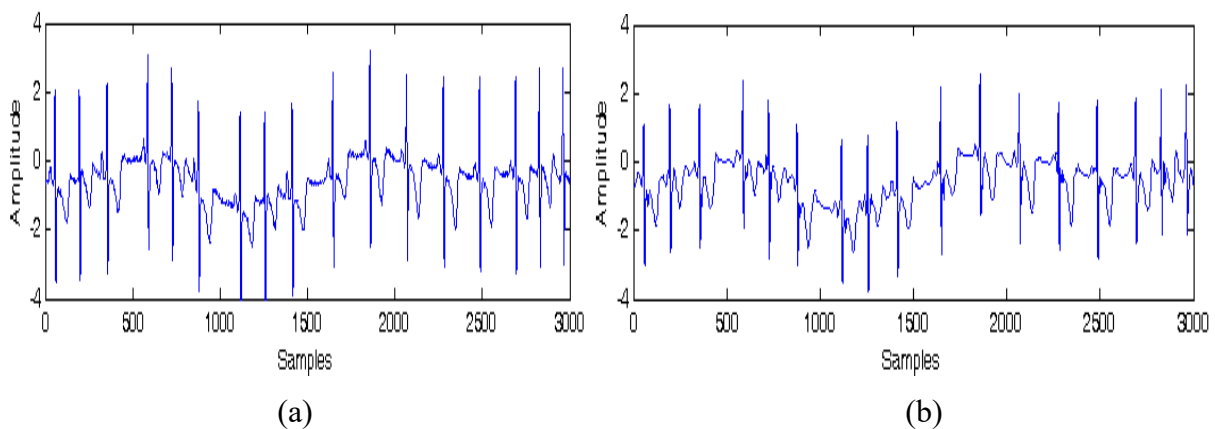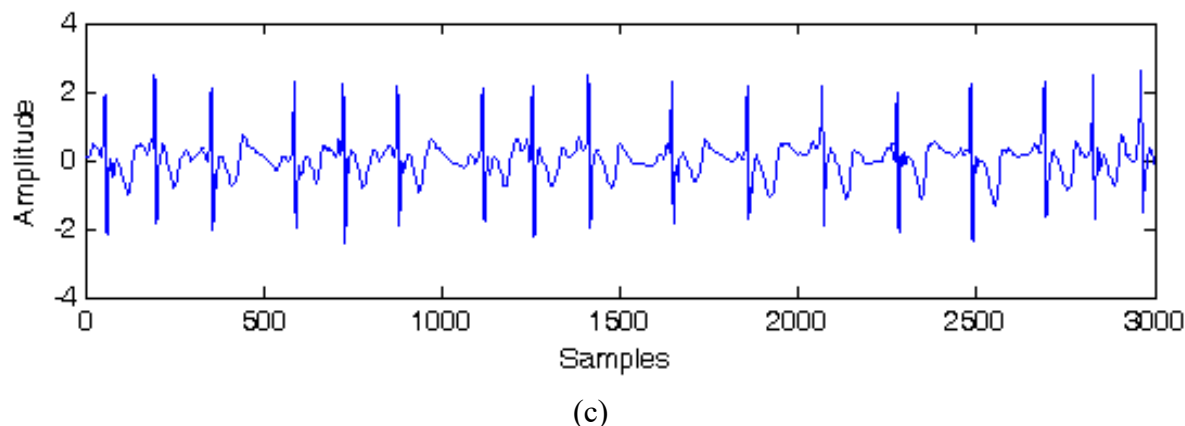
Fig.3. Result of noise removal from AF signal; (a) ECG signal with noise, (b) noise removal using Sqtwolog, (c) noise reduction using Sqtwolog-HL

(a)

(b)

(c)
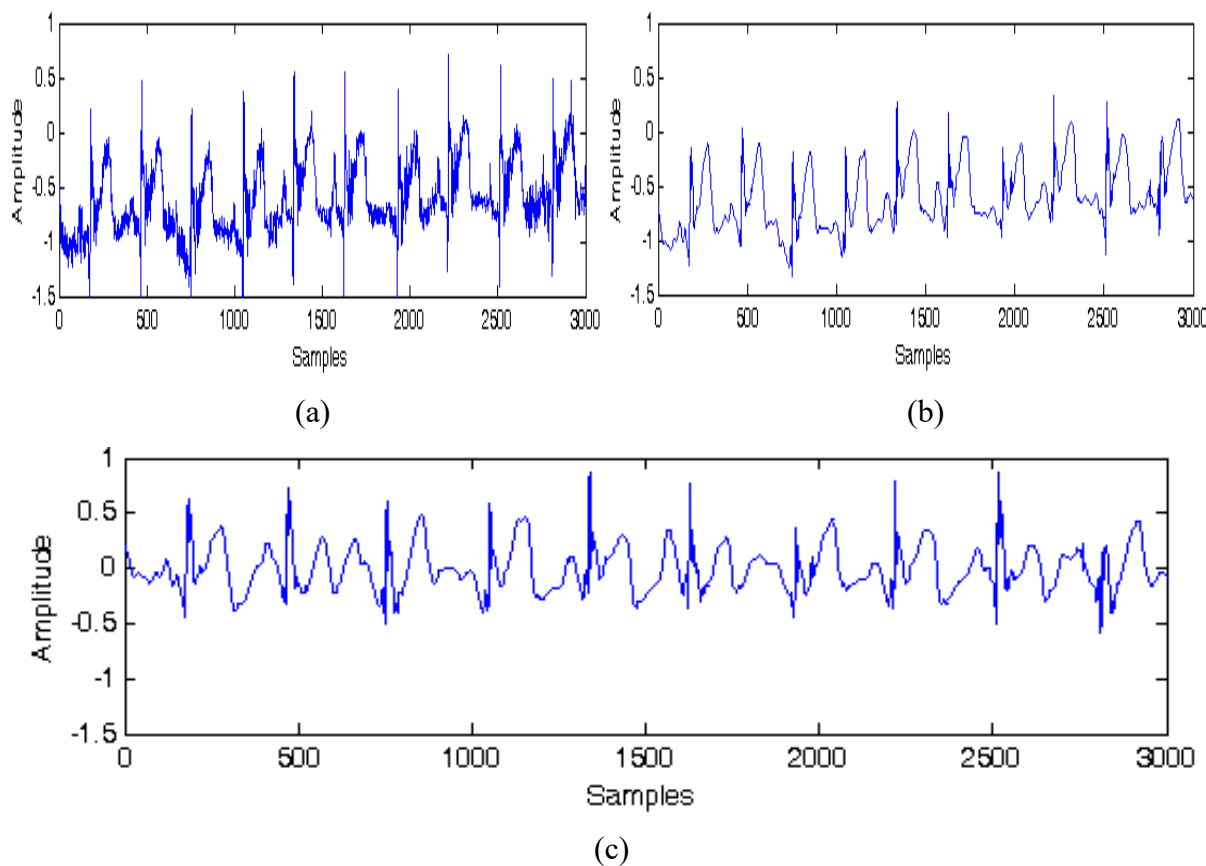
Fig.4. Result of noise removal from LVE signal; (a) ECG signal with noise, (b) noise removal using Sqtwolog, (c) noise reduction using Sqtwolog-HL

A similar experiment to that shown in Fig. 3 was repeated with different ECG signals as shown in Fig. 4. Fig. 4 repeats the sequence as in Fig. 3 that includes Fig. 3(a) signals with noise, Fig. 3(b) result of Sqtwolog denoising method and Fig. 3(c) result of Sqtwolog-HL denoising method. Fig. 3 (b) shows the removal of the high frequency noise using the

denoising technique leaving low frequency noise, while Fig. 3 (c) shows the result without the low and high frequency noise removed by the combination of the denoising and high-pass/low-pass filter. Most of the important information is still present although some noise still corrupted the signal, since the spectrum of the noise overlapped with the ECG signal.

4. CONCLUSION

The combination of two wavelet technique; wavelet based denoising method and wavelet based high-pass/low-pass filter is able to produce better results than denoising methods applied on their own. The experimental results also show the capability of the proposed method to denoise both the low frequency and high frequency noise leaving behind the important information of the original signal.

5. ACKNOWLEDGEMENTS

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