A Comparative Study for Different Methods used for ECG Denoising

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Abstract

ECG signal recording easily suffers from interferences of the environment, such as patient movement, position of electrodes etc. For primary diagnosis, doctors need noise-free ECG signals. This paper presents a detailed study of denoising ECG signals using several techniques such as morphological filtering, Stationary wavelet transform (SWT) and discrete wavelet Transform (DWT) etc. The results received from various techniques are evaluated through MATLAB and their performance is analyzed using parameters like Signal to Noise Ratio (SNR), Mean Square Error (MSE) of the noisy and filtered ECG signals.
Keywords: ECG, Signal Denoising, FIR Filter, Morphological Filtering, SWT, DWT, SNR, MSE

I. INTRODUCTION

An electrocardiogram (ECG) is a recording of heart's electrical activity, which is used to study the heart's functional disorder.A normal ECG signal waveform composed of P wave, QRS complex and T wave and all together they represent one beat of heart. A small U wave is occasionally present. The cardiac cycle begin with the P wave which corresponds to the atrial depolarization in the heart. The most striking part of the ECG is the QRS complex which is followed by P wave. The T wave follows the QRS complex and corresponds to the ventricular repolarization. The amplitude and duration of the P-QRS-T-U wave contains useful information about the nature of disease related to heart. However ECG signal is a non-stationary signal, it is easy to interfere by the different noises while gathering and recording. Fig.1. shows a typical ECG waveform. To remove the non-heart signal from ECG without any degradation is called denoising. An efficient denoising technique removes the artifact without influencing shape of ECG.

The applications of ECG have motivated researchers to develop efficient denoising techniques such as FIR filters, fuzzy logic, wavelet transform, emperical mode decomposition, morphological filtersand adaptive filters. We have analyzed some of the above method in quest of best one.

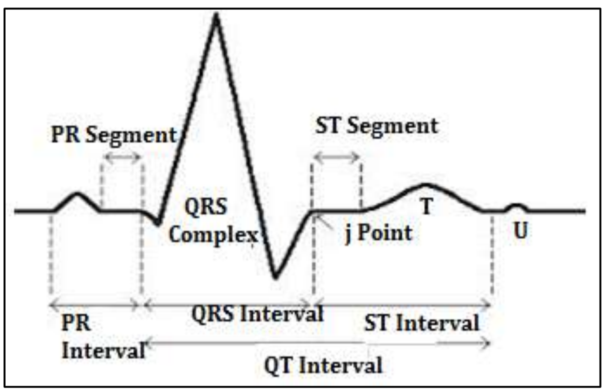


Fig. 1: ECG Waveform

This paper is organized as follows. The artifacts to be removed are discussed in section II, in section III different methods are discussed, section V consists of future scope and the paper is concluded in section IV.

II. ARTIFACTS IN ECG

There are several kind of noises found in ECG recording like power supply interference, electrode impedance noise, motion noise, electromyography i.e. muscle artifact, baseline wandering etc. The most common and influential noises are EMG and baseline wandering.

Baseline wandering is a low frequency noise present in the ECG signal which causes large variation in baseline of the ECG signal and makes it difficult to analyze .This type of noise occurs due to the patient movement, skin resistance, skin-electrodes improper interference.

Electromyography (EMG) noise is a high frequency noise. This type of noise caused by the contraction of other muscles apart from the heart. When other muscles in the region of the electrodes contract, they generate depolarization and repolarization waves that can also be picked up by the ECG [1].

To remove these interferences from the ECG signal, denoising of signal should be done. In this paper, ECG data is collected from data base. Then different denoising techniques are apply on collected ECG data and results of different methods are compared in terms of SNR and MSE.

A. ECG Database

Authors have collected ECG data from Massachusetts Institute of Technology and Boston's Beth Israel Hospital (MIT-BIH) database for research.

III. DIFFERENT DENOISING TECHNIQUES

The various methods of denoising that can be implemented for removal of noise available in the ECG signals are discussed below [2].

A. Morphological Filtering

Morphological image processing is a collection of non-linear operations related to the shape or morphology of features in an image. Morphological operations can be performed on both binary and grey scale images [6]. Structuring element is a pixel window used to scan the image, it plays critical role in morphological operation since it decides the pixel value should change or not. Morphology operations are dilation, erosion, opening and closing.

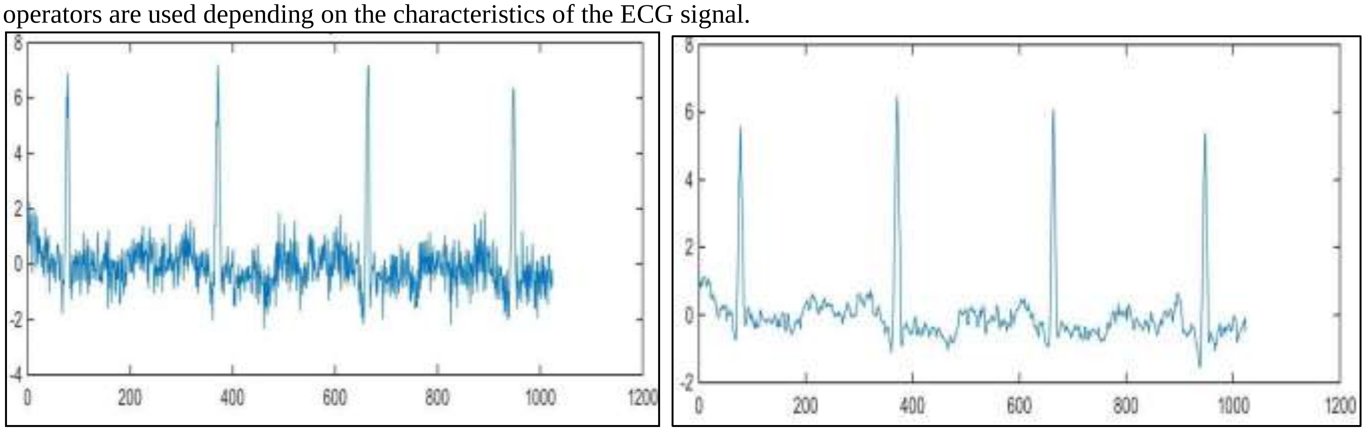
Erosion removes small-scale details from a binary image but reduces the size of regions of interest. Boundaries of each region can be found by subtracting the eroded image from the original image.

Dilation is opposite process from erosion .It adds a layer of pixels to both the inner and outer boundaries of regions. The size and shape of a structuring element influences the results of dilation or erosion. Dilation and erosion are dual operations in that they have opposite effects.

Opening of a data sequence means to slide a structural element along the data sequence from beneath and the result will be the highest point reached by the structural element.

Closing of a data sequence is done by sliding an inverted or flipped version of the structural element from above and the result will be the lowest point reached by the structural element. These two operations are equally important for noise filtering in ECG signal as opening suppresses peaks and closing suppresses pits.

Opening and closing operations are used for baseline correction and noise suppression in conditioning of ECG signal. Some sequences of both the operations are used for conditioning the signal. Different structural elements and different morphological operators are used depending on the characteristics of the ECG signal.



(a) (b)

Fig. 2: (a) Noisy ECG signal (b) Clean ECG signal by using morphological filter

Fig-2 shows MATLAB result of Morphological conditioning of ECG signal.

B. Discrete Wavelet Transform

The time-frequency representation of DWT is performed by repeated filtering of the input signal with a pair of low pass filter (LPF) and high pass filter (HPF) [3]. Low pass filtered coefficients are called Approximation Coefficients (CA) and similarly, high pass filtered coefficients are called as Detailed Coefficients (CD).The CA further decompose into new approximation and detailed Coefficients by using LPF and HPF. This decomposition process is carried out until the required sub band achieved from the given input signal [2].

1) De-Noising Algorithm

- Decomposition: Choose a wavelet whose shape is correlated to ECG, and Compute the wavelet decomposition up to N level.
- Thresholding: After decomposition of signal, Second step to remove noise from signal is thresholding. For each level from 1 to N, apply different thresholding to the detailed coefficients. The selection of right thresholding method will provide better noiseless output. According to D. Donoho's method, the threshold estimate δ for denoising with an orthonormal basis is given by [4].

$$\delta = \sigma\sqrt{2logN}$$

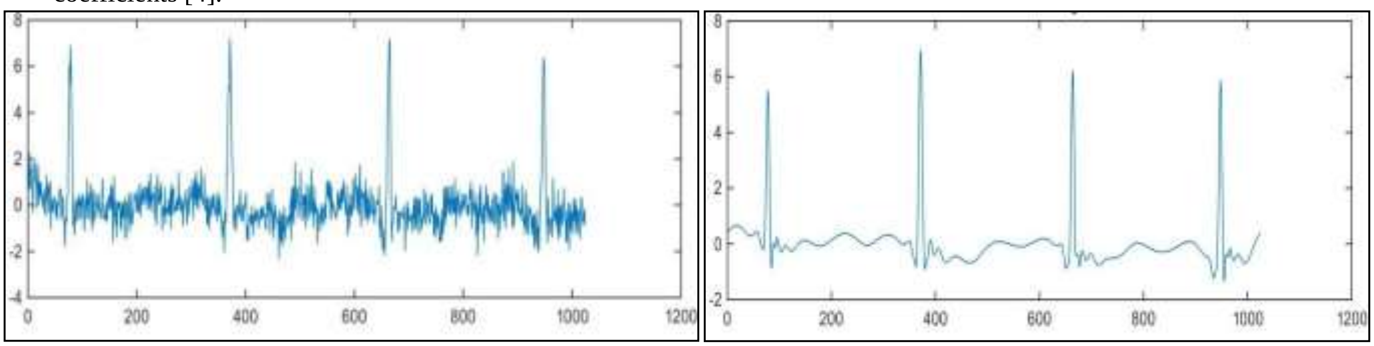
In Hard Thresholding method detail coefficient whose value lies below threshold value are reduced to zero and coefficient with higher value remains unchanged.

$$\breve{X} = \begin{cases} X, & |X| \geq \delta \\ 0, & |X| < \delta \end{cases}$$

Soft Thresholding method, in this type of Thresholding detail coefficient whose value lies below threshold value are neglected and coefficient with higher values are modified as per equation 2

$$\widetilde{X} = \begin{cases} \text{sign}(X) * (|X| - \delta), & |X| \geq \delta \\ 0, & |X| < \delta \end{cases}$$

- Reconstruction after thresholding signal is reconstructed by using original approximate coefficients and modified detail coefficients [4].



(a) (b)

Fig. 3(a): Noisy ECG signal (b): Clean ECG signalby using DWT

C. Stationary Wavelet Transform (SWT)

Stationary Wavelet Transform is also called undecimated wavelet transform. Low pass filter and high pass filter are applied at each stage of SWT decomposition. IN the SWT, the output signal is not decimated. Instead, the filters are up sampled at each level [5]. Modification of filters done at each level, by padding them with zeroes. Computationally SWT is more complex as compared to DWT.

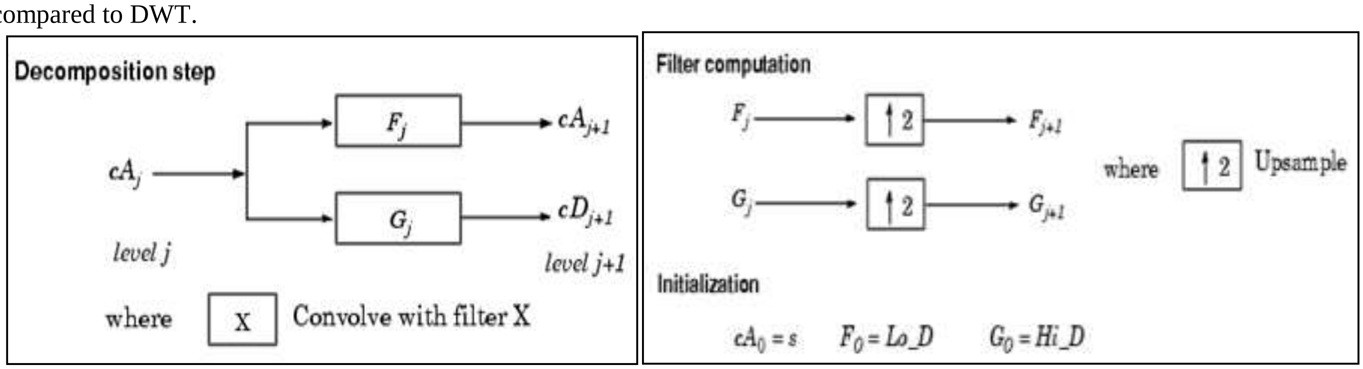


Fig. 4: Decomposition Step

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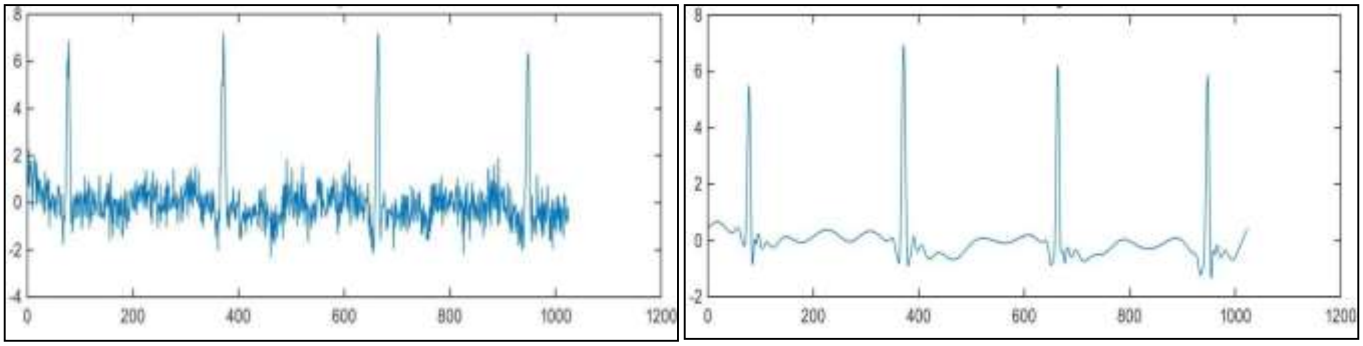

(a) (b)

Fig. 3: (a) Noisy ECG signal (b): Clean ECG signal by using SWT

Different denoising methods and their simulation results are discussed in this paper. Table-1 shows comparison between parameters of these different denoising.

Table – 1
Comparison of SNR and MSE

Method name	*Input SNR (in DB)*	*Output SNR(in DB)*	*MSE*
Morphological filtering	*5*	*10.8477*	*0.0705*
DWT	*5*	*11.2028*	*0.0716*
SWT	*5*	*12.5201*	*0.0469*

IV. CONCLUSION

We have studied different methods to remove baseline and EMG artifacts from ECG as they lead to misinterpretation at the time of diagnosis. The baseline wander and EMG artifacts affect low and high frequency band respectively. We compared the performance of different algorithms in terms of SNR and MSE, SWT gives the superior result compared to rest methods because it retains complete information at the time of signal decomposition.

V. FUTURE SCOPE

The superior method is SWT, but it uses high order of redundancy. Future research should be trying to use tools like dual tree complex transform which reduces the high level of redundancy while keeping most of the information after decomposition.

REFERENCES

[1] Li Su and Guoliang Zhao De-Noising of ECG Signal Using Translation- Invariant Wavelet De-Noising Method with Improved Thresholding Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference Shanghai, China, September 1-4, 2005.
[2] David L. Donoho De-Noising by Soft-Thresholding IEEE TRANSACTIONS ON INFORMATION THEORY, VOL. 41, NO. 3, MAY 1995
[3] Z. German-Sallo ECG Signal Baseline Wander Removal Using Wavelet Analysis S. Vlad and R.V. Ciupa (Eds.): MEDITECH 2011, IFMBE Proceedings 36, pp. 190–193, 2011.
[4] Yan Sun ∗, Kap Luk Chan, Shankar Muthu Krishnan ECG signal conditioning by morphological filtering Computers in Biology and Medicine 32 (2002) 465–479
[5] Manuel Blanco-Velascoa,∗, BinweiWengb, Kenneth E. Barnerc ECG signal denoising and baselinewander correction based on the empirical mode decomposition Computers in Biology and Medicine 38 (2008) 1 – 13
[6] Mikhled Alfaouri and Khaled Daqrouq ECG Signal Denoising By Wavelet Transform Thresholding American Journal of Applied Sciences 5 (3): 276-281, 2008 ISSN 1546-9239.
[7] SA Chouakri1,3, F Bereksi-Reguig2, S Ahmaïdi3, O Fokapu4 Wavelet Denoising of the Electrocardiogram Signal Based on the Corrupted Noise Estimation 0276−6547/05 $20.00 © 2005 IEEE.
[8] S. Poornachandra Wavelet-based denoising using subband dependent threshold for ECG signals Digital Signal Processing 18 (2008) 49–55.