Removal of Baseline Wander from ECG Signal

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Abstract- Electrocardiogram (ECG) has considerable diagnostic significance, and is one of the oldest and most enduring tools used by cardiologists. For diagnostic quality of ECG recordings, signal acquisition must be noise free. The signal acquisition is susceptible to the interference from other biological and environmental sources. Baseline wandering can mask some important features of the Electrocardiogram (ECG) signal hence it is desirable to remove the noise for proper analysis and display of the ECG signal. An accurate method for removing the baseline wander (BW) in ECG on the basis of Empirical Mode Decomposition (EMD) is proposed in this paper. We briefly described the principles and characteristics of the EMD in this paper. To validate the proposed method, the recording from MIT/BIH database is used. In this paper, the median filter is applied to remove BW in ECG for comparison with our EMD method. Our simulated results show that the performance of EMD method is better in SNR and PSD for removing BW in ECG.

Keywords:
BW(Baseline Wander), ECG, EMD, IMF, SNR, PSD

I. INTRODUCTION

The ECG is one of the oldest and most enduring tools used by cardiologists. The principle behind the ECG consists of the electrical activity that is transmitted throughout the body when the heart is depolarized in order to trigger its contraction. ECG measures electrical potentials on the body surface via contact electrodes. Conditions such as movement of the patient, breathing, and interaction between the electrodes and skin cause baseline wandering of the ECG signal. Baseline wandering is one of the noise artifacts that affect ECG signals. This wandering, caused by

1. The subject's movement(artifacts) or breathing
2. Vibrations near to patient and machine
3. Vibrations of the mobile phone or drill machine
4. Any metallic item present near the chest or near electrode.
5. Improper placement of electrodes.

Baseline wandering noise can mask some important features of the ECG signal; hence it is desirable to remove this noise for proper analysis of the ECG signal. This study includes an implementation and evaluation of methods to remove this noise. Section II includes literature survey and existing techniques to remove baseline wander. In section III we elaborate the proposed EMD algorithm. Example and result analysis is carried out in MATLAB is discussed in Section IV. Conclusion is drawn in Section VI.

II. LITERATURE SURVEY

The baseline wander is an extraneous, low-frequency activity in the ECG which may interfere with the signal analysis, making the clinical interpretation inaccurate. When baseline wander takes place, ECG measurements related to the iso-electric line cannot be computed since it is not well-defined. The spectral content of the baseline wander is usually in the range between 0.05-1Hz but, during strenuous exercise, it may contain higher frequencies. The removal of the baseline wander in an ECG signal has been one of the first challenges in biomedical signal processing. A high filter order should be used to produce good results, which increases the computation time. It is important to provide a clear and accurate representation in order for cardiologists to correctly interpret the ECG.

In many situations, the recorded signal is corrupted by different types of noise and interference, originated by another physiological process of the body. When an electrode is poorly attached to the body surface or when an external source such as the sinusoidal 50Hz power line interferes with the signal, the recorded signal is distorted in a way that it could be difficult to perform any automatic diagnosis. Therefore, noise reduction represents a crucial objective of biomedical signal processing[5].

High Pass Filter, IIR Filtering, FIR Filtering, Zero Phase Filtering, Moving Average Approach, Wavelet Approach, Savitzky-Golay Filtering were used for removal of baseline wandering[3] [4][6][7].

For the meaningful and accurate detection, steps have to be taken to filter out or discard all these noise sources. Analog filters may introduce

1. non-linear phase shifts,
2. skewing the signal.
3. Dependability on resistance, temperature, and design.

With more recent technology, Digital filters are now implemented to offer more advantages over the analog one. Digital filters are more precise due to a lack of instrumentation.

Apart from the poor quality of ECG, artifacts can cause serious consequences particularly when they mimic like genuine changes. If ECG artifacts are not recognized by physician, anaesthesiologist or intensivist unnecessary diagnostic and therapeutic measures could be taken. Such actions may subject patients to invasive investigations or they may receive unnecessary medications like antiarrhythmic.

III. PROPOSED ALGORITHM

Empirical Mode Decomposition (EMD)

A new method for analysing nonlinear and non-stationary data has been developed. In this method any complicated data set can be decomposed into a finite and often small number of intrinsic mode functions that admit well-behaved Hilbert transforms. This decomposition method is adaptive, and, therefore, highly efficient. Since the decomposition is based on the local characteristic time scale of the data, it is applicable to nonlinear and non-stationary processes.

With the Hilbert transform, the intrinsic mode functions yield instantaneous frequencies as functions of time that give sharp identifications of embedded structures. The final presentation of the results is energy, frequency, time distribution, designated as the Hilbert spectrum.

The empirical mode decomposition (EMD) algorithm was proposed by Huang et al. [1] for non-linear and non-stationary signal analysis. The algorithm can decompose the signal into narrowband oscillatory components (named intrinsic mode functions (IMFs)) with a final residue signal. The decomposition method used in EMD is called sifting process[2].

An IMF is defined by satisfying two conditions:

1. The number of extrema and the number of zero-crossings should be equal or differ at most by one in the whole dataset.
2. The mean value of the envelope defined by local maxima and minima should be equal to zero at any point.

The goal of the sifting is to subtract the large-scale features of the signal repeatedly until only the fine-scale features remain. The steps of the sifting are as follows:

1. Identify the extrema (maxima and minima) of the signal $x(t)$.
2. Find the upper envelope of the $x(t)$ by passing a natural cubic spline through the maxima, and
3. find the lower envelope of the minima.
4. Compute mean of the upper and lower envelopes and designate as $m(t)$.
5. Get an IMF candidate using the formula

$$h_k(t) = x(t) - m(t) \qquad (1)$$

6. Check the whether properties $h_k(t)$ is an IMF. If $h_k(t)$ is not an IMF, repeat the procedure from step 1. $h_k(t)$ is an IMF, then set

$$r - x(t) - h_k(t) \qquad (2)$$

The procedure from step 1 to step 5 is repeated by sifting the residual signal. The sifting processing ends when the residue r satisfies a predefined stopping criterion. The $h_k(t)$ (k=1 .... n) are being sorted in descending orders of frequency. Finally, the original $x(t)$ can be reconstructed by a linear superposition:

$$x(t) = \sum_{k=1}^{n} h_k(t) + r \qquad (3)$$

where $h_k(t)$ is one k^{th} IMF of the decomposed signal, and r is a residue.

EMD has been widely used for data analysis; such as image processing, bio signals processing, seismic analysis, and detecting mechanical faults of rotating machines. This algorithm has more and more potential on data analysis or artifacts elimination. However, the heavy computational load of the algorithm makes the on-line EMD-based signal processing difficult. Therefore, most of the studies focus on off-line signal processing using the EMD algorithm through a personal computer (PC), and verifies the possibility of signal processing using EMD.

EMD is a batch processing algorithm which needs much iteration loops to decompose a signal into a sum of IMFs. EMD decomposes the signal into a sum of IMFs. An IMF is defined as a function with equal number of extrema and zero crossings (or at most differed by one) with its envelopes, as defined by all the local maxima and minima, being symmetric with respect to zero. So given a signal $x(t)$, it can be expressed as

$$x(t) = \sum_{n=1}^{N} cn(t) + rn(t) \qquad (4)$$

where $cn(t)$ is referred as nth-order IMF. By this convention, lower order IMFs capture fast oscillation modes while higher order IMFs typically represent slow oscillation modes. In above eqn. $rn(t)$ is called the residue which is a constant, a monotonic slope, or a function with only one extremum. It can also be regarded as the last IMF.

For the denoising case, as the QRS complex spreads over the several first IMFs, it cannot be performed by simply discarding lower-order IMFs. The method to filter the noise consists of four steps:

1. Delineate and separate the QRS complex,
2. Use proper windowing to preserve the QRS complex,
3. Use statistical tests to determine the number of IMFs contributing to the noise,
4. Filter the noise by partial reconstruction.

When applying the EMD method to decompose the noisy ECG signal into n IMF components and one final residue, the first IMF includes the highest frequency band component and can be treated as power-line interference.

Furthermore, because baseline wander is usually a low frequency phenomenon, it is mainly involved in the final residue. Therefore, the 'reconstructed' ECG signal with removed power-line interference and baseline wander can be achieved by removing the first IMF and the final residue from the noisy ECG signal respectively.

IV. Methods and Example Results

For analysis, signal is used from MITBIH database. This signal contains baseline wander.

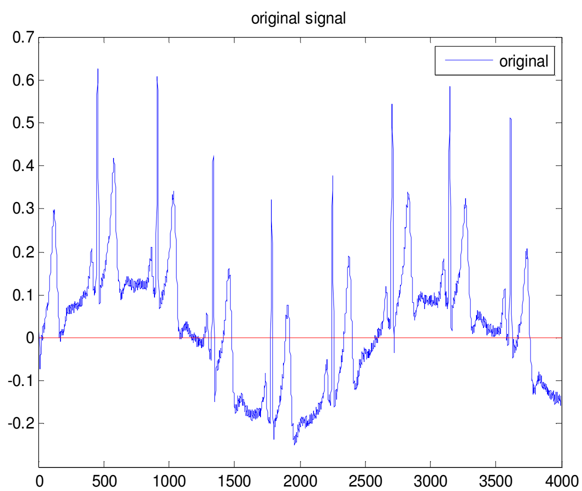

Fig. 1: Original Signal

As a comparison, a median filter is used to remove the BW in the test ECG signal. Fig. 2 displays the result of applying the EMD filter to remove the BW. Fig.3 indicates the result of median filtering.

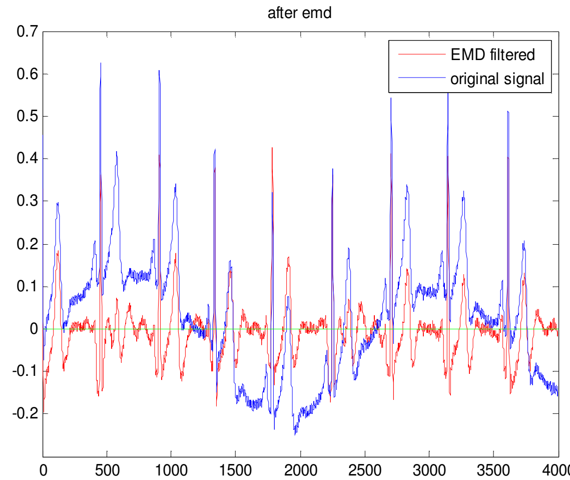

Fig. 2: Signal after EMD Filter

SNR of EMD filter is higher than median filter. EMD filter approach removes almost all baseline wander which shown in Fig.2.

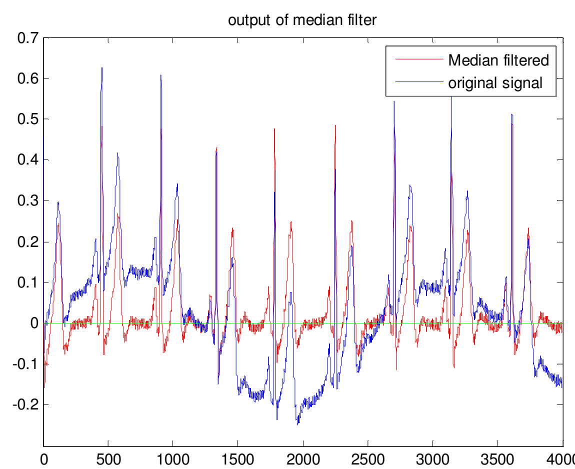

Fig. 3: Signal after Median Filter

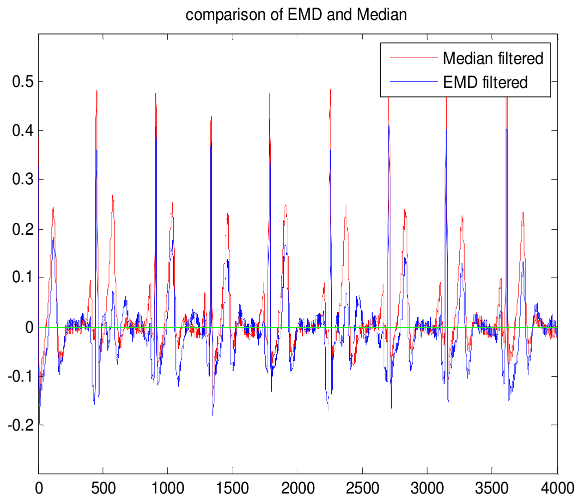

Fig. 4: Comparison of Filters

Median filter also removes baseline wander and gives better SNR but there are some changes in the original amplitude of the signal which is avoided in EMD approach. After EMD filtration the clinical information remains as it is. No change in peaks and amplitude of the original signal is observed in EMD.

Following are the results obtained by implementing the filters like adaptive, median filter and EMD algorithm. The signal contains baseline drift which can be observed in the above figures.

SIGNAL TO NOISE RATIO (SNR)

SNR is an engineering term for the power ratio between a signal (meaningful information) and the background noise. ECG signals normally have a wide dynamic range. SNRs are usually expressed in terms of the logarithmic decibel scale. In decibels, the SNR is 20 times the base-10 logarithm of the amplitude ratio, or 10 times the logarithm of the power ratio:

$$SNR = 10\log\frac{Es}{En} \qquad (5)$$

where Es is a average signal amplitude and En is average noise amplitude measured within the system bandwidth[9].

SNR is important parameter for analysing the performance of various filters. High SNR indicates less noise present in the signal whereas low SNR indicates more noise in the signal. Therefore, SNR is a parameter used to quantify and compare the performance of algorithms and also determine the noise level in an ECG signal. The expression used to calculate SNR is as follows:

$$SNR = 10\log(\text{mean}\frac{(So)}{(So-Sf)}) \qquad (5)$$

where SO= original Signal Sf = filtered signal

	Original signal	Adaptive filter	E.M.D.	Median filter
SNR in dB	-----	6.5528	12.6443	8.4154
Signal Power in dB	-19.4564	-19.5573	-25.0172	-22.9824

Power Spectral Density (PSD)

The power spectral density (PSD) is intended for continuous spectra. The integral of the PSD over a given frequency band computes the average power in the signal over that frequency band. A one-sided PSD contains the total power of the signal in the frequency interval from DC to half of the Nyquist rate. A two-sided PSD contains the total power in the frequency interval from DC to the Nyquist rate.

A function in MATLAB avgpower(Hs) computes the average power in a given frequency band. The technique uses a rectangle approximation of the integral of the Hs signal's power spectral density (PSD). If the signal is a matrix, the computation is done on each column. The average power is the total signal power and the Spectrum Type property determines whether the total average power is contained in the one-sided or two-sided spectrum. For a one-sided spectrum, the range is [0,pi] for even number of frequency points and [0,pi) for odd. For a two-sided spectrum the range is [0,2pi)[8].

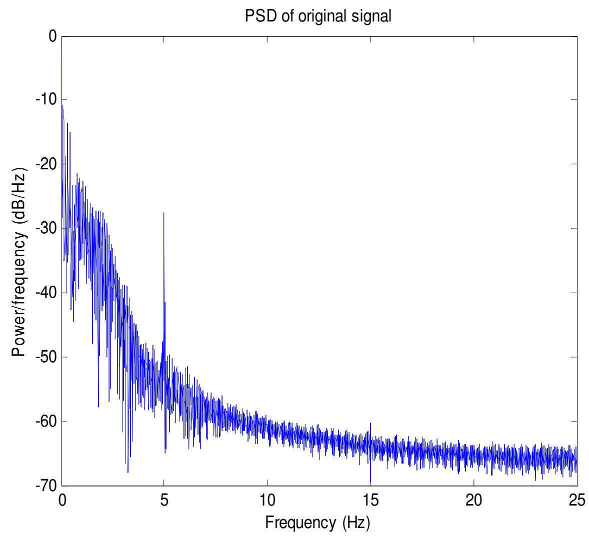

Fig.5 PSD of original signal

The fig.5 shows PSD of the original signal. Fig.6 shows PSD of the EMD filtered signal whereas fig.7 shows PSD of median filtered signal. These graphs show that EMD method is better for removal of BW. Values computed for PSD are shown in table 1.

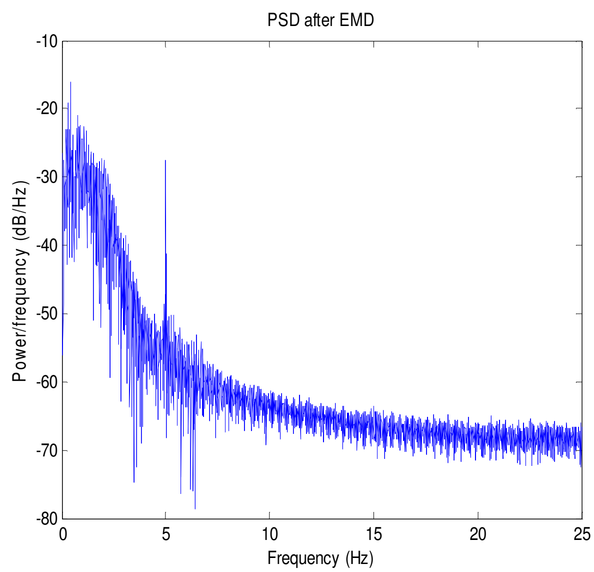

Fig.6 PSD after EMD

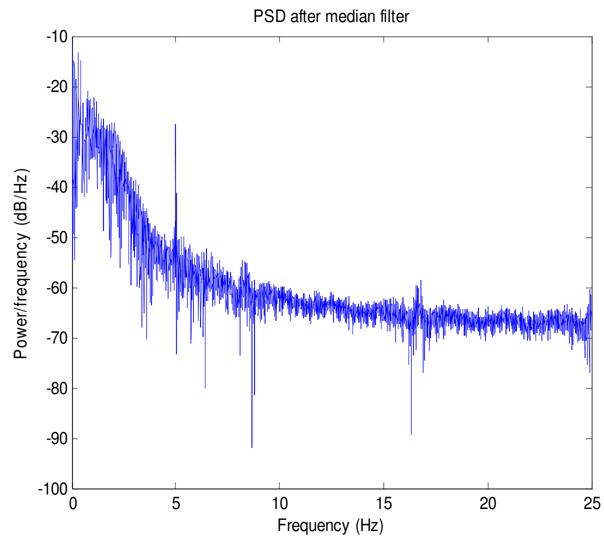

Fig.7 PSD after Median filter

For simulation purpose a simple original signal is generated in MATLAB. White noise is added to this signal. For experiment comparison between EMD, adaptive and median filter is considered. SNR of the added noise is changed and computation is carried out for these filters. The following results are obtained which will suggest that EMD is suitable for removal of low noise as well as high noise present in the signal.

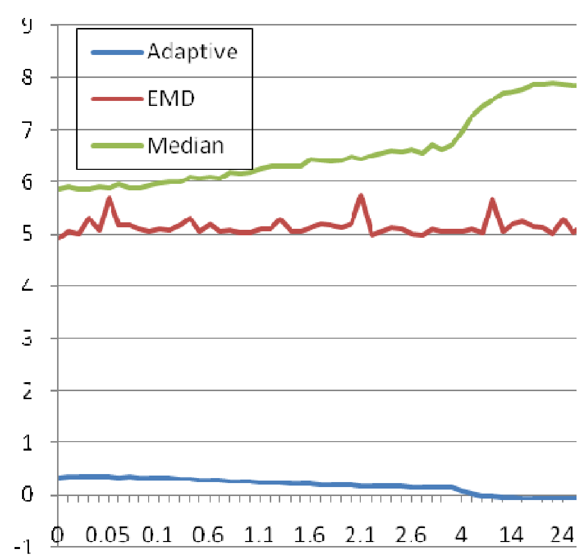

Fig. 8 Comparison of SNRs

The above chart shows the variation in SNR of filters. EMD filter shows approximately constant SNR for different levels of noise present in the signal. Median filter gives increasing SNR with increasing SNR of the original noisy signal. This is because of the decrease in the amplitude of the output of the median filter.

CONCLUSION

For higher noise available in the signal EMD provides approximately constant SNR which is lower than the SNR of Median filter. Baseline drift is completely removed in EMD filter approach without changing the clinical information whereas in Median filter approach baseline drift is not completely removed and the amplitude of the original signal gets reduced after filtration. So EMD approach is useful for removal of baseline wander. For higher frequencies time taken for EMD filtration is somewhat greater because of iterations of IMFs (sifting process).

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