Noise reduction of ECG signals using Empirical Mode Decomposition

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Abstract**—** ECG is an important monitoring measurement of heart activity. Analysis of ECG thus becomes more important in medical terms. Analysis of ECG signals becomes very difficult when noise gets embedded with the signal during monitoring. In this paper noise reduction techniques based on Empirical Mode Decomposition (EMD) for better analysis of ECG signal is proposed. This method is fully data driven approach. It is a powerful algorithm that decomposes noisy signal in oscillatory components called Intrinsic Mode Function (IMF) by a process called shifting. In this paper two different methods of EMD is done and compared among them for better SNR and RSME. Along with this wavelet technique is also done for comparison of signal parameters. This method is evaluated on ECG signals available in MIT_BIH Arrhythmia database.

Keywords— ECG, noise reduction, EMD, MIT_BIH database, wavelet Denoising.

I. INTRODUCTION

ECG is a vital sign monitoring measurement of heart activity. During ECG measurement, there may be various noises such as baselines wander, and power-line interferences, which get along with the ECG information. Therefore, ECG noise reduction is an important issue and it has been widely studied for many years.

Traditional noise reduction method is based on standard filter processing, either by low-pass filter or high pass filter. High frequency noise are removed by low pass filter, while low-frequency vibration, such as baseline wander and are removed by high pass filter. Many signal processing methods are applied on ECG noise reduction, such as wavelet, adaptive filter, and independent component analysis, still an interesting and attractive approach to investigate the ECG filtering characteristics based on EMD.

In EMD, ECG filtering is based on partial reconstruction of intrinsic mode function (IMF). IMF is an intermediate product of empirical mode decomposition (EMD), a preprocessing algorithm of Hilbert–Huang transforms (HHTs). HHT was introduced by Huang, which is a general signal analysis technique and has been widely used in many fields in recent years. There are two steps involved in HHT.

The first step involves the EMD to extract IMF. The second step is the Hilbert transform of the decomposed IMF to obtain time-frequency distribution. EMD is based on the iterative computation of maximum extreme and minimum extreme function. The residual signal, called IMF, is extracted after EMD.

II. EMD ALGORITHM

The EMD involves the decomposition of a given signal x(t) into a series of IMFs, through the *sifting* process. The decomposition is based on the local time scale of the signal and yields adaptive basis functions. The EMD can be seen as a type wavelet decomposition whose sub bands are built up as needed to separate the different components of x(t) . Each IMF replaces then the detail signals of at a certain scale or frequency band. The EMD picks out the highest Frequency oscillation that remains in x(t). There are two requirements for IMF

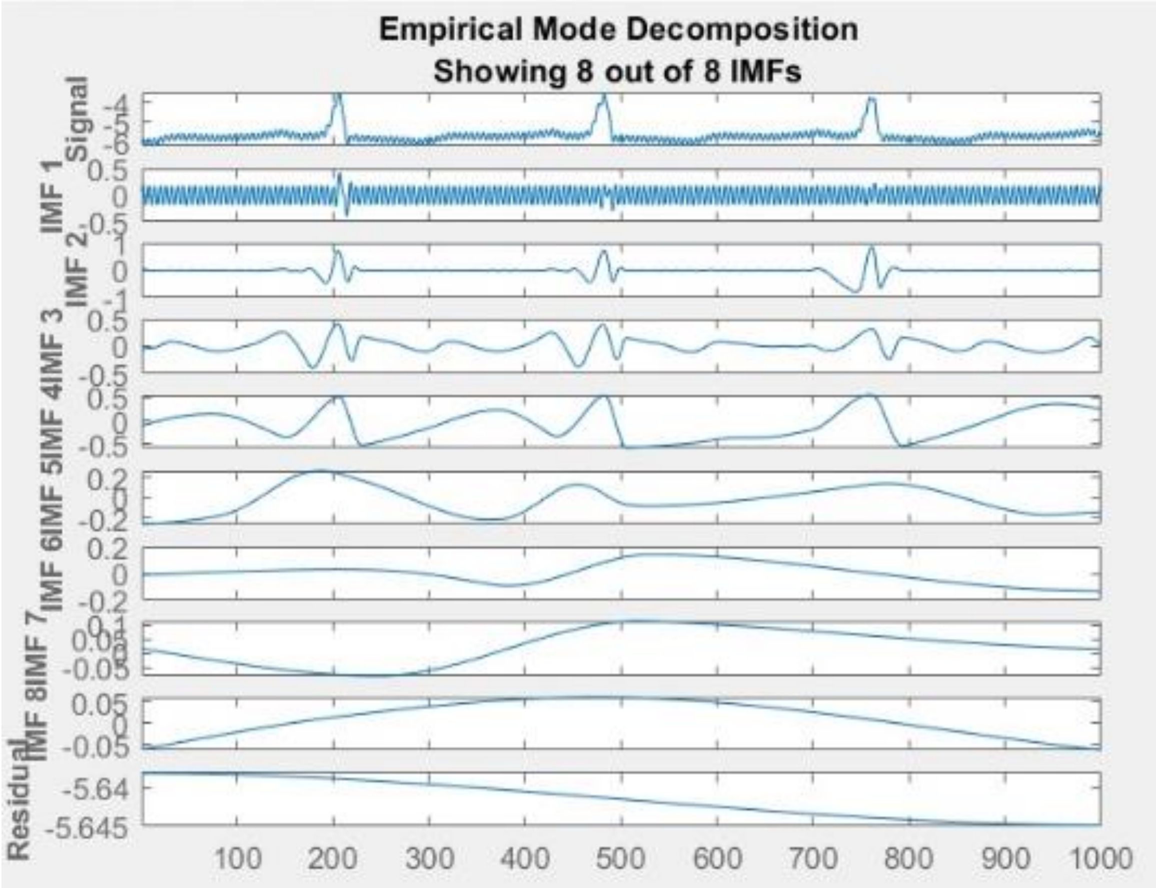

Figure 1. IMF components of PLI noise added MIT-BIH/223 ECG signal

1. The number of extrema and the number of zero crossings are either equal or differ at most by one.
2. At any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero.

Thus, locally, each IMF contains lower frequency oscillations than the one just extracted before. The EMD does not use any pre-determined filter or wavelet function and it is fully data driven method. To be successfully decomposed in IMFs, must has at least two extrema, one minimum and one maximum.

The algorithm for performing sifting on a given signal x(t) is as follows

(i) Identify all the maximas and minimas of x(t).

(ii) Interpolate between minima, ending up with a signal xmin(t) and similarly between maximas to give xmax(t)

(iii) Calculate the average between those two envelopes:

xavg(t) = (xmax(t) + xmin(t))=2 (1)

(iv) Extract the detail: d1(t) = x(t) - xavg(t). d1(t) is given as input to the next iteration of sifting.

After the process of IMF generation, noisy IMF is identified and filtered using filtering techniques. Then the signal is reconstructed for obtaining de-noised ECG signal.

III. METHODS PROPOSED

For all the methods proposed and done in MATLAB input ECG signal taken is ECG signal 223 from MIT-BIH database. Along with this signal PLI noise of 60 Hz is added for the de-noising process.

Method 1. EMD – Removal of 1st IMF

EMD decomposes this noisy ECG into eight IMF components and a residue. The lower-order IMF components correspond to high-frequency components of the ECG and the higher-order IMF components correspond to low-frequency components of the ECG. Simply excluding the identified noisy IMFs in the reconstruction stage corrupts the valuable ECG information. The noisy IMF components which are identified in the PLI noise detection stage are removed from the noisy signal

Method 2. EMD Spectral Flatness

a noisy signal is decomposed using EMD, the noise components are mainly present in the initial IMFs. In this work, Spectral Flatness (SF) measure is used to determine whether a particular IMF is dominated by noise or not. The proposed noise removal method using EMD is illustrated in Fig. 2

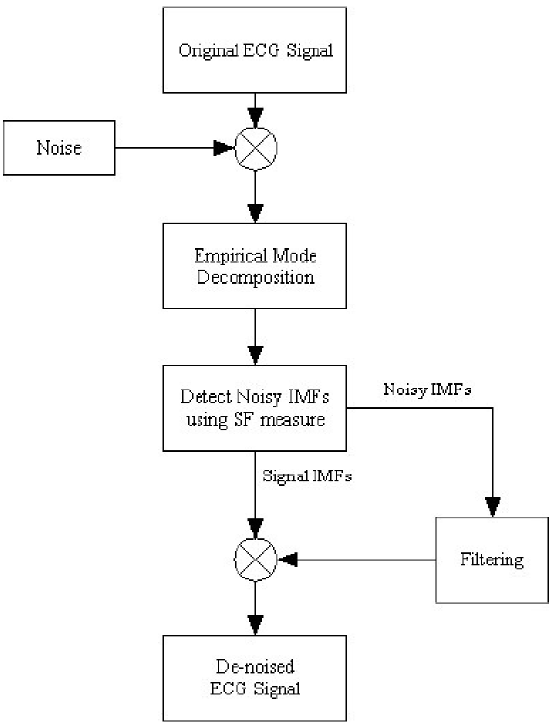

Figure 2. EMD – SP Block diagram

The number of noisy IMFs, n, is obtained by comparing the Spectral Flatness (SF) of each IMF to a threshold T. The Spectral flatness is calculated as the ratio of geometric mean of the power spectrum to its arithmetic mean . It is given

$$\text{Spectral Flatness} = \frac{\sqrt[L]{\prod_{n=0}^{L-1} H(n)}}{\frac{\sum_{n=0}^{L-1} H(n)}{L}}$$

The first n IMFs whose Spectral Flatness is above thethreshold T are considered as noisy IMFs. This method is explained in Fig. 3. The threshold value of spectral flatness, T, is taken as 0.001 based on assumptions.

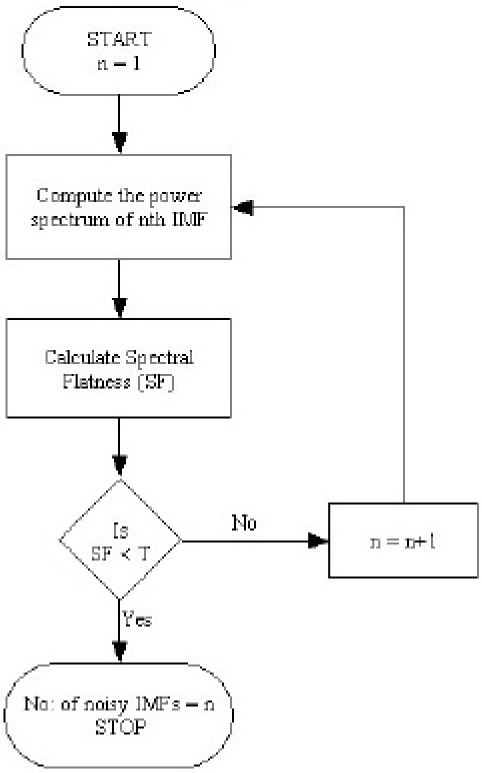

Figure 3. SP – noisy IMF detection

Since significant part of the high frequency content of ECG is in the range of 40-60 Hz [11] the 1st IMF is filtered using a band pass butterworth filter of order 10 with pass band of 40-60 Hz. The remaining noisy IMFs are filtered using low pass butterworth filter of order 10 with cut off frequency of 60 Hz to extract the significant signal components. The ECG signal is reconstructed by adding the filtered IMFs and the remaining signal IMFs.

Method 3. Wavelet technique

This method is used just for comparison purpose along with EMD process. Thus MATLAB in built function is used for de-noising ECG signal.

IV. RESULTS AND COMPARISON

The performance of the methods is evaluated based on the Signal to Noise Ratio (SNR) and Root Mean Square Error (RMSE) The SNR can be represented as the following

$$SNR = \frac{\sum_{t=0}^{L-1} x(t)^2}{\sum_{t=0}^{L-1} n(t)^2}$$

where x(t) is the signal and n(t) is the noise.

RMSE is used to evaluate the quality of the information which is preserved in the denoised ECG signal. RMSE is defined as follows:

$$RMSE = \sqrt{\frac{\sum_{t=0}^{L-1} (x(t) - \hat{x}(t))^2}{L}}$$

where the numerator part is the square error, ^x(t) is the reconstructed ECG signal and L is the length of the signal.

Following are de-noised ECG from different methods proposed;

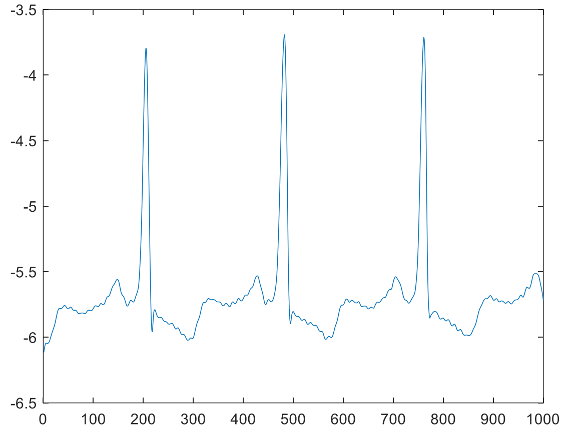

Figure 4. EMD De-noised ECG

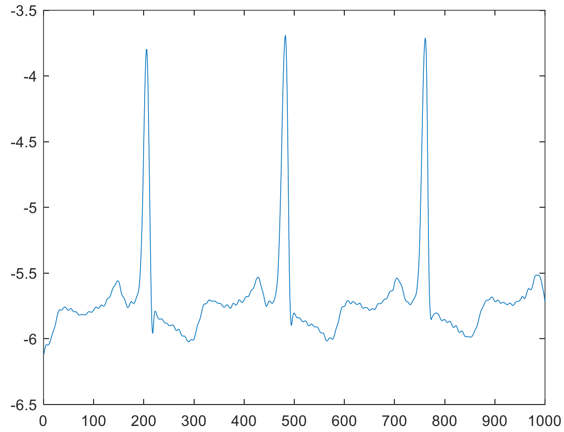

Figure 5. EMD – SP De-noised ECG

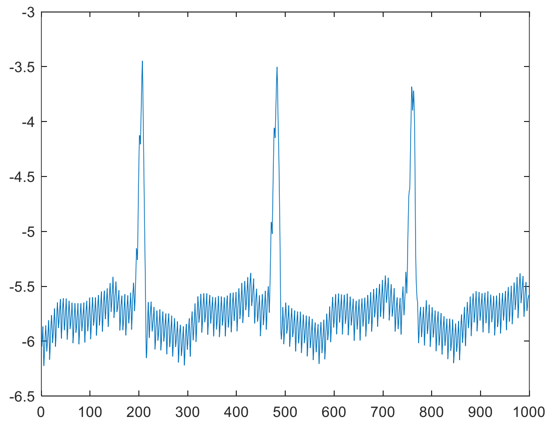

Figure 6. Wavelet techinque De-noised ECG

Now comparing the SNR and RMSE value for different methods proposed,

	EMD	EMD-SP	WAVELET

SNR	5.59	5.24	3.97
RMSE	0.023	0.044	0.11

For better performance of the method it should have better SNR performance and lower RMSE. Thus for the results obtained it is very clear that EMD process is far better than the wavelet technique. Among the EMD and EMD-SP, EMD is better when compared to RMSE value as their SNR are almost equal.

V. CONCLUSION

This filtering method, based on the EMD method, is simple and fully data-driven. The method does not use any pre- or post processing and does not require and does not require any user parameters setting. The proposed algorithm is tested with simulated ECG signals generated by MATLAB function and also validated with the real ECG signals which are available in the MIT-BIH database. The proposed algorithm improves the performance of PLI noise removal using automatic simple PLI noise detection method. Automatic detection of noisy IMFs is done using spectral flatness measure. The noisy IMFs are filtered and then added with signal IMFs to obtain the de-noised ECG signal.

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VI. REFERANCE

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