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Performance Comparison of PF, WT and EMD Algorithms in De-noising of ECG Signal

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Abstract: Different techniques for de-noising of ECG signal are prevalent in recent literatures. The aim of this paper is to compare performance among the Particle Filter (PF), wavelet transforms (WT) and Empirical Mode Decomposition (EMD) methods in context of de-noising of an electrocardiogram (ECG) signal. The performance of a several technique was investigated in cancellation of noise from ECG signal in terms of SNR and RMSE The analysis of the paper provides us the way of selection of the best de-noising technique of ECG signal based on the numerical value.

Keywords: Statistical parameters, Particle filter, Empirical Mode Decomposition, Wavelet transform, ECG De-noising.

I. INTRODUCTION

ElectroCardioGram (ECG) is the record of the electrical potentials produced by the heart during contraction and expansion. It is very essential tool used by medical practioners especially cardiologists to inspect the cardiac malfunctioning or pathological condition of the heart [1].The Electrocardiogram signal usually is in the range of 2 mV having the bandwidth of 0.1Hz to 120 Hz. In normal conditions, Electrocardiogram waveform is having a very expected duration, amplitude and direction. So that it can be easily recognized, assessed, identified and interpreted for a usual or unusual functioning of the heart. The Electrocardiogram signal and heart rate reveals the cardiac fitness of human heart. Any change in heart rate or variation in the morphological form of Electrocardiogram signal is a sign of cardiac arrhythmia. It is noticed and analyzed by investigation of the recorded electrocardiogram waveform. The amplitude and duration of the P-Q-R-S-T-U wave more specifically QRS complex contains the first hand information of the heart disease.

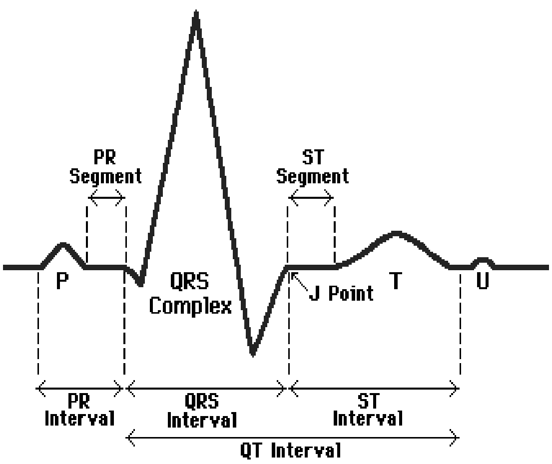

FIG.1 TYPICAL ECG WAVEFORM [2]

The Electrocardiogram signal is a graphical demonstration of the Electro-Mechanical action of the heart pumping that recorded within specific period of time. FIG 1 shows an example of electrocardiogram waveform which consists of a P, QRS, T and small U wave is noticeable in certain cases. In the regular heartbeat, the key parameters are examined which comprise the duration, shape, R-R interval and QRS complex wave of electrocardiogram signal as whole. The fluctuation in these parameters leads to illness of the heart.

ECG signal is contaminated with various artifacts during acquisition for example Power-Line Interference (PLI), Patient–electrode motion artifacts, Electrode-pop or contact noise, and Baseline Wandering and ElectroMyoGraphic (EMG) noise. Analysis of ECG signals becomes difficult to inspect the cardiac activity in the presence of such unwanted signals. So, de-noising of ECG signal is extremely important to prevent misinterpretation of patient's cardiac activity.

The paper is organized as follows. In Section II gives theoretical analysis of de-noising techniques on particle filter, wavelet transform and EMD. In Section III provides the results making a comparison of three different techniques for de-noising of ECG signal. In Section IV Finally the conclusion is drawn in this section.

II THEORETICAL BACKGROUND

A brief description of various techniques such as EMD, Wavelet transform and Particle Filter used for de-noising of ECG signal in this section.

Hilbert-Huang Transform (HHT) was presented by Huang et.al [3], is the combination of Hilbert Transform and EMD. It is very much appropriate for non-stationary and nonlinear signal processing. This transform presents two phases for signal processing. First, Original dataset is converted into an 'n' (number of) Intrinsic Mode Functions (IMFs) through EMD method and then these IMFs components are passed through Hilbert Transform.

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2.1 EMD [4]

Empirical Mode Decomposition (EMD) was presented by Huang et.al [4], decays a signal *y(n)* into sequence of 'n' number of sub-components known as Intrinsic Mode Functions (IMFs).Intrinsic Mode Functions represent oscillatory nature of signal. It is obtained by a organized process known as **sifting**. EMD is fastest decomposition.

CONDITIONS FOR IMF

(1) Number of zero crossings and extremes must fluctuate (differ) at most by 1.
(2) The average of the greater and lower envelopes respectively should be zero.

IMFs of a signal are obtained by an iterative process known as **Sifting Step.**
The sifting Algorithm has the following steps:-

- Detect all the highest and lowest of y*(n)*.
- Insert between maxima to get y_{max}(n) and insert between minima to get y_{min}(n).
- Calculate average between envelopes

y_{avg}(n) = (y_{min}(n)+ y_{max}(n))/2

- Extract details

d_1(n) = y(n) - y_{avg}(n)

d_1(n) is assumed as input to the coming repetitions of sifting.

- The *r_1(n)* is assumed as input to coming repetitions and repetitions are stopped when *r(n)* becomes a monotonic function. This is ensured by limiting Standard Derivation (SD) between k^{th} and $(k-1)^{th}$ iterations.

$$SD = \sum_{n=0}^{L-1} [(d_{k-1}(n) - d_k(n)]^2 \div d^2{}_{k-1}(n)$$

Typical value of SD: 0.2-0.3Sifting.

- If 'N' round of sifting procedure is done on the given signal *y(n)*,then it is decomposed into a sequences of 'n' number of IMFs.

Signal can be reconstructed as:

$$y(n) = \sum_{k=1}^{N} [(h_k(n) - r_N(n)]$$

Where h $_k$(n) are IMFs and r_N(n) is the residue after 'N' sifting repetitions.

DRAWBACKS OF EMD

The major shortcoming of EMD is the mode mixing consequence. End effect and unstable are also a problem with EMD. Mode-mixing indicates that oscillations of different time scales co-exist in a given IMF or oscillations with the similar time scale have been allocated to different IMFs.

2.2 WAVELET TRANSFORM

Wavelet transform is a multi-resolution study as developed by Mallat [5].The wavelet transform evaluates signals in both time and frequency domains unlike Fourier Transform. It is widely used for the non-stationary signals. The wavelet transform was developed to overcome the limitations of STFT. The Wavelet Transform can be classified into continuous and discrete.

Continuous wavelet transforms (CWT)
The Continuous wavelet transform represents a signal as a function of time and scale. The CWT is obtained by changing the scale of the analysis window, shifting the window in time, multiplying the signal and integrating the result over all time [6]
The CWT [6] of a f (t) is given by

$$f(t) = \frac{1}{C} \int_{a=-\infty}^{\infty} \int_{b=-\infty}^{\infty} \frac{1}{a^2} W(a,b) \psi_{a,b}(t)\, da\, db$$

$$W(a,b) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{|a|}} \psi^* \left(\frac{t-b}{a} \right) dt$$

Where a is the scaling parameter and b is shifting parameter. Both a and b are real in nature. The scale parameter 'a' gives the frequency information whereas translation parameter 'b' gives the time information.
The Inverse CWT is given by

where

$$C = \int_{-\infty}^{\infty} \frac{|\psi(\omega)|^2}{|\omega|} d\omega$$

Discrete wavelet transforms (DWT)

The discrete WT is obtained by filtering the signal through a series of digital filters at different scales. The DWT of a signal is calculated by passing it through a series of filters. First the samples are passed through a low-pass filter with impulse response which gives the convolution of two signals [6].

2.3 PARTICLE FILTER [7]

PF is a Bayes estimation algorithm based on Monte Carlo method. It performs the posterior probability density

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function via a number of weighted particles and eliminates particles that have small weights and concentrates on particles with large weights using resample. A common problem with the SIS particle filter is the degeneracy phenomenon, where after a few iterations; all but one particle will have negligible weight.

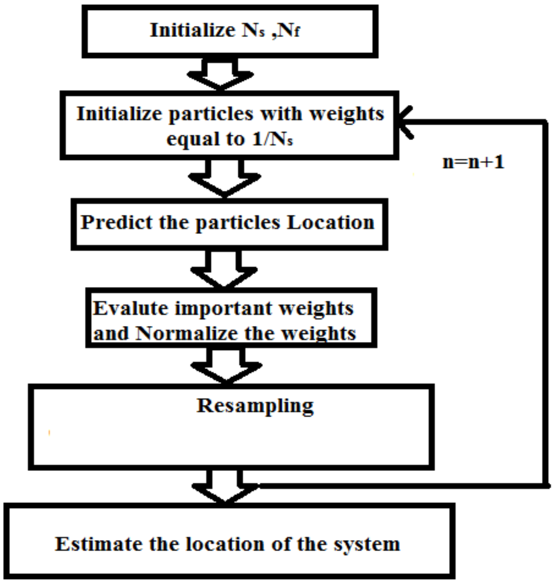

FIG 2.BLOCK DIAGRAM OF THE PF METHOD

When using a particle filter, one can often expect and frequently achieve an improvement in performance by using far more particles or alternatively by employing regularization or using an auxiliary particle filter. The appropriate trade-off between the number of particles and the computational expense is very necessary for each particle. It provides the best qualitative performance with affordable computational effort.

III. RESEARCH PAPERS' REVIEW

There are numerous methods de-noising of ECG signal in the medical research. An extensive literature review carried out of ECG de-noising using different method and techniques has been discussed briefly in this section.Table 1 summarises the works of de-noising of ECG techniques. Different authors have tried different methods to de-noising of ECG signal like wavelet transforms, Adaptive filter, S-transform approaches and so on. The review includes applicability of such methods to de-noising of ECG signal, their advantages and limitations and the scope of any future work, if possible, in this methods.are also summarised in the table.

Paper and methods	**Pros and Cons**	**Improvements Proposed/ Possible**
1.ECG de-noising based on hybrid technique [1] **Methods** 1. Empirical Mode Decomposition 2. Wavelet thresholding	1. The proposed method removes both power line noise and base line wander noise. 2.EMD has good ability to decompose the signal. 3.Wavelet thresholding is good in removing the noise from decomposed signal	Some other combination of hybrid techniques can be implemented. Also VLSI implementation of hybrid techniques has a great scope in future.
2. De-noising of ECG signals using Empirical Mode Decomposition based technique [4] **Methods** 1. Empirical Mode Decomposition 2. Butterworth filter.	1. In the proposed approach, automatic detection of noisy IMFs is done using spectral flatness measure. 2. It shows better SNR performance and lower RMSE compared to Wavelet Transform based technique.	Mode mixing consequence can be improved in future.
3. Genetic Particle Filtering for De-noising of ECG Corrupted by Muscle Artifacts[8] **Methods** 1.Genetic Particle filter	1.The proposed method is used to mitigate the sample degeneracy of PF.	Modification of the GAPF algorithm is under investigation to tackle the adaptive parameters adjustment.

4. A novel ECG signal de-noising method based on Hilbert-Huang Transform [3] **Methods** 1.Hilbert-Huang Transform	1.The proposed method is used for nonlinear and non-stationary signal processing.	There are several future directions of research. HHT method in ECG Signal processing has broad application prospects in future.
5. ECG Signal De-noising Based on Morphological Filtering[9] **Methods** 1. Morphological filtering techniques.	1. Morphological filtering approach is simple, fast and real-time in processing.	Combination of morphological filters and adaptive filters are used for most appropriate structuring element in future.
6. Nonlocal Means De-noising of ECG Signals [10] **Methods** 1. Non-local means method.	1. NLM-based de-noising scheme provides improved signal-to-noise ratio than wavelet based method.	NLM de-noising should be applicable to a wider range of biomedical signals such as EMG or evoked potentials in future.
7. Application of S-Transform for Removing Baseline Drift from ECG[11]	1.The advantage of S-transform based method is due to its inherent properties for which it directly conveys the time-frequency	Also VLSI implementation of hybrid Techniques with S -. transform have

Methods S-Transform	information of a signal while the later does not.	a great scope in future
8. Parabolic Filter For removal of power-line interference in ECG Signal Using periodogram estimation technique [12] **Methods** 1. Parabolic Filter 2.Periodogram Estimation	1. Parabolic Filter is used to eliminate the power line interference50Hz (PLI) in the electrocardiogram signal.	The proposed work may be extended for implementation in Field Programmable Gate Array (FPGA).
9. ECG Signal De-noising Based on Empirical Mode Decomposition and Moving Average Filter. [13] **Methods** 1. Empirical Mode Decomposition 2. Moving Average Filter.	1. The enhancement to the existing EMD based approach with an additional work including moving average filtering to improve the QRS quality.	The combination of the modified EMD approach and smoothing makes the algorithm very much realistic and applicable and can be applied in long term examination of the ECG signal in practical stress test as well as in Holter monitoring that may get affected by the prominent noises.
10. A complete ensemble empirical mode decomposition	1. It delivered better spectral separation of the modes.	In future works statistical studies will be carried out in order to determine

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with adaptive noise [14] **Methods** Complete ensemble empirical mode decomposition	2. It also provides a lesser computational cost. 3. It solves EMD mode mixing problem.	the proper ensemble size and the amplitude of the added noise.
11. Wavelet Based Motion Artifact Removal for ECG Signals [15] **Methods** Wavelet with high-pass/low-pass filtering	Wavelets have the capability to reduce the effects of motion artifact noise.	The proposed method is used to de-noise both the low frequency and high Frequency noise leaving behind the important information of the original signal .It has been improved in future.
12. A Survey on ECG Signal De-noising Techniques [16] **Methods** 1.Wavelet Transform 2.Fuzzy Logic 3.FIR filter 4.Empirical mode Decomposition	1.Equi-ripple notch filter is the best choice to remove power line interference. 2. Empirical mode Decomposition is used to remove baseline wander.	Some methods are focussed to remove power line interference while others are aimed at removing baseline wander and other types of noise. Every method has some disadvantages associated with it. Future research should aim at removing all types of noises from ECG signal using a single hybrid approach

Table 1: Methods, Pros, Cons and Improvements

IV PERFORMANCE EVALUTION MEASURES

The performance of PF, WT and EMD Algorithms in De-noising of ECG Signal is estimated based on the SNR and RMSE.SNR and RMSE stands for Signal to Noise Ratio and Root Mean square Error respectively. These parameters are used to compare a various existing method.

TABLE5.1: COMPARISON OF SNR VALUES FOR DIFFERENT DATABASE OF EXISTING METHODS

Database	Wavelet Based Techniques (SNR in dB)	EMD Based Techniques (SNR in dB)	Particle Filter Method (SNR in dB)
Database1	10.9142	12.9997	14.0853
Database2	11.1984	13.8093	15.2512
Database3	10.1845	13.8138	15.9588
Database4	10.4252	14.0839	16.0254
Database5	11.9732	14.3374	14.8569
Average	**10.9391**	**13.8088**	**15.2355**

TABLE5.2: COMPARISON OF RMSE VALUES FOR DIFFERENT DATABASE OF EXISTING METHODS

Database	Wavelet Based Techniques (RMSE in dB)	EMD Based Techniques (RMSE in dB)	Particle Filter Method (RMSE in dB)
Database1	0.299	0.224	0.198
Database2	0.271	0.215	0.179
Database3	0.310	0.212	0.162
Database4	0.302	0.199	0.152
Database5	0.255	0.191	0.187
Average	**0.287**	**0.208**	**0.175**

From the both tables 1 & 2, it is evident that the performance of the PF algorithm is better than the existing algorithms with different types of artifacts. The SNR results of the PF algorithm show better results and lower Root Mean square Error (RMSE) compared to EMD and Wavelet method.

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V. CONCLUSION

Many investigator were introduced the various approaches for de-noising of ECG signal. This paper makes a comparison between EMD, Wavelet and particle algorithms. This paper includes applicability of such methods to ECG de-noising, their advantages and limitation. The comparative analysis methods presented reveal that the Particle filtering is more efficient than the Wavelet and EMD de-noising method, in terms of the signal-to-noise ratio (SNR) and Root mean square error (RMSE) improvement for corrupted ECG signals. The analysis of the paper provides us the way of selection of the best de-noising technique of ECG signal based on the numerical value and theoretical concept.

VI. COMMENTS FOR FURTHER RESEARCH

There is a future work of this paper to make the same comparison on to other bio-medical signal such as ElectroMyoGraphs (EMG) and ElectroEncephaloGraphs (EEG).These are the signals that records the activities of body muscles and brain respectively. The work of comparison can also be extended to other filter like Kalman Filter, EEMD and Genetic Particle filter.

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