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An Article on ECG Signal Denoising Techniques

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***Abstract*— The presence of noise in an ECG trace complicates the identification analysis. Due to noise the quality of ECG signal is degrades. So the removal of noise is elaborated due to time varying nature of ECG signal. The ECG is widely used for diagnosis and analysis of heart diseases, so a good quality of ECG signal is required. In this article various types of noises corrupting ECG signal and various techniques based on Wavelet Transform, Fuzzy logic , FIR filtering , Empirical Mode Decomposition used in denoising the signal efficiently are presented in this paper. The results are comparing the performances of different denoising techniques based on related parameters are inserted.**

Index Terms— Denoising, ECG, Empirical Mode Decomposition, Fuzzy logic, Wavelet Transform.

I.INTRODUCTION

The electrocardiogram (ECG) is the recording of the electrical activity of heart which is extensively used for the diagnosis of heart diseases. ECG is a weak non-stationary signal which is interfered by various noises e.g. power line interference, baseline drift, electrode contact noise, EMG interference. ECG signal denoising is the process to separate the valid signal component from undesired signals to obtain noise free ECG that facilitates easy and accurate diagnosis. A denoising approach should detect the different noises in the data and filter the data while ensuring the obtained results not influenced by undetected artifacts.

Some of the approaches used for de-noising the ECG signal are adaptive filtering, FIR filtering, Fuzzy logic, Empirical Mode Decomposition and Wavelet transform. Adaptive filtering is the most widely used technique for de- noising. Wavelet transform is the recent approach with different types of thresholding techniques.

The rest of the paper is arranged as follows. The noises which contaminate the ECG signal are presented in section II, in section III various methods of ECG de-noising techniques are presented, in section IV the Future Scope and finally we conclude in section V.

II. NOISES IN ECG

The various types of noise which contaminate ECG signals are Power line interference, Electrode contact noise, Motion artifacts, Muscle contraction, Base line wander, Instrumentation noise generated by electronic devices and Electrosurgical noise[1].

Power line interference: Power line interference consists of 60/50 Hz pickup and harmonics and the amplitude is 50% of peak-to-peak ECG amplitude. Some of the common causes of the 50 Hz interferences are [14]:

- stray effect of the alternating current fields due to loops in the cables
- improper grounding of ECG machine or the patient
- disconnected electrode
- Electromagnetic interference from the power lines
- Electrical equipments such as air conditioner, elevators and X-ray units draw heavy power line current, which induce 50 Hz signals in the input circuits of the ECG machine.

Electrode contact noise: The connection between patient and measuring system is interrupted for a short duration due to improper contact of the electrodes which creates electrode contact noise which is of duration 1 sec and amplitude of which is maximum recorded output of ECG signal with frequency of 60Hz [13].

Motion artifact: Transient base line changes caused by changes in the electrode-skin impedance with electrode motion due to movement of the patient while the ECG is being recorded. [12]. Duration of this noise is 100-500ms with amplitude of 500% peak to peak ECG amplitude[13].

Muscle contractions: Also called as EMG (electromyography) noise which is induced by the patient's movement and is responsible for artifactual milli-volt level potentials to be generated [12]. The standard deviation of this kind of noise is 10% of peak to peak ECG amplitude with duration of 50ms and the frequency content being dc to10 KHz[13].

Baseline Wander: Caused by respiration or patient movement which creates problems in the detection of peaks. Due to wander T peak would be higher than R peak which might be detected as R peak instead.

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Amplitude variation is 15% of peak to peak ECG amplitude[13] .

III. DENOISINGTECHNIQUES

Ying -Wen Bai et. al. in [1] made a comparative study of general notch filter , comb notch filter and equiripple notch filter .The performance is measured with respect to mean square error. It is observed that the equiripple notch filter retains the detail of practical signal effectively at the expense of higher filter order while the comb and general notch filters weaken the features of the ECG signal.

Mashud Khan et. al. in [2] proposed Signal-Noise residue algorithm based on Wavelet theory for ECG signal denoising. The algorithm assumes that a raw ECG signal is linear combination of noise and ECG signal. The symmlet 8 mother wavelet with highest number of vanishing movements and multiscale decomposition of the signal enables accurate estimation of noise and hence it becomes easier to remove the noise with minimal computation.

L Chmelka et. al. in [3] used wavelet based wiener filter to suppress EMG noise from ECG signal. The filtering is based on modification of the coefficients of wavelet transform depending on estimated noise level. For pilot estimation wavelet filtering with hybrid thresholding is used. The results obtained are good for filter banks with short impulse response while worst for filter banks with long impulse response.

Seema rani et. al. in [4] made a comparative study of use of FIR and IIR filters in removing baseline noises present in ECG signal. Spectral density and average power of signal are the two evaluation parameters considered to check the suppression of baseline noises. According to the obtained implementation results, though FIR and IIR filters both have removed the baseline noises due to large order of FIR filter there is a phase delay in FIR filtered waveforms. The computational complexity, memory requirement and power dissipation of IIR filter is less than FIR filters which makes IIR filters the better choice for removal of baseline noises. Table I compares the complexity of FIR and IIR filters [4].

Table I: Comparison of complexity FIR and IIR filters

Filter Type	Min. Order used	No. of Adders	No. of Multipliers	No. of delays
FIR	320	320	321	320
IIR	2	4	4	2

Bingo W. et. al. in [5] formulated some fuzzy rules to integrate different multiwavelets , pre and post filters together to denoise ECG signal. As different multiwavelets ,pre and post filters have different impulse responses and frequency responses , fuzzy rules are used to select and employ the best suitable multiwavelets ,pre and post filters at different noise levels. Though the denoising performance is improved ,choosing a membership function is difficult which seems to be the drawback.

Mahesh Chavan et. al. in [6] designed and implemented digital FIR Equiripple notch filter to remove power line interference from ECG signal. The filter reduces powerline interference successfully however higher order filter is required. This increases the computational complexity and it is difficult to realize the higher order filter. It also increases the delay in response. As compared with the window method, reduction in signal power is more in the Equiripple method. In the window method the number of elements required are less while in Equiripple method more computational elements are required therefore computational time is the major limiting parameter of the Equiripple type digital filter implemented on the noisy ECG signal. The effect of variation in the line frequency is not considered. Table II shows the comparison of different FIR structures for Power Line Interference(PLI) reduction [6].

Table II : Comparison of different FIR structures for PLI Reduction

Filter Design method	Multipliers	Adders	Delays	Power at50 Hz before	Power at50 Hz after
Minimax	1149	2296	2296	-	-
Multiplier free RSS filter	0	37	2248	10	-40
Rectangular window	100	101	101	-27.18	-29.58
Hanning window	100	101	101	-27.18	-28.77
Hamming window	100	101	101	-27.18	-29.18
Kaiser window	100	101	101	-27.18	-29.59
Equi-ripple method	580	579	579	-26.29	-35.75
L.S.Method	101	1010	100	-36.00	-42.00

Manuel B. V. et. al. in [7] proposed a method based on Empirical Mode Decomposition to remove high frequency noise and baseline wander. The signal is decomposed into a sum of intrinsic mode functions which represent simple oscillatory mode .The noise components lie in the first several Intrinsic Mode Functions(IMF). Different IMFs are chosen and processed to successfully achieve the denoising and baseline wander removal. By partial signal reconstruction high frequency denoising is carried out. The method is suitable for real noise cases too.

K.D. Chinchkhede et. al. in [8] have investigated the improvement of raw and noisy ECG signals by various window based FIR filters. The Power Spectral Density and spectrogram analysis was carried out to study the effect of noise on ECG. In order to measure the performance of de- noising, SNR of processed ECG is calculated and correlation coefficient was determined to find the degree of mismatch between raw ECG and filtered noisy ECG. The designed FIR filter with Kaiser window works excellent as compared to the Gaussian, Blackman and Blackman-Harris filter in removing baseline wandering and power line interference under different noisy conditions.

Md. Ashfanoor Kabir et. al. in [9] proposed a windowing method in the Empirical Mode Decomposition domain. Unlike the conventional approaches which completely discard the initial intrinsic mode functions ,the method preserves the QRS complex information in the first three high frequency intrinsic mode functions. The intrinsic oscillatory modes are identified by their characteristic time scales in the signal and then the signal is decomposed into intrinsic mode functions. The noisy signal is enhanced in the Empirical Mode Decomposition domain and then transformed into the wavelet domain in which an adaptive thresholding scheme is applied to the wavelet coefficients to preserve the QRS information .An adaptive soft thresholding is perfomed in the Discrete Wavelet Transform domain even after reconstruction to reduce the noise that remains after the Empirical Mode Decomposition operation. Table III compares the mean Percent Root mean square Difference(PRD) of different denoising methods [9].

Table III: Comparison of the mean PRD (%) for different denoising methods at different input SNR levels

Input SNR Level	EMD soft thresholding	Wavelet soft thresholding	EMD wavelet	Proposed method
6	64.73	58.46	51.87	48.44
10	54.23	47.96	43.38	40.52
15	35.26	32.98	30.40	25.68
20	28.92	20.65	17.55	13.46

Wei Zhang et. al. in [10] proposed a sub-band adaptation filtered algorithm based on wavelet transform to extract a weak ECG signal in a strong noisy environment. It is a hybrid approach that is based on fixed sub-band decomposition and the decorrelation property of wavelet transform and property of adaptation filter. The algorithm successfully improves the extracting precision and speed and provides strong stability.

P. Mithun et. al. in [11] proposed the wavelet-based denoising technique for suppressing EMG noise and otion artifact in ECG which has advantages that this approach oes not require a reference as required in adaptive filtering techniques and also it does not require multi-channel signals as required by ICA-based techniques. Also identification of R-peaks as required in the cubic spline and EMD based techniques are not needed. The discrete Meyer wavelet is the selected wavelet basis function. Combining the features of hard and soft thresholding EMG noise was reduced while by limiting the wavelet coefficients Motion artifact was reduced.

Donghui Zhang in [15] proposed an approach for baseline wander correction and denoising that is based on discrete wavelet transform. The wavelet shrinkage method using Empirical Bayes posterior median is used to reduce the high-frequency noise for which the Symlet wavelet with order 8and decomposition level up to 6 is used.

Table IV: Comparison of Different Wavelets

Algorithm	Mean Error	Error STD
Kalman Filter	0.073	0.076
Moving Averaging	0.215	1.858
Cubic Spline	1.010	3.666

Gordan Cornelia et. al. in [16] used wavelet transform to filter and analyze noisy ECG signal. Through wavelet thresholding all relevant noise are removed of the signal. Signal was decomposed using a three level wavelet decomposition. The Daubechies db1 and db3 wavelets, the symlet sym2 and the first order coiflet coif1 wavelets were used for analysis and it was found that the best results are obtained with the db3 wavelet, and the worst ones with the sym wavelet. Table IV compares different wavelets [16].

Table V: Comparison between baseline removal techniques.

Wavelet	SNR[dB]	QRS detected	Errors [%]
Db1	10	170	0
	5	163	4
	3	150	12
DB3	10	170	0
	5	170	0
	3	166	2
Coif	10	170	0
	5	165	3
	3	157	8
Sym	10	170	0
	5	149	12
	3	143	16

MA Mneimneh et. al. in [17] proposed an adaptive Kalman filter for the real time removal of baseline wandering. The Kalman filter has the ability to simultaneously model both the ECG signal and the baseline wandering. The comparison of the proposed approach is made with moving averaging and cubic spline baseline removal techniques which shows that distortion is minimum in case of the proposed approach. Due to adaptability and convergence factor of Kalman filter the approach fails to remove baseline wander under high frequency changes. Table V shows comparison between baseline removal techniques [17].

Mohandas Choudhary et. al. in [18] made comparative study between Butterworth, Chebyshev Type-I and Chebyshev Type-II based on parameters signal to noise ratio and average power for their use in suppression of noise in ECG signal. It is concluded that Butterworth low pass filter are better.

IV. CONCLUSION

We have presented in this paper a survey on different techniques that aim at removing various types of noise corrupting ECG signal. We find that Equiripple notch filter is the best choice to remove power line interference while to remove motion artifact and EMG noise we should select discrete Meyer wavelet and apply the improved thresholding function which combines features of hard and soft thresholding . To remove baseline wander we suggest to use empirical mode decomposition based approach.

V. FUTURE SCOPE

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 which can be the combination of existing approaches

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