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ECG DENOISING TECHNIQUES: A SURVEY

[1]Shamya C, [1]Shilpa Unnikrishnan M K, [2]Smitha P B
[1]PG Scholar, [2] Assistant Professor ,Dept. of ECE, Thejus College of Engineering
Email: Shamya27@gmail.com

Abstract— This paper describes about different techniques for ECG denoising. This paper focuses on biomedical signal processing area. ECG The ECG signal is a graphical representation of electrical activity generated by rhythmic contractions of the heart. ECG signal is corrupted by presence of different noises like power line interference, channel noise, baseline wander, electromyogram (EMG) Noise, electrode contact noise, and motion artifacts that may lead to wrong interpretation in diagnosis. Efficient denoising techniques are required for the accurate diagnosis of cardiac problems.

Keywords— Electrocardiogram, Denoising, Emperical mode decomposition, Discrete wavelet transform, Adaptive filtering, Bayseian filtering, Kalman filter.

INTRODUCTION

Signal processing plays a significant role in biomedical engineering and diagnostics. For efficient diagnosis of various diseases. Signal processing has a dominant contribution in pattern analysis and feature extraction. Every year, around 25% of deaths in the world are caused by cardiac disorders like arrhythmia.

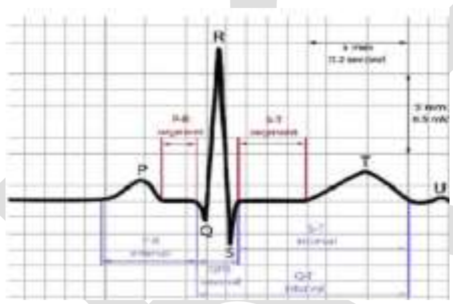

Fig 1: Normal ECG waveform [1]

The electrocardiogram is a diagnostic tool that is used to assess the electrical and muscular functions of the heart. An ECG signal represents the cardiac activity of the human heart recorded by placing electrodes on the skin and is used by the physicians for clinical diagnosis of cardiac abnormalities. The ECG signal is a representation of electrical activity generated by rhythmic contractions of the heart and it can be measured by placing electrodes on the body's surface. An electrode lead, or patch, is placed on both arm and leg and

Six leads are placed across the chest wall. The signals generated at the electrodes are recorded [1].

Fig.1 depicts a normal ECG signal. Each ECG signal of normal heart. It consists of six continuous electromagnetic peaks, ie, PQRST and U. The P wave reflects the activation of the right and left atria. The QRS complex shows depolarization of the right and left ventricles. The T wave, which is generated after QRS complex shows ventricular activation [3]. On the reading of ECG, the atrial repolarization is not recorded. The electrocardiogram can also be used to measure the rate and rhythm of the heartbeat, as well as provides the evidence of blood flow to the heart muscle. The ECG signal will be corrupted due to the presence of different types of artifacts and interferences such as Power line interference, Electrode contact noise, Muscle contraction, Base line drift, Instrumentation noise generated by electronic and mechanical devices, Electrosurgical noise.

The rest of the paper is organized as follows: Noises in ECG signal describes about the different types of noise interfering with the ECG signal. The Section ECG denoising techniques explains about different denoising techniques.

NOISES IN ECG SIGNAL

Power line interference, Electrode contact noise, Motion artifacts, Muscle contraction, Base line wander, Instrumentation noise generated by electronic devices and Electrosurgical noise [2] are the different type of noises which contaminate the ECG signal.

1.POWER LINE INTERFERENCE

Amplitude of the power line Interference is half of peak-to-peak ECG amplitude. Common causes for the 50 Hz interferences are the following

1. stray effect created due to the loops in the cables
2.improper grounding of ECG machine or disconnected electrode on the patient's body
3.Electromagnetic interference produced from the power lines
4.50 Hz signals is induced in the input circuits of the ECG machine due to the presence of electrical equipments such as air conditioner, elevators and X-ray units draw heavy power line current.

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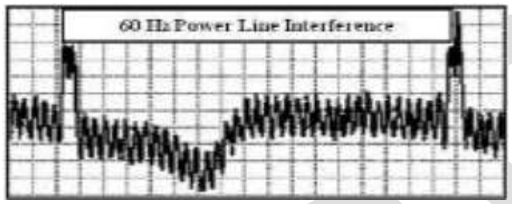

Fig 2: 60 Hz Power Line Interference

2. ELECTRODE CONTACT POTENTIAL

The improper contact of the electrodes between patient and measuring system creates electrode contact noise. It has a duration of 1 sec and amplitude of which is maximum recorded output of ECG signal with frequency of 60Hz [2].

3. MOTION ARTIFACTS

When the ECG is recorded, movement of the patient will cause changes in electrode skin impedance. Duration of this noise is 100-500ms and its amplitude is 500% peak to peak ECG amplitude [2].

4.ELECTROMYOGRAPHY NOISE

Muscle contractions also known as EMG (electromyography) noise which is produced by the patient's movement and is responsible for artefactual millivolt level potentials change in the ECG signal. The standard deviation of this type of noise is 10% of peak to peak ECG amplitude with duration of 50ms and the frequency content being dc to 10 KHz [2].

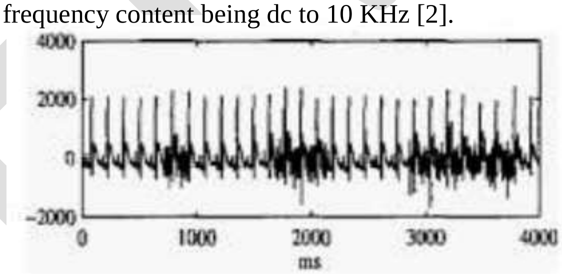

Fig 3: EMG noise in ECG signal

5.BASELINE WANDER

Baseline wander is caused by respiration or due to patient movement which may produce problems in the peak detection. Due to the presence of wander, T peak would be higher than R peak which might lead to misinterpretation of detected T peak as R peak. Amplitude variation is 15% of peak to peak ECG amplitude [2].

ECG DENOISING TECHNIQUES:

ECG signal is recorded from patient's body by placing electrodes on patient body. ECG signal when acquired from patient body is interfered by presence of different noises like power line interference, channel noise, baseline wander, electromyogram (EMG) Noise, electrode contact noise, and motion artifacts that may lead to wrong interpretation in diagnosis. Efficient denoising techniques are required for the accurate diagnosis of cardiac problems. Different ECG denoising techniques are explained below.

1.WAVALET BASED TECHNIQUE

Based on Wavelet theory for ECG signal denoising , Mashud Khan proposed Signal-Noise residue algorithm [5]. The algorithm is based on assumption that a raw ECG signal is linear combination of noise and ECG signal. Accurate estimation of noise is enabled by the use of symmlet 8 mother wavelet with highest number of vanishing movements and multiscale decomposition of the signal .This helps to remove the noise with minimal computation.

L Chmelka et. al. in [4] used a wavelet based wiener filter to suppress the EMG noise from ECG signal. The filtering is done by modifying the coefficients of wavelet transform depending on estimated noise level. For pilot estimation, hybrid thresholding based wavelet filtering is used. The results obtained shows that this filters are good for filter banks with short impulse response while worst for filter banks with long impulse response.

Wei Zhang et. al. in [9] proposed a sub-band adaptation filtered algorithm based on wavelet transform that extract a weak ECG signal in a strong noisy environment. It is a hybrid approach which uses a 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 [10] proposed a denoising technique for suppressing EMG noise and motion artifact in ECG signal based on wavelet. Advantages of this approach is that it does 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. Selected wavelet basis function is discrete Meyer wavelet. 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 [11] proposed an approach based on discrete wavelet transform for baseline wander correction and denoising. In order to reduce the high-frequency noise, wavelet shrinkage method using Empirical Bayes posterior median is used .The Symmlet wavelet with order 8and decomposition level up to 6 is used as the mother wavelet.

Gordan Cornelia et. al. in [12] used wavelet transform to filter and analyze noisy ECG signal. All relevant noise are removed by using wavelet thresholding. A three level wavelet decomposition was used to decompose the signal. The Daubechies db1 and db3 wavelets, the symlet sym2 and the first order coiflet coif-1 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.

Omid Sayadi proposed an bionic wavelet transform (BWT) [15] for ECG denoising. The most distinguishing characteristics of BWT is that its resolution in the time–frequency domain can be adaptively adjusted not only by the signal frequency but also by the signal instantaneous amplitude and its first-order differential [15]. In denoising first the BWT is optimized and then the BWT coefficients are calculated after that hard thresholding and soft thresholding is done. This algorithm has many advantages like the signal denoised by BWT is a smoothed version, Single artifacts do no longer exist, Interference removal is achieved by properly adjusting the center frequency of mother function and the number of decomposition levels [16], For higher input SNR more improvement is obtained.

2.FIR AND IIR FILTER

Seema rani et. al. in [6] made a comparative study on the use of FIR and IIR filters for removing baseline noises present in ECG signal. Two parameters considered to evaluate the suppression of baseline noises are Spectral density and average power of signal Based on the obtained implementation results, though FIR and IIR filters both have removed the baseline noises, IIR filters are efficient as there is a phase delay in FIR filtered waveforms. Produced due to large order of FIR filter Also 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.

Ying -Wen Bai et. al. in [7] 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.

Mahesh Chavan et. al. in [3] designed a digital FIR equiripple notch filter which remove power line interference from ECG signal. Eventhough higher order filter is required , this filter reduces powerline interference successfully. The higher order implementation increases the computational complexity and makes it difficult to realize the higher order filter. Also the delay in response is increased. Reduction in signal power is more in the Equiripple method when compared with the windowing technique. Window method need less number of elements while Equiripple method need more computational elements, Thus computational time is the major limiting parameter of the Equiripple type digital filter .

A technique is proposed in [7] for the improvement of raw and noisy ECG signals by using window based FIR filters. The performance of denoising is measured by calculating the SNR of the processed ECG signal and then 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.

Mohandas Choudhary et. al. in [14] 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 shows better performance when compared to other filters.

3.EMPERICAL MODE DECOMPOSITION:

Empirical Mode Decomposition is proposed in [6] method to remove high frequency noise and baseline wander. The signal is decomposed as sum of several intrinsic mode functions which represent simple oscillatory mode. The first several Intrinsic Mode Functions(IMF)contains the noise components. Inorder to achieve the denoising and baseline wander removal, different IMF are processed. partial signal reconstruction causes high frequency denoising. The method is suitable for real noise cases too.

Md. Ashfanoor Kabir et. al. in [8] proposed a new windowing method in the Empirical Mode Decomposition domain. This method preserves the QRS complex information in the first three high frequency intrinsic mode functions. Characteristic time scales in the signal. The intrinsic oscillatory modes are identified by used to identify the intrinsic oscillatory modes 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. Inorder to reduce the noise that remains after even after the Empirical Mode Decomposition, an adaptive soft thresholding is performed in the Discrete Wavelet Transform domain.

The paper proposed in [18] uses the empirical mode decomposition method Decomposition (EMD) of signal into sum of intrinsic mode functions (IMF) with a final residue is the important feature of EMD. Shifting process is used to estimate the IMFs. In this paper both FIR filter and EMD are used for removing PLI by passing the first IMF through FIR low pass filter and proposes a new technique for removing base line wander. In this technique first determine the number of IMFs that are affected by base line wander noise and then subtract those IMF and final residue from noise ECG signal. The ECG signal is taken from the MIT- BIH database. Parameter used in this paper is RMSE which is calculated for both EMD based method and filter based method and concluded that EMD based method is better and appropriate than filter based method and also have reduced computational complexity [18].

4.BAYESIAN FILTERING:

A nonlinear Bayesian filtering frame-work is proposed by Kazi M D in [16] for the filtering of single channel noisy ECG recordings. The necessary dynamic models of the ECG are based on a modified nonlinear dynamic model, previously suggested for the generation of a highly realistic synthetic ECG. An automatic parameter selection method is also used to facilitate the adaptation of the model parameters to a vast variety of ECGs. This approach is evaluated on several normal ECGs, by artificially adding white and colored Gaussian noises to visually inspected clean ECG recordings, and studying the SNR and morphology of the filter outputs. The results of the study demonstrate superior results compared with conventional ECG denoising approaches such as band-pass filtering, adaptive filtering, and wavelet denoising over a wide range of ECG SNRs. The method is also successfully evaluated on real non-stationary muscle artifact. This method may therefore serve as an effective framework for the model-based filtering of noisy ECG recordings.

5.ADAPTIVE FILTERING:

A least-mean-square algorithm based adaptive filters for removing power line interference from ECG signal is proposed in [16] combines different adaptive filter algorithms: least-mean-square (LMS), Block LMS (BLMS), delay LMS (DLMS), adjoint LMS, filtered -X (XLMS), normalized LMS (NLMS) and fast Fourier transform BLMS (FFT BLMS) for the removal of power line interference from the ECG signal. The real ECG signal and the 50Hz power line interference is generated by using MATLAB. Different performance parameters such as power, SNR, %PRD, ESD are compared. This paper concluded that LMS and NLMS are appropriate than other adaptive filters. As the SNR of LMS filter is lower than NLMS filter. Therefore performance of NLMS is better than LMS for removing 50Hz PLI [16].

The paper proposed in [17] presents the removal of power line interference from the ECG signal by comparing the performance of two adaptive filters: normalized least-mean-square (NLMS) adaptive filter and recursive-least- square adaptive filter with a traditional notch filter in both time and frequency domain. Real ECG signal is taken from the MIT-BIH database and the 50 Hz Power line interference is generated by using MATLAB. For performance measurement different parameters are used such as power spectral density (PSD), spectrogram, signal to noise ratio (SNR), percent root mean square difference (%PRD) and mean square error (MSE). comparison is made between the adaptive filters and notch filter. The high SNR, low %PRD and low MSE and better PSD of adaptive NLMS shows the effectiveness of this filter as compared to others. This paper concluded that adaptive NLMS filter performs better than adaptive RLS and notch filter for removing 50Hz noise properly.

MA Mneimneh et. al. in [13] proposed an adaptive Kalman filter for the real time removal of baseline wandering. Both the ECG signal and the baseline wandering can be removed using the Kalman filter. The comparison of the proposed approach is made with moving averaging and cubic spline baseline removal techniques which 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 5 shows comparison between baseline removal techniques [13].

CONCLUSION

This survey includes the work by different researchers on signal denoising techniques. ECG signal is corrupted by different type of noises like power line interference, channel noise, baseline wander, Electromyogram (EMG) Noise, electrode contact noise, and motion artifacts. Adaptive filtering is the best filtering technique for ECG signal with low frequency SNR. Wavelet technique can be used if signal beat to beat variation is high. EMD can be used to remove high frequency noise.

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