Asian Journal of Convergence in Technology Volume III, Issue II
ISSN No.:2350-1146, I.F-2.71

Pa **Denoising ECG Signal: A Review**

Shanti Chandra[1] Ambalika Sharma[2] , Girish Kumar Singh[3]
Dept. Electrical Engineering
Indian Institute of Technology
Roorkee
chndra.shanti@gmail.com[1], bchs38@yahoo.com[2]

***Abstract*—Heart disease is one of the major problems that needs to be addressed using the latest methods of signal processing. Different measuring parameters are used to identify heart disease. Electrocardiogram (ECG) plays an important role in diagnosis of heart disease. Practically it is not possible to acquire ECG signal without noise. For analysis and interpretation of ECG signal, it is very important to diagnose this signal. In this paper, different kinds of noise present in the ECG signal are illustrated, and several techniques for their removal are discussed.**

Index Terms— ***Artifact, baseline wander, high frequency noise.***

I. INTRODUCTION

Biomedical signal processing and analysis are one of the most challenging research areas since, last 4 decades. Different types of biomedical signals are generated by a human body. One of the important biomedical signals is an ECG (electrocardiogram) signal. ECG is the recording of electrical activity of the heart. Different kinds of noise are also present in this signal. For analysis of ECG signals, the first step is to remove these noises, because these noises can lead to inaccurate diagnosis. Power line interference, baseline wander, motion artifacts, muscle contractions, electrode contact noise and instrumentation noise generated by electronic circuit are various noises present in the ECG signal. For the past 40 years, many researchers, engineers and doctors have tirelessly investigated and designed different techniques to diagnose the ECG signal. Wavelet transform, mathematical morphology, moving average filter, different adaptive filter algorithms, artificial intelligence methods and many other techniques play an important role in removing noise. However, an absolutely noiseless ECG signal, especially in the ambulatory environment still remains a challenge

The aim of this review paper is to discuss several techniques, to a great extent eliminate noise from the ECG signal to provide useful diagnostic information.

In view of the above the present study is organized into 3 parts. First (Section II), brief discussion of ECG signal is presented. Secondly, several techniques used to remove noise in ECG signal are briefly discussed and thirdly, important conclusions are drawn.

II. THE ECG SIGNAL

ECG signal is one of the most important biomedical signals, that represents the electrical activity of the heart governing the entire cardiovascular circulation cycle. ECG signal represents the process of polarization and repolarization of atria and ventricles of the heart [1]. The normal ECG wave is illustrated in Fig.1, that depicts different components of ECG waveform, viz., P wave representing the atrial de-polarization, QRS complex representing ventricular de-polarization and hidden atrial repolarization and T wave representing repolarization of ventricles. From the onset of one PR interval to the onset of the next PR interval is one cycle of ECG signal, However, R-R interval is considered as one cardiac cycle, since R peaks are easily recognizable.

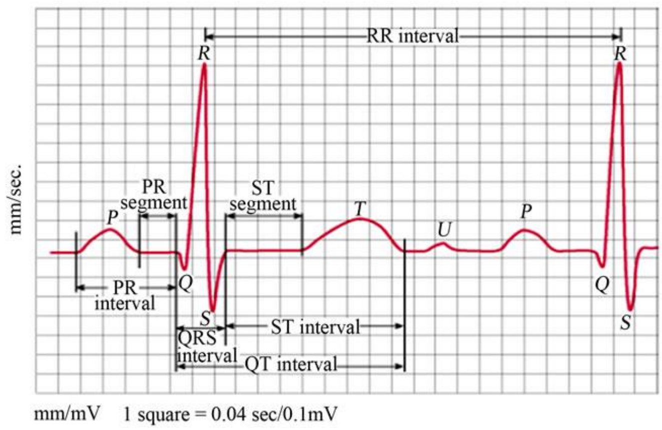

Fig 1. Normal ECG wave [2]

III. LITERATURE REVIEW

An efficient method to clean the ECG signal has been presented by Ahlstrom and Tompkins [3], in which they propose a set of real time digital filters to denoise ECG waveform. Hanning filter is used to remove 60Hz power line interference. After removing 60Hz frequency, high pass filter is designed to remove dc offset. These researchers also used band pass filter for detection of the QRS complex. Linear phase filters to remove baseline drift during exercise designed by Alsti *et al*. work in real time ECG signal processing [4]. Finite Impuls Response (FIR) filters used as a linear phase filter, are represented by Eqn 1.

$$y(nT) = \sum_{k=0}^{N-1} h(kT).x(nT-kT) \quad \ldots\ldots (1)$$

where, $y(nT)$, $h(kT)$, $n(kT)$ and N express respectively, the output signal, impulse response of the filter, input signal and number of coefficients.

Impulsive noise is removed, using morphological operator [5]. In this study, researchers used basic morphological operator such as erosion and dilation for removing impulsive noise, they also, removed baseline drift by applying opening operation followed by closing operation. Further, background normalization has been carried out using drifting and subtraction. The mathematical expressions for erosion, dilation, opening and closing operation are expressed, respectively, by the following Eqns. 2-3.

$$(f\Theta k)(m) = \min_{n=0,\ldots,M-1} f(m+n)-k(n), \quad \ldots\ldots (2)$$

For $m = 0,\ldots, N-M$

$$(f \oplus k)(m) = \max_{n=m-M+1,\ldots,m} f(n)+k(m-n) \quad \ldots\ldots(3)$$

For,

$m = M-1, M,\ldots, n-1$

Where, f and k are two discrete functions with N and M number of sequences, respectively [5].

Adaptive filtering is also used to reduce the noise in a biomedical signal. The technique [6], is used for baseline wander drift elimination. Also, these researchers employed adaptive recurrent filters for noise cancellation of ambulatory ECG data, which includes environmental noise, power line noise, radio frequency noise and other noises. After cleaning the signal, arrhythmia detection was done, accomplished with the specialty of QRS-T complex and ectopic beat detection, P-wave and atrial fibrillation detection. The cascaded structure of adaptive filter has been used to remove baseline wander [7]. A new technique employing IIR notch filter that not only suppresses the transient state(s) in the output, but also improves the performance in noise reduction as compared to other methods is proposed by Pei et al. [8]. Hamilton has compared adaptive and non-adaptive filtering methods to remove noise in the ECG signal, has applied adaptive and non-adaptive notch filter to remove 60Hz signal and concluded that the adaptive filtering technique is less complex [9]. Mathematically, the adaptive filtering function can be represented using Eqns. 4 and 5.

$$e(t) = Ne(t-nT) - e(t-2nT) \quad \ldots\ldots (4)$$

$$f(t) = [x(t)-e(t)] - [x(t-nt)-e(t-nT)] \quad \ldots\ldots (5)$$

where, *e(t)* is noise estimated, *N* can be calculated using Eqn 6.

$$N = 2\cos(2\pi 60T) \quad \ldots\ldots (6)$$

T is the sample period. The transfer function of non- adaptive filter is expressed by Eqn 7 below;

$$H(z) = \frac{1-2\cos(2\pi.60.T)z^{-1}+z^{-2}}{1-2r\cos(2\pi.60.T)z^{-1}+r^2z^{-2}} \quad \ldots\ldots (7)$$

Where, r is the radius of the unit circle [8].

A low frequency noise of 0.44Hz is eliminated using a moving average filter [10] having a transfer function expressed as follows:

$$H(z) = \frac{1}{m}\sum_{i=-r}^{r} z^{-i} \quad \ldots\ldots (8)$$

In the expression above r represents the beginning and the end of the sample points in the raw or unfettered data and m stands for the length of the window. In Fig 2, the moving average operation is depicted.

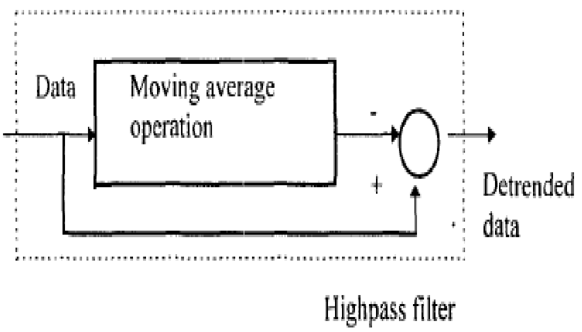

Fig 2. The moving-average operation as a high pass filter [10]

Wavelet transform is very often used to denoise ECG signals, since the past 2 decades. In the same context, Tikkenen used wavelet transform to denoise the ECG signal using a new wavelet packet based algorithm [11]. The research involved the quantitative comparative study of several denoising approaches by means of visual inspection and optimized error measures and the error signal of the denoise ECG data. In Fig 3, is shown an optimized wavelet packet decomposition tree of depth 6 for noise removal.

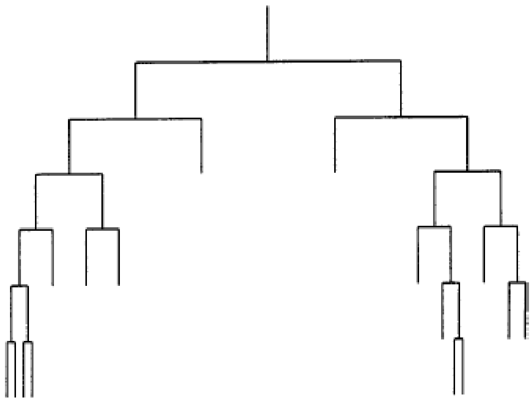

Fig 3. Wavelet transform, optimum wavelet packet decomposition tree of depth 6 [11]

Statistical threshold estimator is used to completely eliminate noise from ECG signal by Agante [12]. Motion artifact in stress is removed from ECG signals by Raya et al. by using adaptive noise cancellation [13], the stress being created by accelrometer. Modified morphological function (MMF) is used for conditioning the ECG signal [14], where the aim of the research is to improve the performance of signal conditioning to achieve reliable ECG signal analysis in terms of low computational burden, low distortion ratio and good signal to noise ratio. In another study, 60Hz noise is reduced using notch filter [15]. The authors first, design FIR filter using the Parks-McClellan method and they also compare different notch filter results. A new approach to remove baseline wander is proposed by Zhang [16]. Discrete wavelet transform (DWT) is used to remove the baseline wander noise and the high frequency noise component is eliminated using the wavelet shrinking method. In another approach, the nonlinear filter bank is used to remove noise components from the ECG signal [17]. Nonlinear filtering improves the performance in terms of less distortion and less computational complexity.

In yet another study researcher employed Elliptical filter for elimination of noise [18]. The transfer function of Elliptical filters being expressed as:

$$|H_a(j\Omega)|^2 = \frac{1}{1+\varepsilon^2 U_N^2(\frac{\Omega}{\Omega_c})} \quad \text{..... (9)}$$

where, ε is the pass band ripple ratio, Ω_c is the cut of edge frequency, $U_N(\_)$ is N^{th} order Jacobian elliptic function and N is the order of filter, that can be calculated as following;

$$N = \left(\frac{K(k)K\sqrt{1-k_1^2}}{K(k_1)K(\sqrt{1-k^2})} \right) \quad \text{..... (10)}$$

where, k is ratio of pass band edge frequency and stop band edge frequency and expressed as:

$$K(x) = \int_0^{\pi} \frac{d\theta}{\sqrt{1-x^2\sin\theta}} \quad \text{..... (11)}$$

Blanco-Velasco *et al.* proposed a new method to enhance the diagnostic value of ECG signal. This method is based on Empirical Mode Decomposition (EMD) to remove baseline wander and high frequency noise [19].

A novel method to suppress noise based on Unbiased and Normalized Adaptive Noise Reduction (UNANR) has been proposed by Wu et al. [20] the performance of this method is better in terms of SNR in the range of 5–20 dB over the 48 ambulatory ECG recordings tested, and analyzed using the standered MIT-BIH Arrhythmia database. In another Independent component analysis (ICA) and principal component analysis (PCA) are investigated to denoise ECG signal [21]. The author has applied 8- channel PCA & ICA to eliminate the unwanted signal. *Chang et al.* proposed an algorithm that is an improvement of EMD algorithm to remove Gaussian white noise [22]. The authors also used FIR Wiener filter for performing the task. A hybrid scheme consisting of Genetic algorithm and wavelet transform has been used by El-Dahshan for ECG signal denoising [23]. The performance of this hybrid scheme is evaluated in terms of SNR and Percentage Root Mean squire Difference method (PRD). In yet another study [24] researchers have presented and compared diffrent technique viz. IIR high pass filter, IIR zero phase, FIR filter, moving average, wavelet, polynomial filter etc. for removal of baseline wander from the noisy ECG data.

A hybrid method is introduced by Kabir and Shahnaz to denoise ECG data [25]. Authors combine two mass valuable algorithms that is wavelet transform and EMD to improve the processing of ECG signal. Comparative analysis is made in terms of PRD and SNR. In another technique, authors improved principal component regression (PCR) approach for processing maternal ECG [26]. The aim of this paper was to remove maternal ECG signal from the abdomen signal with high accuracy. The non-stationary nature of noise contaminating the ECG signal and the spectral overlapping of the noise with diagnostic ECG wave complexes, prompted researchers to undertake another study [27] based on an adaptive filtering approach taking into account two major techniques viz, discrete wavelet transform and artificial neural network (ANN). They developed a new combination of multiresolution property of wavelet decomposition with the rationale of adaptive learning ability of ANNs. The study could provide significant SNR improvement as compared to other algorithm that is capable of only removing fewer number of noise. Another comparatively simple, effective and computationally undemanding method has been proposed that performs noise reduction to increase the accuracy of ECG interpretation [28]. In this work, the researchers have computed the Discrete Fourier series of sampled ECG data, and calculated the Fourier coefficients for the segmented signal.

Eventually, the coefficient corresponding to the noise frequency are eliminated, and by using an inverse operation the processed coefficients are transformed back to time-domain to retrieve the original ECG signal, noiseless and reliable for analysis and interpretation. The method yielded suitable SNR improvement for high frequency noise. Liu and Luan proposed a novel integrated adaptive algorithm to separate the fECG (fetal ECG) from the maternal ECG data [29]. The adaptive integrated algorithm is based on ICA, ensemble empirical mode decomposition (EEMD) and wavelet shrinkage (WS) denoising criteria, denoted by the authors as ICA-EEMD-WS technique for fECG separation and noise reduction. Researchers concluded that the integrated adaptive algorithm gives better result in terms of high SNR, R wave amplitude and smaller mean square error values as compared to the conventional algorithm in signal denoising.

A new methodology is proposed by Mirza et al. to suppress impulsive noise [30]. In this work, an enhanced adaptive impulsive noise cancellation technique based on State Space Recursive Least Square (SSRLS) algorithm is used to eliminate the impulsive noise that causes catastrophic effects in electrocardiography. The method exhibits better results, as regards impulsive noise cancellation in ECG signal, in comparison to Normalized Least Mean Square (NLMS) and Recursive Least Square (RLS) techniques. The proposed scheme not only demonstrates fastest convergence but also excellent tracking characteristics leading to desired and effective results

In another study, by Goel et al. [31], white noise has been removed for obtaining diagnostic information in the ECG signal acquired from MIT/BIH data base. The authors used Welch and Blackman Nuttall window functions to design low pass FIR filters. The performance of the two window based FIR filters is compared by computing Total Harmonic Distortion (THD) and energy levels of the signal. Finally, the authors concluded that Blackman Nuttall window performed better. Another efficient technique based on VHDL (VHSIC hardware description language) implementation is introduced by Belchandan et al. [32]. In this research work, researchers used FIR filter and IIR filter for reducing artifacts in ECG data.

IV. Conclusion

Noise present in the ECG signal leads to inaccurate analysis and diagnosis. Different types of noise and different techniques developed to remove the noise from ECG data has been briefly discussed in this paper. The various type of noise present in the ECG signal are baseline wander, high frequency noise, power line interference, muscles contraction, instrumentation noise etc. The methods reviewed in this study are listed as follows; (1) linear filtering, (2) nonlinear filtering, (3) adaptive filtering, (4) mathematical morphology, (5) wavelet transform, (6) ICA, (7) PCA, (8) PCR, (9) ANN based techniques, (10) EMD, (11) EEMD, (12) SSRLS, (13) NLMS, (14) RLS, (15) VHDL based technique (16) multirate filterbank, (17) MMF and some hybrid methods. In one way or another, each of these methods have created their impact in denoising ECG signals.

References

[1] L. Cromwell, et al. *Biomedical instrumentation and measurements*. Prentice Hall, 1980..

[2] S. Chandramouleeswaran, et al. "Wavelet diagnosis of ECG signals with kaiser based noise diminution." 2012.

[3] M. L. Ahlstrom and W. J. Tompkins. "Digital filters for real-time ECG signal processing using microprocessors." *Biomedical Engineering, IEEE Transactions on* 9, 1985, pp. 708-713.

[4] J. A. Van Alste, et al. "ECG baseline wander reduction using linear phase filters." *Computers and Biomedical Research*19.5, 1986, pp. 417-427.

[5] C. H. Chu and E. J. Delp. "Impulsive noise suppression and background normalization of electrocardiogram signals using morphological operators." *IEEE transactions on bio-medical engineering* 36.2, 1989, pp. 262-273.

[6] N. V. Thakor and Y. S. Zhu. "Applications of adaptive filtering to ECG analysis: noise cancellation and arrhythmia detection." *Biomedical Engineering, IEEE Transactions on* 38.8, 1991, pp. 785-794.

[7] R Jané, et al. "Adaptive baseline wander removal in the ECG: Comparative analysis with cubic spline technique." *Computers in Cardiology 1992, Proceedings of*. IEEE, 1992, pp. 143-146.

[8] S. C. Pei, and C. C Tseng. "Elimination of AC interference in electrocardiogram using IIR notch filter with transient suppression."*Biomedical Engineering, IEEE Transactions on* 42.11, 1995, pp. 1128-1132.

[9] P. S. Hamilton. "A comparison of adaptive and nonadaptive filters for reduction of power line interference in the ECG." *Biomedical Engineering, IEEE Transactions on* 43.1, 1996, pp. 105-109.

[10] S. Canan, et al. "A method for removing low varying frequency trend from ECG signal." *Biomedical Engineering Days, 1998. Proceedings of the 1998 2nd International Conference*. IEEE, 1998, pp. 144-146.

[11] P. E. Tikkanen. "Nonlinear wavelet and wavelet packet denoising of electrocardiogram signal." *Biological cybernetics* 80.4, 1999, 259-267.

[12] P. M. Agante and J. P. M. De Sa . "ECG noise filtering using wavelets with soft-thresholding methods." *Computers in Cardiology, 1999*. IEEE, 1999, pp. 535-538.

[13] M. A. D. Raya. and G. S. Luis. "Adaptive noise cancelling of motion artifact in stress ECG signals using accelerometer." *Engineering in Medicine and Biology, 2002. 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society EMBS/BMES Conference, 2002. Proceedings of the Second Joint*. Vol. 2. IEEE, 2002, pp. 1756-1757.

[14] Y Sun, et al. "ECG signal conditioning by morphological filtering." *Computers in biology and medicine* 32.6, 2002, pp. 465-479.

[15] B. Ying-Wen, et al. "Adjustable 60Hz noise reduction by a notch filter for ECG signals." *Instrumentation and Measurement Technology Conference, IMTC 04. Proceedings of the 21st IEEE*. Vol. 3. IEEE, 2004, pp. 1706-1711.

[16] D. Zhang. "Wavelet approach for ECG baseline wander correction and noise reduction." *Engineering in Medicine and Biology Society, 2005. IEEE-EMB, 27th Annual International Conference of the*. IEEE, 2005, pp. 1212-1215.

[17] J. M. Łęski and N. Henzel. "ECG baseline wander and powerline interference reduction using nonlinear filter bank." *Signal processing* 85.4, 2005, pp. 781-793.

[18] M. S. Chavan et al. "Digital elliptic filter application for noise reduction in ECG signal." *WSEAS transactions on Electronics* 3.1, 2006, pp. 65-70.

[19] M. Blanco-Velasco et al. "ECG signal denoising and baseline wander correction based on the empirical mode decomposition." *Computers in biology and medicine* 38.1, 2008, pp. 1-13.

[20] Y. Wu, et al. "Filtering electrocardiographic signals using an unbiased and normalized adaptive noise reduction system." *Medical Engineering & Physics* 31.1, 2009, pp. 17-26.

[21] I. Romero. "PCA and ICA applied to Noise Reduction in Multi-lead ECG."*Computing in Cardiology*. IEEE, 2011, pp. 613-616.

[22] K. M. Chang and S. H. Liu. "Gaussian noise filtering from ECG by Wiener filter and ensemble empirical mode decomposition." *Journal of Signal Processing Systems* 64.2, 2011, pp. 249-264.

[23] E. S. A. El-Dahshan. "Genetic algorithm and wavelet hybrid scheme for ECG signal denoising." *Telecommunication Systems* 46.3, 2011, pp. 209-215.

[24] M. Kaur and B. Singh. "Comparison of different approaches for removal of baseline wander from ecg signal." *Proceedings of the International Conference & Workshop on Emerging Trends in Technology*. ACM, 2011, pp. 1290-1294.

[25] M. A. Kabir and C. Shahnaz. "Denoising of ECG signals based on noise reduction algorithms in EMD and wavelet domains." *Biomedical Signal Processing and Control* 7.5, 2012, pp. 481-489.

[26] J. A. Lipponen and M. P. Tarvainen. "Advanced maternal ECG removal and noise reduction for application of fetal QRS detection."*Computing in Cardiology Conference (CinC), 2013*. IEEE, 2013, pp. 161-164.

[27] S. Poungponsri and X. H. Yu. "An adaptive filtering approach for electrocardiogram (ECG) signal noise reduction using neural networks."*Neurocomputing* 117, 2013, pp. 206-213.

[28] D. Sadhukhan and M. Mitra. "ECG noise reduction using Fourier coefficient suppression." *Control, Instrumentation, Energy and Communication (CIEC), International Conference on*. IEEE, 2014.

[29] G. Liu and Y. Luan. "An adaptive integrated algorithm for noninvasive fetal ECG separation and noise reduction based on ICA-EEMD-WS." *Medical & biological engineering & computing* 53.11, 2015, pp. 1113-1127.

[30] A. Mirza et al. "Impulsive Noise Cancellation of ECG signal based on SSRLS." *Procedia Computer Science* 62, 2015, pp. 196-202.

[31] S. Goel et al. "Performance analysis of Welch and Blackman Nuttall window for noise reduction of ECG." *Signal Processing, Computing and Control (ISPCC), 2 International Conference on*. IEEE, 2015.

[32] A. K. Belchandan. "Removal of Noises in ECG Signal by using Digital FIR-IIR Filter in VHDL."*Digital Signal Processing* 8.5, 2016, pp. 135-139.