Study of Different Adaptive Filtering Algorithms for Reduction in Baseline Wander in ECG Signal

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***Abstract*: The electrocardiogram (ECG) is the graphical representation of heart's functionality. It is an important tool used for the diagnosis of cardiac abnormalities. ECG signals are usually weak and susceptible to external noise and interference. Adaptive filter is a good tool to reduce the influence of ambient noise/interference on the ECG signals. Adaptive filter uses Least mean squares (LMS) algorithm, as one of most popular adaptive algorithms for active noise cancellation (ANC). The goal of the paper is to show the comparison based on signal to noise ratio of different adaptive filter algorithms like LMS, Normalized LMS (NLMS), Normalized Signed Regressor LMS (NSRLMS), Recursive Least Squares (RLS), Normalized Sign-Sign LMS (NSSLMS), used for the analysis of ECG signals with noise. The filter needs two input: the signal (primary input) and an impulse correlated with the deterministic component (reference input). Several signals to noise ratio were considered. The adaptive filters essentially minimize the mean-squared error between a primary input, which is the noisy ECG, and a reference input, which is either noise that is correlated in some way with the noise in the primary input or a signal that is correlated only with ECG in the primary input.**

Keywords—ECG signal, Noise, Adaptive filtering, LMS, NLMS, RLS, NSSLMS.

I. INTRODUCTION

Biomedical signals generated from human body are often very weak so as to be easily disturbed by various noises. One of the main problems in biomedical data processing like electrocardiography is the separation of the wanted signal from noises caused by power line interference, high frequency interference, extern electromagnetic fields and random body movements and respiration. Different types of digital filters are used to remove signal components from unwanted frequency ranges. It is difficult to apply filters with fixed coefficients to reduce random noises. A doctor can detect different types of deflections by the full form analysis of the ECG signal. Fig. 1 shows the standard ECG Signal.

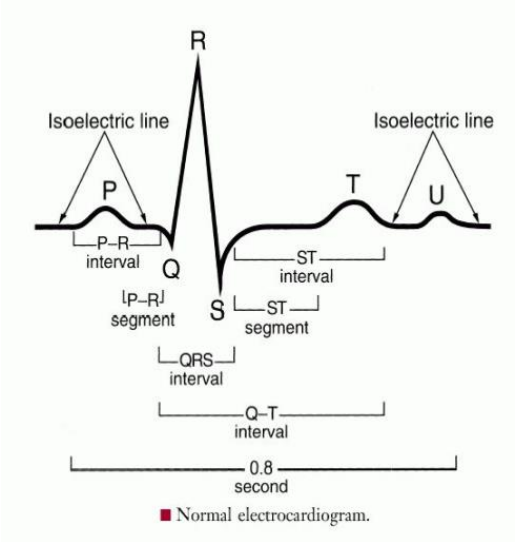

Figure 1: ECG Signal

So, extraction and analysis of this information-bearing signal are complicated, because of distortions from interference. With the help of advanced digital signal processing this work can be shifted from the analogue to the digital domain.

II. SOURCES OF NOISE IN ECG

ECG noise is originated by some environmental and biological sources. These noises are described as follow:

a) **Power Line Interference**: This is the environmental noise in the ECG which is due to ECG recording machine. This noise is because of the alternating feature of the current. It has the frequency of 50 Hz and it is harmonics. To remove this type of noise adaptive filter is used.

b) **Baseline Wander**: It is a type of biological noise that appears in ECG signal. In this noise, an iso-electric line shifts its position. It is contributed by moving electrodes, patient movement, improper electrode contact etc. during recording of ECG signal. The adaptive filter that is used to remove this noise is a special case of notch filtering, with a notch at zero frequency to remove 0-0.5 Hz frequencies. For removal, type I filter is used with reference noise.

c) **Motion Artifact**: This is most difficult biological noise to cancel. The spectrum of this noise is broad and it completely overlaps the ECG signal spectrum. Linear filtering methods are unable to remove this noise source. Adaptive filter can eliminate this noise source by having the adaptive filter reference input set to an impulse value of 1 that corresponds to the beginning of the P-wave. In this way, adaptive filter only subtracts the P-QRS-T complex from the signal and the remainder will be motion artifact. Adaptive filter type- I is used to subtract this noise from the ECG.

d) **Muscle Artifact** : Muscle artifact or electromyography (EMG) comes under the biological noise that appears in the ECG signal. EMG is an electrical potential generated by muscle cells when the cells are neurologically or electrically activated. Muscle artifact can be produced by unwanted reaction to electrodes. To reduce this type of noise, typically more than one ECG lead is used while recording. Type-I adaptive filter applied for motion artifact will also remove EMG from signal.

e) **Instrumentation Noise**: This is environmental noise source which is generated by hardware that is used for recording of the ECG signal. This noise can be removed using Low noise Amplifiers , hence no digital filtering is needed .

III. ADAPTIVE FILTERING TECHNIQUE

An adaptive filter is a filter that self-adjusts its transfer function according to an optimization algorithm driven by an error signal [1]. Because of the complexity of the optimization algorithms, most adaptive filters are digital filters. It adapts to the change in signal characteristics in order to minimize the error.

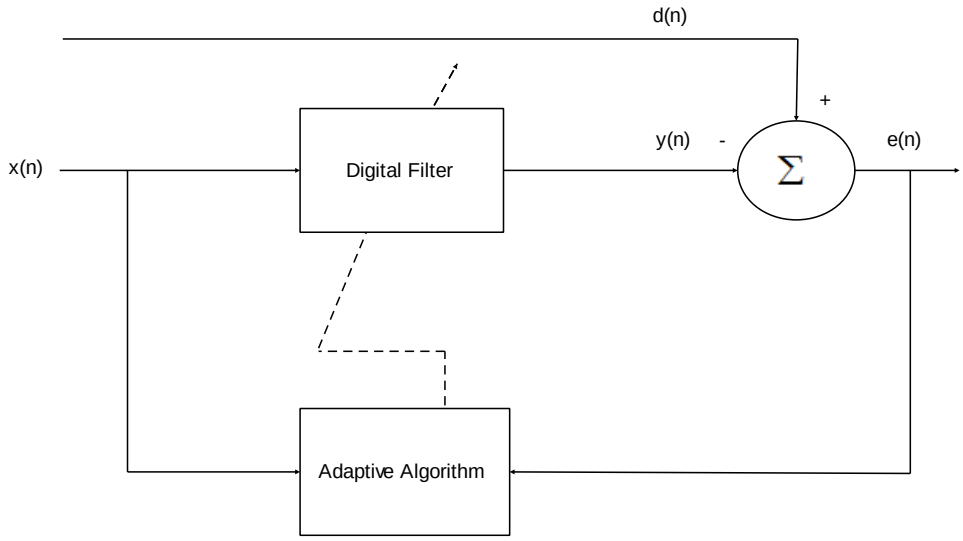

Figure 2: Adaptive Filter

Figure 2 shows the block diagram of an adaptive filter, where x(n) is the digital input signal and d(n) is the desired output. Performance of the adaptive filters is highly dependent on adaptability of adjustable parameters. These parameters are dependent on error signal e(n), which is a difference of desired signal d(n) and output signal y(n) [2].

IV. ADAPTIVE FILTER ALGORITHMS

a) **Least-Mean-Square Algorithm (LMS):** The least-mean-square (LMS) algorithm belongs to the family of the linear stochastic gradient algorithms. It serves minimum two purposes. First, it don't need to know the exact signal statistics, second, these methods possess a tracking mechanism that enables them to track variations in the signal statistics [3]. The simplicity and operational stability are important features of the LMS algorithm.

b) **Normalised Least-Mean-Square Algorithm (NLMS):** In the LMS algorithm, the tap-weight input has a correction which is directly proportional to the size of input. When the size of the input is large, the LMS algorithm experiences a gradient noise amplification problem. In order to solve this problem, the normalized least-mean-square (NLMS) algorithm was developed. The increase of the input makes very difficult (if not impossible) to choose a step-size that guarantees the algorithms stability. Therefore, the NLMS has variable step-size parameter is used.

c) **Recursive Least-Squares Algorithm (RLS):** Contrary to the LMS algorithm, whose aim is to reduce the mean square error, the recursive least-squares algorithm's objective is to find, the filter coefficients recursively, that minimize the least square cost function. The RLS algorithm has an advantage of fast convergence, but on the other hand, it has the problem of a high computational complexity.

d) **Normalized Signed Regressor LMS (NSRLMS) Algorithm:** The conventional LMS algorithm requires L+1 "multiply and accumulate" (MACs). Whereas the NSRLMS algorithm requires L+1 MACs and achieves improved SNR at the cost of 1 additional division than the conventional LMS algorithm.

e) **Normalized Sign-Sign LMS Algorithm (NSSLMS):** The NSSLMS algorithm exhibits better convergence characteristics in terms of both convergence rate and excess mean square error. In order to cope with both the complexity and convergence issues without any restrictive trade off a normalized sign sign LMS algorithm (NSSLMS) for removal of noise from ECG signal is proposed. This algorithm has less computational complexity because of the sign present in the algorithm and good filtering capability because of the normalized term.

V. LITERATURE REVIEW

In 2009, Mohammad Zia Ur Rahman et.al., proposed normalized signed regressor LMS (NSRLMS) algorithm for removal of various artifacts from ECG signal. This algorithm has less computational complexity because of the sign present in the algorithm. It has good filtering capability because of the normalized term. From the simulated results it is clear that NSRLMS removes non-stationary noise efficiently. The proposed treatment provides high signal to noise ratio with less computational complexity [4].

In 2009, Mohammad Zia Ur Rahman, et. al. proposed a simple and efficient normalized Sign-Sign LMS(NSSLMS) algorithm for the removal of different kinds of noises from the ECG signal. The proposed implementation is suitable for applications requiring large signal to noise ratios with less computational complexity. Simulations studies confirm that the SNR of the proposed algorithm is better than that of LMS algorithm and the NSSLMS based adaptive filter removes non-stationary noise more efficiently, the computational complexity of the proposed algorithm is less and hence it is more suitable for wireless biotelemetry ECG systems [5].

In 2014, Uzzal Biswas et. al. have done a broader study for denoising every types of noise involved with real ECG signal. Two adaptive filters, such as, least-mean-square (LMS) and normalized-least-mean-square (NLMS) are applied to remove the noises. For better clarification simulation results are compared in terms of different performance parameters such as, power spectral density (PSD), spectrogram, frequency spectrum and convergence. Analysis of ECG signal, both of noisy ECG signal and filtered signal reveals that adaptive NLMS and LMS filter both reduces the white noise, colored noise, muscle artifact noise, electrode movement noise, baseline wander noise, composite noise and power line interference properly. But the results for different parameters shows that adaptive NLMS filter is more appreciable for removing various types of noises from ECG signal [6].

In 2015, A. C. Mugdha et.al., presented a study on adaptive filter algorithm, in which RLS has been used in cancellation of various noises in ECG signals. They have also performed noise removal using LMS adaptive filter algorithm to compare the performance of RLS algorithm. From results it showed that the LMS algorithm is a rudimentary adaptive filter algorithm whereas, RLS is comparatively much more complex. Spectrograms and convergence plots concluded that this complex nature of RLS algorithm has caused it to remove noises from ECG signals with more efficacy than the LMS algorithm [7].

In 2015, Ishika Sharma, et. al., presented the adaptive filters algorithms for removing noise from the electrocardiogram to receive noise less pure embryo signals. ECG signals Filtering requires a filter which can automatically adapt according to changing input and noise. Adaptive filtering using LMS algorithm has been used to reduce the noise from the desired ECG signals. From results it could be concluded that as the step size is increasing the noise is also increasing as well as the rate of convergence is also increasing. The optimum result is produced when the step size is considered to be as small as possible but it should also be kept in mind while designing adaptive filter that step size should not be taken very small because it will increase the value of rate of convergence[8].

In 2015, Nasreen Sultana, et.al. presented a paper on adaptive filter for denoising the ECG signal based on Least Mean Squares (LMS), Normalized Least Mean Square (NLMS), Affine Projection LMS (APA-LMS) and Recursive least Squares algorithm (RLS) with experimental results. The performances of these algorithms were compared in terms of various parameters such as SNR, PSNR, MSE and Standard Deviation (SD). The performance of NLMS is better than LMS in case of SNR. Convergence speed of all the filters was estimated and results showed that RLS adaptive filter has less convergence speed. That is slower convergence yields better mitigation of noise from the ECG signals. Hence for improving the convergence speed of filters, Recursive Least Squares (RLS) adaptive filtering algorithms are very useful. As RLS have higher computational operations and higher memory requirements [9]

Table 1. Comparison of Different Adaptive Algorithm used for Removal of Baseline Wander in ECG Signal

Type of noise	Algorithm used for noise cancellation	SNR Improvement (in dBs)			
		Mohammad Zia Ur Rahman (2009)	Uzzal Biswas (2014)	Mohammad Zia Ur Rahman (2009)	Nasreen Sultana (2015
Baseline Wander	LMS	5.4583	7.8466	3.4080	2.49
	NSRLMS	7.3418			
	NLMS		7.8475		3.92
	RLS				5.11
	NSSLMS			6.8360	

Table 1 shows the different adaptive algorithms used for the removal of noise reduction in ECG signals.

VI. Conclusions

In this paper different adaptive algorithms are discussed for the noise removal in ECG signal. As for improving the results, one can implement variable step-size algorithm which can help faster convergence algorithm at the start. Faster adaption allows the signal to be analyzed by smaller segments. From all the papers discussed here shows that signal to noise ratio (SNR) is improved much more by using Normalized Least Mean Square (NLMS) algorithm as compare to LMS, NSRLMS, RLS, NSSLMS. it is concluded form survey that as the step size is increasing the noise is also increasing as well as the rate of convergence is also increasing. The rate of convergence and MMSE is having trade off between each other i.e. the optimum result is produced when the step size is considered to be as small as possible but it should also be kept in mind while designing adaptive filter that step size should not be taken very small because it will increase the value of rate of convergence.

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