

Removal of Artifacts from ECG Signal Using RLS Based Adaptive Filter: A Review

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ABSTRACT: The electrocardiogram (ECG) is used for diagnosis of heart diseases. In a few circumstances the recorded ECG signals are corrupted by various noise signals caused by power line interference, base line wander, electrode movement, muscular movement (EMG) etc. These noise signals are known as artifacts. These artifacts mislead the diagnosis of heart which is not desired. To avoid this problem caused by artifacts, removal of these artifacts has become essential. There are various techniques which have been used for artifacts rejection from ECG. Conventional filters remove the artifacts up to some extent but these filters are static filters. These filters cannot update their coefficients with the change in environment where as adaptive filters update their coefficients according to the requirement. There are various adaptive algorithms such as Least Mean Square (LMS), Recursive Least Square (RLS), Normalized Least Mean Square (NLMS) etc. This paper deals with RLS algorithm for removal of artifacts from ECG signal. The filter algorithm is designed using MATLAB and tested on ECG signal corrupted with various artifacts.

KEYWORDS: Adaptive Filter, Artifacts, Electrocardiogram (ECG), Electromyogram(EMG), Least mean square(LMS), Normalized least mean square(NLMS), Recursive least square(RLS), Signal to noise ratio(SNR)

I. INTRODUCTION

Electrocardiogram (ECG) is the record of the electrical potentials produced by the heart. The electrical wave is generated by depolarization and repolarization of certain cells due to movement of Na⁺ and k⁺ ions in the blood. The ECG signal is typically in the range of 2mV and requires a recording bandwidth of 0.1 to 120Hz. The ECG records the electrical activity of the heart, where each heart beat is displayed as a series of electrical waves as shown in Fig 1. ECG signal conveys information about structure and function of heart. The ECG signal is characterized by five peaks and valleys labeled by the letters P, Q, R, S, T. There is a U wave in ECG signal which is having very low amplitude or even more often is absent. Mainly an ECG tracing is a repeating cycle of three electrical entities: a P wave (atrial depolarization), a QRS complex (ventricular depolarization) and a T wave (ventricular repolarization).

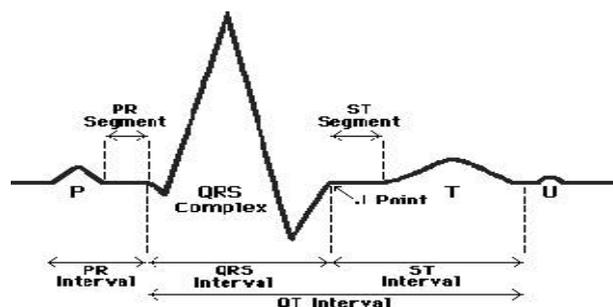


Fig 1. An ECG signal representation

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 4, April 2016

Different noises affect the ECG signal during its acquisition and transmission. Mainly two types of noises are present in the ECG signal. Noises with high frequency include Electromyogram noise, Additive white Gaussian noise, and power line interference. Noises with low frequency include baseline wandering. The noises contaminated in the ECG signal may lead wrong interpretation. The objective is to separate the desired ECG signals and undesired noises as to obtain accurate interpretations of ECG signal. With the latest advancements in electronics, several techniques are used for removal of unwanted entities from signals especially that are implied in the most sophisticated applications. The removal of power line interference from most sensitive medical monitoring equipments can also be removed by implementing various useful techniques. The power line interference (50/60 Hz) is the main source of noise in most of bio-electric signals. The Different types of digital filters (FIR and IIR) have been used to solve the problem. However, it is difficult to apply these filters with fixed coefficients to reduce the power line interference, because the ECG signal is known as a non-stationary signal. Recently, Adaptive filtering has become one of the effective and popular methods for the processing and analysis of the ECG signal.

II. ADAPTIVE FILTER AND RLS ALGORITHM FOR SIGNAL ENHANCEMENT

Adaptive filter play vital role in the elimination of noise in the corrupted signals. A generalized basic adaptive filter structure is shown in Fig 2.

From the figure the desired signal $d(s)$ along with artifact noise and channel noise is given as primary input. Reference $X(s)$ input is given to the other input and filter output can be obtained by using adaptively adjusted weights according to the output error signal $e(s)$. Weight vector for the length of L , is assumed at initial iteration is zero.

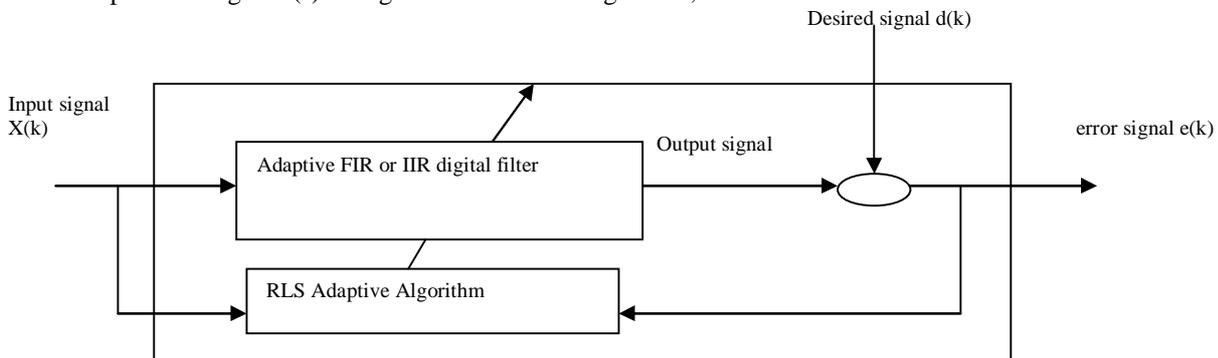


Fig 2. A generalized basic adaptive filter structure

The Recursive Least Squares (RLS) algorithm is based on the well known least squares method. The least squares method is a mathematical procedure for finding the best fitting curve to a given set of data points. This is done by minimizing the sum of the squares of the offsets of the points from the curve. The RLS algorithm recursively solves the least squares problem. In the following equations, the constants λ and δ are parameters set by the user that represent the forgetting factor and regularization parameter respectively. The forgetting factor is a positive constant less than unity, which is roughly a measure of the memory of the algorithm; and the regularization parameter's value is determined by the signal to noise ratio (SNR) of the signals. The vector \hat{w} represents the adaptive filter's weight vector and the M by M matrix P is referred to as the inverse correlation matrix. The vector π is used as an intermediary step to computing the gain vector k . This gain vector is multiplied by the a priori estimation error $\xi(n)$ and added to the weight vector to update the weights. Once the weights have been updated the inverse correlation matrix is recalculated, and the training resumes with the new input values. A summary of the RLS algorithm follows: Initialize the weight vector and the inverse correlation matrix P .

$$W^H(0) = \bar{0} \quad (3.2.1)$$

$$P(0) = \delta^{-1} \quad (3.2.2)$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 4, April 2016

Where δ = Small positive constant for high SNR

Large positive constant for low SNR

For each instance of time $n = 1, 2, 3 \dots$ compute:

$$p(n) = P(n-1) u(n) \tag{3.2.3}$$

$$\pi(n) = \frac{\pi(n)}{\lambda + u^H(n)\pi(n)} \tag{3.2.4}$$

$$d(n) = d(n) - w^H(n-1) u(n) \tag{3.2.5}$$

$$w(n) = (n-1) + k(n) \xi(n) \tag{3.2.6}$$

$$p(n) = \lambda^{-1} p(n-1) - \lambda^{-1} k(n) u^H(n) p(n-1) \tag{3.2.7}$$

An adaptive filter trained with the RLS algorithm can converge up to an order of magnitude faster than the LMS filter at the expense of increased computational complexity.

From the Table I show that, the performance of RLS adaptive algorithm is high as compared to other algorithm due to the less mean-square error (MSE) [12]

Table I
Performance Comparison of Adaptive Algorithms

S.No.	Algorithms	MSE	Complexity	Stability
1.	LMS	1.5×10^{-2}	$2N+1$	Less stable
2.	NLMS	9.0×10^{-3}	$3N+1$	Stable
3.	RLS	6.2×10^{-3}	$4N^2$	High stable

The SNR improvement of LMS, NLMS and RLS adaptive algorithm shown in the Table II at 1.5 kHz sampling rate and different noise variance, according to the table the RLS adaptive algorithm has improved SNR in dB. It concludes that the best adaptive algorithm is Recursive Least Square according to the SNR improvement table and graph of MSE.

Table II
SNR IMPROVEMENT IN DB

Noise variance	Sampling rate(kHz)	SNR Improvement(db) LMS	SNR Improvement (db) NLMS	SNR Improvement (db) RLS
0.02	1.5	8.85	9.85	9.91
0.05	1.5	7.55	8.62	8.89
0.10	1.5	5.12	6.38	7.02

III. RELATED WORK

The noise which commonly disturb the basic electrocardiogram (ECG) are power line interference (PLI). During past few years, various contributions have been made in literature regarding noise removal from ECG signal. Different researchers have worked on power line interference in ECG signal.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 4, April 2016

Elimination of power line interference in the ECG by adaptive filtering, using an external reference signal, was first proposed by Widrow [1]. Advantage of this paper is to reduce periodic or stationary random interference in both periodic and random signals. But at the other side the disadvantages are, with each instant of PLI cancelling was accomplished with little signal distortion and it always requires external reference signal.

Ahlstrom and Tompkins [2] used 60-HZ adaptive filter for ECG signals that used an internally generated reference signal. Adaptive filter with an internally generated reference is less complex, produces less distortion in a typical ECG, and is more effective in removing low level 60-Hz noise. But at the other side Ahlstrom and Tompkins' filter is nearly similar to a nonadaptive, second order, notch filter, implying that the performance of a nonadaptive notch filter and an adaptive notch filter with an internally generated reference is equivalent. If there is small difference occurs in bandwidth then the transient response time of notch filter is also affected and hence the filter will adapt more slowly to changes in noise.

While adopting neural network based nonlinear adaptive filter by Q.Xue, Y.Hu, et al [3] has a better way to eliminate the baseline drift, pseudo-differential effects. But the adaptive filter used in the template, which are subject to the impact of variation of QRS wave, while the neural network of the large amount of arithmetic operations, which has a big limitation for the clinical application of ECG analysis.

A. Ziarani and A. Konrad in [4] proposed adaptive canceller based on first order phase adaptation system. The method presents simple and robust structure. This paper presents structure and performance of the proposed nonlinear adaptive EMI filter and its application in the elimination of power line interference in ECG signals. The structure of nonlinear adaptive EMI filter consisting of only few arithmetic operations and it has a high degree of immunity with respect to an external noise.

S. Marten [5] compare their improved adaptive power line interference canceller (IAC) to the canceller proposed by Ziarani [4] for the reduction of the fundamental power line interference component in ECG recordings. The results show that the value of the adaptation constant vector proposed by Ziarani for the canceller in [4] does not always lead to a successful acquisition phase. In fact, the canceller design is such that the optimal adaptation constant vector is dependent on $d(k)$. Where $d(k)$ is interference signal [5].

The adaptive canceller tracks the amplitude, phase and frequency of the fundamental component and harmonics of the power line interference [5]. The error filter that is implemented in the canceller can reduce the gradient noise cause by the ECG signal and baseline wander [5].

A new method was proposed for removing power line interference in ECG signals based on EMD and adaptive filter [4], [6]. The performance of the method was tested with actual ECG signals. EMD was developed as a non-parametric data-driven analysis tool for nonlinear and non-stationary signal processing. It exhibits an ability to analyze signal with excellent time resolution. Least mean square (LMS) algorithm developed by Window and Hoff is the most widely used adaptive filtering algorithm which is simple and powerful. Results indicate that the method is powerful and useful and the power line interference can be eliminated from the ECG signal

Without affecting its spectrum [4], [6].

Gowri T, Rajesh Kumar P [7] used LMS to RLS adaptive algorithm to remove noise like PLN and muscle noise. For double validation of the signal and for high SNR at the cost of additional computations. Here different adaptive algorithms are used like LMS, RLS, Posterior RLS and for double validation of the signal they have derived LMS-RLS algorithm. But it has high computational complexity.

Vruddhi.L.Dawda, Prof Mohd.Saleem.Sajid [8] presented a survey report on adaptive filter techniques for Removal of PLI from Biomedical signals. This paper deals with an effective adaptive algorithm used for eliminating power line interference from ECG signal. This method cannot be employed to filter out the PLI when corrupted ECG signal has low SNR ratio.

Smita Dubey, Swati Verma [9] proposed Denoising of the ECG signal using NLMS adaptive filtering algorithm [9]. This paper presents an adaptive filtering technique for removing noise from ECG signal using normalized least mean square method. The NLMS is the variant of LMS algorithm that solve the problem of sensitive of pure LMS algorithm by normalizing with the power of the input.

R Madhvi Dasondhi, Virendr K Verma [10] present a review on various methods for ECG signal Denoising [10]. This paper presents Empirical mode Decomposition method for denoising of ECG, also introduced other methods for

International Journal of Innovative Research in Science, Engineering and Technology

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denoising the various methods included in ECG analysis based on wavelet transform and modulus maxima, time frequency dependent threshold, artificial neural networks and mathematical algorithm using window analysis.

Uzzal Biswas and Md.Maniruzzaman [11] presented a paper on removal of power line interference from the ECG signal by comparing the performance of two adaptive filter: 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.

Jyoti Dhiman, Shadab Ahmad, Kuldeep Gulia [12] describes the comparison between adaptive filter algorithm that is LMS,NLMS and RLS. Implementation aspects of these algorithms, their computational complexity and signal to noise ratio are examined. Three performance criteria are used in the study of these algorithms the minimum mean square error, the algorithm execution time and the required filter order.

IV. PROPOSED WORK

Our proposed work is focusing mainly on to improve the signal to noise ratio (SNR) and another factor to be improved is correlation coefficient which gives us the similarity between filtered and nonfiltered signal. The processes involved in this study are as follows :

1. To make the comparative analysis of different available methods of adaptive artifacts removal from literature.
2. To choose the different significant parameters which can analyze the performance of the algorithm.
3. To find a new method for removal of adaptive power line interference and other artifacts from biomedical signal.
4. To write the algorithm for proposed method using software like Matlab.
5. To make an analysis for the performance of implemented algorithm based on the significant parameters.
6. To compare performance of implemented algorithm with available method in the literature.

V. CONCLUSION

This work throws light on the basics of electrocardiogram, artifacts corrupting the ECG signal and ECG enhancement using RLS algorithms. The work begins with the review of some popular work in the field of ECG signal processing. The physiology of heart, heart beat generation, morphology of electrocardiogram are elaborately discussed. Differenttypes of noises that affect the ECG and their origins are also described.

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