



Study of Adaptive Algorithms for Removal of Power Line Interference from Electrocardiogram Signal

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Abstract: In this paper, a comparison of different adaptive algorithms is performed for the effective removal of Power Line Interference (PLI) from Electrocardiogram (ECG) signal and for the enhancement of the ECG signal. The performance of different algorithms is studied and their effectiveness is evaluated in terms of Peak Signal to Noise Ratio. The simulation results for the final filtered output, as well as the Peak Signal to (PSNR) shows that Error Normalized Least Mean Square (ENLMS) algorithm proves an edge over other conventional algorithms. This is well illustrated from the improved performance in the effective elimination of noise with a high value of Peak Signal to Noise Ratio thus proving the effectiveness of ENLMS algorithm.

Keywords: Adaptive, ECG, ENLMS, Enhancement, PLI, PSNR.

I. Introduction

ECG can be regarded as a widely used vital sign sensing as well as a monitoring method for the health of the patient. It is a widely used source for providing diagnostic information regarding the cardiovascular system. The cardiac health of human heart can be well predicted from the heart rate and the ECG signal. Cardiac arrhythmia is a result of the rhythm or change in the morphological pattern of the heart. Basically, a disorder in heart rate causes cardiac arrhythmia [1]. By the analysis of the ECG waveform, these arrhythmias can be detected as well as diagnosed. During the acquisition of ECG signal in clinical environment, it can encounter numerous types of artifacts generated by biological in addition to environmental resources. Power line interference, muscle artifact, motion artifact, respiration movements, baseline wander and instrumentation noise are the ones of primary interest. As a result, there is degradation in the quality of the signal. The other effects includes frequency resolution, the morphology of ECG signal is strongly affected which provides valuable information about heart diseases or arrhythmias. Hence, it is quite essential to reduce interferences in ECG signal and enhance the reliability as well as accuracy for better diagnosis [2].

Different types of digital filters have been presented in literature to solve this problem [3]-[7]. Several approaches are available in literature that makes use of both fixed as well as adaptive filters for efficient PLI cancellation. Recently, adaptive filtering has emerged to be an effective method for PLI cancellation. In [8] the use of deterministic functions as the reference inputs was proposed and the study of steady state mean square error (MSE) convergence of the Least mean Square (LMS) algorithm was considered. In order to cope with the issue of increasing computation complexity, novice algorithms using the signum of either the input signal or the error signal or both were presented [9]. A variety of adaptive notch filter and fixed frequency filter structures have been presented in [10]. However, the use of Notch filter for PLI removal results in ringing. The author in [11] proposed an FFT based algorithm for effective removal of PLI.

II. Adaptive Algorithms

A study of the adaptive algorithms is presented. The Least Mean Square algorithm, Signed Regressor algorithm and Error Normalized Least Mean Square Algorithm are considered for review. A brief introduction of all the algorithms is presented.

A. Least Mean Square algorithm: This is the conventional and most preferred algorithm in terms of easy implementation and simplicity. The update equation for LMS algorithm can be represented as

$$w(n+1) = w(n) + \mu x(n)e(n) \quad (1)$$

Where $w(n+1)$ is the new weight, $w(n)$ is the old weight, μ is the step size, $x(n)$ is the input signal and $e(n)$ is the error signal.

Due to the simplicity and robustness of LMS algorithm, it has become a standard for the adaptive filtering. In addition to this, LMS is much famous for the varying applications in comparison with other linear adaptive algorithms.

B. Signed Regressor Algorithm: This algorithm makes use of the signum of the input signal. The sign present in the algorithm makes the hardware implementation highly simplified (shift and add/subtract operation only). The update equation for the algorithm is as shown:

$$w(n+1)=w(n)+\mu \operatorname{sgn}\{x(n)\}\{e(n)\} \text { i.e.,} \quad (2)$$

$$w(n+1)=w(n)+\mu\{x(n) /|x(n)|\}\{e(n)\} \quad (3)$$

$$w(n+1)=w(n)+\{\mu / x(n)\} x(n) e(n) \quad (4)$$

$$w(n+1)=w(n)+\mu' x(n) e(n) \quad (5)$$

where $\mu'=\mu / x(n)$

The above equation reveals that the sign algorithm may be thought of as an LMS algorithm with a variable step size parameter.

C. Error Normalized Least Mean Square algorithm: In ENLMS, the step size is normalized with reference to error. Instead of using the instantaneous data vector for normalization, the squared norm of the error vector can be used. The length of the error vector is the instantaneous number of iterations. Because the step size is normalized with reference to error, this algorithm is called the Error Nonlinear LMS (ENLMS) algorithm. This algorithm provides significant improvements in decreasing mean-squared error and consequently minimizing signal distortion [18]. The weight update equation can be represented as:

$$w(n+1)=w(n)+\{\mu / \alpha+e^t(n) e(n)\} x(n) e(n) \quad (6)$$

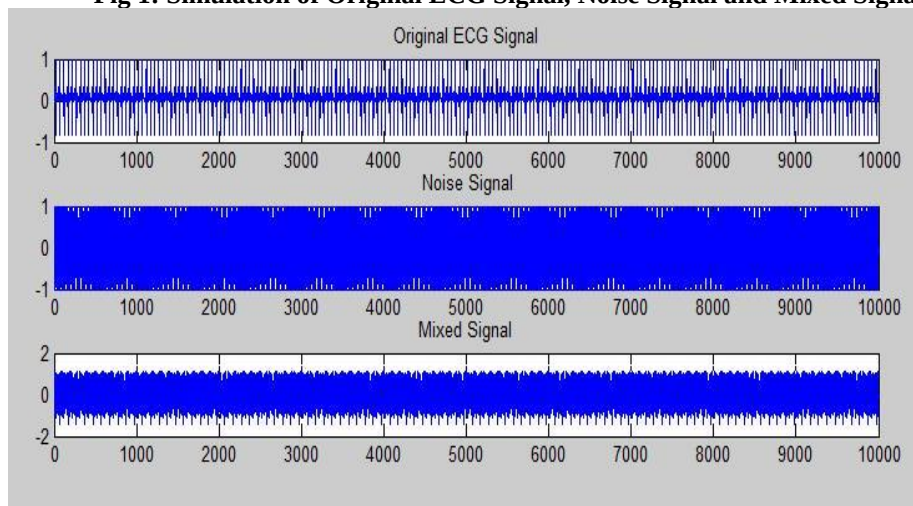
The variable step size can be written as:

$$\mu_e(n)=\mu /[\alpha+e^t(n) e(n)] \quad (7)$$

III. Simulations and Results

The simulation results for the algorithms described in section 2 are discussed and compared on the basis of PSNR and SNR after filtering. All of the simulations are performed using synthetic data via MATLAB. The input signal $x(n)$, that is ECG signal in this case is generated in MATLAB at a frequency of 50 Hz. Then, a Power Line Interference signal is generated in MATLAB with a sine wave of 50 Hz frequency and is labeled as “Noise Signal”. The Original ECG signal and Noise signal are added in order to generate a “Mixed Signal”. The MATLAB simulation is shown as under.

Fig 1: Simulation of Original ECG Signal, Noise Signal and Mixed Signal.



The simulation results show the “Original ECG Signal”, “Noise Signal”, “Mixed Signal” and the “Final Filtered Output”. The simulation containing the following signals is shown for the LMS algorithm, SRA and ENLMS algorithm. It can be analyzed from the figures shown that filtered output is almost a replica of the input signal as shown in figure 2, 3, 4.

Fig 2: Simulation waveform for Final Filtered Output of LMS algorithm

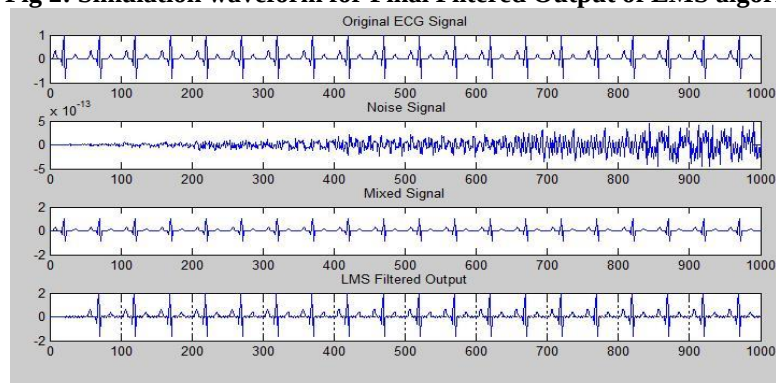


Fig 3: Simulation waveform for Final Filtered Output of SRA

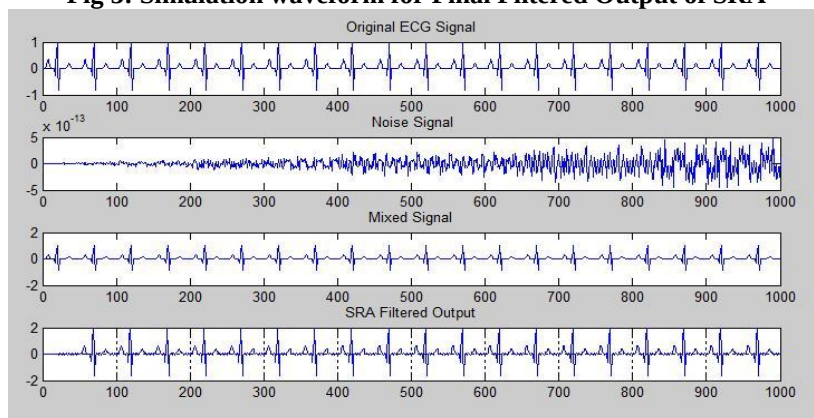
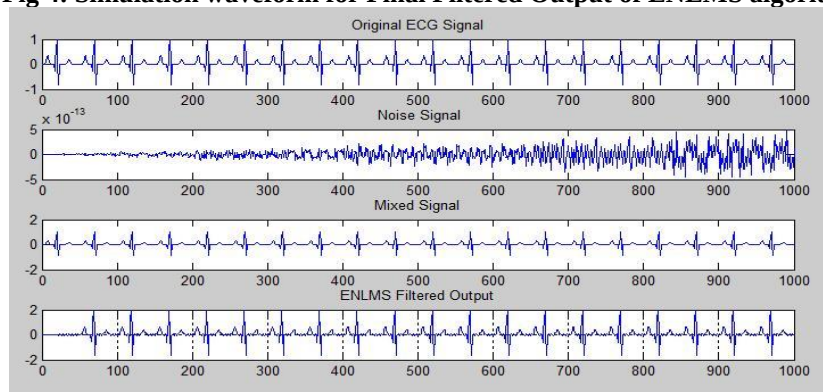


Fig 4: Simulation waveform for Final Filtered Output of ENLMS algorithm



It can be well inferred from the figures given above that the filtered output is a clean noise free ECG signal which is free from the effects of Power Line Interference and is similar to the Original ECG signal. Hence, all these algorithms prove effective in the removal of PLI from ECG signal. Thus, the morphology of the signal is maintained and effective diagnosis of the patient can be achieved.

The figures 5, 6, 7 shows the performance of various algorithms for PSNR. The simulations are carried out in MATLAB and all values are represented in decibels. For effective performance of the different algorithms in terms of PSNR, the higher the value, the better is the performance. The comparison of PSNR values is made in table I and ENLMS algorithm gives the best performance in terms of highest PSNR.

Fig 5: Simulation results for PSNR of LMS Algorithm

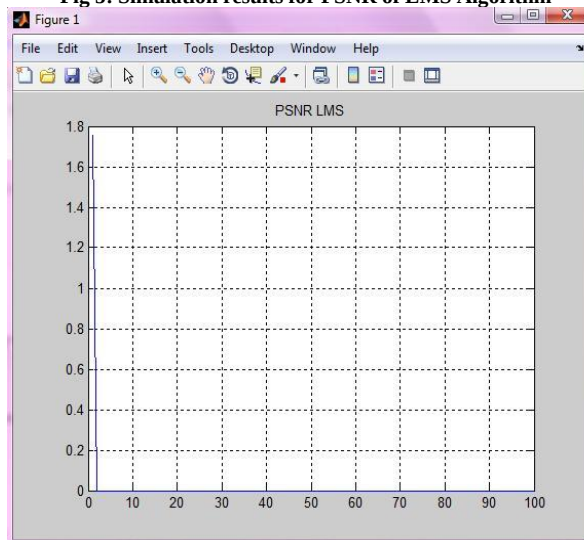


Fig 6: Simulation results for PSNR of SRA Algorithm

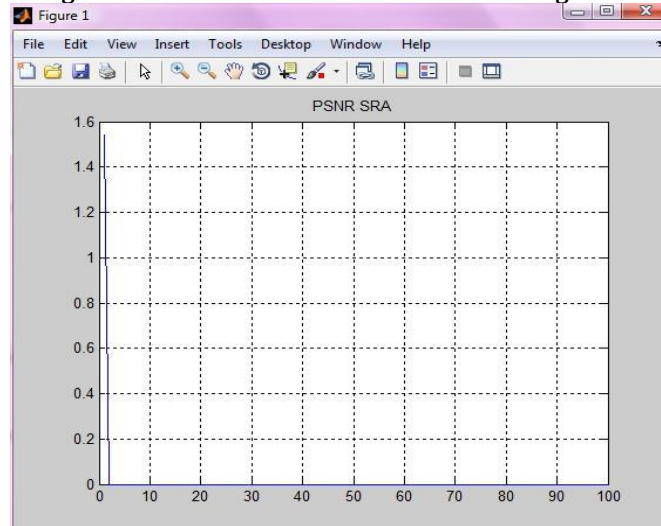


Fig 7: Simulation results for PSNR of ENLMS algorithm

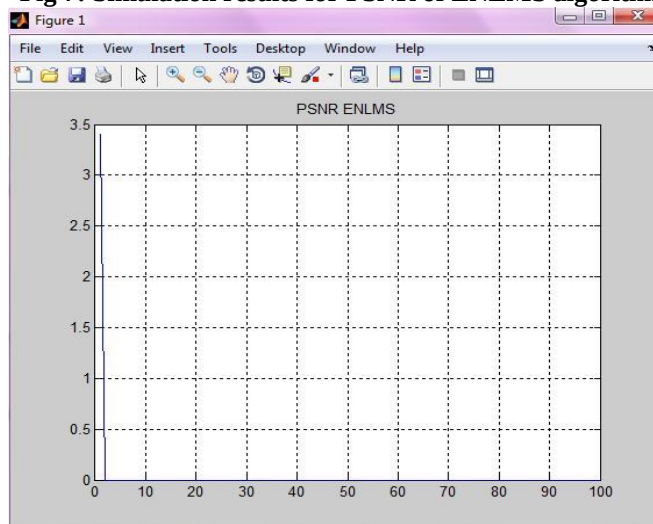


Table I: Comparison of different algorithms in terms of PSNR

ALGORITHM	PSNR
LMS	1.757
SRA	1.596
ENLMS	3.406

IV. Conclusion

The simulation results for the final filtered output proves the performance of LMS, SRA and ENLMS algorithm in effective removal of PLI from ECG signal. Further, the performance measure for comparing the performance of these algorithms proves the effectiveness of ENLMS algorithm over the other two. The highest PSNR value of ENLMS algorithm states that it is the best performing algorithm as compared to LMS and SRA.

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