Removing Power Line Interference from ECG Signal Using Adaptive Filter and Notch Filter

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Abstract— **Performance of two adaptive filters, such as, normalized least-mean-square (NLMS) adaptive filter and recursive-least-square (RLS) adaptive filter are compared with a traditional notch filter both in time and frequency domains to remove the power line interference from the ECG signal. The power spectral density (PSD) and spectrogram analyses are also performed. Different performance parameters, such as, SNR, %PRD and MSE are also calculated. Real time recorded data from the benchmark MIT-BIH arrhythmia database has been used. The result demonstrates superior performance of adaptive NLMS filter for removing power line interference over adaptive RLS and notch filters.**

Keywords-ECG signal; power line interferrence; adaptive NLMS filter; PSD; spectrogram.

I. INTRODUCTION

The ECG signal is extremely important for the diagnosis and evaluation of many cardiac problems. But, when the ECG signal is recorded, it may be corrupted by various kinds of noises, such as, power line interference, base line wandering, electrode contact noise, motion artifacts, muscle contraction, instrumentation noise and electrosurgical noise, etc. [1]. However, the main source of interference is the 50 Hz power line interference, as because it lies in the ECG signal band (0.05-100 Hz), and consequently, affects the ST segment of the ECG signal. The affected ST segment creates problem during the diagnosis of arrhythmia. So, to obtain a reliable ECG signal for the diagnosis of arrhythmia it has become very crucial to remove the 50 Hz power line interference from the recorded ECG signal. Different types of digital filters (e.g., FIR and IIR filters) have been used to solve the problem [2]-[4]. As the ECG signal is non-stationary, hence it is difficult to apply these filters with fixed coefficients for reducing the 50 Hz power line interference. Recently, adaptive filtering has become one of the effective and popular techniques for processing and analysis of the ECG signal [5]-[7]. And, it is well known that the adaptive filter with least mean square (LMS) algorithm show good performance for the analysis of the most of the biomedical signals which are non-stationary. In our previous study [8], it is shown that the adaptive NLMS filter removes the 50 Hz power line interference more effectively among all LMS algorithm based adaptive filters. In this study, traditional notch [9], adaptive RLS [5], and adaptive NLMS filters are investigated and compared to reduce the effect of 50 Hz power line interference from ECG signal. The simulation result reveals that the adaptive NLMS filter is an excellent method to remove the 50 Hz power line interference from ECG signal.

II. MATERIALS AND METHODS

A set of recorded data (record # 100, 104, 105, and 106) are used as an original ECG signal from the benchmark MIT-BIH arrhythmia database [10]. The 50 Hz power line interference is generated by using MATLAB®. The noisy ECG signal is obtained by adding these two signals. To remove the 50 Hz power line interference, the noisy ECG signal is then pass through two adaptive filter algorithms (e.g., NLMS and RLS) and a traditional notch filter. However, the basic block diagrams for understanding the overall adaptive and notch filtering processes are depicted in Fig. 1.

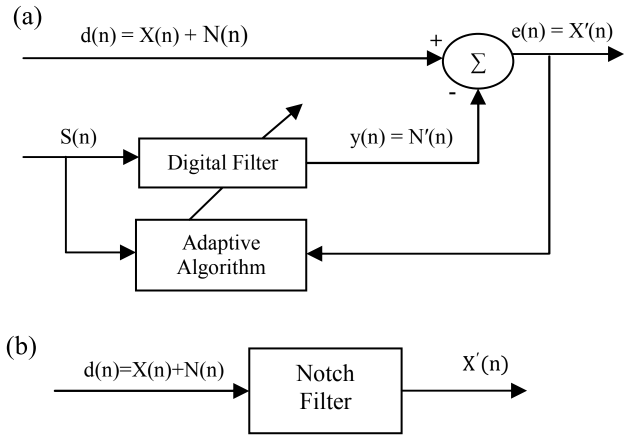


Figure 1. Principles of (a) adaptive and (b) notch filters.

The noisy, as well as, filtered ECG signals are analyzed both in time and frequency domains. Different parameters used to measure the performance of adaptive filters and notch filter are power spectral density (PSD), spectrogram, signal-to-noise ratio (SNR), percentage root mean square difference (%PRD) and mean square error (MSE). Signal Processing Toolbox built in MATLAB® has been used to simulate the program.

III. RESULTS AND DISCUSSION

The 13-bit real data of four patients are used from the benchmark MIT-BIH arrhythmia database [10] mentioned earlier, but we select one patient (record # 105) as a reference to analyze the data and finally get the output. Similarly, it can be described for other patients also. We simulate the 50 Hz power line interference (noise signal), noisy ECG signal, notch filtered, adaptive RLS filtered, and adaptive NLMS filtered ECG signal in time domain, as shown in Fig. 2. The 50 Hz power line interference is also generated matching with the patient ECG signal. By adding these two signal the noisy ECG signal is obtained. Finally, the power line interference is removed using notch filter, in Fig. 2(a), adaptive RLS filter, in Fig. 2(b) and adaptive NLMS filter, in Fig. 2(c). The figure clearly shows that the 50 Hz power line interference is reduced duly.

The time domain filtered information of Fig. 2 is then re-examined in the frequency domain, as shown in Fig. 3. The frequency spectrum of noisy ECG signal, notch, adaptive RLS and adaptive NLMS filtered ECG signal is shown respectively in Fig. 3(a), 3(b), 3(c) and 3(d). By observing these figure it can be said that the 50 Hz power line interference from ECG signal is removed by the filtering method of notch filter, adaptive RLS filter and adaptive NLMS filter.

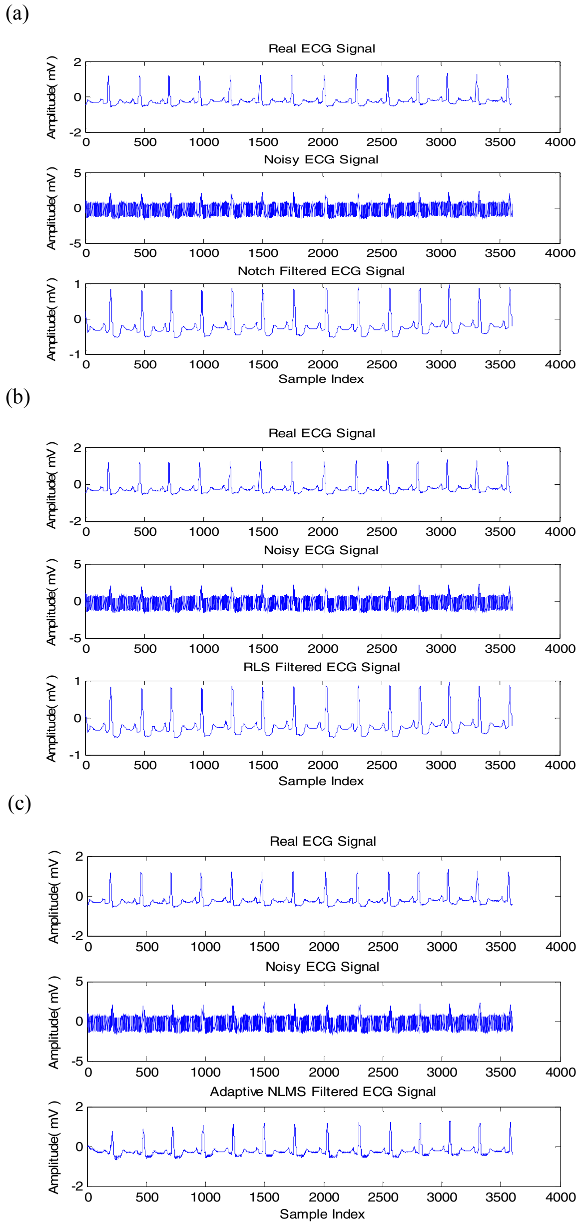


Figure 2. Time domain graphical representation of removing power line interference using (a) notch, (b) adaptive RLS and (c) adaptive NLMS filters (record # 105).

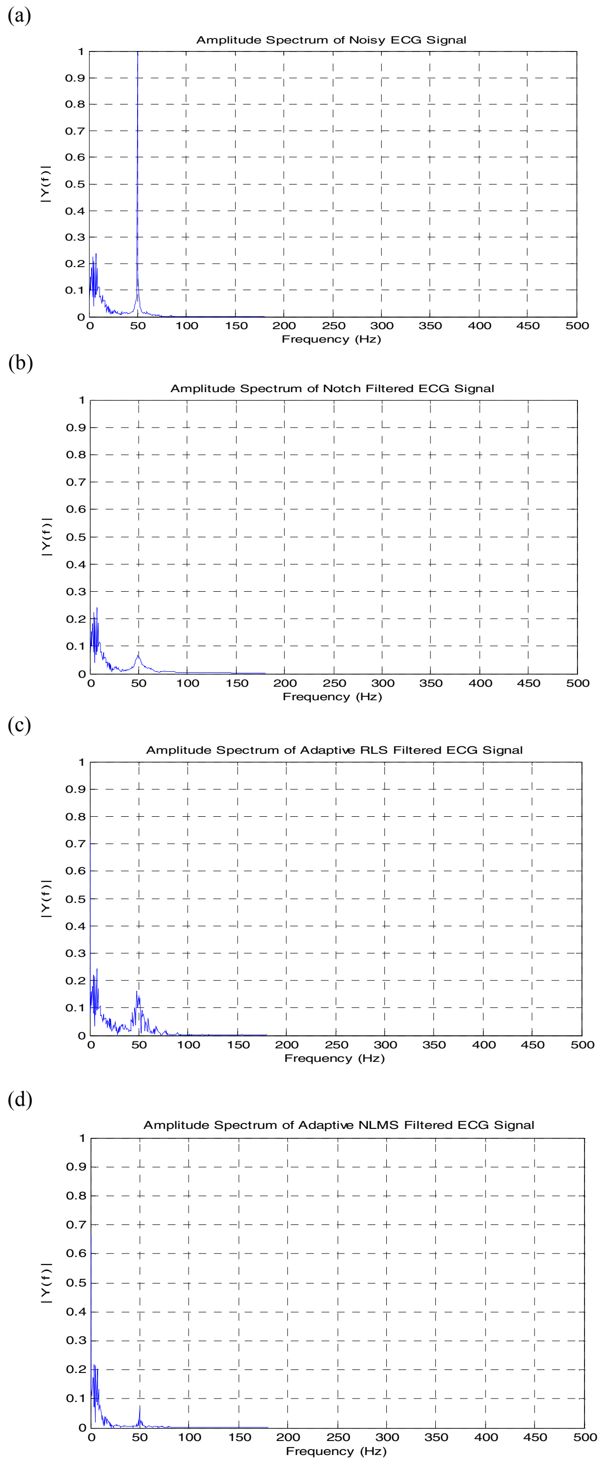
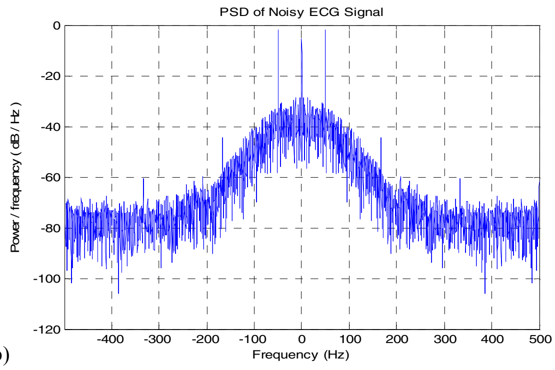


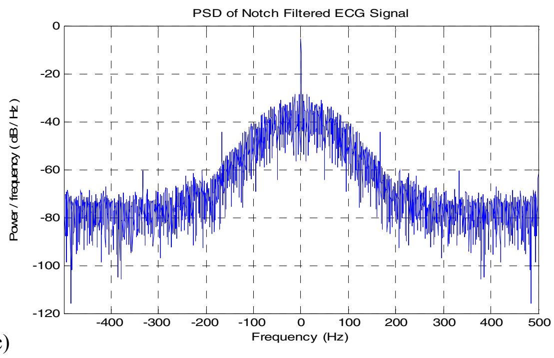
Figure 3. Frequency domain graphical representation of (a) noisy, (b) notch filtered, (c) adaptive RLS filtered and (d) adaptive NLMS filtered ECG signals (record # 105).

Then the power spectral density (PSD) is analyzed for each kind of ECG signals described in Fig. 3. It is reported that the PSD is an excellent performance measurement tool to understand the performance of the filtering techniques applied for reducing noise from the noisy ECG signal [11]. The PSD curves for noisy ECG signal, notch filtered, adaptive RLS and adaptive NLMS filtered real ECG signal is shown respectively in Fig. 4(a), 4(b), 4(c) and 4(d). From Fig. 4 it is seen that, the maximum PSD value of the noisy ECG signal is -1.899dB/Hz. However, when the noisy ECG signal is passed through notch filter, adaptive RLS and adaptive NLMS filter the maximum PSD value corresponding to 50Hz is then reduced to -44.27dB/Hz, -38.77dB/Hz and -46.25dB/Hz respectively.

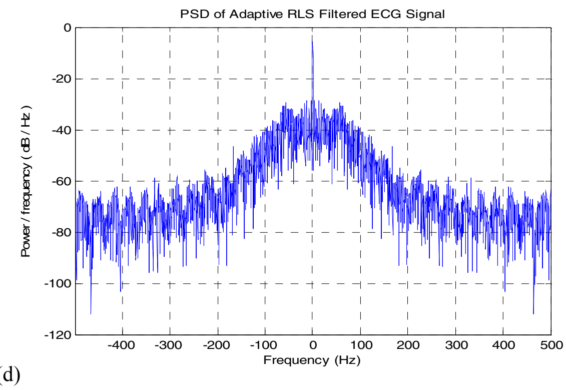
(a)



(b)



(c)



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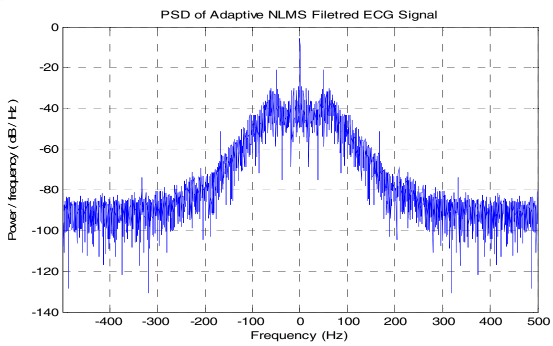
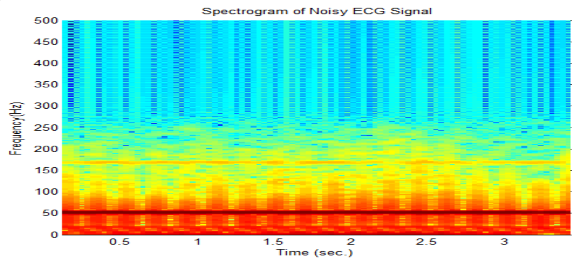


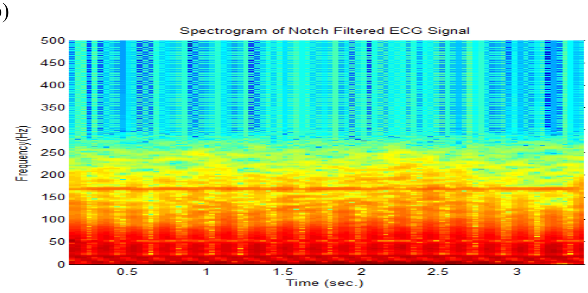
Figure 4. PSD curves of (a) noisy, (b) notch filtered, (c) adaptive RLS filtered and (d) adaptive NLMS filtered ECG signals (record # 105).

After that we plotted spectrograms for each kind of ECG signals described in Figs. 3 and 4. It shows how the spectral density of a signal varies with time. The spectrogram of noisy ECG signal, notch filtered signal, adaptive RLS filtered signal and adaptive NLMS filtered signal is shown in Fig. 5. By observing the Fig. 5(a), 5(b), 5(c) and 5(d) it can strongly be said that the 50 Hz noise in ECG signal is properly reduced by the adaptive NLMS filter than that of the adaptive RLS filter and traditional notch filter.

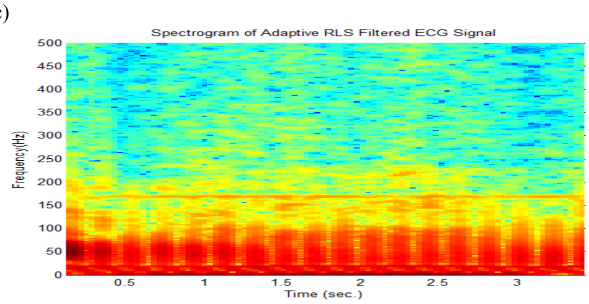
(a)



(b)



(c)



(d)

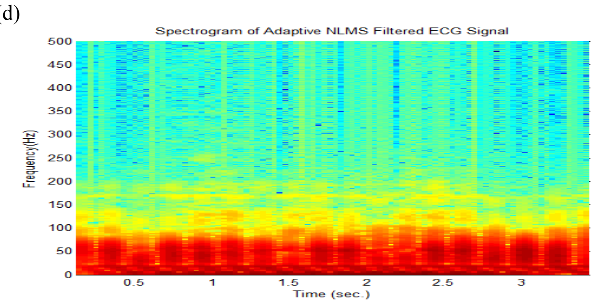


Figure 5. Spectrogram of (a) noisy, (b) notch filtered, (c) adaptive RLS filtered and (d) adaptive NLMS filtered ECG signals (record # 105).

The values of different performance parameters (SNR, %PRD and MSE) of noisy, notch filtered, adaptive RLS filtered and adaptive NLMS filtered ECG signals are finally calculated and shown in Table I. We know that the high values of SNR and the low values of %PRD and MSE are good. From Table I we can see that noisy signal's SNR is very low, but all filtered signals have high SNRs. Also the noisy ECG signal has high %PRD and MSE, but filtering signals have low %PRD and MSE. However, the reconstructed ECG signal obtained from the adaptive NLMS filter has high SNR, low %PRD and MSE than other two filters.

TABLE I. VALUES OF PERFORMANCE PARAMETERS (SNR, %PRD AND MSE)

Performance Parameter	Database Record No. [10]	Filter		
		Notch	Adaptive RLS	Adaptive NLMS
SNR	100	-6.023	-6.089	-5.780
	104	-9.741	-10.014	-9.718
	105	-5.607	-5.534	-5.237
	106	-5.548	-5.028	-4.557
	Average	-6.729	-6.666	-6.323
%PRD	100	1.631	1.910	0.601
	104	1.029	1.900	0.956
	105	1.673	1.353	0.040
	106	4.575	2.199	0.003
	Average	2.227	1.840	0.400
MSE	100	0.120	0.190	0.010
	104	0.023	0.018	0.016
	105	0.046	0.051	0.042
	106	0.059	0.061	0.056
	Average	0.062	0.080	0.031

IV. CONCLUSION

The time and frequency domain analyses reveal that adaptive NLMS filter reduces the 50 Hz power line interference properly. The PSD value obtained for adaptive NLMS filter is better than that of adaptive RLS and traditional notch filters. The result is also conformed by the spectrograms. The adaptive NLMS filter also confirms the superiority with high SNR, low %PRD and low MSE. Thus, the results lead us to conclude that adaptive NLMS filter based denoising method is an effective and optimum technique for reducing 50 Hz power line interference from ECG signal as compared with adaptive RLS and traditional notch filtering techniques.

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