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An Adaptive Filter for Elimination of PowerLine Interference from ECG Signal

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Abstract: ***Power line interference is a challenging problem given that the frequency of the time-varying power line signal lies within the frequency range of the ECG signal. Some technical difficulties involved are low sampling frequency at which the ECG signals are obtained and the low computational resources available at the level of the apparatus. In this paper, adaptive filter for elimination of power line interference from ECG signal using adaptive LMS algorithm and error filter is presented. Most of the energy in the ECG signal is concentrated near the low frequency range; high pass filtering of the error will acquire most of the ECG signal from the error signal. The simulation results show that adaptive LMS algorithm results in high SNR, the required filter length can be short and ease for hardware realization using embedded systems. A method for adaptive notch filter to eliminate power line interference in ECG signal can be used in the medical equipment's to remove noise caused due to AC supply.***

Keywords: Adaptive Filter, LMS, ECG, Power line interference

1. Introduction

An ECG signal is basically an index of the functionality of the heart. For example, a physician can detect arrhythmia by studying abnormalities in the ECG signal. Since very fine features present in an ECG signal may convey important information, it is important to have the signal as clean as possible. The frequency spectrum of this signal spans from near dc frequencies to about 100 Hz. The sampling frequency in most ECG devices is 240 Hz or 360 Hz. Therefore, the spectrum can theoretically include frequencies from zero to 180 Hz. ECG signals are severely distorted by power line noise. Therefore sharp notch filter is essential to separate and eliminate the noise. The notch filter is ineffective because frequency of power line is unstable and varies about fractions of a Hertz, or even a few Hertz [1]. The sharper the notch filter is designed, the more inoperative, or rather destructive, it becomes if any change in the frequency of the power line occurs, turning the notch filter into a band-stop filter by widening its rejection band, and thereby accommodating frequency variations, does not offer any better solution since it will undesirably distort the ECG signal itself [2]. The frequency of the power grid is usually taken as being constant when conventional EMI filters for ECGs are designed. In such arrangements, the system is very delicate with respect to power frequency variations and can become completely inoperative [1].

An ideal EMI filter for ECG should act as a sharp notch filter to eliminate only the undesirable power line interference while automatically adapting itself to variations in the frequency and level of the noise. This adaptation must be done very quickly so as to keep the signal clean all the time. It is supposed to be able to work in low information background, namely that dictated by low sampling frequency, and must be robust.

Adaptive interference cancellers have a general structure as shown in figure 1, that consist of the interference signal called as reference signal d[n], the noisy ECG signal x[n], and the error signal. The error signal is the difference between the estimated signal and the interference, and it is processed by an adaptation sub-scheme in order to find an estimate of frequency. The sub-scheme behavior depends on the adaptation constant vector. It is common practice to assume and to be uncorrelated and configure the adaptation sub-scheme such that the mean-squared error (MSE) is minimized. This is referred to as least mean square (LMS) estimation. After convergence, the error is an estimate for the signal of interest which is the ECG signal [2].In order to improve the estimation of interference parameters, the ECG signal is obtained from the error signal using a high pass filter, called an error filter. Since, most of the energy in the ECG signal is concentrated near the low frequency range; high pass filtering of the error will acquire most of the ECG signal from the error signal shown in figure 2.

In this paper, adaptive filter for elimination of power line interference from ECG signal using adaptive LMS algorithm and error filter is presented. Most of the energy in the ECG signal is concentrated near the low frequency range; high pass filtering of the error will acquire most of the ECG signal from the error signal. The primary objective is to achieve higher signal to noise ratio (SNR). The paper is organized as follows section 1 introduces to power line elimination using adaptive filter, section 2 describes adaptive LMS algorithm with error filtering, results are presented in section 3 and finally concluded in section 4.

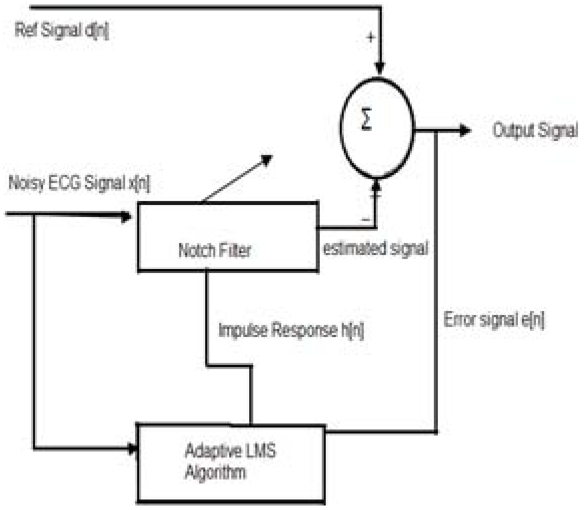


Figure 1: Conventional adaptive interference cancellers

2. Adaptive LMS Algorithm with Error Filter

An ECG Signal with power line interference is given as

$$x[n] = g[n] + p[n] \quad (1)$$

Where x[n] is ECG signal with power line interference, g[n] is clean ECG signal and p[n] is power line interference. The power line interference can be modeled as sinusoidal signal given as

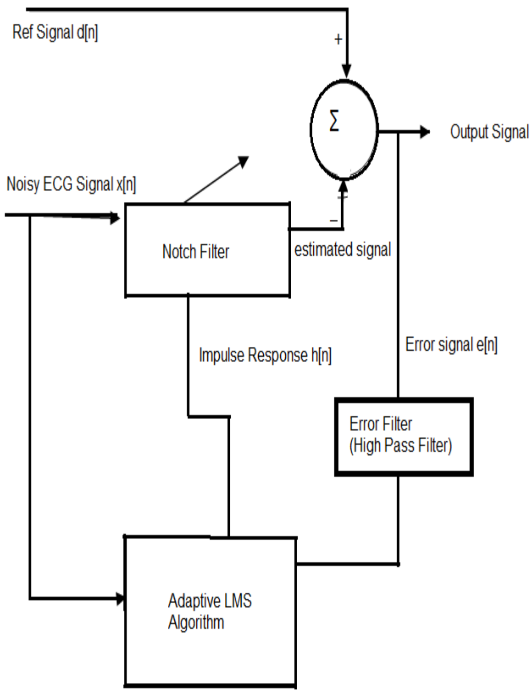


Figure 2: Proposed adaptive interference cancellers

$$p[n] = A\ \sin(\omega n + \ \theta[n]) \quad (2)$$

where A is the maximum amplitude of the signal, ω is the power line frequency and θ is the phase. An estimate of the sinusoidal interference is obtained by estimating the interference parameters A and θ. The estimated sinusoidal interference is then subtracted from the measured ECG signal to obtain a clean ECG signal. The sinusoidal interference parameters A and θ is estimated using adaptive least mean squares (LMS) algorithm [4]. The residual error signal is given as

$$e[n] = y[n] - p[n] \quad (3)$$

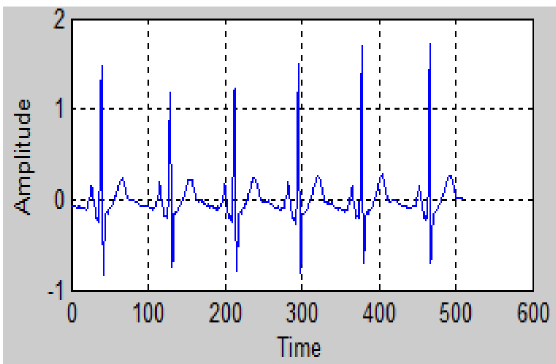
where e[n] is error signal and y[n] is the estimated signal refer figure 2. The estimation of system parameters at the (n+1) sample depends on the estimates at the n sample and the error at the n sample. The amplitude and phase of the sinusoidal interference is varying slowly over time and therefore the amplitude and phase are fairly constant over a small window. Simplified equation for error is given as

$$e[n+1] = y[n] - p[n] \quad (4)$$

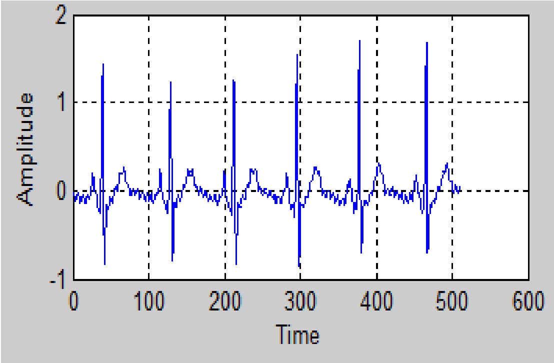
Thus we have tried to reduce the mean square error e[n] by using LMS algorithm. The error signal e[n] contains not only the error due to parameter mis adjustment, but also the ECG signal g[n]. Presence of ECG signal in the error effects the estimation of interference parameter. In order to improve the estimation of interference parameters, the ECG signal is removed from the error signal using a highpass filter, called an error filter. Since, most of the energy in the ECG signal is concentrated near the low frequency range; high pass filtering of the error will remove most of the ECG signal from the error signal [3].Error filtering is performed on the error signal vector and cutoff frequency can be set above 10 Hz to 40 Hz.

3. Results

In order to validate the performance of adaptive filter for elimination of power line interference using LMS algorithm and error filtering, simulation is carried out using ECG signals. The ECG signal is of approximately 173 ms with sampling frequency of 300 Hz. To evaluate the performance of the adaptive filter, noisy ECG signal is synthetically generated using power line interference and clean ECG signal. SNR and correlation coefficient (CC) are used to evaluate the performance of the adaptive filter. SNR is measured at the input and output of the adaptive filter. The input SNR is varied by varying the amplitude of the power line interference. The input SNR is defined as ratio of the power of the ECG signal to the power of sinusoidal interference and output SNR is defined as the ratio of the power of the ECG signal to the residual interference power.Correlation coefficient is between the original ECG signal and the ECG signal with interference removed.

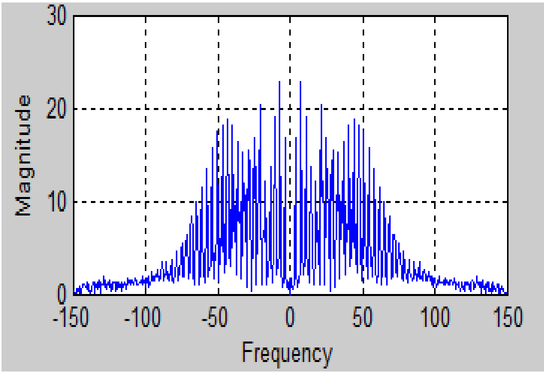


(a): Clean

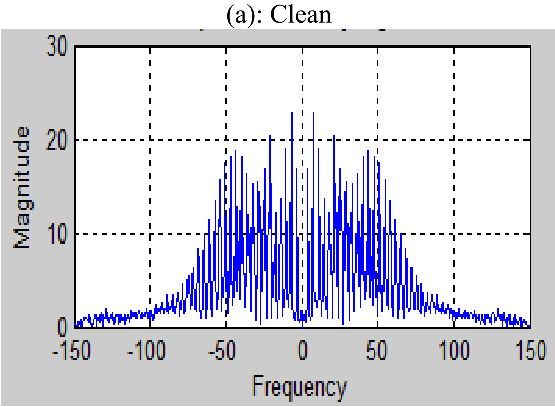


(B) Noisy

Figure 3: ECG Signal

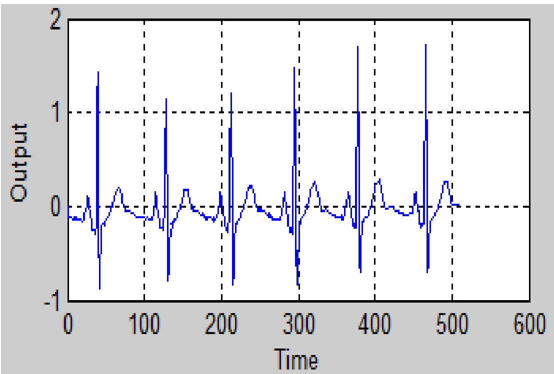


(a): Clean

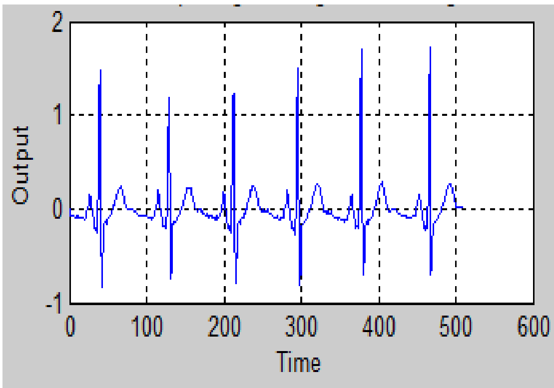


(b): Noisy

Figure 4: Frequency spectrum of ECG signal



(a): Without error filter



(b): With error filter

Figure 5: Output ECG signal

Figure 3 shows the clean and noisy ECG signal and figure 4 shows the frequency spectrum of the clean and noisy ECG signal. Comparison of the adaptive filter with error filter and without error filter is shown in figure 5, absence of error filter does not distort the ECG signal but it is unable to remove power line interference effectively. Table 1 shows the SNR and CC for adaptive power line interference removal with error filter and without error filter. In all the simulation experiments, the initial conditions of the PLI parameters wereset to zero.

Table 1: SNR and CC

Parameter	SNR in	Without Error Filter	With Error Filter
SNR out	30 db	21.8 db	68.2 db
CC		0.9973	0.9999
SNR out	20 db	20.9 db	53.6 db
CC		0.9973	0.9999
SNR out	10 db	17.5 db	40.2 db
CC		0.9973	0.9999

4. Conclusion

In this paper, adaptive filter for elimination of power line interference from ECG signal using adaptive LMS algorithm and error filter is presented. Most of the energy in the ECG signal is concentrated near the low frequency range; high pass filtering of the error will acquire most of the ECG signal from the error signal. The simulation results show that adaptive LMS algorithm with error filter results in high SNR, the required filter length can be short and ease for hardware realization using embedded systems. Simulation experiments clearly show that highest SNR out of 68.2 db is obtained at SNR in of 10 db and correlation coefficient of 0.9999. Absence of error filter does not distort the ECG signal but it is unable to remove power line interference effectively that results in SNR out of 21.8 db and correlation coefficient of 0.9973 at SNR in of 10 db.

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