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Power Line Interference Removal from ECG Signal using Adaptive Filter

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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 that 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 to eliminate the power line interference from ECG signal by the use of adaptive LMS algorithm and low pass filter is presented. Most of the energy in the ECG signal is concentrated near the low frequency range; low pass filtering of the output signal will acquire most of the ECG signal from the error signal. The simulation results show that adaptive LMS algorithm results in high SNR, the needed filter length can be short and ease for hardware realization by the use of 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.*
Index Terms: *Adaptive Filter, Biomedical Signals, LMS Algorithm*

I. Introduction

An ECG signal is the electrical recording of the functionality of the heart. A physician can detect arrhythmia by examining irregularity in the ECG signal. Since very fine features present in an ECG signal carry essential information, so it is important to have the signal as clean as possible[1]. The spectrum of frequency spans from near dc frequencies to about 100 Hz for this signal. The sampling frequency in most of the ECG devices is 240 Hz or 360 Hz. Hence, the spectrum can theoretically include frequencies from zero to 180 Hz. ECG signals are severely distorted by the noise present in the power line. Therefore sharp notch filter is essential to separate and remove the noise. The notch filter is ineffective because frequency of power line is not stable and varies about fractions of a Hertz, or even a few Hertz [2]. The sharper the notch filter is made, the more inoperative, or rather destructive, it becomes if any change in the frequency of the power line occurs. This turns the notch filter into a band-stop filter by widening its rejection band, and thereby accommodating frequency variations, but does not provide any better solution since it will undesirably distort the ECG signal itself [3]. When conventional EMI filters are designed for ECGs, the power grid is usually taken as being constant. In such arrangements, the system is very sensitive with respect to power frequency variations and thus can completely become inactive or inoperative [4].

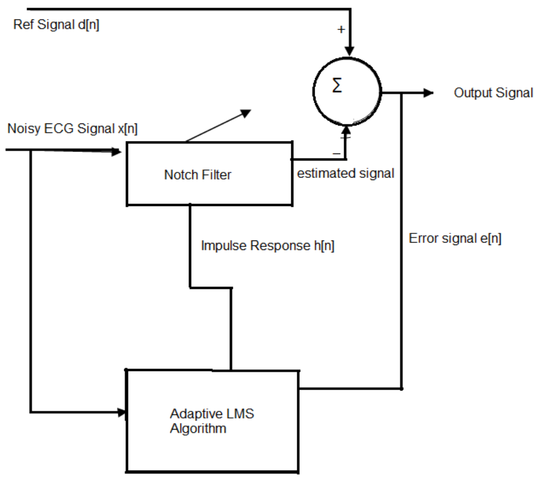


Fig. 1. Conventional adaptive filter

An ideal EMI filter for ECG should act as a sharp notch filter to remove only the undesirable power line interference while adapting itself automatically to the level of noise andthe frequency variations [5]. This adaptation must be done very quickly so that the signal is kept clean all the time. It is supposed to be able to work in low information background, especially dictated by low sampling frequency and must be robust [6].

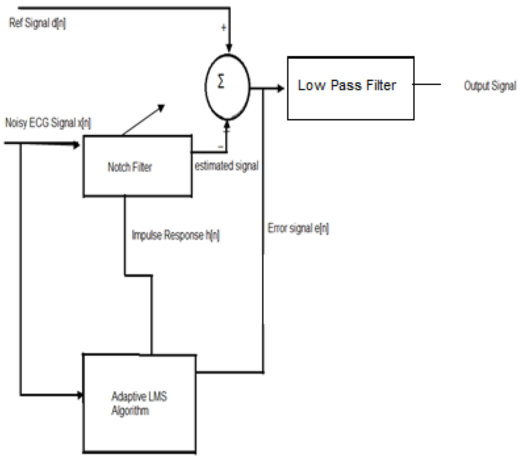


Fig. 2. Proposed interference removal system

The above figure shows the general structure of Adaptive interference cancellers. It consist of the interference signal known as reference signal d[n], the noisy ECG signal x[n], and the error signal. The error signal is calculated as the difference between the estimated signal and the interference. This is processed by an adaptation sub-scheme in order to find an estimate of frequency [7]. The sub-scheme behavior is dependent on the adaptation constant vector. It is a common practice to assume and to be uncorrelated and configure the adaptation sub-scheme in such a way that the mean-squared error (MSE) is minimized [8]. This is referred to as least mean square (LMS) estimation. Now after convergence, the error is a value or an estimate for the signal of interest or desired signal 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 low pass filter. Since, most of the energy in the ECG signal is concentrated near the low frequency range; low 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 removal of power line interference from ECG signal by the use of adaptive LMS algorithm and low pass filter is presented. Most of the energy in the ECG signal is concentrated near the low frequency range; low 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 gives introduction to power line elimination by the use of adaptive filter, section 2 describes about adaptive LMS algorithm with low pass filtering, the results are presented in section 3 and finally concluded in section 4.

II. Adaptive LMS Filter

An ECG Signal with power line interference is given as

$x[n] = g[n] + p[n]$ (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

$p[n] = A\ \sin(\omega n + \theta[n])$ (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 [9]-[12]. The residual error signal is given as

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

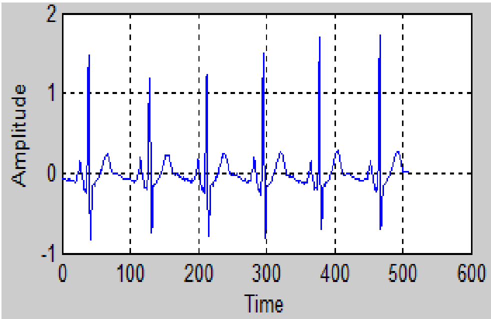
where e[n] is error signal and y[n] is the estimated signal refer figure 2. The estimation of system parameters at the (n+1) sample depends on the error at the n sample and the estimates at the n sample. The phase and amplitude of the sinusoidal interference is varying slowly over time and therefore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

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

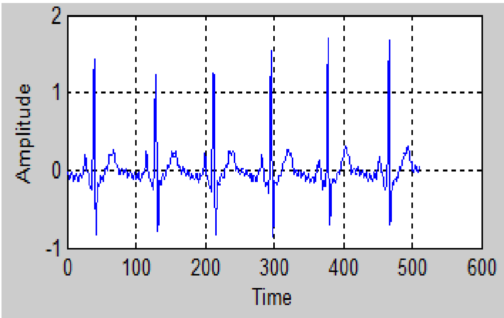
Thus we have tried to reduce the mean square error e[n] by using LMS algorithm. The error signal e[n] contains not only the error due to parameter misadjustment, but also the ECG signal g[n]. Presence of ECG signal in the error effects the estimation of interference parameter. In order to improve the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

III. Results

In order to formalize the performance of adaptive filter for removal of power line interference using LMS algorithm and low pass filtering, simulation is carried out by the use of 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 estimate the performance of the adaptive filter. SNR is measured at the input and output of the adaptive filter. The input SNR is varied or changed 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 calculated between the original ECG signal and the ECG signal with interference removed.

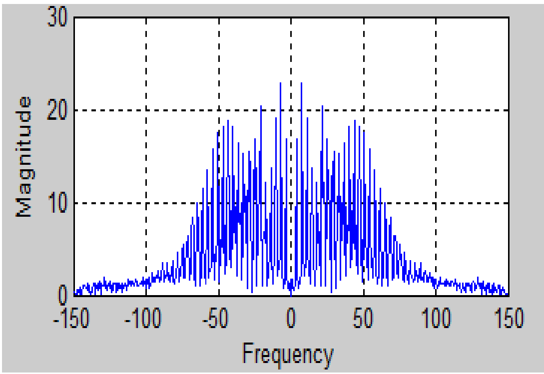


(a) Clean

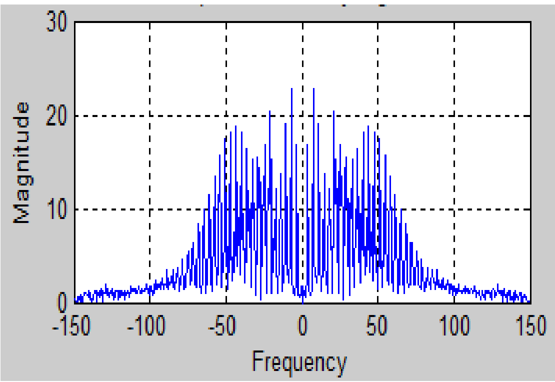


(B) Noisy

Fig. 3. ECG Signal

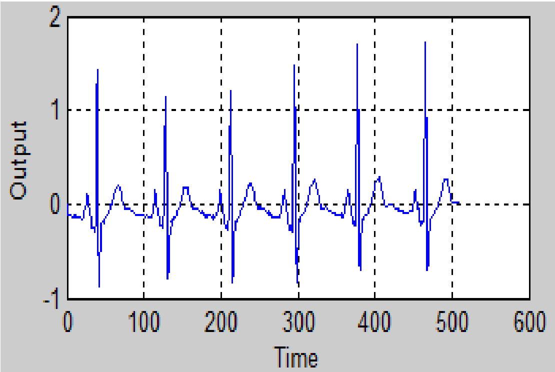


(a) Clean

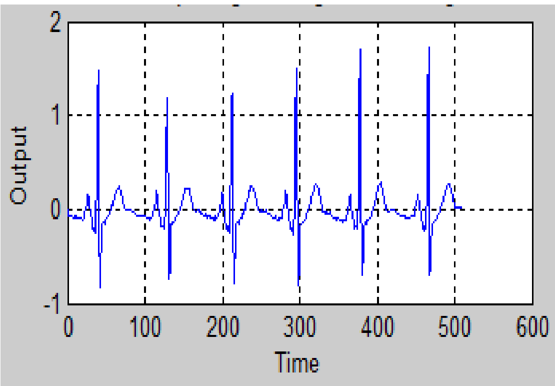


(b) Noisy

Fig. 4. Frequency spectrum of ECG signal



(a) Without low pass filter



(b): With low pass filter

Fig. 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 low pass filter and without low pass filter is shown in figure 5, absence of low pass filter does not distort the ECG signal but it is unable to remove power line interference effectively. Table 1 shows the CC and SNR for adaptive power line interference removal with low pass filter and without low pass filter. In all the simulation experiments, the initial conditions of the PLI parameters were set to zero.

IV. Conclusion

In this paper, adaptive filter to eliminate power line interference from ECG signal using adaptive LMS algorithm and low pass 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 procure most of the ECG signal from the error signal. The simulation results show that adaptive LMS algorithm with low pass filter results in high SNR, the required length of filter can be short and ease for hardware realization by using embedded systems. Simulation experiments clearly show that highest SNR out of 48.2 db is obtained at SNR in of 10 db and correlation coefficient of 0.9999. Absence of low pass filter does not distort the ECG signal but it is not able to remove power line interference effectively which results in SNR out of 21.8 db and correlation coefficient of 0.9973 at SNR in of 10 db. A method for adaptive notch filter to eliminate power line interference in ECG signal can be used in medical equipments to remove noise caused due to AC supply.

Table 1. SNR and CC

Parameter	SNR in	Without low pass filter	With low pass filter
SNR out	30 db	21.8 db	48.2 db
CC		0.9973	0.9999
SNR out	20 db	20.9 db	43.6 db
CC		0.9973	0.9999
SNR out	10 db	17.5 db	40.2 db
CC		0.9973	0.9999

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