Review on Power Line Interference Removal from ECG Signal Using Adaptive and Error Filter

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Abstract: 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. Power line interference may be significant in electrocardiography. Often, a proper recording environment is not sufficient to avoid this interference. ECG signals polluted by power line noise of relatively large amplitude were the frequency of power line interference accurately at 50 Hz or 60 Hz, a sharp notch filter would be able to separate and eliminate the noise. The major difficulty is that the frequency can vary about fractions of a Hertz, or even a few Hertz. Two different approaches have been proposed in literature for this purpose notch filters and adaptive interference cancellers. Notch filters reduce the power line interference by suppressing predetermined frequencies. One of the possible alternatives to take frequency variations into account is the use of an external reference power line signal. 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 technique, available by the use of adaptive filters only, is reported in literature and present serious practical difficulties and is difficult to implement.

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1. Introduction

Power line interference coupled to signal carrying cables is particularly troublesome in medical equipment such as electrocardiograms (ECGs). Cables carrying ECG signals from the examination room to the monitoring equipment are susceptible to electromagnetic interference (EMI) of power frequency (50 Hz or 60 Hz) by ubiquitous supply lines and plugs noise that sometimes the ECG signal is totally masked. Filtering such EMI signal is a challenging problem given that the frequency of the time-varying power line signal lies within the frequency range of the ECG signal. There are some other technical difficulties involved, the most important of which is the low sampling frequency at which the ECG signals are taken and the low computational resources available at the level of the apparatus. 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. 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. 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. One of the possible alternatives to take frequency variations into account is the use of an external reference power line signal. This technique, available by the use of adaptive filters only, is reported to present serious practical difficulties and is difficult to implement. For this reason, other methods, usually very complex and inflexible, are constantly being proposed. 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 with respect to variations in its internal as well as external conditions. An example of internal condition is its settings. External conditions can range from the temperature of the environment in which the equipment is supposed to function to the superimposed noise/distortion on the interfering power signal. The interference is commonly modeled as an additive signal. Therefore, the measured corrupted signal is the sum of the signal of interest and the interference. An ideal power line interference suppression method should eliminate the power line interference while preserving the signal of interest. For this purpose, notch filters and adaptive interference cancellers are two different approaches which can be used. Notch filters reduce the power line interference by suppressing predetermined frequencies. Usually, an infinite impulse response (IIR) filter is adopted. The magnitude and phase spectrum of the ECG signal are less affected by narrow suppression band filters. Therefore, the suppression band of the notch filter should be as narrow as possible. However, this leads to problems whenever the power line frequency is not stable or not accurately known, a mismatch between the suppression band and the power line frequency might lead to inadequate reduction of the power line interference.

2. Literature Review

In this paper [1], we propose an intelligent adaptive noise rejection filter, which tracks and eliminates PLI as well as its harmonics. The proposed system can estimate the frequency of PLI and tune the adaptive filter for precise elimination of PLI as well as its harmonics without the requirement of an auxiliary reference input. The proposed system is based on recursive state space model, inherited with less computational complexity and performs well in a non-stationary environment. The proposed system responds well to the ongoing variations in amplitude and frequency of PLI present in the HRECG signal as well as intra-cardiac signal. In this case the SNR level of input signal is 7.46 dB and the output of proposed system achieves SNR level of 22.14 dB whereas output of notch filter has the SNR level of 15.95 dB. In this paper [2] an improved adaptive canceller for the reduction of the fundamental power line interference component and harmonics in electrocardiogram (ECG) recordings. The method tracks the amplitude, phase, and frequency of all the interference components for power line frequency deviations up to about 4 Hz. A comparison is made between the performance of our method, former adaptive cancellers, and a narrow and a wide notch filter in suppressing the fundamental power line interference component. For this purpose a real ECG signal is corrupted by an artificial power line interference signal. The cleaned signal after applying all methods is compared with the original ECG signal. Our improved adaptive canceller shows a signal-to-power-line-interference ratio for the fundamental component up to 30 dB higher than that produced by the other methods. In this paper [3], an existing adaptive interference canceller is modified by considering the error at the neighboring samples in estimating the power line interference parameters. The performance of the modified adaptive canceller is further improved by using error filtering. The adaptive interference canceller has been modified by replacing the squared-error at each sample by mean-square-error of an error vector in the LMS algorithm. In this paper [4] Kalman based least mean square (KLMS) filter has been proposed. The Kalman based Least mean square filter essentially minimize the mean square error and remove the 50Hz power line interferences. The experimental results shows that the Kalman based LMS filter is more effective compare to other filter techniques. The 4-beat original ECG signal is generated by using MATLAB whose sampling frequency is 500 Hz for each beat and amplitude is 1mv. The 50 Hz power line interference is also generated with sampling frequency of 2000 Hz. The power line interference is then added to the original ECG signal to get the mixed signal. Finally, the power line interference is removed using different adaptive filters based on different algorithms, such as, BLMS, DLMS, XLMS and Kalman based LMS algorithm. One of the major difficulties in biomedical signal processing like ECG is the segregation of the useful signal from unwanted signal affected by Baseline Wander, Power line Interference, High –frequency Noise, Physiological Artifacts etc [5]. Various methods of digital filters are introduced to eliminate real ECG signal from undesirable frequency ranges. It is hard to exert filters with constant coefficients to remove random artifacts, because hum manner is not accurate known relevant on the time. Digital filter method is needed to solve this problem. In usual two kinds of techniques can be subdivided in this paper; there is non-adaptive filters like FIR, IIR and adaptive filters as LMS, NLMS algorithms. Finally we conclude by comparing all filters SNRs, MSEs and frequency spectrum adaptive NLMS algorithm will be the best filter for removing contaminated noises in ECG signal. In this paper [6], Adaptive filtering method can realize effective extraction of non-stationary signals without knowing a priori knowledge about signal and noise, this paper presents an adaptive noise cancellation system for ECG signal base line filtering and power interference suppression, constructs an iterative time LMS algorithm combining variable and fixed step size, which effectively solves the problems of filtering SNR and convergence rate. The experiment results show that this method improves 26.36dB in SNR, eliminates base line drift and power interference effectively, extracts ECG signal accurately and converges quickly, has important practical value in medical clinical diagnosis. A new method of elimination of power line noise in electrocardiogram signals is presented. The proposed method employs, as its main building block, a recently developed signal processing algorithm capable of extracting a specified component of a signal and tracking its variations over time [7]. Design considerations and performance of the proposed method are presented with the aid of computer simulations. The proposed method presents a simple and robust structure which complies with practical constraints involved in the problem such as low computational resource availability and low sampling frequency. Proposed method in this paper [8], a model that includes both interference external to the measuring system and interference coming from its internal power supply. Moreover, the model considers interference directly coupled to the measuring electrodes, because, as opposed to connecting leads, electrodes are not usually shielded. Experimental results confirm that reducing interference coupled through electrodes yields a negligible interference. The proposed model can be applied to other differential measurement systems, particularly those involving electrodes or sensors placed far apart.

3. Overall Analysis of Research Work

For a high quality analysis of the electrocardiogram (ECG), the amplitude of the power line interference should be less than 0.5% of the peak-to-peak QRS amplitude. This corresponds to a signal-to-interference ratio (SIR) of about 30 dB. The SIR is defined as the power ratio between the ECG signal and the power line interference. SIRs between 0 and 40 dB are normally encountered with contact electrodes. With capacitive electrodes the high source impedance can result in large amounts of power line interference and the SIR may be much smaller than 0 dB. The power line interference can contain higher harmonics in addition to the fundamental component. 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. Two different approaches have been proposed in literature for this purpose notch filters and adaptive interference cancellers. Notch filters reduce the power line interference by suppressing predetermined frequencies. Usually, an infinite impulse response (IIR) filter is adopted. However, this leads to problems whenever the power line frequency is not stable or not accurately known, a mismatch between the suppression band and the power line frequency might lead to inadequate reduction of the power line interference. 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. Therefore the notch filter is designed as band-stop filter by widening its rejection band, and thereby accommodating frequency variations, but it does not offer any better solution since it will undesirably distort the ECG signal itself. Adaptive interference cancellers have a general structure as shown in Fig. 1, that consist of the interference signal, the signal of interest, and the corrupted signal. The interference can be represented as a known function of the interference parameter vector. If input signal is a sinusoid, for instance, the interference parameter vector may contain its amplitude and phase. An interference estimate is internally generated as a function of the estimated parameter vector. The error signal is the difference between the corrupted signal and the estimated 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.

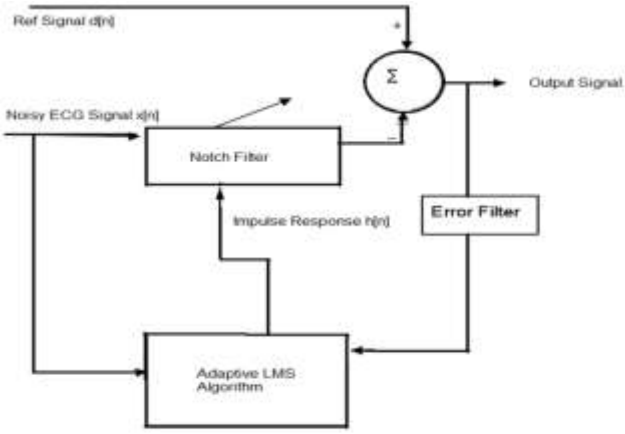

Figure 1 General Structure of Adaptive Interference Canceller

Table 1 shows the comparative table of parameter signal to noise ratio and correlation coefficient

Table 1: Comparative Table

References	**Technique**	**SNR (Max)**	**Correlation Coefficient**
[1]	State space recursive least square	39.72 db	-
[2]	Improved adaptive canceller (LMS)	38 db	-
[3]	Modified adaptive window (LMS)	40.5 db	0.99
[4]	Kalman filter	15.18 db	-
[5]	NLMS	14.3 db	-
[6]	LMS with variable step size	26.36 db	-

4. Conclusion

Adaptive algorithm adjusts the filter coefficient included in the vector w(n), in order to let the error signal e(n) to be the smallest. Error signal is the difference of reference signal d(n) and the filter output y(n). Using this method, adaptive filter can be adapted to the power line frequency set by these signals. When the power line frequency changes, filter through a new set of factors, adjusts for new features. 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. A devise 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.

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