Power Line Interference Removal from ECG Signal using Adaptive and Error Filter

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Abstract— An Electrocardiogram (ECG) signal is electric representation of the activity of human's heart. It is needed to detect the health issues related to heart disease. But sometimes due to mismatches in electrodes signal becomes noisy [2]. Noisy ECG signal may cause difficulty in diagnosis of disease, since very fine features present in an ECG signal may convey important information. So to avoid this, it is important to have the signal as clean as possible. ECG signals may become noisy by power line. The major difficulty in removing this power line interference is that the frequency can vary about fractions of a Hertz, or even a few Hertz. For this use of notch filter to eliminate only the undesirable power line interference while automatically adapting itself to variations in the frequency and level of the noise is one of the best solutions [1]. Proposed method uses the adaptive least mean square (LMS) algorithm for updating the coefficient of notch filter. A method for adaptive notch filter to eliminate power line interference from ECG signal's output is then passes through error filter for achieving the best result. This method can be used in the medical equipments to remove noise caused due to AC supply.

Key words: LMS Algorithm, Adaptive Filter, ECG Signal, Notch Filter

I. Introduction

There are various biomedical signals present in the human body, by examining these biomedical signal one can check the health condition whether that person is clinically fit or not. Electrocardiogram is one of them. ECG signal is electric representation of the activity of human's heart. Various cardiac diseases can be recognized with the help of ECG signal [4].

While recording process of ECG signal, several types of noises may encounter in it. The common type of noises are power line interference (PLI), electrode motion noise (EM), muscle artifacts, baseline wander etc. [4].

The ECG signal is made up of a number of segments or waves of different durations, amplitudes and forms 'slow', low-frequency P and T waves and short and high-frequency Q, R, and S waves, forming the QRS complex. The width of a wave on the horizontal axis represents a measure of time. An upward deflection of a wave is called positive deflection and a downward deflection is called negative deflection. All of the ECG waveforms pattern and variability must be determine accurately to get the better diagnostic result that will show the correct heart disease of the patient. P wave (depolarization /contraction of atria), QRS wave (depolarization of ventricles), T wave (re-polarization of ventricles) and U wave (re-polarization of the papillary muscles), they all are diagnostic critical waves [6].

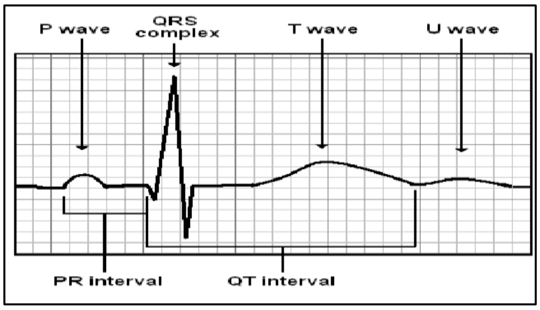


Fig. 3.1: ECG Wave Pattern for One Cardiac Cycle [6].

The power line interference 50/60 Hz is the source of interference in bio potential measurement and it corrupt the biomedical signal's recordings such as Electrocardiogram (ECG), the Electroencephalogram (EEG) and the Electromyography (EMG) which are extremely important for the diagnosis of patients. It is hard to find out the problem because the frequency range of ECG signal is nearly same as the frequency of power line interference. The ECG signal contains the information within the frequency range of around 50 Hz that is why it is called QRS complex. The QRS complex is a waveform which is most important in all ECG's waveforms and it comes into view in usual and unusual signals in an ECG [3].

Adaptive filters are used to eliminate the power line interference (60 Hz) and they are proposed to obtain the impulse response of the normal QRS complex. [4] In the figure above, an uncorrupted ECG signal shows an original signal graph for ECG signal which demonstrate the diagnosis of heart activities for heart patient.

Consequently, it is analysis that how to remove the power line interference of 50/60 Hz which is a problem for biomedical signal measurement. Electromagnetic interface (EMI) from 50/60 Hz power line noise is present in cable holding ECG signal. [5] Several solutions for the removal of power line interference (PLI) have been expressed. The main source of interference is AC power line interference. The interference is caused by magnetic fields as well as by the electric fields. When special signal recording techniques are applied, which minimize the interference therefore some AC noise remains as a consequence of unbalanced input impedances. Further removal of AC noise must be accomplished either by analog or digital filters.

So if the noise changes the amplitude or time duration of the QRS segment then it may result in failure to exactly identify the true condition of patient. Hence, the primary concern is to preprocess the ECG signal, wherein our objective would be to isolate the valid signal component from the undesired noises so that the accurate interpretation of ECG could be carried out [5].

The frequency spectrum of this signal spans from near dc frequencies to about 150 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. An ideal 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.

II. Literature Review

In this paper, an intelligent adaptive noise rejection filter is proposed, 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 on-going 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 [1].

Here the process of noise removal from ECG signal using error nonlinear LMS algorithm ENLMS based adaptive filtering is presented. The input and the desired response signals are properly chosen in such a way that the filter output is the best least squared estimate of the original ECG signal. The proposed treatment exploits the modifications in the weight update formula and thus pushes up the speed over the respective least mean square LMS based realizations. After simulations, conclude that the performance of the error nonlinear LMS algorithm ENLMS is better than the least mean square LMS algorithm in terms of signal to noise ratio increment SNRI.

Here 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 block least mean square BLMS, delayed least mean square DLMS, XLMS and Kalman based LMS algorithm.

In this paper, adaptive filter to eliminate power line interference from ECG signal using adaptive least mean square (LMS) algorithm and low pass filter is presented. The simulation results show that adaptive least mean square (LMS) algorithm with low pass filter results in high signal to noise ratio (SNR). The required length of filter can be short and ease for hardware realization by using embedded systems. 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 low signal to noise ratio (SNR).

This paper compares two algorithms of adaptive filtering method. A comparison is made between least mean square (LMS) and normalized least mean square (NLMS) algorithm of adaptive filtering on the basis of two parameters i.e. signal to noise ratio improvement (SNRI) and average power. The signal to noise ratio improvement (SNRI) is good in normalized least mean square (NLMS) algorithm as compared to least mean square (LMS) algorithm. Normalized least mean square (NLMS) algorithm performs better for noise reduction in the ECG signal but on the cost of excessive mean square error. It results in a more stable ECG signal as compared to least mean square (LMS) algorithm. Normalized least mean square (NLMS) has better convergence speed as compared to least mean square (LMS) due to the adaptive step size. The disadvantage which is faced in these algorithms is the excess mean square error which results in signal distortion which will be tried to rectify in the future work.

III. Adaptive Least Mean Square (LMS) Algorithm

An adaptive filter has two major components: an FIR filter and an adaptive algorithm. The FIR filter transfer function is controlled by variable parameter, computed by adaptive algorithm. Adaptive filters are required for some applications because some parameters of the desired processing operation are not known in advance or are changing.

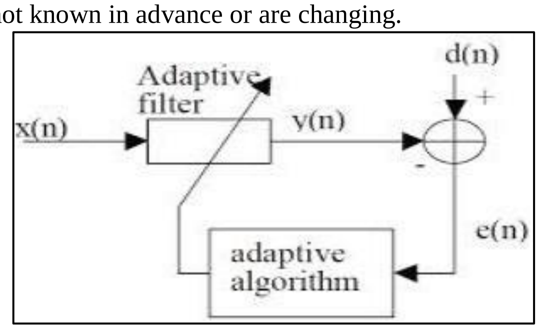


Fig. 1: Adaptive Filter [10].

The closed loop adaptive filter uses feedback in the form of an error signal to refine its transfer function. The algorithm for this project is least mean square (LMS).

IV. IMPLEMENTED METHOD

Implemented method follows the steps as below:

1) Taking input ECG signal. The original ECG signal is taken from MIT BIH Database.
2) Adding power line interference to ECG signal. The 50 Hz or 60 Hz power line interference is generated by using MATLAB.
3) Passing it through Notch filter.
4) Output of Notch filter and noisy ECG signal is going in summation block.
5) Output is drawn out of summation box y(n).
6) Same output goes through Error Filter.
7) Output of error filter goes through Adaptive Filter.
8) Getting Final output y(n).
9) Determine SNR and correlation coefficient.

We have worked on two modules for Removal of Power Line Interference from ECG Signal that are Module without Error Filter and Module with Error Filter. Comparison between these two modules shows which module performs better for ECG noise removal.

A. Implemented Module without Error Filter

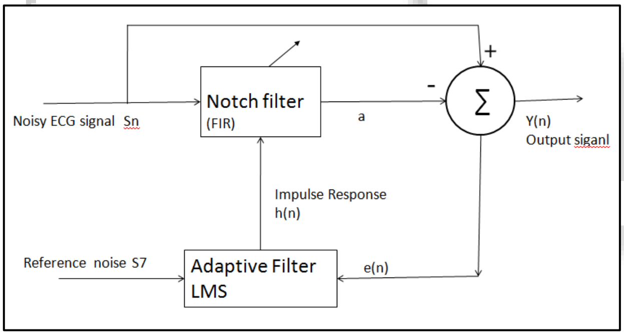


Fig. 2: Block Diagram of Implemented Module without Error Filter

The fig.2 shows the implemented module of without error filter. Here assumption is system is getting a noisy ECG signal, so the noisy ECG signal is directly given as input Sn. Sn is goes to notch filter as well as it input to the summation block.

Notch filter process the signal and output is shown by (a). Next is summation box which accepts the signal (a) and Sn. It pull out the two outputs, one for the final output Y(n) and one e(n) goes to the adaptive filter.

Adaptive filter using the LMS algorithm is uses to update the notch filter so that the notch filter operates to remove noisy signal and gives the nearly original output. System iterates the same loop to provide the better noise removal.

B. Implemented module with error filter

Most of the working of this module is same as the without error filter module. Fig.3 shows the module with error filter. In this the output of summation box (e1(n)) first goes in error filter, in which low frequencies are getting removed. The output of error filter ee1(n) is now goes to the adaptive LMS filter. And it iterates same as the first explained module.

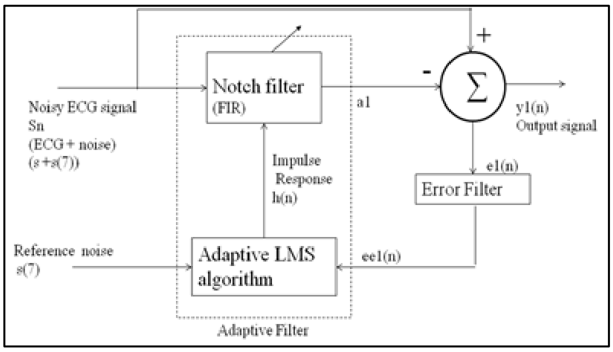


Fig. 3: Block Diagram of Implemented Module with Error Filter

Here the error filter which is a high pass filter is giving the great advantage by removing the low frequencies which consists the most of the pure ECG signal.

Simulation result of with error filter module is shown in following point.

V. SIMULATION RESULTS OF IMPLEMENTED MODULE

In order to validate the performance of adaptive filter for elimination of power line interference using least mean square (LMS) algorithm, simulation is carried out using ECG signals. The ECG signal with sampling frequency of 200 Hz. Signal to noise ratio (SNR) is measured at the input and output of the adaptive filter. The input Signal to noise ratio (SNR) is defined as ratio of the power of the ECG signal to the power of sinusoidal interference and output Signal to noise ratio (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. SNRI is incremented signal to noise ratio which is difference between the output and input signal SNR.

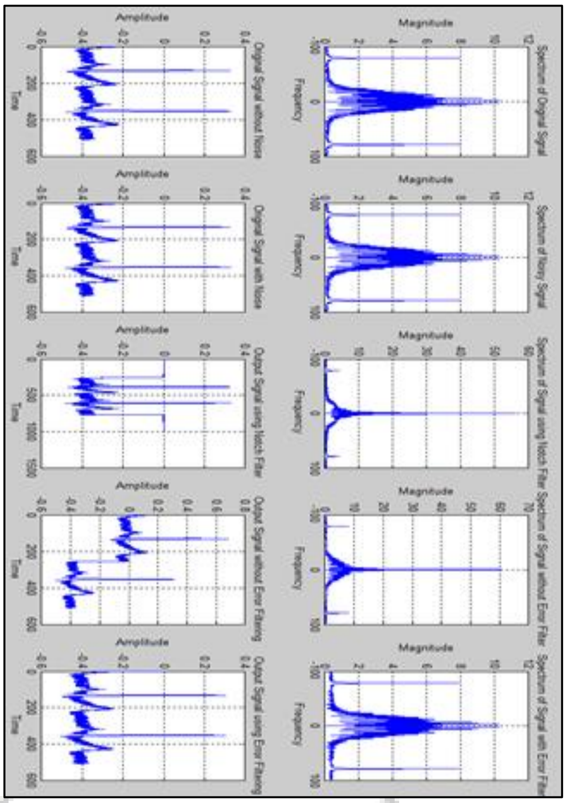
This method is applied on ECG's having record number 100, 101and 103. The obtained result are as follows:

Record No.	SNRI after LMS	SNRI of ENLMS	SNRI of Implemented Work
100	7.8700	11.7140	22.2004
101	7.9841	11.8843	16.29
103	8.2735	11.0548	15.5624

Table 1: Output SNRI (db)

Record no.	Correlation Coefficient (CC)	
	Output without error filter	Output with error filter
100	0.4601	0.9926
101	0.7061	0.9986
103	0.8491	0.9976

Table 2: Correlation Coefficient



Simulation result for Record 100 is as follows:

VI. CONCLUSION AND FUTURE SCOPE

This paper is devoted to the problems and solutions on removal of Power Line Interference. It has been proposed a solution for the power line interference In general FIR filters are used because these types of filters have simple architecture and are logically stable. The LMS algorithm is implemented due to its simplicity and robustness.

The simulation of this project confirms that least mean square (LMS) with error filter is better than error nonlinearity least mean square (ENLMS) algorithm in terms of signal to noise ratio increment (SNRI) by 9.8276 db (record no. 100). For this project, CC is 0.9927 (record no. 100).

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