Removal of Artifacts and other frequency tones from Electrocardiogram using Adaptive filter algorithm

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Abstract—**The ECG signals are often affected by noise from various sources. The power line interference (50/60 Hz) is the main source of noise in most of bio-electric signals. The research paper presents the removal of power line interference from ECG signal using the advanced adaptive filtering technique with LMS (least mean square), NLMS (normalized least mean square) algorithm and the removal of power line interference and other single frequency tones using Notch Filter. In this paper the noisy ECG signal passes through designed adaptive filter based upon advance LMS algorithm, NLMS algorithm and Notch Filter analyses the output of filter on the basis of mean square error and signal to noise ratio. Also the convergence time of LMS and NLMS algorithms have been estimated.**

Keywords- ***ECG signal, LMS,*** **NLMS, Notch Filter, Adaptive 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. While recording process of ECG signal, several types of noises may encounter in it. The four main parts commonly used in medical ECG terminology are P-wave, QRS-complex, T-wave and U-wave, which are shown in Figure 1. The origins of these waves are:

- P wave: sequential activation (depolarization) of the right and left atria
- QRS complex: right and left ventricular depolarization
- T wave: ventricular repolarisation
- U wave: repolarisation of the papillary muscles, rarely seen.

In ECG signal the common type of noises are given below

1. Baseline wander interference
2. Power line interference
3. Muscle contraction noise
4. Electrosurgical noise
5. Motion artifacts

ECG preprocessing generally takes care of denoising the ECG signal. The base line wandering and the power line interference are the most substantial noise and can strongly affect the ECG signal analysis. Base line wandering usually comes from respiration and lies between 0.15 and 0.3 Hz. The power line interference is a narrow-band noise centered at 50/60 Hz with a bandwidth of less than 1 Hz.
Remove or minimize these interferences prior to further diagnosis for any medical application. The QRS segment is very important and it is predominantly used for clinical observation. So if the noise changes the amplitude or time duration of the segment then recognizing the true condition of patient is very difficult task. Therefore the primary concern is to preprocess the ECG signal. The objective is to separate the valid signal component from the undesired noises so that the accurate interpretation of ECG could be done.

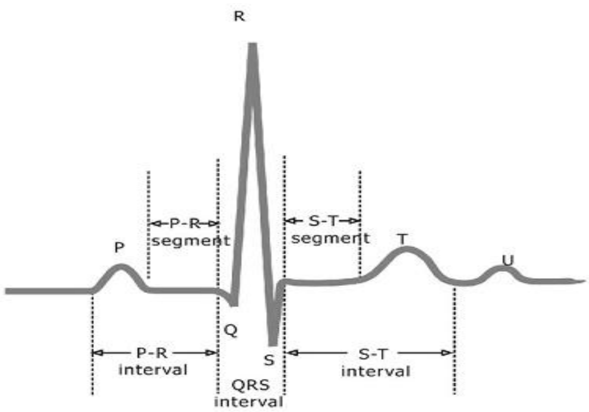

Fig. 1 ECG Waveform

II. ADAPTIVE FILTER IN SIGNAL PROCESSING

Noise in ECG Signal can be removed by the filters with adjustable coefficients called the adaptive filters. An adaptive filter is a filter that self-adjusts its transfer function according to an optimizing algorithm. Adaptive technique uses algorithms, which enable the adaptive filter to adjust its parameters to produce an output that matches the output of an unknown system. Least mean squares (LMS) and normalized least mean Square (NLMS) algorithm are a class of adaptive filter used to mimic a desired filter by finding the filter coefficients that related to producing the least mean squares of the error signal. Many researchers are working for the removal of noises with the help of various techniques. Sorror Behbahani *et. al.* [6] investigated the LMS algorithm of the adaptive filter and compared it with the non-fault tolerant adaptive filters for the ECG noise removal. The LMS algorithm requires very little computational power or memory even when handling complex signal processing. The comparison between the Adaptive filtering Techniques and non-fault tolerant techniques show that the non-fault tolerant techniques fail to give the right response. These non-fault tolerant techniques are unable to remove the nonstationary or dynamic noise from the ECG signal. The adaptive filtering techniques are able to remove the dynamic or nonstationary noise from the ECG signal. The power line interference (PLI) comes in category of Dynamic noise because PLI is occurred due to electrical signal and it may be vary with respect to time. So adaptive filtering approach can readily remove 50/60 Hz artifact noise and give best ECG signal without losing parts of it. The main advantage of the LMS algorithm is its simplicity both in terms of the memory requirement and the computational complexity. The NLMS algorithm provides better output response as compare to LMS algorithm. As the LMS algorithm does not use the exact values of the expectations, the weights would never reach the optimal weights in the absolute sense, but a convergence is possible in mean. That is, even though the weights may change by small amounts, it changes about the optimal weights. However, if the variance, with which the weights change, is large, convergence in mean would be misleading. This problem may occur, if the value of step-size is not chosen properly. If step size is chosen to be large, the amount with which the weights change depends heavily on the gradient estimate, and so the weights may change by a large value so that gradient which was negative at the first instant may now become positive. And at the second instant, the weight may change in the opposite direction by a large amount because of the negative gradient and would thus keep oscillating with a large variance about the optimal weights. On the other hand if step size is chosen to be too small, time to converge to the optimal weights will be too large. The main drawback of the "pure" LMS algorithm is that it is sensitive to the scaling of its input x(n). This makes it very hard (if not impossible) to choose a learning rate step size that guarantees stability of the algorithm [20]. The Normalized least mean squares filter (NLMS) is a variant of the LMS algorithm that solves this problem by normalizing with the power of the input.

III. LITERATURE SURVEY

The power line interference and baseline drift is the classical problem in the ECG processing, which produces the art factual data that makes it difficult to measure the ECG parameters accurately. Chavan *et. al.* [15] compares the performances of Butterworth filter, Chebyshev I filter, Chebyshev II filter, and elliptical filter. When different filters were used the signal power after filtration was reduced. Syed Zahurul Islam *et. al.*[2] present the paper on removal of noise from ECG (Electrocardiogram) signal or nullify AC and DC noises using the two adaptive algorithm- the LMS and the RLS . This paper shows the performance between these algorithms based on their parameters and the effect of filter length and the corresponding correlation coefficient. Yatindra kumar et. al. [18] presents the paper on performance analysis of different filters for power line interference Reduction in ECG signal. The best three algorithms have been used for performance analysis of ECG signal. First one is Frequency domain filtering (Notch filter), second is Optimal (Wiener) filtering, third is Adaptive filtering. The result shows that the adaptive filtering after tuning the taps to some optimum value gives the best result. E. Farahabadi et. al. [19] presents the paper on Noise removal from Electrocardiogram Signal Employing an Artificial Neural Network in Wavelet Domain. In this paper , the wavelet transform and also a neural network based on adaptive filters and used for removal of noise from ECG signal

IV. IMPLEMENTATION PROCEDURE

3.1 LMS algorithm

The LMS algorithm belongs to the class of stochastic gradient methods [7] as this algorithm operates on stochastic inputs depicts in figure 2. Consider x(n) input vector of time delayed input values given as

$$x(n) = [x(n)x(n-1) \ldots\ldots x(n-L+1)]^t \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

And the tap weight vector at the *n*th index is

$$w(n) = [w_0(n)w_1(n) \ldots\ldots w_{L-1}(n)]^t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The steps in implementing the tap-weighting adaptation are

Step 1. Assume a value for w(n) at time n
Step 2. Compute the filter output given by the Equation

$$y(n) = w^t(n)x(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Step 3.Evaluate the estimation error given by the Equation

$$e(n) = d(n) - w^t(n)x(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where d(n) is the desired response available initially

Step 4. Compute the next filter weight using the update Equation

$$w(n+1) = w(n) + \mu x(n)e(n) \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots (5)$$

Where μ is denotes the step-size parameter.

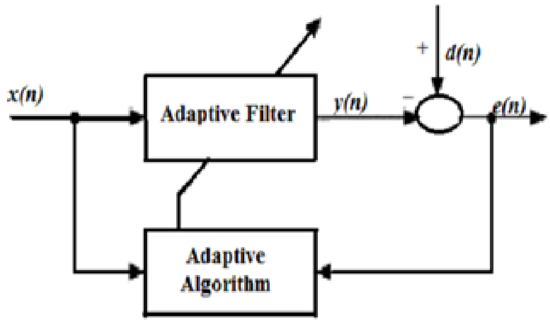

Fig.2 Basic Adaptive filter structure

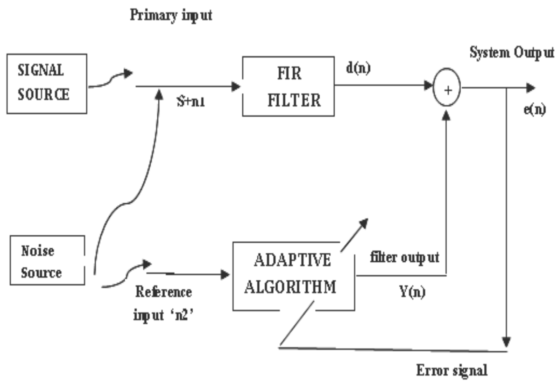

Fig.3 Advance adaptive structure

Figure 3 shows the advance adaptive structure. In this structure of filter the primary signal pass through FIR filter then becomes desired signal d(n).FIR filter is used to reduce the noise from primary signal.
Fig. 4 shows the block diagram of the LMS algorithm, note that the error is feedback to effect weight adaptation that will ultimately result in a better estimation of x *(n).*

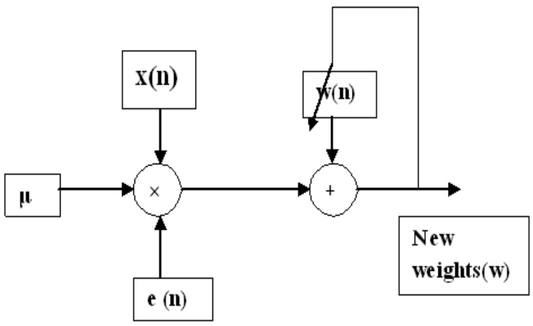

Fig.4 Block diagram of LMS algorithm

Here for the ECG signal enhancement, the ECG signal s(n) is corrupted with the noise signal p(n) and is applied to the filter whose output is y(n). Since the signal and noise are uncorrelated, the mean square error (MSE) is,

$$E[e^2(n)] = E\{[s(n) - y(n)]^2\} + E[p^2(n)] \ldots \ldots \ldots \ldots \ldots (6)$$

Minimizing the MSE [2] results in the filter output which is the best least squares estimation of the signal s(n).

3.2 NLMS algorithm

The NLMS algorithm is a modified form of the standard LMS algorithm [11,12]. The NLMS algorithm updates the coefficients of an adaptive filter by using the following equation 7.
The NLMS algorithm becomes the same as the standard LMS algorithm except that the NLMS algorithm has a time-varying step size μ(n). This step size improves the convergence speed of the adaptive filter.

$$w(n+1) = w(n) + 2\mu \frac{x(n)}{\|x(n)\|^2} e(n) \ldots \ldots \ldots \ldots \ldots \ldots . (7)$$

3.3 Notch Filter

It is well known or simplest filter to remove the power line interface notch filter compute the Fourier transform of the signal delete undesired component and the inverse Fourier transform. Humming which is known as low frequency noise has been taken and added in the original ECG signal. The noisy ECG signal is passed through notch filter and windowed sinc low pass filter, which filtered out hum and high frequency noise portion from the ECG signal. The Frequency response characteristics of Notch Filter with nulls at frequencies ω_0 and ω_1 shown in figure 5.

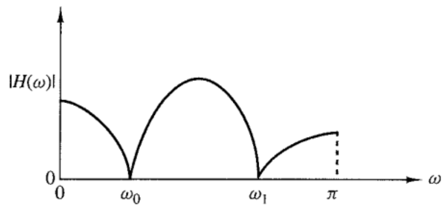

Fig.5 Freq. Response characteristics of Notch filter

We are adding the original ECG signal of sampling frequency 800 Hz with 50Hz PLI and other frequency tones like sine wave of 375 Hz, π/4 phase shift and cosine wave of 375 Hz, 2π/7 phase shift. The desired output has then achieved at the final output

V. SIMULATION RESULTS

In our experiment firstly the ECG signal of sampling frequency 3600 Hz added with the power line interference

(50 Hz sine wave frequency) noise signal. Then mixed signal pass through simple FIR filter of 16 orders and another random noise signal applied to the LMS adaptive filter shown in figures 6.

The original ECG signal, noise signal (50Hz), mixed signal (ECG signal added with noise signal), error signal, filtered output ECG signal shown in figure 6.1, 6.2, 6.3, 6.4, 6.5 respectively. Same noisy signal pass through NLMS adaptive filter and the response shown in figure 7.

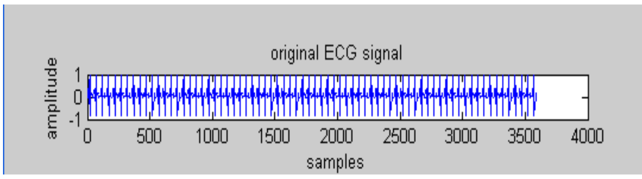

Fig.6.1 original ECG signal

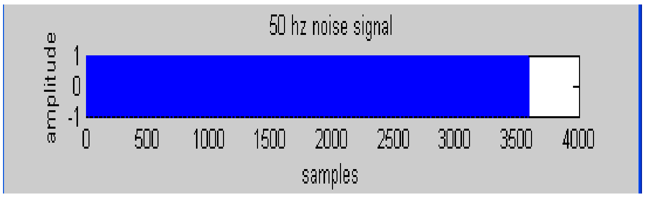

Fig.6.2 50 Hz noise signal

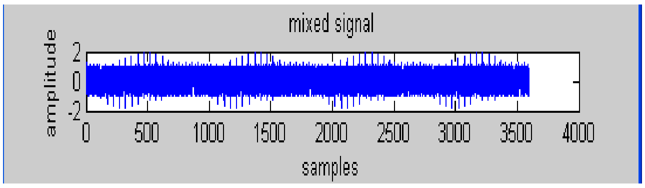

Fig.6.3 mixed signal

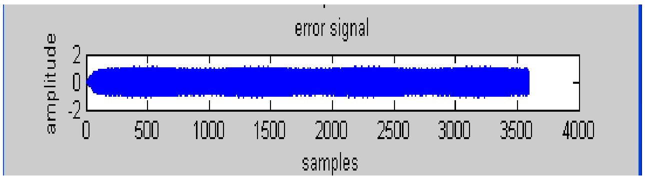

Fig.6.4 error signal

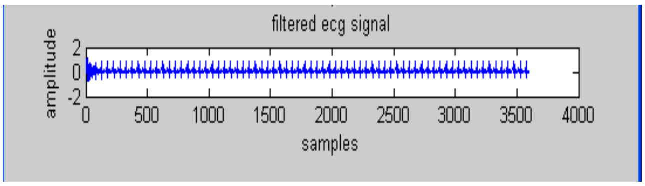

Fig.6.5 filtered output ECG signal

Figure 8 shows the removing of power line interference (50/60Hz) and other frequency tones using notch filter. The ECG signal with sampling frequency 800Hz added with PLI and other frequency tones. Notch filter is able to remove nonstationary or dynamic PLI and other frequency component of signal. Figure 9 shows that the convergence curves of NLMS algorithm for PLI cancellation. The NLMS algorithm converges in very less time as compare to LMS algorithm.

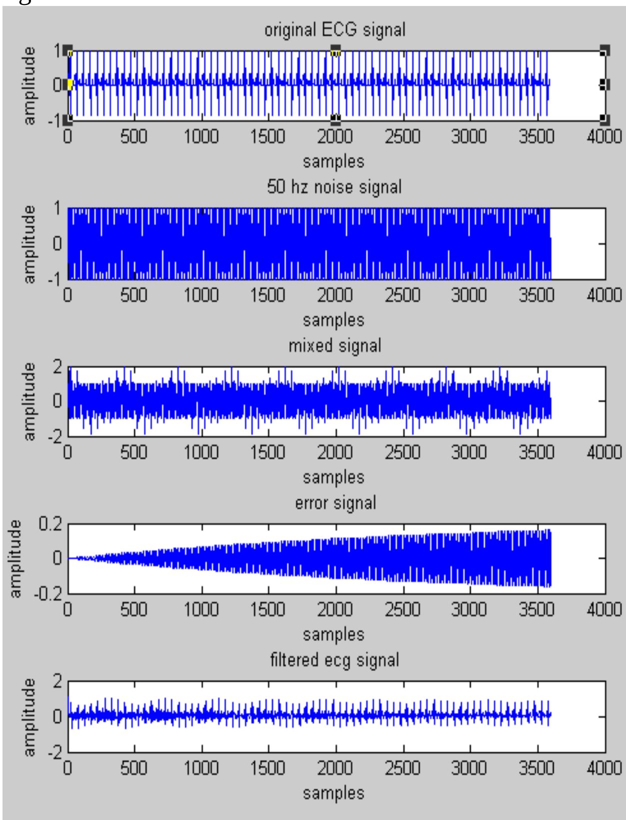

Fig.7 signal analysis using NLMS algorithm

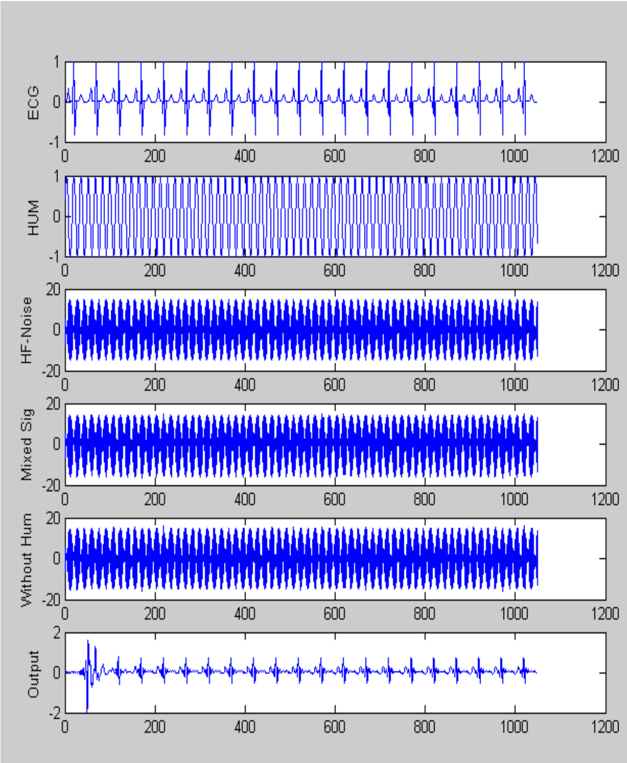

Fig.8 PLI, other freq. tone remove using notch filter

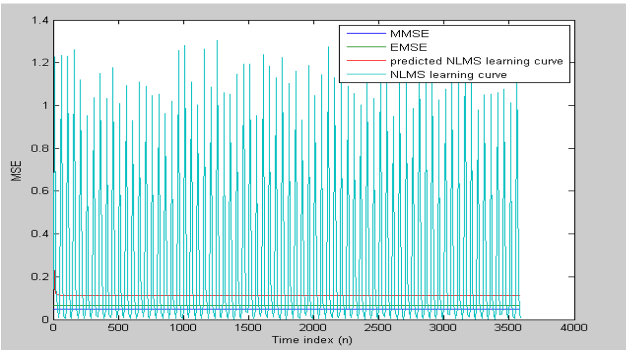

Fig. 9 Convergence curve of NLMS algorithm for PLI cancellation

The mean square error (MSE), signal to noise ratio (SNR) corresponding to step size (mu), shown in table I.

TABLE I
OUTPUT RESPONSE

Step Size (μ)	**Filter length(M)**	**LMS**		**NLMS**	
		SNR (db)	**MSE**	**SNR (db)**	**MSE**
0.005	16	10.79	0.0481	11.25	0.0351
	32	10.86	0.0423	12.03	0.0336
0.009	16	10.88	0.0480	11.56	0.0335
	32	11.02	0.0371	12.56	0.0324

VI. CONCLUSIONS

In this paper the problem of noise cancellation from ECG signals using adaptive filtering approach is proposed and tested on real ECG signals obtained from MIT-BIH data base. Adaptive filter with LMS algorithm is providing the better result than other conventional techniques and the NLMS algorithm provides better SNR and MSE as compare to LMS algorithm. In LMS, NLMS algorithm the SNR increasing and MSE value decreasing when the step size is small value shown in table I. The convergence time is less in NLMS as compare to LMS algorithm. The Notch filter is able to remove the power line interference PLI (50/60Hz) and other frequency component.

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