Design Simulation and Analysis of Efficient De-noising of ECG Signals with Adaptive Filtering Algorithms & Patch Based Method

Anita Yadav(M.TECH Scholar)[1], Manish Mukhija(Asst. prof.)[2]

[1,2]Department of Computer Science, Modern Institute of Technology and Research Center, Alwar, Rajasthan, India

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Abstract— ECG signals have been proven a very versatile tool for detection of cardiovascular diseases. But during recording of these signals, the ECG data gets contaminated by various noise signals caused by power line interference, base lone wander, electrode movement, muscle movement (EMG) etc. These noise signals are known as artifacts. These artifacts mislead the diagnosis of heart which is not desired. To avoid this problem caused by artifacts, removal of these artifacts has become essential. There are various techniques which have been used for artifacts rejection from ECG. Conventional filters remove the artifacts up to some extent but these filters are static filters. These filters cannot update their coefficients with change in environment.

Hence adaptive filters, now days, are used for artifact removal from ECG signals. Adaptive filters update their coefficients according to the requirement. There are various adaptive algorithms such as Leas Mean Square (LMS), Recursive Least Square (RLS), Normalized Least Mean Square (NLMS) etc are present. Moreover, there is one more method is described which is patch based and used for artifact rejection from ECG signals. This method was previously used only for image denoising but now it has been using for artifact rejection from biomedical signals.

Indexed Terms- ECG, EMG, LMS, NLMS, RLS

I. INTRODUCTION

ECG records carry information about abnormalities or responses to certain stimuli in the heart. Some of the characteristics of these signals are the frequency and morphology of their waves. These components are in the order of just a few up to 1mV and their frequency content within 0.5Hz and 100Hz depending on individual [1]. The morphology and frequency are analyzed by physicians in order to detect heart disorders and heart related pathologies. However, the ECG signal is generally with other biological signals like electroencephalogram, electromyogram, baseline Wander and power line interference. Due to the presence of artifacts, it is difficult to analyze the ECG, for they introduce spikes which can be confused with cardiological rhythms. Thus, noise and undesirable signals must be eliminated or attenuated from the ECG to ensure correct analysis and diagnosis [1].

The removal of artifacts in ECG signals is an essential procedure prior to further diagnostic analysis in many clinical applications, e.g., detection of QRS complexes, classification of ectopic beats, analysis of asymptomatic arrhythmia, extraction of the fetal ECG signal from the maternal abdominal ECG, diagnosis of myocardial ischemia, diagnosis of atrial fibrillation, and ECG data compression.

The goal of ECG signal enhancement is to separate the valid signal components from the undesired artifacts, so as to present an ECG that facilitates easy and accurate interpretation[2].

In recording a heart beat (an ECG), which is being corrupted by a PLI (50Hz/60Hz) noise (the frequency coming from the power supply(50Hz) in many countries) [3]. We remove the noise is to filter the signal with a notch filter at 50 Hz. However, due to slight variations in the power supply to the hospital, the exact frequency of the power supply might (hypothetically) wander between 47 Hz and 53 Hz. A static filter would need to remove all the frequencies between 47 and 53 Hz, which could excessively degrade the quality of the ECG since the heart beat would also likely have frequency components in the rejected range [5]. To circumvent this potential loss of information, an adaptive noise cancellation filter [4] has been used. The adaptive filter would take input both from the patient and from the power supply directly and would thus be able to track the actual frequency of the noise as it fluctuates. Such an adaptive technique generally allows for a filter with a smaller rejection range, which means, in our case, that the quality of the output signal is more accurate for medical diagnoses[5].

II. LEAST MEAN SQUARE ADAPTIVE ALGORITHM

The LMS algorithm is extensively used in different application of adaptive filtering due to low computational complexity, stability and unbiased convergence. In any signal's processes there can be error occurred in the required output. There must be suitable algorithm needed to manipulate this problem. The least mean square (LMS) algorithm is introduced to minimize the error between a given preferred signal and output of the linear filter by adjusting recursively the parameters of a linear filter [6]. The more suitable and basic algorithm for the adaptive filtering is LMS, which is also famous for the stability of the system [7].LMS is the most important algorithms in whole family of algorithms, which has been developed for minimizing the error [8]. Least mean square algorithm has lots of benefits in different applications; it has been productively used in many applications due to the following performance aspects. LMS have the ability to reject noisy data due to minute step size parameter μ. LMS demonstrate slowly time varying system [7]. In general LMS adaptive filter removes noise or obtains a desired signal by adapting the filter coefficient with least-square algorithm based on given filter. The performance of the LMS algorithm is very high and it is simple in implementation for the removal of low frequency noise.

The suitable value for step size parameter μ can be selected according to the applications requirement [10].

$$\overline{w}(n+1) = \overline{w}(n) + 2\mu e(n)\overline{x}(n)$$

LMS is used for the simplification of gradient vector computation. [6] The overview of the structure and operation of the LMS algorithm can be discussed according to LMS algorithm's properties and its processes. [9] The main property of LMS algorithm is its convergence behavior in a stationary environment. [6] LMS is a linear adaptive filtering algorithm and is consists of two basic processes.

Filtering Process: Filtering process is used to calculate the output of linear filter and to generate an estimated error by comparing this output with a desire response. [9]

An Adaptive Process: An adaptive process is used for the automatic adjustment of the filter's parameters in accordance with the estimated error. [9]

The overview of least mean square (LMS) algorithm is shown in figure 2.1. The primary input has been taken, where 'X' is the reference input. The error signal occurs for the desired output, there LMS adaptive filter has employed to manipulate the error.

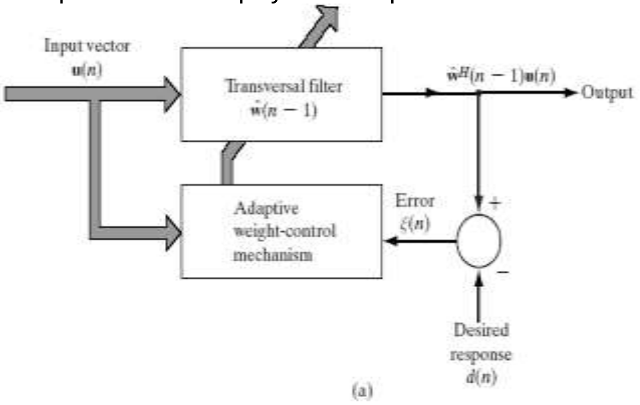

Fig: 2.1: Adaptive Filter

1. Filtering : $y(n) = \overline{W}^T(n)\overline{x}(n)$

2. Error estimation : $e(n)=d(n)-y(n)$

3. Tap-weight vector adaptation : $\overline{W}(n+1) = \overline{W}(n) + 2\mu e(n)\overline{x}(n)$

The equation above shows the desired signal and the filter output, where d(n) is the desired signal and y(n) is the filter output. For the minimization of error signal the input vector x(n) and e(n) are employed. Here it needs to work according to the criterion that is supposed to minimize.

III. PATCH BASED NON LOCAL MEANS METHOD

NL is an image de-noising process based on non-local averaging of all the pixels in an image. In particular, the amount of weighting for a pixel is based on the degree of similarity between a small patch centered on that pixel and the small patch centered around the pixel being de-noised [14]. If compared with other well-known denoising techniques, such as the Gaussian smoothing model, the anisotropic diffusion model, the total variation denoising, the neighborhood filters and an elegant variant, the Wiener local empirical filter, the translation invariant wavelet thresholding, the NL-means method noise looks more like white noise [13]. Image denoising has been a subject of interest in the field of image processing for many years. Noise is inherent during image acquisition. Reducing the amount of noise in an image makes the image more pleasing to the eye and it is also an important pre - processing step since it improve s the performance of high level tasks such as edge detection and object tracking There are many different denoising algorithms, but most belong to one of the following three c lasses :

1. Filters that act on a local region within an image, like mean, median or Gaussian filters.

2. Filters that take the entire image into consideration, such as frequency do main filters which reduce noise in the Fourier or wavelet domain; and Neighborhood filters , which act on pixels with similar gray level values .

A. Basic Nonlocal Means Algorithm

Nonlocal means denoising [11] addresses the problem of re-covering the true signal u given a set of noisy observations, v = u + n, where n is additive noise. For a given samples, the estimate ˆu(s) is a weighted sum of values at other points t that are within some "search neighborhood' N (s)

$$\hat{u}(s) = \frac{1}{Z(s)} \sum_{t \in N(s)} w(s,t)v(t)$$

where $Z(s) = \sum_t w(s,t)$, and the weights are [7]

$$w(s,t) = \exp\left(-\frac{\sum_{\delta\in\Delta}(v(s+\delta)-v(t+\delta))^2}{2L_\Delta\lambda^2}\right)$$

$$\equiv \exp\left(-\frac{d^2(s,t)}{2L_\Delta\lambda^2}\right)$$

Where, λ is a bandwidth parameter, while Δ represents a local patch of samples surrounding s, containing L_Δ samples; a patch of the same shape also surrounds t. Although a variety of patch weightings are possible [11], square patches centered on the points of interest are most common [12.] The novelty of NLM is that the weighting w(s, t) depends on the patch similarity, not on the physical distance between the points s and t. Averaging similar patches helps to preserve edges in contrast to more typical filtering (cf., convolution by a Gaussian smoothing kernel) [12].

Assuming self-similarity extends throughout the signal, the neighborhood N (s) is ideally taken to be the entire signal, so the averaging process is fully nonlocal. However, the computation scales linearly with the size of N (s), so N (s) is usually limited to reduce computation [12].

IV. SIMULATION & RESULTS

To denoise the ECG data with LMS adaptive filtering algorithm, the ECG signal is generated in MATLAB. To contaminated the ECG signal 50 Hz power Line Interference is also generated in MATLAB. Then to validate the denoising process, the generated power line interference noise is added to generated ECG signal. The generated ECG signal, noise signal along with noise added ECG signal is shown below:

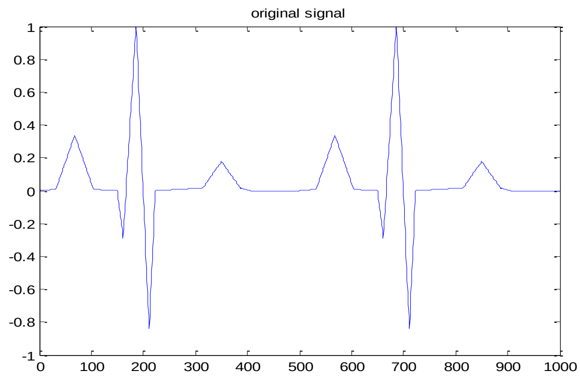

Fig 4.1: ECG Signal generated in MATLAB

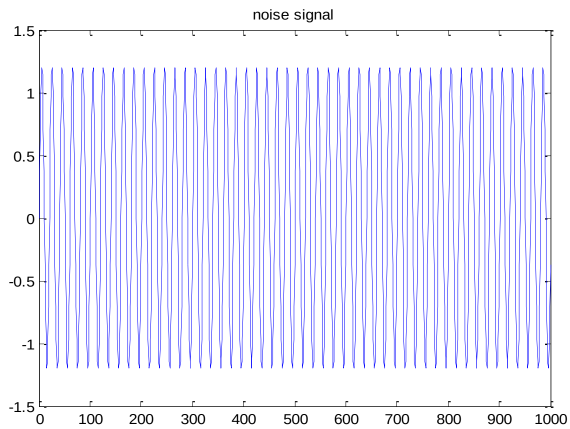

Fig 4.2: Power Line Interference Noise generated in MATLAB

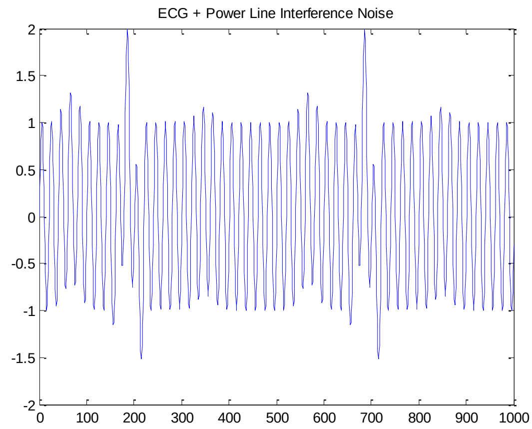

Fig 4.3: ECG Signal + Noise

This ECG signal mixed with noise is then filtered by LMS adaptive algorithm. The ECG signal free from power line interference is obtained successfully and shown below in figure 4.4.

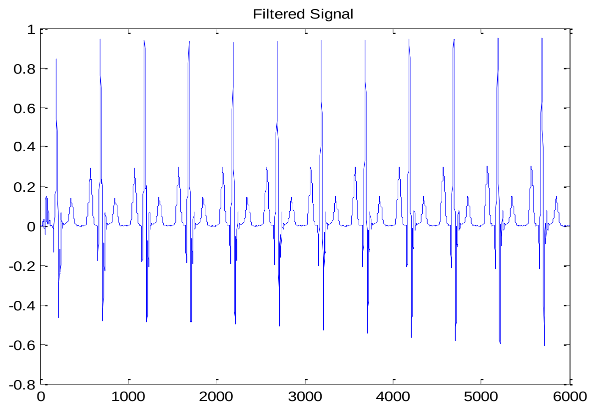

Fig 4.4: Filtered ECG Signal from 50 Hz Power Line Interference Noise

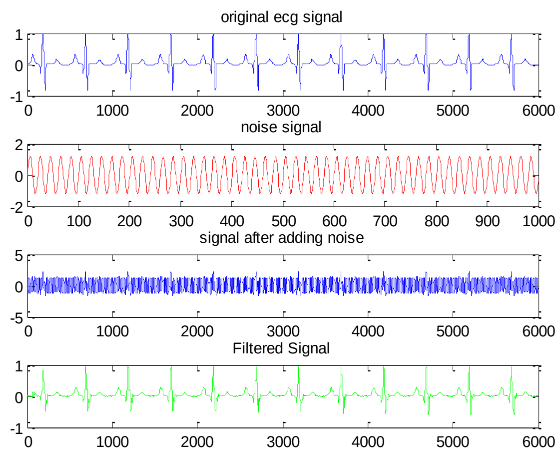

Fig 4.5: Original Signal, 50 Hz Noise Signal, ECG Signal + Noise & Filtered Signal with LMS Adaptive Filtering

In this method, The ECG data from MIT-BHE database is taken. Then 10 db SNR noise is created in MATLAB environment. The noise is added in ECG signal. The denoising of this mixed signal is done using Patch Based Non Local Means algorithm. The results are shown as follow:

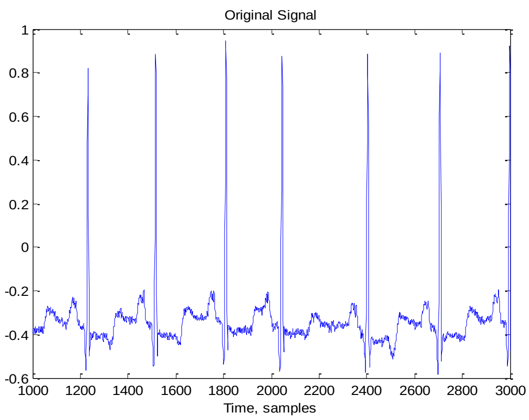

Fig 4.6: ECG waveform from MIT-BHE Database

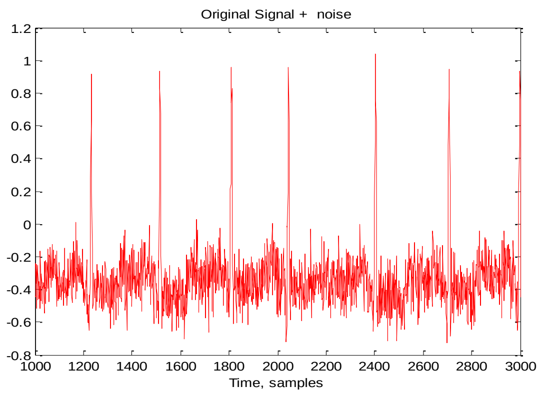

Fig 4.7: ECG Signal + Noise

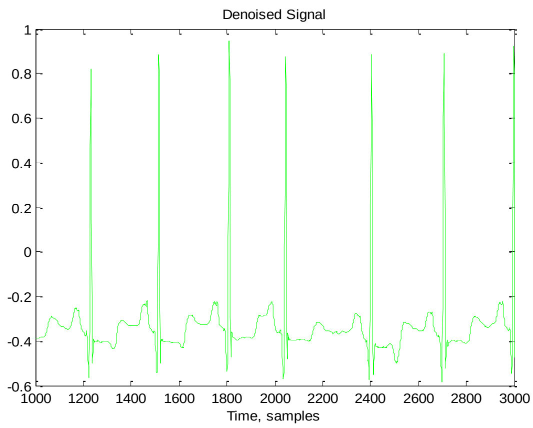

Fig 4.8: Filtered ECG Signal with Patch Based Method

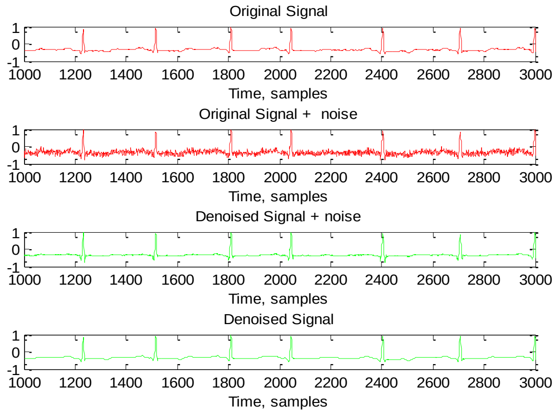

Fig 4.9: Original Signal, Noise Signal, ECG Signal + Noise & Filtered Signal with Patch Based Method

V. CONCLUSION & FUTURE SCOPE

In this paper, the ECG signal contaminated with power line artifact is denoised with Least Mean Square (LMS) adaptive algorithm. The ECG signal is created. The power line noise with 50 Hz frequency is created and added with ECG signal. This ECG signal contaminated with power line noise is then filtered using Least Mean Square (LMS) adaptive algorithm. The denoised ECG signal is then recovered. The Patch Based Non Local means method has also removed the noise from the ECG signal successfully. The LMS algorithm is simple, robust and easy to implement.

In future, algorithm with fast convergence can be developed for denoising of ECG signal since the LMS adaptive algorithm has slow convergence.

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