



A combination of RLS algorithm with Wavelet transform for Detection and Removal of OA from EEG signal

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Abstract: Brain is considered as controller of whole body. Electroencephalogram is the measure for Brain's electrical activity. During sending and receiving of internal body signal, it generates the Electrical signal on scalp. Various noise and artifact are present in raw recording of EEG signal. Opening or closing of eye directly effects on EEG recording, and is considered as OA artifacts. Many researchers currently are working in this direction. In proposed method, DWT is used with Adaptive method. DWT is used to detect OA zone and create reference signal. Adaptive Noise canceller is actively cancelling OA from EEG using reference channel and primary channel. EEG is a non-stationary and nonlinear signal, so conventional filter does not give good result. DWT is repetitive filter bank which detects low frequency zone where OA is highly affected. Thresholding is technique to remove noise in primary way but improper selection of threshold value may remove true EEG signal. Proposed method is combination of two techniques which improves the result.

Keywords: EEG (Electroencephalogram) EOG (electro oculogram) RLS (recursive Least Square) LMS (Least Mean square) OA (ocular Artifact) MSE (Mean square Error) MAE (Mean Absolute Error) DWT (Discrete wavelet transform) PSNR (Peak signal to Noise ratio)

I. Introduction

The Electroencephalogram is valuable and distinctive measure of electrical activity of brain. It is represented as a graphical display of a voltage of brain function that is recorded over time. The physiological system that is responsible for movement, emotion, intelligence, thinking and environment stimulation, is called nervous system. Brain cells continually send messages for various physiological activities that can be picked up as small electrical impulses on the scalp. The process of picking up and recording the impulses is known as an EEG. EEG signals are measured from peak to peak and normally range from 0.5 to 100 μ V in amplitude. Electroencephalography waveforms can be classified into four basic groups: delta (0.4-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), Gamma (above 30 Hz) [16] [17].

Due to very low amplitude, EEG signals are susceptible to artifacts and noises. The noise can be electrode noise or can be generated from the body itself. Many types of noise contaminate the signals during recordings such as the electrode noise, baseline movement, EMG disturbance, eye movements, eye blinks and sometimes ECG disturbance. The noise in the EEG signal is called the artifact and these artifacts are needed to be removed from the original signal. Artifacts make analysis and further processing of the EEG signals difficult.

Ocular Artifact is a physiological noise that directly implicate in recording of EEG signal activity. OA creates difficulties for Physician to distinguish the normal EEG and Abnormal EEG. OA is generated by eye activity like movement of eye, suddenly opening or closing of eye. OA artifacts are typically large amplitude and low frequency in nature and mainly concentrate on the low frequency region of EEG signals. Due to nonlinear and non-stationary characteristic of signal, we cannot apply conventional filtering technique for removal of artifact. There is some overlapping of spectrum, so conventional low-pass filtering or high pass filtering techniques cannot be applied for effective minimization of EOG artifact from corrupted EEG signals [2].

II. Wavelet Transform

A. Discrete Wavelet Transform

Discrete wavelet transform is one of noble technique to analyze signal based on frequency as well as time. DWT provide time and frequency information of signal [10] [11].

Wavelets are generated by mother wavelet function $\Psi(t)$, which follows two properties: zero mean and unit length. Basis functions are generated by scaling (s) and shifting (l) of mother wavelet function.

$$\Psi_{s,l}(t) = \frac{1}{\sqrt{s}} \Psi\left(\frac{t-l}{s}\right)$$

The signal is separated into "detail" and "approximation" using the multi resolution decomposition algorithm. The DWT execute repeating filter with different time –frequency localization of input signal by using pair of

filters called low pass filter (LPF) and high pass filter (HPF). Every time Cutoff frequency is considered as middle of input signal frequency [12].

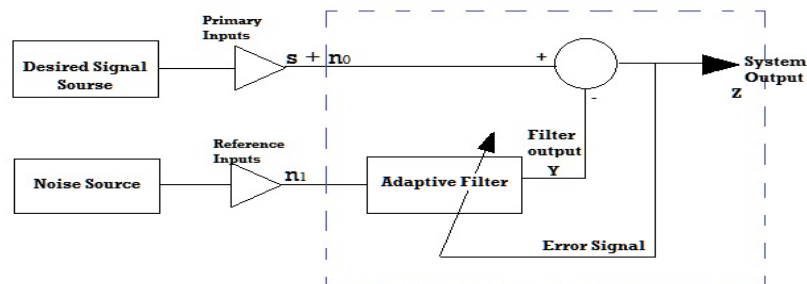
B. Thresholding

Based on statistical parameter, value of threshold is selected for remove the noise from signal. There are two types of technique use for thresholding named as hard thresholding and Soft thresholding. Hard thresholding function tends to have larger variance. It is unstable; means it is very sensitive towards a small change in signal. Soft thresholding function is more stable than hard thresholding and it tends to have bigger bias [3] [5].

III. Adaptive Filtering Method

An adaptive filtering is active filtering technique for noise reduction in non-linear signal as well as linear signals. This method required two inputs called a primary input and second one is reference input. Primary signal is the combination of desired signal and noise signal and Reference signal is highly correlated with noise and is involved with Primary signal [7].

Figure 1 Adaptive Noise Canceller



Suppose we have signal s which is affected by noise n_0 than input to primary channel becomes $s + n_0$. We have device that records only the noise characteristics signal, then recorded noise signal is called reference signal n_1 . Desired signal s is uncorrelated with noise n_0 and n_1 . But n_0 and n_1 is highly correlated with each other. The noise n_1 is given to filter which creates an output y that is close as a possible replica of n_0 . This output is cancelled from the primary input $s + n_0$ to create the overall system output $z = s + n_0 - y$.

If we know the characteristics of the reference noise signal over which the noise signal is transmitted to the primary and reference signals; as per mathematically theory, it is possible to design a fixed filter capable of changing n_1 into n_0 . The filter output is subtracted from the primary input, and the system output is only desired signal.

A. Recursive Least Square algorithm:

Recursive least square is adaptive filtering method for active noise cancellation. Main principal of RLS algorithm is minimizing mean square error. If we have observed real valued input vector $x(n) = [x_0(n), x_1(n), x_2(n) \dots \dots \dots x_{N-1}(n)]^T$ and Tap weight vector $W(n) = [W_0(n), W_1(n), W_2(n) \dots \dots \dots W_{N-1}(n)]^T$ than we obtain filter output as inner product of input vector and tap weight vector $y_n(k) = W^T(n)x(k)$ for $k = 1, 2, 3, \dots, n$.

We have not specified any particular structure for elements of the input vector $x(n)$. The corresponding estimation error would be then

$$e_n(k) = d_n(k) - y_n(k)$$

Filter output and corresponding estimating error are computed using $W(n)$ at instant n , which is obtained by minimize the weighted sum of error squares over all the instants n . Error signal and input vector hold the identity,

$$E[e_0(n)x_i(n)] = 0$$

Where $x_i(n)$ is the i th element of tap-input vector $x(n)$ and $E[\cdot]$ denotes statistical expectation. This is called principle of Orthogonality [7] [6].

B. Computation step for RLS algorithm:

- 1) Compute the gain vector

$$u(n) = \Psi_\lambda^{-1}(n)x(n)$$

$$k(n) = \frac{1}{\lambda + x^T(n)u(n)}u(n)$$
- 2) Filtering

$$\hat{y}_{n-1}(n) = \hat{W}^T(n-1)x(n)$$
- 3) Error Estimation

$$\hat{e}_{n-1}(n) = d(n) - \hat{y}_{n-1}(n)$$
- 4) Tap-weight vector adaption

$$\begin{aligned} \hat{W}(n+1) &= \hat{W}(n) + k(n)\hat{e}_{n-1}(n) \\ 5) \quad \Psi_{\lambda}^{-1}(n) \text{ update equation} \\ \Psi_{\lambda}^{-1}(n) &= \lambda^{-1}(\Psi_{\lambda}^{-1}(n-1) - k(n)[x^T(n)\Psi_{\lambda}^{-1}(n-1)]) \end{aligned}$$

IV. Proposed Method

The recorded EEG signals are affected by OAs that is considered as an additive noise within the EEG signal. So, we can express the relation between recorded EEG signals, true EEG signals, and noise mathematically by following equation:

$$\text{EEGrec}(n) = \text{EEGtrue}(n) + K \cdot \text{OAs}(n)$$

Where, EEGrec (n) recorded EEG signal, EEGtrue (n) is due to electrical activity of brain without interference of OA and OAs (n) is electrical activity due to eye movement.

A. Proposed Method Algorithm:

- 1) Choose a proper wavelet function and level for decomposition of EEG signal
- 2) Apply DWT and decomposed signal into approximate and detailed coefficients
- 3) Choose proper threshold value and apply thresholding technique in each detailed coefficients.
- 4) Reconstruct signal using Inverse discrete wavelet transform considered as Reference Signal
- 5) Apply Reference signal and Primary signal (Recorded signal) for Adaptive noise canceller
- 6) Synthesize the output EEG signal

V. Simulation Result

In this paper, EEG signals data had been taken from '<http://www.physionet.org>' [15]. This data are recorded according to 10-20 system. In this recording, eight electrode positions are recorded at 256Hz sampling frequency and amplitude in microvolt. The simulation is done using Matlab.

Major issue is detecting OA zone from EEG. By using DWT, the OA zone is been detected from Recorded EEG signal. Symlet 7 is used as wavelet function. Figure 2 shows the detail and approximate co-efficient at level-8 before thresholding. We see that frequency at every next level decreasing due to repetitive filter structure. Next stage global thresholding is applied for every detail co-efficient. Figure 3 shows the detail and approximate co-efficient at level-8 after thresholding.

Figure 4 shows the recorded EEG signal and DWT based Denoised EEG signal that used as Reference Signal for adaptive noise canceller.

Figure 2 Detail and Approximate Co-efficient at Level-8 of EEG signal

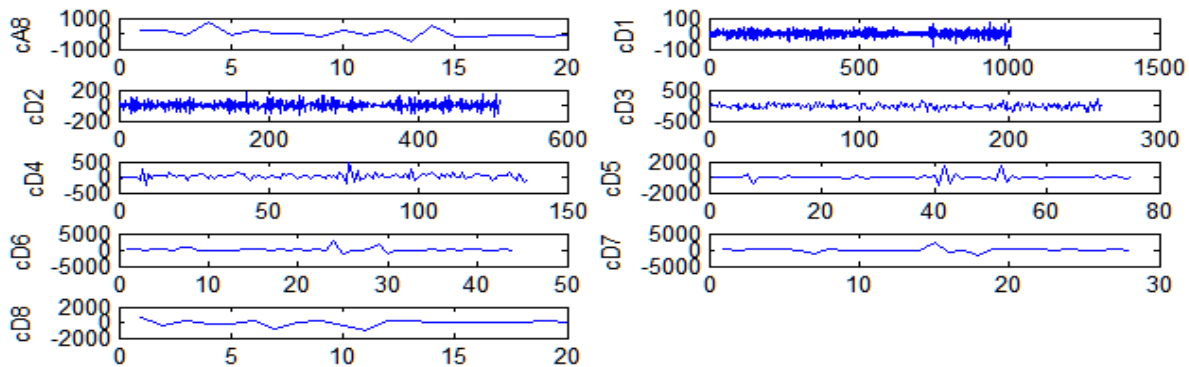
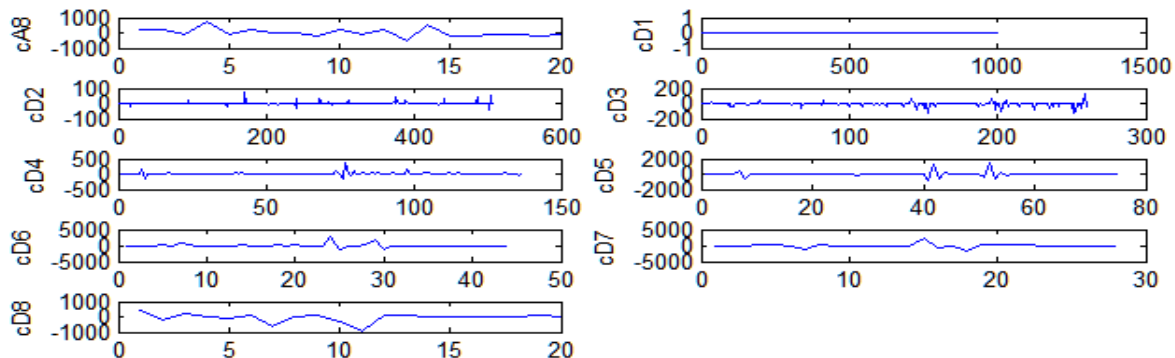


Figure 3 Detail and Approximate co-efficient At Level-8 after Thresholding



In the next stage adaptive Noise canceller method is applied. We used RLS algorithm for Noise cancelation. RLS algorithm has less computing time. LMS algorithm is difficult to track the signal when noise is unstable. Convergence of LMS algorithm depended on step size and selection of step size is also difficult. Generally, following parameters are used for EEG signal analysis.

$$MSE = \frac{1}{N} \sum_{i=1}^N (EEG_{\text{output}} - EEG_{\text{input}})^2$$

$$MAE = \frac{1}{N} \sum_{i=1}^N |EEG_{\text{output}} - EEG_{\text{input}}| = \frac{1}{N} \sum_{i=0}^N |\text{Error}|$$

$$PSNR = 10 * \log\left(\frac{\text{Max}(EEG_{\text{input}})}{MSE}\right)$$

Where, N is length of Sample EEG data.

Figure 4 wavelet function symlet7 at level-8 [i] Recorded EEG [ii] DWT based Denoised Signal

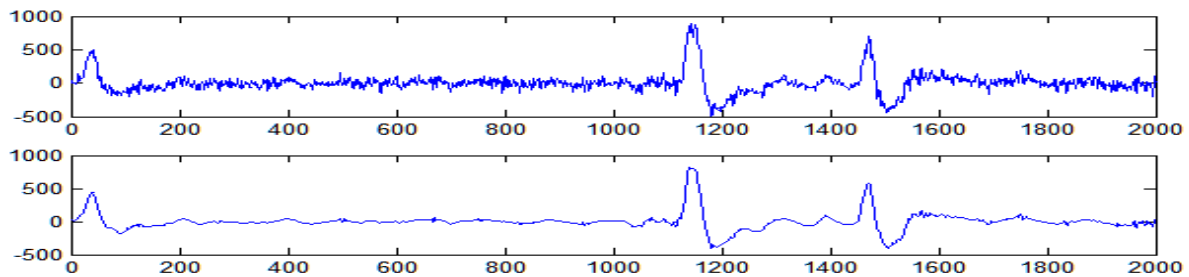
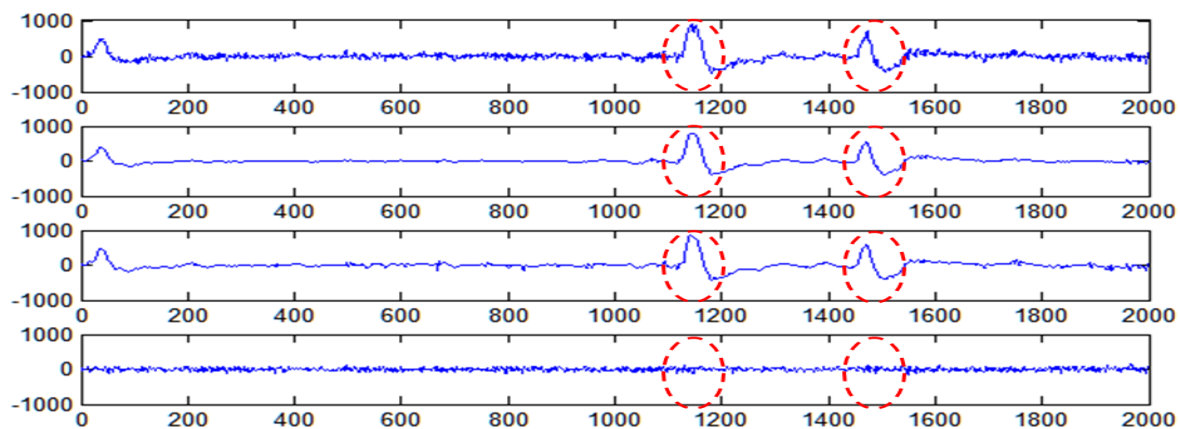


Figure 5 shows the synthesis of EEG signal after the application of RLS algorithm with forgetting factor $\lambda=0.9$ and DWT at level-8 with Symlet-7 wavelet function. We can see that error signal is also changed due to the value based on that filter weight is adjusted.

Figure 5 RLS algorithm and DWT at level-8 [i] Recorded EEG signal [ii] Reference Signal [iii] Error Signal [iv] Adaptive Corrected EEG signal



Adaptive filter actively removes the noise. For every iteration, error is computed and based on this filter weight is adjusted. Figure 6 shows the MSE value verses iteration graph. We can see that when artifact comes its value is changed and try to minimize.

Figure 6 MSE vs. Iterations

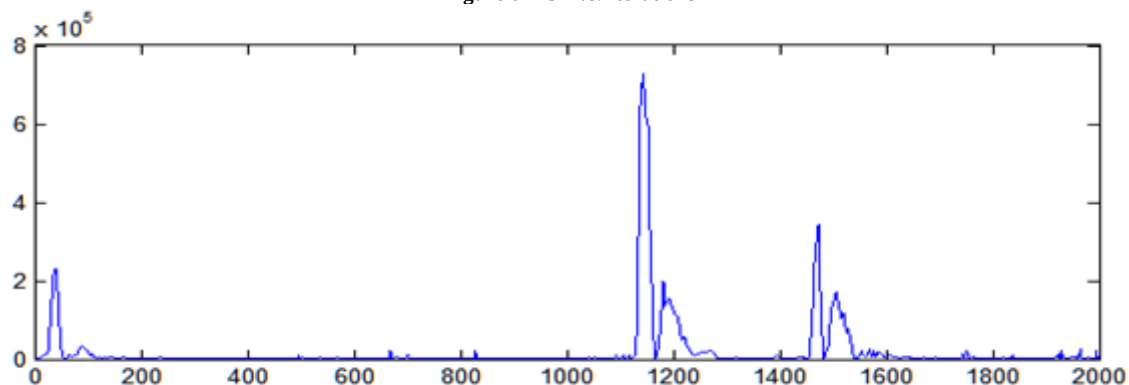


Table I show the Resultant Parameter DWT at Level-8 with sym-7 wavelet function

Method		MSE	MAE	PSNR(db)
Simple LMS	Step size = 0.1	Nan	Nan	Nan
	Step size =0.00000005	1.89x10 ⁴	71.88	-13.3056
RLS	Forgetting factor =0.9	1.96x10 ⁴	72.92	-13.4660
	Forgetting factor =0.5	2.06x10 ⁴	77.42	-13.6680

We analyze that Resultant parameter are improved. Choosing the proper value of forgetting factor we remove artifact from EEG signal. Generally forgetting factor is close to unity for better result. Results compared with LMS algorithm as shown in table-1.

VI. Conclusion

OA is one most extremely affecting artifact in EEG signal recording. In proposed method, DWT is used for detecting OA zone. For adaptive active noise canceller method, it requires a good reference channel which is highly correlated with noise. DWT is used for creating a reference channel for an adaptive method. Proper Selection of forgetting factor gives excellent result for OA removal and synthesis true EEG. We analyze that forgetting factor that close to unity give good performance to remove OA. In DWT, higher value of decomposition level gives good result. Proposed method gives improvement in resultant parameters compared to LMS algorithm. RLS have less calculation, so its takes less time to computation.

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