EOG Artifact Correction from EEG Signals for Biomedical Analysis

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ABSTRACT
The electroencephalogram records the electrical activity of the brain and is the main resource of information for studying neurological disorders. Corruption of EEG signal is caused by occurrence of various artifacts like line interference, electro-oculogram, electrocardiogram, and muscle activity. These artifacts increase the difficulty in analyzing the EEG and obtaining clinical information. The ocular artifact detection and correction from EEG is of considerable significance for both the automatic and visual analysis of brainwave activity by neurologists for proper diagnosis. In this paper, a statistical method for removing ocular artifacts from EEG recordings through thresholding and correlation is proposed. EEG database of 325 samples from Colorado state university is used for experimentation. The mean, variance, standard deviation, and correlation are the performance metrics used. The results show that the proposed method significantly detects and removes the EOG and line frequency artifact without loss of important part of original EEG.

General Terms
Signal processing, Biomedical analysis.

Keywords
Electroencephalogram (EEG), artifacts, Electro-oculogram (EOG), correlation.

1. INTRODUCTION
The human body is filled of electrical signals, which can be picked up and analyzed. Significance of the human body has never decreased and research on it has never been stopped since hundreds years ago. Among all physiological signals, EEG signals are accepted and productive in the application of mental state detection of a person. The EEG was first measured in humans by Hans Berger in 1929. EEG refers to the recording of brains spontaneous electrical activity over a short time period. Electrical impulses produced by nerve firings in the brain diffuse through the head and can be measured by electrodes positioned on the scalp. The EEG provides a coarse analysis of neural activity and has been utilized to non-invasively study cognitive processes and the composition of the brain. EEG utilized by neurologists for diagnosis of diseases such as, schizophrenia, Alzheimer, dementia and apnea. For proper diagnosis of any disease, analysis of the EEG signals should be correct. For appropriate analysis one must eliminate the noise due to facial muscle movements, eye blinking etc. [1] [2]
The Electrical activity of the brain has amplitude in the microvolt range. In a practice, EEG is measured at the scalp using a surface electrode. Due to the variability of impedance and the potential for transmission of infectious disease, type electrode is no longer normally used. The most frequent
electrode presently used is a gold-plated disc 10 mm in diameter. Electrode positions and names are specified by the International 10–20 system for most medical and research applications. This system assures that the naming of electrodes is consistent across laboratories. In most clinical applications, 19 recording electrodes (plus ground and system reference) are used. A smaller number of electrodes are typically used when recording EEG from neonates. The 10-20 system shown in Figure 1 was proposed to standardize the collection of EEG. The reference electrodes are positioned on non-active sites such as forehead or earlobes. EEG electrodes are placed on scalp. The recorded signal is achieved by subtracting signal measured below the eye from one measured above the eye. The data is stored up at 250 samples per seconds and digitized with 12 bits of precision sets of 10 sec as shown in figure 2.
An illustration of four seconds of EEG data as shown in Figure 2, recorded at 250 samples per second from seven sites. The two spikes are the result of eye blinks on the recorded data. The electrical fluctuations originated by brain activity and recorded as EEG are generally in the range of –50 to 50 μV. Eye blinks have higher amplitude and often have voltages of over 100 μV. [1] The seven sites of Electrodes are labeled according to the International 10-20 system. Eye Blink: The eye blink signal is very frequent in EEG data (see Figure 3). It creates a high amplitude signal that can be several times greater than the EEG signals of importance. Because of its high amplitude an eye blink can corrupt data on all electrodes, even those at the back of the head, these are often measured more directly in the EOG, pairs of electrodes positioned above and around the eyes. Unfortunately, these measurements are contaminated with EEG signals of interest and so simple subtraction is not a removal option even if a precise model of EOG diffusion across the scalp is exist. These noise, or unnecessary signals produced by patient, sources comprise: line noise from the power grid, eye blinks, eye movements, heartbeat, breathing, and other muscle activity. Some of these, such as eye blinks, produce voltage alterations of much higher amplitude than the endogenous brain activity. In this condition the data must be rejected unless that signals which are produced by patient can be removed from the data.

2. LITERATURE REVIEW
A number of methods has been proposed for EOG artifact correction from EEG. Due to the limitation of EEG signal recording technology, physiological artifacts, especially those generated by eye (EOG) with EEG, may change the characteristics of the neurological event in EEG. The ocular artifact correction based on Linear Combination and

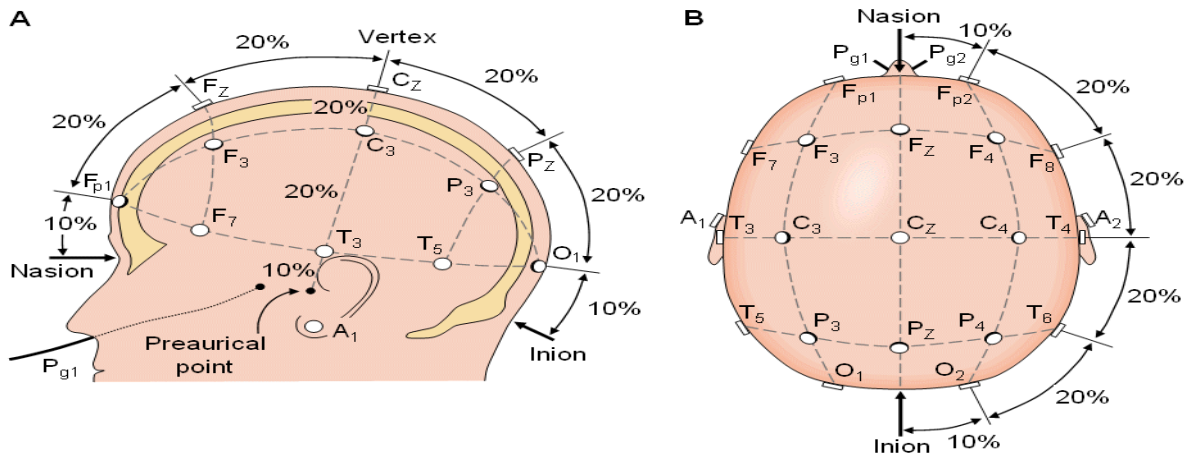

Fig 1: 10-20 electrode placement system

which considers the Bi-directionality between the EOG and the EEG signal. He uses the advanced model to reduce the EOG artifacts from the BCI competition IV dataset. *W. Jin et. al.* [4] proposed a new EOG correction model for EOG artifacts, where the EEG contained in the EOG is considered, and thus avoid removing part of the EEG signal by subtracting the EOG signal. In order to apply this new model in online BCI signal processing, he implement the AR (autoregressive) filtering model of the EEG activity to identify the EOG artifacts, only if it exists, the EEG correction method are performed and tested on the BCI competition 2008 dataset IIa.

Independent Component Analysis (ICA) has already shown to be an efficient and appropriate technique for EEG de-noising.[15] While ICA is used to correct ocular artifact, the solution is how to recognize the artifact component. Now many processing methods have been proposed. However, most of these methods were manually or semi-automatically implemented, which was time-consuming. In his work, *D. Zhu et. al.* [5] an ICA-based method was proposed to automatically correct eye blink artifact in the case of no reference EOG from multi-channel EEG recordings. *Devuyst, S. et. al.* [6] uses method based on a modification of ICA algorithm which gives hopeful results but only using a single-channel EEG (or EOG) and the ECG. *Teixeira A.R. et. al.*

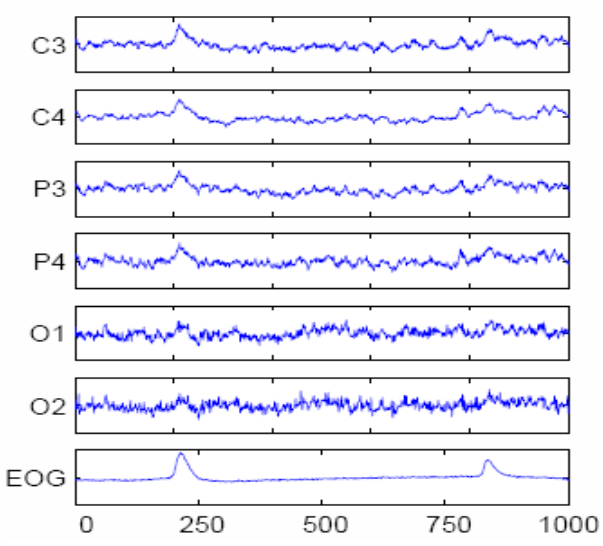

Fig 2: A four-second sample of EEG data.

[7] uses techniques consists of modified version of Singular Spectrum Analysis (SSA) and kernel Principal Component Analysis (KPCA) implemented using a reduced rank approximation of the kernel matrix. *Kierkels J.M et. al.* [8] showed the second-order blind identification correction algorithm in combination with six EOG electrodes executes best for all EEG configurations calculated on the simulated data. *Zikov T. et. al.* [9] proposed technique is based on an over-complete wavelet expansion of the EEG which first uses a stationary wavelet transform (SWT) on the corrupted EEG, then thresholding of the coefficients in the lower frequency bands is performed and the de-noised signal is reconstructed. *P. He et. al. [13]* describes a method for removing ocular artifacts based on adaptive filtering, uses separately recorded vertical EOG & horizontal EOG signals as two reference inputs. Each reference input is first processed by a finite impulse response filter of length M and then subtracted from the original EEG. The method is implemented by a recursive least squares algorithm that includes a forgetting factor to track the non-stationary portion of the EOG signals.

3. EOG CORRECTION

The corruption of EEG by different kinds of artifacts such as eye movements and blinks caused improper diagnosis and analysis of EEG. The artifact may affect the detection of EEG data of interest and obstruct the analysis of EEG recordings. The traditional method of the eye-blink suppression is the removal of the segment of EEG data in which eye blinks occur. Eye blinks are usually detected by means of data recorded from electrodes placed above and below the subject's eye. An eye blink is said to have occurred if the signal amplitude exceeds a given threshold. All EEG segments in which eye blinks take place are then removed.[2] There are different types of artifacts caused by eye. They are:

3.1 Eye Movement:

The eye is electrically charged with the cornea positive

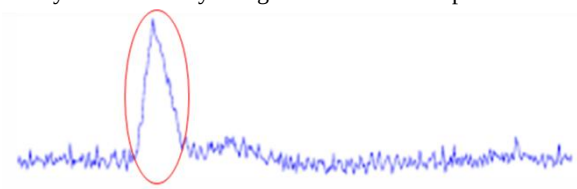

Fig 3: Eye blink effect in EEG signal

relative to the fundus, so any movement of the eye results in potentials that can be recorded from anterior leads. These potentials can rarely be mistaken for frontal lobe activity. The eyes are almost always moving.[10]

3.1.1 Lateral Eye Movements:

Lateral gaze results in the positive cornea moving toward the temple to the side of gaze. The differential effect of lateral gaze on the two sides makes for simple identification of this as a non cerebral potential. Lateral eye movements are frequently associated with lateral rectus spikes. Typically, the spike will be followed by a slower positive potential on the side to which the eye moved.[10]

3.1.2 Eye Blink:

An eye blink causes the equal positive potential in the frontopolar regions, but the subsequent eye opening is basis for negative deflection. The subsequent negative deflection differentiates an eye blink from mere eye closure.[10][14]

3.1.3 Vertical Eye Movements:

Downward gaze results in the positive cornea moving away from the frontal lobe, so negativity is observed in frontal leads. The reverse is correct for upward gaze. Since the eyes move up and down mutually the potentials from the two sides are synchronous. One must remember the likelihood of the prosthetic eye, producing unilateral eye movement artifact. Certain vertical eye movements have characteristic patterns, including eye blinks, eye opening, eye movements, eye closure, and eye fluttering. [10]

3.1.4 Eye Closure:

Eye closure results in Bell's phenomenon, an upward deviation of the eyes. This will be associated with a positive deflection in the frontopolar electrodes. The reason that the tracing returns to baseline is the low frequency filter.[10]

3.1.5 Eye opening:

Eye opening results in a negative potential in the frontopolar electrodes plus alteration in the posterior rhythm. The attenuation of the posterior rhythm with eye opening and reappearance with eye closing are good clues to the presence of vertical eye movements, although the technician should point out this phenomenon along with other patient movements. Eye closure in restoration of the posterior dominant frequency may be slightly faster immediately after closure and, therefore, should be measured a few seconds after eye closure.[10]

3.1.6 Differentiating eye movement:

- Certain eye movements such as eye blinks have a stereotypic appearance, different from frontal slow activity. In addition, vertical eye movements are generally limited to, or at least markedly predominant, in the frontopolar electrodes is eye movement artifact until proven otherwise.
- Pathologic frontal slow activity tends to be linked with a slow background, with activity in the theta or delta range. A normal background will suggest that slow activity restricted to the frontal region most likely represents eye movement artifact.
- Patients with marked vertical eye movements will often have prominent lateral eye movements as well, which can be easily recognized.

If there is still uncertainty leads are placed around the eye to record eye movements specifically. On the disc are Figures and instructions on identification and differentiation of eye movement artifact. Since the major difficulty will be with vertical eye movements, infraorbital leads are enormously helpful.[10][12][14]

3.2 Proposed EOG correction method

Figure 4 shows the block diagram of proposed EOG correction method. The detail explanation is as follows:

3.2.1 Preprocessing:

Preprocessing includes filtering. In this, noise added input signal is considered. Maximum frequency of input signal is 0.5 Hz to 100 Hz. As we know, sampling frequency is twice the maximum frequency therefore it is equal to 250 Hz. So after sampling we get normalized signal. The signal passes through LPF. Here we also amplify the input signal of low amplitudel. The EEG and EOG data were band pass filtered with a broadband anti-aliasing filter from 0.5 to 100 Hz and a 50 Hz notch filter, sampled with 250 Hz and 12 bit quantization. The dynamic ranges for EEG and EOG were ±100 lV and ±1 mV, respectively.

The digital EEG signal is stored electronically and can be filtered. Typical settings for the HPF and a LPF are 0.5-1 Hz and 35–70 Hz, respectively. The high-pass filter filters out slow artifact, such as electrogalvanic signals and movement artifact, whereas the low-pass filter filters out high-frequency artifacts, such as electromyographic signals. An additional notch filter is typically used to remove artifact produced by electrical power lines(50 Hz).

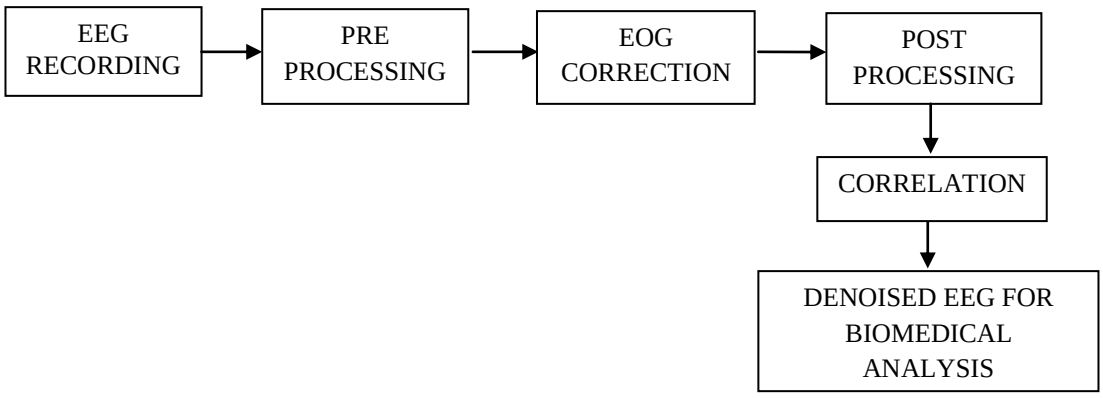

Fig 4: Block diagram of Proposed EOG correction method

3.2.2 EOG correction:

EOG correction method used to remove amount of ocular potential recorded by the EEG (as a proportion of the potentials recorded by the electroocculogram), and to subtract this from the EEG. By performing this we are able to reduce the effect of ocular potentials on the EEG, and this in turn permits us to enhance the amount of important EEG data.

3.2.3 Post processing:

This processing filtering. In this signal passes through HPF again. Then we calculate all the performance metrics here.

3.2.3 Correlation

After this we find out the correlation of thresholded signal with original signal. It ensures us the availability of useful information in EEG with the removal of artifactual components.

4. RESULTS

The EEG dataset used for experimentation is open available from website of Colorado state university. Data is a cell array of cell arrays. Each individual cell array is made up of a subject
string, task string, trial string, and data array. Each data array is 7 rows by 2500 columns. The 7 rows correspond to channels c3, c4, p3, p4, o1, o2, and EOG. Across columns are samples taken at 250 Hz for 10 seconds, for 2500 samples. For example, the first cell array looks like 'subject 1' 'baseline' 'trial 1'[7x2500 single]. Recordings were made with reference to electrically associated mastoids A1 and A2. EOG was recorded between the forehead above the left browline and another on the left cheekbone. Eye blinks were detected by means of a separate channel of data recorded from two electrodes placed above and below the subject's left eye. Recording was carried out with a bank of Grass 7P511 amplifiers whose band pass analog filters were set at 0.1 to 100 Hz. [11]

Subjects 1 and 2 were employees of a university and were left-handed age 48 and right-handed age 39, respectively. Subjects 3 through 7 were right-handed college students between the age of 20 and 30 years old. All were mail subjects with the exception of Subject 5. Subjects performed five trials of each task in one day. They returned to do a second five trials on another day. Subjects 2 and 7 completed only one 5-trial session. Subject 5 completed three sessions. [11]The subjects were asked to perform five mental tasks:

- Baseline task: The subjects were asked to relax as much as possible.
- Letter Composing task: The subjects were instructed to mentally write a letter to a friend or relative without vocalizing.
- Multiplication task: The subjects were given nontrivial multiplication problems, such as 49 times 78.
- Counting task: The subjects were asked to visualize a blackboard and to imagine numbers being written on the board sequentially.
- Rotation task: The subjects were asked to imagine a particular three dimensional block figure being rotated about an axis.

Data was recorded for 10 seconds during each task and each task was repeated five times per session. In this work the algorithms were applied to the subjects having more than one session of EEG signal which were subjects 1, 3, 6 and 5[11].

Table 1-5 gives the results after calculation for each task for subjects. In figure 5, we can see the EOG signal with artifact detection and correction. The output of correlation is same to the original signal. The performance measures used for analysis of proposed method are

1. Mean,
2. Standard Deviation,
3. Variance,
4. Correlation.

Table 1. Result table of baseline task

EEG DATA		MEAN	STD DEV	VAR	XCORR
Subject	Trial				
1	1	-0.013	5.15	26.47	1044.6
2	1	0.032	4.88	23.81	6523.9
3	6	0.011	9.27	85.92	736.5
4	1	-0.013	10.56	111.45	1123.6
5	11	0.073	64.38	4.14E+3	33552

Table 2. Result table of multiplication task

EEG DATA		MEAN	STD DEV	VAR	XCORR
Subject	Trial				
1	1	0.13	36.47	1.33E+3	1126.3
2	1	-0.23	22.63	512.16	336640
3	6	0.05	9.165	83.99	18233
4	1	0.65	53.03	2.81E+3	2618494
5	11	-0.03	15.85	251.25	6091.9

Table 3. Result table of letter composing task

EEG DATA		MEAN	STD DEV	VAR	XCORR
Subject	Trial				
1	1	0.029	5.16	26.64	5361.1
2	1	-0.02	18.58	345.25	3026.3
3	6	0.027	8.89	79.08	4474.3
4	1	-0.017	28.39	806.17	1736.2
5	11	0.65	23.13	535.15	2597300

Table 4. Result table of rotation task

EEG DATA		MEAN	STD DEV	VAR	XCORR
Subject	Trial				
1	1	-0.019	4.538	20.59	2362.4
2	1	0.031	5.41	29.27	6135.4
3	6	0.19	26.98	727.98	217990
4	1	-0.23	31.16	971.2	324475
5	11	0.53	6.61	43.73	1772000

Table 5. Result table of Counting Task

EEG DATA		MEAN	STD DEV	VAR	XCORR
Subject	Trial				
1	1	0.39	14.06	197.70	9526
2	1	0.05	15.99	255.94	16463
3	6	0.02	9.11	83.02	2939
4	1	0.04	47.64	2.27E+3	8991.2
5	11	-0.07	15.82	2.50E+2	37421

4.1 Mean

The *arithmetic mean* is the "standard" average, often simply called the "mean". For samples 1,2,3,….,*n* the mean is given by,

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

4.2 Standard Deviation

Standard deviation (σ) shows how much variation or "dispersion" exists from the average (mean, or expected value). It is given by:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad (2)$$

Where, σ is the standard deviation,
x_i is the i^{th} input value,
$\bar{x}$ is the mean value.

4.3 Variance

Variance is a measure of how far a set of numbers is spread out. It is calculated by:

$$Var(X) = \sum_{i=1}^{n} p_i \cdot (x_i - \bar{x}) \qquad (3)$$

Where, Var is the variance,
x_i is the i^{th} input value,
$\bar{x}$ is the mean value.

4.4 Correlation

Correlation is used as similarity measure. If we have a series of *n* measurements of *X* and *Y* written as x_i and y_i where $i = 1, 2, ..., n$, then correlation *r* between *X* and *Y*. The sample correlation coefficient is written as,

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} \qquad (4)$$

where x and y are the sample means of *X* and *Y*, and s_x and s_y are the sample standard deviations of *X* and *Y*.

5. CONCLUSION

The method is easy to implement, stable, and presents a low computational cost. The proposed method is evaluated using only six EEG and one EOG channel. The removal of ocular artifact from scalp EEGs is of considerable significance for both the automated and visual analysis of underlying brainwave activity. The proposed method can remove Ocular Artifacts in the EEG and easily identify the artifact zones for removing the artifacts. From the results, comparing with the other existing methods, the suppression of ocular artifacts in dB is improved by our proposed method. In all types of task in all subjects, artifacts were sufficiently attenuated, without removing important and practical information. EOG correction is an efficient technique for improving the quality of EEG signals in biomedical signal processing and analysis.

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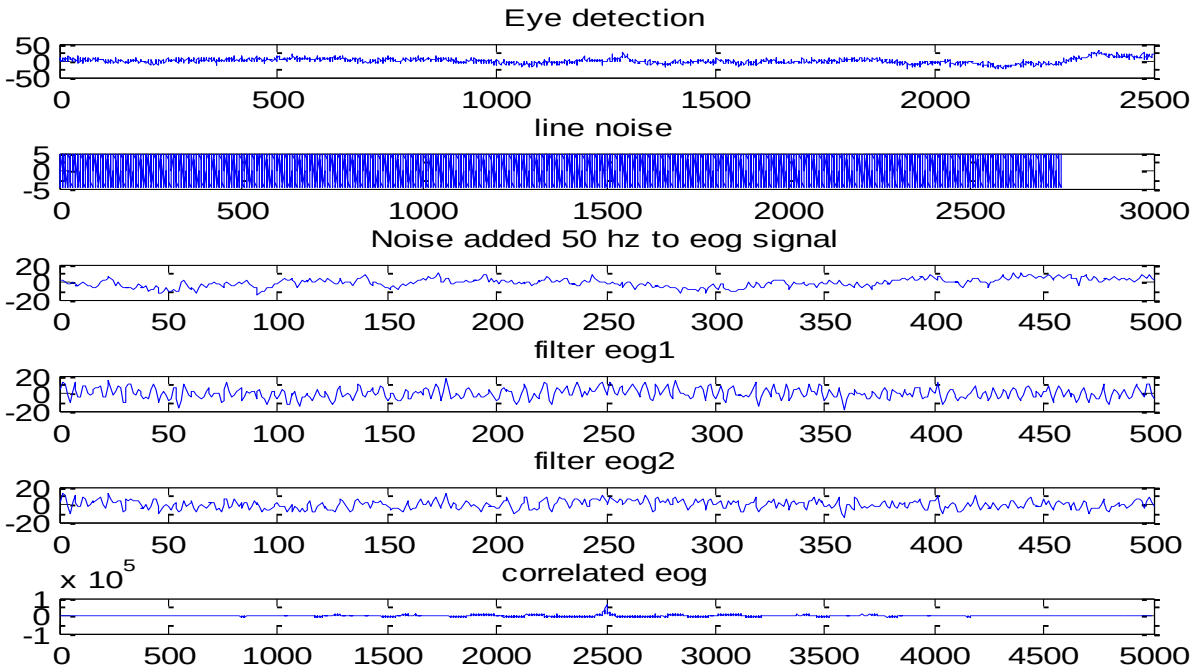

Fig 5: EOG with artifact and Corrected EOG