Real Time Eye Blink Artifacts Removal in Electroencephalogram Using Savitzky-Golay Referenced Adaptive Filtering

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Abstract— **Eye blink artifacts cause a major problem to electroencephalograph (EEG) signals since they introduce serious distortion to the signals. The implementation of algorithm to eliminate those artifacts automatically and at real time becomes highly important when considering the recent focus on portable EEG applications. In this paper, we propose a real-time eye blinks artifact removal using adaptive filtering without an additional reference electrode. The proposed method utilizes a Savitzky-Golay (SG) filter to estimate a blink component from the noisy EEG signals, and then is used as a reference in adaptive noise cancellation system. We demonstrate the reliability of the proposed method by using both simulated and real EEG datasets. The estimated blink artifacts by the proposed method are compared to the original blink signals measured by electrooculograph (EOG). The performance of the filters in terms of removing the blink components from the noisy signals are also compared between the proposed SG referenced and a conventional EOG referenced adaptive filtering. The results show that the proposed method is able to estimate the blink artifacts with high correlation to the original blink signals and remove the artifact successfully.**

Keywords— **Eye blink artifact, adaptive filtering without reference, Savitzky-Golay filter, Electroencephalogram (EEG).**

I. INTRODUCTION

The contamination of physiological artifacts such as pulse, muscle and ocular artifacts in electroencephalogram (EEG) signal is inevitable. These artifacts reduce the quality of the brain signals which could bias the analysis results. Electrooculograph (EOG) artifact, particularly, is a major problem that causes distortion in EEG signal generated by blinks and eye movements. The magnitude of this artifact can goes up to ten and hundred times larger than the original EEG signals [1]. In many cases, artifacts are handled by discarding the contaminated segments based on a visual judgment from the expert. However, this could bring a great loss of valuable data and it is a long process, thus, is not suitable for long term recording such as sleep stage study. Hence, the process to remove or suppress the artifacts while leaving the relevant EEG signals become highly important.

Blind source separation (BSS) is a popular approach used in separating the artifacts from a noisy signal. Among the BSS approaches, independent component analysis (ICA) is one of the method used for EEG artifacts removal which was first proposed by Makeig *et. al* [2]. It has become a widely accepted method, especially for blink removal owing to its good performance in separating the artifact component from noisy EEG signals. However, ICA requires visual inspection in order to choose and to remove the artifact components. Thus, several approaches which are a combination of ICA with other techniques have been proposed to overcome those limitations [3]–[5]. Besides, ICA entails a data from multi channel EEG to perform the separation of independent components, making it difficult to be implemented in single-channel EEG. In recent years, the focus is on the wearable EEG device for real-time applications. Thus, single-channel EEG is more reliable for its simplicity, light weight and suits the real environment.

Adaptive noise cancellation system is an approach for noise removal using adaptive filtering [6] which can be operated in real time and available for both single and multi channels EEG. It is suitable for non-stationary signals through its ability to adjust itself according to the changing environment. The filter suppresses the noise by subtracting a reference from the measured EEG signal based on linear regression process. A reference is a signal which is correlated with the artifact and carries the properties of the artifact. Usually, this reference is taken by placing an additional electrode to record the artifact signal, and delivers it as an input reference to the filter. For example, a method of using a cascade of three adaptive filters was proposed [7]. This method uses three different additional channels to cancel out the ocular, muscle and pulse artifacts. Recently, a method of using a camera based or eye tracker based reference to eliminate blinks and movement artifacts have been proposed [8], [9]. The filtering results of using a camera based reference outperform the EOG electrode based reference. Nevertheless, the requirement for those additional sensors or channel in adaptive filter brings both the hardware size and cost problems. This is unfavorable for recent applications that demand on compactness and portability in the real environment. On top of that, adaptive filter requires different reference channel for different type of artifacts.

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In this paper, we present a method of removing the eye blink artifacts on real time using adaptive filtering without an additional reference channel. We propose a method to estimate eye blink from single-channel EEG by adopting a Savitzky-Golay (SG) filter. The output from the SG filter is then used as a reference input in adaptive noise cancellation system. We demonstrate the potential of this method by using a simulation and a real EEG dataset. The proposed method is then compared with the conventional method that use EOG channel for reference. This paper is organized as follows. Section II discusses the overview of the adaptive noise canceling system and the implementation of SG filter in the system, followed by the description on how to prepare the dataset. The result is then presented in Section III. Finally, Section IV concludes the findings.

II. METHODOLOGY

A. Savitzky-Golay Filter

A Savitzky-Golay filter is a method of data smoothing based on local least squares polynomial approximation, proposed by Savitzky and Golay in 1964 [10]. This filter was originally developed for noise removal in analytical chemistry, but then has been found to be attractive in the area of signal processing and image processing. The filter output is computed as shown in the equation below.

$$Y_j = \sum_{n=-n_L}^{n_R} C_i y_{j+i} \quad (1)$$

Here, n_L is the number points used to the left of a data point i, and n_R is the number of points to the right after point i. C_i is a fixed value taken from a set of weighting factors developed by Savitzky and Golay. n describes the window size where $n = n_R + n_L$. The center value is replaced with the output from the model. The major advantage of this method is that it has a property to preserve the peak shape, such as peak height and width, which are often affected when adopting other smoothing techniques. This feature is advantageous in estimating the magnitude and frequency of eye blink signal. The measured EEG signal will be filtered using the above equation, and the filtered value will be set as the input reference for adaptive noise cancellation system.

B. Adaptive Filtering

The use of conventional fixed filtering methods, such as low-pass filter and high-pass filter to attenuate the artifacts is not really recommended since there is a possibility of overlapping frequency spectra between EEG signal and the artifacts [11]. Adaptive filtering is one of the best choices to overcome a time-invariant problem of those non-adaptive approaches. An adaptive algorithm updates the filter coefficient by a feedback process to make the output as close as possible to the desired response. In this study, we use ANFIS as the adaptive algorithm. Figure 1 illustrates a schematic of adaptive filtering for adaptive noise canceller system. From the diagram, the signal source is the original recorded EEG signal with blink artifacts, d(n). The adaptive filter aims to estimate clean EEG signal e(n), by predicting the artifacts (blinks) components, y(n) from the measured EEG signal, d(n). For this, we require a reference input, x(n) which correlates with the blinks artifact tend to be removed. Thus, here we use the smoothed values from SG filter as an artifact reference to estimate the eye blinks.

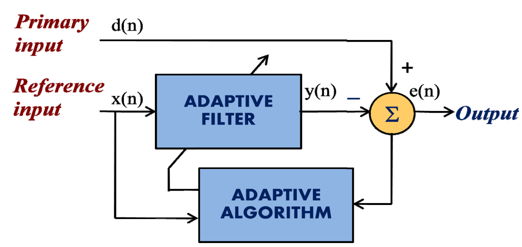

Fig. 1 Adaptive Noise Cancellation

C. Simulation Dataset

The algorithm is tested using simulation dataset and real EEG dataset with eye blink artifacts. For simulation dataset, we first simulate the clean EEG signal using a MATLAB function proposed by Yeung *et*. al [12]. The blink artifacts are simulated by a sinusoid with random amplitudes and shapes, added with 20 dB of white noises. The simulated blink-contaminated EEG signals were then obtained by combining the simulated clean EEG signal with the simulated eye blink. For a real EEG dataset, the recordings were performed using a cap type multi-channel EEG, g.tec, with 256 Hz of sampling rate. The device measured 14 locations of EEG channel plus 1 vertical EOG signal. For dataset preparation, we only used a measured signal at Fp1, since this channel is considered as a severely affected channel by blinks. The subjects were asked to blink according to metronome sound that will be played every 5 seconds. The total length of the experiment is 55 seconds.

D. Performance Analysis

For validation purpose, we compare the results of the proposed method with the conventional method which uses the measured EOG signals as artifact reference. We measure the similarity between the corrected signal of the proposed method and the reference (estimated by EOG referenced) using signal to noise ratio (SNR), mean squared error (MSE) and correlation coefficient. SNR and MSE are calculated as follows:

$$SNR = 10\,log\frac{\sum_{i=1}^{N} x(i)^2}{\sum_{i=1}^{N}(x(i)-\bar{x}(i))^2} \quad (2)$$

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(x(i)-\bar{x}(i))^2 \quad (3)$$

where $x(i)$ is the target EEG signal (corrected EEG by EOG reference) and $\bar{x}(i)$ is the corrected EEG signal by the proposed method. N represents the length of the signal.

III. RESULTS

The filtering results of the simulated signals are shown in Figure 2. The estimated eye blink shown in figure indicates no significant differences compared to the simulated blink signals. Similarly, the estimated signal by the proposed method successfully follows the target signal and eliminates the blink components as shown in the figure. The SNR and MSE of the proposed method with reference to the target signal are 20.23 and 4.60×10^{-6}, respectively.

The result for the real dataset is shown in Figure 3. We compared the estimated blinks and estimated FP1 signal after being corrected by the proposed and conventional method. From the figure, it can be seen that the performance of both filters are comparable in terms of estimating the eye blinks and correcting the measured EEG signals. The figure indicates that the estimated blink using the SG filter is very similar to the one that use the conventional approach. The SNR and MSE value between EOG referenced filter and SG referenced filter is 16.98 and 3.39×10^{-5} respectively. Next, we analyzed the result using correlation coefficient at zero lag to measure the similarity between the reference signal and the estimated signals from both filters. The correlation coefficient indicates the similarity degree between two signals where one is the highest correlation. The coefficient values between the measured EEG signal and estimated EEG obtained using SG reference and EOG reference filtering are presented in Table 1. From the table, the estimated FP1 from both methods present low correlation with measured FP1 showing that the filter largely removed the blink component from the noisy signal. Meanwhile, high correlation can be seen in estimated eye blinks prove that the estimated eye blinks are very similar to the original blinks signal measured by EOG electrode. The proposed method presents close values to the values presented by conventional method which confirm its reliability in removing the artifact even though without an additional artifact channel reference.

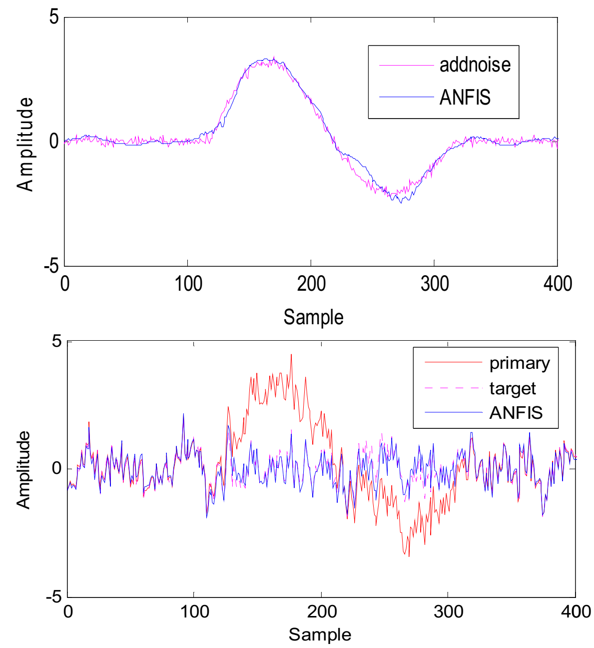

Fig. 2 Performance of the proposed method on simulated signals; simulated eye blink and estimated eye blink by ANFIS (top), simulated EEG signal and estimated signal by ANFIS (bottom).

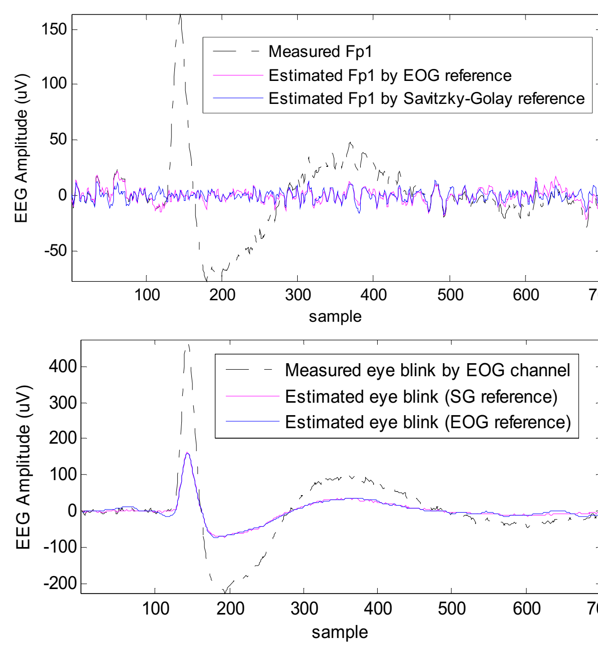

Fig. 3 Performance comparison of adaptive filters on real EEG dataset; measured and estimated EEG signal (top), measured and estimated eye blink signal (bottom).

Table 1 Correlation coefficients on both methods

Compared Signals	*Correlation Coefficient*	
	Savitzky-Golay referenced	EOG referenced
Measured FP1 / Estimated FP1	0.1478	0.1892
Measured EOG / Estimated eye blink	0.9899	0.9984

IV. CONCLUSIONS

The major advantage of adaptive filter is its availability for online processing and single-channel data. Both conditions are vital for recent applications on portable EEG. The requirement for reference channel in adaptive filter however, is something need to be considered. Hence, the filter which can be operated without an additional reference channel is very promising to tackle both of the size and cost problem for portable EEG. The general concept of SG filter is to filter out high frequency components while leaving the lower frequency components in the output. It is a type of low-pass filter, thus we found it is suitable to be used in estimating the blink component which is concentrated on lower frequencies. Nevertheless, there are some limitations in this study. Since the proposed SG filter is a type of low-pass filter, a verification on lower frequency in the corrected EEG signals need to be conducted to ensure minimal loss of relevant data on low frequency. The second limitation is the validation analysis is performed by assuming that the corrected signal using EOG reference is a clean signal in order to measure the value of SNR and MSE. In real environment, the real value of EEG signal is unknown, thus a systematic artificial model is required to measure the percentage of real EEG signal retained in the corrected signal.

In this paper, we proposed an eye blinking artifact removal method using Savitky-Golay filter referencing in adaptive filtering. We performed the proposed method for blink artifact removal using single-channel EEG signal (FP1). The proposed method has successfully estimated the blink signal with high correlation to the original blink signal recorded by EOG electrode. We then adopted ANFIS in adaptive noise cancellation system to remove the blink component from measured EEG signal, by applying the estimated blink signal generated by Savitzky-Golay filter as artifact reference. The filter performance using the proposed referencing method is then compared with the ANFIS filter using EOG reference. We verified the effectiveness of the proposed method on both simulation dataset and real dataset.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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