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Removal of Artifacts in Multi-channel Visual Evoked Potentials

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***Abstract*— The primary goal of this work is to introduce temporal artifact detection strategy to remove artifacts in multichannel evoked potentials. An artifact is defined as any signal that may lead to inaccurate classifier parameter estimation. Temporal domain artifact detection tests include: a standard deviation (STD) test that can detect signals with little or abnormal variations in each channel, a clipping (CL) test detect amplitude clipped EPs in each channel and a kurtosis (KU) test to detect unusual signals that are not identified by STD and CL tests. An attempt has been made to apply these techniques to 14-channel visual evoked potentials (VEPs) obtained from four different subjects.**

Keywords **– evoked potentials, standard deviation , clip, kurtosis.**

I. INTRODUCTION

Evoked potentials (EPs) are event related potentials (ERPs) superimposed in electro-encephalogram (EEG). Evoked potentials are usually considered as the time locked and synchronized activity of a group of neurons that add to the background EEG. Evoked Potentials indicate how well the brain is processing stimuli from the sense organs (eg. eyes, ears or skin) and can help diagnose illnesses.

An evoked potential (EP) is a signal that is generated as a result of the transmission of information induced by the application of a sensory stimulus to a sensory pathway. Examples of such stimuli are electric stimuli, visual stimuli, and auditory stimuli [1]. The application of a stimulus invokes a sequence of action potentials that is transmitted via a nervous pathway to the central nervous system (CNS).

The activation of different parts in the nervous pathway leads to variations in the electromagnetic field that can be recorded on the scalp. Using surface electrodes a sequence of positive and negative peaks can be recorded; such a sequence is called a sensory evoked potential. These peaks are characterized by their amplitude and time after the stimulus, at which they occur the (post stimulus) latency. Evoked potentials are simultaneously recorded on the scalp with the spontaneous EEG.

The EEG signal has much larger amplitude than the evoked potential. Averaging techniques are used to extract the signal related to the stimulus and reduce the amplitude of the ongoing EEG signal.

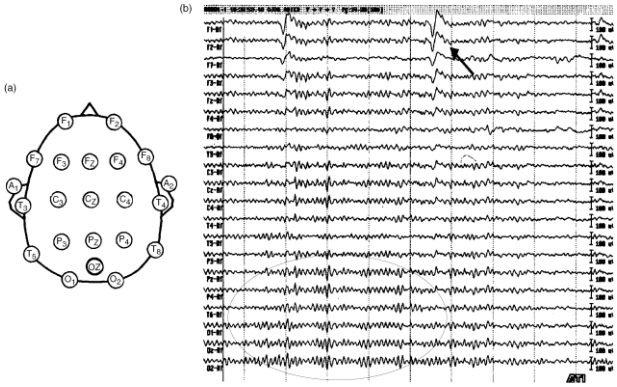

Fig. 1. The M single channel EPs in response to stimulus c.

Evoked potentials are used extensively in the study of human brain functions and in clinical investigations to study normal and abnormal brain functions. They are used to test conduction in the visual, auditory, and somatosensory systems. During surgery they can be used to monitor the condition of structures at the operative site. Fig.1. shows M single channel evoked potentials in response to stimulus c.

Sensory evoked potentials can also be used for monitoring effects of anesthetics on the central nervous system (CNS). The choice of stimulus type to be used depends on the part of the nervous system to be investigated and the circumstances under which measurements are to be made.

We define artifacts as patterns in the training set that lead to inaccurate estimation of classifier parameters and patterns in the test set that yield misleading performance evaluations. In real time classification, such artifacts can give inaccurate test results which can have serious consequences, such as inaccurate diagnosis in clinical evaluations [2].

Visual evoked potentials are very useful in detecting blindness in patients those cannot communicate, such as babies or animals. If repeated stimulation of the visual field causes no changes in EEG potentials then the subject's brain is probably not receiving any signals from his/her eyes. Other applications include the diagnosis of optic neuritis, which causes the signal to be delayed. Fig.2 (a) shows visual evoked potential recording setup where pattern reversal method is used as stimulus, and Fig.2 (b) shows a typical visual evoked potential.

Artifacts in EP waveform recordings typically result from voltage changes due to eye blinks, eye movements, muscle activities, and power line noise. Artifact detection in EPs is essential because artifacts are known to frequently occur in evoked potential data acquisition [3]-[7].

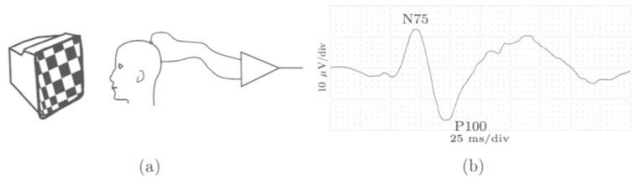

Fig.2. Visual evoked potentials. (a) Recording setup where pattern reversal method is used as stimulation and (b) typical VEP morphology.

II. ARTIFACT DETECTION STRATEGY

Artifacts are rejected by first removing signals with excessively large amplitude variations or signals with little or no amplitude variations using a standard deviation test. Signals with samples that have been clipped are removed using a clipping test [8]-[9]. Kurtosis test is used to detect and reject artifacts that are not detected by standard deviation test. It enhances the peaks of the average evoked potentials. These tests can be used to identify faulty stuck-at recording channels that always give the same readings.

If a channel has stuck at fault, the EPs of that channel are discarded from further analysis. We assure that, if an artifact occurs in one channel then the responses of all the channels are also artifacts. This assumption is valid as the EPs of neighboring channels are highly correlated. Therefore for a given trial, if an artifact is detected in any one or more channels, single trial data of all the channels for that trial are removed.

The three tests are described using $z_{m/c;n}$ to represent single trial EP n, $n = 1,2,...,N$, in the ensemble of class c, c = 1,2,…,C, recorded at channel m, m = 1,2,…,M. Where N is the number of single trial EPs in each ensemble, C is the number of brain activity categories, and M is the number of channels. The c-class ensemble of EPs collected at channel m will be referred to as m/c ensemble [10]-[13].

A. The clipping (CL) test

This test is designed to exclude single trials whose amplitude have been clipped. An evoked potential will be detected as a clipped signal if more than λ samples have the same maximum or minimum values .

To determine if $z_{m/c;n}$ is clipped,

let $\lambda_1 = \max\left[z_{m/c;n}(k) \right]$

and $\lambda_2 = \min\left[z_{m/c;n}(k) \right]$,

where $z_{m/c;n}(k)$ is sample *k, k=1,2,…,K,* of $z_{m/c;n}$

Let

$$v_{1k} = \begin{cases} 1, & \text{if } z_{m/c;n}(k) = \lambda_1, k = 1,2,...,K \\ 0. & \text{otherwise} \end{cases}$$

Similarly let

$$v_{2k} = \begin{cases} 1, & \text{if } z_{m/c;n}(k) = \lambda_2, k = 1,2,...,K \\ 0, & \text{otherwise} \end{cases}.$$

The single trial EP $z_{m/c;n}$ is clipped if

$$\sum_{k=1}^{K} v_{1k} \geq \lambda \quad \text{or} \quad \sum_{k=1}^{K} v_{2k} \geq \lambda .$$

If $z_{m/c;n}$ is clipped for one or more values of m, then the MCEP $z_{c;n}$ is regarded as clipped and removed from the ensemble of class c. The parameter λ is not a function of c. Fig.3 shows an example of a clipped evoked potential.

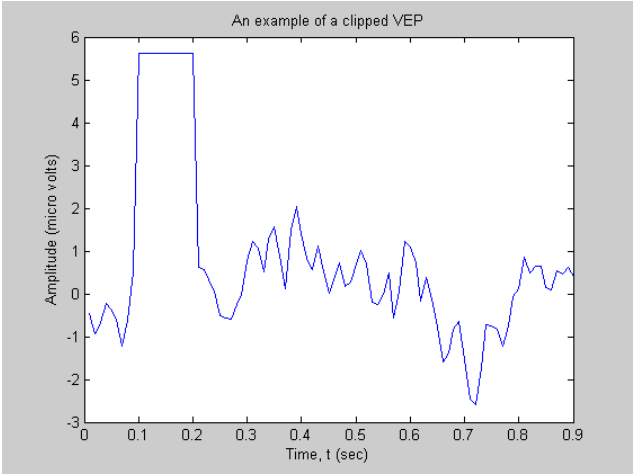

Fig. 3. A signal with clipped peaks

B. The Standard Deviation test

Standard deviation of a single trial response $z_{m/c;n}$ in the m/c ensemble is defined as

$$\sigma_{m/c;n} = \left(\frac{1}{K} \sum_{k=1}^{K} \left(z_{m/c;n}(k) - \hat{z}_{m/c;n} \right)^2 \right)^{1/2}$$

If the standard deviation $\sigma_{m/c;n}$ of the samples of a single trial response $z_{m/c;n}$ in the m/c ensemble is outside a threshold window $[\tau_{\sigma 1}, \tau_{\sigma 2}]$, then *n*th single trials of all M channels are regarded as artifacts and are discarded from the m/c ensemble [14]. That is, multi channel EP $z_{c;n}$ is an artifact,

if $\delta_n \geq 1$.

Where $\delta_n = \sum_{m=1}^{M} \rho_{m/c,n}$

and

$\rho_{m/c,n} = 1$, if $\sigma_{m/c;n} < \tau_{\sigma 1}$ or $\sigma_{m/c;n} > \tau_{\sigma 2}$, $m = 1,2,\ldots,M.$

The threshold $\tau_{\sigma 1}$ is selected to be close to zero, in order to detect responses that are relatively constant over the entire duration of the event related potential (ERP), whereas the threshold $\tau_{\sigma 2}$ is determined empirically. If the standard deviation is less than the threshold $\tau_{\sigma 2}$, or greater than the threshold $\tau_{\sigma 2}$ for all n at any c, the channel is regarded as faulty and the EPs of the faulty channel are removed from further processing. Fig.4 shows an example of artifact detected by standard deviation test.

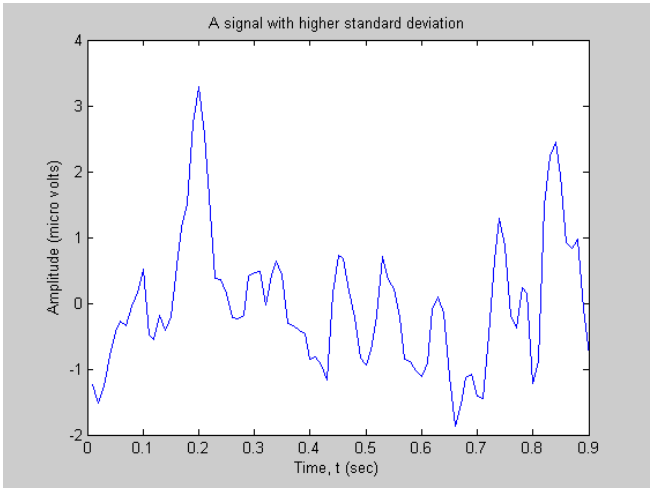

Fig. 4. One of the artifact signals detected by standard deviation test.

C. The Kurtosis test

Kurtosis is the fourth order moment, which is useful in the detection of transients due to external noise such as switching on/off of electrical or electronic equipment.

If the kurtosis

$$\kappa_{m/c;n} = \frac{1}{K} \sum_{k=1}^{K} \left(\frac{z_{m/c;n}(k) - \hat{z}_{m/c;n}}{\sigma_{m/c;n}} \right)^4$$

of the samples of a single trial response $z_{m/c;n}$ in the *m/c* ensemble is outside a threshold window $[\lambda_{\kappa_1}, \lambda_{\kappa_2}]$, then the *n* th single trials for all M channels are regarded as artifacts and are discarded from m/c ensemble.

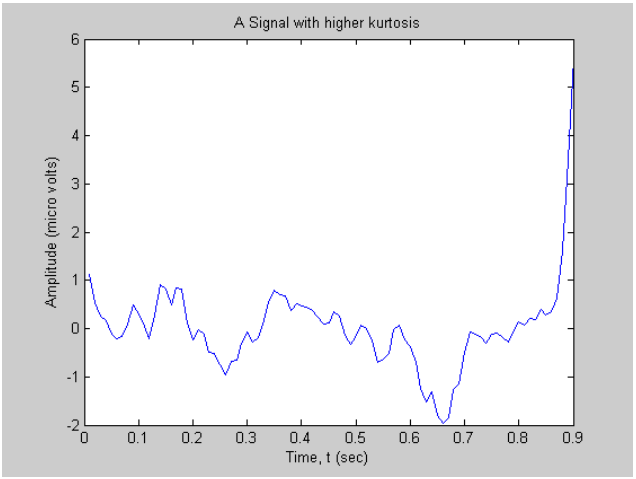

Fig. 5. One of the artifact signals detected by kurtosis test.

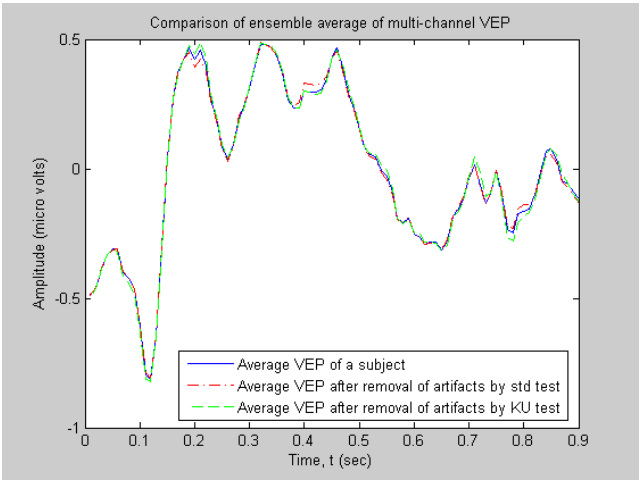

Fig.6. Comparison of average of actual VEP with average VEP after removal of artifacts using standard deviation test and kurtosis test.

This test detects and excludes signals with higher peaks so that average evoked potential will be smoothened. Fig.5 shows an artifact detected by kurtosis test. Fig.6 shows a comparison of averages of actual evoked potential with average VEP after removal of artifacts using standard deviation and kurtosis tests.

Quality Factor

Quality factor, $\theta = 1 - \hat{\theta}$

Where $\hat{\theta} = \frac{a}{N}$

a = No. of artifacts detected
N = No. of trials of data tested

III. SIMULATION AND RESULTS

The artifact detection strategies using standard deviation test, clip test and kurtosis test were applied to 14-channel VEP ensembles acquired from four different subjects. Single trial EPs having clipped peaks, lower (close to zero) or higher standard deviation or kurtosis or both, are detected as artifacts and removed while classifying the EPs. Examples of artifacts detected by standard deviation and kurtosis are shown in Fig. 3 to Fig. 5.

Following table shows details of artifacts detected in 14-channel 71-trial evoked potentials of a typical subject

No. of atrtifacts detected using standard deviation test alone	3
No. of artifacts detected using kurtosis test alone	3
No. of artifacts detected using KU test after removal of artifacts using STD test	2
Total no. of artifacts detected using STD and KU tests	5
Quality factor before removal of artifacts	91.55%
Quality factor after removal of artifacts using STD test but before removal of artifacts using KU test	92.65%
Quality factor after removal of artifacts using STD and KU tests	100%

IV. CONCLUSIONS

The primary objective of this work is to identify and reject artifacts. The artifacts were first detected using a sequence of within channel standard deviation and clipping tests. Some more artifacts which could not be detected by these two tests are identified by using kurtosis test. It is observed that removal of artifacts using kurtosis test improves peaks of the average VEP and also it improves the performance of evoked potential classifiers, much more effectively in addition to that provided by standard deviation test.

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