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Processing of visual Evoked Potentials

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Abstract- The primary goal of this work is to introduce temporal artifact detection strategy to detect non responsive channels and trials in evoked potentials by tracing out the signals with very low energy and to remove artifacts in multichannel evoked potentials. The non responsive channels and trials are identified by calculating the energy of the average evoked potential of each channel, and the energy of the average evoked potential of each trial. Then channel wise and trial wise median test is conducted to detect and remove non-responsive channels and trials. 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, a kurtosis (KU) test to detect unusual signals that are not identified by STD and CL tests, mode deviation test to detect the signals with large mode deviation and correlation test to detect the signals with less correlation. An attempt has been made to apply these techniques to 14-channel visual evoked potentials (VEPs) obtained from different subjects.

Keywords- evoked potentials, energy, median, standard deviation, clip, kurtosis, mode deviation, correlation .

1. 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 [26]. 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.

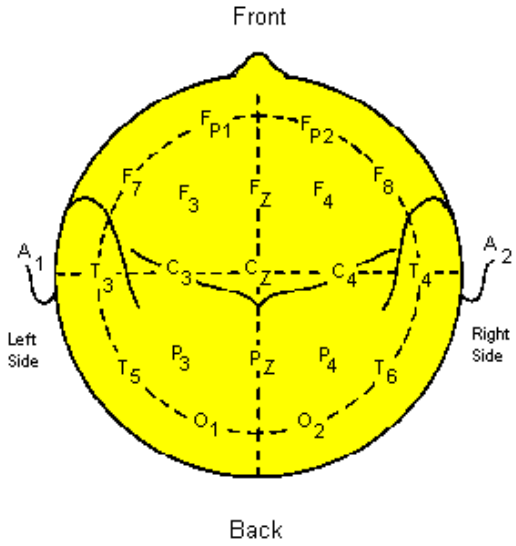

Fig. 1. Placement of electrodes on the human scalp to record multi-channel evoked potentials.

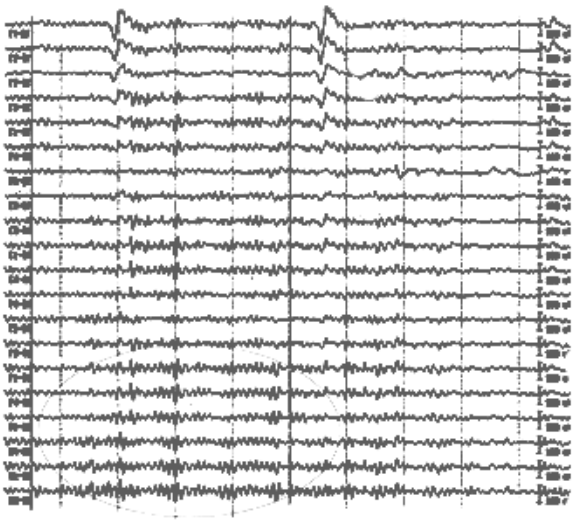

Fig.2. The M-channel single trial EPs in response to stimulus c.

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 somato sensory

systems. During surgery they can be used to monitor the condition of structures at the operative site. Fig.1. shows the placement of electrodes to record multi-channel evoked potentials. Fig.2. 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 [16].

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.3 (a) shows visual evoked potential recording setup where pattern reversal method is used as stimulus, and Fig.3 (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 [13],[17],[20]-[22].

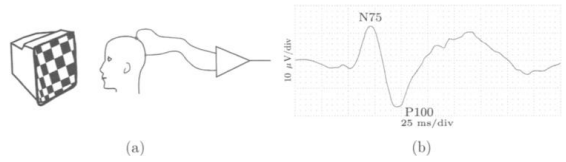

Fig.3. Visual evoked potentials. (a) Recording setup where pattern reversal method is used as stimulation and (b) typical VEP morphology.

2. Median Test

Several researches are going on to improve the quality of bio-medical signals. Errors in averaging of small signal samples can be reduced more efficiently by using median rather than mean [1]-[3]. Artifacts in visual evoked potentials caused by eye movement, eye blink, external noise, internal noise of recording instruments, etc., are removed by using different techniques such as blind component separation, multichannel median test, standard deviation etc., [22]and[27].

A. Removal of Non Responsive Channels

1. If a channel has stuck at fault, the EPs of that channel are discarded from further analysis. Some of the channels may not respond to a particular class of stimulus. In such cases, the non responsive channels may be detected as follows. k^{th} sample of N – trial average evoked potential of each of the M channels is computed using the equation (1).

$$Z_{m/c}\ \ k\ \ = \frac{1}{N}\sum_{n=1}^{N} Z_{m/c;n}\ \ k\ , \quad \begin{matrix} m = 1,2,...,M \\ k = 1,2,...,K \end{matrix} \tag{1}$$

Where $Z_{m/c;n}\ \ k$ is the k^{th} sample of n^{th} trial of m^{th} channel evoked potential in response to stimulus *c*. Energy E_{Z_m} of N – trial average of each channel *m* is calculated using the equation (2).

$$E_{Z_{m/c}} = \sum_{k=1}^{K} Z_{m/c}^2(k) \quad m = 1,2,...,M \tag{2}$$

Let $\overline{E}_{Z_{ch/c}}$ be the median, $E_{Z_{ch/c}\max}$ be the maximum value and $E_{Z_{ch/c}\min}$ be the minimum value of $E_{Z_{1/c}}, E_{Z_{2/c}}, ..., E_{Z_{M/c}}$.

Define $d_{ch/c} = E_{Z_{ch/c}\max} - \overline{E}_{Z_{ch/c}}$ as the distance between the median and maximum value of energy of M – channels.

The channels providing average evoked potentials with energy less than $\overline{E}_{Z_{ch/c}} - d_{ch/c}$ are detected as non responsive channels, and removed from the channel averaging process. This will improve the peaks average EP responses.

B. Removal of Non Responsive Trials

2. If the subject is not ready, or diverted from the stimulus, then evoked potentials of some trials may be non responsive. In such cases, the non responsive trials may be detected as follows. k^{th} sample of M – channel average evoked potential of each of the N trials is computed using the equation .

$$Z_{c;n}\ \ k\ \ = \frac{1}{M}\sum_{m=1}^{M} Z_{m/c;n}\ \ k\ , \quad \begin{matrix} n = 1,2,...,N \\ k = 1,2,...,K \end{matrix}$$

Where $Z_{m/c;n}\ \ k$ is the k^{th} sample of n^{th} trial of m^{th} channel evoked potential in response to stimulus *c*. Energy E_{Z_n} of M – channel average of each trial *n* is calculated using the equation .

$$E_{Z_{c;n}} = \sum_{k=1}^{K} Z_{c;n}^2(k) \qquad n = 1,2,...,N$$

Let $\overline{E}_{Z_{tr/c}}$ be the median, $E_{Z_{tr/c}\max}$ be the maximum value and $E_{Z_{tr/c}\min}$ be the minimum value of $E_{Z_{c;1}}, E_{Z_{c;2}}, ..., E_{Z_{c;N}}$.

Define $d_{tr/c} = E_{Z_{tr/c}\max} - \overline{E}_{Z_{tr/c}}$ as the distance between the median and maximum value of energy of N – trials.

The trials providing average evoked potentials with energy less than $\overline{E}_{Z_{c;tr}} - d_{tr/c}$ are detected as non responsive trials, and removed from the trial averaging process .

Removal of such trials will improve the peaks of average VEP responses, on addition to that provided by removing non responsive channels.

3. 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 [6],[18]. 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 [12],[19],[24]and[25].

(i) 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

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

Similarly let

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

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

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

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.

(ii) 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 computed by the equation (5) 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 [22]. That is, multi channel EP $z_{c;n}$ is an artifact,

if $\delta_n \geq 1$.

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

Where 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,…,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 $\tau_{\sigma 1}$, 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.

(iii) 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.

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

If the kurtosis of the samples of a single trial response $z_{m/c;n}$ in the *m/c* ensemble computed using the equation (6) 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.

(iv) Mode deviation test

The mode deviation (also called the mode absolute deviation) is the mean of the absolute deviationsof a set of data about the data's mode. For a sample N size, the mode deviation is defined by

$$\mathrm{MD} \equiv \frac{1}{N}\sum_{i=1}^{N}|x_i - \bar{x}|,$$

where $\bar{x}$is the mode of the distribution.

If an artifact occurs, the individual samples of an evoked potentials deviates more from their mode values, resulting large mode deviation. In this test we identify the signals that are having high mode deviation as artifacts.

This test is 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.

The mode of m[th] channel and n[th] trial evoked potential is denoted by

$\bar{z}_{m/c;n} = \mathrm{mode}\{z_{m/c;n}(k)\}$ m=1,2,3……M

n= 1,2,3……N

Then the mode deviation of m[th] channel and n[th] trial evoked potential $r_{m/c;n}$ is given by

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

for m=1,2,3……M

n= 1,2,3……N

let $r_{max} = max(r_{m/c;;n})$ for m=1,2,3……M

n= 1,2,3……N

If $r_{m/c;n} > 0.9 * r_{max}$, then $z_{m/c;n}(k)$ is considered as an artifact and is discarded from the m/c ensemble.

(v) Correlation Test

We can use correlation to compare the similarity of two sets of data. Correlation computes a measure of similarity of two input signals as they are shifted by one another. The correlation result reaches a maximum at the time when the two signals match best.

In signal processing, cross-correlation is a measure of similarity of two waveforms as a function of a time-lag applied to one of them.

For real discrete functions x(n) and y(n), the cross-correlation[7] is defined as

$$r_{xy}(l) = \sum_{n=\infty}^{\infty} x(n)y(n+l)$$

Usually the signals of all channels and trials are to highly correlated. If an atifact occurs, the correlation among successive signals decreases. In this test we obtain the ensemble average of signals corresponding to all channels and trials. We identify the signals that are less correlated with the ensemble average as artifacts.

This test is 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].

k^{th} sample of N – trial average evoked potential of each of the M channels is

$$Z_{m/c}(k) = \frac{1}{N}\sum_{n=1}^{N} Z_{m/c;n}(k)$$

for m=1,2,….M

k=1,2,….K

Where $Z_{m/c;n}\ k$ is the k^{th} sample of n^{th} trial of m^{th} channel evoked potential in response to stimulus *c*.

Then k^{th} sample of N - trial, M - channel average evoked potential is

$$Z_c(k) = \frac{1}{M}\sum_{m=1}^{M} Z_{m/c}(k),$$

For k=1,2,…K The cross correlation of ensemble average Z_c with individual signals is given by

$$r_{m/c;n}(l) = \sum_{k=1}^{K} Z_c(k)\,Z_{m/c;n}(k+l)$$

for l=1,2,…..2K-1

m=1,2,….M

n=1,2,…..N

Let $R_{m/c;n}(l) = \left|r_{m/c;n}(l)\right|$

$$R(n,n) = \frac{1}{L}\sum_{l=1}^{L} R_{m/c;n}(l),$$

Then

where L=2K-1

for m=1,2,…..M

n=1,2,……N

Let $\lambda_1 = \max\left[R(n,n)\right]$

and $\lambda_2 = \min\left[R(n,n)\right]$

and $d = median\left[R(n,n)\right]$

Then, Let, $d_1 = d - \lambda_2$

$d_2 = \lambda_1 - d$

$dd = d - d_2$

If the correlation coefficient of the samples of a single trial response $z_{m/c;n}$ in the m/c ensemble is less than the threshold ‘dd’ then *n*th single trials of all M channels are regarded as artifacts and are discarded from the m/c ensemble [14].

4. Results

The median test was applied to 14-channel 71-trial VEP ensembles acquired from different subjects. Channel wise and trial wise average EPs having low energies were detected and removed while classifying the EPs.

The artifact detection strategies using standard deviation test, clip test, kurtosis test, mode deviation test and correlation test were applied to 14-channel VEP ensembles acquired from different subjects. The table 1. Shows N1,P1,N2 of visual evoked potentials of a typical subject . we observed that the peaks of average EP responses are improved.

Fig.4 and fig.5 shows a comparison of averages of actual evoked potential with average VEP after removal of non responsive channels and trials and artifacts using standard deviation, kurtosis, mode deviation and correlation tests.

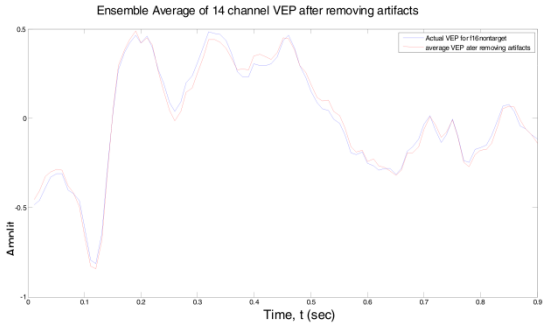

Fig. 4 Comparison of average of VEP before and after removal of artifacts for f16 nontarget.

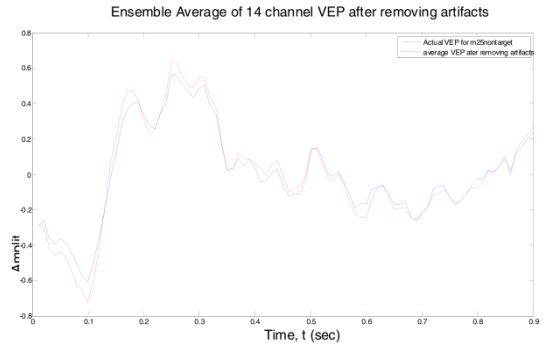

Fig. 5 Comparison of average of VEP before and after removal of artifacts for m25 nontarget.

Table 1.

Subject	N1				P1				N2			
	actual		After removing artifacts		Actual		After removing artifacts		actual		After removing artifacts	
	Latency in sec	Amplitude in µv	Latency in sec	Amplitude in µv	Latency in sec	Amplitude in µv	Latency in sec	Amplitude in µv	Latency in sec	Amplitude in µv	Latency in sec	Amplitude in µv
f16nontarget	0.12	-0.812	0.12	-0.84	0.19	0.466	0.19	0.5	0.26	0.035	0.26	-0.01
m25nontarget	0.1	-0.6	0.1	-0. 7	0.25	0.56	0.25	0.65	0.35	0.018	0.35	-0.02

5. Conclusions

The primary objective of this work is to identify and reject non responsive channels and trials and to identify and reject artifacts in the acquisition of evoked potentials. Energy of average EP of each channel, and of each trial is obtained. Then non responsive channels and trials are detected and removed by using channel wise and trial wise median test respectively. This improves the peaks of average EPs and hence classifier performance. 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, mode deviation test and correlation 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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