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ELECTROENCEPHALOGRAM ELECTROOCULOGRAPHIC ARTEFACTS POWER SPECTRUM ANALYSIS

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Abstract

Since noninvasive electroencephalogram (EEG) was discovered, started its wide use for medical diagnostics. Soon after that, attempts for using the EEG for devices' control were made. In both cases, electrooculographic (EOG) artefacts, especially subjects eye-blinks, noticeably contaminate EEG power spectrum and impede the analysis and classification of the signal. Artefacts are noises introduced to the EEG signal by not central nervous system (CNS) sources of electric fields inside and outside subjects body. In this paper, an analysis of the power spectrum of eye-blinking artefacts is described with a connection of using EEG for pattern recognition during mental tasks performance based brain-computer interface (BCI), working with α- and μ-rhythms (8-13 Hz) brain potentials. The goal of the study is to determine the influence of eye-blinks' power spectrum on EEG and choose a method for their handling.

Introduction

The ability to communicate is a typical and determinated characteristic of human beings and plays a vital role in their relationship. This communication is richer and more sophisticated than any other form of communication. Verbal and written messages are usually sent by the mouth or hands and received by the eyes or ears with the mediation of the brain. While the communication between humans has been extensively developed and studied, the communication between humans and machines is in its initial phase. The progress of neurology and computer science give the possibility to establish an immediate connection between human brain and the computer - Brain computer interface (BCI).

BCI will raise the quality of life of disabled people, offering a new communication channel. Brain control could be used by healthy people too, as additional possibility for control.

The Alternative Control Technology (ACT) program of the US Air Force Research Laboratory, Dayton, Ohio, among the variety of hands-free controls, using input from eyes, head, speech and electromyographic (EMG) includes the use of electroencephalographic (EEG) systems that allow communication with computers while the pilots' hands remain engaged in other activities [1].

Most of BCI studies use EEG, recorded from the human scalp. EEG is a noninvasive and easy to perform method, which does not require expensive and heavy equipment [2].

During EEG recording the subject moves and glances about, as it is expected of anyone asked to sit in a chair for a long time and engage in repetitive tasks, requiring mental effort. The movements introduce periods of electrical noise (artefacts) that are difficult to discriminate from neural activity.

Frontal muscles EMG can dominate the β- or μ-brain rhythms frequency range at frontal locations. Eye-blinks (known as electrooculographic (EOG) artefacts) can affect the θ- or even μ-rhythm range at frontal and central scalp locations [3, 4]. Thus, as it is possible the user to control output device by raising his eyebrows or blinking his eyes the mentioned EMG activity might obscure the user's actual EEG control.

Artefacts can dramatically alter the EEG recorded at the scalp [5], to bring to false results and conclusions during the investigation of EEG-based BCI. Studies, pretending neuroprosthesis control [6], show this risk. Later study [7] proves frontal muscles EMG influence over the control.

There are, however, other sources [**8**, 9], where the authors pretend increased data transfer rate and specially state that the investigations are done without any artefact removal, "...No (!) trials were rejected due to artifacts" [**8**].

As a result of this conflicting information, a decision was taken to study the subjects eye-blinks power spectrum in the context of particular use of EEG and after that choose a method for their handling.

In this paper an investigation of eye-blinks' influence over the EEG intended for *pattern recognition technique* based BCI, using α- and μ-rhythms in 8-13 Hz range is described. BCI uses the patterns issued during various tasks, evoked increasing brain activity, like visual presentation of four images, imaginary image rotation, imaginary human body limbs rotation, mathematical tasks, hyperventilation etc.

EOG artefacts analysis

In the study, an EEG database, recorded in the Technical University of Delft. the Netherlands, where in 2004 started a project on building an EEG-based BCI, is used.

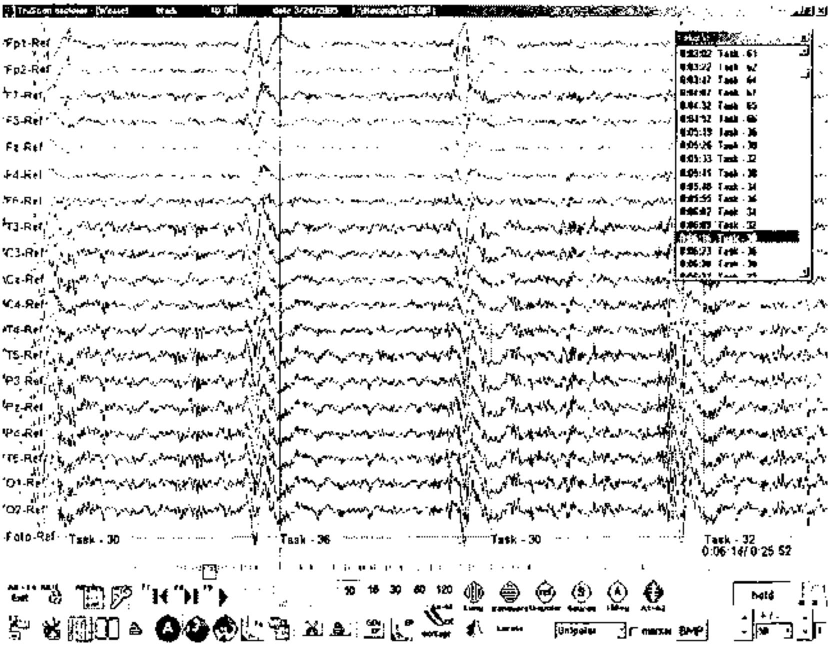

Fig. 1. Tasks'succession. The vertical lines mark every task's start. Eye-blinks stand at every tasks end out by their five times higher amplitude

To find out EOG artefacts influence over the working range power spectrum. an analysis of the planned blinks at every tasks end during the *visual presentation* tasks - having numbers 30, 32, 34, 36 - including *visual presentation* on the monitor screen respectively of *yellow triangle, green dot, red cross* and *blue lines* in one session, Fig. 1, is done. Every task runs 5 times in one session. The tasks follow each other in a pseudorandom order, to avoid the subjects learning. According to the experiment schedule, the first 5-seconds EEG are free from blinks. The next 3-seconds contain a planned blink. A model for the analysis is synthesized as (1). (2):

$$(1) \qquad P_{av}^{b}(k) = \frac{1}{RN} \sum_{m=1}^{R} \left[X_{R}^{b}(k) X_{R}^{b*}(k) \right]$$

(2) $$P_{av}^{nb}(k) = \frac{1}{RN}\sum_{m=1}^{R}\left[X_R^{nb}(k)X_R^{nb*}(k)\right]$$, where

$P_{av}^{b}(k)$, $P_{av}^{nb}(k)$ are the average powers for k frequency respectively for segments with blinks and without blinks.

f_s is the sampling rate, 256 Hz.

N is the number of input discretes for the analysis. The ratio N / f_s defines the frequency resolution.

X^{b}, X^{nb} are arrays which contain the frequency components, calculated after the Fourier analysis of the input segment which contains, x^{b}, and which does not contain a blink, x^{nb}. A N-point Hamming window $H(N)$, according to (3) is applied in advance:

(3) $$X(k) = \sum_{n=0}^{N-1} x(n)e^{-i2\pi kn/N}H(n)$$, where

X^{b*}, X^{nb*} are the corresponding complex conjugate arrays.

As a result of a preliminary study [10], the length of the eye-blinks is determinated as approximately 3 s (they depend on the particular subject and his psycho-physiological condition). The spontaneous and planned blinks' study [11] stated, that they have equal duration. The result allows to study the planned blinks during tasks' 3X performance. They are in predefined time segments and could be processed automatically. Averaging the power spectrum of blinks during different mental tasks' performance is possible, as a base for the comparison parts of EEG without blinks, recorded just before the blinks during the same tasks' performance are taken. A result of other preliminary study of mental tasks characteristics [14], states that tasks 3X have similar patterns.

Every blink is selected in three-second interval (768 discretes), enveloped parts from EEG before and after the visible maximum, Fig. 2. Other three-second segments just before the blinks are selected from the same tasks. The white noise level (neighbor neurons' activity [12]) in the averaged power spectrum is $\sqrt{20}$ times lower [13] in comparison with the white noise of a single segment.

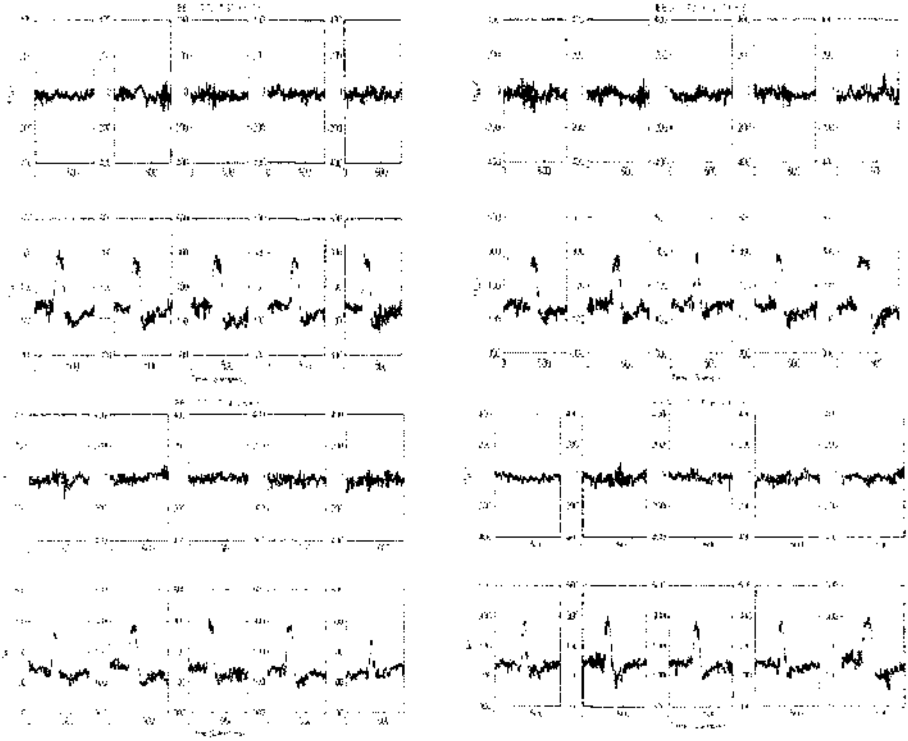

Fig. 2. EEG segments from one session selected for the analysis

Every blink is selected in three-second interval (768 discretes), enveloped parts from EEG before and after the visible maximum, Fig. 2. Other three-second segments just before the blinks are selected from the same tasks. The white noise level (neighbor neurons' activity [12]) in the averaged power spectrum is $\sqrt{20}$ times lower [13] in comparison with the white noise of a single segment.

Graphs of the averaged power spectra envelopes of the segments with and without blinks in all EEG channels are shown in Fig. 3.

The EEG amplitude without blinks is different for every channel. It is the lowest in frontal placed Fp1 and Fp2, Fig. 1. Channels Fp1 and Fp2 are the most suitable to discover eye-blinks by controlling the EEG amplitude in the time domain. When the threshold is properly set, errors probability could be minimal.

The blinks' power spectrum is concentrated in the 2-3 Hz frequency band. The blinks could be discovered by controlling the powers of 2-3 Hz frequency components after the Fourier analysis is done.

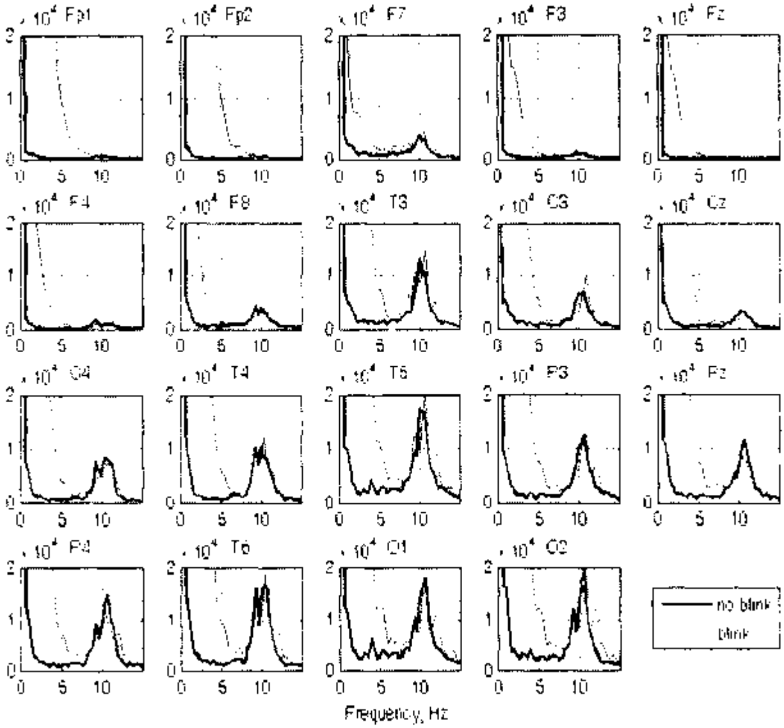

Fig. 3. Averaged power spectra in all channels

From the averaged power spectra man can see that the blinks influence is different in particular channels. In the segments with blinks, in frontal placed electrodes Fp1, Fp2, F7, F3, F4 and F8, averaged powers of working range frequency components dominate over the averaged powers of the segments without blinks. This obviously is a result of the eye-lids activation EMG potentials. In the rest of the channels C3, C4, P3, P4 etc there are frequencies with lower power in segments with blinks. Unlike sources, where EOG artefacts are defined as "no CNS artefacts", the author's suggestion is that the work range frequencies power reduction in segments with blinks is a result of brain activity. Consequently, it is wrong to define eye-blinks' influence in every channel as a result only of EMG artefacts' diffusion along and/or across the scalp accordingly to particular rules [15].

Besides low frequencies, powers of segments with blinks differ from blinks-clean segments more than 50% for frequencies in the range 8-13 Hz. This difference is commensurable and in some channels higher than the expected power changes as a result of mental tasks performance. Blinks presence definitely lowers the the probability for right mental tasks classification. Consequently, it is inadmissible to analyze segments that contain blinks without any preprocessing.

To have blinks free EEG segments for the study, a decision is taken, to reject the segments which contain subjects eye-blinks. Unlike EEGs used in the medical practice, where a short lasting part could contain very important information (for epilepsy diagnosis) and it is not allowed to loose it, mental tasks last a long time. The database is big enough and rejecting parts with eye-blinks will not lower the matter of the study.

Conclusions and future work

EOG artefacts identification, determination of their influence on the working range and its elimination from real data are necessary steps in EEG processing. They are inevitable when the data are intended to train the BCI classificator.

The power spectrum of the subject's eye blinks is concentrated in the range between 0,5-3 Hz. The power of the low frequency components is many times higher than the power of the EEG without blinks.

In the range 8-13 Hz, in part of the electrodes (T5, T6, O1, O2 etc), the power introduced by the blinks, is in times higher than the energy of the signal without blinks and much higher than the power difference, that is a result of the mental task's performance (which is 10-20% [14]). This correlation can bring considerable errors during the classification. In the study of BCI, working with brain rhythms in the range 8-13 Hz, eye-blinking artefacts should be eliminated.

The results of the study will be used to prepare the input vector for training the BCI classificator.

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АНАЛИЗ НА ЧЕСТОТНИЯ СПЕКТЪР НА ЕЛЕКТРООКУЛОГРАФСКИ АРТЕФАКТИ В ЕЛЕКТРОЕНЦЕФАЛОГРАМИ

Пл. Маноилов

Резюме

С откриването на неинвазивната електроенцефалограма (ЕЕГ). започва нейното широко прилагане в медицинската диагностика. Скоро след това се извършват експерименти по прилагане на ЕЕГ за управление на устройства. И в двата случая електроокулографските (ЕОГ) артефакти. по-точно премигванията на очите на субекта, забележимо повлияват енергийния спектър на ЕЕГ, с което затрудняват анализа и класифицирането на сигнала. Артефактите са шумове, внесени в ЕЕГ от непринадлежащи към централната нервна система (ЦНС) на субекта източници на електрически полета в и извън човешкото тяло. В статията се описва анализ на енергийния спектър на премигвания, във връзка с прилагане на ЕЕГ в мозък-компютър интерфейс (МКИ), базиран на метода разпознаване на образци, получени при изпълнение на мисловни задачи, работещ с а- и m-мозъчни ритми в диапазона 8-13 Hz. Изследването има за цел да определи влиянието на енергийния спектър на премигванията върху ЕЕГ, за да се избере подходящ метод за тяхната обработка.