ON-LINE AUTOMATIC SUPPRESSION OF ARTIFACTS IN MULTI-DIMENSIONAL SIGNALS USING ICA

Korshakov A. V.**, Frolov A.A.*, Bobrov P.D. *
*Institute of Higher Nervous Activity and Neurophysiology RAS, Moscow, Russia,
**Russian Science Center "Kurchatovsky Institute", Moscow, Russia

Abstract. This paper concerns promising method of extraction and excluding of eye-movement (or EOG in general) and some other artifacts from EEG recordings. The method is based on Independent Component Analysis (ICA) procedure. The method of EEG filtering in question can be tuned on-line to achieve desired precision level.

Variety of procedures have been proposed for on-line correction of multidimensional signals, including methods based on regression analysis, principal component analysis and others. One of the most promising methods is Independent Component Analysis (ICA) providing blind separation of independent sources (BSS) [1]. The method proposed in the paper handles multi-dimensional recording of electroencephalogram (EEG) during on-line signal acquisition to control Brain-Computer Interface (BCI). BCI is a system intended to establish a channel for direct communication of human brain activity with technical devices. One of the most promising approaches is based on the recognition of EEG patterns specific for different mental tasks. When the subject imagines voluntarily the performance of a task, the corresponding EEG pattern is recognized and transformed into the command to external technical device. For our BCI project we chose imagination of movements as mental states transformed to external commands. Since eye movements and blinks produce stable specific patterns of EEG activity they can disguise EEG patterns related to movement imagination. Moreover eye movements and blinks can be used by subjects for not voluntary or even voluntary BCI control. Thus suppression of EOG artifacts in EEG is crucial for BCI based on recognition of mental states. The origin of these artifacts is the electrical processes in the retina that can be presented in terms of equivalent dipolar current sources. Eye movement changes dipole direction and blink changes the geometry of the eyeball covering due to lowering of the eyelids. Both effects produce corruption in multi-dimensional EEG signal overlapping in amplitude as well as in frequency band with signals corresponding to brain activity related to motion imaginary. Commonly artifact detection is handled by the experimenter guided only by his experience [2-5]. More rigorous method is based on off-line ICA decomposition and so called topographical approach [4]. According to this approach, criterion for identification and exclusion of ICA components related to eye movements and blinks from EEG data is the similarity of electrical potential distribution provided by these components with those obtained by modeling. We suggest the following procedure for on-line EOG artifact suppression. BCI experiments should begin with short special EEG recording for calibration of artifact classifier. Calibration is based on ICA decomposition and automatic exclusion of artifact related components.

Experimental data. In our experiments data were acquired using rejecting 1-30 Hz FIR filter and 200 Hz sampling frequency ADC, 32 electrodes located according to international 10-20 EEG registration system were used. Several experiments with different number of EOG electrodes (from 3 and up to 9) located near eyes of subject were carried out. Acquired information was transferred to PC via USB interface for further processing.

The subjects were 4 healthy men and 2 women from 20 to 30 years old.

Instructions for subjects were displayed on the PC screen or vocalized by the experimenter in the experiments with closed eyes. Subjects were given some time to understand an instruction. During this period the EEG analysis was not performed. EEG recordings related to different instructions were marked for their further separation.

There were 30 instructions totally such as "left arm real movement", "left arm movement imagination", "right arm real movement", "right arm movement imagination", "rest" (with open and with closed eyes), “both legs real movement”, “left leg real movement”, “left leg movement imagination”, eye movement in different directions (with open and closed eyelids as well), blink and so on.

The most essential for implementation of BCI is a correct recognition and processing of mental states related to imagination of limb movements. EEG recordings corresponding to eye movements and blinks were used to train classifier to recognize EOG artifacts to be suppressed.

Methods. Artifact classifier learning was based on processing the recordings related to the following 9 instructions: “blink”, “move eyes upward from central position”, “downward from upper to central position” and so on for bottom, left and right gaze positions. Acquisition of these recordings was called calibration procedure. These recordings form the calibration data set which will be referred to as *X*. ICA decomposition was applied to X. In this study “RUNICA” and “SOBI” BSS methods implemented in EEGLab (MATLab toolbox) were used. As a result of ICA decomposition we obtained matrices W and A to present X as

$$X = W \cdot A \tag{1}$$

Here *A* is n-by-m matrix of activities or source functions and *W* is n-by-n weights matrix where n is a number of electrodes and m is a number of recording samples. Each column of *A* is composed by activities of *n* different sources at each moment. Element *Wij* of matrix *W* defines the contribution of *j*-th source to the potential recorded by *i*-th electrode. According to ICA theory, statistical dependency of obtained source activities is minimal. Since EOG artifacts are assumed to be independent of EEG it is expected that the artifacts can be separated by ICA as particular components [6-8].

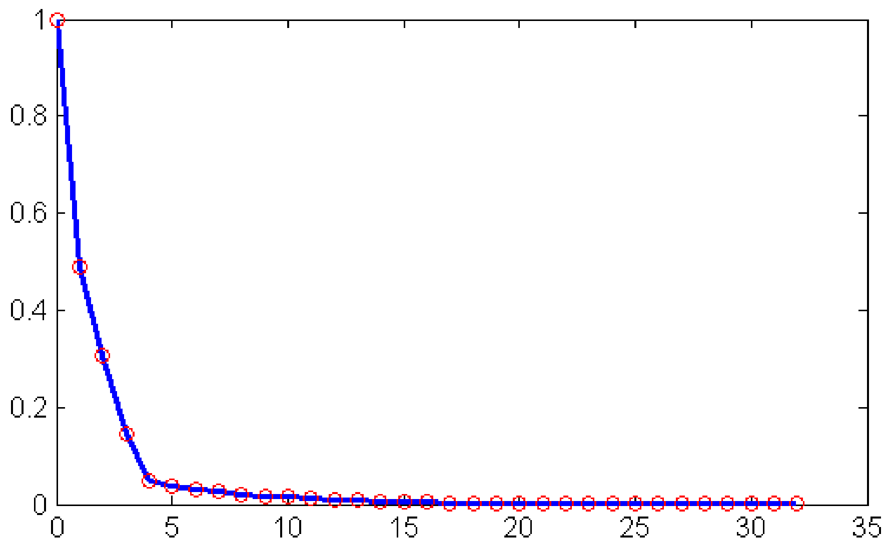

Fig.1. Decrease of the total variance of signals recorded from 6 EOG electrodes after subtraction of k (abscissa) ICA components for subject # 1.

The components of ICA decomposition were sorted according to their contribution to the variance of EOG electrodes and the components having more than 5% of variance contribution were treated as EOG related (Fig.1). For the case shown in Fig. 1 four components were selected. Fig. 2 demonstrates the good correspondence between selected ICA components and recordings of eye movements and blinks. The first component takes up the artifacts related to blinks and downward movements. This results from the fact that downward eye movements are accompanied by lowering of the upper eyelid similar to its movement during blinks. The other components relate to left, right and upward eye movements. It is interesting that two horizontal eye movements were separated as independent components. However this separation is not the common case since left and right eye movements provoke very similar EEG artifacts.

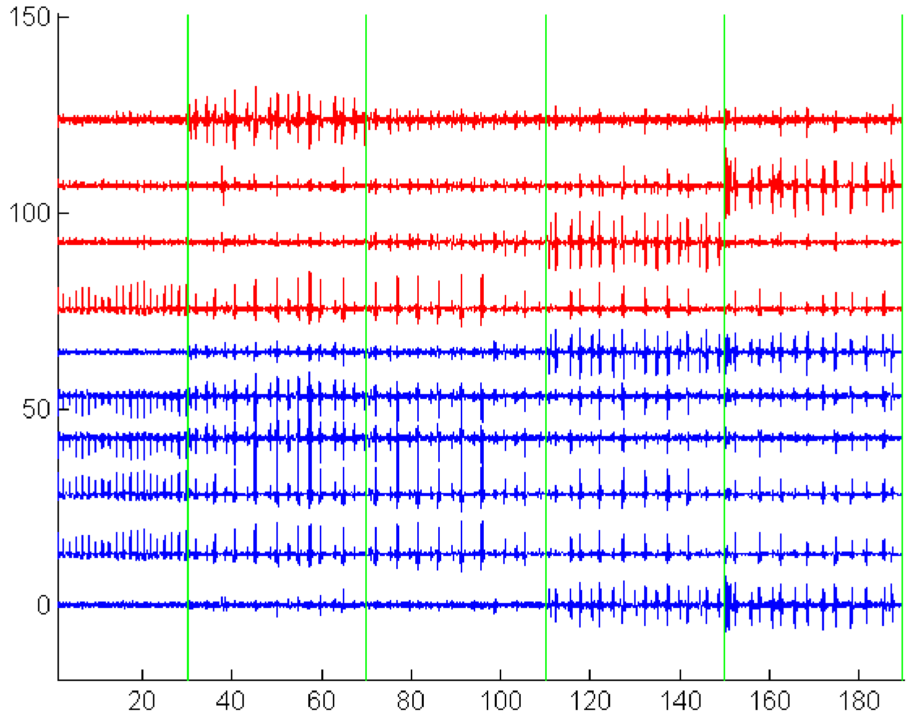

Fig.2. Correspondence between native recordings for 6 EOG electrodes (blue) and activity of 4 selected ICA components (red). Green lines separate recordings with blinks, upward, downward, left and right eye movements.

Let k ICA components be identified as EOG related and $j_1 \ldots j_k$ are their numbers. Then their contribution to EEG is calculated according to equation:

$$X_{EOG} = W_{EOG} \cdot A$$

Here W_{EOG} is a matrix obtained from W by setting to zero all columns except those with numbers $j_1 \ldots j_k$. To exclude EOG artifacts from EEG X_{EOG} must be subtracted from X:

$$X_{EEG} = X - X_{EOG} = \left(W - W_{EOG}\right) \cdot A = \left(W - W_{EOG}\right) \cdot W^{-1} \cdot X \, ,$$

where we used that according to (1) $A = W^{-1} \cdot X$. Hence

$$X_{EEG} = M \cdot X \, , \qquad (2)$$

where $M = \left(W - W_{EOG}\right) \cdot W^{-1}$. We used the obtained matrix M for on-line EOG artifact suppression before EEG pattern recognition by BCI classifier. Since matrix M depends on electrode positions we performed calibration procedure in each experimental session.

Model. To elucidate the distributions of potentials related to EOG artifacts over the human head computer modeling was used. The distributions were estimated by solving the direct EEG problem using Boundary Elements Method (BEM) for a model head with two dipolar current sources simulating the corneoretinal potentials. The corneoretinal potential, generated in each eye was approximated by a single equivalent dipole located near the center of the eye [4]. The head was modeled as a set of different volumes including two eyeballs and two eyelids, each volume having its own conductivity. The conductivities of the brain tissue, bones, skin, intraocular fluid etc. were taken from [9]. The solution was performed by implementation of the algorithm described in [10] accelerated by means of technique developed in [11]. Direct solution of EEG problem provides distribution of electrical potentials over the head surface given dipole direction and eyelid position. Since direct solution of EEG problem is quasi-static we simulated only four different eye movements: upward, downward, left and right from the central position instead of eight performed by subjects during the calibration. Gradually changing dipole direction or eyelid position during simulation of an eye movement or blink we obtained time dependent potential changes which were filtered by the same filter as EEG recordings.

Results. Subsequent analysis showed that different eye movements could be entirely described by corresponding rotation of the equivalent dipolar source, while nature of the blink artifact was still obscure. Hence, the matter needs further investigation. Several ICA components were interpreted as ocular artifacts related to eye movement in four directions and blink by comparing them to the computed artifact patterns. The example of filtering results of blink-polluted EEG recording region shown at fig 3.

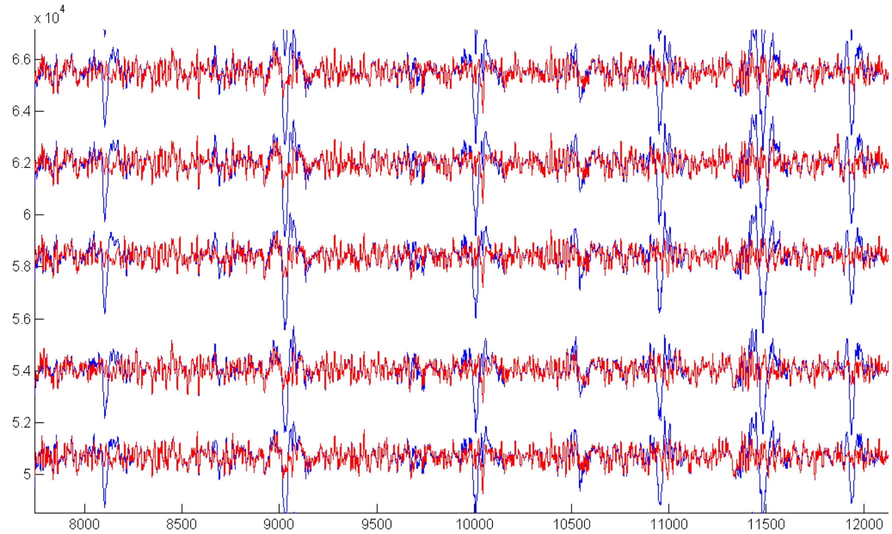

Fig. 3 . Example of EOG artifacts suppression at occipital and parietal electrodes by the algorithm described above. Blue and red lines represent native and filtered recordings, respectively.

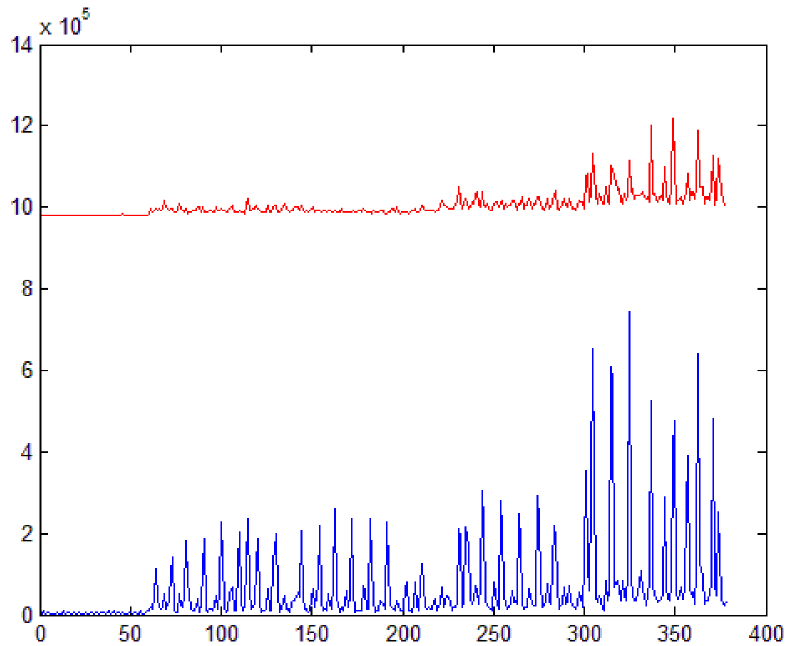

Fig.4. Covariance curves before (blue) and after (red) filtration (one of frontal EEG-electrodes). Abscissa – time window number.

An objective criterion of quality of EOG artifact suppression, can be build based on correlation principle. The implementation was as follows. EEG recording was scanned with 500 ms window and with special threshold algorithm places indicates EOG movements and/or blink were detected. Among all of these windows “mean EOG movement” were calculated. The next step taken – is second scanning of EEG recording and calculation of covariance between mean movement and signal in current window. This procedure were performed to signal before and after ICA base artifact suppression method applied. Fig 4 represents the comparative results before (blue line) and after (red line) artifact suppression procedure performed upon one of frontal electrodes EEG recording, containing several eye movements artifacts. Artifact suppression results noticeable degradation of covariance between mean artifact-like signal feature and signal it self in several time-windows of EEG-recording. It appears to be almost at 6 times lower after filtration then before.

Conclusion. On-line EOG artifact suppression is crucial to functioning of BCI systems based on mental state recognition. Excluding of noise and artifacts improves results of mental sate classification algorithms which in turn improves performance of BCI system as whole. Filtering procedure, described in paper however is subject dependent.

References:

1. *Andrzej Cichicki, Shun-ichi Amari*. Adaptive Blind Signal and Image Processing. Learning algorithms and applications.JOHN WILEY & SONS, LTD 2003.
2. *Andrzej Cichicki, Sergei L. Shishkin, Toshimitsu Musha, Zbigniew Leonowicz, Takashi Asada, Takayoshi Kurach.* EEG filtering based on source separation (BSS) for early detection of Alzheimer’s disease. Clinical Neurophysiology Magazine March 2005. pp. 246-254.
3. *Hans Hallez, Bart Vanrumste, Roberta Grech, Joseph Muscat, Wim De Clercq, Anneleen Vergult, Yves D'Asseler, Kenneth P Camilleri, Simon G Fabri, Sabine Van Huffel, Ignace Lemahieu.* Review on solving the forward problem in EEG source analysis. Journal of NeuroEngineering and Rehabilitation. November 2007. http://www.jneuroengrehab.com/content/4/1/46
4. *Terence W. Picton, Patricia van Roon, Maria L. Armilio, Patrick Berg, Nicole Ille, Michael Scherg*. The correction of ocular artifacts: a topographic perspective. Clinical Neurophysiology 111 (2000) 53-65.
5. *RJ Croft, RJ Barry* Removal of ocular artifact from the EEG: a review *Neurophysiologie Clinique/Clinical Neurophysiology*, Vol. 30, No. 1. (February 2000), pp. 5-19.
6. *Garrick L. Wallstroma, Robert E. Kassb, Anita Millerc, Jeffrey F. Cohnd, Nathan A. Fox.* Automatic correction of ocular artifacts in the EEG: a comparison of regression-based and component-based methods. International Journal of Psychophysiology 53 (2004) pp. 105–119.
7. *V.Krishnaveni, S.Jayaraman, S.Aravind, V.Hariharasudhan, K.Ramadoss*. Automatic Identification and Removal of Ocular Artifacts from EEG using Wavelet Transform MEASUREMENT SCIENCE REVIEW, Volume 6, Section 2, No. 4, 2006.
8. *Tzyy-ping Jung, Scott Makeig, Colin Humphries, Te-Won Lee, Martin J. mcKeown, Vicente Iragui, Terrence J. Sejnowski.* Removing electroencephalographic artifacts by blind source separation. *Psychophysiology, 37* 2000, 163–178.
9. *G Lindenblatt, J Silny. A model of the electrical volume conductor in the region of the eye in the ELF range. Phys. Med. Biol. 46 (2001) 3051--3059 PII: S00319155(01)229212*
10. *Kybic J., Clerc M., Faugeras O., Keriven R., and Papadopuolo T.* Physics in medicine and biology 51(5):1333-46, 2006 Mar 7.
11. *Zhu Z., Song B., White J.* – A general and extensible fast integral equation solver based on a pre-corrected FFT algorithm. [Online]. Available: http://web.mit.edu/people/zhzhu/toms.pdf:8p.