Szczepan PASZKIEL
DEPARTMENT OF ELECTRICAL, CONTROL & COMPUTER ENGINEERING, OPOLE UNIVERSITY OF TECHNOLOGY
76 Prószkowska St., PL-45-272 Opole, Poland

Using LORETA Method Based on the EEG Signal for Localizing the Sources of Brain Waves Activity

Abstract

The article presents the possibility of using the method of imaging brain activity, LORETA *LOw Resolution Electromagnetic TomogrAphy*), that can base on electroencephalographical and magnetoencephalographical readings. Thanks to using the above-mentioned method, it is possible to localize the sources of the activity of individual signals registered on the head surface. This is very significant regarding construction of the brain-computer interfaces in order to conduct proper identification and classification of signals obtained during electroencephalography.

Keywords: electroencephalography, LORETA, signal, brain computer-interfaces.

1. Introduction

The following techniques of brain examinations are popular: electroencephalography (EEG), functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), positron emission tomography (PET).

A problematic issue during constructing the brain-computer interfaces – BCI is the issue of proper identification of the EEG signal sources. In order to obtain that, for the purposes of the conducted works, a LORETA technique [1] was used based on the idea of solving the inverse problems and estimating distribution of neurons' electrical activity in three-dimensional space. This technique is currently frequently used for electrophysiological measurements and its efficiency has been verified in numerous research laboratories. The following entities, among others, worked on this issue: Pascual Marqui, Esslen, Kochi, Lehmann in 2002. While this article does not focus on the verification itself, but more on the correlation of the technique with the brain-computer technology.

LORETA is a method facilitating visualization of the EEG signals sources identified as electric dipoles for the purposes of elaborating the three-dimensional model of brain [2]. Thus, LORETA is an estimation method that does not supplement the EEG signal with new information. Nevertheless, thanks to this method it is possible to estimate sources of certain signals in the human brain [3]. These can be then used in the process of control based on the BCI technology [4]. It is currently one of the most dynamically developing paths of implementation of new media for communication between a human and a machine.

The main purpose of the article is the characteristics of inverse problem based on the identification of the source of the potential of the human brain. For the purposes of the conducted experiment, a short characterization of the LORETA method was presented. An alternative method used for spatial localization of the signals sources is the Common Spatial Pattern technique.

2. Forward and inverse problem

The inverse problem also called the inverse issue is frequently found in the field of technical sciences [5]. It occurs when some parameters of a certain model have to be determined basing on the values that are possible to observe [6,7]. In the case of electroencephalography it is a signal measured on the head surface based on the information created in its specific source in a form of the activity of neurons and their mutual correlation [8]. Assuming that $I(t)$ is a set of active dipoles of the signal sources, it is possible to determine the potentials measured on the head surface as (1):

$$x(t) = \sum_{i \in I(t)} K_i j_i(t) \qquad (1)$$

where: i – i^{th} localization of dipoles based on the three-dimensional space: x, y, z, while $x(t) = (x_1(t), \ldots, x_N(t))^T$ is a vector of data from N of measuring electrodes registered in a moment of time t, K – number of matrices/occurrences of a certain set, $j(t)$ – estimated vector. Dipole is characterized by the changing amplitude and constant orientation [9].

$$K_i = (k_{i(x)}, k_{i(y)}, k_{i(z)}),\ K = (K_1, \ldots, K_I) \qquad (2)$$

Finally, we are able to express the problem occurring during the measurements with the linear formula (3):

$$x(t) = Kj(t) \qquad (3)$$

where:

$$j = (j_1^T, \ldots, j_I^T)^T,\ j_i = (j_{i(x)}, j_{i(y)}, j_{i(z)})^T \quad i \in \{1, \ldots I\} \qquad (4)$$

The fundamental rule during creation of the brain-computer interfaces is proper observation and acquisition of data registered on the head surface. During this operation, it is necessary to localize the sources of potentials in the human brain. As it was mentioned in the introduction to this paragraph, in such case we deal with the inverse problem, for the purpose of which, we defined the vector $j(t)$ [10]:

$$j(t) = T^T x(t) \qquad (5)$$

where:

$$T^T = (T_1, \ldots, T_I)^T \qquad (6)$$

I – number of voxels in the cortex space. Voxel is an element of the volume in the brain space for which we assume a constant value concerning the density and direction of the passing-through current. T^T is an inversion of the matrix K. Usually, the voxels are determined by subdividing uniformly the solution space, which is usually taken as the cortical grey matter volume or surface. At each voxel there is a point source, which may be a vector with three unknown components or a scalar.

3. LORETA method

We can distinguish three kinds of the LORETA techniques for the brain activity imaging - verification of the sources of signals created in the brain: LORETA, sLORETA (standardized LORETA), eLORETA (exact LORETA). sLORETA is characterized by low spacial resolution that decreases with the decrease in the levels of identification. An unique feature of the sLORETA method is a fact of high accuracy of the point sources in the ideal conditions [11]. eLORETA is a method which was created in the University of Zurich, it was extended by the quasi-linear methods, thanks to which it should be possible to maintain zero number of errors of localization. Nevertheless, as it can be concluded from the research, the sLORETA method is characterized by higher accuracy in the aspect of including biological artifacts than the eLORETA method.

The main original matrix of transformation for the sLORETA, that is the standard low resolution electromagnetic tomography, is (7):

$$Z = (KK^T + \alpha H)^+ \quad (7)$$

where: $Z \in R^{NxN}$ and is symmetrical. H – centering matrix. α – coefficient thanks to which we increase the resistance to disturbances. $\gamma_i(t)$ is defined by the formula presented below (8) assuming that $i \in \{1,.., I\}$.

$$\gamma_i(t) = j_i^T(t)[T^T K]_i^{-1} j_i(t) \quad (8)$$

where: $[T^T K]_i$ is the diagonal matrix of the dimensions of 3×3, T^T is a minimal standard of the transposed matrix. At the same time, thanks to using the sLORETA method it is possible to separate active sources of the EEG signal [11].

The eLORETA method is based on the correlation of the matrix diagonal with its weights. The eLORETA technique is defined by the formula (9) where $q \in \{1,.., Q\}$.

$$\Theta_i^{-1} = [K_i^T (K\Theta^{-1}K^T + \alpha H)^+ K_i^T]^{1/2} \quad (9)$$

The issue of the eLORETA method grounds on the optimization based on the formula (10):

$$\min_{\Theta} \| I - [\Theta^{-1}K^T(K\Theta^{-1}K^T + \alpha H)^+ K\Theta^{-1}] \|_F^2 \quad (10)$$

That is met by the following formula (11), where $i \in \{1,.., I\}$

$$\Theta_I^2 = K_i^T (K\Theta^{-1}K^T + \alpha H)^+ K_i \quad (11)$$

Θ is determined by the matrix (12).

$$\Theta^{-1} = \begin{bmatrix} \Theta_1^{-1} & & 0 \\ & \ddots & \\ 0 & & \Theta_I^{-1} \end{bmatrix} \quad (12)$$

4. Material

Due to low level of the method's complexity and its easy correlation with mobile equipment, and also applications on the working stations, for the purpose of research, the electroencephalography was used. On this basis the device manufactured by Emotiv: EPOC+ NeuroHeadSet operates. This device comprises of 14 measuring electrodes plus 2 reference electrodes, frequency range 0.16 – 43 Hz with 16-bit information processing.

Data for the experiment were taken in the NeuroScience Laboratory of the Opole University of Technology. Five persons (on average 22 years old) subjected to the measurements were taken in a sitting position. The measurement lasted 5 minutes, it was repeated 30 times for each condition: elevated concentration – solving mathematical problems, organism's calmness – closed eyes, processing standard information from the surroundings – eyes open. The signals were measured according to the Emotiv conception (Figure 1).

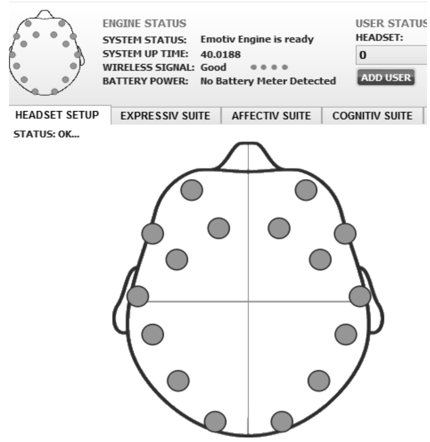

Fig. 1. Visualization of electrodes in the panel's application Emotiv

Emotiv EPOC+ NeuroHeadset was used as the measuring device. After taking samples of signal they were filtered high and low frequency using the software with which biological artifacts like nervous tic of the examined persons, temporary clenching eyelids, etc. Were removed within the executed experiment, one matrix for each waveband: alpha, beta, delta, theta was determined.

For the purposes of LORETA techniques applied raw data. Rectangular window for the analysis was specified based on the research Lubar, Congedo, Askew conducted in 2003 [12].

During the EEG signal analysis, special attention needs to be paid to the artifacts, this is the next significant problem when using the BCI technique, right after the verification of the signal sources. Unfortunately, if the EEG signal is not proportional to the electrical potential generated by the brain, disturbances occur. They deform the real course of the brain waves. According to their origin, artifacts can be divided into: technical and biological. Influence of the sources is directly proportional to the generated signal amplitude and inversely proportional to the distance between the sources and the EEG electrodes. Changes in conductivity occurring between the electrodes and the head surface can also be accounted as artifacts.

Technical artifacts are removed from the EEG signal by using low-pass filter. Sources of technical artifacts include, among others: electric power network, medical equipment and work stations, etc. Biological artifacts are created as a result of: eye balls movement, skeletal muscles movement, body movement against the electrodes (head shaking), heartbeat, arterial pulse, sweat or sebum secretion from the skin, clenching teeth, swallowing.

5. Methods used

During the conducted research, the LORETA-Key was used. The measurement space was determined based on the atlas of Brain Imaging Center at the Montreal Neurological Institute, through dividing the brain into 2394 voxels of the dimensions of: 7 × 7 × 7 mm [13].

For the purposes of the conducted data analysis, each voxel of the fixed current density was standardized in the range of the amplitude up to 9 mm using the three-dimensional filter, and then subjected to logarithmic transformation in order to approximate the data using the Gaussian function. In a case of using the LORETA technique, it is important to decrease the errors caused by the anatomical structure of the head and errors caused by the incorrect localization of the sources. Unfortunately, the local maximums of the function can be shown in other places than they really occur. Then, the spatial normalization bases on the process of normalization of the square root from the sum of the squares of the current density.

Thanks to using the above-mentioned mathematical apparatus it is possible to eliminate the incorrect values inserted by, for instance: skull thickness changeable between certain persons, differences in the electrodes' impedances, etc. Estimation of the current amplitude density allows to provide data for further statistical analysis. Experiment was conducted for the waves: alpha, beta, theta and delta, voxel after voxel, using the t-test [14]. For the above-mentioned ranges of waves, the sLORETA technique was used for the analysis of the current amplitude density.

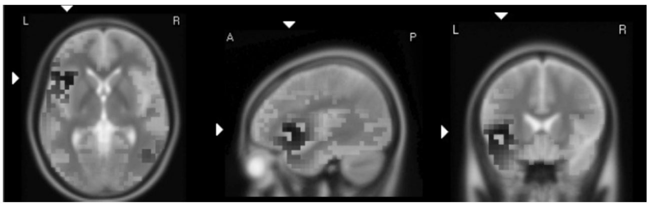

Fig. 2. Example visualization of brain activity for the entire course of five people, based on the sLORETA technique for the state of elevated concentration. The figure shows the density of currents

Figures 2 and 3 show the example visualizations of the changes in activity of certain areas of the brain activity of the human brain using standardized *Low Resolution Electromagnetic Tomography. Figure 2 shows the activity of the sources of electroencephalographical signals for the elevated concentration that. Figure 3 shows the activity of the EEG signal sources for* the state of processing standard information from the surroundings of the examined persons.

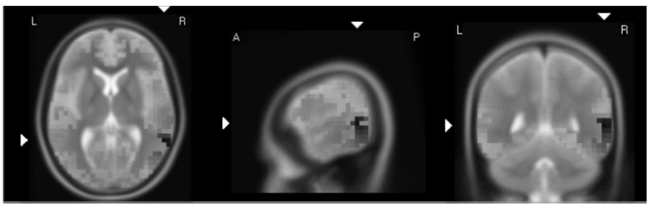

Fig. 3. Example visualization of brain activity for the entire course of five people, based on the sLORETA technique for the state of processing standard information from the surroundings

6. Conclusions

For the purposes of the research, sLORETA method was chosen for imaging brain activity in relation to three states: concentration, calmness, standard processing. Properly conducted identification of the electroencephalographic signals sources using the sLORETA technique allowed to obtain information on creation of specific changes in the EEG signal readings for a specific measuring electrodes. Changes in the amplitude of signals correlated with specific sources of their creation in the human brain observed in the above-mentioned group of people in relation to the tested states of concentration can be successfully used to execute control with the brain-computer technology.

LORETA enables to execute visualization of incorrect brain structures' activity, at the same time, determining artifacts within the range of frequency band and spatial localization, what allows to conduct much more advanced analyses than the standard analysis based on the electroencephalography. Thanks to the LORETA technique, it is possible to determine more accurately the neurological phenomena occurring in the human brain based on the information contained in the EEG signal, thus, understanding them better. Due to using the LORETA method, it is not necessary to limit the number of bipolar point sources because the current distribution on the entire brain surface is calculated directly. Then, we obtain three-dimensional tomographic scan, received assuming low value of spatial resolution. It is worth noting that thanks to using the LORETA method it is possible to specify new hypotheses concerning the cognitive functions conducted in the brain.

7. References

[1] Pascual-Marqui R. D., Michel C.M., Lehmann D.: Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. International Journal of Psychophysiology. 18, 1994, pp. 49-65.

[2] Frei E., Gamma A., Pascual-Marqui R. D., Lehmann D., Hell D., Vollenwider F.: Localization of MDMA-induced brain activity in healthy volunteers using low resolution brain electromagnetic tomography (LORETA). Human Brain Mapping, 2001, pp. 152-165.

[3] Paszkiel S.: Augmented reality of technological environment in correlation with brain computer interfaces for control processes, Advances in Intelligent Systems and Computing 267 - AISC, Springer, Conference Proceedings Citation Index (ISI Proceedings), Switzerland 2014, pp. 197-203.

[4] Billiot K. M., Budzynski T. H., Andrasik F.: EEG patterns and chronic fatigue syndrome. Journal of Neurotherapy, 1997, pp.20-30.

[5] Pascual-Marqui R. D.: Review of methods for solving the EEG inverse problem. International Journal of Bioelectromagnetism 1999, pp. 75-86.

[6] Congedo M., Lotte F., Lécuyer A.: Classification of Movement Intention by Spatially Filtered Electromagnetic Inverse Solutions, Physics in Medicine and Biology, 2006, 51, pp. 1971-1989.

[7] Lotte F., Lécuyer A., Arnaldi B.: An inverse Solution based Feature Extraction Algorithm using Fuzzy Set Theory for Brain-Computer Interfaces. IEEE Transactions on Signal Processing, 2009, 57, pp. 3253-3263.

[8] Christian J. C., Morzorati S., Norton J.A., Williams C. J., O'Connor S., Li T. K.: Genetic analysis of the resting electroencephalographic power spectrum in human twins. Psychophysiology, 1996, pp. 584-591.

[9] Fuchs M., Wagner M., Köhler T., Wischmann H. A.: Linear and Nonlinear Current Density Reconstructions. Journal of Clinical Neurophysiology, 1999, pp. 267-295.

[10] Besserve M., Martinerie J., Garnero L.: Improving quantification of functional networks with EEG inverse problem. Evidence from a decoding point of view Neuroimage, 2011.

[11] Pascual-Marqui R. D.: Standardized low resolution brain electromagnetic tomography (sLORETA): technical details. Methods & Findings in Experimental & Clinical Pharmacology 2002, pp. 5-12.

[12] Lubar, J., Congedo, M., Askew, J.H.: Low-resolution electromagnetic tomography (LORETA) of cerebral activity in chronic depressive disorder. Int, J. Psychophysiol. 49 (3), 2003, pp. 175-185.

[13] Collins D. L., Neelin P., Peters T. M., Evans A. C.: Automatic 3D intersubject registration of MR volumetric data into standardized Talairach space, Journal Comput. Assist. Tomogr., 1994, pp. 192-205.

[14] Congedo M., Finos L., Turkheimer F.: A Multiple Hypothesis Test Procedure based on the sum of Test-Statistics. 10th Annual Meeting of the Organization for Human Brain Mapping, June 13-17, Budapest, Hungary, 2004, Abstract on CD.

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Szczepan PASZKIEL, PhD, eng.

Szczepan Paszkiel currently working in the Institute of Control and Computer Engineering on the Faculty of Electrical Control and Computer Engineering at Opole University of Technology. He is a graduate of Informatics and Management and Production Engineering at Opole University of Technology. He is a grant holder and winner of many contests for young scientists. He has been conducting research on processing the EEG signal. He is an author and co-author of many scientific publications.

e-mail: s.paszkiel@po.opole.pl