

DOI: 10.5604/01.3001.0010.4837

ANALYSIS OF APPLIED REFERENCE LEADS INFLUENCE ON AN EEG SPECTRUM

Małgorzata Plechawska-Wójcik¹, Kinga Wesolowska², Martyna Wawrzyk², Monika Kaczorowska¹, Mikhail Tokovarov¹

¹Lublin University of Technology, Institute of Computer Science, ²Lublin University of Technology, Faculty of Mechanical Engineering

Abstract. The article presents the analysis of various kinds of montage applied in the analysis of electroencephalographic data. The present study covers analysis of data obtained as a result of EEG examination of several persons with the age of 23–24 years. Every person has undergone an examination with appliance of 21 electrodes in accordance with classic EEG record method applying the 10–20 system. The examined persons were asked to perform the following activities: sitting steadily with opened eyes, sitting steadily with closed eyes as well as typical cognitive activity i.e. silent reading of given text. Every fragment has been subjected to initial data analysis (filtering, artifact correction) and used for spectral analysis afterwards. The whole analysis has been realized on the basis of four EEG montage examples (two bipolar and two monopolar). For each of them comparative analysis concerning the following points has been carried out: EEG spectra as well as other measures, such as activity maps, diffraction histograms for separate waves and spectrum charts for the selected electrodes.

Keywords: electroencephalography, EEG spectra, EEG montage

ANALIZA WPLYWU DOBORU ODPROWADZEŃ REFERENCYJNYCH ZAPISU EEG NA UZYSKANE WIDMO

Streszczenie. Artykuł przedstawia analizę zastosowania różnego rodzaju montażu w analizie danych elektroencefalograficznych (EEG). Zaprezentowane studium przypadku obejmuje analizę danych z badania EEG kilku osób w wieku 23–24 lat. Każda osoba poddana została badaniu z wykorzystaniem 21 elektrod w klasycznym zapisie EEG z wykorzystaniem systemu 10–20. Osoby badane poproszone zostały o następujące aktywności: spokojne siedzenie z oczami otwartymi, zamkniętymi a także typową aktywność poznawczą – czytanie zadanego tekstu w myślach. Każdy fragment został poddany wstępnej analizie danych (filtracja, korekcja artefaktów) a następnie wykorzystany do analizy widmowej. Cała analiza została zrealizowana w oparciu o cztery przykładowe montażu EEG (dwa bipolarne i dwa monopolarne). Dla każdego z nich zrealizowano analizę porównawczą w odniesieniu do widm EEG a także innych miar, takich jak mapy aktywności, histogramy rozkładu poszczególnych fal oraz wykresy widmowe dla wybranych elektrod.

Słowa kluczowe: elektroencefalografia, widma EEG, montaż EEG

Introduction

Electroencephalography (EEG) is non-invasive diagnostic method used for examination of brain bioelectrical activity by the means of a device called an electroencephalograph. This device records electrical changes appearing in the millions of brain neuron cells. EEG electrodes are placed at the surface of the head. Specially designed cap is used to keep them in proper position.

The first study on human EEG was conducted in 1929 by the German psychiatrist Hans Berger. This discovery provided a new neurologic and psychiatric diagnostic tool designed especially for purposes of neurologic diagnosis and neurosurgical operative procedures planning [14].

Nowadays EEG recordings might be visible at computer screen and saved to a computer memory. Currently available EEG analysis software make it possible to analyze previously recorded data repeatedly and with different settings. One of such setting is the location of reference electrode (electrodes) known as a montage [17]. It is possible to apply different kind of montages [12, 18]. Their schemes might have significant impact on the EEG data analysis [16]. This paper is dedicated to analysis of the different montage types application to the typical EEG analysis.

1. Electroencephalography

Electroencephalography is the research method aimed at studying bioelectrical brain function as well as the functional state of the central nervous system. EEG is useful in the diagnosis of many nervous system diseases e.g.: epilepsy, insomnia, headaches and migraines, brain tumors and injuries. Also EEG is very important for monitoring and diagnosis of consciousness disturbances as well as emotional disorders and attention deficit disorders causing difficulties in learning process. BCI (Brain-Computer Interface) is widely applied for EEG. It enables to establish the connection with external world through detecting brain waves. A special game based on EEG exists, it is aimed at training concentration by strengthening the desired brainwave rhythms. Network authentication or identification of a person is based on unique characteristics of processed EEG signal. In this purpose the system consisting of computer and special sensors

transmitting the collected signal to the evaluation unit is used. The kit allows to maintain effective communication between computer and brain in on-line mode, so for example applets in a smartphone can be controlled by mood and emotions [10].

Currently EEG research methodology is well established. In standard clinical study 19 electrodes are placed on the head surface. This distribution is widely known as 10-20 system recommended by the International Federation of Clinical Neurophysiology. It consists of eight electrodes on each hemispheres and three electrodes in the midline [4].

The electrodes are marked as follows:

- seven electrodes on the cortex of the frontal lobes: Fp1, Fp2, F3, F4, F7, F8, FZ,
- three electrodes on the border of the parietal and frontal lobes: C3, C4, CZ,
- three electrodes over the parietal lobes: P3, P4, PZ,
- four electrodes over the temporal lobes: T3, T4, T5, T6,
- two electrodes over the occipital lobes: O1, O2,
- and two reference electrodes attached to the earlobe: A1, A2.

Correct electroencephalography record of a health adult has some characteristic features. Human sitting with eyes closed has a dominant rhythm in the form of regular alpha wave activities. It properly differentiated spaces i.e. with an amplitude decreasing from occiput anterior. Leads in front leading dominated by low-voltage operation beta.

Under normal physiological conditions brain waves are found in the frequency range 1–100 Hz and an amplitude between 5 and several hundred μV . In the case of pathology (for example, damaged cells or impairment of the chemical conduction) some of these pathologies might occur in EEG record: delay or acceleration of the speed of flow, increase or decrease of the amplitude, change of their shape or configuration [7].

There are several EEG waves occurring in typical record (Fig. 1). There are several wave types amongst them:

- delta waves (δ),
- theta waves (θ),
- alpha waves (α),
- beta waves (β),
- gamma waves (γ).



Fig. 1. Wave types of EEG signal. Source: own work

Delta waves (δ) have the frequency value up to 4 Hz. Mainly they are observed in the third and fourth stage of deep sleep (also called Stage NREM).

Theta waves (θ) are the waves with frequency values from 4 Hz to 8 Hz. Theta activity may be observed during hypnotic states such as trance, hypnosis and light sleep. They are associated with 1 (nap) and 2 (light sleep) stages of NREM sleep. Different kind of theta is associated with cognitive activity and particularly with attention as well as with memory processes. Consciousness at this frequency makes possible control of physical pain and even bleeding in extreme cases. Thinking becomes restless at this frequency and ability of logical thinking disappears, what can be seen clearly on the example of thinking activity during dreaming.

Alpha waves (α) have frequency of 8 Hz to 13 Hz. Amplitude is approximately 30- 100 μ V. Alpha waves are clearly visible in the absence of visual stimuli (when eyes examined person are closed). Their suppression occurs during visual perception. Alpha waves are also associated with the state of relaxation and a reduced level of cognitive activity, e.g. during lying with closed eyes before going to sleep and in the morning during awakening. This wave type is used in the techniques of accelerated learning.

Beta waves (β) are the wave type with a frequency from 13 to 30 Hz, their amplitude is below 30 μ V. They reflect the commitment of the cerebral cortex in cognitive activity. Beta waves of small amplitude appear during the periods when the attention is focused. Additionally they can be caused by various pathologies, and chemicals substances such as benzodiazepines. Benzodiazepines are drugs with anxiolytic, sedative, hypnotic, anticonvulsant action.

Gamma waves (γ) have the frequency value around 26–100 Hz. Gamma activity is associated with higher cognitive processes such as perception and sensory memory. Gamma waves with the frequency of about 40 Hz are related to perceptual consciousness (connected with impressions and perception) as well as to integration of various sensory modalities (sight, hearing, sense of smell and touch) [2].

2. EEG configuration

EEG signal is received as voltage difference between two electrodes. There are many possibilities to make connections of electrodes. These connections are known as montages, which is a design of electrodes derivations. Nowadays recording EEG data on computer makes it possible to apply many types of montages in one study [11], in order to obtain various results of EEG test [9]. Two types of montages are commonly distinguished: bipolar montage and referential montage. Obviously, there are more montage types available [3]. Among them one can find (Fig. 2):

- Bipolar montage. In Bipolar montage voltage difference is measured by connection two adjacent electrodes. For instance Fp1 is connected together with F7 or F3. This type is particularly used to test selected fields activity of nerve cells, not entire brain.
- Referential montage (Monopolar montage). In this case voltage difference is measured between electrodes and a special electrode, which is called the referential electrode. This montages are applied for examining the activity of all nerve cells. (By using this montage, it is easy to detect various nerve disease of brain, e.g. epilepsy).

- Monopolar montage (M3). In this type montage electrodes A1 and A2 are defined as referential electrode. The electrodes of the left hemisphere of the brain and electrodes Fz, Pz are linked with A1, and with A2 the right hemisphere and electrode Cz.
- Average Reference montage (M4). It is necessary to mention Average Reference montage, in which values off all electrodes (without reference electrode) are summed up and averaged. Finally, difference between average and referential electrode is measured.
- Laplacian montage. This kind of montage is very similar to common average reference montage, but the difference is that there are local weighted average reference. It means, that average of neighboring electrodes are taken into account. It is very useful especially for low or moderate artifacts [6].

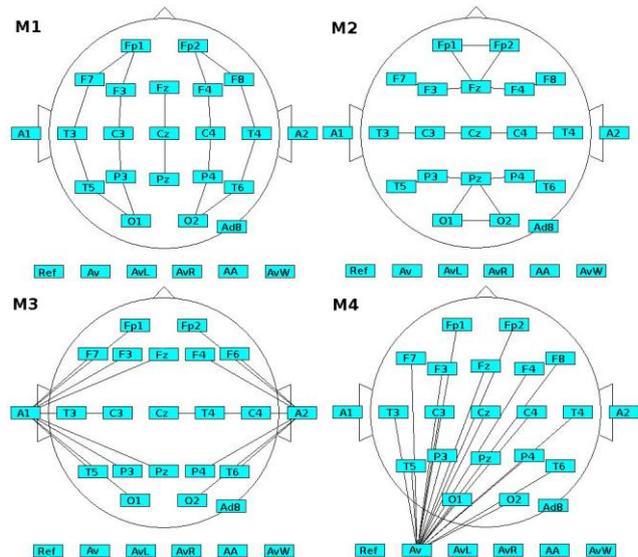


Fig. 2. Four types of montages (M1- longitudinal bipolar, M2 – transverse bipolar, M3 – monopolar with ears reference, M4 – monopolar with average reference)

3. Spectral analysis

Spectral analysis is used for data analysis in various domains. Spectrum analysis is analysis in terms of a spectrum of frequencies based on time series. It may have application for instance in engineering, astronomy and geophysics. Increasingly spectral analysis is applied in medical diagnostics.

A human brain emits specific waveforms, which may be gathered by using EEG (electroencephalography). Spectral analysis is used for examination of brain activity.

Spectral analysis is a mathematical approach to quantify the EEG. It decomposes a signal into its constituting frequency components. Quantitative electroencephalography (QEEG) has been accepted for clinical application for example in epilepsy.

The transition from the time domain to the frequency domain is performed using the Fourier transform. Each of spectral analysis is based on the Fourier transform. Fourier analyzer transforms a signal over time into a frequency. It is a tool to analyze neural signals.

There are several methods of spectral analysis. First of them is harmonic analysis. Harmonic analysis is applied in case if signal is composed of a sum of individual oscillatory components. There are also Blackman-Tukey Transformation and MESA – Maximum Entropy Spectral Analysis.

The fast Fourier transform is the method for obtaining the EEG spectrum [1].

A fast Fourier transform (FFT) algorithm computes the discrete Fourier transform (DFT). It manages to reduce the complexity of computing the DFT [15].

The sampling frequency must be consistent with the sampling theorem. If the sampling theorem is not respected, aliasing appears. Aliasing causes that signals to become indistinguishable.

In the frequency domain spectrum of the signal is multiplied in the sampling.

If the maximum frequency sampling signal (width of the spectrum) exceeds a half the sampling frequency, next recurring spectrums begin to overlap. According to the theorem of Kotelnikov-Shannon the original signal can not be reproduced with distorted samples. Figure 3 shows spectrum analysis in the time and frequency domain.

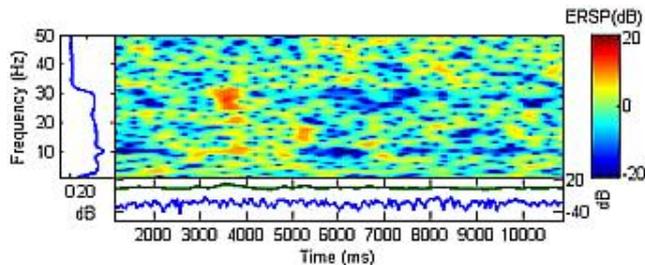


Fig. 3. EEG analysis in the time and frequency domain. Source: own work

4. Testing procedure

Participants took part in experiment in a quiet testing room in dedicated laboratory with artificial lighting. The experimenter explained the procedure. The participants were instructed to minimize body movement to minimize potential artefacts in their EEG signals and to fixate on the centre of the monitor.

The 21 channel EEG amplifier – Mitsar EEG 201 – was applied to record EEG data. EEG amplifier transmitted data to computer with the native software (EEG Studio). The room was illuminated with standard fluorescent light and outside light was blocked to remain stable conditions for experiment's durations.

The samples were recorded with frequency of 500 Hz. The signal was gathered from nineteen using cup-shaped electrodes located over the user scalp according international 10–20 EEG standard (Fig. 4). Electrodes were placed in a special EEG cap to keep them in the right position. In addition, the ground electrode was placed in the centre of the frontal lobe and two reference electrodes (A1, A2) were placed on ears.

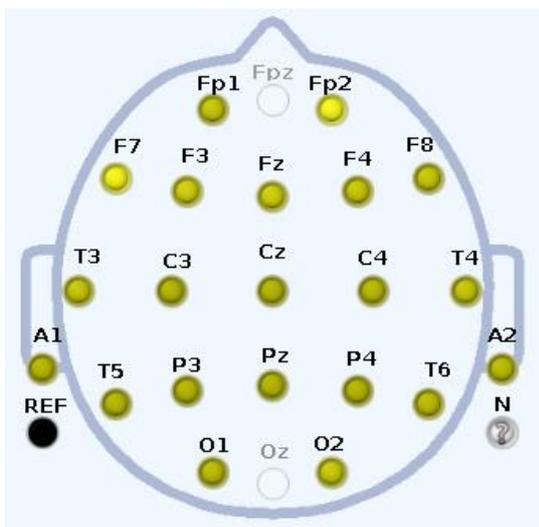


Fig. 4. EEG electrodes localization

The signal was gathered from four participants. They were asked to perform standard activities:

- sitting quietly motionless looking straight ahead – resting state data– sitting with eyes closed and open,

- sitting performing cognitive processing action: reading book quietly – cognitive activity action data,
- artefacts generating like blinking, speaking, hyperventilation – noised data.

EEG signal preprocessing covered signal filtration (including frequency filtration) and artefact elimination. As the EEG signals have low amplitude, which is usually less than 100 μV , its quality and high signal-to-noise ratio is important.

Frequency filtration was applied to remove noisy part of the signal containing low level of information (such as signal frequencies lower than 3 Hz or higher than 45 Hz) as well as signal interfering with external electronic devices (signal with a frequency of 50–60 Hz).

Another important preprocessing step is artefact correction. It enables flatter unwanted signals. Depending on their origin, they can be divided into two groups: technical artefacts related to the registration signal and biological artefacts originating from the examined person. The first group is related to electric field noise and inaccurate attached electrodes. The second group of artefacts is related to the physiology of a patient: sweating, blinking and eye movement, tongue, head and neck muscles movements as well as electrical activity of the heart.

In the study Principal Component Analysis (PCA) [8] and Independent Component Analysis (ICA) [5] were applied to remove the artifacts [13]. Depending on needs, ICA or both, PCA followed by ICA were applied.

5. Analysis of the montage influence on the EEG spectrum

EEG spectra in the study were generated based on FFT method. The analysis was performed regarding four different EEG montages originating from different montage types including these presented at Fig. 1. All applied montages were generated based on the same EEG recording fragments where 21 electrodes were used. From the long, lasting almost one hour recordings several seconds fragments were chosen for the analysis. Different activity fragments, such as sitting with eyes open, closed and cognitive action processing were analyzed separately.

The analysis process covered noised EEG signal filtration and artifact correction with PCA and/or ICA method.

The analysis covered comparison of several aspects. The analysis included data visualization (such as tables and charts, brain activity maps, raw data presentation). Several comparison methods were applied in the study. They are:

- Brain activity maps generated for both, signal amplitude and power,
- EEG asymmetry visualization,
- EEG spectra calculated for both, signal amplitude and power,
- Histograms presenting EEG waveform distribution,
- Chosen waveform ratio (such as alpha/theta ratio).

Brain activity records obtained as a result of brain examination with monopolar electrode montage can be presented as a map of activity, whereas the map of brain activity as per examination with bipolar electrode montage cannot be made due to the fact that for bipolar montage the voltage difference of every electrode is measured in relation to two neighboring electrodes, so there is no single reference level to build up a potential map, because a potential is always relative and needs a single specified reference point.

The analysis covered a series of different results. Some of them, the most significant are presented in Fig. 5 – Fig. 15. Fig. 5–7 present histograms obtained for one example EEG recording. Histograms were generated for both, power and amplitude spectra, whereas figures present results for power spectra obtained for example electrodes (Fp2,Cz,T4) and for all montages. Fig. 8–9 show maps of EEG power and amplitude spectra. Maps were generated for two of montages: monopolar (M3) and monopolar average (M4). Presented fragments are

related to eyes opened, eyes closed and reading. The scale for each single map was unified (for power spectrum $0.4 \mu V^2$, for amplitude spectrum $0.7 \mu V$). Fig. 9–14 were generated for both, power and amplitude spectra for the selected electrodes (Fp2,Cz,T4,P3).

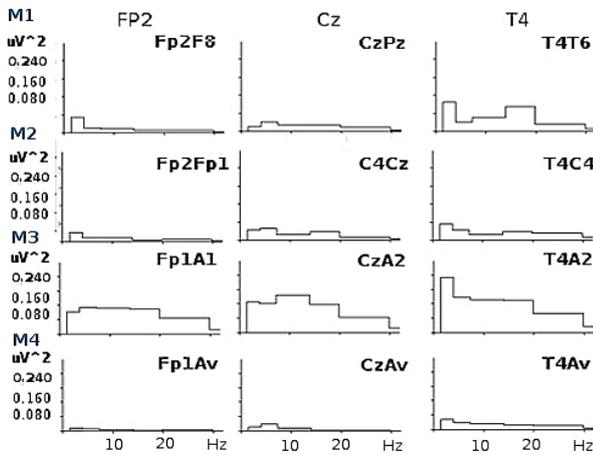


Fig. 5. EEG waveforms histogram for EEG power spectra for all montages. Fragment: eyes open

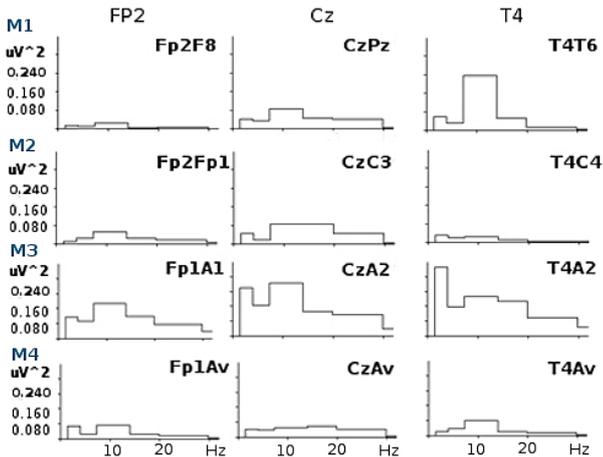


Fig. 6. EEG waveforms histogram for EEG power spectra for all montages. Fragment: eyes closed

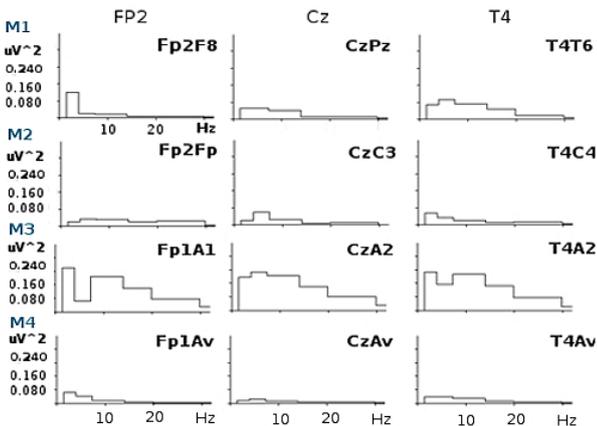


Fig. 7. EEG waveforms histogram for EEG power spectra for all montages. Fragment: cognitive activity – reading

For each user activity fragment was shown for the same scale which was mentioned previously. For each fragment single, the most characteristics waveform was chosen. Alpha waveform was presented for eyes closed, beta 1 waveform was shown for eyes opened and beta 2 was presented for reading.

All results presented in Fig. 3–13 prove that there are visible differences between particular montages. Results visible in Fig. 3–5, obtained for unified scale, indicate that montage M3 (monopolar with ears reference) is the most accurate for observing general spectral analysis results for the whole surface of the head and for all electrodes analysed simultaneously. Other montages, especially bipolar, are dedicated rather to analysing particular, usually narrow area of the head. The most visible differences might be noticed for eyes closed fragment, where one can notice differences in waveform distribution among different montages.

More general character of monopolar montages are confirmed also by results presented in Fig. 6–7, where brain activity maps are presented. These results might be generated only for monopolar montages. Differences in map coloring are due to unified scale obtained for results of both montages. Obtained results, analysed also for other scales (not shown) indicate similar conclusions and no significant differences between activities of particular brain areas. Results of Fig. 10–15 present values of the most characteristic waveforms for each single fragment (eyes opened, eyes closed, reading) for four chosen electrodes. For both, amplitude and power spectrum it might be noticed, that results for M3 montage (monopolar montage with ears reference) occurred to be the most informative. Noticeable differences between electrodes and particular waveforms might also be observed for the M4 montage (monopolar montage with average reference). Bipolar montages occurred to be less significant.

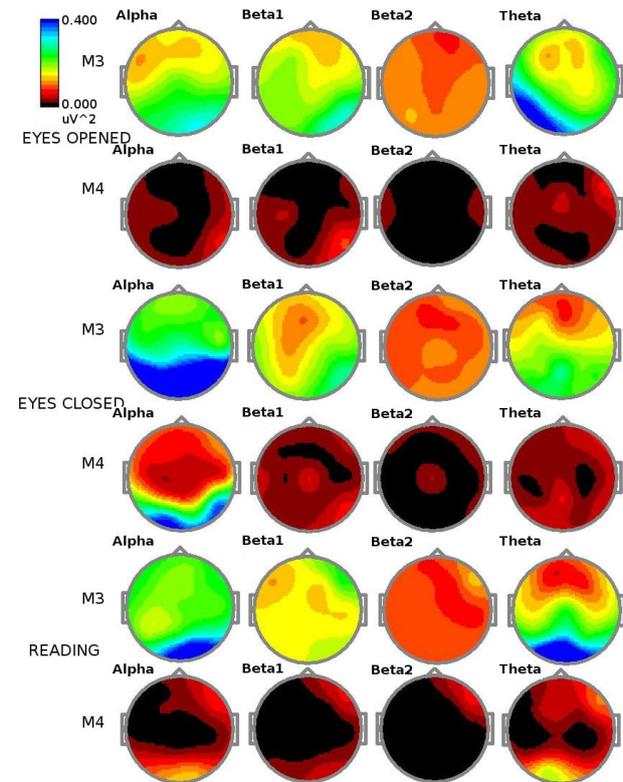


Fig. 8. Maps of EEG power spectra for bandranges for montage monopolar and monopolar average. Fragments: eyes opened, eyes closed and reading

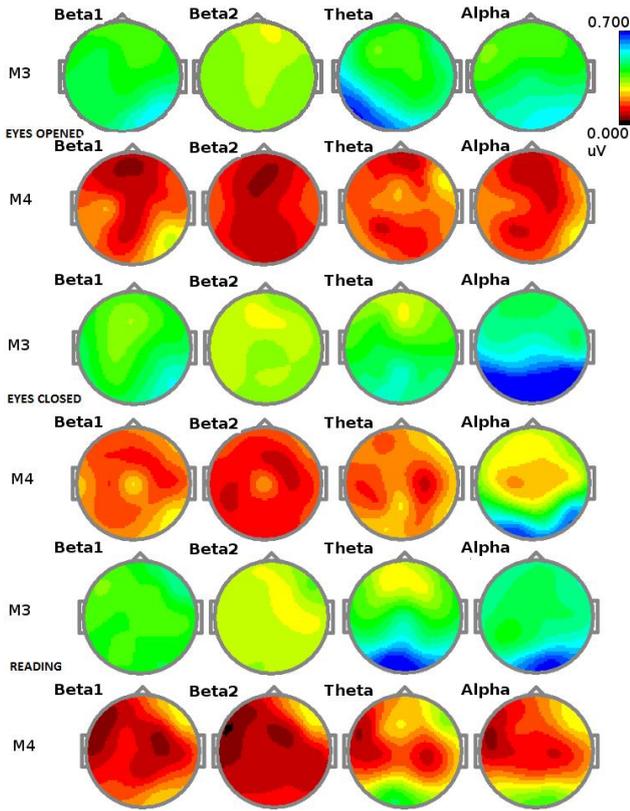


Fig. 9. Maps of EEG amplitude spectra for bandranges for montage monopolar and monopolar average. Fragments: eyes opened, eyes closed and reading

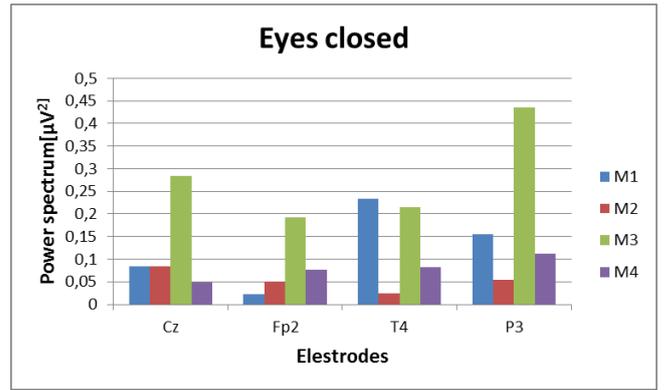


Fig. 12. Power spectrum chart for the selected electrodes

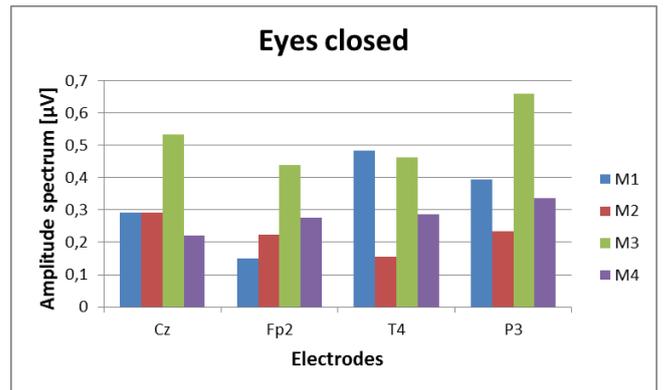


Fig. 13. Amplitude spectrum chart for the selected electrodes

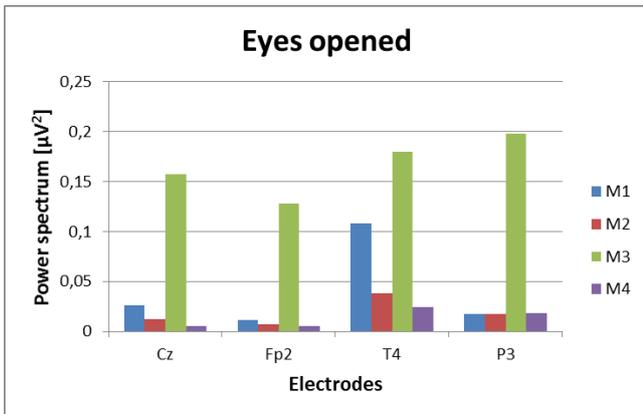


Fig. 10. Power spectrum chart for the selected electrodes

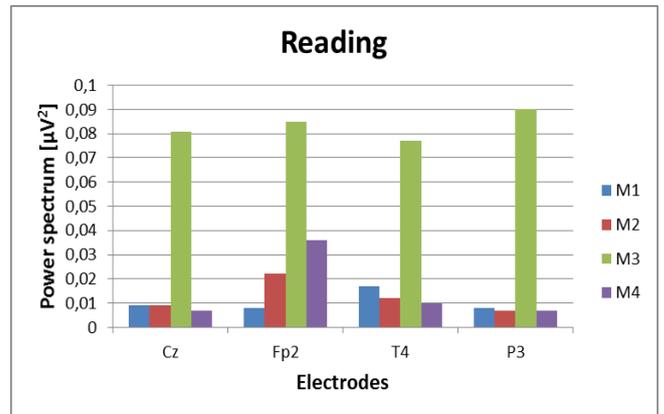


Fig. 14. Power spectrum chart for the selected electrodes

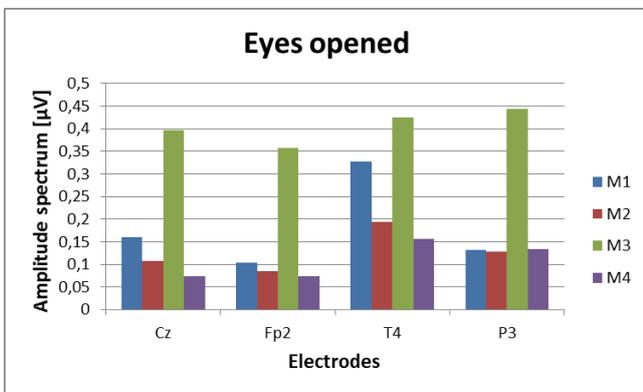


Fig. 11. Amplitude spectrum chart for the selected electrodes

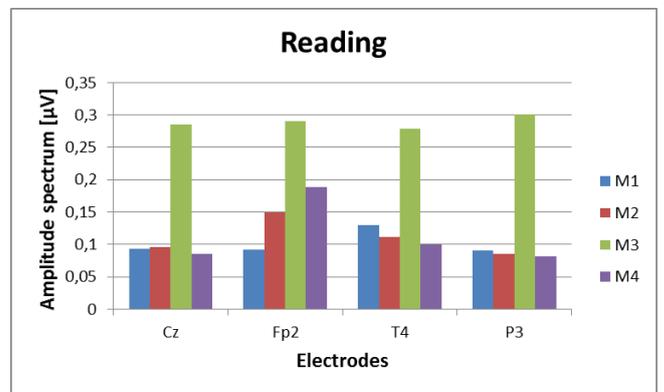


Fig. 15. Amplitude spectrum chart for the selected electrodes

6. Summary

The paper present the analysis of various kinds of EEG montages and its application to typical EEG data analysis. The case study presented in the paper covered analysis of data obtained as a result of EEG examination of several persons with the age of 23–24 years. Data were gathered with classic EEG record method applying the 10–20 system. The examined conducted several activities: sitting steadily with opened eyes, sitting steadily with closed eyes as well as typical cognitive activity i.e. silent reading of given text. After initial data analysis (filtering, artifact correction), the main analysis was performed. It covered EEG spectra analysis, histogram analysis, brain activity and waveforms comparison done for four EEG montage examples (two bipolar and two monopolar). Presented results show that the most informative and simultaneously the most versatile results were obtained for monopolar montage, especially for the montage with ears reference. Bipolar montages occurred to have some limitations regarding generating brain activity maps. What is more, the results prove that bipolar montages are less useful in general, covering the whole spectrum of electrodes, brain activity.

Bibliography

- [1] Adeli H., Ghosh-Dastidar S., Dadmehr N.: A wavelet chaos methodology for analysis of EEGs and EEG subbands to detect seizure and epilepsy. *IEEE Trans. Biomedical Eng.* 54(2)/2007, 205–211.
- [2] Automated Neural Network Detection of EEG Spikes. *IEEE Engineering in Medicine and Biology[J]*, (3/4)/1995, 0739–5175.
- [3] Atcherson S. R., Gould H. J., Pousson M.A., Prout T. M.: Variability of electrode positions using electrode caps. *Brain Topogr.* 20/2007, 105–111.
- [4] Cunnington R., Ianssek R., Bradshaw J. L., Phillips, J. G.: Movement-related potentials associated with movement preparation and motor imagery. *Experimental brain research* 111(3)/1996, 429–436.
- [5] Croft R., Barry R.: EOG correction: a new perspective. *Electroencephalogr. Clin. Neurophysiol.* 107/1998, 387–394.
- [6] De Weerd A. W., Despland P.A., Plouin P.: Neonatal EEG. The international federation of clinical neurophysiology. *Electroencephalogr Clin Neurophysiol Suppl.* 52/1999, 149–157.
- [7] Farwell L. A., Donchin E.: Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. *Electroencephalography and clinical Neurophysiology* 70(6)/1988, 510–523.
- [8] Joyce C., Gorodnitsky I., Kutas M.: Automatic removal of eye movement and blink artifacts from eeg data using blind component separation. *Psychophysiology* 41/2004, 313–325.
- [9] Kulaichev A. P.: Optimal choice of a reference electrode for EEG recording. *Moscow University Biological Sciences Bulletin* 71(3)/2016, 145–150.
- [10] Mak, J. N., Wolpaw, J. R.: Clinical applications of brain-computer interfaces: current state and future prospects. *Biomedical Engineering, IEEE Reviews* 2/2009, 187–199.
- [11] Miller K., Halpern C.: Stereotactic Bony Trajectory Preservation for Responsive Neurostimulator Lead Placement Following Depth EEG Recording. *Cureus* 8(3)/2016.
- [12] Ng S. C., Raveendran, P.: Comparison of different Montages on to EEG classification. In 3rd Kuala Lumpur International Conference on Biomedical Engineering 2006, Springer Berlin Heidelberg, 365–368.
- [13] Patel R., Gireesan K., Sengottuvel S., Janawadkar M. P., Radhakrishnan T. S.: Common Methodology for Cardiac and Ocular Artifact Suppression from EEG Recordings by Combining Ensemble Empirical Mode Decomposition with Regression Approach. *Journal of Medical and Biological Engineering* 2017, 1–8.
- [14] Pfürtscheller G., Neuper C.: Motor imagery and direct brain-computer communication. *Proceedings of the IEEE* 89(7)/2001, 1123–1134.
- [15] Stasinski R.: Radix-K FFT's using K-point convolutions. *IEEE Transactions Signal Processing* 42/1994, 743–750.
- [16] Tanner A. E., Särkelä M. O., Virtanen J., Viertiö-Oja H. E., Sharpe M. D., Norton L., Young G. B.: Application of subhairline EEG montage in intensive care unit: comparison with full montage. *Journal of Clinical Neurophysiology* 31(3)/2014, 181–186.
- [17] Tokariev A., Sampsä V., Palva J.: Analysis of infant cortical synchrony is constrained by the number of recording electrodes and the recording montage. *Clinical Neurophysiology* 127(1)/2016, 310–323.
- [18] Trambaiolli L. R., Lorena A. C., Fraga F. J., Kanda P. A. M. K., Nitrini R., Anghinah R.: Does EEG montage influence Alzheimer's disease electroclinic diagnosis? *International Journal of Alzheimer's Disease*, 2011.

Ph.D. Małgorzata Plechawska-Wójcik
e-mail: m.plechawska@pollub.pl

Małgorzata Plechawska-Wójcik is assistant professor in Lublin University of Technology, in Faculty of Electrical Engineering and Computer Science. Her research interests include computer systems, bioinformatics, electroencephalography, and systems supporting medical diagnostics as well as knowledge management systems, software engineering and database.



Eng. Monika Kaczorowska
e-mail: monika.kaczorowska@pollub.edu.pl

Monika Kaczorowska is the fourth year student of Computer Science at Lublin University of Technology. She is interested in EEG signals and algorithms.



Kinga Wesolowska
e-mail: kinga.wesolowska@pollub.edu.pl

Kinga Wesolowska is second year student of Biomedicine Engineering at the Faculty of Mechanical Engineering of Lublin University of Technology. She is interested in EEG signals analysis.



Martyna Wawrzyk
e-mail: martyna.wawrzyk@pollub.edu.pl

Martyna Wawrzyk is second year student of Biomedicine Engineering at the Faculty of Mechanical Engineering of Lublin University of Technology. She is interested in EEG signals analysis.



M.Sc. Eng. Mikhail Tokovarov
e-mail: mikhail.tokovarov@pollub.edu.pl

Mikhail Tokovarov is a Ph.D. student and an assistant lecturer at Lublin University of Technology, in Faculty of Electrical Engineering and Computer Science. He is interested in microelectronics, mathematics, signal processing and algorithms as well as in electroencephalography.



otrzymano/received: 11.05.2016

przyjęto do druku/accepted: 01.06.2017