The use of electroencephalography as a future-oriented brain-computer interface. Current concepts, solutions, technologies that allow communication through thoughts

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Nowadays, brain-computer interfaces are gaining more and more popularity. Research centers develop new methods of human communication with devices through thoughts. There are many methods used for this kind of interfaces, however, the most widespread is electroencephalography (EEG). There are many reasons for this fact, it is a method that is relatively cheap compared to other methods. Less complex technical tools and apparatus are required to operate it. Another advantage of this method, unlike others, is its non-invasiveness. Unfortunately, current brain-computer interfaces do not offer high data rates. However, time plays a smaller role when we are dealing with a disabled person who regains the ability to communicate with the world through the interface controlled by thoughts. This paper is the beginning of a series of papers in which the author will describe in detail the elements of brain-computer interfaces, as well as improvements that can be applied to them to improve their properties.

Keywords: Brain-computer interface, BCI, Electroencephalography, EEG.

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1. Introduction

Currently, in the world, a person can communicate with devices using many different interfaces. The computer is mainly used via keyboard and mouse. The touch interface used to operate the phone or tablet is very popular. The ideal interface for communication with the machine, often used in movies and science-fiction literature, is control with thoughts. Unfortunately, current BCI systems working with the use of EEG signal do not allow comfortable communication using “direct thoughts”. The main limitation of these interfaces is the speed of communication. So why are such huge efforts made by large research teams to improve their operation?

The possibility of direct human interaction with a computer (without manual handling of peripheral devices) opens new channels of information transfer in medicine, psychology, multimedia and military techniques. Particularly important are the applications of this interface in medicine both in the cognitive aspect, the functioning of the human brain, and practical as the only chance for development for people affected by neurological diseases. The brain-computer interface can help in communicating with the outside world people in severe stages of neurological diseases such as amyotrophic lateral sclerosis, subcortical stroke, Guillain-Barre syndrome, cerebral palsy or multiple sclerosis [1]. Annually, about two thousand people in Poland (and in all European Union countries, about 24 thousand) suffer from amyotrophic lateral sclerosis, a neuro-degenerative disease of the nervous system that destroys part of the central nervous system responsible for movement, but does not affect sensation, cognitive ability and intellect. People who fall into it, gradually lose control over their own body and in 2 to 3 years reach a state in which they have no possibility of communication with the environment. Another group of people who should be able to communicate with the environment using BCI, is about 14 thousand people, which during the year in Poland suffers from strokes, and in particular brainstem strokes. Approximately 1,2 thousand victims of traffic accidents should be added to these groups, as a result of which the cervical spinal cord was damaged [2]. In such cases, the brain-computer interface is to enable simple communication with the environment, control of prostheses, a wheelchair or even an intelligent building.

Direct brain reactions to external stimuli are also used in neuromarketing [3]. Tools used in psychophysiological research are used there. Thanks to them, you can choose and optimize marketing stimuli, for example billboards or film sequences. In practice, this reduces the duration of the shot from an advertising movie by several times.

Intensive attempts to use BCI technology for military purposes are also under way. Ultimately, the systems support the control of fighters or facilitate communication on the battlefield. However, it should be noted that these are only attempts and a long way to the final result. At present, it is possible to implement systems that support the control process.

First researcher who proposed brain-computer interface was Jacques J. Vidal in 1973. The schema of BCI is illustrated in Figure 1.

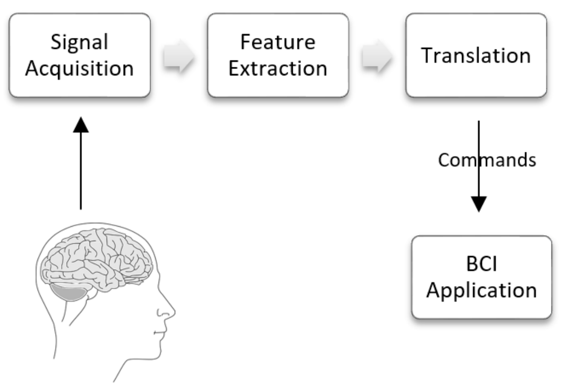

Fig. 1. The brain-computer interface proposed by J. Vidal [4]

2. Methods of analyze brain activity

There are many methods to analyze brain activity. Most common approach to distinct different methods focuses on invasiveness.

Invasive BCIs are implanted directly into the grey matter of the brain during neurosurgery. One of invasive method is IntraCortical Recordings (IR) which provide better recording quality compared to less invasive technologies and also offer the best temporal and spatial resolutions. The main drawback of intracortical probes is they limited durability and progressive deteriorating of recorded signal quality. For now none of the probes that were created are capable of totally overcoming the long-standing effects of foreign body reaction. After insertion of the foreign object, foreign body reaction starts his work and begin stream of events that promote electrode's deterioration [5].

Electrocorticography (ECoG) is a partly invasive method that measures the electrical activity of the brain taken from beneath the skull in a similar way to non-invasive electroencephalography, but the electrodes are embedded in a thin plastic pad that is placed above the cortex, beneath the dura mater [6].

Non-invasive methods:

- Magnetoencephalography (MEG)
- functional Magnetic Resonance Imaging (fMRI)
- Near InfraRed Spectroscopy (NIRS)
- Positron emission tomography (PET)
- Electroencephalography (EEG).

This paper focuses on the most widely used method which is Electroencephalography. It is caused by several factors. The reason why this method is popular is that is less expensive compared to other methods. In addition, MEG, fMRI, PET methods are technically complex and hence they will not be used in general-purpose devices. Methods that are based on images, are in fact characterized by a better location of brain activity, but this activity is dependent on blood flow, which is characterized by a high time constant and prevents rapid communication [7].

The biggest advantages of electro-encephalography in the application to BCI include: assessment of brain activity occurring at the moment of signal registration, operation in many environmental conditions, low cost of implementation in comparison with other methods. A very significant advantage of electroencephalography is the relative ease of use. After a short training, the user can use it at home.

3. Electroencephalography

Hans Berger made the discovery and first record of brain activity on humans. He began his work on the study of electroencephalographic record on a man in 1920. In 1929, he recorded a three-minute recording of an electroencephalographic signal using only one bipolar channel. In his report he described alpha waves as the main component of the EEG signal [8]. Currently, electroencephalography is understood as a non-invasive diagnostic method that is used to study bioelectrical brain function. The study is most often used in medicine and consists in the proper placement of electrodes on the surface of the scalp. The electrodes record changes in the electrical potential derived from the activity of neurons in the cerebral cortex. After appropriate amplification of potentials with the help of the electroencephalograph, you can register the recording of these signals in the form of the so-called electroencephalogram.

Electrical potentials are registered in the given place using electrodes. The potential registered with the electrode is the resultant of all potentials generated by various sources of the electromagnetic field. We must remember, therefore, that the EEG record contains potentials from the inside of the skull (brain activity) as well as other electrophysiological signals and signals coming from external disturbances [9].

In fact, the activity of individual neurons is not measured, but the resultant electric field, generated by a huge number of neurons located relatively close to the electrode. EEG reflects the resultant electrical activity of brain cells at a given moment. This activity is associated with all processes in which the brain is involved. These activities include: planning, remembrance, learning, receiving stimuli, analyzing stimuli, making decisions or concentrating attention. In addition, the brain administers processes that we do not realize, such as: functioning of the digestive system, coordination of complex movements, breathing.

EEG is used in wide medical applications such as:

- location of areas of the brain damaged after head injury,
- monitoring vigilance, coma and brain death,
- stroke diagnosis,
- diagnosis of brain cancer,
- nervous system testing,
- control of the depth of anesthesia,
- epilepsy examination and location of epileptic seizures,
- testing the impact of medicines,
- monitoring of brain development,
- studies of sleep disorders,
- research on mental disorders,
- diagnosis of alcohol disease.

4. EEG Rhythms

The EEG signal is individual for each individual, but undergoes significant, specific changes depending on the psychophysical factors affecting the person at the moment. It was found that in the case of a well-functioning, healthy organism, certain specific EEG rhythms (waves) can be distinguished. Rhythms are characterized by parameters such as shape, amplitude and frequency of changes. It is worth mentioning that the waves depend on many psychophysical factors and change with age.

Most often the following rhythms are distinguished (Figure 2):

- Gamma (above 40 Hz) – describes the state associated with consciousness, perception, mental activity,
- Beta (from 12 to about 28 Hz) – occur during daily activity, in anxiety, and under the influence of certain drugs,
- Alpha (from 8 to 13 Hz) – characteristic for the state of wakefulness in the conditions of relaxation, especially with closed eyes,
- Theta (from 4 to 7 Hz) – occur during deep meditation, intense dreams, and intense emotions,
- Delta (from about 0.5 to 3 Hz) – occur in a deep sleep state, in small children and in the case of some type of brain damage.

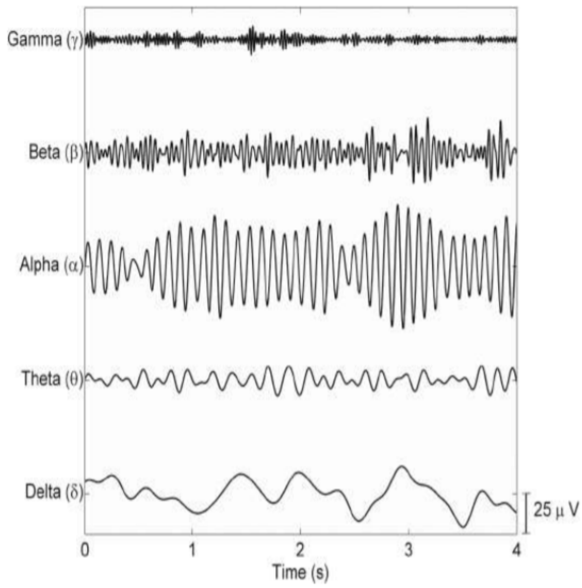

Fig. 2. Different EEG rhythms [10]

5. Design of the EEG based BCI system

In the BCI system the intentions of the user are read directly from EEG waves. Certain, extracted characteristics of these waves (signals) are classified and “translated” in real time into orders used to control a computer, prosthesis, wheelchair or other devices. The diagram of the most important stages of the brain-computer interface is shown in Figure 3.

To collect the EEG signal, electrodes (from a few to 128 electrodes) are applied to the scalp with a gel. Then the signal is transmitted to the electroencephalograph, where the signals are amplified and transmitted to the computer in digital form.

Pre-processing usually involves signal filtration and other methods of removing noise and interference (e.g., physiological artifacts). At this stage, digital filters, spatial filters, signal whitening methods or blind separation are used. After this stage, signals are obtained from which the features can be extracted.

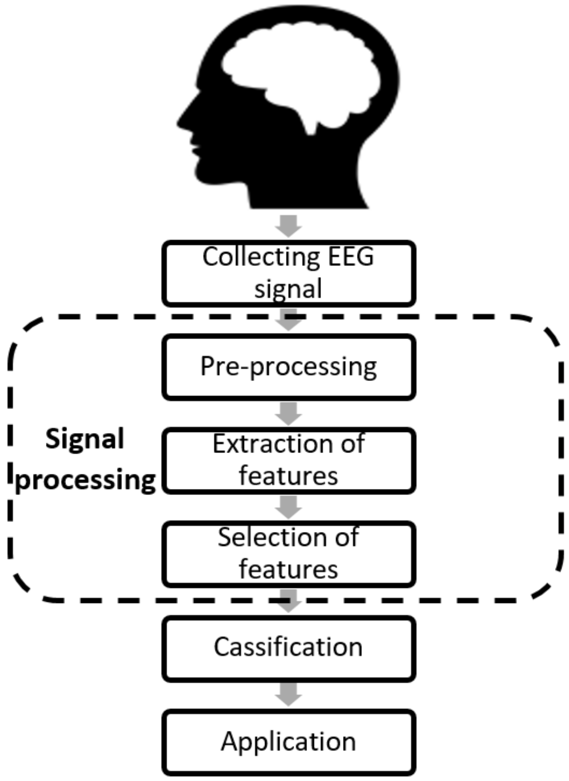

Fig. 3. The scheme of brain-computer interface

Extraction of features is a process that allows the extraction of the most useful information from the EEG record. The whole range of signal analysis methods is used, for example: higher order statistics, time-frequency analysis, autoregressive models, wavelet analysis. As a result of the extraction, feature vectors are formed. Having knowledge about the attributes belonging to a given class, you can start to build (and train) the classifier.

The classifier’s task is to assign a newly registered EEG record to a specific predefined class. Most often at this stage different kind of methods are used:

- artificial neural networks,
- linear discriminant analysis,
- naive Bayes classifier,
- support vector machine,
- decision trees.

Classified EEG signals are most often used to control a virtual keyboard (communication with the environment via text). There are also attempts to use BCI systems to control a robot, prosthesis and even a smart building. It is worth noting that objects controlled by brain-computer interfaces can have built-in “own intelligence”. For example, a wheelchair or robot has built-in sensors and actuators that do not allow it to collide with an obstacle.

6. Quality assessment measures for BCI systems

The speed of brain-computer interfaces is a very important matter. Any interface to be widely used must have the certain speed. In case of BCI these speeds are not large. However, when we look, that the main applications of BCI is to help people with disabilities – speed is not the most important thing for them, what matters the most is achieving the intended result.

It is hard to compare different kind of interfaces, which have different kind of applications on the same scale. In this situation information transfer rate (ITR) is used. It is defined as the amount of information transmitted via the interface per unit of time. Information transfer rate (expressed in bits per second) for BCI systems with N mental tasks (possible choices), for average effectiveness expressed as P and time to make a choice T (in seconds) is defined as [11]:

$$ITR = \frac{60}{T}(\log_2 N + P\log_2 P + (1-P)\log_2 \frac{1-P}{N-1}) \quad (1)$$

Tab. 1. Summary of selected BCI systems

Research group	Application	Average ITR
Tübingen University Germany	Synchronized switching on and off of the device	6 bit/min
Illinois University USA	Virtual keyboard 6x6	9 bit/min
Rochester University USA	Synchronous control of five elements in a virtual building	12 bit/min
Graz University of Technology Austria	Synchronous keyboard interface, prosthesis and cursor control	17 bit/min
Wadsworth Center USA	Move the cursor	22 bit/ min
University of Technology in China	Synchronous control via the panel	27 bit/min
European	Asynchronous	33 bit/min

Union ABI Project JRC	control of a mobile robot	
EPFL Switzerland	Asynchronous 2D object control	25 bit/sec

7. Conclusions

At present, no major breakthrough is expected in brain-computer systems built using EEG signals. This applies to both new brain potentials and modules of the BCI system itself, which is signal acquisition, processing and analysis. However, it is believed that it is possible to improve the results of the operation, and above all to contribute to the popularization of interfaces. In most cases, seemingly trivial factors are mentioned here, but they have enormous practical significance, such as the color and shape of the light object for the synchronous interface.

When it comes to signal acquisition, there are many limitations that contribute to the fact that brain-computer interfaces can be hostile to both constructors and users. One of them is the lack of specialized devices in mass production for the needs of BCI systems. Medical devices, often several dozen channels, are expensive and have large dimensions. This also applies to the method of mounting the electrodes. The most commonly used for this purpose is conductive paste (for several, sometimes even several dozen electrodes). It seems that the development of new electrodes, for example dry ones, made of nanotubes, will enable comfortable mounting.

In addition, modules of signal processing, analysis and classification are a very important element of BCI systems. Here, new methods are also sought: extracting a useful signal, minimizing the number of electrodes, the place where electrodes are attached, new algorithms for extraction of features, convenient automatic and effective methods for selecting traits. In the construction of such executive elements as, for example, wheelchairs or intelligent buildings, account should be taken of the speed and fallibility of the interfaces.

8. Bibliography

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Wykorzystanie elektroencefalografii jako przyszłościowego interfejsu mózg-komputer. Aktualne koncepcje, rozwiązania, technologie pozwalające komunikować się za pomocą myśli

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W obecnych czasach interfejsy mózg-komputer zyskują coraz większą popularność. Ośrodki badawcze opracowują nowe metody komunikacji człowieka z urządzeniami za pomocą myśli. Jest wiele metod stosowanych do tego rodzajów interfejsów, jednak najbardziej rozpowszechnioną jest elektroencefalografia. Jest wiele powodów tego faktu, to metoda, która jest stosunkowo tania w porównaniu z innymi. Do jej obsługi wymagane są mniej złożone technicznie narzędzia i aparatura. Kolejnym atutem tej metody w przeciwieństwie do innych jest jej nieinwazyjność. Niestety obecne interfejsy mózg-komputer nie oferują dużej szybkości przesyłania danych. Jednak czas odgrywa mniejszą rolę, gdy mamy do czynienia z osobą niepełnosprawną, która odzyskuje możliwość komunikacji ze światem za pomocą interfejsu sterowanego myślami. Artykuł jest początkiem serii artykułów, w których autor będzie szczegółowo opisywał elementy interfejsów mózg-komputer, a także usprawnienia, jakie można do nich zastosować, aby polepszyć ich właściwości.

Słowa kluczowe: Interfejs mózg-komputer, BCI, elektroencefalografia, EEG.