Analysis of brain waves according to their frequency

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***Abstract*—**The primary purpose of this article is to show and analyse the brain waves, which are activated during different activities. At the first part of the paper, we describe the theoretical information about Brain-Computer Interface and the types of this technology. The article mainly focuses on the non-invasive Brain-Computer Interface, which is used in the experimental part. Experimental part is based on EEG technology, which is represented by devices from Emotiv System. This article provides the measurement with the Emotiv EPOC headset and the application Emotiv Brain Activity Map. There are used two type of analysis. The first type of measure engaged logical-analytical reasoning by solving the mathematical exercise. The second type is a dedicated relaxed mind during listening to relaxing music. At the last of the paper, we display the result as the visualization of brain activity. There are shown the brain waves, which are activated in each situation.

***Keywords*—**Brain-Computer Interface, Brain waves, EEG, Emotiv

I. Introduction

The nervous system is composed of two parts. The central nervous system (CNS) and the peripheral nervous system (PNS). The CNS consists of the human brain and spinal cord. Conversely, the PNS consists of the nerves and ganglia outside of the brain and spinal cord.

Human brain controls body function, such as heart activity, movement, speech, but also thinking itself, memory or emotion perception. Brain activity could be measured by the neurologic examination method – electroencephalography (EEG). The principle of this method is capturing electric potential.

If the central nervous system is damaged, some body functions may be restricted. Brain computer interface systems could offer these people improved communication and independence.

Recent developments in BCI technology may see such hands-free control method realised. A BCI is a communication and control system in which the thoughts of the human mind are translated into real-world interaction without the use of the common neural pathways and muscles. For example, users of the BCI system can switch a light or change TV channels using only their imagination and without any physical movement. Recent advances in the human brain and BCI research reveal that BCI-based devices and technologies can play a significant role in the future [1] – [4].

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The article begins with theoretical information about BCI and its types. After that, there is mentioned signal acquisition, where the brain wave distribution is described by frequency. The next topic in this article is device and measurement. There are described device and application, which have been used. Also, there is defined using types of measurements. The following is the Results section with the measurement results, which are displayed as visualization of brain activity.

II. Brain-Computer Interface

Brain Computer Interface acquires and analyses brain signals in real time to control external devices, communicate with others, facilitate rehabilitation or restore functions.

There are three parts of Brain Computer Interfaces. Invasive, Non-invasive and Partially invasive.

A. Invasive Brain-Computer Interface

Invasive Brain Computer Interface systems are used for the best quality signals. These electrodes are implemented into the cortical issue. These types of system are used for paralyzed people, or it could be used for restoring vision by connecting the brain with external cameras. Although these BCI system provide the best quality signals, the system is prone to scar-tissue build-up. The scar-tissue cause a weak signal, which can be even lost. Because the body reacts to a foreign object in the brain [2].

B. Partially-Invasive BCI

Partially Invasive Brain Computer Interfaces are implanted into the skull, but outside the brain. Electrocorticographic (ECoG) uses the same technology as non-invasive electroencephalography, but the electrodes are embedded in a thin plastic pad that is placed above the cortex, beneath the dura mater. These systems produce a good signal, but weaker than Invasive BCI [2].

C. Non-invasive BCI

Non-Invasive Brain Computer Interfaces means electrodes are emplaced on the surface of the skull to record changes in EEG state. The signal, which is producing has the weakest values in spite of this, the non-invasive BCI is the safest and easiest way to record EEG [2]. The schema of brain computer interface system is shown in Figure 1.

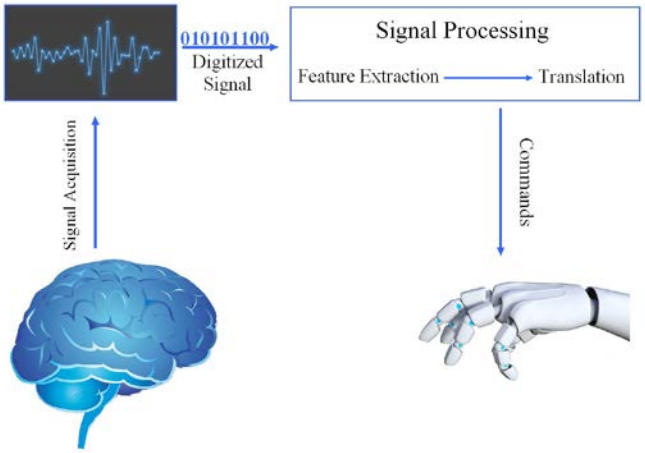

Fig. 1 Basic flow diagram of BCI scheme

III. Signal Acquisition

EEG technology is the most prevalent method of signal acquisition for Brain-Computer Interfaces. Many EEG systems are using the International 10/20 system. This system is an electrode placement strategy, which ensures ample coverage over all parts of head [4].

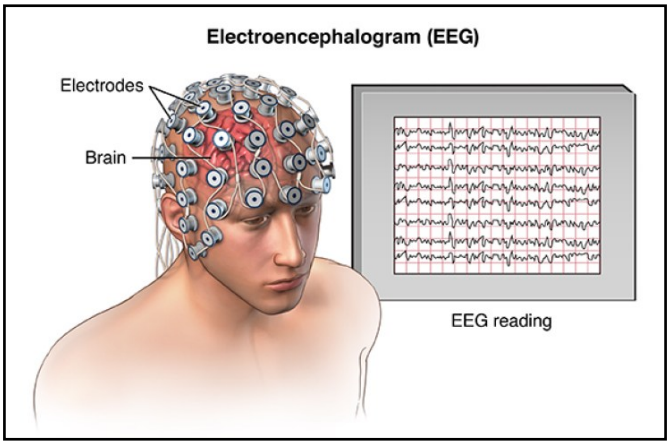

Fig. 2 Electroencephalogram technology [5]

Brain signals are acquired by electrodes on the surface of the head. Then these signals are digitized and processed to clean and denoise data to enhance the relevant information embedded in the messages. After that, a step called the feature extraction is used. It means that certain features characterize the brain patterns used in BCIs. Describing the signals by a few relevant values is called feature extraction. Next step is a translation. This step assigns a class to a set of features extracted from the signals. This class corresponds to the type of mental states identified. Finally, the translation into a command, which means the command is associated with an acquired mental state to control the application.

The most important criteria of evaluation EEG are frequency. Frequency is a criterion for assessing abnormalities in clinical EEG and for understanding functional behaviours in cognitive research [6].

In Table 1 there can be seen five major brainwaves distinguished by their different frequency ranges (Figure 3).

Table 1 Brain wave distribution by the frequency of band wave.

Name of the frequency	The frequency of band wave (Hz)
alpha α	8 - 13
beta β	13 - 30
delta δ	0.5 - 4
gamma γ	>30
theta θ	4 - 8

Each brain wave has a different frequency, amplitude (Figure 3) and meaning. Alpha α waves connect the gap between our conscious thinking and subconscious mind. It helps us to calm down, or it promotes a feeling of relaxation. Beta β waves are active in a waking state. This frequency is visible in logical-analytical reasoning. In their activity, we focus on a problem-solving. Delta δ waves occur during meditation in a state of deep sleep or coma. Abnormal delta activity may occur with the person, has learning disabilities or have difficulties maintaining conscious awareness (such as in cases of brain injuries). Gamma γ waves are essential for learning, memory and information processing. Theta θ waves are involved in sleep or daydreaming. This brainwave can indicate intuition or automatic tasks [7].

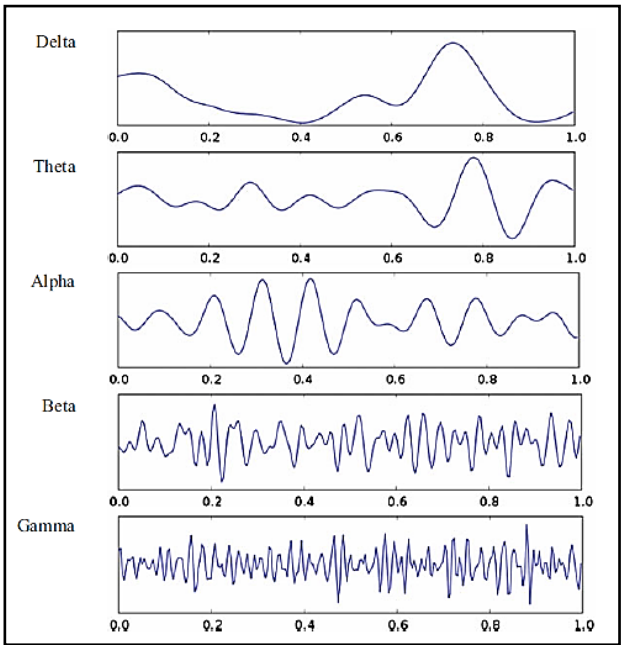

Fig. 3 Five major brain waves distinguished by their different frequency ranges [6].

IV. Devices

The problem of using BCI in the academic field is a high price. The best option for educational purposes is using the Emotive EPOC device (Figure 3), which is designed and manufactured by Emotiv System. The device comprises a wireless helmet that enables the reading of feelings, emotions, and intentions of the user. The cost of this device is 799$ for a Research Development Kit.

A. *The Emotiv EPOC*

The Emotiv EPOC device is based on the International 10/20 system. This headset consists of the 16 sensors on the scalp. Two of these sensors are references.

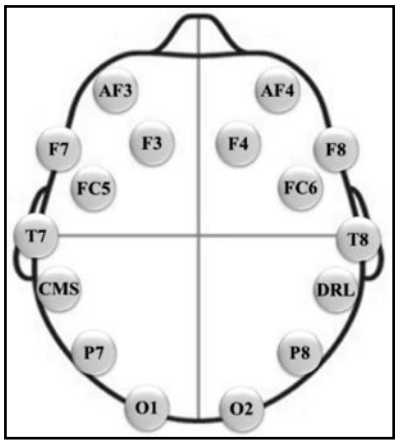

Fig. 4 The International 10/20 system

The device records signal sequentially at 128 Hz with a sufficient resolution of 14 bits per channel and a frequency response in the range of 0.16 to 43 Hz. Besides, it provides 2.4 GHz wireless data transmission with a battery that allows continuous operation for 8 hours. One of the advantages of the system is the possibility of contacting electrodes with the skin of the head to reach the electrodes with a physiological solution instead of a conventional conductive gel. Conversely, one of the disadvantages is a problem with the connection of the sensors.

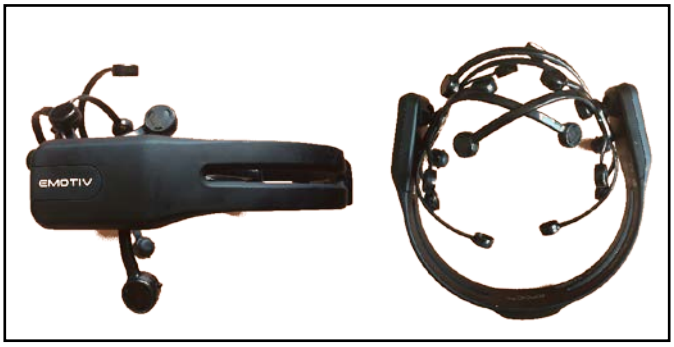

Fig. 5 Wireless helmet Emotiv EPOC.

B. *Emotiv Brain Activity Map v3.3.3*

Measurement takes place in application Emotiv Brain Activity Map v3.3.3 (Figure 6), which is developed by Emotiv Systems. The cost of this application is 9.95$. The app is also available for two platforms – Windows and MacOS.

The application measure and display real-time data of four types of brain waves. Alpha, Beta, Theta and Delta. Each of these frequencies allows the adjustable gain to see detailed information and relative strengths between different brain regions. Adjustable buffer size allows viewing instant responses or average activity over more extended periods.

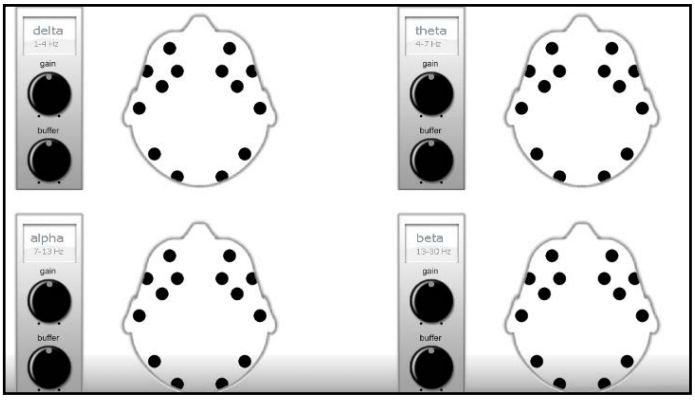

Fig. 6 Application Emotiv Brain Activity Map v3.3.3 developed by Emotiv Systems.

Controlling this application is quite easy. The menu bar contains five options, which the most important options are Tools and Contact Quality. The tools option provides saving and loading data. Tab Contact Quality shows the right connection of helmet sensors. The proper connection of sensors indicates a green colour (Figure 7).

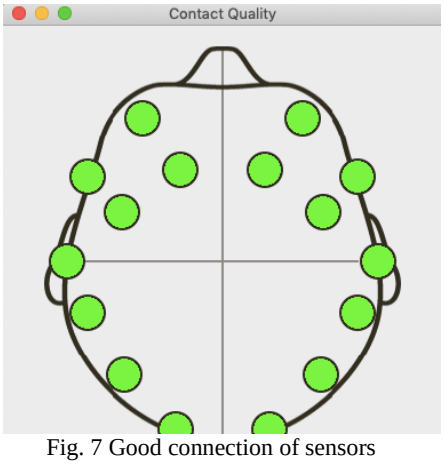

Fig. 7 Good connection of sensors

There are four colours, which indicates a quality of signals (see Table 2).

Table 2 Colours providing quality of the signal

Colour	Quality of signal
Black	No signal
Red	Bad signal
Orange	Poor signal

Green	Good signal

If the electrodes show a red or orange colour (see Figure 8), you must fix the sensors on the helmet manually. The sensors must touch the bare skin of the head. The right connection of sensors gives the best quality signal due to this there is the main disadvantage. If the tested person has long hair, there may be a bad connection because of the isolation.

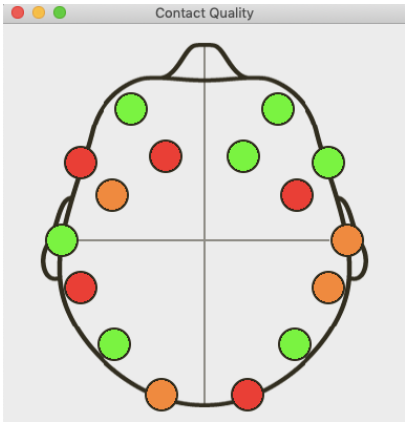

Fig. 8 Poor connection of sensors

V. Measurement

The primary purpose of this measurement is to prove the existence of the brain waves. This experimental part, where divided into two groups. These groups were chosen as an example of two different actions. The first group was based on activating brain waves, which are responsible for analytical and logical reasoning or solving problems. The second group was based on enabling brain waves, which are responsible for a relaxed mind.

The measurement was carefully selected and took place in the office. There were used devices, which were mentioned in the previous section, also a computer, office supplies (paper, pen). During the measurement, the office was closed because the measure has to take place in silence.

Fig. 9 The office, where the measurements were taken

In the first type of measurement, the brain activity was considered about logical and analytical reasoning. The brain activity was produced during solving the mathematical exercise. Where analysis brain activity, which is produced by logical and analytical reasoning. The measurement was performed while solving the mathematical exercise.

The following type of measurement was based on a relaxed mind. Measurements were taken in a quiet room with relaxing music. Three types of relaxation music were used in this paper.

VI. Results

Results are taken as a visualization of brain activity. The colour of the weakest signal is blue. As the strength of signal increases, the colour changes to red. This is shown in Figure 10.

Fig. 10 Spectrum of signal colours from the weakest to the strongest

A. The measurement based on logical and analytical reasoning

In the first measurement, the person used for the measurement was given a mathematical exercise with the command to solve it.

At the beginning of the measurement, it was detected that the main roles play beta and theta waves. It was proved that beta waves occur when solving a problem or they are visible at logical-analytical reasoning. It can be seen in Figure 11.

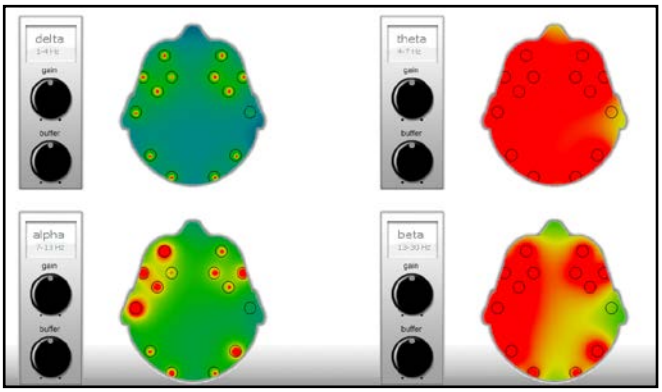

Fig. 11 Brain activity at the beginning of the measurement of the problem solving

After one minute, the view has changed. Now, there are active only theta waves. It is because the testing person solved the exercise in the past. This was explained that theta waves occurred during the automatic problems solving. This can be seen in Figure 7.

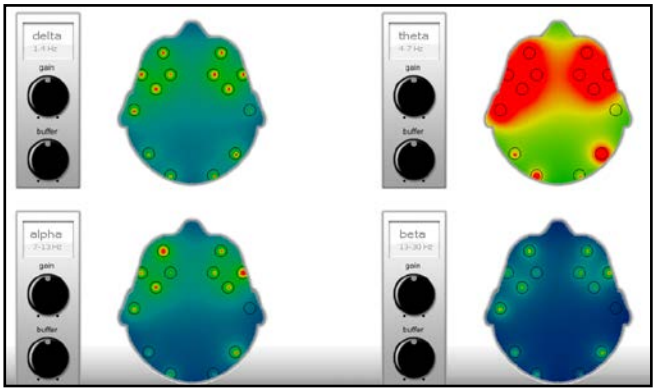

Fig. 12 Activation of theta brain waves

B. *The measurement based on a relaxed mind*

The second measurement was concerned with a relaxing mind. The person used for the experiment was taken a seat with a quiet room with the command to close their eyes and relax. After that, the relaxing music was played. Relaxing music should activate alpha waves. In this experiment, it is used three types of relaxing music. Each of that proved it. It can be seen in Figure 8 and Figure. 9.

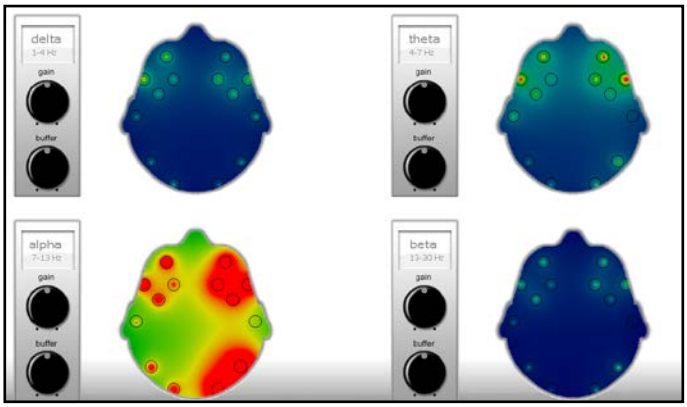

Fig. 13 Brain activity during the first type of listening relaxing music.

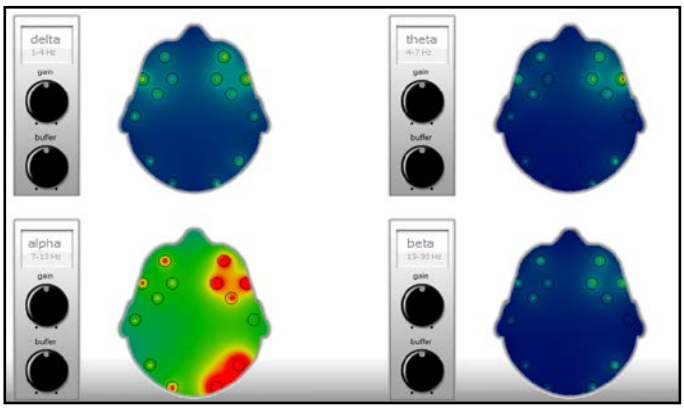

Fig. 14 Brain activity during the second type of listening relaxing music

The last of the relaxing music also actives theta waves. Explaining the presence of theta waves is likely to be the beginning of deep relaxation. This is shown in Figure 15.

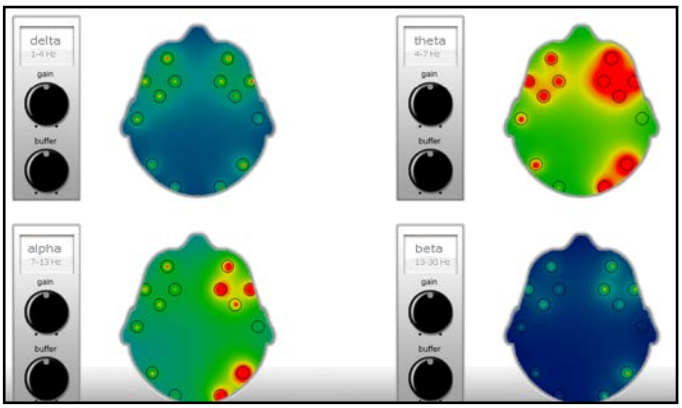

Fig. 15 Brain activity during the third type of listening relaxing music

VII. Conclusion

This paper briefly described what Brain Computer Interface and its types is. After that, electroencephalogram has been described. EEG is a non-invasive method can also be used for academic purposes. The measurement was mainly concerned with the frequency of brain waves. Brain waves that occur during problem solving or relaxation, have been measured by the application Emotiv Brain Activity Map.

Our research deals with the BCI system, which was identified by brain waves in two different actions. Firstly, we managed to measure data while the person was solving a problem. Secondly, we measured the person while relaxing. There were used the type of relaxing music. After that, we evaluated and described the collected data.

This measurement is the beginning of further research. Future work lies primarily with the purchase of a PRO license that will enable the raw EEG signal to be processed further. The raw EEG signal can also be processed in other applications instead of Emotiv applications. This type of measurement could be taken by people with epilepsy or other abnormalities in clinical EEG. BCI technology is a relatively new research area with great application potential. This is mainly a possible improvement in the quality of life for patients with permanent neurological deficits. By implementing this method into neuro-rehabilitation practice, we can improve the patient's health and mental state.

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