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EEG Signal Analysis for Monitoring Concentration of Operators

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Abstract:
Often, operators of machines, including unmanned ground vehicles (UGVs) or working machines, are forced to work in unfavorable conditions, such as high temperatures, continuously for a long period of time. This has a huge impact on their concentration, which usually determines the success of many tasks entrusted to them. Electroencephalography (EEG) allows the study of the electrical activity of the brain. It allows the determination, for example, of whether the operator is able to focus on the realization of his tasks. The main goal of this article was to develop an algorithm for determining the state of brain activity by analyzing the EEG signal. For this purpose, methods of EEG signal acquisition and processing were described, including EEG equipment and types and location of electrodes. Particular attention was paid to EEG signal acquisition, EEG signal artifacts, and disturbances, and elements of the adult's correct EEG recording were described in detail. In order to develop the algorithm mentioned, basic types of brain waves were discussed, and exemplary states of brain activity were recorded. The influence of technical aspects on the recording of EEG signals was also emphasized. Additionally, a block diagram was created which is the basis for the operation of the said algorithm. The LabVIEW environment was used to implement the created algorithm. The results of the research showing the operation of the developed EEG signal analyzer were also presented. Based on the results of the study, the EEG analyzer was able to accurately determine the condition of the examined person and could be used to study the concentration of machine operators.

Keywords: *Electroencephalography, EEG, signal processing, Fourier analysis, LabVIEW, biofeedback, operator concentration, UGV*

1. Introduction

The method of studying the electrical activity of the brain is called electroencephalography (EEG). The complex electrical activity of the brain produces highly irregular EEG signals. Attempting to record the electrical representation of brain activity is a technically difficult activity. The main problem in this type of measurement is the need to amplify the human brain potentials about a million times and convert them into a waveform. The extra-cerebral potentials, which mainly consist of the movements of the examined person, are also amplified, while their amplitude often exceeds the amplitude of the cortical potentials. The lack of consideration and correction of this phenomenon, similar artifacts, and the interference itself make the recording of mentioned signals unreadable [1].

In recent years, progress has been made in the field of electroencephalography, which has resulted in many new applications [1, 2]. Advances in technology have significantly improved EEG machines. As a result, the availability and the number of users of these devices have increased significantly. For many years, EEG has been the basic research in medicine—for example, in the diagnosis and treatment of epilepsy. It is often the only possible alternative to imaging examination, such as computed tomography.

Electroencephalography is also used in psychiatry and psychology. Moreover, neurofeedback enables people to improve their health by using signals from their bodies. Using the phenomenon of biological feedback (biofeedback) of the EEG signal, children suffering from concentration disorders are successfully treated. Biological feedback is used to regain movement for people with muscle paralysis [1–4].

Biofeedback can also be used in non-medical areas, which is the subject of scientific research [5–12]. It could be used to study the concentration of operators of unmanned ground vehicles (UGVs) or working machines. It is known that such employees often have a huge responsibility resulting from the work they perform. The use of, for example, heavy equipment requires enormous concentration and carries a considerable risk of a large amount of damage in the event of a potential operator error. UGV operators are also exposed to enormous stress during the execution of tasks (especially in the case of remote control or teleoperation), which can contribute to the failure of the mission. Therefore, it is necessary to maintain concentration at a high level and possibly check this factor every time period, which is possible with the use of EEG.

The main purpose of the article is to develop an algorithm with an implementation that would enable the determination of the state of brain activity. In the implementation of the mentioned goal, particular attention was paid to the selection of the programming environment with the help of which the algorithm was developed and the possibility of its subsequent application to study the concentration of machine operators.

2. Methods of Signal Acquisition and Processing

Complex brain activity produces highly irregular EEG signals and the aforementioned irregularity makes it very interesting because of its importance in modern technology and medicine [1, 13, 14].

2.1. Source of EEG Signals

Most likely, the main sources of the EEG signal are neurons, and more precisely, they may be action potentials, inhibitory postsynaptic potentials (IPSP), and long-term depolarization of neurons. Action potentials induce short (up to 10 ms) local currents in the axon with a limited electric field. In turn, the postsynaptic potentials are longer (50–200 ms) and have a larger electric field [1, 13, 14].

2.2. EEG Electrodes

The electrodes are transmitters through which the electrical potentials of the cortex are transferred to the amplification device. Due to the shape and hairiness of the skin of the head, the requirements for EEG electrodes should meet two conditions: they should have a relatively small contact surface and provide comfort to the examined person. Standard EEG electrodes are small disks made of non-reactive metals (Fig. 1). For this purpose, several types of metals are used, including gold, silver, or silver chloride. The electrode must be in close contact with the skin to ensure low impedance and thus minimize environmental and electrode artifacts. There are also other types of electrodes, the so-called needle electrodes, but due to their invasiveness and high resistance, they are used rarely [1].

In the research carried out as part of this study, contact electrodes were used (Fig. 1), which are a combination of a contact surface (diameter of about 5 mm) and a plastic holder mounted in a cap covering the entire head. The most commonly used electrodes are Ag/AgCl [13].

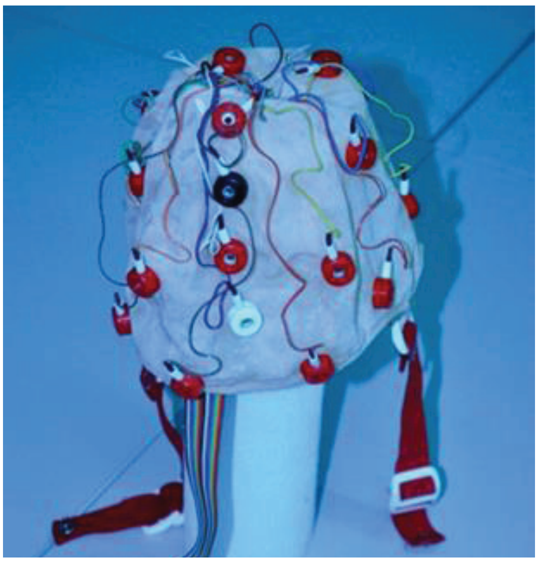

Figure 1. EEG cap used in the measurements

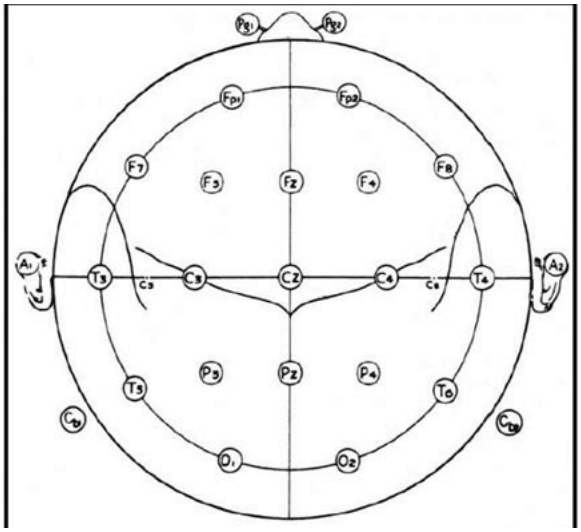

Figure 2. Standard electrode positions. Own elaboration based on [1]

2.3. Electrode Location

The arrangement of the electrodes is standardized. The most commonly used electrode placement system is the International System 10–20 [1]. This system corresponds approximately to the anatomical structure of the brain and is based on precise measurements of the skull with the use of several characteristic points. Figure 2 shows the locations of the electrodes in the mentioned system.

The use of specialized caps as in Fig. 1 allows for omitting each measurement, which greatly facilitates the examination. Each of the electrodes corresponds to a large anatomical region of the brain. Moreover, odd numbers refer to the left hemisphere of the brain, and even numbers refer to the right hemisphere. The symbols of the electrodes correspond to the Latin names of the regions: F – frontal area, Fp – prefrontal area, P – parietal area, O – occipital area, T – temporal area, A – ear electrodes, C – central area, Sp1/Sp2 – wedge electrode [1, 13, 14].

2.4. Types of Electrode Leads

The summation of the inhibitory postsynaptic (IPSP) and excitatory (EPSP) potentials in the neural network causes the generation of electric currents flowing in the cells. The phenomenon of the current flow creates fields that move centrifugally away from the place where the electric phenomenon occurs. The field impact decreases with increasing distance from the source. This necessitates the most accurate placement of the electrodes so that the recorded signals best reflect the phenomena under study. Therefore, two types of leads are used: unipolar and bipolar [1, 13, 14].

Measurement with the unipolar leads (used in measurements) records changes in voltage between one electrode and the point representing the reference potential. This method, however, is not free from artifacts, such as an artifact from an alternating current network with a frequency of 50 Hz. The bipolar leads, on the other hand, extend the number of electrode combinations. In this solution, both electrodes represent the bioelectric activity of the brain, and the resulting record is a representation of the potential difference between the two measuring points used. In this case, a signal that has an equal effect on both sources will not cause a potential difference. Said method of connecting the electrodes offers a greater number of possible connections depending on the diagnostic need [1].

2.5. EEG Equipment

Electroencephalographic recorders are digital devices in which the analog signal is converted into digital and the following technical parameters are associated with their operation: sampling frequency, recording speed, and sensitivity. In addition, all EEG devices must also include resistance-capacitive circuits, which are both low-pass and high-pass filters. Low-pass filters attenuate unwanted high frequencies, such as muscle action potentials. Usually, they are set at 60 Hz to cut the 50 Hz artifact disturbance. In turn, high-pass filters similarly attenuate low-frequency signals [15].

The average characteristics of the analyzed EEG recorder are a large number of channels (8-32) and the use of a program switch at the input of the device, which enables the connection of each measurement path with each electrode (unipolar system) or with a pair of electrodes (bipolar system). The ALIEN recorder with 32 channels was used in the research (Fig. 3) [16].

Another characteristic feature of the device is the built-in electrode impedance measurement system. A small value of impedance allows one to obtain a good electrical contact, and thus obtain a better measurement, with a smaller distance from noise. The correct value of the impedance between the electrode and the scalp should not exceed 5 kΩ, although in some measurements even 20 kΩ is allowed [16].

Figure 3. EEG module used in the measurements

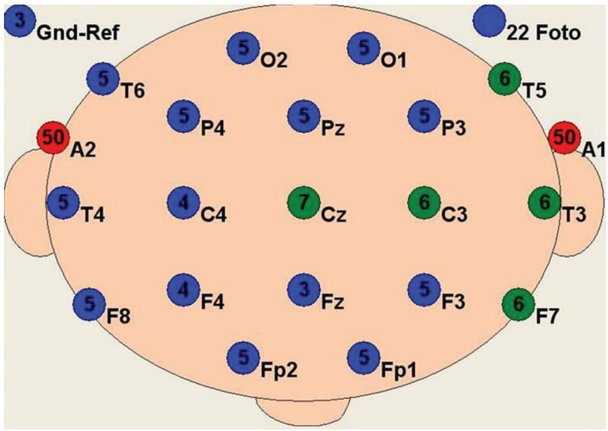

Figure 4. Graphical representation of the electrode resistances

3. EEG Signal Acquisition

TruScan software was used to acquire the EEG signal. The default sampling frequency is set to 128 Hz; it is also necessary to set the values of other parameters, such as sensitivity (70 μV), and the bandpass filter, which will determine the recorded frequency band, which is interesting for the analysis [16].

Single electrodes can be connected or the abovementioned cap can be used (contains 32 optimally positioned electrodes). Examples of the resistance values of individual electrodes are shown in Fig. 4.

The red color means an unacceptable resistance value, which makes the measurement impossible. Yellow indicates resistance at the limit of admissibility, while the minimum transient resistance is described by two colors: blue and green. In the case of red color, the position of the corresponding electrode should be corrected.

3.1. EEG Signal Artifacts and Disturbances

The phenomenon of artifacts, or undesirable phenomena that distort the analyzed signal, is associated with the measurements of all signals, especially those with such a small amplitude. Depending on their origin, artifacts are divided into:

- physiological: their cause is the functioning of human organs that are not the subject of research in the electrodiagnostic examination carried out at a given moment,
- technical: their cause is primarily the measurement method itself, imperfection of the equipment used, and the occurrence of physical phenomena completely unrelated to a given electrodiagnostic measurement in the measuring space [1, 13].

Physiological artifacts cannot be eliminated by using more precise equipment, but it is possible to significantly reduce their impact by trying to create the best possible conditions [1, 13]. The most important EEG signal artifacts are [1]:

- “crackling” of the electrode: caused by the leaky contact of the electrode with the human skin.

This causes a very sudden, but short-term increase in the impedance of the electrode.

- action muscle potentials: the most common artifact, which, when present in large numbers, completely interferes with EEG measurements.
- 50 Hz artifact (from AC network): an artifact arising as a result of high impedance or often bad grounding related to the proximity of an electrical apparatus, which appears as a rhythmic frequency of 50 Hz in Europe.
- tremor artifacts: caused by repetitive limb movements, which also cause head movements. The artifact causes small oscillations that affect the occipital electrodes.
- chewing artifacts: muscle action potentials characterized by a frequency consistent with the movement of the jaws (Fig. 5).
- artifacts related to tongue movements: they are characterized by slow, chaotic potentials indicating delta waves in the analysis (Fig. 6).
- motion artifacts: common, characterized by high amplitudes and the rapid decay of value. They coexist with body and head movements and are directly related to muscle artifacts (Fig. 7).
- blinking artifact: it is characterized by high amplitude potentials, the deviations of which are synchronous with the huge downward inclinations of the curve (Fig. 8).

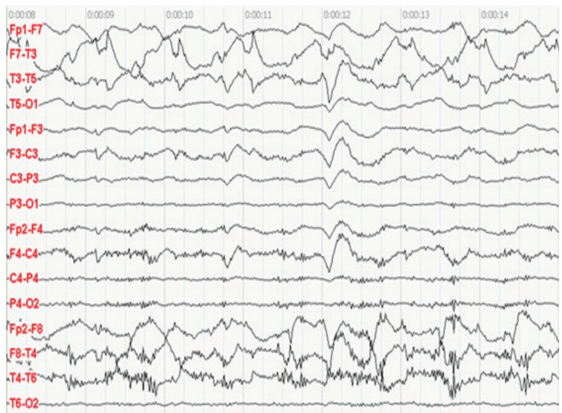

Figure 5. Laboratory-recorded adult EEG signals containing chewing artifacts

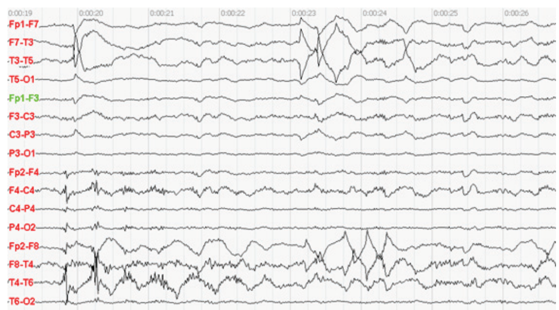

Figure 6. Laboratory-recorded adult EEG signals containing artifacts related to tongue movements

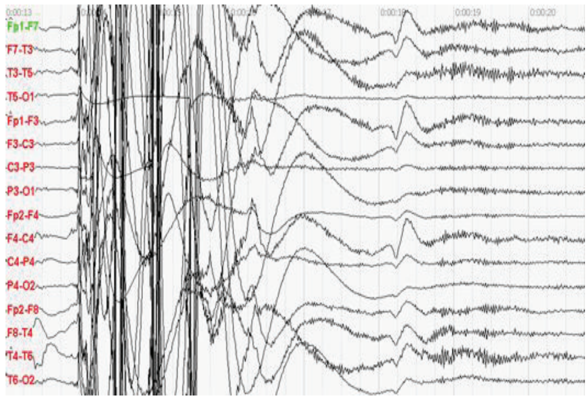

Figure 7. Laboratory-recorded adult EEG signals containing motion artifacts

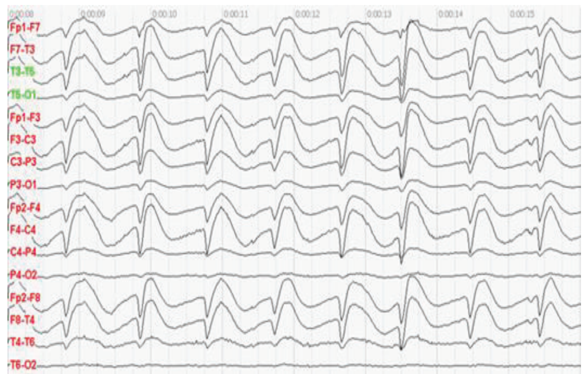

Figure 8. Laboratory-recorded adult EEG signals containing blink artifacts

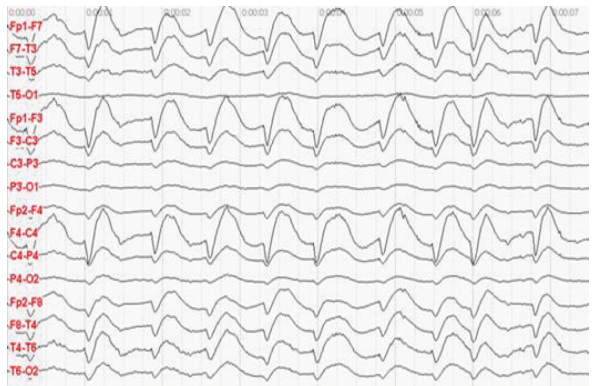

Figure 9. Laboratory-recorded adult EEG signals containing artifacts related to the sideways movement of the eyeballs

- artifacts related to sideways movements of the eyeballs: characteristic, sharply delimited out-of-phase potentials. This phenomenon is directly caused by the action of the lateral straight muscles (Fig. 9).

If physiological artifacts are found in the EEG signals, then their influence can be largely reduced by proper description. Some artifacts, such as eyelid blinking or eye movements, can be identified because their presence is characterized by a characteristic distinctness of the measurement itself. A very difficult issue is also the problem of automatic identification of the disturbances generated as a result of these artifacts [1].

On the other hand, technical artifacts are usually the result of improper electrode placement, poor skin contact, and the actual conduct of tests in an environment that may be electromagnetically disturbed (cables, transformers, etc.). However, a lot of EEG laboratories are currently equipped with shielded rooms, which eliminates the risk of this type of interference [1].

3.2. Elements of the Correct EEG Recording of an Adult

The recording of the bioelectrical activity of the brain consists of brain wave rhythms of different frequencies and amplitude, and their number and distribution determine the regularity or possible pathologies. Among the brain waves, there are the following waves: delta, theta, alpha, beta, and gamma, and each of them is responsible for a specific type of brain activity: sleep, concentration, tension, and so on [1, 13, 14].

Delta waves (0.5–4 Hz) are an indicator of focal brain damage. Delta wave is the slowest of all brain waves. It appears during deep sleep. On the other hand, they do not appear in the normal EEG recording of an adult in the waking state, because their presence always indicates brain dysfunction [1, 13, 14].

Theta waves (4–8 Hz) are customary in the EEG of adult wakefulness, but their absence does not necessarily mean any dysfunction. These waves are associated with states of concentration, intense thinking, and visualization [1, 13, 14].

The alpha rhythm (8–12 Hz) is the main basic rhythm of an adult normal EEG. The alpha rhythm is defined as a rhythmic frequency between 8 Hz and 13 Hz (sometimes 12 Hz), which is usually the highest in the occipital region. Alpha wave is the axis of the bioelectrical activity of the brain. Moreover, this wave is directly related to the state of concentration. Excess alpha may indicate problems in learning processes. The basic characteristic of these waves is that they show best when the person is relaxed and awake with their eyes closed [1, 13, 14].

Beta waves (12–40 Hz) are the background of most people's brain waves. The rhythm occurs and dominates in the state of consciousness when a person is awake and receives signals from the environment with all senses. Beta waves are divided into:

- Low waves, the so-called SMR (12–15 Hz),
- Medium waves, the so-called Beta 1 (15–20 Hz),
- High waves, the so-called Beta 2 (20–32 Hz) [1, 13, 14].

Gamma waves (32–200 Hz) are responsible for experiencing strong emotions and associative processes. The frequencies in the range: 32–50 Hz are the only frequency group found in any part of the brain. This is why it is assumed that when the brain has to process information in different parts simultaneously, it uses the 40 Hz frequency to process information simultaneously [1, 13, 14].

3.3. Sample EEG Signals of an Adult

During the EEG measurements, in addition to recording numerous examples of artifacts described in Section 3.2, the following states were recorded:

- State of relaxation

  The record of the state of relaxation shown in Fig. 10 was recorded during the examination of the author of the article, who was awake during the measurements with his eyes closed. Small deviations and a relatively uniform signal flow in all leads indicate the dominant alpha rhythm.

- Hand movement

  The recording shown in Fig. 11 was recorded during the examination of the author of the article, who moved his hands during the measurements. Visible significant sudden changes in amplitudes indicate artifacts related to the functional muscle potential. The artifact interferes with the results, especially on the frontal, parietal and temporal electrodes, but the signals from the rest of the electrode pairs are only minimally disturbed.

- Blinking and moving the head

  The record shown in Fig. 12 was recorded during the examination of the author of the article, who moved his head and blinked his eyelids during the measurements. The visible significant sudden changes in amplitudes, especially in the Fp1-F3 pair, indicate the dominant nature of the blink artifact. On the other hand, the artifact related to the head movement is visible in the form of "waving" also on the pair of Fp1-F3 electrodes.

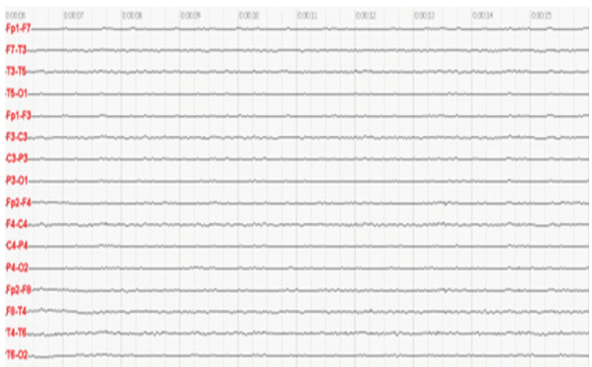

Figure 10. Record of the relaxed state of a healthy adult

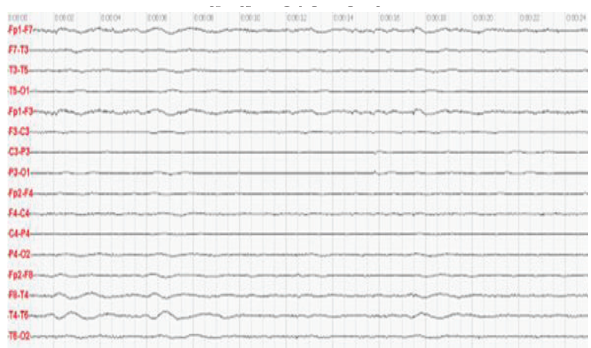

Figure 11. Record of muscle artifacts: hand movement

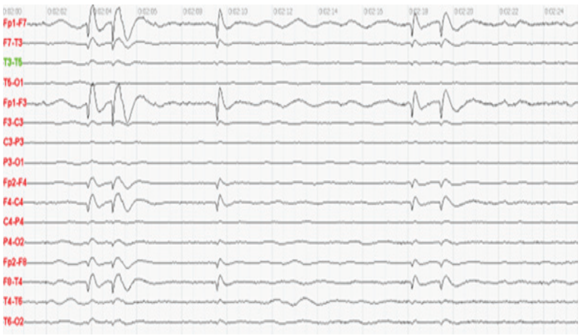

Figure 12. Record of muscle artifacts: blinking eyelids and moving the head

4. Development of the EEG Signal Analysis Algorithm

The main goal of the developed algorithm is to analyze the recorded EEG signals in order to obtain information about the present frequency bands. Confidence that the detected frequencies are the brainwaves being searched is obtained by examining the amplitude of the filtered band and the mean square value of the signal band. The scope of the aforementioned indicators that meet the problem under consideration is presented in Table 1. In turn, the first and second columns of the table lists the names of the brain wave along with the considered frequency band.

However, there are numerous exceptions to the accepted norms for brain waves. In such cases, a very helpful indicator in the assessment of the human condition is the percentage of Fourier transform amplitude values of specific frequency bands in a noise-free signal. It is especially useful when the analysis is based on the limitations of the amplitude, and root mean square (RMS) values described in Table 1 do not give satisfactory results. By calculating what percentage of the entire frequency spectrum is a given frequency band occupying the area assigned to brain waves, it is easy to determine what the real state of the examined person is. Real-time observation of changes in the content of individual phases in the signal is the basis of biofeedback training.

Figure 13 shows an algorithm for analyzing the recorded EEG signal. To work properly, it needs information about the frequency value with which the EEG signal was sampled. This information is necessary to determine the Nyquist limit (half the value of the sampling frequency). The algorithm assumes that it is enough to narrow the frequency range to (0.5–45) Hz in order to analyze the basic brain wave bands. Of course, it is possible to examine the signal in a broader spectrum, but it does not add any additional information about the condition of the examined person. Moreover, measurements with frequencies close to 50 Hz should be done carefully due to the presence of an artifact from the electrical network with the aforementioned frequency [17–20].

Table 1. Division of brain waves according to frequency bands [1, 13, 14]

Brain wave	Frequency range [Hz]	Amplitude [μV]	RMS [μV]
Delta	(0.5–4)	approx. 50	<20
Theta	(4–7.5)	<30	10 (max. 15)
Alpha	(7.5–13)	20–100	6–10
SMR	(12–15)	<20	4
Beta 1	(12–30)	<20	3
Beta 2	(20–30)	<20	<6–8
Gamma	(31–45)	ND	ND

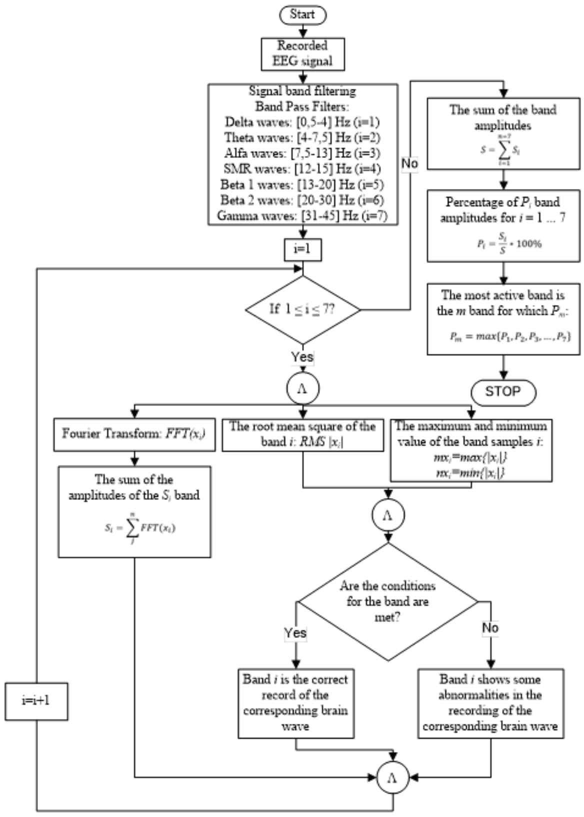

Figure 13. Block diagram of the algorithm

After the initial filtering of the signal, a series of 7 band-pass filters are performed. The main band of the analyzed signal should be divided into smaller bands corresponding to their physiological counterparts (frequency ranges shown in Table 1). Then, calculation operations (RMS, amplitudes) are performed, as well as a parallel Fourier transform along with the calculation of the partial sum of the amplitudes of a given band. The above algorithm provides important information about the individual frequency bands of the signal through the mentioned mathematical operations. These data can be used to build a system supporting the interpretation of the EEG signal itself.

The basic parameter that should be taken into account when interpreting the EEG signal is the so-called theta/beta ratio, which represents the share of slow waves in the work of the brain. For an adult, the factor is 1–2, while for children it is usually 2–3. On the other hand, people who have problems with concentration usually show the value of the discussed coefficient above 3. An important parameter in assessing the correctness of the EEG signal is the content of the Beta 2 band. This parameter is compared with the content of the SMR and Alpha bands. The Beta 2 band content parameter should be lower than the SMR. If not, high Beta 2 levels may be due to muscle artifacts (tight neck muscles, etc.). Moreover, Beta 2 often increases its value locally as a result of strongly experienced emotions [1, 13].

Observing the percentage of individual bands may also help in the interpretation of the results, thanks to the use of the physiological consequences of the occurrence of subsequent bands described in Section 3.1, including:
- the high percentage of gamma waves may indicate that the tested person is moving,
- the high percentage of theta waves may indicate that the examined person is in a state of sleep [1, 13, 14].

This information is not decisive in the process of EEG analysis but is a great help because it highlights some deviations from the norm and signals some negative phenomena. Often the signal from individual electrodes is tested to obtain confidence in the results of the EEG signal analysis. This approach is usually more efficient than the simultaneous analysis of the EEG signal from several probes.

4.1. Implementation of the Algorithm in the LabVIEW Environment

The LABVIEW environment was chosen to implement the algorithm. Figure 14 shows the appearance of the front panel of the EEG analyzer.

The user has to enter the file path, input the sampling rate, and set how many electrodes are to be taken into account during the signal analysis. To aid in the selection of leads, a map of the person's head was created, showing the position and arrangement of the electrodes. Each time an electrode is selected, the appropriate electrode indicator lights up on the map and thus indicates the region of the brain that is taken into account during the examination. After specifying the electrodes, the user has to input the size of the data packet. It specifies the number of samples analyzed per second and is displayed in the graphs.

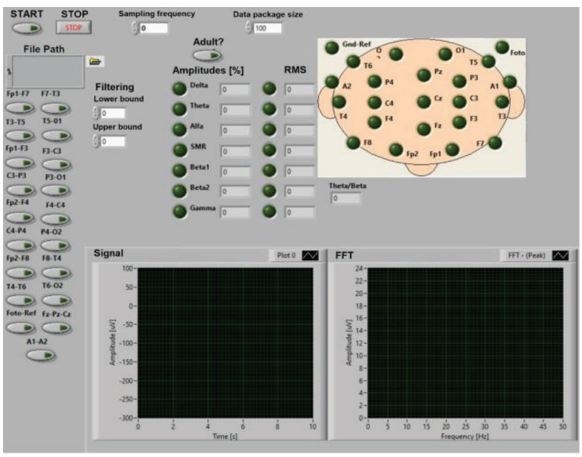

Figure 14. The appearance of the front panel of the EEG analyser

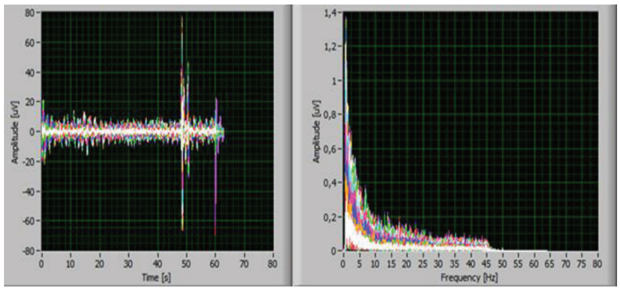

Figure 15. Signals from all electrodes in the time domain and their Fourier transform in the case of person's state of concentration

4.2. EEG Measurements

The results of the analysis of selected EEG signals are presented in the following section. The first two sections concern the analysis of the two signals recorded in the laboratory. The person whose brainwaves were recorded was an adult male (author of the article). The first section (4.2.1) shows the recorded brain waves while solving a crossword puzzle, while the second section (4.2.2) shows the EEG signals during everyday activity.

4.2.1. Adult's state of concentration

Figure 15 shows the obtained graphs of the analysed signals together with their Fourier transforms.

As can be seen in Fig. 15, time domain signal waveforms are in the range ($-80\ \mu$V, $80\ \mu$V). The occurring sudden increases in the signal amplitude are related to the presence of muscle artifacts, which in this case means that the examined person made movements with the eyeballs and eyelids. It should be mentioned that the examined person sat on a chair during the examination and was supposed to focus on solving the crossword puzzle while trying not to make any movements with the limbs, torso, and head. In turn, in the frequency domain, the signal has the highest values for low frequencies up to about 10 Hz. The visible sudden jump in the amplitude value recorded for the frequency of 50 Hz is related to the occurrence of the previously presented "50 Hz" artifact from the alternating current network.

As can be seen in Fig. 16, the most numerous frequency band are delta waves, which are present in the analyzed signal: about 33%. The theta wave band turned out to be also very numerous in this respect, the content of which in the signal is: about 14%. High values of this indicator for waves with such low frequencies are also due to the factory settings of the EEG adapter (hardware delay). The Theta / Beta ratio is in the optimal range: (1.2), which means that the patient has no problems with concentration. In turn, relatively high contents of Beta1 and Alpha waves, around 11%, testify to the very fast work of the brain, which is dominant in solving intellectual problems. The content of the Beta 1 wave is the lowest among the entire frequency band of Beta waves, which is a normal phenomenon.

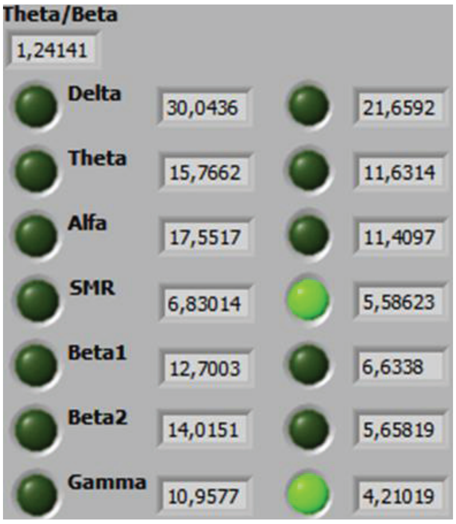

Figure 16. Visualization of the results by the EEG analyser in the case of person's state of concentration

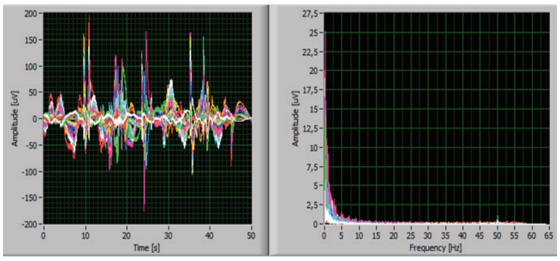

Figure 17. Signals from all electrodes in the time domain and their Fourier transform in the case of person's movement

As can be seen in Fig. 16, brain waves achieve very low mean square mean values (values on the right in Fig. 16), which are not consistent with those shown in Table 1. It is for this reason that none of the bands has met all the amplitude limits (left LED in Fig. 16).

4.2.2. Movement of an adult

Figure 17 shows the obtained graphs of the analyzed signal together with their Fourier transforms.

As can be seen in Fig. 17, the time domain signal is much more complex than that shown in the previous section in Fig. 15. In this case, the examined person made a large number of different movements: eye movements, eyelid blinking, to more complex hand or head movements. It should be mentioned that the examined person sat on a chair during the examination. The sensitivity of the equipment and the relatively short wiring made it impossible to move with the whole body. Thus, all the mentioned artifacts contribute to signal irregularity and huge amplitude values in the time domain: a maximum of about 200 μV. In the frequency domain, on the other hand, most of the signal lies in the low frequency range down to about 10 Hz. The "50 Hz" artifact is hardly noticeable here due to the domination of other artifacts in the signal under consideration.

As can be seen in Fig. 17, the most numerous frequency band are delta waves, which account for approximately 47% of the analyzed signal. This is the result of numerous artifacts overlapping the signal. Some of the artifacts, such as blinking and eye movements, cause sudden spikes in the signal amplitude and, through their almost immediate action, introduce additional high frequencies into the signal spectrum. On the other hand, some other artifacts, mainly related to movement, such as movements of the limbs and head, grow freely coexisting with the movements of the body and head. As already mentioned, the movements of the examined person during the recording of the signal could not be too dynamic, mainly due to the sensitivity of the equipment used to record the EEG signal. It is for this reason that the discussed movements were slow, which was expressed in the form of such a huge percentage of the Fourier transform amplitude in the entire EEG signal.

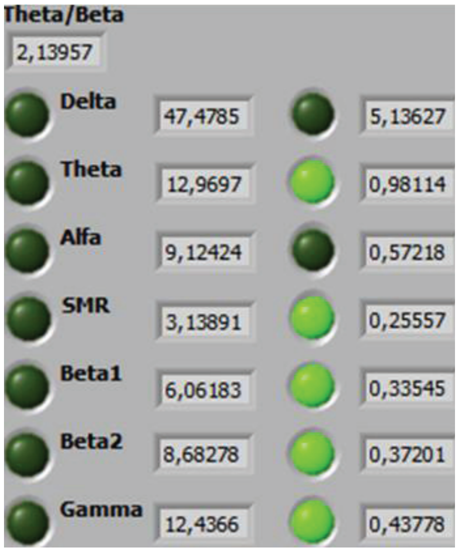

Figure 18. Visualization of the results by the EEG analyzer in the case of person's movement

Relatively low content of alpha waves and the entire beta wave band results from the dominant influence of artifacts on the EEG signal. Gamma waves at a relatively high level of 12% indicate the presence of these motion artifacts. The Theta Beta ratio is around 2.14 and it is not in the optimal range: (1, 2), but only slightly beyond its limit. As can be seen in Fig. 18 all brain waves except for the delta wave reach very low mean square mean values (values on the right side of Fig. 18), which are not consistent with those presented previously in Table 1.

4.3. Discussion

In order to present the results of the EEG analyzer performance, two characteristic measurements of the EEG signal were selected: the state of concentration and movement. In all cases, the measurements were taken from an adult. Due to the fact that the discussed cases were quite easy to register, the registration of muscle artifacts (presented in subsection 3.3) is not an easy activity.

The created analyzer enables a more accurate assessment of the tested person's condition than the TruScan software dedicated by the manufacturer, used to acquire measurements. The program created in the LabVIEW package allows one to view the results of the measurements in real time. In addition, the user can observe a series of waveforms and the Fourier transforms of the signal (before and after the pre-filtering process). It also has the ability to filter the signal in the user-specified band. A number of indicators provide ongoing information about the parameters of the EEG signal.

The created analyzer works correctly based on the presented results, but the limited number of recorded EEG signals and the lack of information on the direct influence of age on the parameters of brain waves contributed to the fact that some of the analyzer's operating parameters were adopted intuitively. It can lead to an inaccurate mapping of the results of the signal analysis when, for example, the operator is an elderly or very young person.

5. Conclusion

In order to present how the implemented EEG signal analyzer works, two characteristic measurements of the EEG signal of an adult person were selected: the state of concentration and the daily activity of the brain. Based on the results of the implemented solution, it should be emphasized that in each of the cases it was able to accurately determine the condition of the examined person. On this basis, it was assumed that the developed methodology for conducting the analysis and the adopted algorithm is correct.

The implemented solution enables an accurate assessment of the condition of the examined person and could be used to study the concentration of machine operators. The user can preview the results of the analysis and can observe the Fourier transform of the signal. It also has the ability to filter the signal in the user-specified band. A number of indicators provide ongoing information about the parameters of the brainwave signal.

The algorithm has several "rigidly" adopted parameters in the analysis of brain waves. Moreover, they are not met for every person, which can lead to errors in the results. Attempting to change the current algorithm to an algorithm using fuzzy logic would provide an opportunity to develop the work in the future. In the signal analysis process itself, there is also a wide range of tools that could improve the properties of the implemented algorithm, such as wavelet analysis and neural networks.

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