jet INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2020, VOL. 66, NO. 4, PP. 607-612
Manuscript received May 20, 2020; revised October, 2020. DOI: 10.24425/ijet.2020.134018

Biofeedback Therapy Application with EEG Signal Visualization and the Optimization of Success Factor Algorithm

Paweł Kielan, Marek Kciuk, Jakub Piecyk

***Abstract*—In this paper the biofeedback therapy application is presented. The application is implemented in desired biofeedback system based on RaspberyPI. The EEG signal is taken using popular headset with forehead probe and ear reference one. A patient is trying to focus on desired task and should keep attention level above threshold, the threshold is given and monitor by therapist. The success factor during one therapy session should be more than about 80%, so therapist have to control the threshold. The application consists algorithm for automatic threshold correction based on interview with experienced therapist.**

***Keywords*—Biofeedback therapy, EEG, success factor, RaspberyPI, brain waves**

I. Introduction

THE treatment of certain types of the human brain disorders in the functioning or the improvement of its performance is carried out using a technique called biofeedback (BF). Biofeedback therapy is currently considered the only safe interference in the work of the brain in contrast to pharmacological methods, which usually have an adverse effect, especially with long live use.

There are many illnesses which can be cured using different types of biofeedback. There are variety of illnesses but there are not all of them: cerebral palsy, migraine and chronic headache accidental head and brain injuries, paresis and paralysis of muscles, autism, attention deficit, hyperactivity disorder (ADHD), memory impairment, sleep disturbance, addiction, muscle cramps, learning problems, e.g. discussion, dysgraphia, dyscalculia, attention deficit disorder, motion sickness, anorexia and bulimia, depression cardiovascular diseases asthma, constipation, diabetes [14]. As it can be seen there are three groups. First group brain disorders, second group difficulties and third group body illnesses.

The biofeedback therapy is applied for brain activity improvement. In this scope it is possible to: improve memory, concentration and speed of thinking, reduction of reaction time, reducing emotional tension and increasing resistance to stress, improving self-control, mute, improving self-esteem, facilitating the learning of especially foreign languages, improving creativity and creative thinking [2].

Different kinds of human body signals are applied for biofeedback. It can be EEG, EKG, HRV, HEG, GSR, breath or other, which we can acquire [10]. Fusion of above signals can be taken into account as well. The patient is trying to keep desired signal above threshold using his mental ability: focus on the task or trying to stay relaxed along the therapy session. The session takes from 3 to 15 minutes and depends on patient – his age, disorder, and task. After short brake session is repeated 3 to 5 times. The therapy supervisor is therapist, who control threshold along the session and try to achieve success factor above given value in range of minimum 50% or above. Success factor is defined as time of signal above threshold to session time. High value of success factor is one of factors which mobilize the patient to work [7,8].

Typical biofeedback applications leave the task of threshold controlling to therapist. The therapist must divide his attention between application and behaviour of a patient. There is an idea to support therapist by taking control of the threshold value in an application with dedicated algorithm. The algorithm is proposed, it is called ATCA. The biofeedback system with some novel solutions is proposed, an automatic threshold control algorithm is implemented. Based on interview with experienced therapist the rules for controlling the threshold were specified:

- the threshold should change slightly with high inertia,
- the most important factor is signal wave gradient,
- initial value in new session should be the same as final in previous one,
- the main changes should be done in first 50-75% session time,
- in final part of the session time the threshold should be constant, but it may be eventually changed.

II. EEG waves and Brain computer Interfaces

Electrical brain activity (EEG) was discovered more than hundred years ago by Caton. The external probes (which don't need to be applied with surgery) were discovered in 1929 by Hans Berger and it caused idea of controlling machines without hands or voice just using the brain waves. First machines controlled by a human brain were built in 1970. There are two branches of EEG applications. One of them uses brain waveforms for controlling machines, second ones utilizes waveform artefacts caused by winks [3,11,13].

This research was supported by the European Union from the European Social Fund in the framework of the project "Silesian University of Technology as a Center of Modern Education based on research and innovation" POWR.03.05.00-00-Z098/17.

First Author Second Author and Third Author are with Silesian University of Technology, Faculty of Electrical Engineering, Chair of Mechatronics (e-mail: pawel.kielan@polsl.pl, marek.kciuk@polsl.pl, jakubpiecyk95@gmail.com).

© The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0, https://creativecommons.org/licenses/by/4.0/), which permits use, distribution, and reproduction in any medium, provided that the Article is properly cited.

The EEG signal is divided into different ranges of frequencies and amplitudes which corresponds to different brain activities. The alfa waves in range 8-12Hz and is rhythmic activity of relaxed brain and closed eyes. The alfa waves disappear over time mental effort (e.g. performing math tasks) or through eye opening. The delta waves in range 0,5-4Hz and high amplitude appears during the deep sleep, they are called Slow Wave Activity (SWA). The theta waves in range 3-7Hz appears during shallow sleep, meditation or hypnosis. It is supposed that they are related to the effect of the absorption of learned content and the transfer of memories from short-term to long-term memory. The beta waves in range 1-30Hz which are divided into subranges corresponds to daily brain activity. They are divided into low beta (12-15Hz), medium beta (15-18 and high beta (above 19Hz). Some medications cause specific beta wave activity. The gamma waves in range 30-80 corresponds to movement activity, and memories. There is high gamma in range from 80Hz to 200Hz. The gamma waves are associated with perception [5]. There are other waves as well. Exemplary brain waves are presented in Fig. 1.

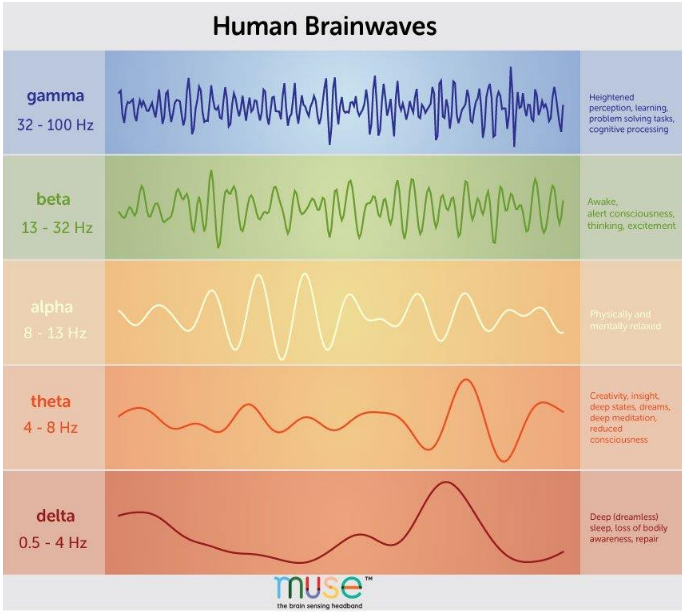

Fig. 1. Brain waves [1]

There are many application works. They are called Brain Machine Interface (BMI). The main branches are military (e.g. controlling airplane), medicine, prothesis (e.g. controlling wheelchair by paralyzed person, voice synthesisers for communication with others). One of the most recognizable is voice synthesis for prof. Stephen ’a Hawking, who is suffers from amyotrophic lateral sclerosis. EEG is one kind in wide range of human signals employed in biofeedback therapy [12]. In this scope EEG biofeedback therapy is applying BMI system for improving or coerce brain activity. It can be used i.e. for ADHD, focus problem, stutter or epilepsy or many more. The cheap electronics facilitate access to such solutions which utilize different kinds of commercial headset and dedicated smartphone applications for learning, therapy or fun [4,6].

BMI systems work in closed loop, where EEG signal is acquired, processed and in result, desired task is controlled, which can be observed by a human, who see results of his brain activity. It is presented in Fig. 2.

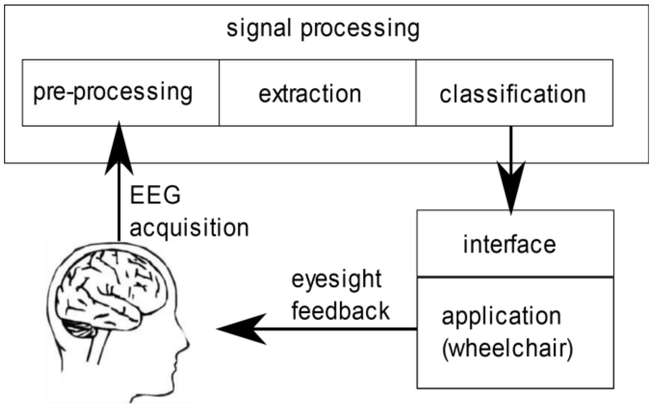

Fig. 2. Schematic of BMI system [9]

The current technological level of BMI interfaces does not allow us for using them to control machines or robots, so there are no industrial applications.

III. Biofeedback Therapy System

The proposed therapy system is dedicated for 8 – 12 years old children (both girls and boys), so visualization and therapy protocol are optimized for that age. The therapy protocol is dedicated for improving attention of the child. The system must be portable and therapist friendly as well. So, biofeedback therapy system is kind of BMI system, in which closed loop is for a patient, who control the visualization, but control value (threshold) is controlled by a therapist, who is supervisor of the therapy process.

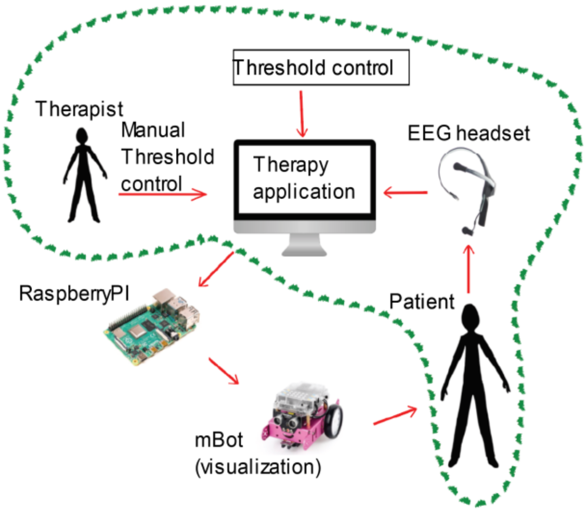

Fig. 3. Block diagram of the system

The hardware of designed system is based on RaspberryPI 3B single board computer. The utilizing biofeedback signal EEG wave is acquired by NeuroSky Brainwave Mobile 2 headset which realize pre-processing and returns values of the brain certain wave frequencies, it gives also two additional values of attention and meditation, which are results of pre-processing build in headset control system. Data exchange is done via

Bluetooth connection. It is possible to monitor additional signals (HRV and GSR) as support signals, but the signals are not taken into account in signal processing, they are just displayed in therapist control panel. The therapist has additional information about patient's state e.g.: he is stressed because his heart works fast and he has wet skin. The visualization object which is seen by patient as feedback is a small wheel robot called MakeblockmBot, which runs along the line. It realizes typical line follower task but activation signal is given from a host using Bluetooth. The simple task is easy to understand for a patient and causes interest. The robot is moving if chosen brain wave is above threshold. The therapist control panel is done as website in local Wi-Fi network. Therapist may log into the server with different kinds of devices like laptop or smartphone. System doesn't need dedicated screen.

IV. The Therapy Application

The main aim of the application is controlling BMI therapy system, where attention value from the headset is processed to move command for the mobile linefollower robot. It requires the integration of given above modules.

The headset manufacturer shares SDK library which is called Think Gear Connect (TGC). It is an application which exchanges data with headset and enables programmers to communicate with it using TCP/IP local server technology. The data structure is JSON object, so it gives possibility to use wide range of programming languages which are able to decode JSON data format.

The mBot robot is controlled via Bluetooth connection using virtual serial port. All programming environments enables to establish connection and data exchange in this scope, it is necessary to program robot with dedicated algorithm written in Arduino.

The application is written in Java using built in libraries and frameworks. The TGC data exchange was realized using Processing Library using classes Think Gear for communication with TGC and MindWave, which is interface class, GUI is done using JavaFX framework. Fig. 4 presents implemented structure of classes.

The logic of application is implemented in Controller class. FXML Classes utilizes GUI. Additional Classes like CSV and My Timer realize saving therapy data into log file and control time of therapy session.

The application is written using multithreading. Different activities work with different rates, some of them must be synchronized each other. The TGC gives new value each 1s, it must be synchronized with graphs on the control panel. Each graph works in a separate thread, which is put to sleep and activated every second to synchronize the waveforms. The robot mBot must be controlled according to the control signal from the application but acceleration and braking processes must be taken into account. Separate threads are used to monitor the connection status with the robot and headset.

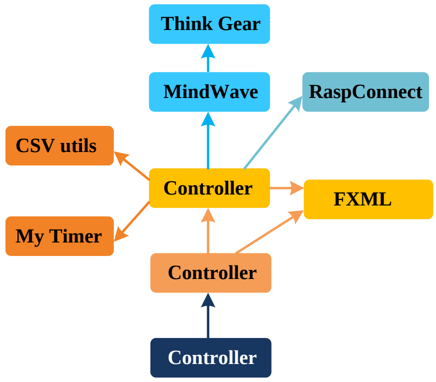

Fig. 4. Application class hierarchy

V. Therapist Control Panel

Therapist control panel is part of therapy application. A typical control panel is colorful, which distracts the therapist. In addition, a large number of settings and configuration options impede the application preparation process. This can discourage the patient and upset the therapist.

The main duty of the control panelis presenting brain waves in shapes of bar graph and time waves graph. It enables to check other parts of the system: connection with a headset and robot. It presents values of additional signals. It enables therapist to change threshold manually, visualise actual and historical threshold value in time wave graph and enables to switch to automatic control. The screen is presented in Fig. 5.

Fig. 5. The therapist control panel

The structure of control panel was discussed with experienced therapist. Different versions were presented and discussed. Final view consists important information, the most important ones are presented in big objects, supported ones are smaller or even reduced to icons (e.g. connection with a headset is presented as three circles representing strength of the signal, connection with the robot is an icon of robot with red or green dot representing active connection with the robot). Number of control elements e.g. buttons or sliders is reduced.

The control panel does not contain many motley elements that divert attention from the most important information. The therapist sees all waveforms on a smaller graph, he can choose the most important ones on a large graph and conduct therapy focusing only on selected ones, while others are still on the screen.

VI. AUTOMATIC THRESHOLD CONTROL ALGORITHM

The Automatic Threshold Control Algorithm (ATCA) is implemented in Control class. It is based on guidelines presented in first chapter and recorded exemplary sessions with manual threshold control done by therapist.

The following assumptions were made to develop the ATCA algorithm:

- Success Factor should be about 60%.
- The increasing threshold should stimulate the patient to effort by constantly raising the level of the threshold when the patient is doing better and better.
- The decreasing threshold should reduce the patient's frustration when he is not rewarded for a long time by reducing his value.
- Compared to manual therapy, the automatic threshold should be changed frequently to support patient stimulation.
- The threshold should be adjusted individually to the patient.

The actual value of success factor is calculated and taken into accounting next iteration. The first step is comparison of actual Attention value and threshold. In next step actual value is compared with last two values for gradient detection of the signal. Based on that flags “growFlag”, “decreaseFlag” and other variables are modified. Based on the variable values and actual success factor, a decision is made to keep or change the threshold value and about direction of the changing. The threshold is kept or modified of given step size which depends on gradient of the signal. The decision is done based on therules: growFlag or decreaseFlag is true, actual value of success factor, actual value is above the threshold, gradient of the signal is rising or failing. The simplified ATCA is presented in Fig. 6.

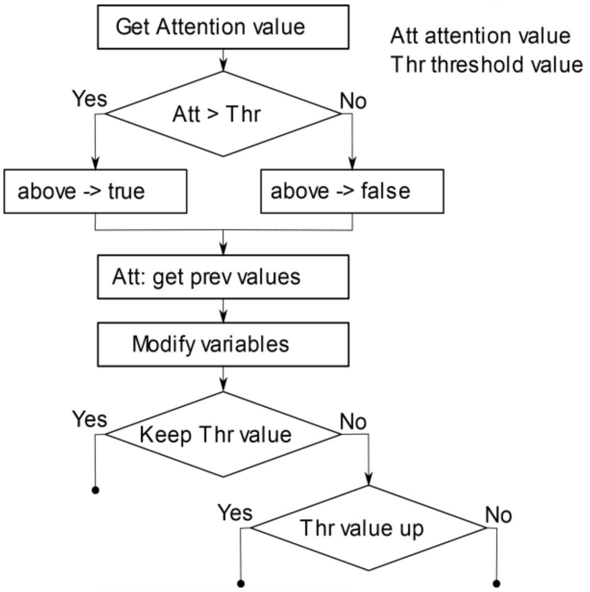

Fig. 6. ATCA block diagram

VII. AUTOMATIC AND MANUAL THRESHOLD CONTROL COMPARISON

The referenced therapy sessions were recorded. There were attention sessions and meditation sessions taken into account. Five with manual threshold control and five with automatic threshold control using ATCAin each session.The attention focused sessions expected success factor was 60%, while meditation focussed sessions expected success factor was 80%. The next figures present two chosen ones for each series. Waveforms shown in Fig. 7 are examples of attention series, waveforms shown in Fig. 8 are examples of meditation series. Results of group of five series are presented in tables bellow.

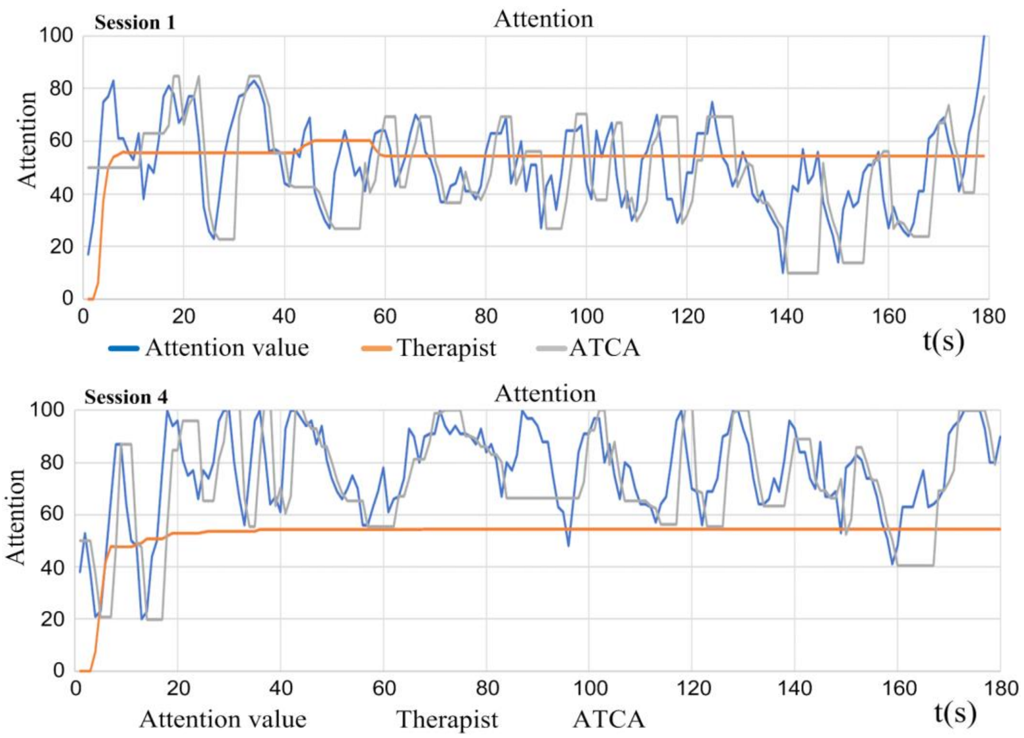

Fig. 7. Example timewaves of therapy sessions for attention focus

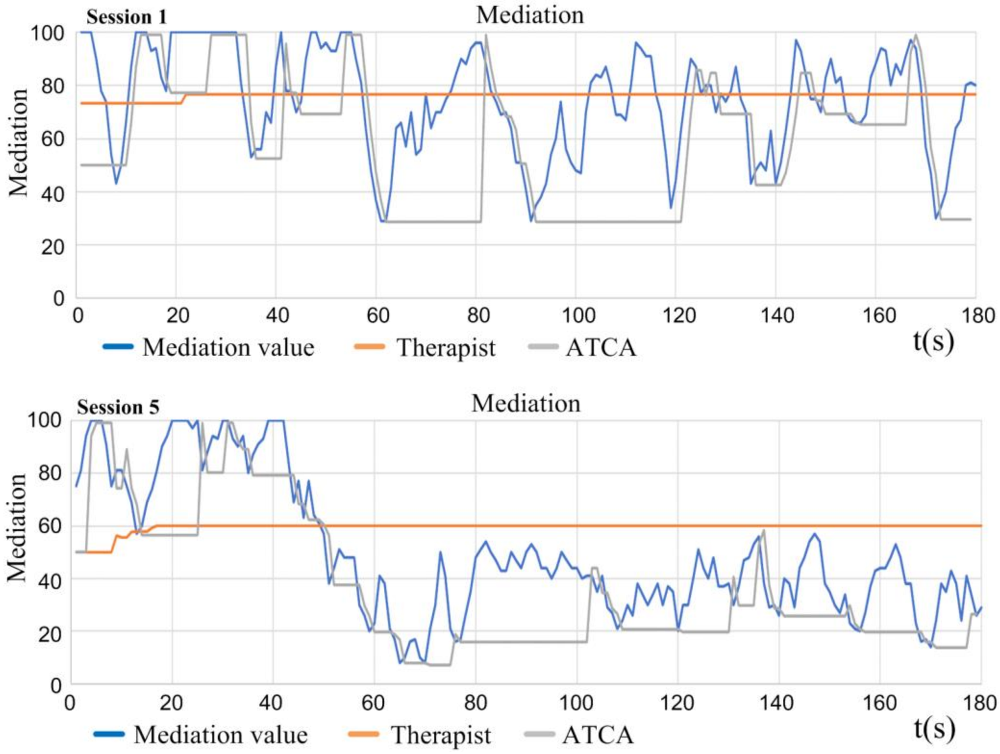

Fig. 8. Example timewaves of therapy sessions for meditation focus

The recorded sessions were compared and results of the comparison are presented in tables. The comparison aim is success factor comparison. The therapist manual threshold control results are presented in Table I, and automatic ATCA control results are presented in Table II for attention session, while therapist manual threshold control results are presented in Table III and automatic ATCA control results are presented in Table IV for meditation session.1 the bottom of each table base statistic computations are presented: average value of success factor and tolerance calculated as a difference between highest and lowest value.

TABLE I
THERAPIST CONTROL RESULTS (ATTENTION)

Session No	Success factor	threshold decreasing	threshold increasing
1	43%	5	10
2	31%	3	11
3	66%	1	14
4	93%	1	13
5	45%	1	7
avg	56%		
tolerance	62%		

As it can be seen in Fig. 7 and Fig. 8. The therapist keeps the threshold value in almost constant level, he makes minor adjustments. In contrast ATCA changes the value very often and tries to keep up against the attention value. In result (as it can be seen in above tables) ATCA gives more robust value of success factor but it needs many more threshold changes. The therapist keeps the threshold value much more but with much higher tolerance of the success factor. In all cases the expected value of success factor was not achieved but ATCA values are very close.

TABLE II
ATCA CONTROL RESULTS (ATTENTION)

Session No	Success factor	threshold decreasing	threshold increasing
1	55%	47	53
2	55%	38	44
3	53%	32	51
4	53%	48	38
5	55%	75	53
avg	54%		
tolerance	2%		

TABLE III
THERAPIST CONTROL RESULTS (MEDITATION)

Session No	Success factor	threshold decreasing	threshold increasing
1	53%	0	1
2	42%	0	1
3	27%	0	3
4	37%	0	4
5	26%	1	5
avg	37%		
tolerance	27%		

TABLE IV
THERAPIST CONTROL RESULTS (MEDITATION)

Session No	Success factor	threshold decreasing	threshold increasing
1	78%	34	19
2	78%	34	19
3	76%	43	6
4	79%	30	34
5	79%	37	14
avg	78%		
tolerance	3%		

CONCLUSION

The above presented results give very interesting notice. The rules presented at the beginning are very hard to implement because same of them are mutually exclusive. The brainwave is characterized by high volatility, so it is very hard to achieve high level of success factor utilizing algorithm trying to keep threshold almost constant. In result the tolerance of the success factor is very high. The standard therapy software doesn't give the information about that factor, so therapist uses his experience and knowledge about patient without objective information. In result the therapist has not objective information about therapy effect, he can decide about efficiency of therapy based on patient behaviour.

The ATCA tries to imitate brainwave for achieving best value of success factor. In this scope frequent and rapid changes of threshold are done. In result the assumed success factor is achieved with a little tolerance and close to desired value.

Advantages of the designed system

- There is no screen visualization for a patient, so people (children) with epilepsy can safely undergo therapy,
- Common (therapist and patient) create different paths for a robot mBot before therapy makes patient more engaged,
- Additional signals (other brainwaves, GSR and HRV) are taking into account by therapist for better understanding state of a patient,
- Simple therapist interface does not distract therapist,
- Automatic threshold control allows the therapist pay more attention to a patient behaviour,
- Web page control panel makes the system easier and more user friendly for therapist,
- The success factor achieved with high certainty level.

In fact, there are no data of ATCA algorithm efficiency in therapy process because the system is not approved for biofeedback therapy with patients. All presented results presented as referenced sessions were made with one of system author as patient.

The system is a prototype which is under development. There are proposals of development directions:

- Choosing other brain wave for therapy for giving therapist more flexibility and enables to cure other brain illness,
- Log patient data and his sessions data in database for analysing progress of the therapy, for improving therapy and consultations with other specialists,
- Log into server from Internet for watching session, it may be enabled for parents or other therapists,
- Using fusion of signals (EEG, GSR, HRV) for improve threshold control for achieving better therapy results, but the ATCA must be improved for taking account additional signals by implementing next point idea,
- Applying artificial intelligence (e.g. artificial neural network or machine learning) for improving threshold control, which will be able to utilizing more signals and historical data of the patient, which are collected in database,
- The robot velocity may be dependent on the difference between the measured value and threshold for trying faster completing therapy task.

REFERENCES

[1] A Deep Dive into Brainwaves: Brainwave Frequencies Explained. https://choosemuse.com/blog/a-deep-dive-into-brainwaves-brainwave-frequencies-explained-2/

[2] R. J. deBeus, D. A. Kaiser "Neurofeedback and Neuromodulation Techniques and Applications", 2011,

[3] M. Górska, M. Olszewski „Interfejs mózg-komputer w zadaniu sterowania robotem mobilnym". PAR 3, 2015

[4] F. L. da Silva "EEG: Origin and Measurement". In: Mulert C., Lemieux L. (eds) EEG - fMRI. Springer, Berlin, 2009, DOI: 10.1007/978-3-540-87919-0_2

[5] Dawson G. D. Cerebral responses to electrical stimulation of peripheral nerve in man. Journal of Neurology Neurosurgery & Psychiatry, 10, 1947.

[6] K. Sowndhararajan, S. Kim "Influence of Fragrances on Human Psychophysiological Activity: With Special Reference to Human Electroencephalographic Response". Sci. Pharm. 2016, 84,

[7] E. J, Develaar "Computational approach to developing cost-efficient adaptive threshold algorithms for EEG neurofeedback" In: International Journal of Structural and Computational Biology, Symbiosis 2017

[8] A. Skwara, E. Kornacka-Skwara „Zastosowanie mechanizmu biologicznego sprzężenia zwrotnego w procesie kształtowania umiejętności" In: Pedagogika 2012

[9] A. Cudo, E. Zabielska, B. Bałaj, (2011). „Wprowadzenie w zagadnienie interfejsów mózg-komputer" In: O. Gorbaniuk, B. Kostrubiec, D. Musiał, M. Wiechetek, Studia z Psychologii w The John Paul II Catholic University of Lublin (2011)

[10] G. M. McKee (2008) "Biofeedback: An overview in the context of heart-brain medicine", Claveland Clinic Journal of Medicine,

[11] A. Okupińska, A. Krzwowiąza, „Biofeedback jako efektywna metoda w terapii deficytów poznawczych w ujęciu teorii umysłu", Neurokognitywistyka w patologii i zdrowiu, 2011-2013,

[12] Biofeedback and Visceral Learning, Annual Reviews, Annual Review of Psychology1978;

[13] EEG & Neurofeedback in Rehabilitation. In: Injuries in Athletics: Causes and Consequences. Springer, Boston, MA, 2008

[14] H. Walkowiak: EEG BIOFEEDBACK: Charakterystyka, zastosowanie, opinie specjalistów. Studia Edukacyjne nr 36, 2015, Poznań 2015