Development of a Low-Cost and User-Friendly Neurofeedback Tool to treat Depression, Insomnia, Anxiety, Pain and ADHD using an Arduino and Android Application

Sheba Michael Moyosola
Politehnica University of Bucharest
Bucharest, Romania
mikkshebs@gmail.com

Mitrea Dan Alexandru
Politehnica University of Bucharest
Bucharest, Romania
dan_alex_2005@yahoo.com

Goga Nicole
Politehnica University of Bucharest
Bucharest, Romania
n.goga@rug.nl

Al Gayar Sarmad Monadel S.
Politehnica University of Bucharest
Bucharest, Romania
sarm.moon85@gmail.com

Bujor Pavaloiu
Politehnica University of Bucharest
Bucharest, Romania
klingo_w@yahoo.com

Costin Boiangiu
Politehnica University of Bucharest
Bucharest, Romania
costin.anton.boiangiu@gmail.com

Abstract— ***The main objective of the paper is to achieve the implementation of an economical and user-friendly neurofeedback tool that can be used to treat pain, addiction, aggression, anxiety, autism, depression, Schizophrenia, epilepsy, headaches, insomnia, Tourette syndrome, Attention Deficit Hyperactivity Disorder (ADHD), also used for the treatment of brain damage caused by stroke, trauma, and other causes in developing countries using EEG signal analysis. The analysis and the detection of the EEG can be achieved with the help of a home-made neurofeedback-built system. The technical and clinical EEG spectrum can be subdivided into – Alpha, Beta, Theta and Gamma ranges. The report will focus on the frequencies of the Beta band in accordance to the analysis of the power values and the output of the EEG analysis will be required to control the video and-or audio feedback. [22]***

Keywords— BCI, EEG, Neuro-feedback, Beta wave, Arduino, Low cost

I. INTRODUCTION

Neurofeedback (NF) is an automatic control system that provides real-time data of patients' brain activity, the aim of which is to develop self-learning strategies which can adjust the brain signals [28]. During neurofeedback treatment, the electroencephalography (EEG) is carefully recorded in a real-time manner. This type of approach has been proven to be quite efficient in ameliorating a variety of the symptoms by which patients with different disorders are afflicted, such as anxiety, depression, affective disorders, post-traumatic stress disorder, degenerative motor disorders, epilepsy, or brain injury [24, 27]. Through the use of NF, patients may be able to develop personal strategies that benefit self-regulating areas of the brain and networks which are usually directly linked to mental imagery based on the received signal-feedback which is thought to disclose the pattern of neural signal [30]. You can measure NF signals either by targeting one or more areas of the brain [28] or by simply examining signals all-across the brain. [3]

Neurofeedback training focuses on brain development, measuring in real-time certain areas of neural activity and, accordingly, sending feedback to the trainee. This is successfully put in practice through visual, auditory or audio-visual stimulation of the subject so that the specific putative neural substrates that are characteristic of certain pathological conditions or behaviors start self-regulating [26].

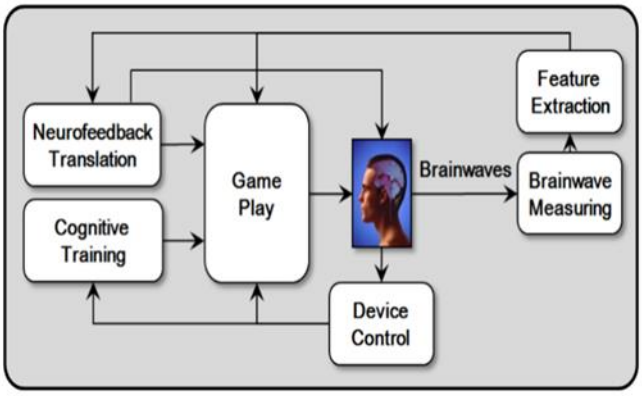

Fig. 1. Description in block form

1.1 Electroencephalography (EEG)

Electroencephalography (EEG) is a clinical imaging system that detects scalp electrical action created by the brain structures. The EEG (Electroencephalogram) is characterized as the electrical movement of alternating type recorded from the scalp after being picked-up by metal terminals/electrodes and conductive media. Electroencephalographic reading is an entirely non-intrusive system that patients and neuro-typical children and adults can be connected to repeatedly with moderately no hazard or constraint [1]. Measuring is accomplished by the electrodes that are looped down the lead-wires with the amplified inputs where the amplification is carried out. When electrodes are used, the space between the electrode terminal and the skin has to be loaded with conductive paste so as to reduce the chance of contact impedance at electrode skin interface. [5]

1.2 Brain waves

At the base of every one of our thoughts, emotions and behaviors can be interpreted as the communication between neurons inside our brains. Brainwaves are formed when electrical pulses are synchronized from different masses of neurons exchanging information with each other.

Brainwaves are detected using sensors placed on the scalp. They are divided into bandwidths to describe their functions (below), but are best thought of as a continuous spectrum of consciousness; from slow, loud and functional - to fast, subtle, and complex. Our brainwaves change as indicated by what we're doing and feeling. Usually, when slower brainwaves are prevalent, we feel tired, slow, lazy, or dreamy.

Brainwave speed is estimated in Hertz (cycles/second) and is isolated into groups of moderate, direct, and fast waves. Examples of brain neurons have rich data about neuronal exercises. When neurons are active, they deliver electrical pulses. By setting terminals on the scalp, the electrical movement of the brain, known as EEG, can be recorded.

Thus, EEG is created by a particular kind of synchronous movement of neurons, which are known as pyramidal neurons, and the electrical yield is therefore reflected in the accompanying regions of the skin where the cathodes are found. Their amplitudes and frequencies can perceive distinctive examples of electrical movements, known as brain waves.

Recurrence shows how quick the waves waver which is estimated by the quantity of waves every second (Hz), while the energy of these waves is estimated by microvolt (μV). [12]

1.2.1 Brainwave interpretation

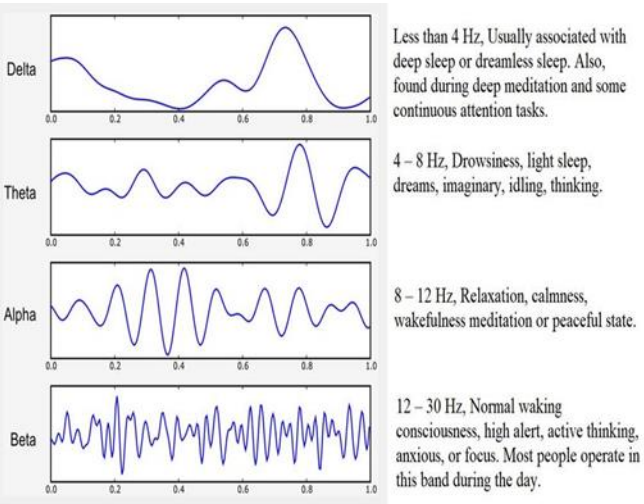

Fig. 2. Brainwave Interpretation

1.2.1 INFRA-LOW (<.5HZ)

Infra-Low brainwaves (otherwise called Slow Cortical Potentials), are believed to be the fundamental cortical rhythms that underlie our higher brain capacities. Their moderate nature makes them hard to distinguish and precisely measure, so few investigations have been carried out. They seem to play a noteworthy part in brain timing and system functionalities. [5]

1.2.2 Delta waves (.5 TO 3 HZ):

Delta waves tend to have the highest amplitude and the slowest frequencies. It is normally seen in adults showing slow wave sleep and in newborns. It is usually most prominent frontally in adults and in the back of the head when it comes to children. Delta brainwaves are slow, loud brainwaves (low recurrence and profoundly infiltrating, similar to a drum beat). [6]

1.2.3 THETA WAVES (3-7) Hz:

Theta waves occur mostly in the parietal and temporal regions. Theta occurrence is abnormal in alert adults but can be normal during sleep.

Theta brainwaves happen regularly when resting but at the same time are predominant in profound meditation. Theta waves are our portal to learning, memory, and instinct. In theta, our faculties are pulled back from the outside world and concentrated on signals starting from inside. We regularly just experience that nightfall state transitorily as we wake or rest. [6]

1.2.4 ALPHA WAVES

Alpha brainwaves are predominant amid discreetly streaming thoughts, and in some meditative states. Alpha is the resting state for the brain. Alpha waves help general mental coordination, tranquility, alertness, brain/body mix and learning. [12]

Alpha waves (8-13) Hz: Alpha waves can be noticed mainly from the occipital lobe but also from the parietal and frontal regions. They are produced when a person is in a conscious, relaxed state with closed eyes. [11]

1.2.5 BETA WAVES

Beta brainwaves are responsible for waking condition of awareness when consideration is coordinated towards cognitive. It is displayed when we are cautious, occupied with critical thinking, judgment, basic roles, or other demanding mental activities.

Beta brainwaves are additionally separated into three groups; Lo-Beta (Beta1, 12-15Hz) can be thought of as a 'quick sit out of gear'. Beta (Beta2, 15-22Hz) appears when one is engaged in a demanding activity or trying to make sense of something. Beta (Beta3, 22-38Hz) appears when the mental process is in an exceedingly clamorous state, coordinating new encounters, high nervousness, or excitement. Beta waves (13- 30) Hz are acquired from the parietal, central and frontal lobes. They occur in alert or anxious states. [10]

1.2.6 GAMMA

Gamma brainwaves are the fastest of brain waves (high recurrence, similar to a woodwind), and identify with concurrent preparing of data from various brain territories. Gamma brainwaves pass data quickly and unobtrusively.

The most inconspicuous of the brainwave frequencies, the brain must be calm to get to gamma.

Gamma is likewise over the recurrence of neuronal terminating, so how it is created remains a puzzle. It is theorized that gamma adjust discernment and awareness, and that a more noteworthy nearness of gamma identifies with extended cognizance. [16]

1.3 Comparison of EEG Bands

When our brainwaves are in disarray, issues will surface in our enthusiastic or neuro-physical wellbeing as a response. Research has identified brainwave designs related to a wide range of neurological conditions.

Over-excitement in certain brain regions is connected with nervousness, rest issues, nightmares, hyper-watchfulness, imprudent conduct, outrage/hostility, unsettled despondency, incessant nerve torment and spasticity. Under-excitement in certain brain zones prompts despondency, thoughtlessness, interminable torment and a sleeping disorder. A blend of under-excitement and over-excitement is found in instances of tension, sorrow and ADHD.[20]

1.4 EEG characteristics

This can be described by contrasts in Theta and Beta (Sensory Motor Rhythm SMR, Beta, high Beta) waves. EEG has slower and higher theta waves in frontal and focal districts in ADHD as compared to others. The normal overabundance is 32% [5]. It likewise does exclude enough quick beta waves (15-18) in frontal, focal and fleeting locales [6, 7]. Contrasted with neuro-typical subjects, the frequency of high Beta waves (22-30) is higher while the amplitude of SMR (12-15) is lower [8, 9].

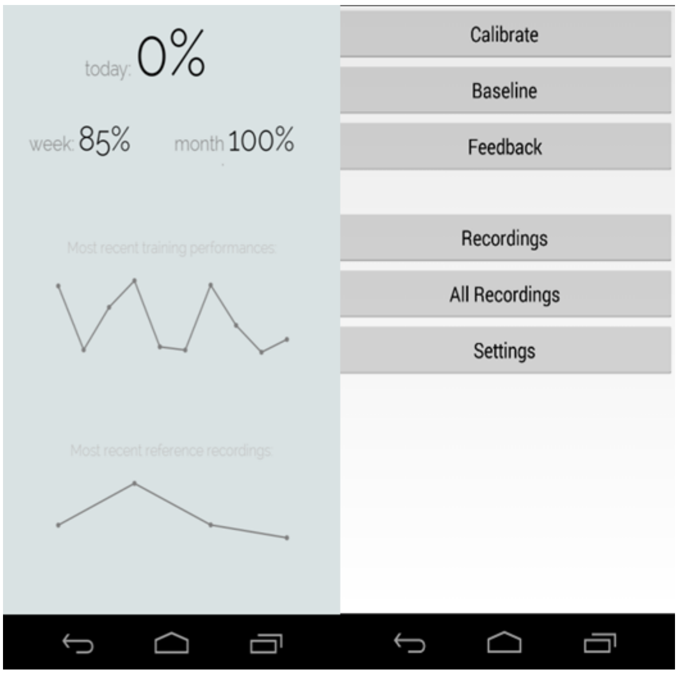

Fig. 3. Android Application showing the output test

II. Methodology

2.1 Main Components of EEG

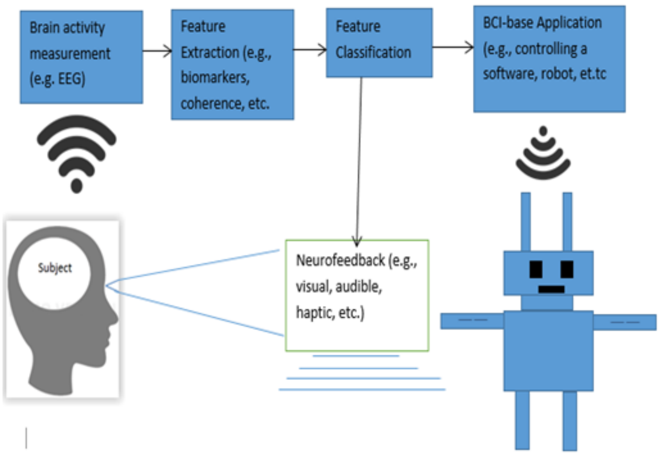

Fig. 4. Looping

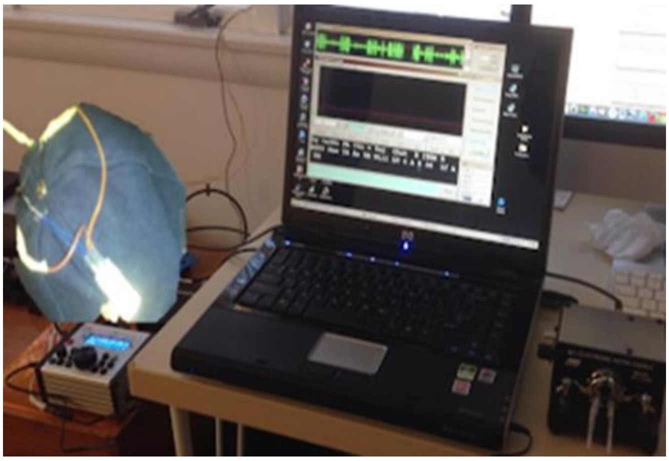

Fig. 5. BCI Waveform Output

2.2 Materials and Methods:

These are the tools used in this report and they are divided into two main parts, respectively the EEG acquisition circuit and processor unit.

2.2.1 EEG acquisition circuit

In this part, we will be using (Ag-AgCl) circle electrodes by cleaning the coveted scalp areas with alcohol and applying conductive glue. Ag-AgCl electrodes are cheap and can precisely record moderate changes in potential. Used scalp terminals comprise of plates with drives connected to an amplifier. In the frontal area, eye movement can cause slight problems, yet that is highly unlikely to ever happen. Central locations (C3-C4 bi-polar placement) are therefore chosen [12]. As shown in Figure 4, the circuit is comprised of three sections: procurement, enhancement and separation [2,13-19]. The objective is to execute a convenient battery-worked EEG intensifier with a fitting data transfer capacity. Since the EEG has frail amplitudes, a conceivably high gain amplifier is required. The proposed circuit picks up to 17000 and a 0.16-50 Hz data transfer capacity. Circuit pieces are recreated by Proteus programming and actualized on a board. They are delineated in the figures identified with the accompanying areas.[21]

III. AMPLIFICATION/FILTERING (CIRCUIT DIAGRAM)

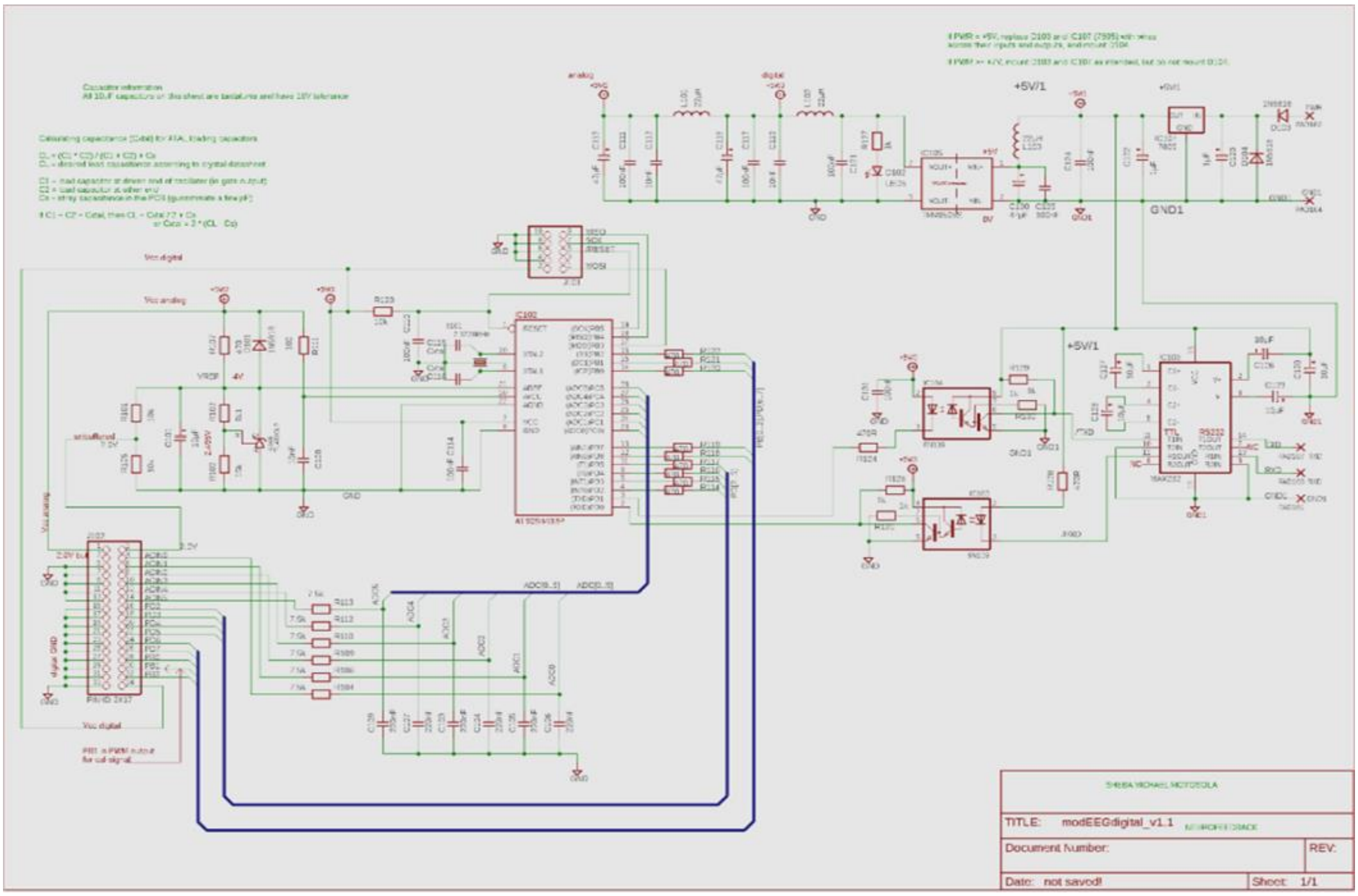

Fig. 6. Amplification and acquisition circuit

3.1.1 First stage of amplification/filtering

The first phase of the amplification process (gain range 9-19) is accomplished by the Instrumentation Amplifier (IA) INA114 which is appropriate for therapeutic applications, minimal effort, has a little size, offers incredible exactness with low balance voltage, can work with low power supplies and has a high normal mode dismissal proportion. It is basic for the enhancement of the bipolar distinction of potential (C3-C4) recognized by terminals. In the recommended circuit, INA114 is controlled by the Rg (3.3 K Ω) esteem which is conveyed by the blend of R4 (5 K Ω) and R5 (5 K Ω) in parallel with R3 (5 K Ω) as showed in Figure 6. The mix is associated with pins 1 and 8 [6]. Since the criticism resistor between the initial two inner enhancers in the IA chip is 25 K Ω, the general mix prompts the initial step pick up esteem: [16]

$AI_{gain} = 1 + [(2*25) / Rg]$
$= 1 + [50/((R_3*R_s)/(R_3+R_s))]$
$= 16$ (1.1)
$R_4+R_5=R_s$

A high pass detached channel made out of resistor and capacitor segments is then associated with evacuate the DC counterbalance voltage as demonstrated in Figure 2. The cut-off recurrence is ascertained as takes after:

$Fc = 1/ (2* \Pi*R * C)$

Where R = R7 = 1 M Ω, and C = C3 = 1µF (Figure 2). Fc is accordingly chosen to be 0.16 Hz. This cut-off decides the most reduced data transmission recurrence of the recommended circuit. [17]

3.1.2 Second stage of amplification/filtering

The second phase of the amplification is accomplished by a UA741. It is a universally useful operational intensifier highlighting balance voltage invalid capacity, high basic mode input voltage go, nonappearance of hook up and internal steadiness. The potential pick up extend is 48.6-1001. In the proposed circuit, a potentiometer (2 K Ω) is associated with UA741 keeping in mind the end goal to help enhance the flag [13]. Utilizing a 2 K Ω potentiometer in arrangement with a 100 Ω resistor-associated with the altering pin 2-in addition to an input 100 K Ω resistor-associated with the stick 6-prompts a pick up to 51 as delineated in Figure 6.[22]

Gain = 1 + (Rfeedback/Rinverting)
= 51
Rinverting = R6 + Rpotentiometer = 100 Ω + 2 KΩ
Rfeedback = R = 100 KΩ

A high pass channel is then associated (Figure 6) to expel the DC balance voltage, which may come about because of second phase of intensification. The cut-off recurrence dictated by R and C4 is computed utilizing condition (1.2). Its esteem is 0.16Hz.

3.1.3 Third stage of amplification/filtering

The third phase of amplification is comprised of a noninverting UA741 operational intensifier; it is a functioning low pass channel [2]. The picked capacitor C8 and resistor R esteems are 4 K Ω and 0.81μF, separately (Figure 6). The channel rejects in this manner the frequencies higher than 50Hz. By substituting estimations of Rfeedback (R=4 K Ω) and Rinverting (200 Ω) in condition (2), the pick up of the third phase of enhancement is observed to be 21(Figure 4).[22]

3.1 Driven right leg circuit

A DRL circuit reduces the regular mode impedance commotion as demonstrated in Figures 5 and 6. In the recommended circuit, two low power JFET input operational speakers TL062 are used for DRL. It includes high info impedance, low information inclination present and low info balance current. Likewise, it shields the client from the intensifier by constraining the current to an innocuous level [13].

3.2 Power supply and reference

A 9V battery and a controller were used in the circuit. The controller is essential in instances of little motions in the information voltage. It prompts a 5V yield voltage. In our work, the voltage controller 7805 chip (Figure 7) was used. It is then associated (pin3) to a splitter 7905 that drives (0.5*5)V to a virtual ground and maintains a strategic distance from unequal states [2,20,21] as showed in Figure 7. Finally, the oscilloscope displays analog output.

IV. Validation of EEG Recording Accuracy

The EEG signals recorded by the proposed circuit have been contrasted with chronicles made by the advertised biomedical instrumentation unit SIP 385-1.

4.1 Processing part

By testing each deficiency, there is less Beta movement [22, 23]. In our work, we set up a Beta action voltage edge with the goal that, when the EEG Beta adequacy progresses becomes lower than the edge, an associated straightforward amusement is delayed by the framework. The general handling framework, which can be observed in Figure 8, is made out of: good quality yield flag issued from the beforehand itemized EEG Circuit, Arduino chip, workstation and an advanced diversion. A programming stage has been accomplished using Arduino IDE coding/library and MATLAB. [2]

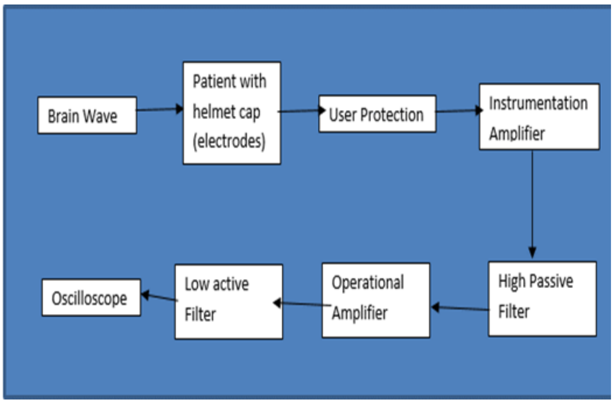

Fig. 7. Activity Block Diagram

A/D convertor

In the wake of planning the securing circuit, there is a requirement for an A/D convertor, keeping in mind the end goal to change over the simple yield flag issued from our outlined circuit into an advanced frame that can be exchanged with the preparing unit. An Arduino processor module has been utilized for that reason.[23]

3.3 Arduino Microprocessor

Arduino is a low-cost open source physical computing platform based on a simple input/output (I/O) board and a development environment that implements the processing language. Arduino can be used to develop stand-alone interactive objects as well as to convert measured data from analog to digital and send it to a PC using (com 3). It reads the value from the specified analog pin and converts it with a 10-bit analog to digital converter and resolution up to 4.9 mV per unit (Figure 8). It takes about 0.0001s to read an analog input. This yields maximum reading rate of about 9600 times per second. It is a pertinent choice to acquire accurate EEG signal according to the Shannon Theorem. The Arduino chip reads the analog input on pin 0 and prints the result to the serial monitor. The chip pin A0 is connected to the center pin of a potentiometer and the outside pins to +5V and ground. In the presented work, the Arduino chip has been programmed with the help of a PC via a USB cable. The open-source Arduino Software (IDE) with its rich library enables the writing of the code and uploads it to the board. MATLAB software has also been operated in order to visualize and to perform further analysis of digital recorded signals. [22]

3.4 Determination of the threshold

Keeping in mind the end goal, that is, to determine the threshold we have compared between the patient and control group on the basis of EEG data amplitudes and spectra, the first thing to do is use the Fourier Transform to change information from time space to recurrence area.

The acquired spectra are then separated into EEG groups. Thereafter, just sifted EEG spectra divides identified with the range 12-18 Hz are contemplated in light of the fact that normal volunteer waves have a tendency to be higher than ADHD cerebrum waves in SMR and beta groups, and in order to cancel artifact

The trigger is consequently initiated when the relative power esteem diminishes beneath a particular limit. The edge esteem has been tentatively concentrated with a specific end goal to be embedded in the programming code considering the normal and standard deviation of intensity region esteems to be higher than ADHD brain waves in SMR and beta bands, and in order to cancel the artifact.

The spectral power curve has been subsequently calculated through the squared Fourier Transform magnitude over a real-time moving window. The window length can be changed in the code according to the user. Finally, the area under the spectral power curve of Beta band was calculated via integration. Relative Power of Beta band (Beta power/ overall signal power) was used as the trigger to switch off a connected game.

3.5 *Validation of spectral analysis accuracy*

With the expectation of verifying the Arduino results, the EEG spectral power values resulted from the Arduino processor has been contrasted with values computed by MATLAB flag *processing toolbox*. [22]

3.6 *Connecting a video game with Arduino*

To finish the Feedback framework, a minimal effort handheld computer game comfort, with direct CPU execution and determination, has been connected to the Arduino chip by means of a transfer segment. In the recommended circuit and programming codes, if the EEG information adequacy achieves the limit or less at the frequencies 12-15 Hz or 15-18 Hz respectively, the amusement will quit working until the patient builds his/her concentration capacity to achieve the best pinnacle of a neuro-average tyke. Only after this is achieved, does the game restart. [13]

3.7 *Proteus Simulations*

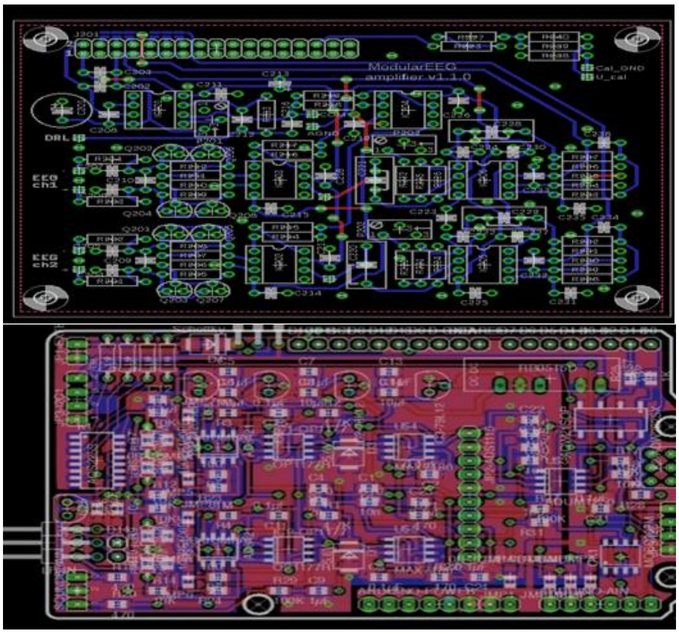

Fig. 8. Main PCB Circuital Diagram

V. ARCHITECTURAL DIAGRAM/STRUCTURE

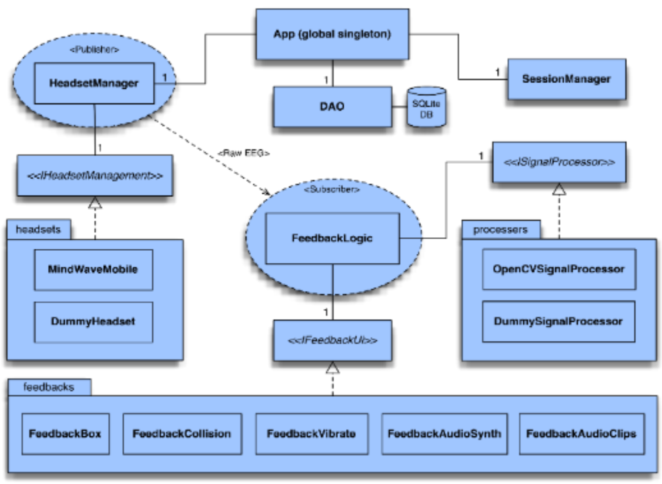

Fig. 9. Architectural Diagram

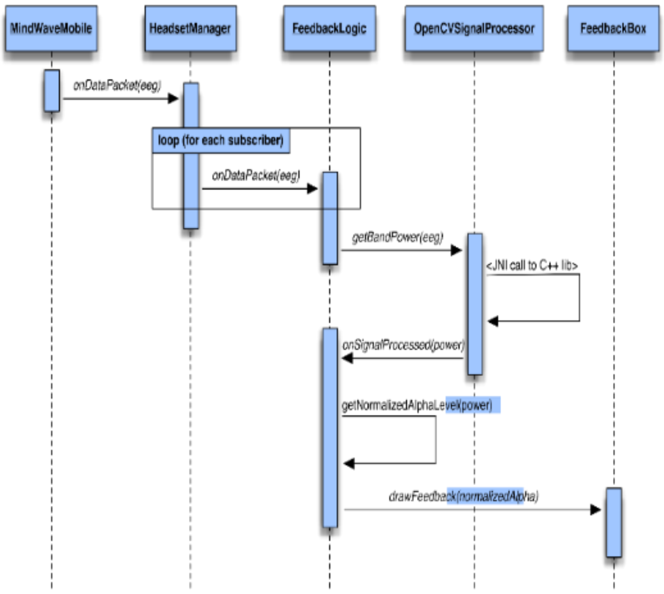

Fig. 10. Sequence Diagram

VI. MOTIVATION

Reduced attention span increased motor activity and specific learning disabilities affect school age children with ADHD, as well adults at work. The resulting poor performance, frequent getting up and other motor over activity ('fidgeting', 'gossiping', etc.) can jeopardize the educational and social progress of children and adolescents despite their above-average intelligence. The treatment chosen is often drug medication, but biofeedback is an alternative form of treatment with a sustained therapeutic effect that goes beyond even those of pharmacotherapy.

Often, the so-called *frequency band training* is used in the treatment of Insomnia, Anxiety, ADHD and other brain-disorders. In short, different frequency bands are active in the brain, which in turns are each associated with different states. Thus, high alpha band activity indicates a mild relaxed state, while beta waves are associated with attention and concentration. [21]

Advantages

1. The sensors used have a high sensitivity and are easy to handle.
2. Low cost system providing maximum functionalities.
3. The user has real-time knowledge of what is happening in some state, thereby having the option of manual override.
4. Low maintenance and low power consumption.
5. The system is more compact compared to the existing ones, hence it is easily portable.
6. Can be easily modified to improve the setup and add new features.
7. Time saving.
8. Provides a user-friendly interface, hence it will have a greater acceptance rate by the technologically unskilled users.
9. Feedback for every command is given by the system.
10. Malfunctioning of a single sensor will not affect the whole system. [5]

Disadvantages

1. No self-test system to detect malfunction of sensors.
2. Requires uninterrupted power supply.
3. Limited Range.
4. The system doesn’t have decision making capacity.[5]

CONCLUSION

The aim of the report is now to change the ratio of the different EEG frequency bands to one another in order to achieve a relaxed but concentrated state. For example, if this succeeds, the energy content of the beta band is increased which should promote increased attention and is reduced in the so-called theta band, which should reduce distractibility. By using user-friendly feedback types, the motivation for therapy is aroused and maintained among the young ADHD clients. So while the children practice their skills with fun in body-controlled PC games, the therapist records the values and accompanies the therapy. Other biofeedback modalities such as skin conductance training or EMG training can be supportive in future. [21]

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