Study of Stimulation Effects on Different Bands of EEG Signal

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This thesis report is submitted to the Department of Biomedical Engineering (BME), Khulna University of Engineering & Technology (KUET), Khulna-9203, for the partial fulfillment of the requirement for the degree of Masters of Science in Biomedical Engineering.

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DECLARATION

This is to certify that the thesis work entitled "**Study of Stimulation Effects on Different Bands of EEG Signal"** has been supervised by Prof. Dr. Mohiuddin Ahmad, Professor of the Department of *Electrical and Electronic Engineering (EEE)*, Khulna University of Engineering & Technology (KUET), Khulna-9203, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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This thesis paper is dedicated to my

beloved Parents

& honorable Supervisor

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ABSTRACT

Brain–computer interfaces (BCIs) are the communication bridge between the human brain and a computer which may be implemented on the basis of steady-state evoked potentials (SSEPs). A brain–computer interface is a direct communication pathway between the brain and an external device. BCIs are often directed at assisting, augmenting, or repairing human cognitive or sensory-motor functions. The field of BCI research and development has since focused primarily on neuroprosthetics applications that aim at restoring damaged hearing, sight and movement. The objectives of the research is to check the different stimulation effects of human brain, to improve the accuracy, higher information transfer rate (ITR), desired bandwidth (BW), and signal to noise ratio (SNR) of BCIs and to identify Power and Energy of different Stimulation Effects on Alpha and Beta bands of EEG signal. In this research the power and energy of Alpha and Beta bands of EEG signal for different stimulation were determined and signal analysis, signal processing, Fast Fourier Transform (FFT), Statistical parameter methods were used. The performance of stimulator depends on many factors such as size and shape of stimulator, frequency of stimulation, luminance, color, and subject attention. Information Transfer Rate (ITR) varies with the change of frequency and size of the visual stimuli. In this research, a circular repetitive visual stimulator (CRVS) of different diameter (2", 2.5"and 3"), color (RGB), frequency (10, 15 and 20 Hz) was used. When the size of the stimulator changes from 2" to 2.5" a greater increase of Alpha wave (58.18%) is observed than Beta wave (13.68%). But a further increase in size from 2" to 2.5" a greater decrease of Alpha wave (45%) is observed than Beta wave (36.59%).

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ABBREVIATIONS

BCI	Brain Computer Interface
BMI	Brain Machine Interface
BW	Bandwidth
CAR	Common Average Referencing
CT	Computed Tomography
CRVS	Circular Repetitive Visual Stimulator
dB	Decibel
DNI	Direct Neural Interface
EBS	Electrical Brain Stimulation
ECG	Electrocardiography
EEG	Electroencephalogram
ECoG	Electrocorticography
EROS	Event-related Optical Signal
ERPs	Event Related Potentials
EP	Evoked Potentials
FBS	Focal Brain Stimulation
FFT	Fast Fourier Transform
FIRDA	Frontal Intermittent Rhythmic Delta and Aposteriorly
fMRI	Functional Magnetic Resonance Imaging
Hz	Hertz
I-EEG	Intracranial Electroencephalogram
ITR	Information Transfer Rate
MEG	Magnetoencephalogram
MRI	Magnetic Resonance Imaging
MMI	Mind Machine Interface
NIRS	Near-infrared Spectroscopy
OIRD	Occipital Intermittent Rhythmic Delta
PET	Positron Emission Tomography
SD-EEG	Subdural Electroencephalogram
SP	Signal Processing
SSVEP	Steady State Visual Evoked Potential
SPECT	Single Photon Emission Computed Tomography
SNR	Signal to Noise Ratio
μ V	Microvolt's

LIST OF SYMBOLS

α	Alpha
β	Beta
δ	Delta
λ	Lamda
θ	Theta
π	Pi
η	Eta
μ	Mu

Chapter 1

Introduction

Chapter Outlines :

1.1. Introduction:

Electroencephalography (EEG) is a non-invasive method to record electrical activity of the brain along the scalp. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time, as recorded from multiple electrodes placed on the scalp [1].

Diagnostic applications generally focus on the spectral content of EEG, that is, the type of neural oscillations that can be observed in EEG signals. EEG is most often used to diagnose epilepsy, which causes abnormalities in EEG readings. It is also used to diagnose sleep disorders, coma, encephalopathies and brain death [1]-[2].

EEG used to be a first-line method of diagnosis for tumors, stroke and other focal brain disorders, but this use has decreased with the advent of high-resolution anatomical imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT). Despite limited spatial resolution, EEG continues to be a valuable tool for research and diagnosis, especially when millisecond-range temporal resolution (not possible with CT or MRI) is required [3]. The typical EEG signal and its various bands are shown in Fig 1.1.

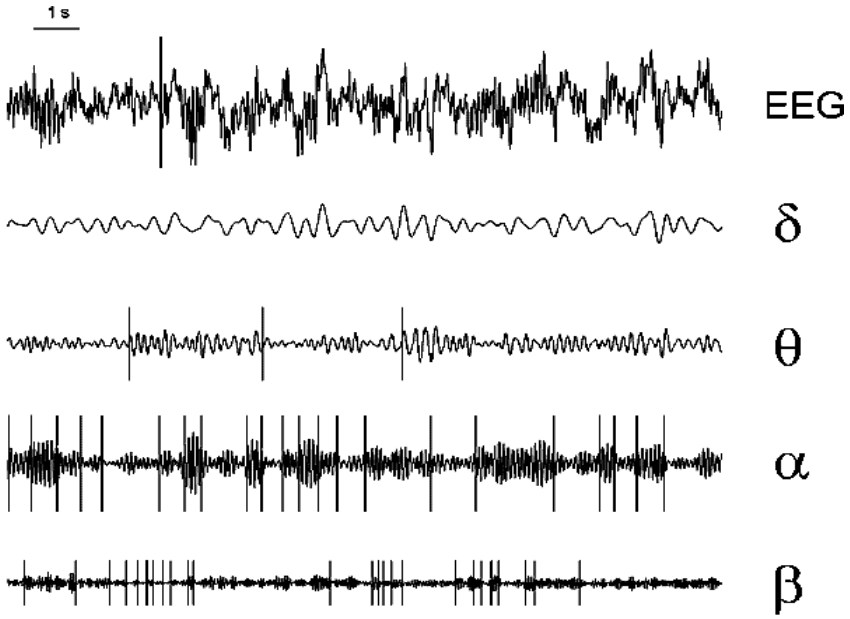


Fig 1.1.Typical EEG signal and its various bands.

Derivatives of the EEG technique include evoked potentials (EP), which involves averaging the EEG activity time-locked to the presentation of a stimulus of some sort (visual,

somatosensory, or auditory). Event-related potentials (ERPs) refer to averaged EEG responses that are time-locked to more complex processing of stimuli; this technique is used in cognitive science, cognitive psychology and psychophysiological research [3]-[4].

1.1.1. Origin of EEG Signal:

During more than 100 years of its history, encephalography has undergone massive progress. The existence of electrical currents in the brain was discovered in 1875 by an English physician Richard Caton [4]. Caton observed the EEG from the exposed brains of rabbits and monkeys. In 1890, Polish physiologist Adolf Beck published an investigation of spontaneous electrical activity of the brain of rabbits and dogs that included rhythmic oscillations altered by light. Beck started experiments on the electrical brain activity of animals. Beck placed electrodes directly on the surface of brain to test for sensory stimulation [5]. His observation of fluctuating brain activity lead to the conclusion of brain waves. In 1912, Russian physiologist Vladimir Pravdich-Neminsky published the first animal EEG and the evoked potential of Electroencephalography [6]. Napoleon Cybulski and Jelenska-Macieszyna photographed EEG recordings of experimentally induced seizures. In 1924 Hans Berger, a Germ an neurologist, used his ordinary radio equipment to amplify the brain's electrical activity measured on the human scalp. He announced that weak electric currents generated in the brain can be recorded without opening the skull, and depicted graphically on a strip of paper. The activity that he observed changed according to the functional status of the brain, such as in sleep, anesthesia, and lack of oxygen and in certain neural diseases, such as in epilepsy. Berger laid the foundations for many of the present applications of electroencephalography. Richard Caton also used the word electroencephalogram as the first for describing brain electric potentials in humans. He was right with his suggestion that brain activity changes in a consistent and recognizable way when the general status of the subject changes, as from relaxation to alertness. Later in 1934 Adrian and Matthews published the paper verifying concept of “Human Brain Waves” and identified regular oscillations around 10 to 12 Hz which they termed “Alpha Rhythm” [6].

1.1.2. Medical and Research Applications of EEG:

The greatest advantage of EEG is speed. Complex patterns of neural activity can be recorded occurring within fractions of a second after a stimulus has been administered. EEG provides less spatial resolution compared to MRI and PET. Thus for better allocation within the

brain, EEG images are often combined with MRI scans. EEG can determine the relative strengths and positions of electrical activity in different brain regions [5]-[6]. According to R. Bickford research and clinical applications of the EEG in humans and animals are used to [7]:

- Monitor alertness, comma and brain death;
- Locate areas of damage following head injury, stroke, tumor, etc.;
- Test afferent pathway's (by evoked potentials);
- Monitor cognitive engagement (alpha rhythm);
- Produce biofeedback situations, alpha, etc.;
- Control anesthesia depth ("servo anesthesia");
- Investigate epilepsy and locate seizure origin;
- Test epilepsy drug effects;
- Assist in experimental cortical excision of epileptic focus;
- Monitor human and animal brain development;
- Test drugs for convulsive effects;
- Investigate sleep disorder and physiology.
- EEG and the related study of ERPs are used extensively in neuroscience, cognitive science, cognitive psychology, neurolinguistics and psychophysiological research. Many EEG techniques used in research are not standardized sufficiently for clinical use [7].

Symmetry of alpha activity within hemispheres can be monitored. In cases of restricted lesions such as tumor, hemorrhage, and thrombosis, it is usual for the cortex to generate lower frequencies. EEG signal distortion can be manifested by reduction in amplitude; decrease of dominant frequencies beyond the normal limit; production of spikes or special patterns. Epileptic conditions produce stimulation of the cortex and the appearance of high-voltage waves (up to1000 μV) referred to as "spikes" or "spike and wave". EEG patterns have been shown to be modified by a wide range of variables, including biochemical, metabolic, circulatory, hormonal, neuroelectric, and behavioral factors. As the EEG procedure is non-invasive and painless, it is being widely used to study the brain organization of cognitive processes such as perception, memory, attention, language, and emotion in normal adults and children. For this purpose, the most useful application of EEG recording is the ERP (event related potential) technique [8].

1.1.3. Information from EEG:

To study brain function exist, several methods including functional magnetic resonance imaging (fMRI), positron emission tomography, magnetoencephalography (MEG), nuclear magnetic resonance spectroscopy, electrocorticography, single-photon emission computed tomography, near-infrared spectroscopy (NIRS), and event-related optical signal (EROS). Despite the relatively poor spatial sensitivity of EEG, it possesses multiple advantages over some of these techniques [9].

Hardware costs are significantly lower than those of most other techniques. EEG prevents limited availability of technologists to provide immediate care in high traffic hospitals. EEG sensors can be used in more places than fMRI, SPECT, PET, MRS, or MEG, as these techniques require bulky and immobile equipment. For example, MEG requires equipment consisting of liquid helium-cooled detectors that can be used only in magnetically shielded rooms, altogether costing upwards of several million dollars; and functional magnetic resonance imaging (fMRI) requires the use of a 1-ton magnet in, again, a shielded room [8].

EEG has very high temporal resolution, on the order of milliseconds rather than seconds. EEG is commonly recorded at sampling rates between 250 and 2000 Hz in clinical and research settings, but modern EEG data collection systems are capable of recording at sampling rates above 20,000 Hz if desired. MEG and EROS are the only other noninvasive cognitive neuroscience techniques that acquire data at this level of temporal resolution [9]. EEG is relatively tolerant of subject movement, unlike most other neuroimaging techniques. There even exist methods for minimizing, and even eliminating movement artifacts in EEG data EEG is silent, which allows for better study of the responses to auditory stimuli. EEGdoes not aggravate claustrophobia, unlike functional magnetic resonance imaging (fMRI), PET, MRS, SPECT, and sometimes MEG [10].

EEG does not involve exposure to high-intensity (>1 Tesla) magnetic fields, as in some of the other techniques, especially MRI and MRS [11]. These can cause a variety of undesirable issues with the data, and also prohibit use of these techniques with participants that have metal implants in their body, such as metal-containing pacemakers.EEG does not involve exposure to radio ligands, unlike positron emission tomography. ERP studies can be conducted with relatively simple paradigms, compared with IE block-design fMRI studies

extremely non-invasive, unlike electrocorticography, which actually requires electrodes to be placed on the surface of the brain [12].

1.1.4. Method of EEG:

In conventional scalp EEG, the recording is obtained by placing electrodes on the scalp with a conductive gel or paste, usually after preparing the scalp area by light abrasion to reduce impedance due to dead skin cells. Many systems typically use electrodes, each of which is attached to an individual wire [13]. Some systems use caps or nets into which electrodes are embedded; this is particularly common when high-density arrays of electrodes are needed. Electrode locations and names are specified by the International 10–20 system for most clinical and research applications (except when high-density arrays are used).This system ensures that the naming of electrodes is consistent across laboratories [15]. In most clinical applications, 19 recording electrodes (plus ground and system reference) are used. A smaller number of electrodes are typically used when recording EEG from neonates. Additional electrodes can be added to the standard set-up when a clinical or research application demands increased spatial resolution for a particular area of the brain. High-density arrays (typically via cap or net) can contain up to 256 electrodes more-or-less evenly spaced around the scalp. Each electrode is connected to one input of a differential amplifier (one amplifier per pair of electrodes); a common system reference electrode is connected to the other input of each differential amplifier. These amplifiers amplify the voltage between the active electrode and the reference (typically 1,000–100,000 times, or 60–100 db of voltage gain) [15].

In analog EEG, the signal is then filtered (next paragraph), and the EEG signal is output as the deflection of pens as paper passes underneath. Most EEG systems these days, however, are digital, and the amplified signal is digitized via an analog-to-digital converter, after being passed through an anti-aliasing filter. Analog-to-digital sampling typically occurs at 256–512 Hz in clinical scalp EEG; sampling rates of up to 20 kHz are used in some research applications. During the recording, a series of activation procedures may be used. These procedures may induce normal or abnormal. EEG activity that might not otherwise be seen. These procedures include hyperventilation, photic stimulation (with a strobe light), eye closure, mental activity, sleep and sleep deprivation. During (in patient) epilepsy monitoring, a patient's typical seizure medications may be withdrawn [16].

The digital EEG signal is stored electronically and can be filtered for display. Typical settings for the high-pass filter and a low-pass filter are 0.5-1 Hz and 35–70 Hz, respectively. The high-pass filter typically filters out slow artifact, such as electro galvanic signals and movement artifact, whereas the low-pass filter filters out high-frequency artifacts, such as electromyographic signals. An additional notch filter is typically used to remove artifact caused by electrical power lines (60 Hz in the United States and 50 Hz in many other countries) [17].

As part of an evaluation for epilepsy surgery, it may be necessary to insert electrodes near the surface of the brain, under the surface of the dura mater [16]. This is accomplished via burr hole or craniotomy. This is referred to variously as "electrocorticography (ECoG)", "intracranial EEG (I-EEG)" or "subdural EEG (SD-EEG)". Depth electrodes may also be placed into brain structures, such as the amygdala or hippocampus, structures, which are common epileptic foci and may not be "seen" clearly by scalp EEG. The electrocorticographic signal is processed in the same manner as digital scalp EEG (above), with a couple of caveats. ECoG is typically recorded at higher sampling rates than scalp EEG because of the requirements of Nyquist theorem—the subdural signal is composed of a higher predominance of higher frequency components. Also, many of the artifacts that affect scalp EEG do not impact ECoG, and there for display filtering is often not needed. A typical adult human EEG signal is about 10 μV to 100 μV in amplitude when measured from the scalp [18] and is about 10–20 mV when measured from subdural electrodes. Since an EEG voltage signal represents a difference between the voltages at two electrodes, the display of the EEG for the reading encephalographer may be set up in one of several ways. The representation of the EEG channels is referred to as a montage [19].

1.1.5. Limitations of EEG:

EEG has several limitations. Most important is its poor spatial resolution. EEG is the most sensitive to a particular set of post-synaptic potentials, those generated in superficial layers of the cortex, on the crests of gyridirectly abutting the skull and radial to the skull. Dendrites, which are deeper in the cortex, inside sulci, in midline or deep structures (such as the cingulate gyrus or hippocampus), or producing currents that are tangential to the skull, have far less contribution to the EEG signal. EEG recordings do not directly capture axonal action potentials.

An action potential can be accurately represented as a current quadrupole, meaning that the resulting field decreases more rapidly than the ones produced by the current dipole of post-synaptic potentials. In addition, since EEGs represent averages of thousands of neurons, a large population of cells in synchronous activity is necessary to cause a significant deflection on the recordings [20]. Action potentials are very fast and, as a consequence, the chances of field summation are slim. However, neural back propagation, as a typically longer dendritic current dipole, can be picked up by EEG electrodes and is a reliable indication of the occurrence of neural output. Not only do EEGs capture dendritic currents almost exclusively as opposed to axonal currents, they also show a preference for activity on populations of parallel dendrites and transmitting current in the same direction at the same time. Pyramidal neurons of cortical layers II/III and V extend apical dendrites to layer I. Currents moving up or down, these processes underlie most of the signals produced by electroencephalography. Therefore, EEG provides information with a large bias to select neuron types, and generally should not be used to make claims about global brain activity. The meninges, cerebrospinal fluid and skull "smear" the EEG signal, obscuring its intracranial source [21].

It is mathematically impossible to reconstruct a unique intracranial current source for a given EEG signal, as some currents produce potentials that cancel each other out. This is referred to as the inverse problem. However, much work has been done to produce remarkably good estimates of, at least, a localized electric dipole that represents the recorded currents [22].

1.1.6. Different Wave patterns of EGG:

Delta is the frequency range up to 4 Hz. It tends to be the highest in amplitude and the slowest waves. It is seen normally in adults in slow wave sleep. It is also seen normally in babies. It may occur focally with subcortical lesions and in general distribution with diffuse lesions, metabolic encephalopathy hydrocephalus or deep midline lesions. It is usually most prominent frontally in adults (e.g. FIRDA - Frontal Intermittent Rhythmic Delta) and posteriorly in children (e.g. OIRDA - Occipital Intermittent Rhythmic Delta).

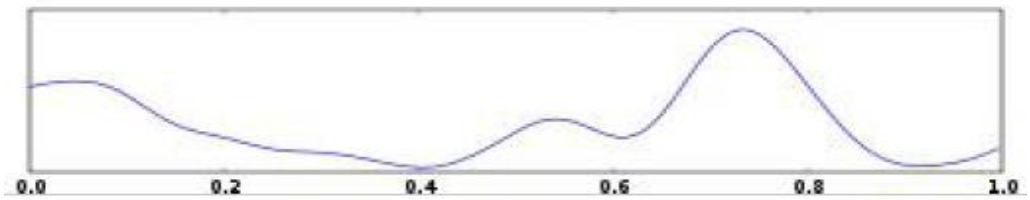


Fig 1.2: Delta Waves.

Theta is the frequency range from 4 Hz to 7 Hz. Theta is seen normally in young children. It may be seen in drowsiness or arousal in older children and adults; it can also be seen in meditation. Excess theta for age represents abnormal activity. It can be seen as a focal disturbance in focal subcortical lesions; it can be seen in generalized distribution in diffuse disorder or metabolic encephalopathy or deep midline disorders or some instances of hydrocephalus. On the contrary, this range has been associated with reports of relaxed, meditative, and creative states.

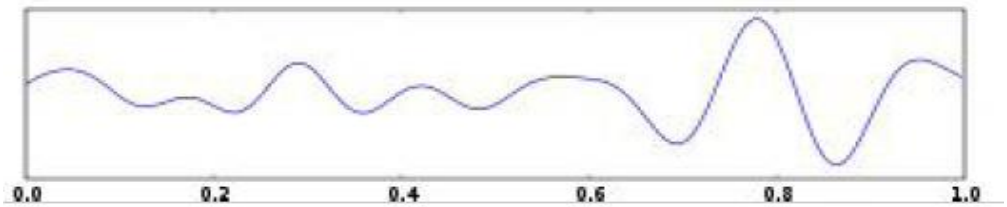


Fig 1.3: Theta Waves.

Alpha is the frequency range from 7 Hz to 14 Hz. Hans Berger named the first rhythmic EEG activity he saw as the "alpha wave". This was the "posterior basic rhythm" (also called the "posterior dominant rhythm" or the "posterior alpha rhythm"), seen in the posterior regions of the head on both sides, higher in amplitude on the dominant side. It emerges with closing of the eyes and with relaxation, and attenuates with eye opening or mental exertion. The posterior basic rhythm is actually slower than 8 Hz in young children (therefore technically in the theta range). In addition to the posterior basic rhythm, there are other normal alpha rhythms such as the mu rhythm (alpha activity in the contralateral sensory and motor cortical areas) that emerges when the hands and arms are idle; and the "third rhythm" (alpha activity in the temporal or frontal lobes). Alpha can be abnormal; for example, an EEG that has diffuse alpha occurring in coma and is not responsive to external stimuli is referred to as "alpha coma".

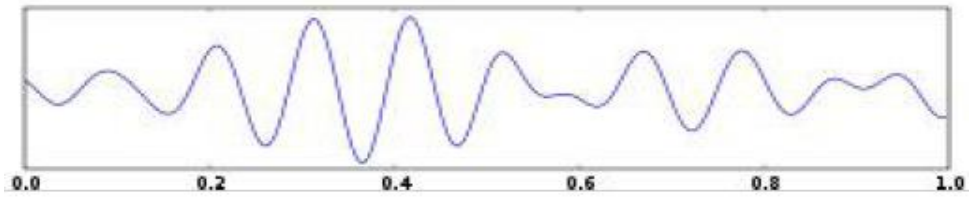


Fig 1.4: Alpha Waves.

Beta has the frequency range from 15 Hz to about 30 Hz. It is seen usually on both sides in symmetrical distribution and is most evident frontally. Beta activity is closely linked to motor behavior and is generally attenuated during active movements. Low amplitude beta with multiple and varying frequencies is often associated with active, busy or anxious thinking and active concentration. Rhythmic beta with a dominant set of frequencies is associated with various pathologies and drug effects, especially benzodiazepines. It may be absent or reduced in areas of cortical damage. It is the dominant rhythm in patients who are alert or anxious or who have their eyes open.

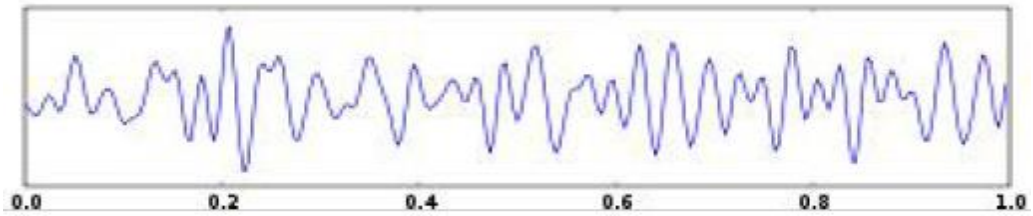


Fig 1.5: Beta Waves.

Gamma has the frequency range approximately 30–100 Hz. Gamma rhythms are thought to represent binding of different populations of neurons together into a network for the purpose of carrying out a certain cognitive or motor function.

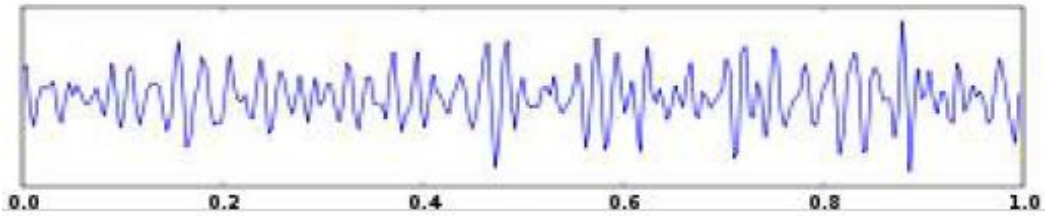


Fig 1.6: Gamma Waves.

1.2. Theoretical Background of EEG Signal:

Establishing a new communication of human behavior to interact with the outside world through their brain waves has become an active research area in the physiological signal analysis field. The human brain is the part of the body that regulates almost all of the human behavioral activity. The brain's electrical charge is maintained by billions of neurons. Neurons are electrically charged (or "polarized") by membrane transport proteins that pump ions across their membranes.

Neurons are constantly exchanging ions with the extracellular milieu, for example to maintain resting potential and to propagate action potentials. Ions of similar charge repel each other, and when many ions are pushed out of many neurons at the same time, they can push their neighbors, who push their neighbors, and so on, in a wave. This process is known as volume conduction.

When the wave of ions reaches the electrodes on the scalp, they can push or pull electrons on the metal on the electrodes. Since metal conducts the push and pull of electrons easily, the difference in push or pull voltages between any two electrodes can be measured by a voltmeter. Recording these voltages over time gives us the EEG. The electric potential generated by an individual neuron is far too small to be picked up by EEG or MEG. EEG activity therefore always reflects the summation of the synchronous activity of thousands or millions of neurons that have similar spatial orientation. If the cells do not have similar spatial orientation, their ions do not line up and create waves to be detected. Pyramidal neurons of the cortex are thought to produce the most EEG signal because they are well-aligned and fire together. Because voltage fields fall off with the square of distance, activity from deep sources is more difficult to detect than currents near the skull. Scalp EEG activity shows oscillations at a variety of frequencies. Several of these oscillations have characteristic frequency ranges, spatial distributions and are associated with different states of brain functioning (e.g., waking and the various sleep stages). These oscillations represent synchronized activity over a network of neurons. The neuronal networks underlying some of these oscillations are understood (e.g., the thalamocortical resonance underlying sleep spindles), while many others are not (e.g., the system that generates the posterior basic rhythm). Research that measures both EEG and neuron spiking finds the relationship between the two is complex, with a combination of EEG power in the gamma band and phase in the delta band relating most strongly to neuron spike activity.

1.3. Mathematical Representation of EEG Signal:

Many devices are used to process various kinds of biomedical signals, such as EEG, electromyogram (EMG), electroneurogram (ENG), electroretinogram (ERG), electrooculography (EOG), and electrocardiogram (ECG) to diagnose diseases [27]. These devices use the nervous system, which consists of a large number of excitable connected cells called neurons that rapidly and specifically communicate with different parts of the body

through electrical signals. The nervous system consists of three main parts: the brain, the spinal cord and peripheral nerves. It functions to control the body and communicates through electric signals [28]. The brain signals are acquired using electrodes mounted directly on the scalp. The combination of these signals is illustrated in Equation (1):

$$X(t) = [X_1(t), X_2(t), \dots, X_m(t)]^T \quad (1)$$

Where X(t) is the recorded EEG signal, "t" denotes transposition and "m" is the number of channels. The rows of the input matrix are EEG signals recorded at different electrodes, whereas the columns represent the variations in the signals at different time points. Before the EEG signal is displayed or stored, it can be processed to eliminate low-frequency or high-frequency noise and other possible artifacts. The user is frequently interested in the amplitude of the signal; hence, critical points in its processing need careful treatment to reduce artifacts that contaminate signals, which can lead to wrong results and conclusions. Equation (2) shows a model that represents the recorded mixed EEG signal X(t) with time, varying source signal s(t), and mixing matrix A added to the external noise n(t).Considering only the X(t) is available, several assumptions are needed to estimate the matrix "A" and the signal s(t):

$$X(t) = As_m(t) + n_m(t) \quad (2)$$

1.4. Factors affecting SSVEP based BCI:

There are many factors which affect the performance of SSVEP based BCI. Among these factors stimulation type, frequency, color, SNR of SSVEP signals have all an effect on the SSVEP response they elicit.

1.4.1. Stimulation Type:

Literatures of SSVEP based BCI generally covers the stimulation type using light, single graphic, or pattern reversal stimuli. The SSVEP response to these three types of stimuli is different. Pattern reversal stimuli can produce a more pronounced SSVEP than single graphic stimuli modulated at the same frequency [14]. In [15] light and single graphic stimuli were generate at 4.6, 10.8, and 16.1 Hz. It was found that the SSVEP response elicited by an LED was larger than that by a rectangle stimulus on a computer screen. Also it was stated that the SSVEP response for light stimuli was larger than that for pattern reversal in [13]. This might explain

why we found that the bit rates of BCIs using LED stimuli appearto be higher compared to those of BCIs using computer screens. For each of these results, most variables were fixed (e.g., luminance, contrast, and color). At present, no general conclusions can be drawn because many conditions have not been tested and variables can interact with each other. For instance, the power of the SSVEP response is affected by both frequency and color of the stimuli [16].

From the vantage point of implementation, it is in general easier to build a BCI that employs a computer screen as it mainly relies on software development and no hardware modification is necessary. Furthermore, BCI designers are completely free in their choice of development platform for the implementation of this software. In [18]many papers are reviewed which uses cube, rectangle, arrow shaped stimulation pattern and their performances have been shown in tabular form. There are many differences in those performance indicating that shape is also a vital factor for affecting the performance of SSVEP based BCI.

1.4.2. Stimulation Frequency:

As mentioned in Section 1.4.1, the stimulus frequencies used in SSVEP research can be classified into three frequency bands, that is, low (1–12 Hz), medium (12–30 Hz) and high (30–60 Hz). The largest SSVEP amplitudes were observed near 10Hz followed by 16–18 Hz and the high frequency subsystem showed the smallest response[1]. SSVEP based BCI used the medium and low frequency band although their frequency varied ominously. However, these two frequency bands, have some disadvantages. First, subjective assessments showed that frequencies between 5 and 25Hz are more irritating than higher ones; visual fatigue would easily occur. Second, flash and pattern reversal stimuli can provoke epileptic seizures especially in the 15–25 Hz range [28]. Third, the low frequency band covers the alpha band (8–13 Hz) which can cause a considerable amount of false positives. All of these disadvantages can be avoided by using the high frequency band [18].

1.4.3. Stimulation Color:

Color is a important aspect of human perception and could be natural for human to be used in BCI control. Some researchers have studied the impact of different colors on brain activity. Increased beta and decreased alpha power were observed when human were exposed to red and blue light than dark [8]. The comparison between red and blue color stimulus was made in [9][10] in which powers of theta, alpha and beta brainwave were reported to be larger for red

than blue stimulus. The above work was focused on offline analysis to identify the differences between different color stimuli in a statistical way. As the powers of different brainwave frequencies responding to color stimulus can be analyzed to identify potential BCI control signals, we need to pay attention to the effect of color on these BCIs.

It was reported in [16] that red, yellow, and blue light stimuli have different effects on the SSVEP in combination with the used frequency. Red light elicited the strongest response when modulated at 11 Hz, but SSVEP strength went downhill fast for surrounding frequencies. Blue light stimuli elicited a slightly weaker strongest response around 13 Hz, but were less sensitive to the used frequency. The SSVEP strength elicited by yellow light was lower and less dependent on the used frequency [18]. Another study that focused on stimulus color showed that the second and fourth harmonic of the SSVEP are affected differently by chromatic and achromatic checkerboard stimuli [17]. At present, green, red, gray, black, and white stimuli have been used for SSVEP-based BCIs. It is difficult to decide which color is the best, because at present there is no comparison that shows how color influences the performance of SSVEP-based BCIs. A good solution for practical applications could be to use stimuli whose colors can be dynamically adjusted in order to take circumstances or the user's characteristics into account. So in this research I have used different colors for analyzing their effect on SSVEP.

1.5. Problem Statement:

This research will mainly focused on the study of different Stimulation Effects on Alpha and Beta bands of EEG signal experiments in the field of biomedical engineering, integrating modern techniques and information. The goals of the research is to check the effect of different stimulation effects of human brain, to improve the accuracy, higher information transfer rate (ITR), desired bandwidth (BW) and signal to noise ratio (SNR) of BCIs and to identify Power and Energy of different Stimulation Effects on Alpha and Beta bands of EEG signal.

The specific objectives of the proposed research work are summarized as follows:

(i) To check the effect of different stimulation effects of human brain.

(ii) To identify Power and Energy of different Stimulation Effects on Alpha and Beta bands of EEG signal. To check the SNR, MES of the proposed research.

(iii) To choose perfect stimuli which may outfit the performance of SSVEP based BCIs and safety of BCIs.

1.6. Scope of the Research:

The scope of the research is given bellow.

1. This research will help to detect different stimulation effects of human brain which is helpful for medical diagnosis.
2. This research will help to choose perfect stimuli which may outfit the performance of SSVEP based BCIs and safety of BCIs. Perfections of stimuli can enhance the SSVEP Signal to Noise Ratio (SNR), reduce the complexity of extracted signal processing, increase the targets detection, help subjects to pay attention and allow independent BCI operation.
3. This research will help to design the software for investigating for the effect of frequency, color and different size of circular stimulator on the performance (power, energy and ITR).

1.7. Structure of this Thesis:

The research work presented in this thesis is organized in five chapters. These five chapters are structured as follows:

Chapter 1 is entitled "Introduction". This chapter describes the background of EEG signals analysis, overview of our proposed work & the implementation of our research. It also includes aim of this thesis.

Chapter 2 is entitled "Literature Review". It introduces critical points of other related researches and comparing with our proposed work.

Chapter 3 is entitled "Methodology". This chapter describes the EEG signal recording techniques, proposed Block Diagrams, proper subject selection, signal extraction using desired condition, signal analysis method for feature extraction.

Chapter 4 is entitled "Results and Discussion". This chapter describes the acquisition unit, design stimulator, subject condition and signal extraction, graphical analysis and tabular analysis based on the extracted features from the analysis of these data.

Chapter 5 is entitled "Conclusion and Future Research".

Chapter 2

Literature review

Chapter Outlines :

2.1. Related works

2.2. Comparative Discussion

2.1. Related works :

In accordance with the concept of modern biomedical engineering, brain–computer interface (BCI) is a direct communication pathway between the brain and an external devices. BCIs are also called mind-machine interface (MMI), or direct neural interface (DNI), synthetic telepathy interface (STI) or brain–machine interface (BMI). BCIs are often directed as assisting, augmenting or repairing human cognitive or sensory-motor functions. A typical BCI system is shown in Fig 2.1.

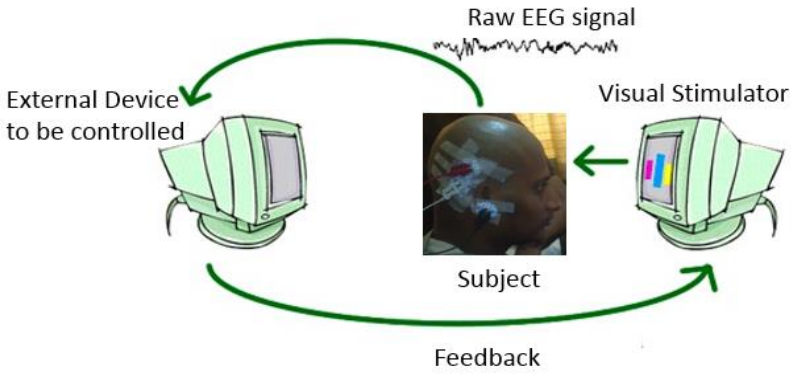


Fig 2.1: BCI system to communicate with external devices.

Various techniques are now available to monitor brain function, e.g., electroencephalography (EEG), magneto-encephalography, functional magnetic resonance imaging, and positron emission tomography. The latter three techniques are technically demanding and expensive. At present, EEG is the optimal choice for BCI implementation [9]-[10]. For the comparing of other system, the VEP-based BCI is considered a dependent BCI because the generation of the VEP depends on the control of eye movements via the output pathways of cranial nerves and extra-ocular muscles. The EEG reflects the electrical activity of the brain, which can be recorded directly from the scalp in non-invasively way using surface electrodes [11]. EEG measures the electrical potentials generated to the excitatory and inhibitory post-synaptic potentials developed by cell bodies and dendrites of pyramidal neurons [12]-[13] as shown in Fig 2.1. EEG signals, as one of the biological signals, are μV range (0.5 to ~ 100μV) at low frequency (0.5 to 30 ~ 40Hz). They are usually referred to as rhythms and are classified into five frequency band [9].

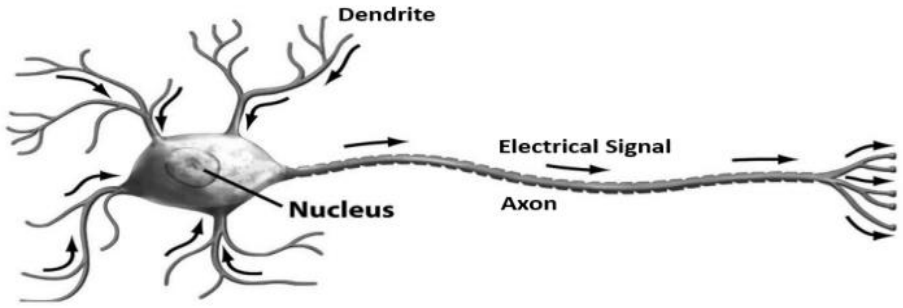


Fig. 2.2: Neuron general structure and generation of electrical signal (EEG Signal) due to external stimulation.

The electrical activity of brain due to visual stimulation is known as the Visual evoked potential (VEP) which may be measured from the scalp of human brain. The frequency of stimulation of steady-state VEP (SSVEP) and VEP is different in magnitude. For VEP approximately 2 Hz for the stimulator is most commonly used whereas about 6Hz stimuli are used for SSVEP which produce a periodic response called SSVEP. In modern BCI system, SSVEP are most commonly used due to its short-term identification, high SNR for data transmission for wireless BCI [14]-[15].

The extracted EEG signal contains 5 frequency bands in which Delta waves lie within the range of 1–4 Hz. These waves are prominent during conditions of deep sleep. Theta waves lie within the range of 4–8 Hz. They appear between the states of consciousness and drowsiness. Theta waves have been associated with creative inspiration and deep meditation. Alpha waves lie within the range of 8–13 Hz. These waves indicate both a relaxed awareness state without any attention. A beta wave is the EEG signal with a frequency range of 13–30 Hz. Beta waves are associated with active thinking, active attention, focus on a particular thing, or during solving concrete problems. High-level beta wave resembles a panic state. The frequencies above 30 Hz (mainly 36-44 Hz) correspond to the gamma range. These low amplitude and rarely found waves are used to detect certain brain diseases. They also indicate event-related synchronization (ERS) of the brain [16]-[17]. The bit rates, comfort and safety of SSVEP based BCI depends on the nature, size, shape, frequency and color of CRVS. The selection of SSVEP for the stimulation of brain, it is advisable to consider these essential elements of SSVEP-based BCIs [19]. Existing papers focus on general VEP-based BCIs [20] and signal processing algorithms applied to BCIs [21].

Table 2.1: Frequency band, Pattern and Amplitude of EEG signal.

Sl. #	Brain waves	Pattern of the wave	Voltage	Frequency range (Hz)	Subject condition
1	Delta (δ)		10 mV	1-4	Profound sleep
2	Theta (θ)		10 µV	4-8	Light sleep
3	Alpha (α)		50 µV	8-13	Relax state
4	Beta (β)		10-20 µV	13-30	Activity or thinking state
5	Gamma (γ)		5-10 µV	36-44	Abnormal condition

2.2. Comparative Discussion:

Steady-state visual evoked potential (SSVEP) is used for Brain-Computer Interface that requires little training for user, offers high information transfer rate and higher accuracy in living environments. To elicit an SSVEP, a Repetitive Visual Stimulus (RVS) of circular shape has been proposed to the subjects in different ways. RVS is rendered on a computer screen by flashing graphical patterns. The properties of SSVEP depend on the rendering device and frequency, size, shape and color of the stimuli. But, literatures on SSVEP-based BCI are seldom provided with reasons for usefulness of rendering devices or RVS properties. The aim of this research is to study the effect of all these stimulation properties on performance of SSVEP while elicited by a circular shape. A correlation matrix is made to help selection of any suitable SSVEP stimulator. The percentage change in energy and power from one kind of stimulation to another is also shown in this research. Performance achieved in different cases has been compared with each other for apposite understanding. This will help a researcher to select proper stimulation types to elicit SSVEP.

Identification of different colors using brain stimulation is a new research area in the present world. Authors in [33] have been concluded that parametric method does not provide good performance for EEG signal while non-parametric method lack of detail information on the EEG analysis and therefore, the performance of the methods used will depend on the specific EEG application. Frequncy distribution through FFT of EEG signals was eliminated and the repletion of frequency was measured, for comparing between epileptic and healthy subjects [34].

Authors in [35] have been studied the invariability of brain-wave representations of simple patches of colors and simple visual shapes and their names, the words blue, circle etc. and the recognition rate was 60% to 70% of the test-sample brain waves.

On the other hand, in this research, one of the vital factors of stimulation in BCIs (circular shape with different size, color and frequency) is briefly analyzed. In this research the effect of size, frequency and color of a circular stimuli on the power and energy of EEG signal has been also analyzed.

Chapter 3

Methodology

Chapter Outlines :

3.1. EEG Signal Recording Techniques

3.2. Proposed Block Diagrams

3.3. Software & hardware description

3.4. Brain Stimulation

3.5. Signal Extraction using Desired Condition

3.6. Signal Preprocessing

3.7. Signal Analysis

3.8. Energy and power calculation

3.1. EEG Signal Recording Techniques:

Electroencephalographic measurements employ recording system consisting of

- Electrodes with conductive media
- Amplifiers with filters
- A/D converter
- Recording device.

Electrodes read the signal from the head surface, amplifiers bring the microvolt signals into the range where they can be digitalized accurately, converter changes signals from analog to digital and personal computer (or other relevant device) stores and displays obtained data. Scalp recordings of neuronal activity in the brain, identified as the EEG, allow measurement of potential changes over time in basic electric circuit conducting between signal (active) electrode and reference electrode. Extra third electrode, called ground electrode, is needed for getting differential voltage by subtracting the same voltages showing at active and reference points. Minimal configuration form one-channel EEG measurement consists of one active electrode, one (or two specially linked together) reference and one ground electrode. The multi-channel configurations can comprise up to 128 or 256 active electrodes.

3.1.1. Recording Electrodes:

The EEG recording electrodes and their proper function are critical for acquiring appropriately high quality data for interpretation. Many types of electrodes exist, often with different characteristics. Basically there are following types of electrodes:

- Disposable (gel-less and pre-gelled types)
- Reusable disc electrodes (gold, silver, stainless steel or tin)
- Read bands and electrode caps
- Saline-based electrodes
- Needle electrodes

For multichannel montages, electrode caps are preferred, with number of electrodes installed on its surface. Commonly used scalp electrodes consist of Ag-AgCl disks, 1 to 3mmin diameter, with long flexible leads that can be plugged into an amplifier. AgCl electrodes can accurately record also very slow changes in potential. Needle electrodes are used for long

recordings and are invasively inserted under the scalp. Skin preparation differs, generally cleaning of the skin surface from oil and brushing from dried parts is recommended. With disposable and disc electrodes, abrasive paste is used for slight skin abrasion. With cap systems, abutting needle at the end of injection is used for skin scraping, which can cause irritation, pain and infection. Especially when person's EEG is measured repeatedly and cap is mounted for the same electrode points, there is a threat of certain pain and bleeding. That is why the right hygiene and safety protocol should be kept.

Using the silver-silver chloride electrodes, the space between the electrode and skin should be filled with conductive paste also helping to stick. With the cap systems, there is a small hole to inject conductive jelly. Conductive paste and conductive jelly serve as media to ensure lowering of contact impedance at electrode-skin interface. In 1958, International Federation in Electroencephalography and Clinical Neurophysiology adopted standardization for electrode placement called 10-20 electrode placement system. This system standardized physical placement and designations of electrodes on the scalp. The head is divided into proportional distances from prominent skull landmarks to provide adequate coverage of all regions of the brain. Label 10-20 designates proportional distance in percent between ears and nose where points for electrodes are chosen. Electrode placements are labelled according adjacent brain areas: F (frontal), C (central), T (temporal), P (posterior), and O (occipital).

High impedance can lead to distortions which can be difficult to separate from actual signal. It may allow inducing outside electric frequencies on the wires used on the body. Impedance monitors are built in some commercially available EEG devices. In order to prevent signal distortions impedances at each electrode contact with the scalp should all be below 5 K Ohms, and balanced within 1 K Ohm of each other. Similar standard is required for clinical use of the EEG and for publication in most reputable journals. Practically, impedance of the whole circuit comprising two electrodes is measured, but built in impedance checks usually display results already divided by two. Control of all impedances is desirable also after finishing every single measurement. Several different recording reference electrode placements are mentioned in the literature. Physical references can be chosen as vertex (Cz), linked-ears, linked-mastoids, ipsilateral-ear, contralateral-ear, C7 reference, bipolar references, and tip of the nose. Reference-free techniques are represented by common average reference, weighted average reference, and source derivation. Each technique has its own set of advantages and disadvantages. The choice

of reference may produce topographic distortion if relatively electrically neutral area is not employed. Linking reference electrodes from two earlobes or mastoids reduces the likelihood of artificially inflating activity in one hemisphere. Nevertheless, the use of this method may drift away "effective" reference from the midline plane if the electrical resistance at each electrode differs. Cz reference is advantageous when it is located in the middle among active electrodes, however for close points it makes poor resolution. Reference-free techniques do not suffer from problem s associated with an actual physical reference. Referencing to linked ears and vertex (Cz) are predominant. With modern instrumentation, the choice of a ground electrode plays no significant role in the measurement. Forehead (Fpz) or ear location is preferred, but sometimes wrist or leg is also used. The combination of all active electrodes with reference and ground electrode compose channels. The general configuration is called montage.

3.1.2. Amplifiers and Filters:

The signals need to be amplified to make them compatible with devices such as displays, recorders, or A/D converters. Amplifiers adequate to measure these signals have to satisfy very specific requirements. They have to provide amplification selective to the physiological signal, reject superimposed noise and damages through voltage and current surges for both patients and electronic equipment. The basic requirements that a biopotential amplifier has to satisfy are:

- The physiological process to be monitored should not be influenced in any way by the amplifier.
- The measured signal should not be distorted.
- The amplifier should provide the best possible separation of signal and interferences.
- The amplifier has to offer protection of the patient from any hazard of electric shock.
- The amplifier itself has to be protected against damages that might result from high input voltages as they occur during the application of defibrillators or electrosurgical instrumentation.

The input signal to the amplifier consists of five components. The desired biopotential, undesired biopotentials, a power line interference signal of 50/60 Hz and its harmonics, interference signals generated by the tissue/electrode interface, and noise. Proper design of the amplifier provides rejection of a large portion of the signal interferences. The desired biopotential appears as the differential signal between the two input terminals of the differential amplifier. The amplifier gain is the ratio of the output signal to the input signal. In order to

provide optimum signal quality and adequate voltage level for further signal processing, the amplifier has to provide a gain of 100-100,000 (the highest need not to be the best, combination of meters is involved, e.g. the range of the A/D converter, sampling rate, noise of the used elements) and needs to maintain the best possible signal-to-noise ratio.

In order to decrease an impact of electrically noisy environment differential amplifiers must have high common-mode rejection ratios (at least 100 dB) and high input impedance (at least 100 M Ohms). The common-mode rejection ratio is the ratio of the gain of differential mode (wanted signal) over the gain of the common mode (original input signal between the inputs and ground). Special electrically shielded rooms minimize the impact of urban electric background, in particular 50/60 Hz alternating current line noise. For usual medical purposes, shielded room is not necessary. For research purposes when maximal amount of information is desired, shielded room is used. Then amplifiers run on batteries and an optical cable leads to the PC standing outside from the shielded space. In addition to the optical cable, electrical/optical and optical/electrical converters are necessary. Usually information of interest lies bellow this line noise and we can use low-pass filters with cut-off bellow 50/60 Hz, or for keeping higher frequency bands a notch filter can be applied, that is able to reduce only a narrow band around 50/60 Hz (but distorts phases). When computers are used as recording devices, channels of analog signal are repeatedly sampled at a fixed time interval (sampling interval), and each sample is converted into a digital representation by an analog- to-digital (A/D) converter. The A/D converter is interfaced to a computer system so that each sample can be saved in the computer's memory. The resolution of the converter is determined by the smallest amplitude that can be sampled. This is obtained by dividing the voltage range of the A/D converter by 2 raised to the power of the number of bits of the A/D converter. A/D converter usually uses minimally 12 bits (discerning 4,096 value levels). Ability to resolve 0.5 μ V is recommended. Sufficient sampling rate is required, at least double of the highest frequency component of our interest. Analog (hardware) filters have to be integrated in the amplification unit. A high-pass filter is needed for reducing low frequencies coming from bioelectric flowing potentials (breathing, etc.), that remain in the signal after subtracting voltages toward ground electrode. Its cut-off frequency usually lies in the range of 0.1-0.7Hz. To ensure that the signal is band limited, a low-pass filter with a cut-off frequency equal to the highest frequency of our interest is used (in the range from 40 sampling rate). Analog low-pass filters prevent distortion of the

signal by interference effects with sampling rate, called aliasing, which would occur if frequencies greater than one half of the sampling rate survive without diminishing.

Once data are stored, digital filtering can be used. The strength of the analog filters is limited thus for displaying and processing of the signals further decreasing of DC components is usually needed. It is possible to choose from linear (FIR, IIR) filtering or novel non-linear filtering methods. The choice should be done according to the objectives put on the signal processing. Predominantly finite impulse response (FIR) filters are used which do not distort wave phases. The data points width typically ranges on the order of 1000 and one of the window function should be chosen. Filters should be designed in a way to influence useful signal properties minimally. Before performing the final measurement, the whole EEG system should be tested.

Inter-channel calibrations with known wave signal parameters should not display significant discrepancies. The output noise (referred to input) consists mainly from the noise caused by the analog amplifier circuitry and by A/D converter circuitry. Noise value should be consistent with manufacturer information, about 0.3-2 μV pp.(range from negative peak to positive peak) but this value depends on the way of noise estimation and on the system configuration (low-pass filter, sampling rate, choice of circuitry). The noise can be determined by connecting the inputs of the amplifier together, or abased them into a salty solution, or "short-circuiting" the inputs, and then measuring the output of the amplifier. The number of useful information bits can be counted as a power of two from the ratio of average EEG signal amplitude over the noise amplitude (e.g. 50 μV/1 μ V results in over 5 bits). One of the limitations of recordings is due to storage requirements. For example, 1 hour of eight channels 14-bit signal sampled with 500 Hz occupies 200 MB of the memory. There exist portable recording systems used for longer monitoring of a subject without limiting movement of a person.

3.1.3. Artefacts:

Among basic evaluation of the EEG traces belongs to scanning for signal distortions called artefacts. Usually it is a sequence with higher amplitude and different shape in comparison to signal sequences that doesn’t suffer by any large contamination. The artefact in the recorded EEG may be either patient-related or technical. Patient-related artefacts are unwanted physiological signals that may significantly disturb the EEG. Technical artefacts, such

as AC power line noise, can be decreased by decreasing electrode impedance and by shorter electrode wires. The most common EEG artefact sources can be classified in following way:

Patient related:

- Any minor body movements
- EMG
- ECG (pulse, pace-maker)
- Eye movements
- Sweating

Technical:

- 50/60 Hz
- Impedance fluctuation
- Cable movements
- Broken wire contacts
- Too much electrode paste/jelly or dried pieces
- Low battery

3.2. Proposed Block Diagrams:

The main purpose of the research is to determine the stimulation effect on alpha and beta bands of EEG signal. The proposed methodology of this research is shown in Fig. 2. The steps are discussed below:

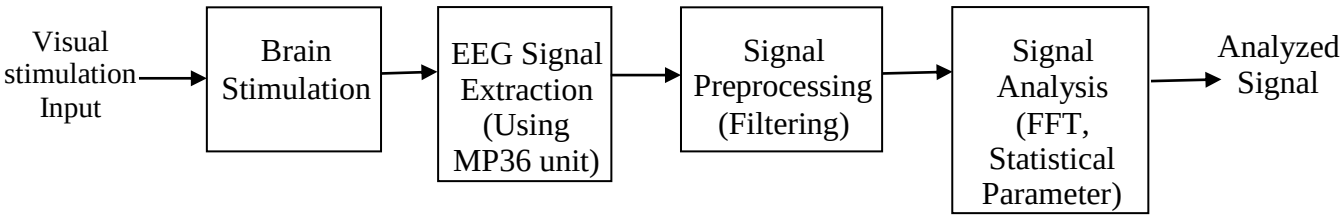


Fig. 3.1: Proposed block diagram for EEG signal.

3.3. Software & Hardware description:

I have used two softwares in this research work. They are Biopac Student Lab and visual frequency generator. The information about the software is given below.

3.3.1. Biopac Student Lab(BSL) Pro 3.7.3& BIOPAC MP36 acquisition unit:

The Biopac Student Lab (BSL) *PRO* System performs two basic functions: acquisition and analysis. The acquisition settings determine the basic nature of the data to be collected, such as the amount of time data will be collected for and at what rate data will be collected. The BSL

PRO System is a computer-based data acquisition system that performs many of the same functions as a chart recorder or other data viewing device, but is superior to such devices in that it transcends the physical limits commonly encountered (such as paper width or speed). Data collection generally involves taking incoming analog signals and sending them to the computer, where they are (a) displayed on the screen, and (b) stored in the computer's memory (or on the hard disk).

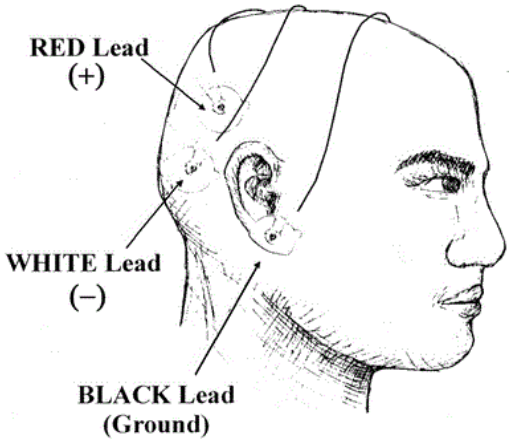
These signals can then be stored for future examination, much as a word processor stores a document or a statistics program saves a data file. Graphical and numerical representations of the data can also be produced for use with other programs. The Biopac Student Lab *PRO* consists of several major components, including hardware and software. The BSL *PRO* software allows to edit data and control the way it appears on screen, and performs four general functions: Controls the data acquisition process, performs real-time calculations (such as digital filtering and rate detection), performs post-acquisition transformations (such as FFT's and math functions), handles file management commands (saving, printing, etc.) The heart of the BSL System is the MP3X data acquisition unit. This unit takes incoming signal and converts them into digital signals that can be processed with computer. The MP3X connects to computer via the USB adapter (USB1W).

3.3.2. BIOPAC MP36:

Acquisition is defined as data collection from an external source (such as electrodes connected to an amplifier). BSL *PRO* acquisitions require hardware connections and software setup. The MP3X is designed to accept amplified small analog signals and large analog signals (up to ±10 Volts). Specific connections to the MP3X acquisition unit will vary greatly, depending on the amount and type of data collected. The most common applications of the BSL *PRO* involve amplified signals collected from electrodes and/or transducers. Picture of BIOPAC MP36 acquisition unit is shown in Fig.3.2.

Fig. 3.2: Picture of BIOPAC MP36 acquisition unit.

The MP36R Research System is a flexible, powerful tool for life science research and teaching. An internal microprocessor controls data acquisition and communication with the computer after an analog to digital conversion. The actual electrode placement is shown in Fig. 3.3.



(a) (b)

Fig. 3.3: Electrode placement position for EEG acquisition.

The two common types of input devices that connect to the front of the MP3X to interface between the subject and the hardware are electrodes and transducers. Electrodes directly reflect the electrical signal generated by the body, and transducers convert a physiological signal into a proportional electrical signal. One can also connect I/O devices to the MP3X.

Electrodes are relatively simple instruments that attach directly to a subject's skin surface and pick up electrical signals in the body. Electrode lead cables connect to the electrodes and send the signal to the MP3X unit. The MP3X amplifies the signal and sends it to the computer and the Biopac Student Lab *PRO* software. Depending on where electrodes are placed, different types of signals will be picked up.

Transducers convert a physiological parameter (such as clench force, blood pressure, or Galvanic Skin Response) to a proportional electrical signal. One example of this is the respiration transducer, which is like a rubber band that stretches with ones chest. It measures how much larger his/her chest becomes when ones breathe in, and how much smaller it becomes when one exhales. A device inside the transducer converts this physical change into an electrical

signal, which can then be sent to the Biopac Student Lab *PRO* System and relayed to computer, where it is plotted on the screen.

I/O devices are specialized Input/Output devices, such as push-button switches and headphones. Regardless of the type of device connected, every sensor or I/O device connects to the MP3X acquisition unit using a "Simple Sensor" connector. The Simple Sensor connector is designed so that there is only one way to plug it into the MP3X, so one doesn't have to worry about plugging things in upside down or into the wrong socket. One doesn't have to screw the end of the Simple Sensor into the computer port unless you want to this makes it easy for one to experiment with different transducers.

3.4. Brain Stimulation:

Electrical brain stimulation (EBS), also referred to as focal brain stimulation (FBS), is a form of electrotherapy and technique used in research and clinical neurobiology to stimulate a neuron or neural network in the brain through the direct or indirect excitation of its cell membrane by using an electric current. It is used for research or for therapeutical purposes.

Electrical brain stimulation (EBS) is a routine clinical practice during surgical evaluation of patients with epilepsy and resection of special cases of brain tumor. During EBS, a volley of electrical discharges is delivered directly to several brain regions of interest in awake human subjects to map their functional involvement in sensation and movement, or cognitive functions such as language and memory. On the basis of functional mapping of the brain, the clinician draws a plan for the resection of the involved brain tissue without causing major sensorimotor or cognitive impairments.

In **Fig. 3.4** a typical block diagram of a stimulator is shown in which MUX block is used to select any item among three.

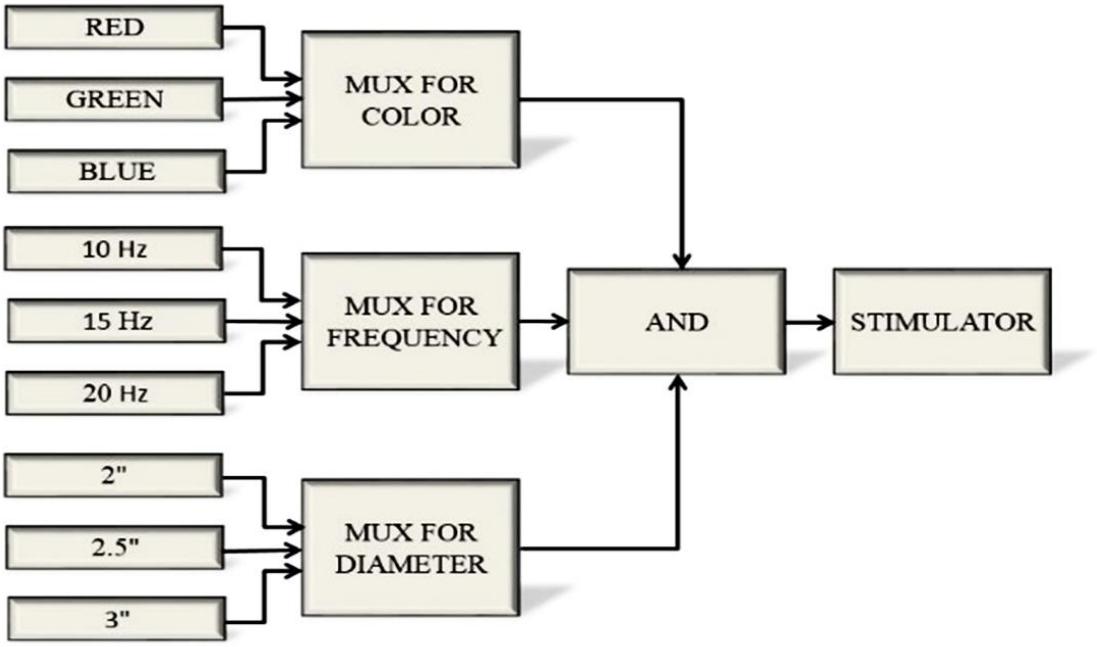


Fig 3.4: Typical visual stimulator with color, frequency and diameter variation arrangement. Then three MUXed output are ANDed to visually stimulate the human brain for the raw EEG extraction. In this stimulator the color, frequency and diameter of a circular visual stimulus is varied to change the stimulation pattern.

Electrical Brain Stimulation (EBS) can be considered as a useful tool for functional mapping in the human brain. Contrary to most neuroimaging studies, which do not probe directly the necessity of a given brain region in a particular cognitive function, EBS can provide direct observations about the necessity of the stimulated region for the perceptual or behavioral function that is being studied.

3.4.1. Effects of Brain Stimulation:

A comprehensive review of Brain Stimulation research compiled a list of many different acute impacts of stimulation depending on the brain region targeted. Following are some examples of the effects documented [32].

- **Sensory**: Feelings of body tingling, swaying, movement, suffocation, burning, shock, warmth, paresthesia, feeling of falling, oscillopsia, dysesthesia, levitation, sounds, phosphenes, hallucinations, micropsia, diplopia, etc.

- **Motor**: Eye movements, locomotion, speech arrest, automatisms, laughter, palilalia, chewing, urge to move, crying without feeling sad, etc.
- **Autonomic**: Blushing, mydriasis, change in blood pressure and breathing, apnea, nausea, tachycardia, sweating, etc.
- **Emotional**: Anxiety, mirth, feeling of unreality, fear, happiness, anger, sadness, transient acute depression, hypomania, etc.
- **Cognitive**: Acalculia, paraphasia, anomic aphasia, recalling memories, "going into a trance", "out of this world", conduction aphasia, hemispatial neglect, alexia, déjà vu, reliving past experiences, agraphia, apraxia, etc.

3.5. EEG Signal Extraction Using Desired Condition:

In this step raw EEG signal will be extracted from the brain using the various stimulation patterns as described in the previous step. EEG signal for different stimulation pattern in visual stimulator will be recorded by the acquisition unit (Fig. 4.1) which will be further processed in next step.

3.6. Signal Preprocessing:

After signal acquisition phase, signals are to be pre - processed. Signal pre - processing is also called as Signal Enhancement. In general, the acquired brain signals are contaminated by noise and artefacts. The artefacts are eye blinks, eye movements (EOG), heart beat (ECG). In addition to these, muscular movements and power line interferences are also mingled with brain signals [7]. Artefact removal can be done using Common Average Referencing (CAR), Surface Laplacian (SL), Independent Component Analysis (ICA), Common Spatial Patterns (CSP), Principal Component Analysis (PCA), Single Value Decomposition (SVD), Common Spatio -Spatial Patterns (CSSP), FrequencyNormalization (Freq - Norm), Local Averaging Technique (LAT), Robust Kalman Filtering, Common Spatial Subspace Decomposition (CSSD) etc. The most frequently used methods are ICA, CAR, SL, PCA, CSP and Adaptive Filtering**.**

In this step raw EEG signal will be used as input of the preprocessing unit. Usually different types of filtering will be used to get the preprocessed EEG signal which is shown in Fig. 3.4. Raw EEG signal for different stimulation pattern in visual stimulator will be filtered here.General signal processing methods are used to process EEG signals with some

modification. EEG signal analysis undergoes four stages as follows: recording stage, dancing stage,feature extraction stage, and classification stage. These processes are summarized in Figure 3.4. The implementation of these stages must be sequential, starting from the recording stage to the classification stage. At each stage, several operations should be carried out before sending the signal to the next stage.

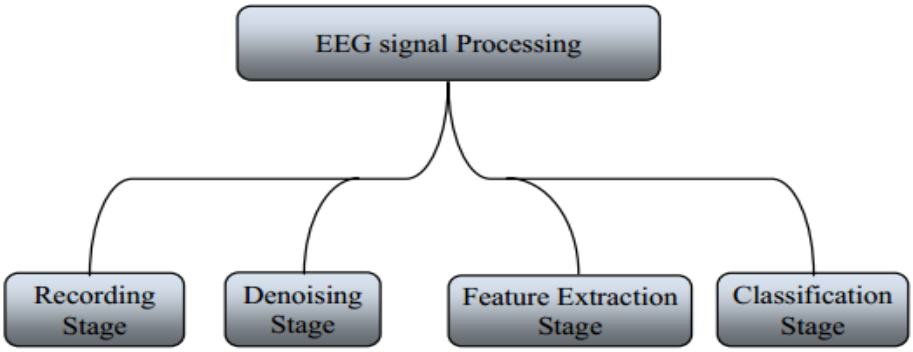


Fig 3.5. The main stages that use to process EEG signal.

3.6.1. Filtering for signal processing:

In signal processing, a filter is a device or process that removes from a signal some unwanted component or feature. Filtering is a class of signal processing, the defining feature of filters being the complete or partial suppression of some aspect of the signal. Most often, this means removing some frequencies and not others in order to suppress interfering signals and reduce background noise. However, filters do not exclusively act in the frequency domain; especially in the field of image processing many other targets for filtering exist. Correlations can be removed for certain frequency components and not for others without having to act in the frequency domain.

There are many different bases of classifying filters and these overlap in many different ways; there is no simple hierarchical classification. Filters may be:

- Linear or non-linear
- Time-invariant or time-variant, also known as shift invariance. If the filter operates in a spatial domain then the characterization is space invariance.
- Causal or not-causal: depending if present output depends or not on "future" input; of course, for time related signals processed in real-time all the filters are causal; it is not necessarily so for filters acting on space-related signals or for deferred-time processing of time-related signals.

- Analog or digital.
- Discrete-time (sampled) or continuous-time.
- Passive or active type of continuous-time filter.
- Infinite impulse response (IIR) or finite impulse response (FIR) type of discrete-time or digital filter.

3.6.2. Feature Extraction:

After obtaining the noise free signals from the signal enhancement phase, essential features from the brain signals were extracted. For feature extraction from EEG signals use methods like Adaptive Auto Regressive parameters (AAR), bilinear AAR, multivariate AAR, Fast Fourier Transformations (FFT), PCA, ICA, Genetic Algorithms (GA), Wavelet Transformations (WT), Wavelet Packet Decomposition (WPD).Among these ICA, PCA, WT, AR, WPD, FFT are mostly used.

3.7. Signal Analysis:

The preprocessed EEG signal will be further processed using various software such as MATLAB, BIOPAC and ACQKNOWLEDGE. In this signal analysis step the EEG signal has processed by frequency transform, statistical and wavelet analysis method. The preprocessed EEG signal is band pass filtered to obtain the two desired EEG waves namely alpha and beta. Energy and power of these two waves are calculated. Feature extraction and analysis block is shown in Fig. 3.5.

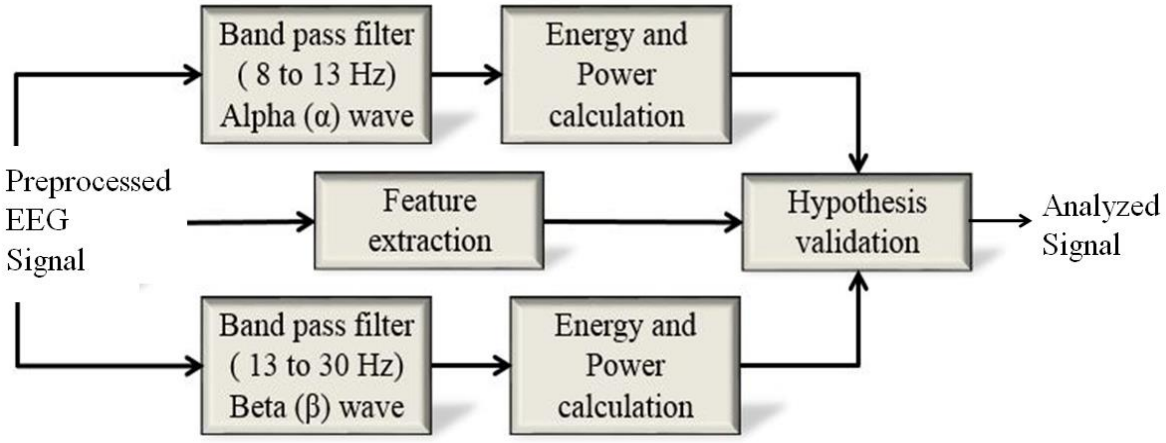


Fig 3.6: Feature extraction and analysis block.

3.8. Energy and Power Calculation:

First of all the selection of stimulation shape is done from the available patterns in the visual frequency generator software. After selecting the shape the frequency and color is selected from the frequency and color option of the software. The subject is made understand clearly about the jobs he should done while extraction of signal. He is told to sit at relax condition at a distance 30 cm in front of the screen.

Then this selected pattern is displayed by the computer screen. The subject is told to look at that pattern. Then signal is extracted using BIOPAC MP36 acquisition unit and Biopac Student Lab PRO (version 3.7.3). The extraction period was about 20 seconds. The extracted signals are saved in .mat format for analysis using MATLAB. For calculating the energy of the signal the equation used is,

$$E = \frac{1}{N}\sum_{n=0}^{N} |x_{EEG}(n)|^2 \quad (1)$$

For calculating the power the used equation is,

$$P = E \times N \quad (2)$$

In the first equation, the term $x_{EEG}(n)$ is the extracted EEG signal. It is defined as follows.

$$x_{EEG}(n) = \{x(0), x(1), x(2), x(3), x(4), \dots\dots\dots\dots\dots\dots\dots\dots x(N)\} \quad (3)$$

Where N indicates the length of the matrix formed by the data. After calculating the power and energy they are tabulated. If a & b are two signals then, their correlation coefficient can be found using `normxcorr2(a,b)` function in MATLAB. This function is used for finding the correlation coefficient.

Chapter 4

Results & Discussion

Chapter Outlines :

4.1. **Visual Frequency Generator Software:**

The stimulator was designed in Java. There was provision for selecting the frequency, color and Shape. There is provision of selecting one of the color from an array of 280 colors. The frequency is also selectable by typing it in the box right to the string 'Frequency' as in Fig. 4.2. Here the specification process of length and diameter for circular stimulation is shown in Fig. 4.2. By using this process, signals were extracted which includes circle of 2, 2.5, 3 inch diameter and each are of red, green & blue color for different Hz.

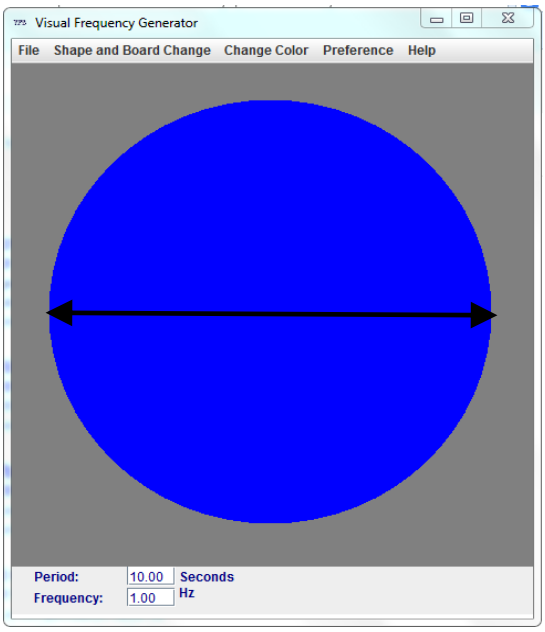
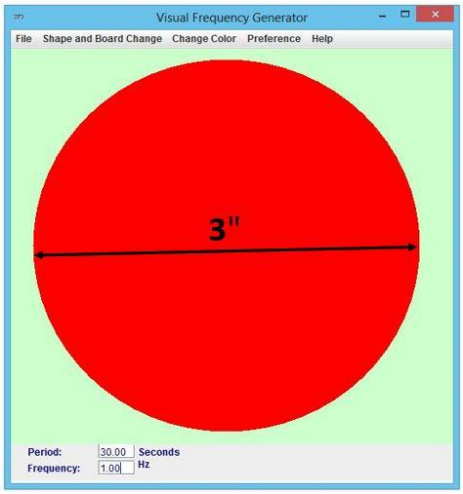
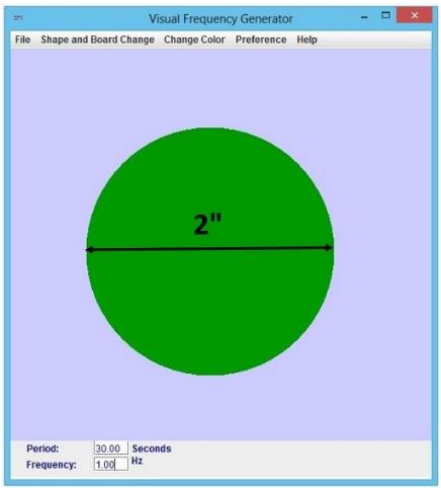


Fig. 4.1: Pictorial view of Visual frequency generator with specification of diameter of circular stimulation pattern.

4.2. Design of Stimulator:

To stimulate the brain visually, a stimulator is designed using JAVA script. A typical screen shot of this stimulator is shown in the Fig. 4.2 (a) and (b). The characteristics of extracted signal depends on the configuration of laptop used for the visual stimulation. The configuration used for our stimulation was Intel (R) core (TM) 2 Duo CPU T6600 @2.20 GHz, 4 GB RAM (Installed memory) and 32-bit OS. The refresh rate of the display was 60 Hz.

(a) 



(b)

Fig. 4.2: Screenshot of the visual stimulator for two different size and color (a) for red color of diameter 3" (b) for green color of diameter 2".

4.3. Subject Condition and Signal Extraction:

EEG signals were extracted from 3 healthy subjects (aged 23+/-1) at BME lab of KUET, Khulna-9203, Bangladesh, using the stimulation patterns as depicted in Fig. 4.2. The subject was made to seat in front of a display at a distance of 30 cm and asked to gaze at the visual stimulator in relaxed mode as shown in Fig. 4.4. The statistical information of the subject used in experiment is given in a Table 4.1.

TABLE 4.1: INFORMATION OF EXPERIMENTAL SUBJECTS.

SL. No.	Subject Index	Age	Height	Weight
1	S1	21	5'7"	69 kg
2	S2	23	5'5"	64 kg
3	S3	22	5'4"	63 kg

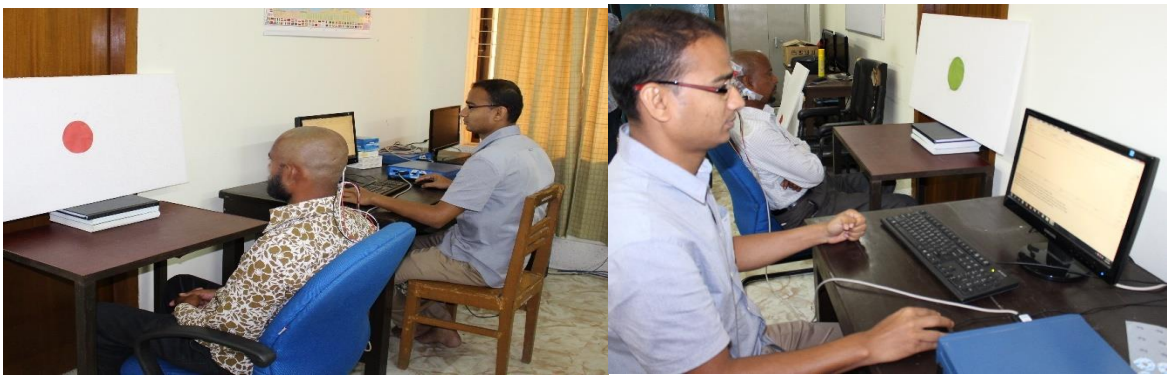
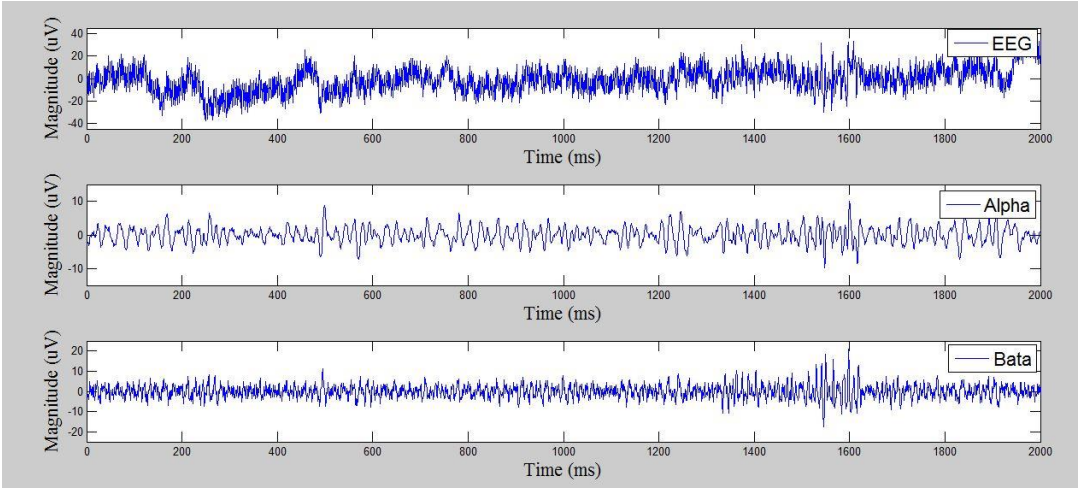


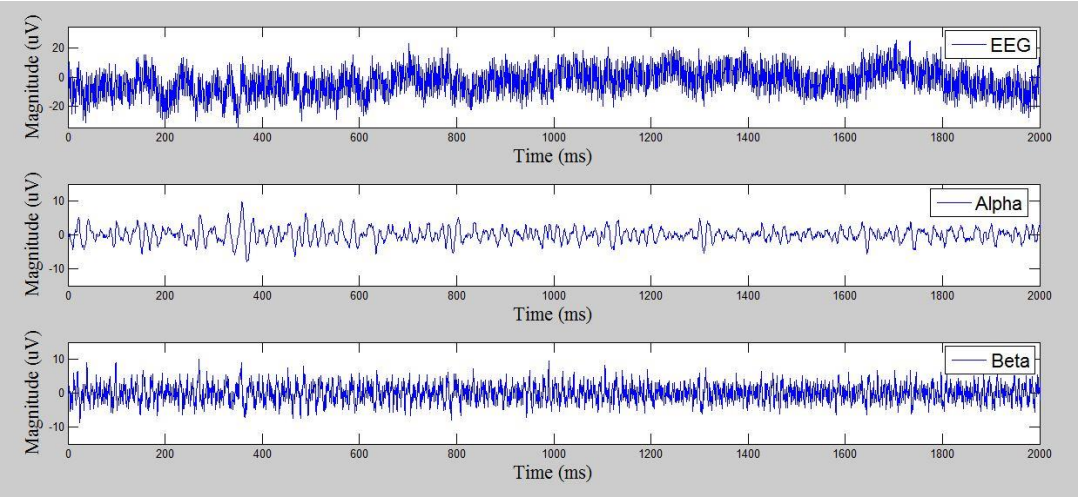
Fig. 4.3: Pictorial view of signal extarction.

4.4. Graphical Analysis:

Fig. 4.4 shows the typical EEG signal for different conditions (green, 10 Hz and 3" dia. & green, 20 Hz and 2.5" dia.). There corresponding Alpha and Beta wave are also shown obtained by filtering the raw EEG signal.



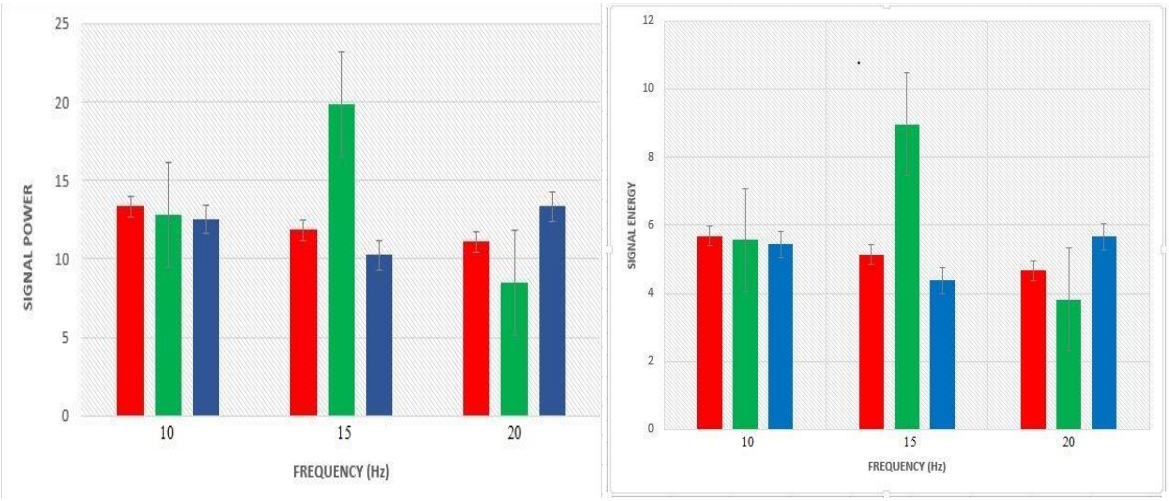
(a)



(b)

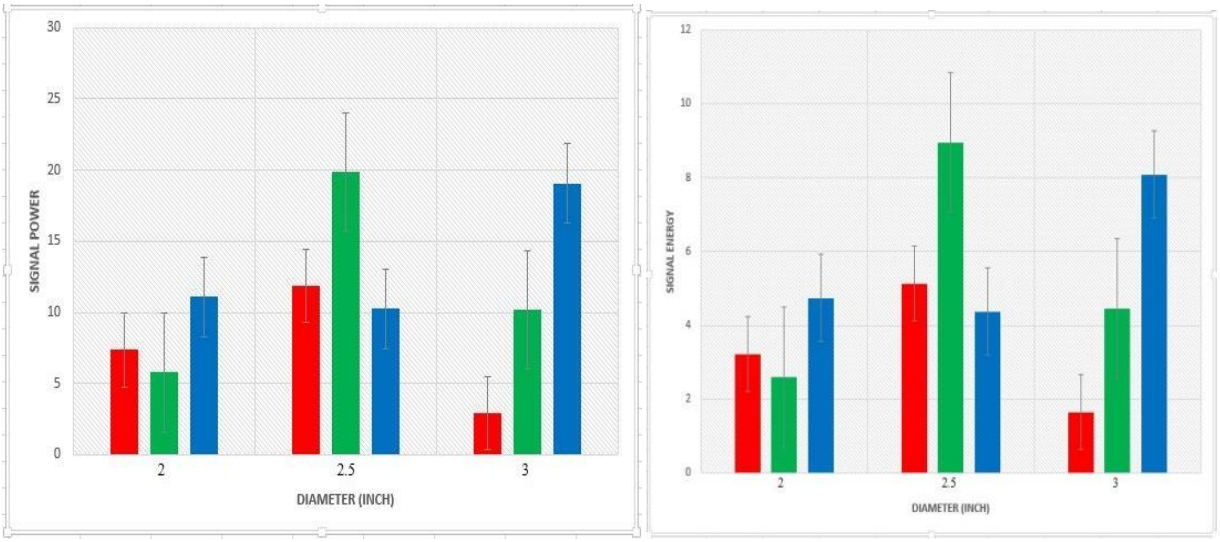
Fig. 4.4: Typical EEG signal and their Alpha and Beta bands (a) for green, 10 Hz and 3" dia. (b) for green, 20 Hz and 2.5" dia. Stimulator.

Fig. 4.5 (a) and Fig. 4.7 (a) represents a power variation with different frequency and size respectively for alpha (α) wave. Fig. 4.5 (b) and Fig. 4.6 (b) represents an energy variation with different frequency and size respectively for alpha (α) wave. Maximum power and energy is obtained at a frequency of 15 Hz for Green colored stimulation. Similar results is found when size of the stimulator is varied. Maximum power and energy is obtained at 2.5 inch diameter of the stimulator for Green color stimulator.



(a) (b)

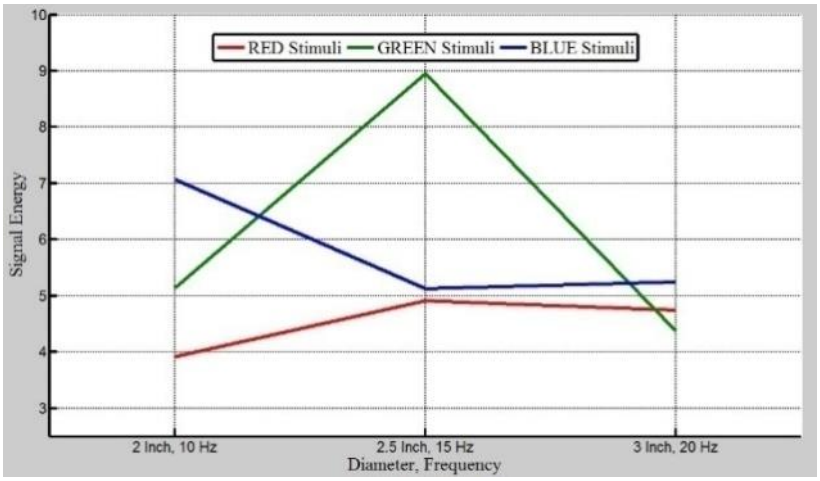
Fig. 4.5: Variation of a) power and b) energy of Alpha wave with frequency.



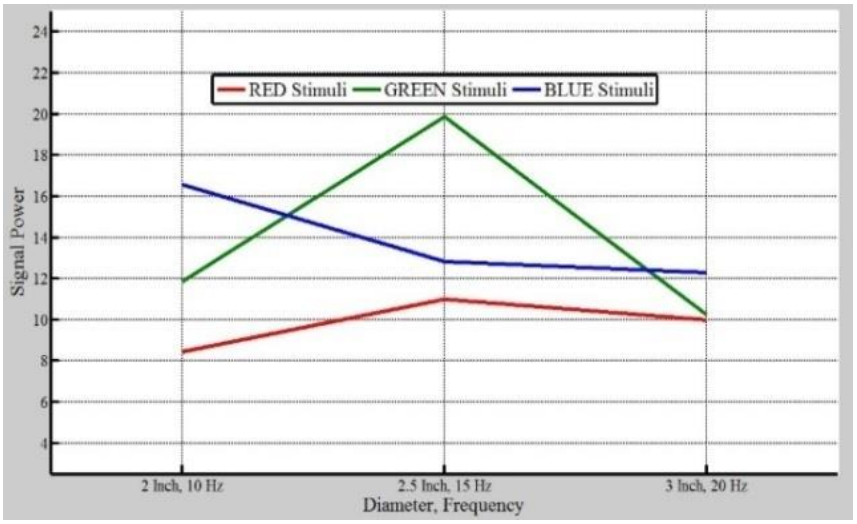
(a) (b)

Fig. 4.6: Variation of (a) power and (b) energy of Alpha wave with size.

The variation of energy and power with respect to variation of frequency and size of the stimulator simulateneously is shown in Fig. 4.6 (a) and (b). The maximum value of power and energy for Green and Red stimulator is found at 15 Hz, 2.5 inch whereas for Blue colored stimulator it is at 10 Hz, 2 inch. But at 20 Hz, 3 inch both power and energy is minimum for all stimulators (Red, Green and Blue).



(a)



(b)

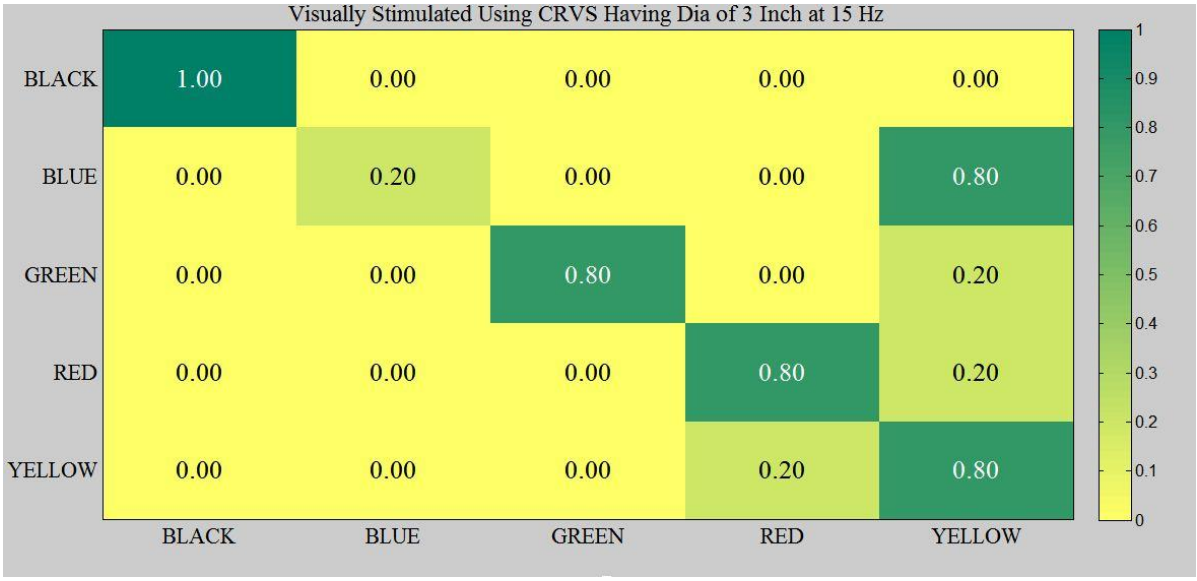
Fig. 4.7: Variation of a) power and b) energy of Alpha wave with size and frequency simultaneously.

4.5. Confusion Matrix as a Heat Map:

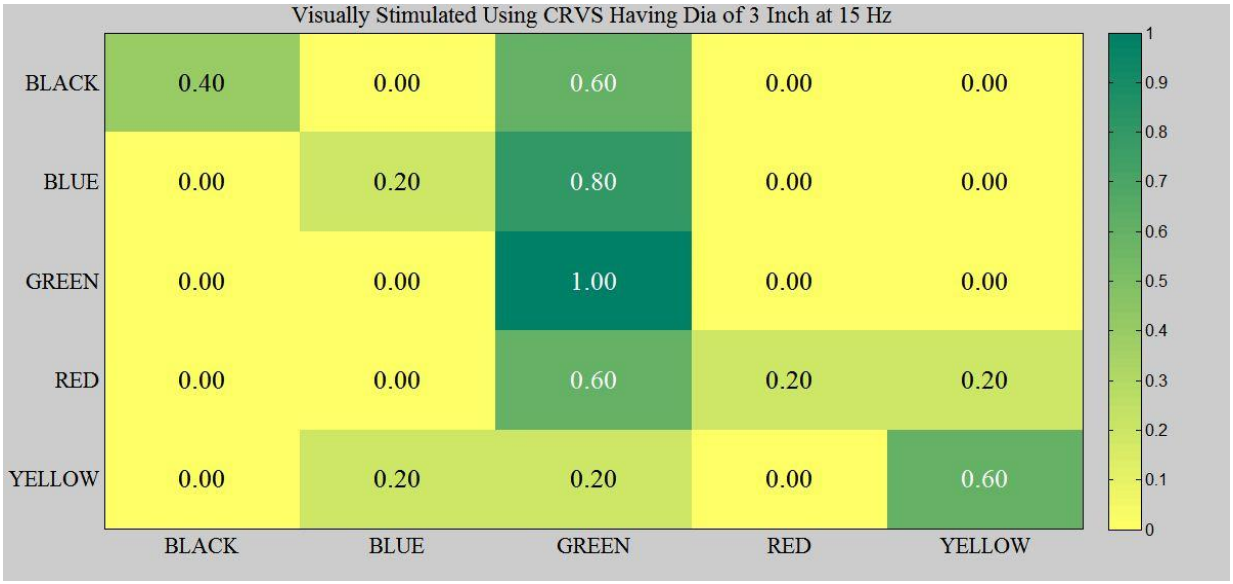
The maximum value of power and energy for Green and Red stimulator is found at 15 Hz, 2.5 inch whereas for Blue colored stimulator it is at 10 Hz, 2 inch. But at 20 Hz, 3 inch both power and energy is minimum for all stimulators (Red, Green and Blue). Confusion matrix is describing the SVM (Support Vector Machines) classifier data representation as a heat map, which shows the color variation effect on brain stimulation. Confusion matrices for visually stimulated using CRVS having 3 inch diameter at 15 Hz frequency are shown in Fig. 4.8 (a), (b), (c) and (d) where 1.00 means the color changing effect's correlation on brain stimulation is hundred percent and 0.00 means there is no change of effect for those colors. The other values of coefficients are describing the partial change of effect such as 0.20 means slight change, 0.50 means medium change and 0.80 means high change.

Fig. 4.8 (a) is representing the confusion matrix for alpha band where showing that changing from color black to black creates hundred percent change on the effects of brain stimulation as coefficient is 1.00. Correlation coefficient of change of effect for yellow-yellow, red-red, green-green and blue-yellow is 0.80. A slight change of effect has been found for blue-blue, yellow-red, red-yellow and green-yellow. Similarly, Fig. 4.8 (b), (c) and (d) are representing for Beta, Delta and Theta band respectively. For beta band correlation coefficient 1.00 has been found only for green-green color change. Besides 0.80 has been found for blue-

green. For Delta band 1.00 has only been found for black-black color change. Theta band analysis shows that black-black and green-green color change creates the complete change of effect on brain stimulation as value has been found 1.00.

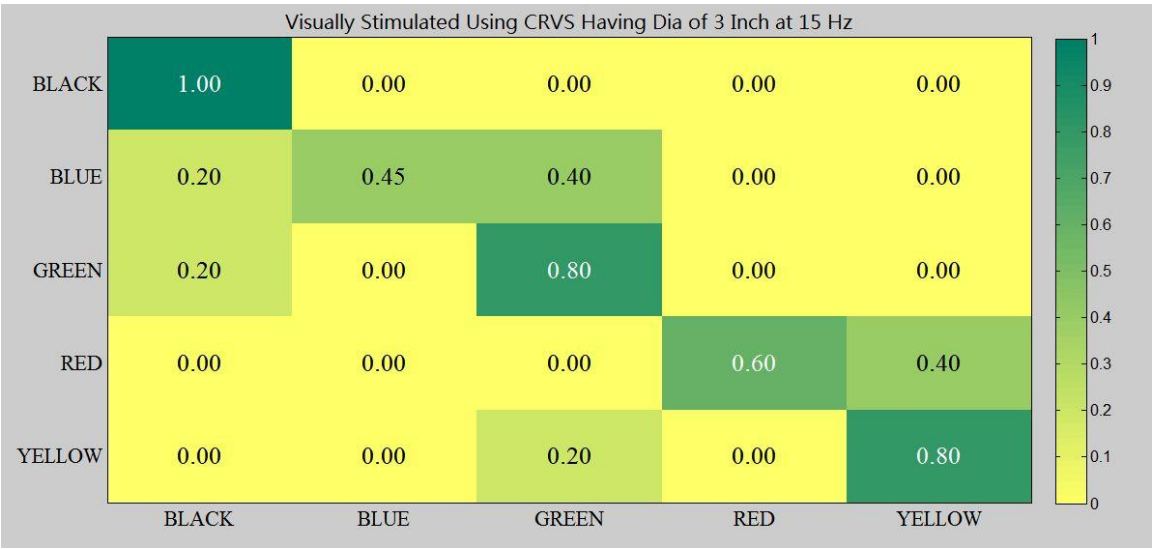


(a)

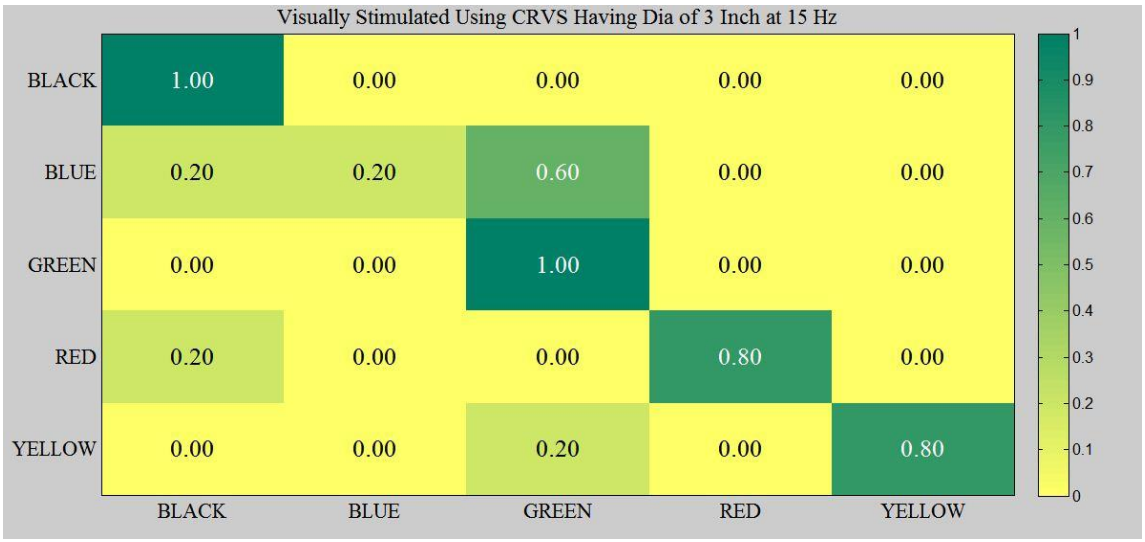


(b)

Fig. 4.8: Confusion matrix as heat map of visually stimulated using CRVS for (a) alpha (b) beta (c) delta and (d) theta band.



(c)



(d)

Fig. 4.8: Confusion matrix as heat map of visually stimulated using CRVS for (a) alpha (b) beta (c) delta and (d) theta band.

4.6. Tabular Analysis:

Table 4.2: Power and Energy Representation for Alpha (left) and Beta (right) Wave.

Size	Color	Frequency	Power	Energy $x10^4$
Dia. 2"	Red	10	08.4456	3.9138
		15	07.3631	3.2265
		20	06.7715	3.0418
	Green	10	10.9952	4.9126
		15	05.7648	2.5982
		20	12.4226	5.36.3
	Blue	10	09.9841	4.7426
		15	11.0890	4.7393
		20	09.9060	4.2328
Dia. 2.5"	Red	10	13.3596	5.6791
		15	11.8485	5.1375
		20	11.0775	4.6603
	Green	10	12.8196	5.5701
		15	19.8871	8.9572
		20	08.5000	3.8207
	Blue	10	12.5278	5.4308
		15	10.2475	4.3726
		20	13.3325	5.6596
Dia. 3"	Red	10	07.2947	3.2600
		15	02.9098	1.6441
		20	16.5685	7.0714
	Green	10	11.9091	5.0781
		15	10.1972	4.4531
		20	12.8156	5.1326
	Blue	10	14.0363	6.0032
		15	19.0413	8.0821
		20	12.2827	5.2447

Size	Color	Frequency	Power	Energy $x10^4$
Dia. 2"	Red	10	10.9882	5.0919
		15	08.0786	3.5401
		20	06.9502	3.1228
	Green	10	11.9855	5.3596
		15	05.0837	2.2912
		20	12.7792	5.5254
	Blue	10	09.7388	4.6259
		15	11.7749	5.0267
		20	09.3626	4.0049
Dia. 2.5"	Red	10	12.4912	5.2973
		15	10.9886	4.7646
		20	10.6620	4.4855
	Green	10	13.8182	6.0012
		15	14.7698	6.6523
		20	09.0435	4.0552
	Blue	10	09.8160	4.2552
		15	13.5118	5.7655
		20	16.7164	7.0961
Dia. 3"	Red	10	07.9213	3.5367
		15	15.0496	6.3719
		20	14.0546	5.9901
	Green	10	12.0974	5.1583
		15	09.8610	4.3106
		20	12.4612	5.2973
	Blue	10	15.0447	6.3142
		15	15.0496	6.3719
		20	12.3397	5.2690

Table 4.3: Correlation Matrix.

	Dia. 2" Red 10 Hz	Dia. 2" Red 15 Hz	Dia. 2" Red 20 Hz	Dia.2" Red 15 Hz	Dia.2.5" Red 15 Hz	Dia.3" Red 15 Hz	Dia.2" Red 10 Hz	Dia.2" Green 10 Hz	Dia.2" Blue 10 Hz
Dia. 2" Red 10 Hz	1	-.0598	-0.0129	-0.0598	-0.0065	0.1078	-0.0549	0.1472	0.0097
Dia. 2" Red 15 Hz	-0.0598	1	0.0191	1	0.0110	0.0155	-0.0499	0.0464	-0.0197
Dia. 2" Red 20 Hz	-0.0129	0.0191	1	0.0191	-0.0284	0.0830	-0.0012	-0.1011	-0.0982
Dia.2" Red 15 Hz	-0.0598	1	0.0191	1	-0.0110	-0.0155	-0.0498	0.0460	-0.0197
Dia.2.5" Red 15 Hz	-0.0065	-0.0110	-0.0283	-0.0110	1	0.0480	-0.1029	0.2444	-0.0199
Dia.3" Red 15 Hz	0.1078	-0.0154	0.0830	-0.0154	0.0480	1	-.00606	0.0008	-0.0909
Dia.2" Red 10 Hz	-0.0549	-0.0498	-0.0011	-0.0498	-0.1029	-0.0606	1	0.2781	-0.0777
Dia.2" Green 10 Hz	0.1472	0.0460	-0.1011	0.4060	0.2444	0.0008	0.2781	1	-0.0537
Dia.2" Blue 10 Hz	0.0096	-0.0197	-0.0982	-0.0197	-.0199	-0.0909	-0.0777	-0.537	1

From Table 4.2, for a fixed size and color of the stimulator the power and energy of the Alpha wave for different frequency of stimulation is found. The change in power and energy of Beta wave is exactly opposite to that of the Alpha wave as given by the above table.

Table 4.3 shows the correlation matrix for different combinations of size, frequency and color of the stimulator. The correlation matrix is found by correlating each row with each column. When stimulation condition is same correlation provides maximum value. Negative correlation indicates opposition between two stimulation conditions.

Chapter 5

Conclusion & Future Research

Chapter Outlines :

5.1. Conclusion

5.2. Future Research

5.1. Conclusion:

Brain Computer Interfaces (BCIs) based on the SSVEP permits for the communication with the physical world after paying attention to the visual stimulator. In this research, one of the vital factors of all stimuli in BCIs viz. circular shape with different size, color and frequency is briefly analyzed. In this research the effect of size, frequency and color of a circular stimuli on the power and energy of EEG signal has been also analyzed. The number of target detection also depends on the refresh rate of the monitor and the number of stable timers supported by the system. This research helps to choose perfect stimuli which may outfit the performance of SSVEP based BCIs and safety of BCIs. Perfections to stimuli can enhance the SSVEP Signal to Noise Ratio (SNR), reduce the complexity of extracted signal processing, increase the targets detection, help subjects to pay attention and allow independent BCI operation.

5.2. Future Research:

Brain-computer interface (BCI) is a collaboration between a brain and a device that enables signals from the brain to direct some external activity, such as control of a cursor or a prosthetic limb. The interface enables a direct communications pathway between the brain and the object to be controlled. Research is still in beginning stages. The current technology is crude. Ethical issues may prevent its development. Electrodes outside of the skull can detect very few electric signals from the brain. Electrodes placed inside the skull create scar tissue in the brain. Advanced signal processing make the BCIs (Brain Computer Interface) more sophisticated. Since in EEG techniques, the electrodes are placed against the scalp, as a consequence, this approach is not nearly as accurate as direct neural contact. To overcome this limitation, much more accurate non-invasive technology Magnetoencephalography (MEG) may be used to extract Signal.

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ACHIEVMENT

The achievement during the M.Sc. study period is mention below-

International Journal

1. Md. Kamrul Hasan, Md. Shazzad Hossain, **Tarun Kanti Ghosh**, Mohiuddin Ahmad, "***A SSVEP Based EEG Signal Analysis to Discriminate the Effects of Music Levels on Executional Attention***", American Journal of Bioscience and Bioengineering, Science Publishing Group , Vol. 3, Issue 3-1, pp. 27-33, May, 2015.

International Conference

1. Md. Kamrul Hasan, Rushdi Zahid Rusho, Toufiq Md. Hossain, **Tarun Kanti Ghosh**, and Mohiuddin Ahmad, "***Design and Simulation of Cost Effective Wireless EEG Acquisition System for Patient Monitoring***", 3rd International Conference on Informatics, Electronics & Vision (ICIEV), IEEE (DOI: 10.1109/ICIEV.2014.6850797), DU, Dhaka, Bangladesh, pp.1 - 5 , 23-24 May 2014.