WIRELESS BRAIN-MACHINE INTERFACE SYSTEM BASED ON MULTI-CHANNEL VISUAL FLICKERS

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Approved by submission

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Advisor

Date: 1 Aug 2016

Abstract

Wireless brain-machine interface system based on multi-channel visual flickers

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Brain-Machine Interface (BMI) enables peoples with disabilities communicate the outer world by using electroencephalogram (EEG) signal. As a result, the visual stimulation is being recognized to be a most efficient stimulus for a multiple BMI system. Recently, steady-state visual evoked potential (SSVEP) is employed as a stimulator due to it plays an important role in the response to various visual parameters, i.e., flickering rate (F), intensity (I), and duty cycle (D). The SSVEPs are practical and useful in research because of its excellent signal-to- noise ratio and relative immunity to artifacts. However, another one of the possible paradigms, namely, the event-related potential (ERP) based BCI. In this project, therefore, we offline investigated the effectiveness of SSVEP and ERP visual flickering paradigms for BCI system in terms of optimizing the parameter of visual simulation. Different experimental conditions were compared to achieve the best performance. Subjects were instructed to fixate LED light source then record associated SSVEP waveform on O1 and O2 channels. The variation in displaying of the presentation stimuli during a task was examined thereby demonstrating the high usability, adaptability and flexibility of the visual stimulator and determine the optimal visual parameters for the subject comfort.For example, based on SSVEP experiment, this project has achieved an accuracy rate of 80% at the frequency of 13 Hz, 67.5% at 14 Hz, 72.5% at 15Hz, 77.5% at 16Hz, 75% at 17Hz and 66.25% at 18 Hz. For the ERP experiment, the accuracies were 73.75% and 85% for MFS-based ERP and MURS-based ERP, respectively.

Acknowledgements

First of all, we would like to express our sincere thanks to our project advisor, Dr.Montri Phothisonothai, for his invaluable help and guidance throughout the software project and provide the opportunities and experiences to us by giving a chance to presenting this project at the International Conference on 8^{th} Knowledge and Smart Technology (KST). We are most grateful for his teaching and advice. We would not have achieved this far without all the support that I have always received from him.

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Finally, we most gratefully acknowledge our parents for all their support throughout the period of this project.

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Chapter 1

Introduction

1.1 Motivation

Nowadays, The technology is used for the advantages in many fields, for example, an ultrasound machine in the medical field, a soil and crop sensor in the agriculture field, a robotic arm for move the product in industry field and also the several technologies for a facility in daily life. At present, one of the technologies which are interesting and important is technology to improve a quality of life of the disabilities. The invention of equipment which can be interacted by using non-muscular communication channel can help these kinds of people in daily life or in the emergency.

For those people with physical or mobile impairment, one of the common problems in daily life is that they cannot completely control equipment that is designed for ordinary people. Making the equipment for the disabled people to help them can be interacted or communicated by using brain signal instead of muscle that is one of the choices to solve their problem. The technology that obtains the brain signal and translates the brain signal to communicate or interact with the external device is called Brain-Computer Interface (BCI). At present, there are three types of BCI, divided by the stimulation : Auditory BCI Imaginary BCI and Visual BCI. Each type has the different advantages and disadvantages. First is the auditory BCI that is easy to analyze the brain signal but it has slow interpretation and the sound from this BCI can annoy other people. Next, imaginary BCI is the fastest way to stimulate the brain but the subject should be trained before using this BCI and it has a low rate of success. The last one is visual BCI that is the easiest way to obtain the brain signal However, it cannot use in case of the epilepsy person.

Our project will use the visual type of Brain-Computer Interface to control the application for the disabled people. We use brain signal from the subject to control programs or devices. When the user was stimulated by the flicker, the brain will generate waveform and be the different pattern from others.

1.2 Objective

The objective of this project is to make the user able to communicate or interact with our equipment by using brainwave. This can help the disabled people when they need some emergency or facilities.

Furthermore, our purpose is to study various techniques to record and translate the brainwave to interact with the external devices.

1.3 Scope of work

The scope of this project can be summarized as follows:

- Study the theories and techniques of recording EEG waveform.
- Make an equipment which a user can cognitively interact or use the system by brain-wave without using muscle function.

1.4 Contributions

In this project, we have developed a control module for users to interact with software by using EEG signal. Our work demonstrates a brand new alternative way to help users in a more convenient way or help immobilize-able users with limited control on their parts of the body. We hope that a control module and software that we have developed will provide great advantages and only minor disadvantages to the project.

1.5 Procedure

We separate that work into 6 phases.

1. Plan the project
2. Research and study on EEG cognitive
3. Design the equipment
4. Implement the system
5. Doing an experiment
6. Testing program

ID	Task Name	Duration	Start	Finish	Predecessors
1	1 ERP	81 days	Sat 8/15/15	Mon 12/7/15	
2	1.1 Lesson learn	23 days	Sat 8/15/15	Tue 9/15/15	
3	1.1.1 Emotiv	7 days	Sat 8/15/15	Mon 8/24/15	
4	1.1.2 10/20 system	7 days	Mon 8/24/15	Tue 9/1/15	
5	1.1.3 Optimal visual condition	7 days	Mon 8/21/15	Tue 9/1/15	
6	1.1.4 EEG	7 days	Mon 8/24/15	Tue 9/1/15	
7	1.1.5 ERP	10 days	Thu 8/27/15	Wed 9/9/15	
8	1.1.6 Digital signal processing	5 days	Wed 9/9/15	Tue 9/15/15	7
9	1.1.6.1 Peak detection	5 days	Wed 9/9/15	Tue 9/15/15	
10	1.1.6.2 Feature scaling	5 days	Wed 9/9/15	Tue 9/15/15	
11	1.2 Hardware design	10 days	Wed 9/2/15	Tue 9/15/15	5
12	1.2.1 Design the visual stimulator	10 days	Wed 9/2/15	Tue 9/15/15	
13	1.2.2 Design software control	10 days	Wed 9/2/15	Tue 9/15/15	
14	1.3 Software design	23 days	Wed 9/16/15	Fri 10/16/15	13
15	1.3.1 Software design pharse	15 days	Wed 9/16/15	Tue 10/6/15	
16	1.3.2 GUI phrase	13 days	Wed 9/16/15	Fri 10/2/15	
17	1.3.3 Emotiv status and real time graph	10 days	Mon 10/5/15	Fri 10/16/15	6,7,16
18	1.1 Implementation	26 days	Mon 10/19/15	Mon 11/23/15	14
19	1.4.1 Arduino- Control flicker	7 days	Mon 10/19/15	Tue 10/27/15	12
20	1.4.2 Implement visual stimulators	10 days	Wed 10/21/15	Tue 11/3/15	12
21	1.4.3 ERP feature extraction	10 days	Mon 10/19/15	Fri 10/30/15	7,17
22	1.4.4 Program function	15 days	Tue 11/3/15	Mon 11/23/15	16
23	1.4.4.1 music	7 days	Tue 11/3/15	Wed 11/11/15	
24	1.4.4.2 video	7 days	Tue 11/3/15	Wed 11/11/15	
25	1.4.4.3 etc.	9 days	Wed 11/11/15	Mon 11/23/15	
26	1.5 Experiment	43 days	Wed 9/16/15	Fri 11/13/15	12
27	1.5.1 Experiment	10 days	Wed 9/16/15	Tue 9/29/15	
28	1.5.2 Analysis	10 days	Mon 11/2/15	Fri 11/13/15	27,21
29	1.6 Testing	10 days	Tue 11/24/15	Mon 12/7/15	26,18
30	1.6.1 Testing program	10 days	Tue 11/24/15	Mon 12/7/15	
31	2 SSVEP	85 days	Mon 1/4/16	Sat 4/30/16	1

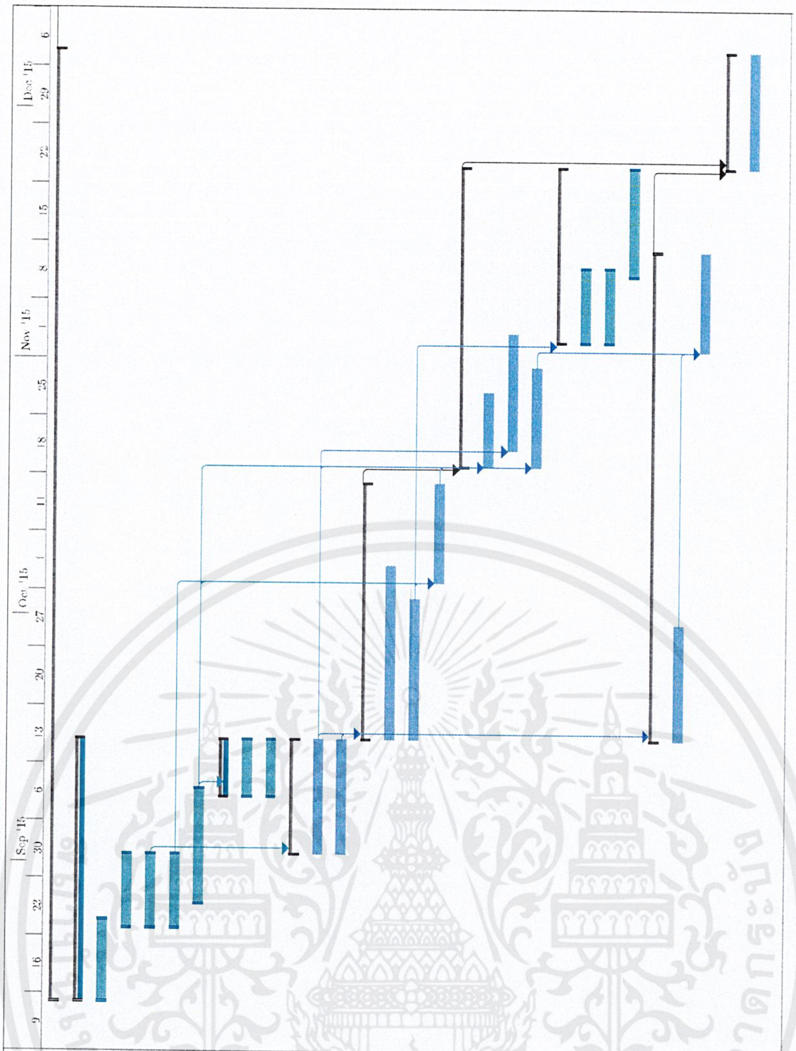

Figure 1.1: The grant chart to control the plan of project for semester one

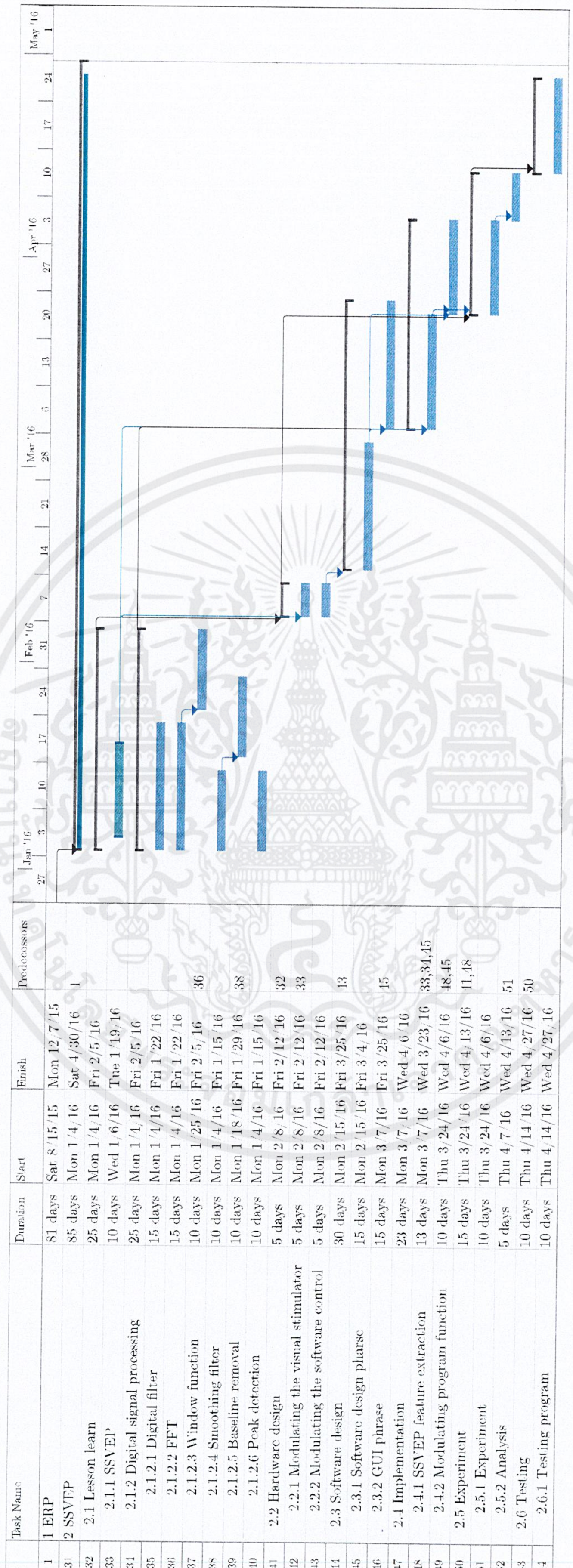

Figure 1.2: The grant chart to control the plan of project for semester two

Chapter 2

Problem description and related work

2.1 Problem description

Nowadays, there are many people who have been born with a disabled body from various reasons. Most of them always have a limitation of their living that be different from ordinary people. At present, one of the main problems of the disabled person is lacking help and ignore from other people. Using knowledge from the scientific and engineering field to make a brain-computer interface machine is the way to help these people to have the living like the ordinary people. For our project, we decide to assist the patient or physically disabled people that can't completely move their body part to interaction without helping from other people such as Paralysis, Spinal cord injured, Stoke and ALS.

2.2 Review of related works

2.2.1 Multitasking with BCI machine[1]

The multitasking with BCI machine experiment from EPFL Professor Jos del R. Millan. This experiment develops the BCI machine which allows the user to control the robot direction to move by using EEG signal and real-time communicate with other people via the camera that mount on the robot.

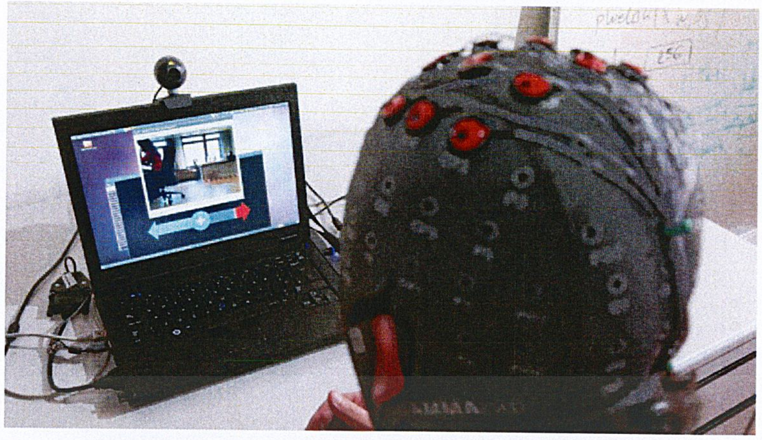

Figure 2.1: The subject control robot use brain wave and communicate via camera at same time

2.2.2 Real-time control of a robotic arm using a brain-computer interface[2]

SSVEP control of robotic arm experiment from the Applied Signal Processing in Engineering and Neuroscience Lab (ASPEN Lab) of Old Dominion University.

This Lab is used to develop an application which using EEG headset to control the robotic arm. The subject should gaze on the one of the flickers in front of him for control or command the direction of the robotic arm.

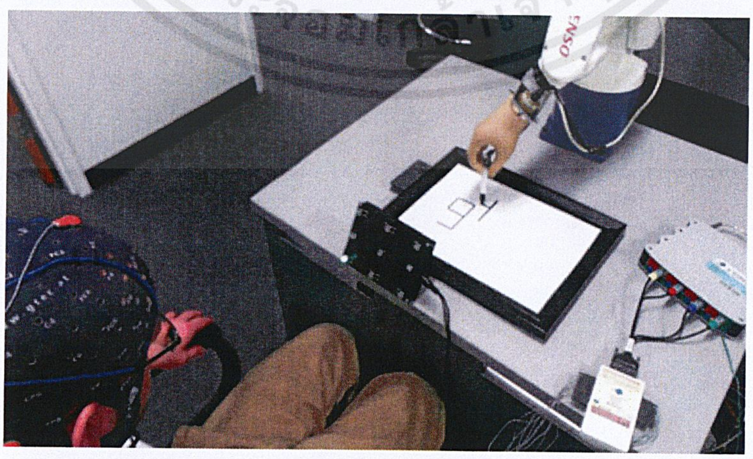

Figure 2.2: The subject control s robotic arm by fixate at stimulation ligth using SSVEP

2.2.3 Visual stimuli for the P300 brain-computer interface: A comparison of white/grey and green/blue flicker matrices[3]

P300 speller has mainly used white/grey flicker matrices as visual stimuli but they are not reducing the fatigue condition of the user. Parra and colleagues evaluated what color is reducing the fatigue condition of the user. In their study, five single-color stimuli have been implemented. There are white, blue, red, yellow and green.

In this experiment, the green/blue chromatic flicker emerged as the safest and evoked the lowest rate of EEG spikes. The result showed that the accuracy rate was higher in response to the luminance chromatic flicker condition(LC) than in response to the luminance(L) or chromatic(C) flicker condition.

In conclusion, most users preferred green and blue make them feel less strain on the eyes. The subjects found that they could use green stimulus for longer periods as compared with red and blue in all frequency range.

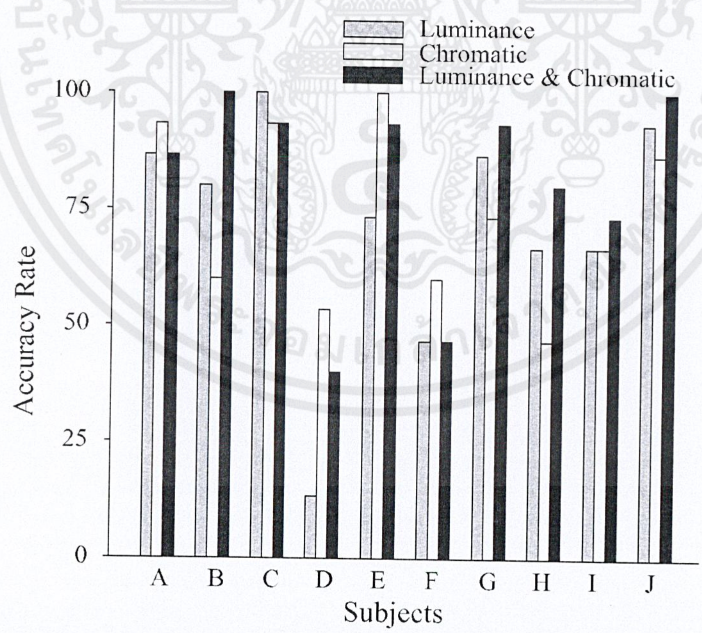

Figure 2.3: Accuracy rates for each subject. The accuracy rates in L, C, and LC conditions for each subject (AJ) are indicated by grey bars, white bars, and black bars, respectively.

2.2.4 Validation of the Emotiv EPOC EEG gaming system for measuring research quality auditory ERPs[7]

There are two kinds of equipment for obtaining a brain signal as follow: Researching headset and Gaming headset. Studying this research can be concluded that the Gaming headset can be use as well as the Research headset because of the result of an experiment showed that the characteristics of the Gaming headset's graph are very similar to the graph of Research headset.

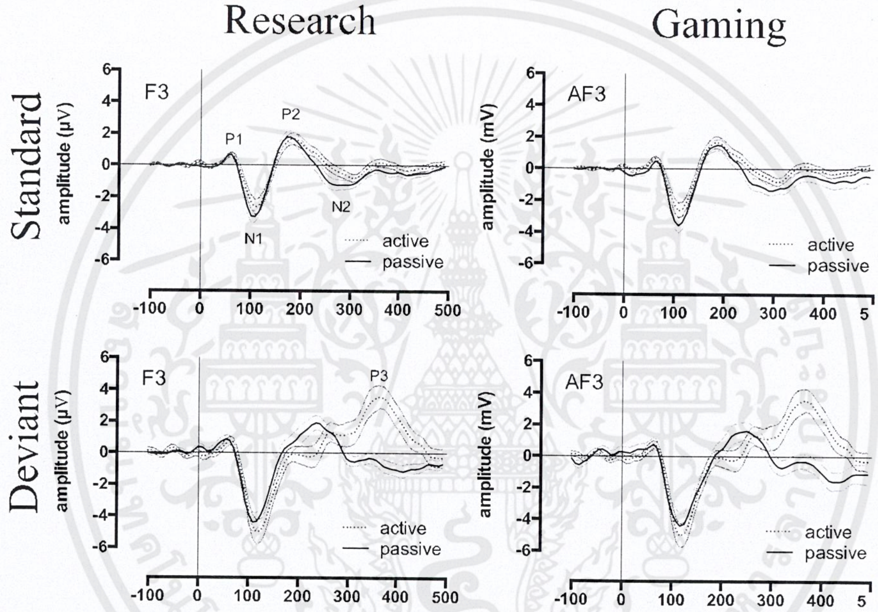

Figure 2.4: Research and gaming system ERP waveform by condition, tone type, and hemisphere. Group ERP waveform for research (left-side) and gaming (right-side) systems. All graphs display waveform for the passive and active (counting deviant tones) listening conditions. The upper 4 graphs depict the left-hemisphere-activity (F3 and AF3) and the lower 4 graphs depict the right-hemisphere-activity (F4 and AF4). Rows 1 and 3 depict waveform elicited by the standard tones, rows 2 and 4 depicts waveform elicited by the deviant tones. Error waveform (in gray) represent the standard error of the mean. For passive and active (counting deviant tones) listening conditions

2.2.5 c-VEP Brain-Computer Interface (BCI)[8]

Code-modulated visual evoked potentials (c-VEP) is one of the kinds of BCI. c-VEP uses pseudorandom code to modulate different visual stimuli. The figure 2.5 A shows the configuration and modulation of the c-VEP BCI system

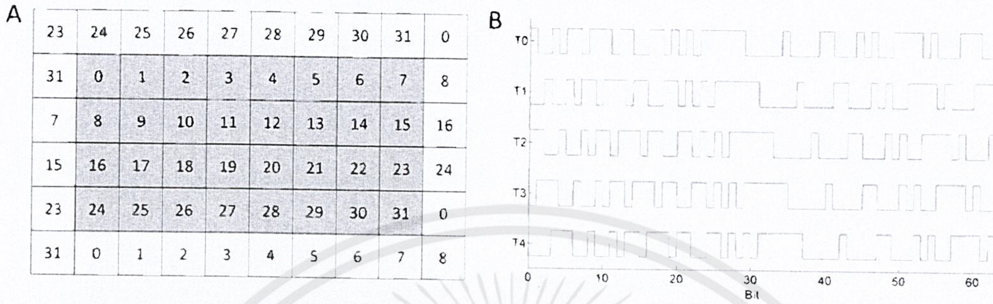

Figure 2.5: A: The gray area shows the 32 target stimuli with the number referring to number of target. The stimuli in white area are the complementary, which are synchronized to the target with same number. B: Modulation sequence for the first 5 targets. The sequence of a target is shifted by 2 bit in respect to its preceding target.

2.2.6 SSVEP-based brain computer interface using the Emotiv EPOC[9]

After the data was obtained from the headset, the two occipital channels were averaged together which help eliminated some noise between two channels. Because SSVEP is base on a particular frequency being present in the EEG data, the signal processing should be accomplished by using a Fourier transform to convert from the time domain into the frequency domain. After averaged the data, The result from converting is a frequency spectrum. Then, squaring the amplitude of each frequency component in this spectrum. This result was collected as active signal spectrum After that using a baseline removal method to further improve the results of signal isolation for the identification of SSVEP response. A baseline was recorded while the user was viewing a solid 50 percent gray screen without present any visual stimulation. After the data was recorded, Begin the method by using a Fourier transform with baseline spectrum and then reduce the noise by using a smoothing filter. Finally, the smoothed baseline spectrum was subtracted from the active signal spectrum. Finally, the result from this is the spectrum that can classify the observed data.

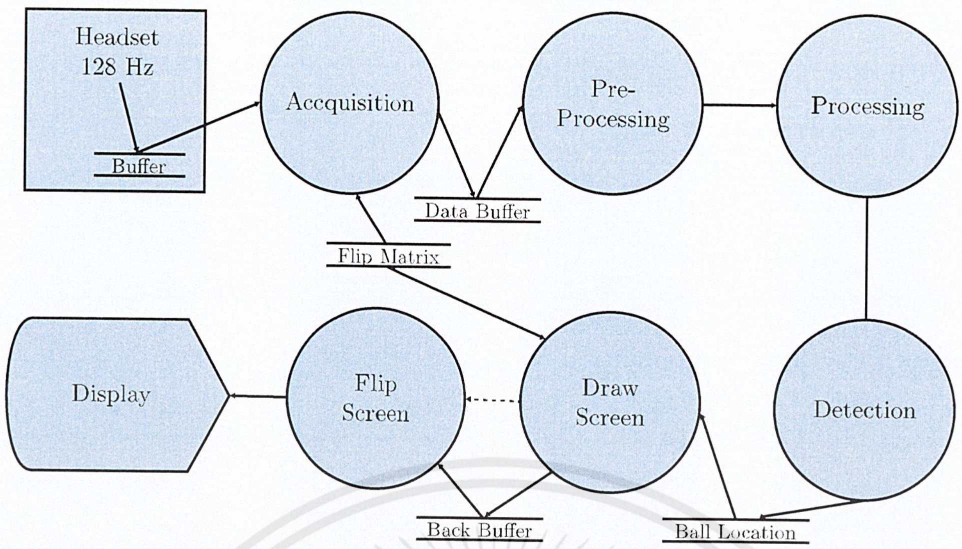

Figure 2.6: Diagram of data processing in EEG headset device [9]

2.2.7 A Survey of Stimulation Methods Used in SSVEP-Based BCIs[10]

The stimulus frequency can be divided into three bands. that is low (1-12 Hz), medium (12-30 Hz) and high (30-60 Hz). The largest SSVEP amplitudes were observed near 10 Hz followed by 16-18 Hz. Therefore, the most of the SSVEP-based BCIs use low and medium frequency bands. However, These two frequency bands have the disadvantage. First, the subjective evaluation shows that frequency between 5 and 25 Hz are more annoying than higher ones which visual fatigue would easily occur. Second, flash and pattern reversal stimuli can provoke epileptic seizures, especially in the 15-25 Hz range. 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 higher frequency band.

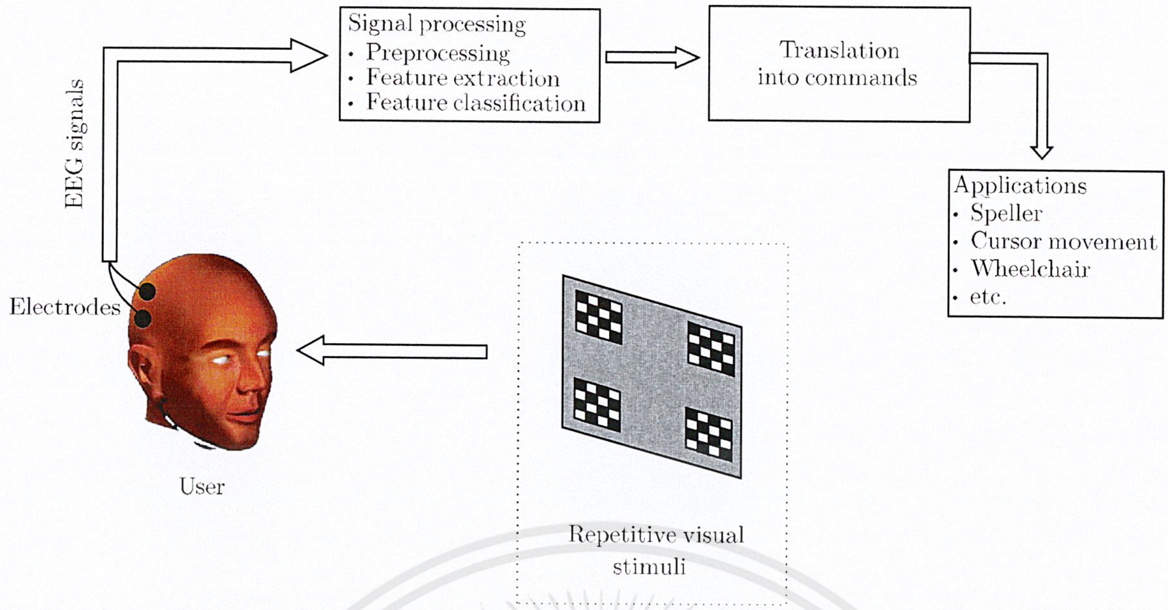

Figure 2.7: Functional model of an SSVEP-based BCI

2.2.8 Human EEG responses to 1-100 Hz flicker[11]

Human EEG responses to 1-100 Hz flicker is stimulated in visual cortex. Herrmann reported that the SSVEP responses exhibited resonance phenomena around 10,20,40 and 80 Hz

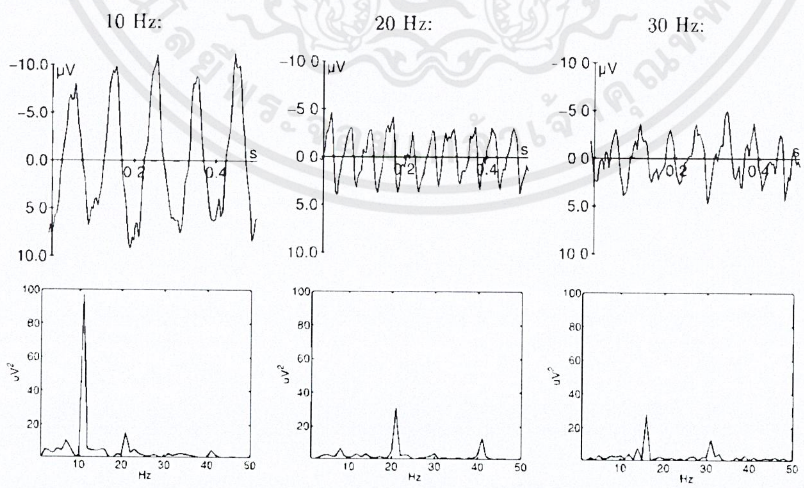

Figure 2.8: SSVEPs of a single subject in response to 10 Hz (left), 20 Hz (middle) and 30 Hz (right) stimulation (top row) and the corresponding FFT frequency spectra (bottom row)

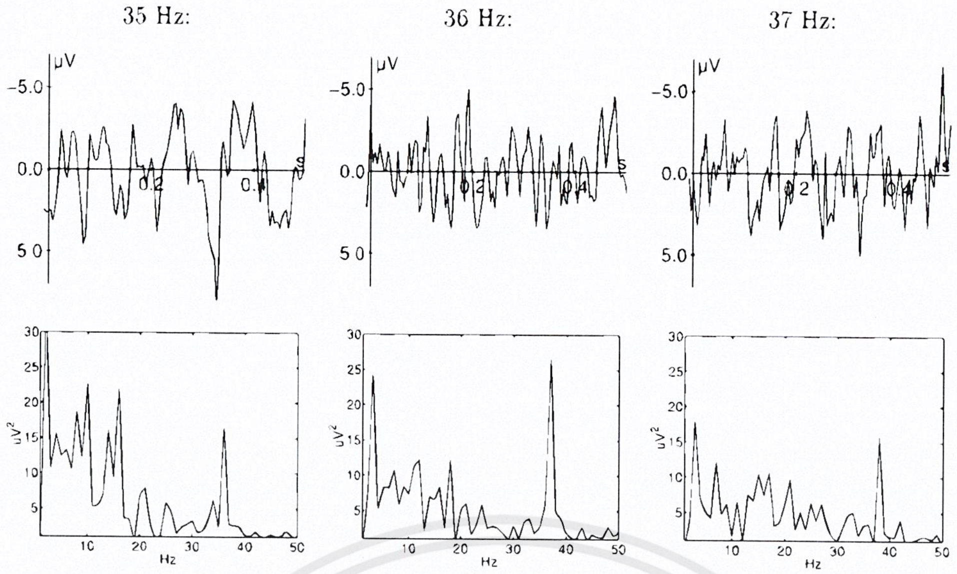

Figure 2.9: SSVEPs of a single subject in response to 35 Hz (left), 36 Hz (middle) and 37 Hz (right) stimulation (top row). The corresponding FFT frequency spectra show an increase of power at 36 Hz for 36 Hz stimulation (middle) as compared to adjacent frequencies (left and right)

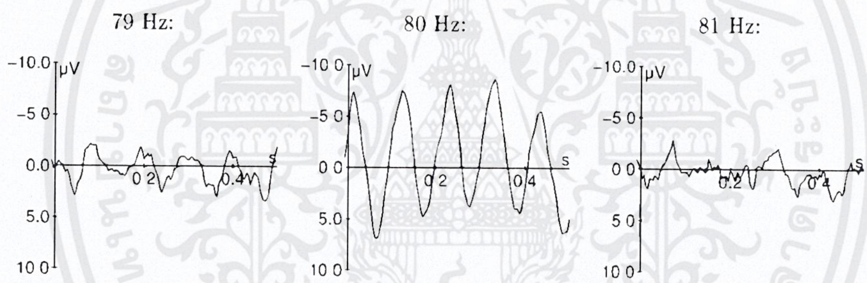

Figure 2.10: SSVEPs in response to flicker frequencies 79 (left), 80 Hz (middle) and 81 Hz (right). The VEP shows clear 10-Hz oscillations at 80 Hz which are not as prominent for the adjacent frequencies

2.2.9 Effect of higher frequency on the classication of steady-state visual evoked potentials[10]

This research developed an SSVEP-based BCI speller using multiple LEDs flickering with low frequencies (6 to 14.9 Hz) with a duty cycle of 50 percent, or higher frequencies (26 to 34.7 Hz) with duty cycles of 50 percent, 60 percent, and 70 percent. The four different experimental conditions were tested with 26 subjects in order to investigate the impact of stimulation frequency and duty cycle on visual fatigue by evaluated with a questionnaire survey after they did the experiment.The questionnaire used a five-level satisfaction rating score of 1

: unacceptable, 2 : uncomfortable, 3 : acceptable, 4 : comfortable, and 5 : delightful.

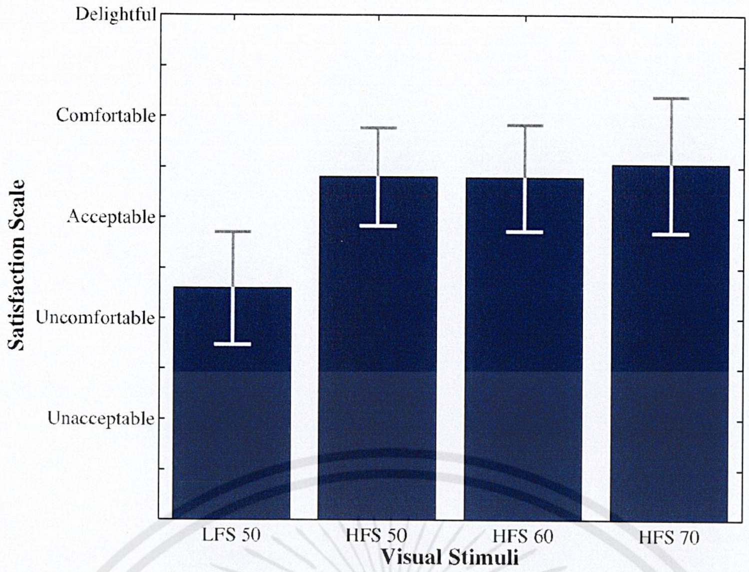

Figure 2.11: Comparison of visual fatigue scores obtained in the questionnaire survey. Higher scores indicate higher satisfaction.Most of subject evaluate that the LEDs flickering with higher frequencies with duty cycle of 70 percents is the most delightful.

Chapter 3

Background knowledge

3.1 Electroencephalography (EEG)

EEG is a technique for studying the electrical activities within the brain using electrodes that attached to the surface of the scalp. Wires attach these electrodes to a machine, which records the electrical impulses. The results are either printed out or displayed on a computer screen. A different pattern of electrical impulses can denote the various form of epilepsy[12]. It is also used to diagnose sleep disorders, coma, encephalopathies, and brain death.

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) refers to averaged EEG responses that are time-locked to more complex processing of stimuli. While Steady state visually evoked potential (SSVEP) refers to stable EEG waveform which has the same or multiple of the frequency of the visual stimulus

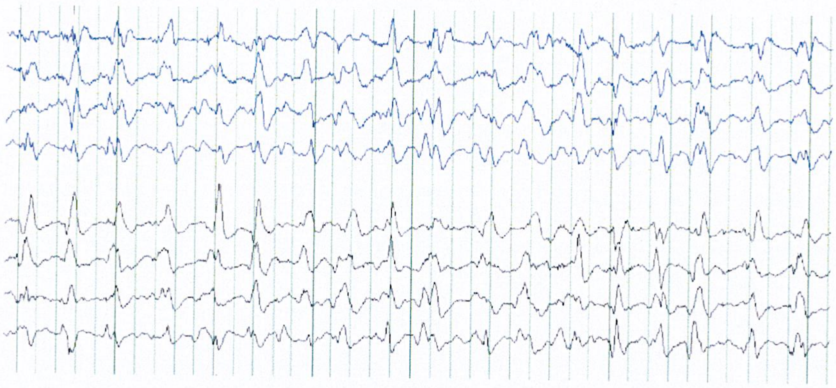

Figure 3.1: EEG signal

3.2 Event-related potential (ERPs)

Event-related potentials (ERPs) are very small voltages generated in the brain structures in response to specific events or stimuli. They measure brain response that is directed result of a specific sensory, cognitive or motor event. To see the brain's response to a stimulus, the experimenter must conduct many trials (usually in the order of 100 or more) and average the results together, causing random brain activity to be averaged out and the relevant waveform to remain, these stimuli can be visual, auditory, tactile and even olfactory and gustatory.

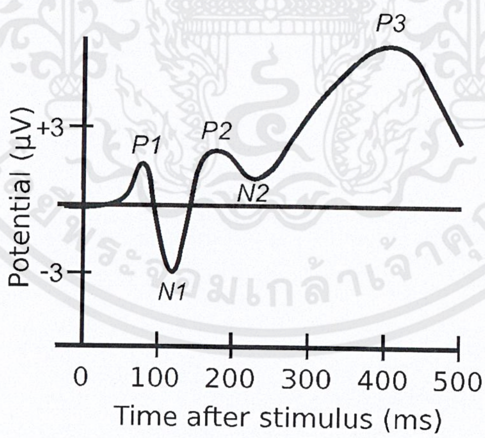

Figure 3.2: Averaged ERP waveform

3.3 Steady state visually evoked potential (SSVEP)

Steady State Visually Evoked Potentials or SSVEPs are EEG signals that are natural responses to visual stimulation. When the subject is in meditation state the brain will generate a stable EEG waveform. But when the subject's retina is stimulated by a visual stimulus which ranging from 3.5 Hz to 75 Hz, the brain generates electrical activity at the same or multiple of the frequency of the visual stimulus.

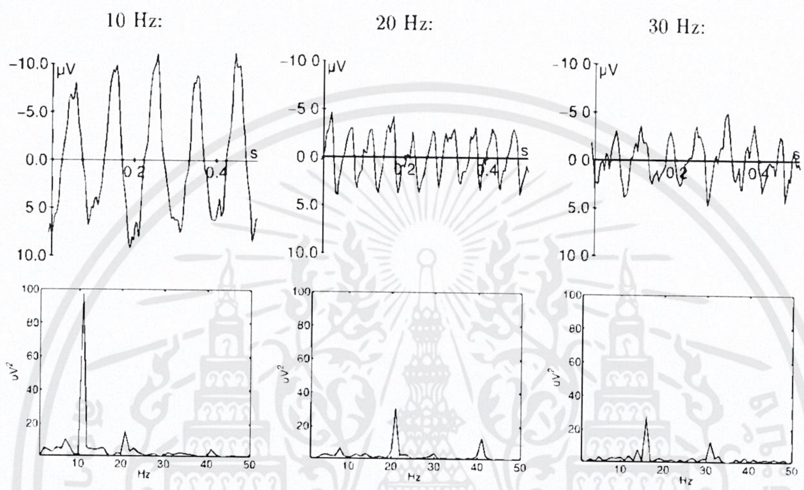

Figure 3.3: SSVEPs of a single subject in response to 10 Hz (left), 20 Hz (middle) and 30 Hz (right) stimulation (top row) and the corresponding FFT frequency spectra (bottom row)

3.4 Cerebral Cortex

The human brain consists of several parts. The part that makes human more intelligent than any animals are Cerebrum. The cerebrum is the largest part of human brain. The physician divides the cerebrum into four parts. There is frontal lobe, parietal lobe, temporal lobe and occipital lobe. The frontal lobe locates at the front of the brain. It controls the creative thought, thinking, problem solving and muscle movements. The parietal lobe locates behind the frontal lobe. It involved in the visual functions, languages, reading and sensory controls. Temporal lobe situates beneath both frontal lobe and parietal lobe. It implicates in control memories, speech and hearing languages. Occipital lobe locates at occipital. It related with a human vision controls. Due to our project study about the human visualization, so we focus on the occipital lobe

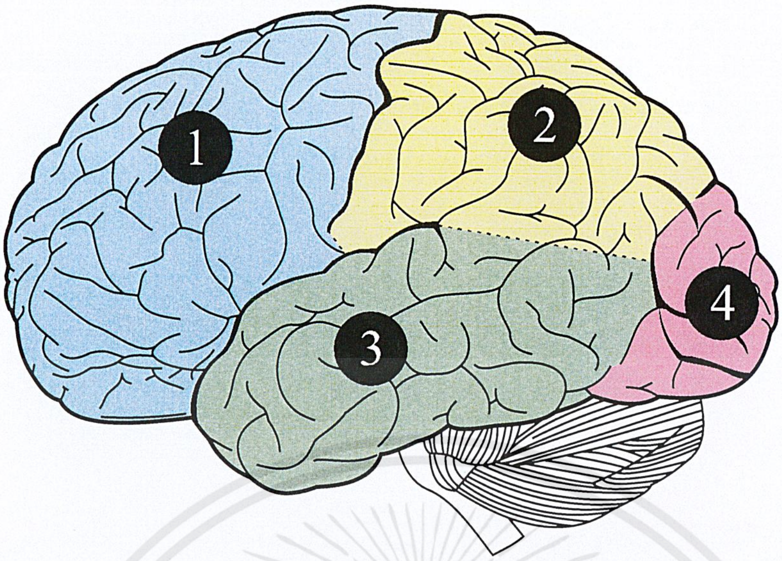

Figure 3.4: Cerebral cortex part 1.Frontal lobe, 2.Parietal lobe, 3.Temporal lobe, 4.Occipital lobe

3.5 Feature scaling (normalization)

Feature scaling is used to normalize the range of independent variables or features of data to have the properties of a standard normal distribution. To make in some machine learning algorithms work properly. It is usually performed while in the data pre-processing step. The calculation is determined the distribution mean and standard deviation for each feature. Next, we subtract the mean from each feature. Then divide the values which already subtracted by mean, by its standard deviation.[13]

$$x' = \frac{x - \overline{x}}{\sigma} \tag{3.1}$$

where x' is the original feature vector,$\overline{x}$ is the mean of the feature vector,σ and is its standard deviation.

3.6 Uniform distribution[14]

The Uniform or Rectangular distribution has random variable restricted to a finite interval $[a, b]$ and $f(x)$ has a constant density over the interval.

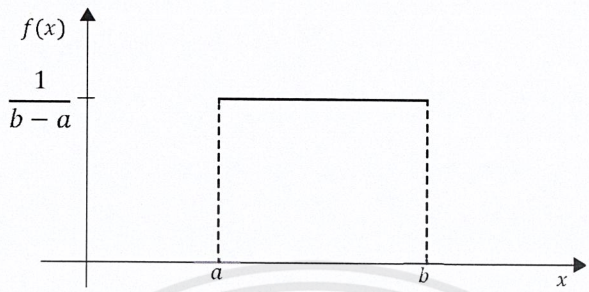

Figure 3.5: An illustrate of uniform distribution

The function $f(x)$ is defined by:

$$f(x) = \begin{cases} \frac{1}{b-a} & \text{if } a \leq x \leq b \\ 0 & otherwise \end{cases} \tag{3.2}$$

Where : $f(x)$ is distribution between a and b, a and b are boundary of distribution.

3.7 10/20 international system

The 10/20 international system is a recognized method to describe and apply the location of scalp electrodes in the context of EEG test. This system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. The 10/20 international system refers to the actual distance between adjacent electrodes are either 10 % or 20 % of the total front-back or right-left distance of the skull. Each site has letters to identify the lobe and a number to identify the hemisphere location. The letters F stands for frontal lobe, T is temporal lobe, C is central lobe, P is parietal lobe, and the last one is O means occipital lobe. Even numbers refer to electrode positions on the right hemisphere and odd numbers refer to the electrode positions on the left hemisphere.

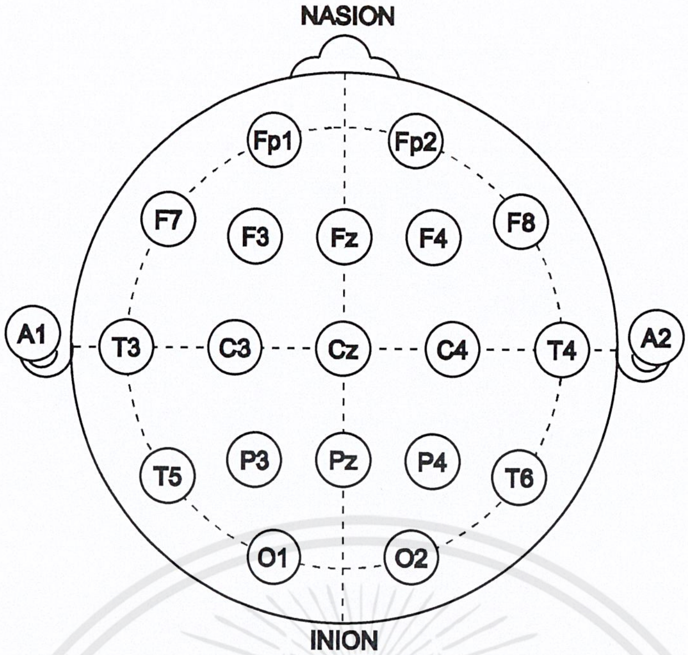

Figure 3.6: International 10-20 locations system[15]

3.8 Standard deviation

Standard deviation(SD) is a measure of the spread of scores within a collection of data. If the SD is high, the distribution is high. If the SD is low, the distribution is low.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}} \tag{3.3}$$

Where : σ is a sample standard deviation, $\bar{x}$ is mean of the sample, x_i is the i^{th} measurement, N is number of sample.

3.9 Low-pass filter

The Low-pass filter only allows the frequency signal that is below cut-off frequency.

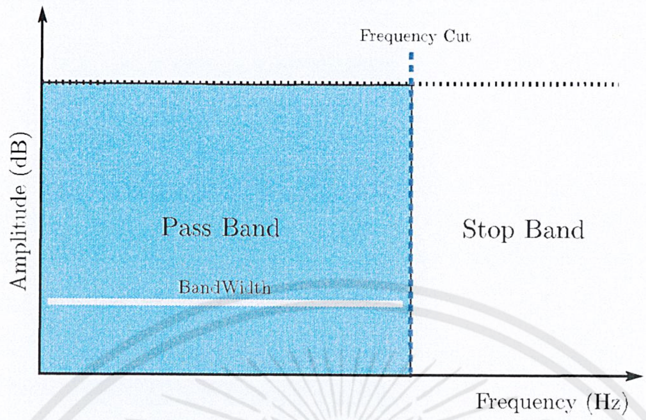

Figure 3.7: Low-pass filter

3.10 High-pass filter

The High-pass filter only allows the frequency signal that is higher than cut-off frequency.

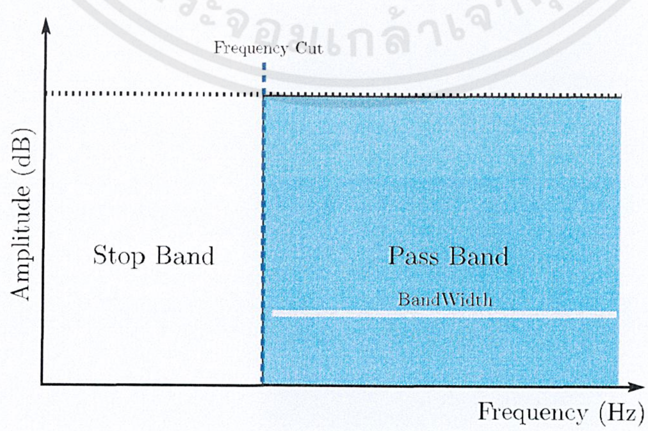

Figure 3.8: High-pass filter

3.11 Band-pass filter

The Band-pass filter only allows the frequency signal that is in the specified range.

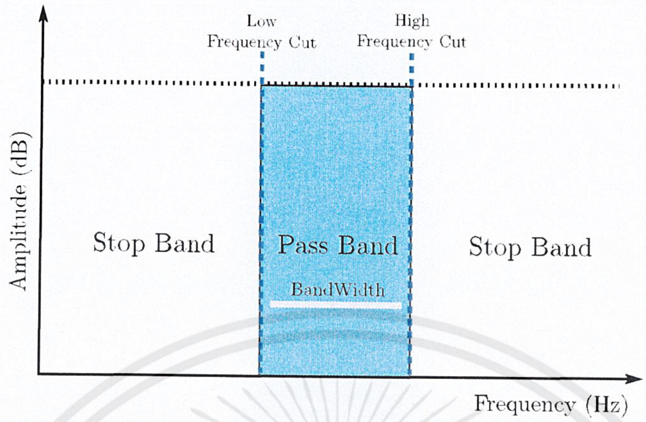

Figure 3.9: Band-pass filter

3.12 EEG band [5]

EEG band determined as a fixed range of wave frequency and amplitudes over a time scale. In Scientific field classify into 5 types,

3.12.1 Delta band δ

The lowest frequency in the range of 0-3 Hz. It occurs during the deepest levels of relaxation and restorative, healing sleep.

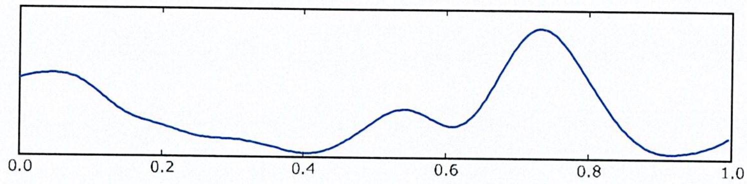

Figure 3.10: Delta Band

3.12.2 Theta band θ

The frequency ranges between 4-7 Hz. We can investigate the situation of intuitive, creative and imagery.

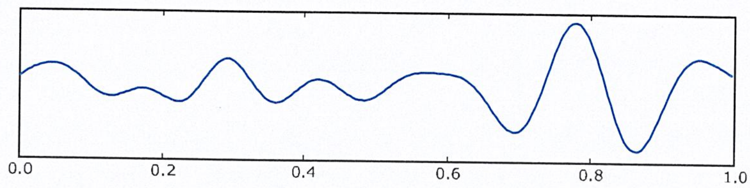

Figure 3.11: Theta Band

3.12.3 Alpha band α

The frequency ranges between 8-12 Hz. it is a gap between conscious thinking and subconscious mind. It occurs during the situation that our mind calm, so we can obtain the strongest EEG brain signal in this frequency range.

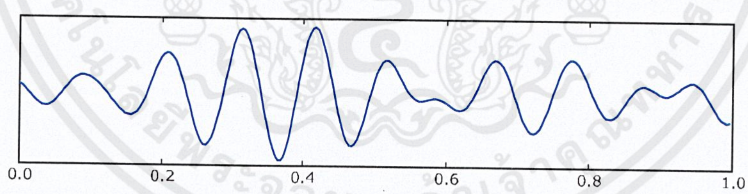

Figure 3.12: Alpha Band

3.12.4 Beta band β

The frequency range between 12-30 Hz.it is known as high-frequency low-amplitude that usually occur while awake. We can investigate this band at the situation of memory, problem-solving conscious thought and, logical thinking.

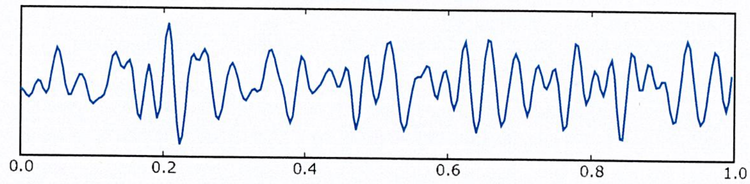

Figure 3.13: Beta Band

3.12.5 Gamma band γ

The frequency ranges between 30-100 Hz. This wave may be implicated in creating the unity of conscious perception and are involved in learning new material, higher processing tasks and, cognitive functioning.

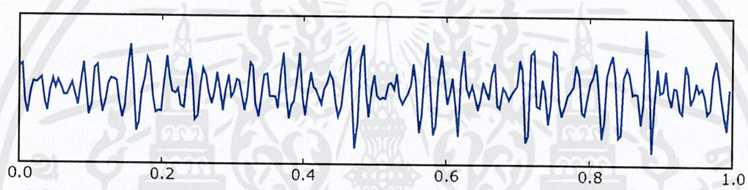

Figure 3.14: Band-pass filter

3.13 Fourier transform

The Fourier transform is the mathematical model which uses to transform signal in the time domain into the frequency domain. Every signal can be broken down into a combination of a trigonometric function. The amplitude of each the frequency are note down in the frequency spectrum.

From the figure 3.15, the first graph is the signal in the time domain that is a periodic square wave. The second graph is a square wave are decomposed to sin and cosine function. The last graph is amplitudes of the second graph, which is a frequency spectrum

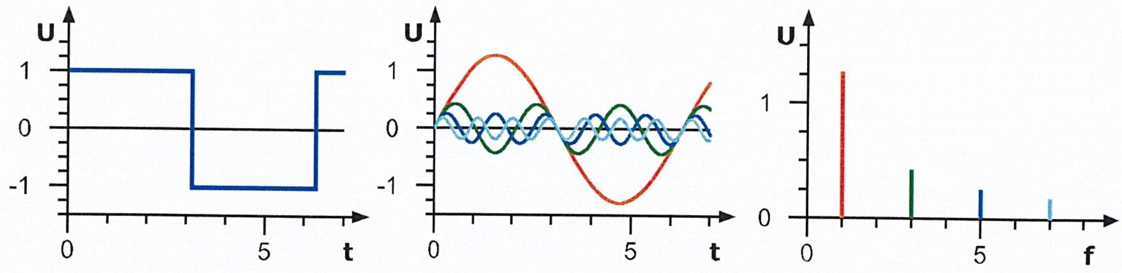

Figure 3.15: Fourier transform concept[4]

3.13.1 Continuous Fourier transform

The Fourier transform for continuous signal.

$$\hat{f}(\xi) \equiv \int_{-\infty}^{\infty} f(x)e^{-2\pi jx\xi}dx \tag{3.4}$$

Where x is time variable and ξ is frequency

3.13.2 Discrete Fourier transform

The Fourier transform for discrete signal.

$$X_k = \sum_{i=1}^{N} x_i e^{-2\pi ij/N} dx \tag{3.5}$$

Where k is discrete variable and N is sampled data point x_j(where $j = 1, 2, 3, ..., N$)

3.13.3 Fast Fourier transform

Fast Fourier transform (FFT) is a algorithm to perform Fourier transform, Which reduce complexity of Discrete Fourier transform from $O(n^2)$ to $O(n \log n)$ where n is data size.

3.13.4 Windows function

Windows function is the mathematical function that used to improve artifacts of the Fourier transform by dividing the large time signal into a small subset of the total signal before applying the FFT.

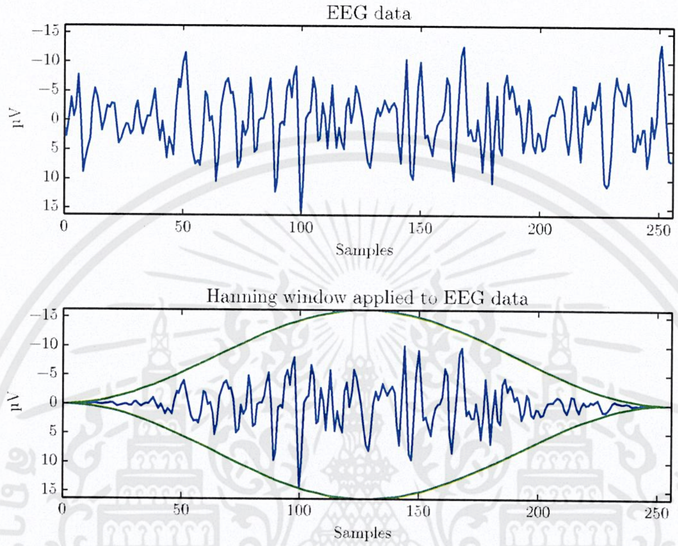

Figure 3.16: Shows an example of a Hanning window applied to EEG data[4]

3.14 Smoothing filter

Smoothing filter is the method that uses to eliminate random the noise in the signal or reduce a warping in the signal or used to see the trend line of the signal. The simplest smoothing filter is the moving average, it is easy to understand and use. It operates by averaging number in a range of point from the input signal. to produce each point of the output signal.

$$y[i] = \frac{1}{M} \sum_{j=1}^{M-1} x[i+j] \tag{3.6}$$

Where : $x[\ ]$ is the input signal, $y[\ ]$ is the output signal, M is the number of point in the average.

3.15 Baseline removal

Baseline removal is the peak analysis technique that used to improve the signal by removing the baseline from the data either by including a baseline function when fitting a sum of functions to the data or by actually subtracting a baseline estimate from the data. Baseline was established by recording the EEG data while the user was not being presented with any stimulus.

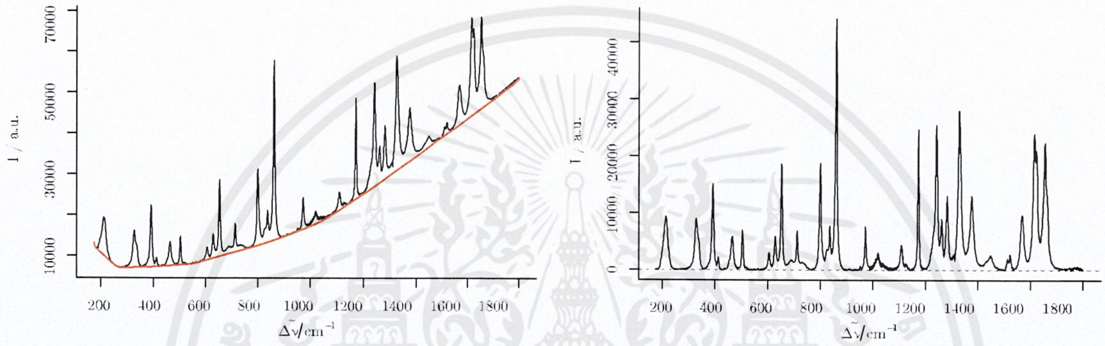

Figure 3.17: The left graph is shown the baseline of the signal in red line. After correct the baseline, the result is the right graph[6]

3.16 Material background

3.16.1 Gravitech Gerora LED[16]

The full-color Light-emitting diode (LED) driver which is use for stimulating the subject has an LED light WS2812 model mounted on. It can chain connected with the same model. It can be controlled by a programmed Arduino. The luminous intensity is 550 to 700 mega candela for red, 1100-1400 mcd for green, and 200-400 mcd for blue.

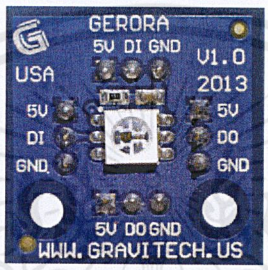

Figure 3.18: Gravitech Gerora LED base on WS2812

3.16.2 Arduino UNO[17]

The Arduino Uno is a microcontroller board based on the ATmega328 that is an open source platform. It has 14 input/output pins6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. The USB connection for upload the software into the Arduino and VCC or supply for connecting the peripheral circuit.

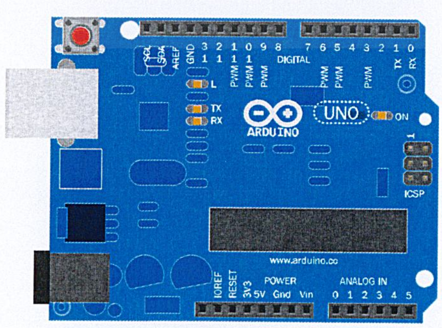

Figure 3.19: Illustrate of Arduino UNO board

3.16.3 EPOC headset by Emotiv™[18]

The wireless headset Emotiv EPOC research edition, it records EEG data in 14 channel of International 10-20 Locations system with Sequential sampling rate at 128 per second (2048 Hz internal) with resolution 14 bit (16 bit Analog to digital converter, 2-bit instrumental noise floor discarded), the bandwidth is in range 0.2 to 45 Hz with digital notch filters at 50Hz and 60 Hz

Figure 3.20: EPOC headset by Emotiv™

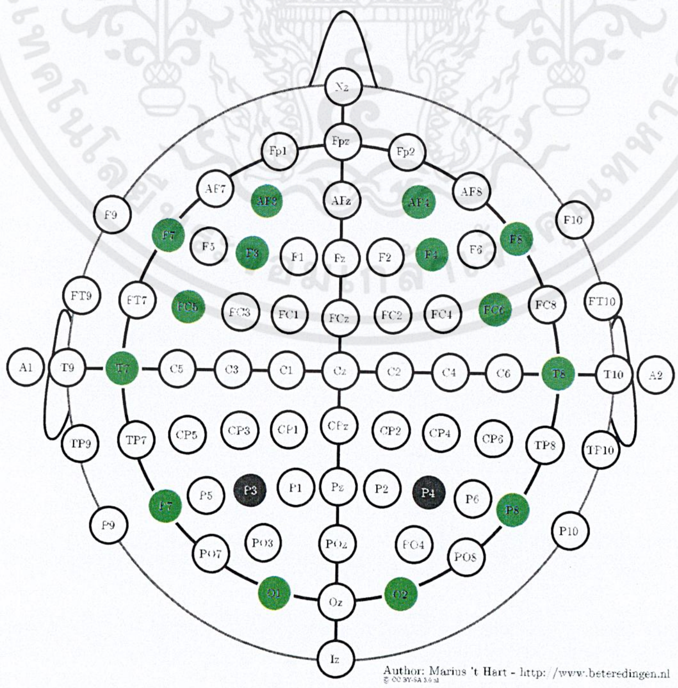

Figure 3.21: Wireless EEG Emotiv hardware layout in 10/20 international system. All available channels are marked in green. Reference channels are marked in black

Features	Emotiv EEG neuroheadset
Number of channels	14 (plus CMS/DRL references, P3/P4 locations)
Channel names (International 10-20 location)	AF3,F7,F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4
Sampling method	Sequential sampling. Single ADC
Sampling rate	128 samples per second (Hz) (2048 Hz internal)
Resolution	14 bits 1 LSB = 0.51 μV (16 bit ADC, 2 bits instrumental noise floor discarded)
Band width	0.2-45 Hz, digital notch filters at 50 Hz and 60 Hz
Filtering	Built in digital 5th order Sinc filter
Dynamic range (input referred)	8400 μV (pp)
Coupling mode	Ac coupled
Connectivity	Proprietary wireless, 2,4 GHz band
Power	Li-poly
Battery life (typical)	12 hours
Impedance Measurement	Real-time contact quality using patented system

Table 3.1: Emotiv EPOC features, taken from `http://emotiv.com/upload/manual/sdk/EPOCSpecifications.pdf`

Chapter 4

Requirement analysis and Software design

4.1 Requirement for application

4.1.1 Functional requirement

- The system allows user to control machine using brainwave.
- The system allows user to check the EEG headset status.
- The system allows administrator to see the authentication result.
- The system allows administrator to see real-time graph of each band.
- The system allows administrator to check the EEG headset status.
- The system allows user to save information into the system.
- The system shows the analysis result.
- The system allows user to access the functions in the program using brainwave.

4.1.2 Non-functional requirement

- The system uses C# language to develop software.
- The system uses Windows Presentation form and Visual studio to create user interface.
- User friendly: The UI is look clear, simple, easy to use and understand.
- Performance: The system shows and records the EEG brainwave in real-time.

4.2 Use case Diagram

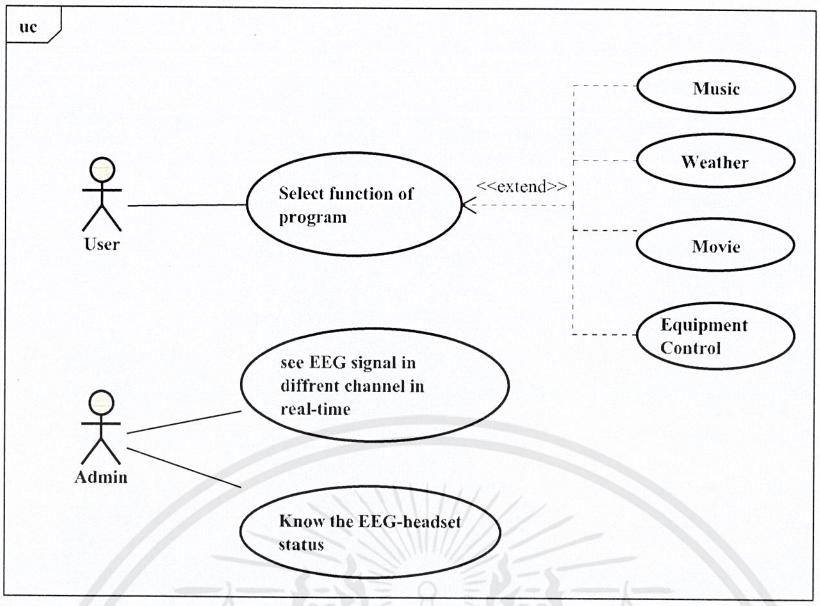

Figure 4.1: Use case diagram for ERPs

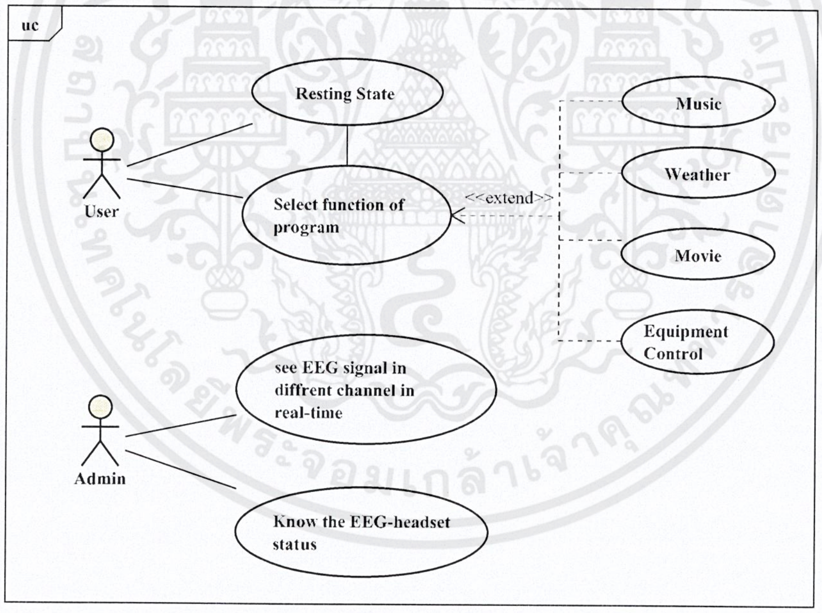

Figure 4.2: Use case diagram for SSVEP

4.2.1 Use case description for user and admin

- **Expanded description of "Know the EEG-headset status use case"**

Use case: Know the EEG-headset status

Actor: Admin

Goal: To make sure that the Emotiv headset will record EEG with the proper signal.

Overview: The admin will equip the Emotiv headset on the subject(user) head then observes the EEG-headset status to make sure that Emotiv headset will record SSVEP with the proper signal for the starting program for subject.

Typical course of events:

User	System
1. Subject asks admin to access the system	
2. Subject is equipped the Emotiv headset by admin	
	3. The system returns the EEG-headset status (Green light) to admin
4. Admin starts the program for subject	

Alternative: The system returns poor EEG-headset status (red light) to admin and admin will move the EEG-headset to proper position (status green light) before admin starts the program.

- **Expanded description of the "See EEG signal in different channel real-time" use case**

Use case: See EEG signal in different channel real-time.

Actor: Admin

Goal: to observe the abnormal activities of brainwave and subject.

Overview: Admin must observe everything which take place in the chamber even the subjects EEG to make sure that everything works fine.

Typical course of events:

User	System
1. Subject asks admin to access the system	
2. Subject is equipped the Emotiv headset by admin	
3. Subject fixates on the flickers of stimulus	
4. Admin observes subject brainwave signal in different channels	
	5. The system accepts the EEG of user

Alternative: Admin detects the abnormal magnitude EEG waveform then asks the subject to re-equip again.

- **Expanded description of the "See peak of frequency domain" use case**

Use case: See peak of frequency domain

Actor: Admin

Goal: To let admin know that the system is in work in progress

Overview: The system allows the admin to see the peak of the frequency domain to let admin ensure that the system is calculating the subjects feature pattern while recording their SSVEP waveform.

Typical course of events:

User	System
1. Subject asks admin to access the system	
2. Subject is equipped the Emotiv headset by admin	
3. Subject fixates on the flickers of stimulus	
	4. The system will calculate the feature pattern and show the result of calculation to admin
5. Admin observes the subject's peak frequency domain	

- **Expanded description of the "Resting state" use case**

Previous cases: -

Use case: Resting state

Actor: User

Goal: To obtain the EEG of user in general state which use to compare with other state.

Overview: This is a step that every user must pass this step to control the program in next step. The EEG of the user that be obtained in this step we use it like a baseline.

Typical course of events:

User	System
1. Subject asks admin to access the system.	
2. Subject is equipped the Emotiv headset by admin	
	3. The system will show the status of Emotiv headset
4. Admins will tell subject about Emotiv's status is good	
5. Subject fixates on the flickers of stimulus	
	6. The system will obtain the EEG of subject to use in next step

- **Expanded description of the "Select the menu program" use case**

Previous cases: Resting state

Use case: Select the menu program

Actor: User

Goal: To be granted select the menu program from the system.

Overview: This is also the step that every user who want to grant select the menu to control the program. The EEG of the subject has to match to the EEG that subject is recorded the baselines EEG.

Typical course of events:

User	System
1. Subject passed the resting state process	
2. Subject fixates on the flickers of stimulus	
	3. The system will record the subject's EEG
	4. The system will match the EEG with the EEG of subject's baseline
	5. The system will determine what menu that user want to select
	6. The system will select the menu of the program

- **Expanded description of the "Music" use case**

Previous cases: Select function of program

Use case: Music

Actor: User

Goal: To access the function of menu program to play the music in program.

Overview: This is a step when subject pass the select function of program state. There are many function of program, this state is one of the functions of program.

Typical course of events:

User	System
1. Subject passed the select function of program process.	
	2. The system will access the music function of the program to play music.
	3. The system will show the function of the music program.
4. Subject fixates on the flicker of stimulus	
	5. The system will record subject's EEG
	6. The system will match the EEG with the EEG subject's baseline
	7. The system will detect the function of the music program

- **Expanded description of the "Weather" use case**

Previous cases: Select function of program

Use case: Weather

Actor: User

Goal: To access the function of menu program to show the weather of the day.

Overview: This is a step when subject pass the select function of program state. There are many function of program, this state is one of the functions of program.

Typical course of events:

User	System
1. Subject passed the select function of program process.	
	2. The system will access the music function of the program to show the weather.
	3. The system will show the function of the weather program.
4. Subject fixates on the flicker of stimulus	
	5. The system will record subject's EEG
	6. The system will match the EEG with the EEG subject's baseline
	7. The system will detect the function of the weather program

- **Expanded description of the "Movie" use case**

Previous cases: Select function of program

Use case: Movie

Actor: User

Goal: To access the function of menu program to play the movie.

Overview: This is a step when subject pass the select function of program state. There are many function of program, this state is one of the functions of program.

Typical course of events:

User	System
1. Subject passed the select function of program process.	
	2. The system will access the music function of the program to play the movie.
	3. The system will show the function of the movie program.
4. Subject fixates on the flicker of stimulus	
	5. The system will record subject's EEG
	6. The system will match the EEG with the EEG subject's baseline
	7. The system will detect the function of the movie program

- **Expanded description of the "Equipment control" use case**

Previous cases: Select function of program

Use case: Equipment control

Actor: User

Goal: To access the function of menu program to control the equipment.

Overview: This is a step when subject pass the select function of program state. There are many function of program, this state is one of the functions of program.

Typical course of events:

User	System
1. Subject passed the select function of program process.	
	2. The system will access the music function of the program to control the equipment.
	3. The system will show the function of the equipment control program.
4. Subject fixates on the flicker of stimulus	
	5. The system will record subject's EEG
	6. The system will match the EEG with the EEG subject's baseline
	7. The system will detect the function of the equipment control program

4.3 Activity Diagram

4.3.1 Activity diagram of resting state

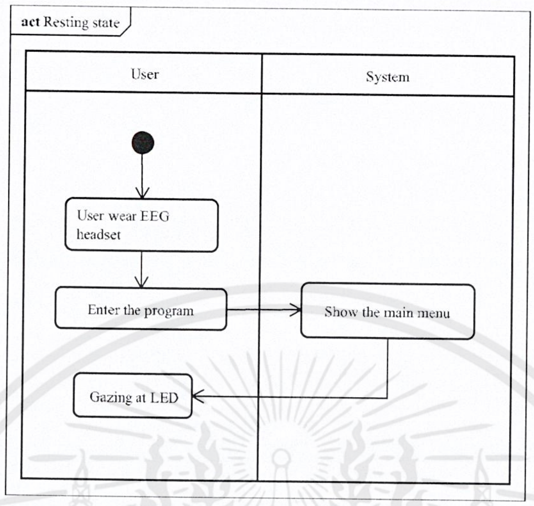

Figure 4.3: Activity diagram of resting state

4.3.2 Activity diagram of ERP

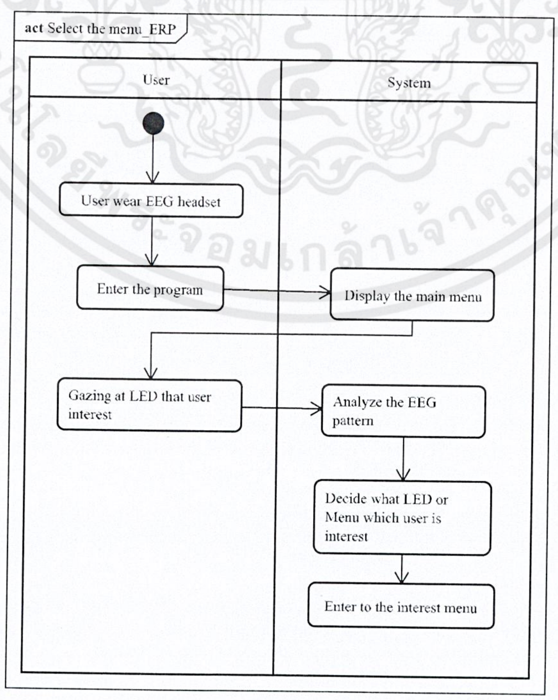

Figure 4.4: Activity diagram of ERP

4.3.3 Activity diagram of SSVEP

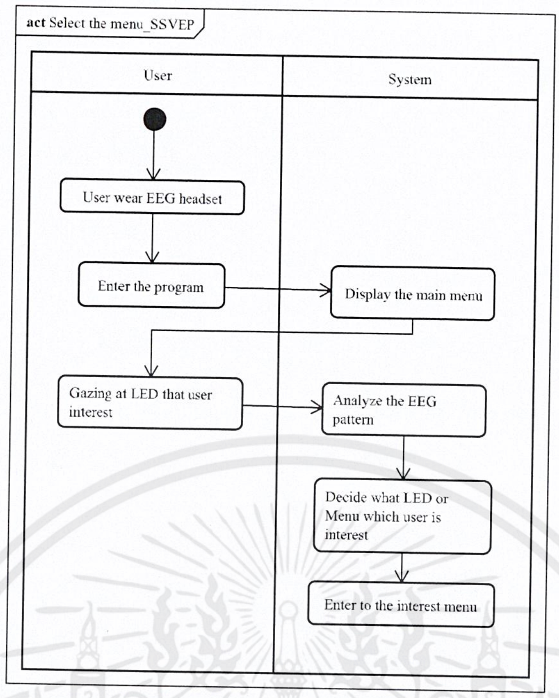

Figure 4.5: Activity diagram of SSVEP

Chapter 5

Software design

5.1 System architecture

In our project, we use two algorithms to stimulate the subject. First, we use ERPs which is different in stimulating time. Second is SSVEP which difference in stimulating frequency. This is our system architecture design.

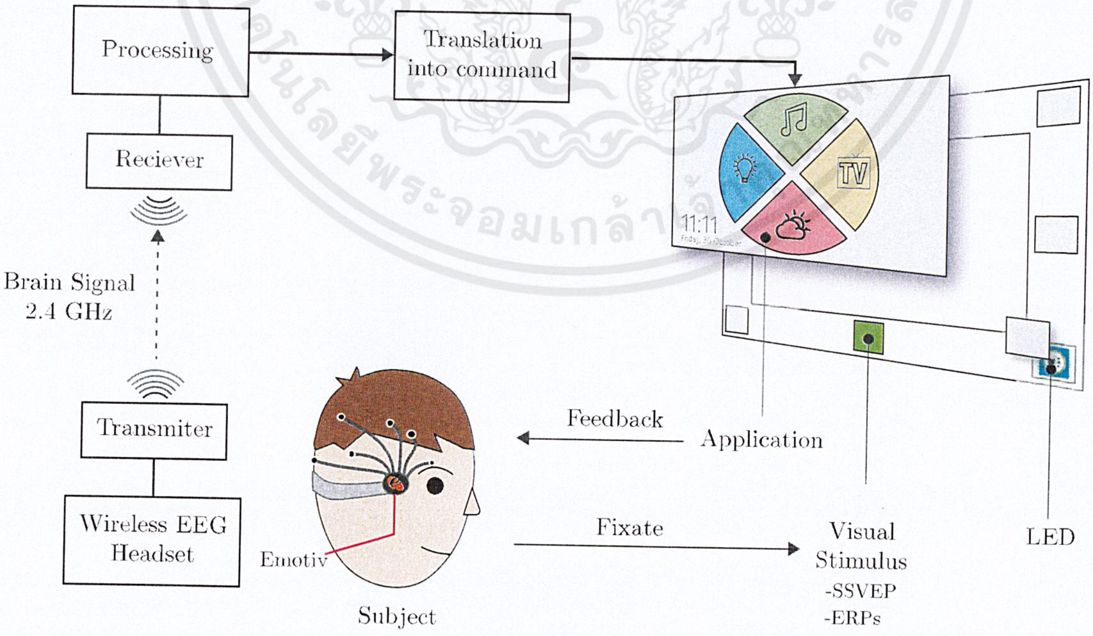

Figure 5.1: System architecture design

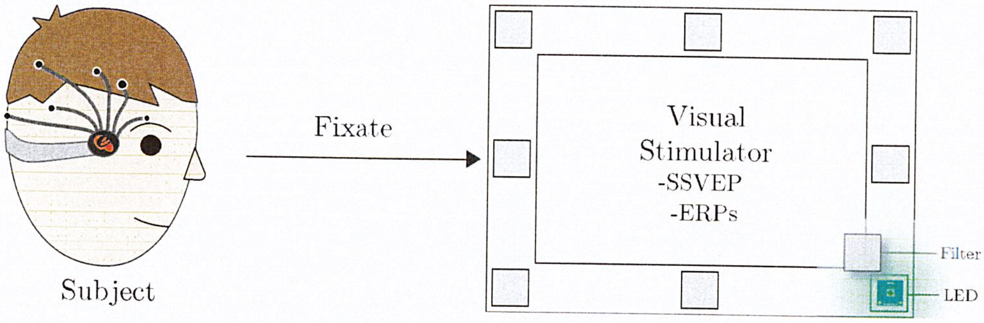

Figure 5.2: Subject fixate at visual stimulator target

5.1.1 Visual stimulator

In each visual stimulator, a target is contained with one LED to make light stimuli. We use Gravitech Gerora RGB LEDs to be a light source, which is controlled by Arduino Uno. The parameter of LEDs is consisted of flickering frequency, duty cycles, intensity, color, status tell it is turned on or off. It can use in ERPs and SSVEP method.

In ERPs method, we use visual stimulator with four targets, because it takes a lot of time to surely classify. To make a classification process fast. The optimal number of target for the program to operate is four.

In SSVEP method, we use visual stimulator with eight targets. Because it takes less time than ERPs. The functional is similar to ERPs method, but it adds four function shortcuts.

5.1.2 Wireless EEG Headset

To use the application subject has to fixate at the stimuli target which has different functional. Before the experiment, the subject has to equip the EEG recording headset. We use Emotiv Epoc, a wireless EEG headset to recording the EEG. Then subject has to fixate at the stimulation, the brain will generate a ERPs or SSVEP, the wireless headset will record it. Because it is visual, the position in 10-20 system that used to record EEG is O1 and O2. Then we can use for classification. Then the recorded brainwave will be transmitted via 2.4GHz wireless for further processing.

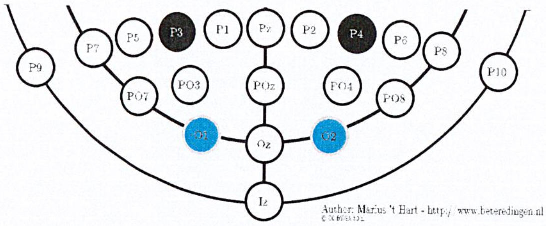

Figure 5.3: The location of electrodes recorded on occipital lobe(O1 and O2) in this project

5.1.3 Processing

The processing process is receiving a recorded EEG signal result from the wireless headset via the 2.4GHz wireless receiver. The ERPs and SSVEPs will use a different algorithm to process. To know which target subject fixate at, in ERPs, we will use P300 theory. In SSVEP, we will use Fourier Transform. Then it will send classification result to translate into command.

5.1.4 Translate into command

After we know which target subject fixate at, it will be translate into command. Because each target is associated with one function, then it will match the target from processing with the function. And it will tell the application to do that function. the subject will get feedback that it do function that they want.

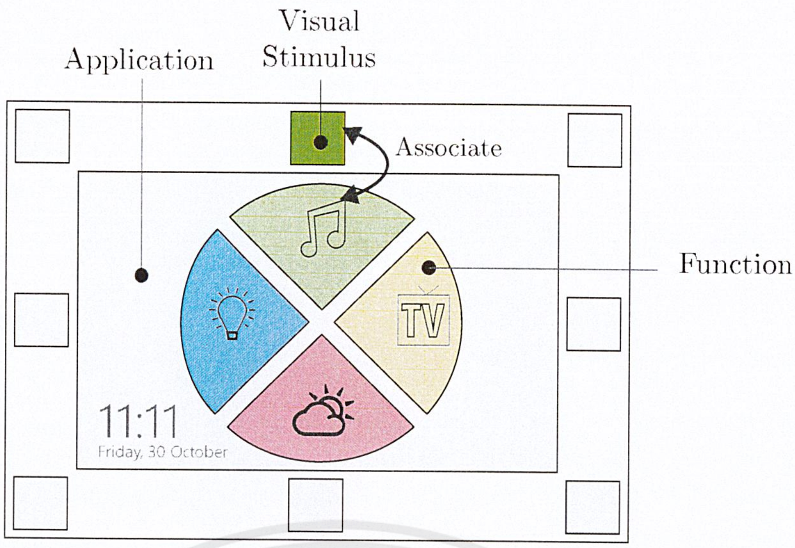

Figure 5.4: The application with visual stimulator, each visual stimulus target are associated with a function. In the figure the top center visual stimulus is associated with the green function. If the subject fixate at the top center, the application will open the music page.

5.2 Class Diagram

Class diagram description, starting with the most importance class, EventController, it is connecting Emotiv headset to system, PageSwitcher, and Serial communication classes together to make a program work in unison,

EmoEngin is a library use for connecting our program to an Emotiv headset. Emotiv class is a substitute of a headset. It has a property of wireless signal quality, electrode contact quality, battery level which is obtained via EmoEngin. The signal class represents the EEG signal that obtains from Emotiv headset. In this project is use the only occipital channel, so the attribute is only O1 and O2. The SignalProcessing class contains an algorithm to process EEG signal to a frequency domain to perform analysis and to have standardized by normalization. The Classifier class is to classify a feature from the processed signal. the result will tell which flicker user fixate at. then it will send the result to EventController to do further step.

After obtaining the result from classification, the EventController will tell the page switcher to change page. EquipmentUI, MusicUI, MovieUI, NewfeedUI, all the user interface pages inherit from UI interface for PageSwitcher can easily control, also easily add new UI page.

The SerialCommunication Class is a class that connects to Arduino via Serial port. It will encode a control command to Arduino to control the LEDs , which Arduino part also have a SerialCommunication class to decode the command that receives via a serial port. Then it will send the command to LEDController to control the LEDs via Arduino's pin. LED class represents for an LEDs. It can control to turn on or off , change color, and frequency.

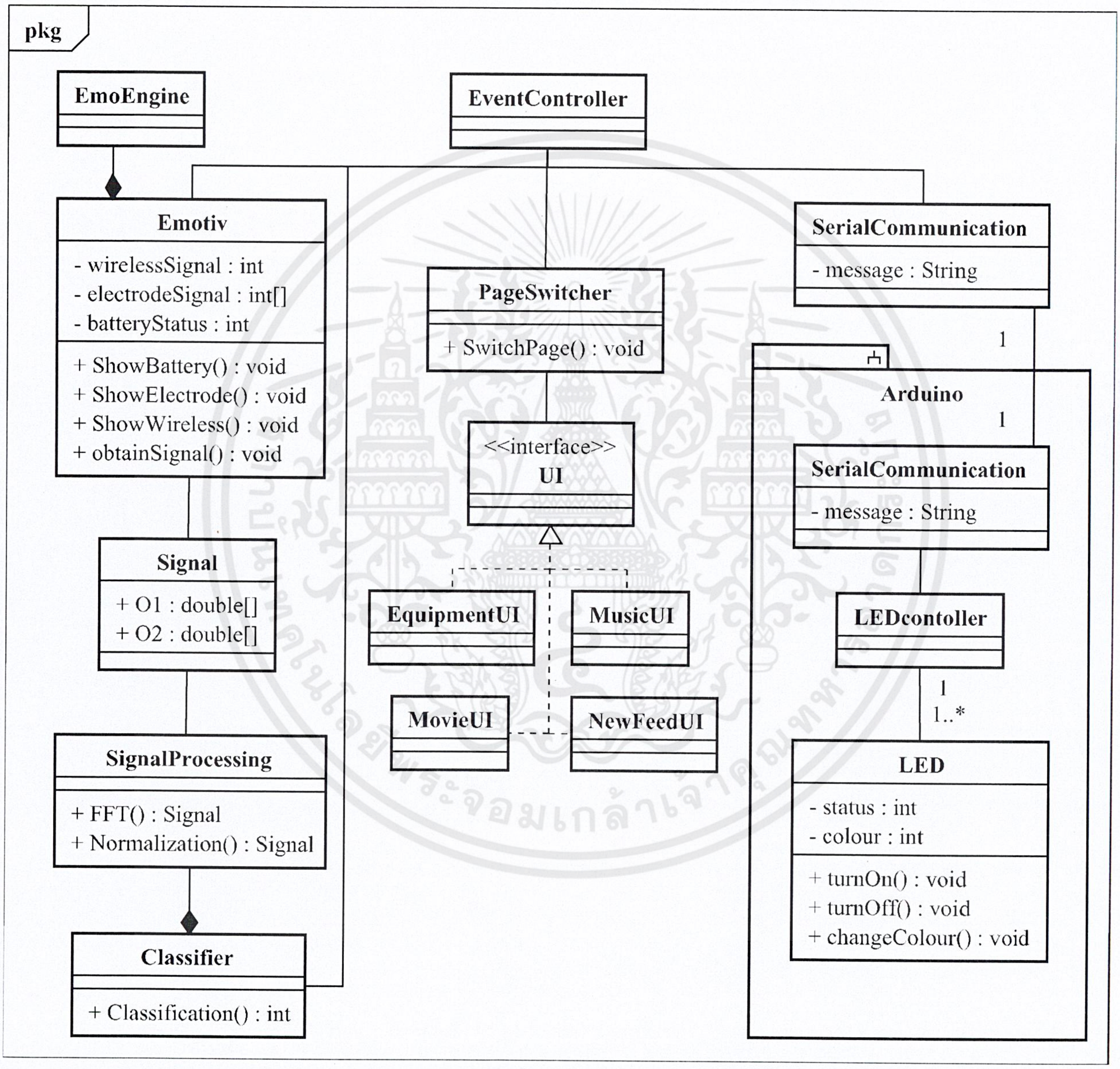

Figure 5.5: Visual Stimulator

Chapter 6

Development

6.1 Chamber for the experiment

Because we use the light to stimulate the subject, so we need to have the light that enters the subject's retina are only from the stimulus, also help to increase an accuracy of the result. Therefore, we use the experiment chamber from our senior project.[19]

Inside the chamber, it is dark, only light from the visual stimulator are allowed. The subject will have a chair to sit on. The visual stimulator is set on the table. The distance between the visual stimulator and subject's eye is 30 cm. the subject will sit on a chair, the visual stimulator will start its work. the subject's EEG will transmit wirelessly to the computer to processing and classification. After the classification process done, it will do the function that it is assign to.

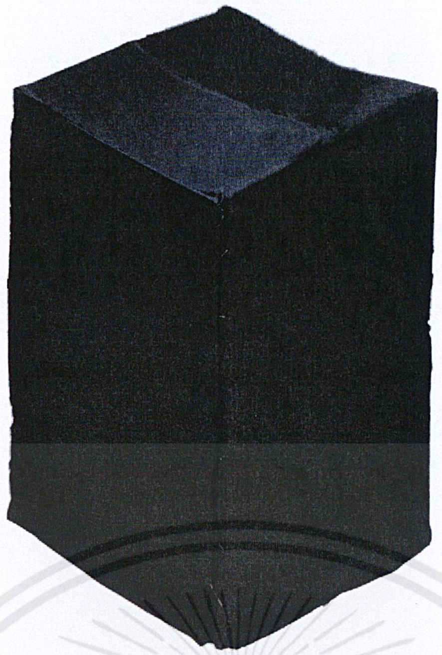

Figure 6.1: Experimental Chamber for Visual Evoked Potential(VEP)experiment

Figure 6.2: Experiment Chamber dimension

The chamber is made from PVC pipeline and black fabric. The dimension of the chamber is W x D x H : 1.5 x 1.5 x 1.9 meters.

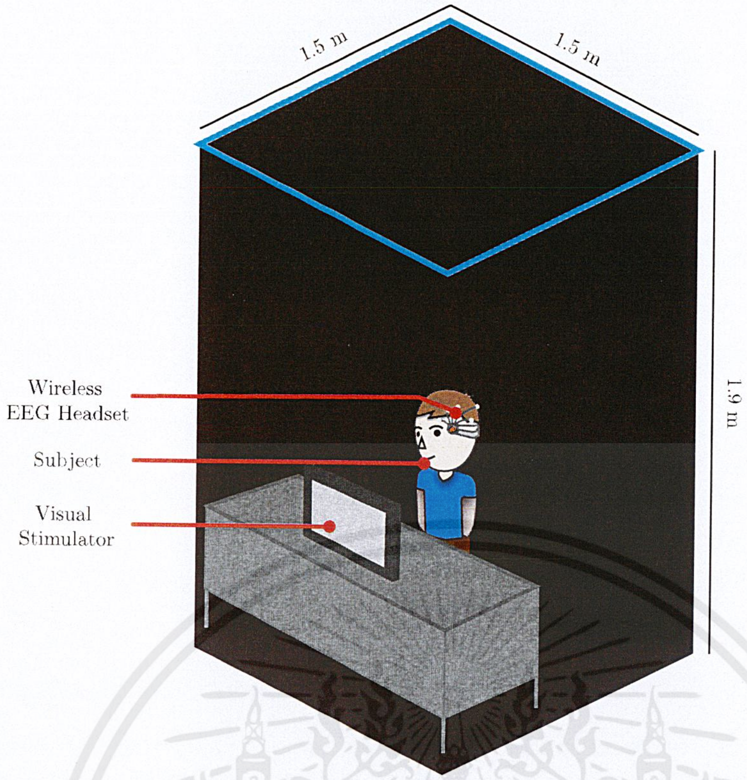

Figure 6.3: Inside experiment Chamber

6.2 Visual stimulator

The visual stimulator is made from crystal clear acrylic plastic, 14 pieces assemble together. The two pieces, front, and back, they have dimension 36 x 28 cm with the window size 26 x 18 cm, to display the application. The front will have a black sticker to hide the wire that connects each LED together. The windows size for the each stimulus is 4 x 4 cm. The other eight pieces are for cover the side, outside top and bottom pieces have the dimension with 36 x 2 cm, the inside have 26 x 2 cm. the outside left and right pieces have dimension 28 x 2 cm, the inside have dimension 18 x 2 cm.

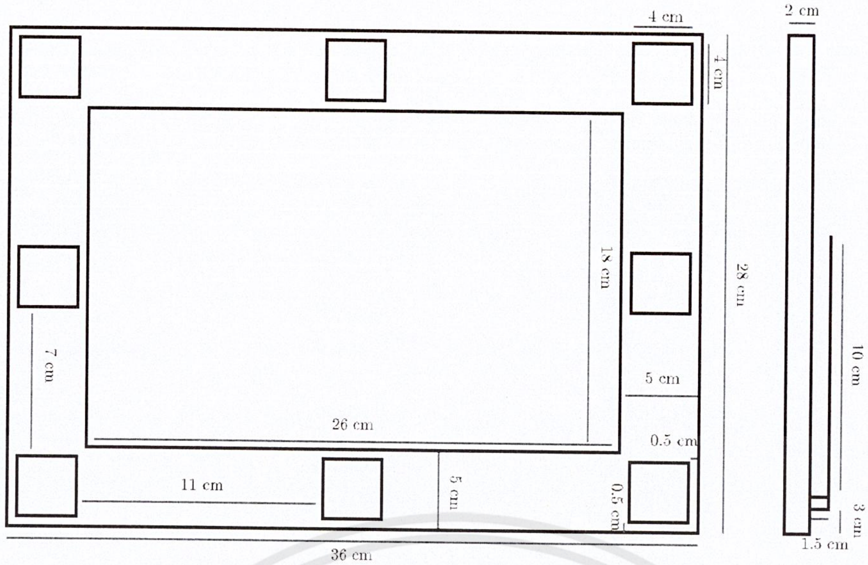

Figure 6.4: Blueprint of Visual Stimulator

In the middle windows, it is for the application to give feed back to the user, also the for display the dynamic functional of the visual stimulate. We use the tablet to be the display. So we make the stand for the tablet to fit in.it used 10 x 20 acrylic plastic to be back support and the depth is 1.5 cm. for ERPs we use four visual stimulator targets, and SSVEP we use eight visual stimulator targets.

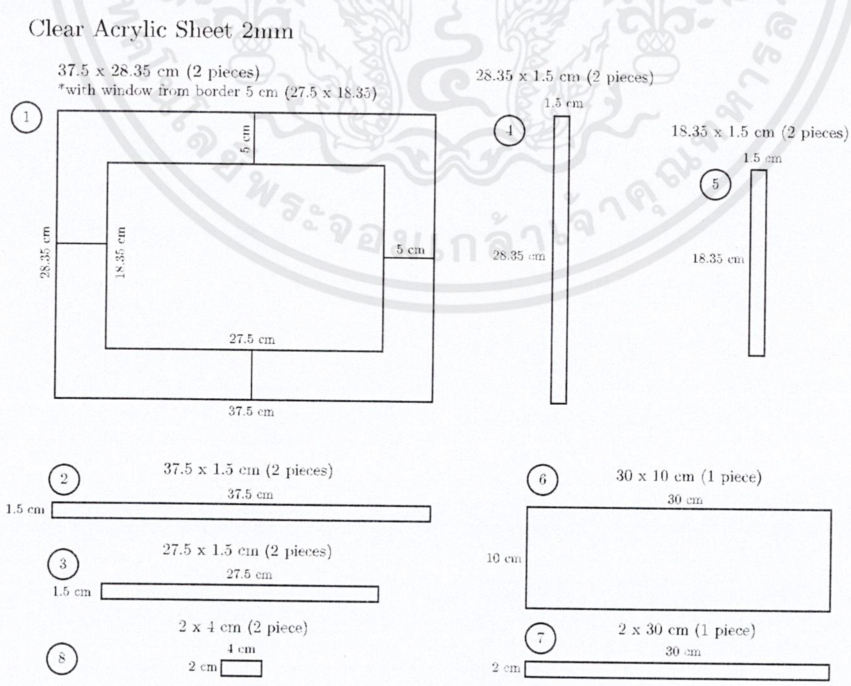

Figure 6.5: Component of visual stimulator made from acrylic plastic

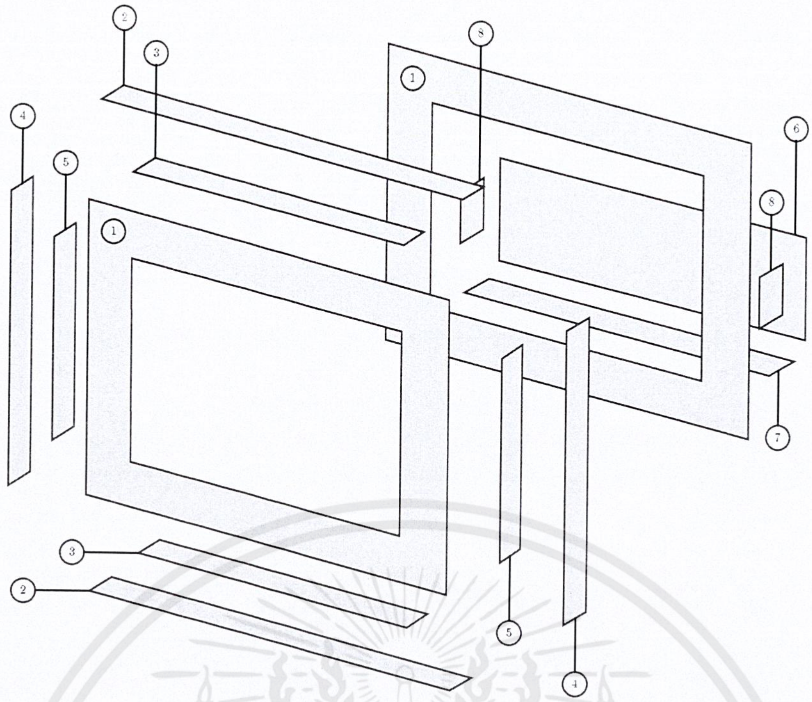

Figure 6.6: Component of visual stimulator assemble with part number from Figure 6.5

In each visual stimulator, it has one LED install, with a light filter to reduce the hardness of light, and to spread the light to fill out the window.

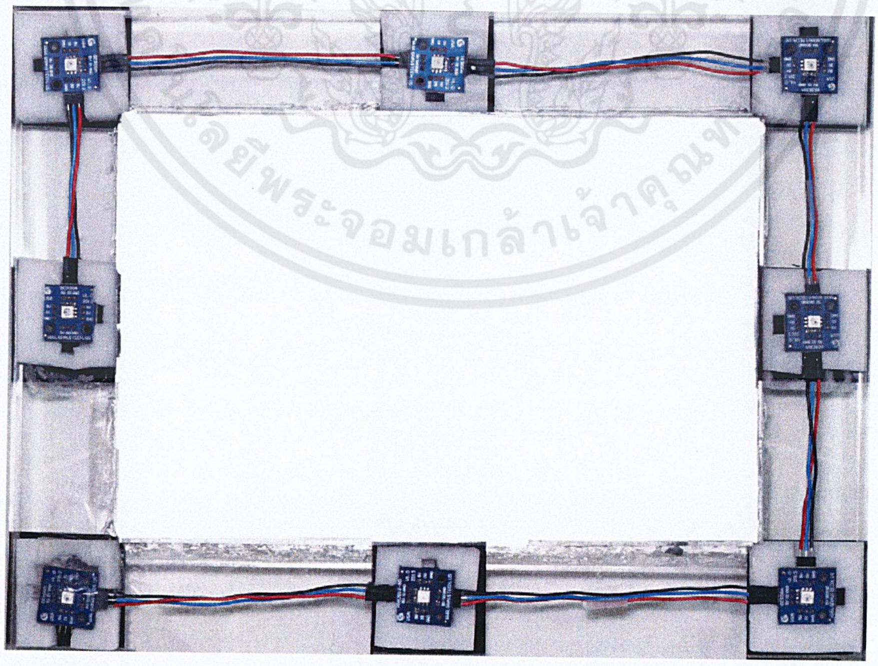

Figure 6.7: Visual Stimulator with LEDs wireing

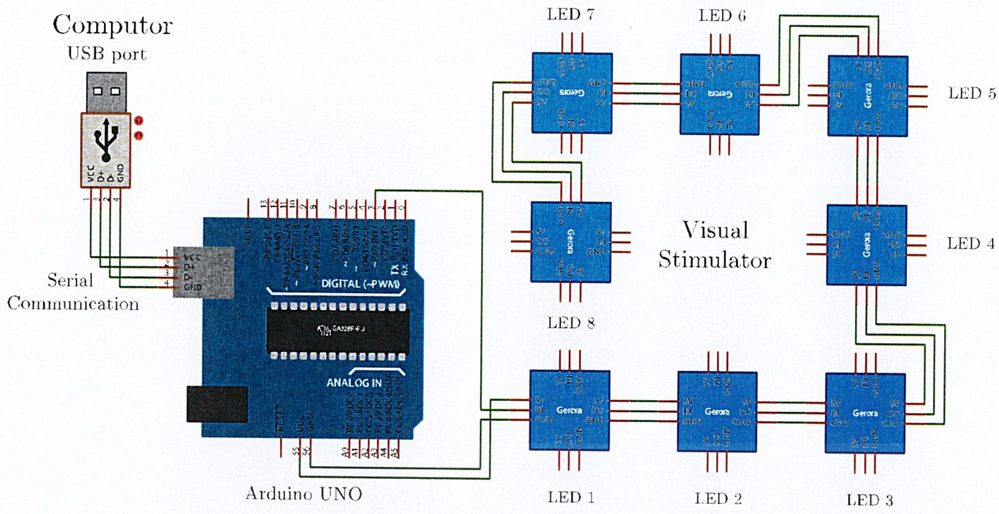

Figure 6.8: Circuit diagram for Visual Stimulator

Figure 6.9: While in experiment

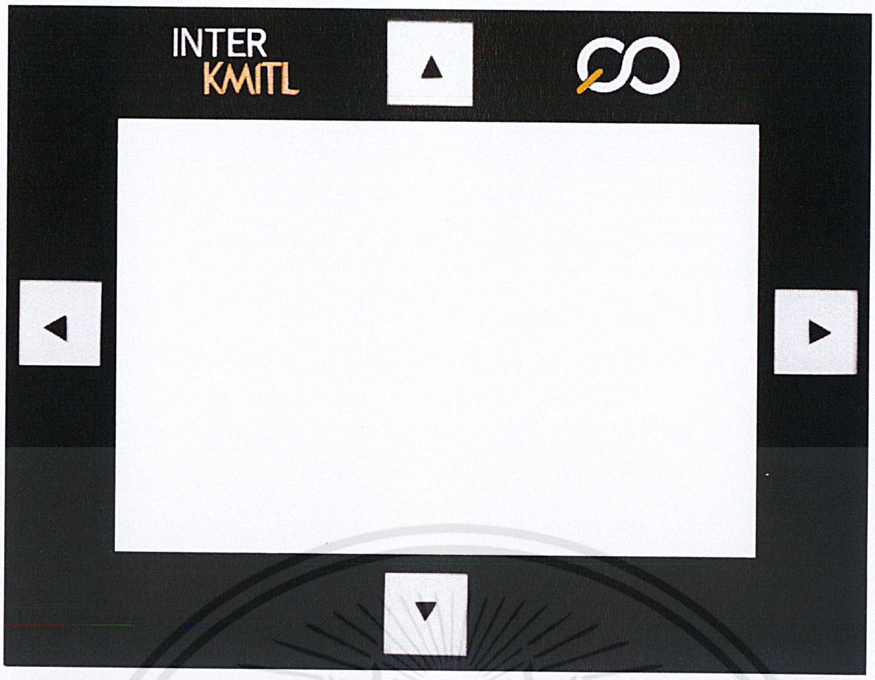

Figure 6.10: Visual Stimulator with four targets used for ERPs

Figure 6.11: Visual Stimulator with eight targets used for SSVEP

6.3 Visual stimulator parameter

From the review in chapter 2, the parameter of visual stimulator that make the subject have less fragile such as duty cycle, colour, intensity is set to be 70 percent duty cycle, green colour, 50 percent intensity.

Duty Cycle	**Intensity(%)**	**color**
70%	50%	Green

Table 6.1: Visual stimulator parameter

6.4 Entertainment System Program

The windows application program to illustrate the use of SSVEP and ERPs, giving the feedback to subject. The user interface is designed for easy to use. There are four main commands which associated to the visual stimulator, up, down, left, right. In the main menu page (figure 6.12) it shows four main functions of the program, music on top, the movie on right, light in right and, weather in the bottom. In the music page (figure 6.13) the user can turn up and down the volume by select right and left command, and can skip the track by select up command and, going back to the main menu by select down command. On the right of this page, it is a current playing music's name and artist display in white text and the playlist of next song in the bottom. In the movie page, it will play a movie in the middle. The user can turn up and down the volume by select right and left command, play, and pause by select up command and, going back to the main menu by select down command. In the weather page (figure 6.15), it shows the current time, date, location, temperature, and weather status. The user can only select back command to go back to the main menu. In the light page (figure 6.16), the user can turn on or off the external light by select left toggle command and go back to the main menu select bottom command. In the setting page (figure 6.17), the user cannot reach this page, the only way to enter this page is by having the assistance select the gear icon on the main menu page. this page shows the status of the Emotiv EPOC such as battery level, wireless signal status, electrode contact quality of P3, P4, O1 and, O2 in 10-20 position system. the assistance can start the visual stimulator by press connect button and the program will start the visual stimulator and connect to Emotiv to obtain EEG automatically.

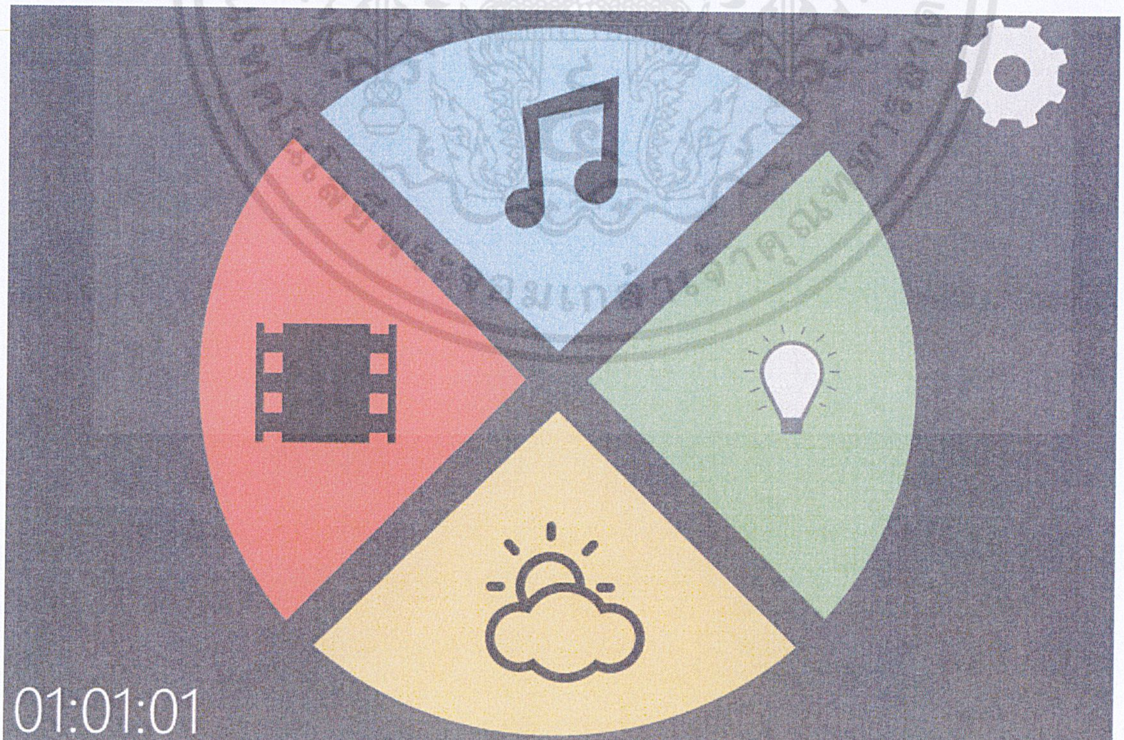

Figure 6.12: Main Page

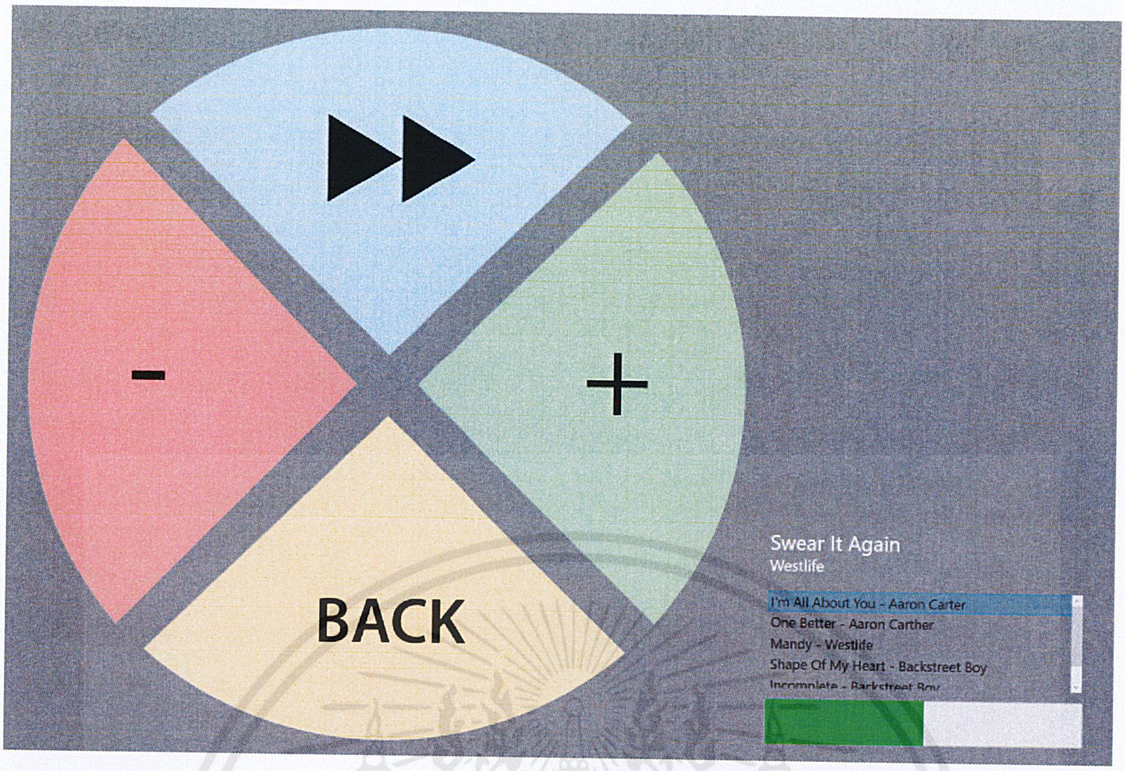

Figure 6.13: Music Page

Figure 6.14: Movie Page

Figure 6.15: Weather Page

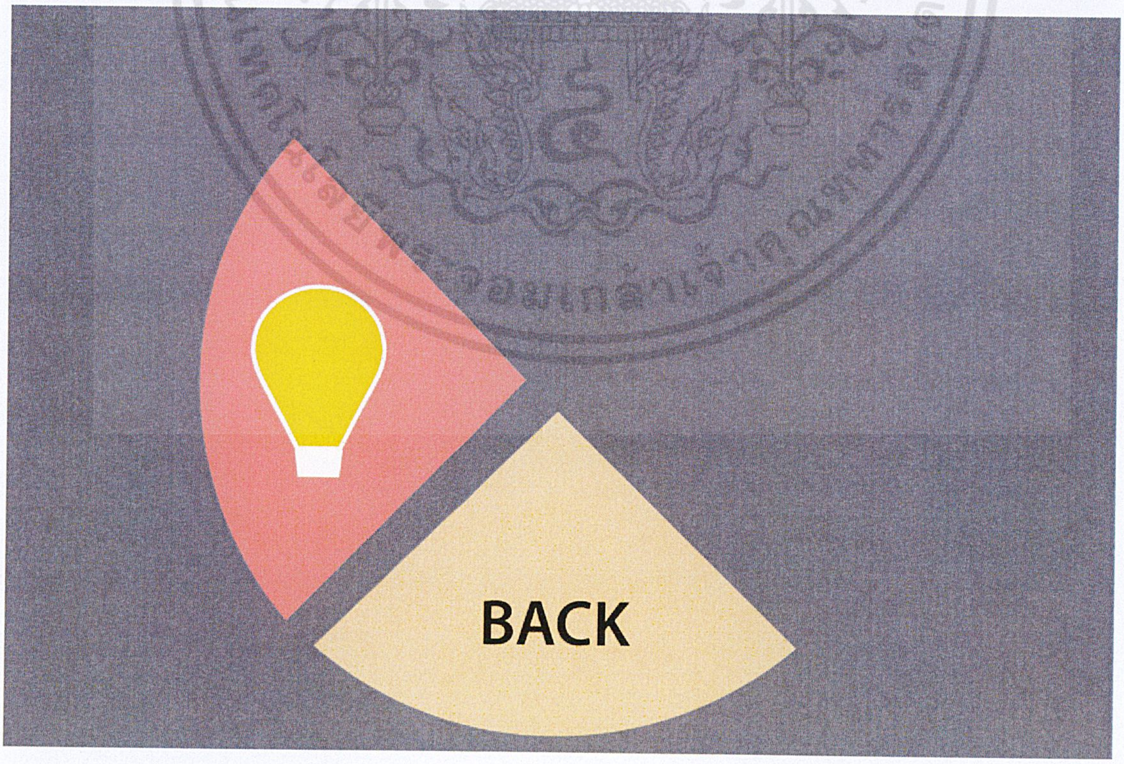

Figure 6.16: Equipment Page

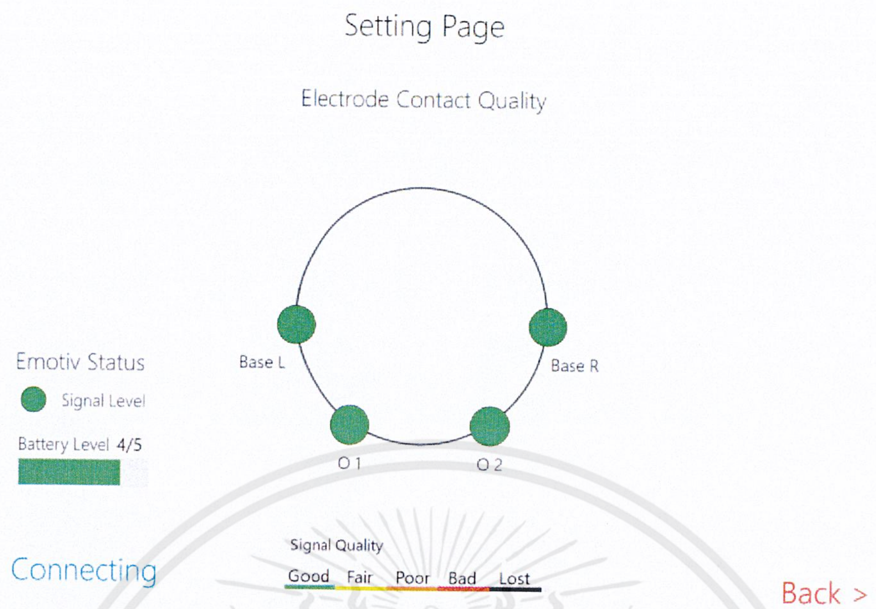

Figure 6.17: Setting Page

Chapter 7

Experiments and results

7.1 Hardware for the experiment

In our project, first, we plan how to investigate the EEG data from the subject. There are 2 categories to investigate the data those are software and hardware. When we know like that we go to study how is it different between software and hardware that use in this project and when we already study in it, so we know that hardware is better than software. The number of frequencies that can be produced is limited and depends on the refresh rate of the LCD screen. The frequencies is limited by the screen and cannot be personalized in relation to the user. In the other hand, LED is more flexible of usage than the LCD screen. We plan to design the hardware to use it in the experiment. This is materials that we use in our project.

7.1.1 EPOC headset by Emotiv™

The wireless headset Emotiv EPOC research edition, it records EEG data in 14 channel of International 10-20 Locations system with Sequential sampling rate at 128 per second (2048 Hz internal) with resolution 14 bit (16 bit Analog to digital converter, 2-bit instrumental noise floor discarded), the bandwidth is in range 0.2 to 45 Hz with digital notch filters at 50Hz and 60 Hz.

We use this equipment in our experiment to obtain the EEG from the subjects and we use EEG that we can obtain from the user to apply in our project.

Figure 7.1: EPOC headset by Emotiv™

7.1.2 Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328 that is an open source platform. It has 14 input/output pins6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button, The USB connection for upload the software into the Arduino and VCC or supply for connecting the peripheral circuit.

In our experiment, we use the Arduino UNO board to control the hardware which we use to stimuli subjects to get the EEG from subjects to apply it in our project.

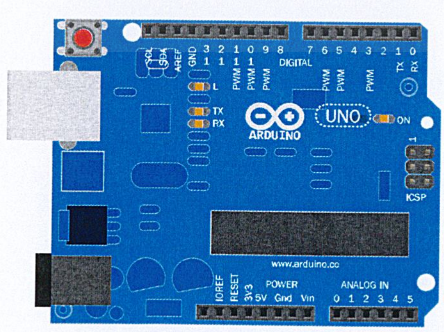

Figure 7.2: Illustrate of Arduino UNO board

7.1.3 Gravitech Gerora WS2812S LED

The full-color Light-emitting diode (LED) driver which is use for stimulating the subject has an LED light WS2812 model mounted on. It can chain connected with the same model. It can be controlled by a programmed Arduino. The luminous intensity is 550 to 700 mega candela for red, 1100-1400 mcd for green, and 200-400 mcd for blue.

For this hardware, we use it be flickers to blink the LED that in this board. We can control the frequency, intensity, and color of LED. This hardware is controlled by the Arduino Uno board to stimuli subjects to get the EEG to apply in our project.

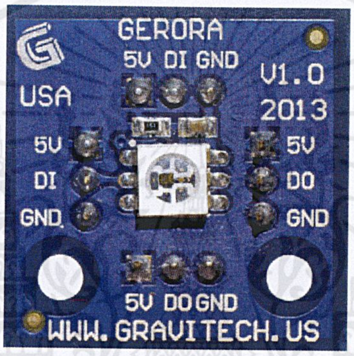

Figure 7.3: Gravitech Gerora LED base on WS2812

7.1.4 Visual stimulus (ERP)

As the Figure 7.4 show our prototype visual stimulator. It consists of the Arduino board and gravitech gerora WS2812 LED board. This stimulator uses to stimuli subjects to get EEG. This stimulator blinks the light from LED 1 to LED 4 respectively. This stimulator was used in Experiment I and II.

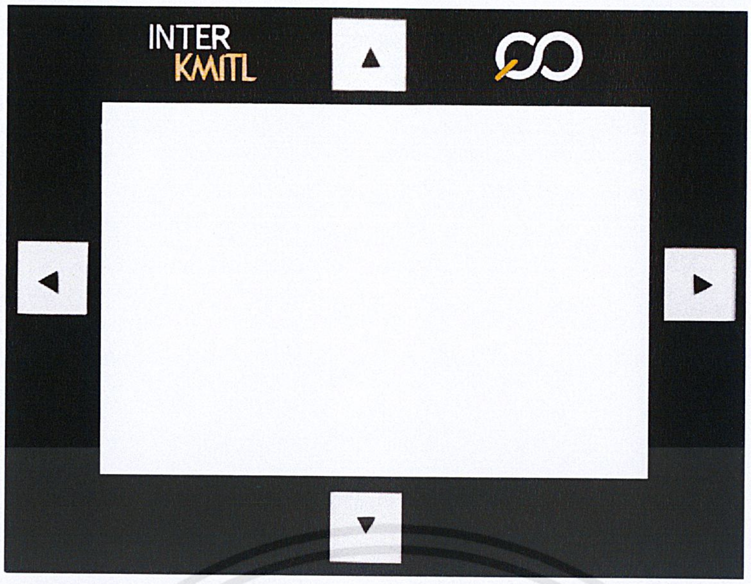

Figure 7.4: Visual Stimulator with four targets used for ERPs

7.1.5 Visual stimulus (SSVEP)

This visual stimulator was developed based on the previous visual stimulus(ERP). The difference between this stimulator and previous stimulator is this stimulator has 8 flickers and each flicker has different frequencies, which was used in Experiment III and IV.

Figure 7.5: Visual Stimulator with eight targets used for SSVEP

7.2 Experiment I

7.2.1 Experimental Paradigm I

- **Subjects**

  In this experiment, we use 4 subjects. There are SS,OK,WP and NT that is the nickname and firstname of subjects.

Subjects	Age	Sex
SS	22	Male
OK	22	Male
WP	21	Male
NT	21	Male

Table 7.1: Subjects of experiment I

- **Visual Stimulator** In this experiment, we use 4 visual stimulator[LED 1(Y_1),LED 2(Y_3),LED 3(Y_5),LED 4(Y_7)]
- **Stimulus** For one trial, we use 11, 15, 19, 23 seconds respectively.
- **Trials** We recorded 3, 5, 7, 9 times for each set of parameter.
- **Environment** In this experiment, we control the light illuminate value at 37 Lux.
- **Parameters**

  There are 4 parameters. First is flickering type, stimulus, sample length and epoch time.

Parameter	Experiment A	Experiment B
Stimulus	Normal Flickering Sequence (NFS)	Modular Flickering Sequence (MFS)
Flickering type	Flickering Sequence (FS)	
Sample Length	64 samples/epoch	
Epoch time	500 ms	

Table 7.2: Experimental paradigm I

In this experiment, we set the duty cycle to be 0.7 and light intensity to be 50%. The experimental paradigm is shown in table 7.2, we set the flickering type, sample length, epoch time, duty cycle, intensity and frequency to be the same. There is some difference in stimulus. We have 2 experiment of stimulus. First is Normal Flickering Sequence (NFS) , NFS means a flicker will blink 1 time per LED is shown in figure 7.6. Modular Flickering Sequence (MFS) means a flicker will blink 3 times for each LED as shown in figure 7.7. We will do this for 3, 5, 7 and 9 trials respectively for each subject to obtain the EEG. We obtain the data around 20 times for each subject and calculate average from data to obtain the accuracy of this experiment.

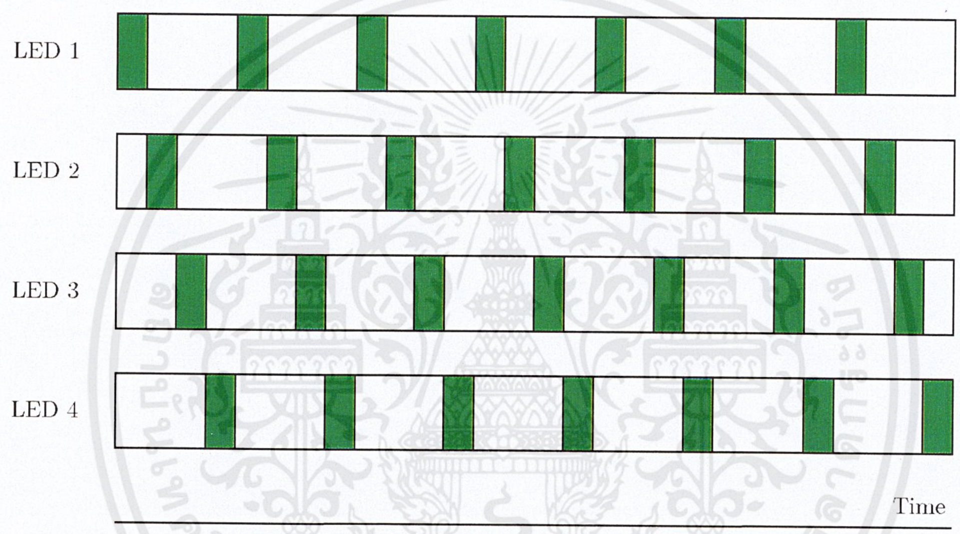

Figure 7.6: Normal Flickering Sequence (NFS)

Figure 7.7: Modular Flickering Sequence (MFS)

7.2.2 Experiment result I

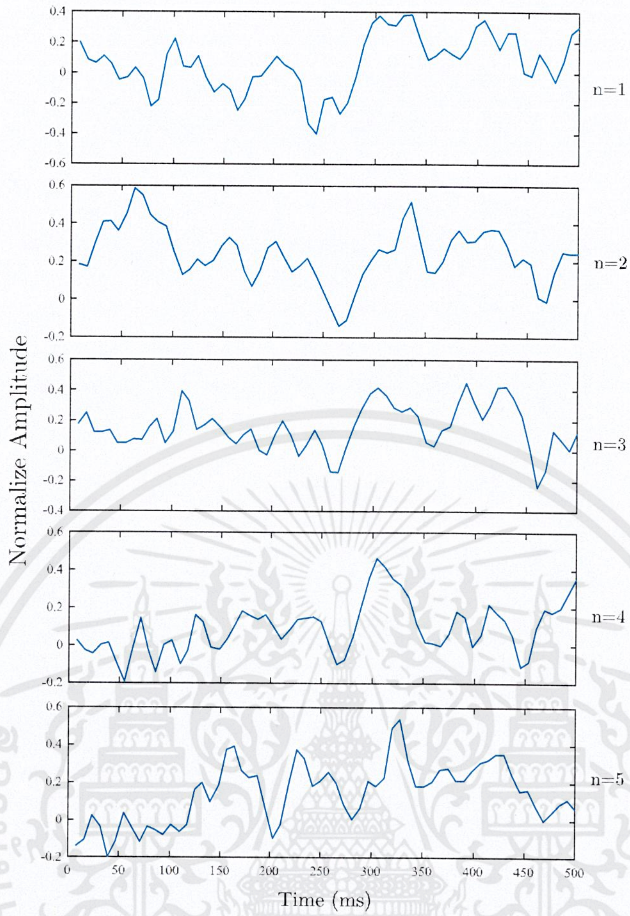

Figure 7.8: Raw data of EEG from subject "OK", n trials ; n = number of trials for each subjects to calculate the averages.

From the Figure 7.8, displays an example of raw EEG data obtained from the subject "OK". 'n' in Figure 7.8 means the number of trials for each subject .In this figure, we adjust n to 5. After obtaining these 5 trials of raw data, we will calculate the average of these raw data as shown in Figure 7.10

From the figure 7.9, we obtain the average of EEG data from subject "OK" ,which uses only in 1 flicker. However, we use 4 flickers in our experiment. When we merge all of average EEG data, we will get the data in figure 7.10. In the figure 7.10, we obtain the EEG data of flickers line Y_1, Y_3, Y_5 and Y_7 for experiment I from trial= 5, subject = "OK". When we receive the EEG data of each flicker (Figure 7.10), we use a range of 290-350 millisecond to classify which flicker that the subject fixate. From figure 7.10, we will see the 4 lines of

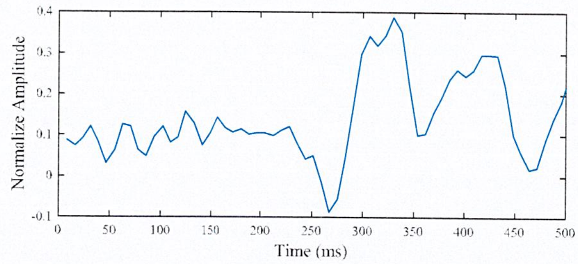

Figure 7.9: The averaged EEG data of subject "OK" from raw data in Figure 7.8

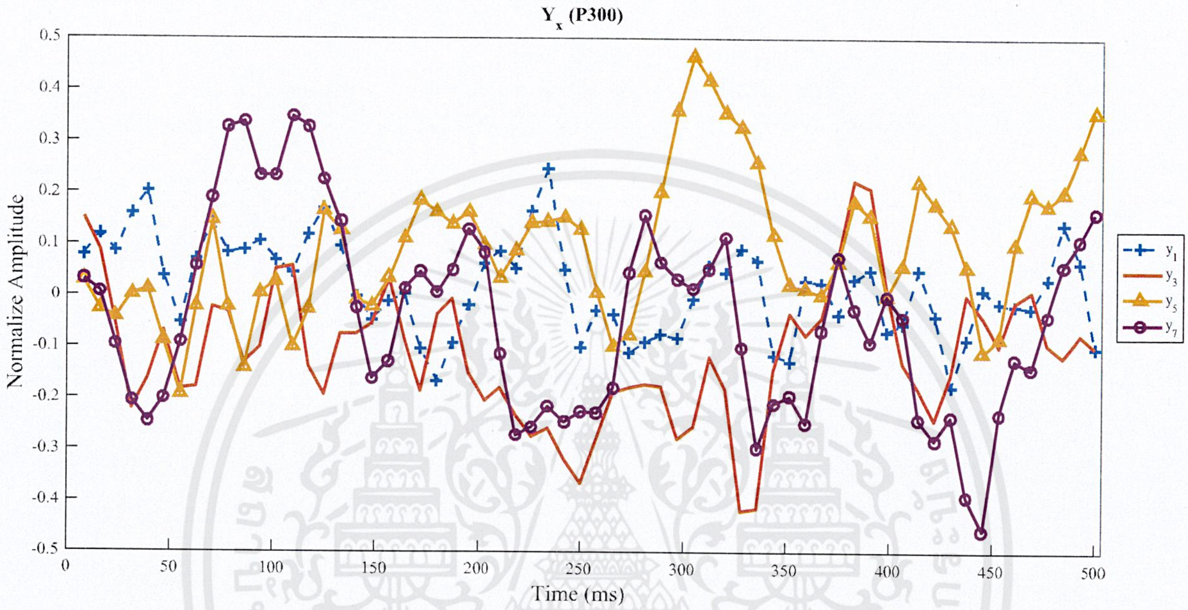

Figure 7.10: EEG data of subject "OK" ,trial = 5 from flickers Y_1, Y_3, Y_5 and Y_7

the graph. Y_1 the EEG data from flicker 1, Y_3 is from flicker 2, Y_5 is from flicker3, and Y_7 is from flicker 4. Each line means that we collect the data of the subject for 3 trials and compute the average of the EEG data that we get in each line. When we have already computed the average, we apply the normalization to all of the data which are averages to compare with each other. In this figure, the flicker that the subject fixate is Y_5 or flicker 3.

From the figure 7.11, we have a comparison graph of the first experiment A and the second experiment B. Both are different in stimulus. EXP A's stimulus is NFS, whereas EXP B is MFS. This graph illustrates the accuracy of EXP A and EXP B, where the trial = 7. The accuracy of EXP A is equal to 57.5% and EXP B is equal to 67.5%. We can see that EXP B is more accurate than EXP A in any trials that we use.

The result of this experiment is shown in Table 7.3 with the same set of parameter

Figure 7.11: Comparison between the result of experiment A and B

for each stimulus, sample length, epoch time, duty cycle, intensity, and frequency. From the Table 7.2,the first row, we can see the accuracy of "SS" in MFS is better than NFS in the same row. Another subject "WP" in the fourteenth row, we can see the accuracy of MFS is better than NFS too. We found each subject have better accuracy in the MFS than NFS. We found another thing that is the trial of the experiment. We will compare the accuracy between "OK" in the first row and "OK" in fourteenth row. The result is "OK" in the fourteenth row is better than "OK" in the first row. The main factor is the number of trial that we use in each experiment. We found that when we use more trials, the accuracy is increased too.

Trial	Total time [s]	Subject	Accuracy of stimulus	
			static	Modular
3	11	OK	25	40
		WP	40	40
		SS	35	30
		NT	30	40
5	15	OK	45	45
		WP	50	55
		SS	45	65
		NT	55	55
7	19	OK	60	65
		WP	55	70
		SS	55	70
		NT	60	65
9	23	OK	65	70
		WP	65	80
		SS	70	75
		NT	65	70

Table 7.3: Experiment result I

7.3 Experiment II

7.3.1 Experimental Paradigm II

- **Subjects**

  In this experiment, we use 4 subjects. There are SS,OK,WP and NT that is the nickname and firstname of subjects.

Subjects	Age	Sex
SS	22	Male
OK	22	Male
WP	21	Male
NT	21	Male

Table 7.4: Subjects of experiment II

- **Visual Stimulator** In this experiment, we use 4 visual stimulator[LED 1(Y_1),LED 2(Y_3),LED 3(Y_5),LED 4(Y_7)]

- **Stimulus** For one trial, we use 11, 15, 19, 23 seconds respectively.
- **Trials** We recorded 3, 5, 7, 9 times for each set of parameter.
- **Environment** In this experiment, we control the light illuminate value at 37 Lux.
- **Parameters**

There are 4 parameters. First is flickering type, stimulus, sample length and epoch time.

Parameter	Experiment A	Experiment B
Flickering type	Modular Flickering Sequence (MFS)	Modular Uniform Random based Sequence (MURS)
Stimulus	Modular	
Sample Length	64 samples/epoch	
Epoch time	500 ms	

Table 7.5: Experimental paradigm II

In this experiment, we set it to be the same as experiment I. However, there is a difference in flickering type. In this experiment, we use a Modular Flickering Sequence (MFS) and Modular Uniform Random based Sequence (MURS) The MFS means that the flicker will blink from LED1 to LED4 respectively. The MURS is used to randomly select the flickers to blink. We have 3,5,7 and 9 trials for each subject to obtain the EEG to be the same as experiment I. We will obtain the EEG and calculate the average and accuracy of this experiment.

From the result of experiment I, the modular stimulus is better than static stimulus. So, we will use the modular stimulus in this experiment. In this experiment, the flickers will be the same as figure 7.12 and figure 7.13. In figure 7.12 is shown the MFS. The flicker will blink from LED1 to LED4 and it will blink 3 times per each LED. In the same way, the figure 7.13 is shown the MURS that means each flicker will blink randomly and blink 3 time for each flicker.

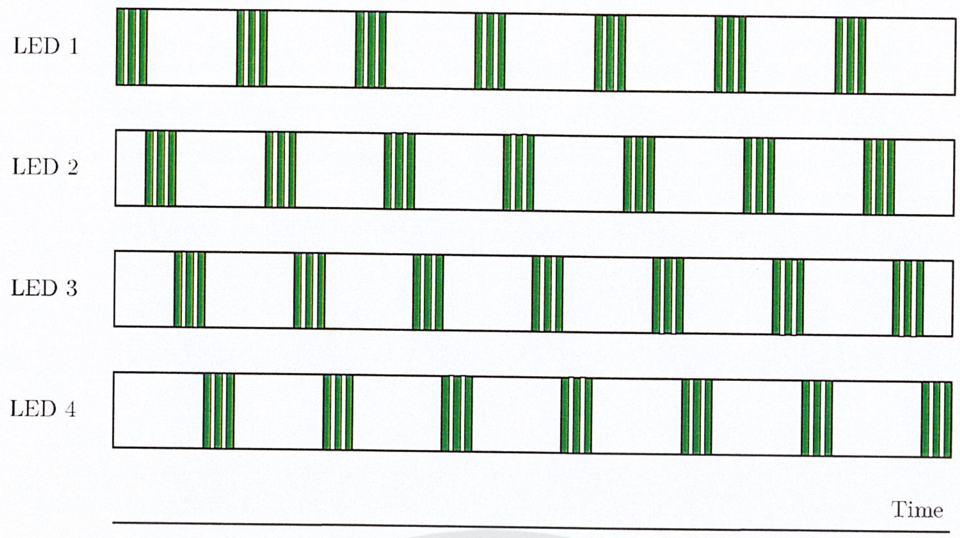

Figure 7.12: Modular Flickering Sequence (MFS)

Figure 7.13: Modular Uniform Random based Sequence (MURS)

7.3.2 Experiment result II

In this experiment, we use the method to find the accuracy be the same as the experiment I. We obtain the raw EEG data from each subject and calculate the average data from the trials which be set.When we calculated the average of EEG data, we use this average data to find the accuracy of this experiment.

From the figure 7.14, we have a comparison graph of the first experiment EXP A and the second experiment EXP B. Both are different in flickering types. EXP A's flickering type is MFS, whereas EXP B has MURS. This graph display the accuracy of EXP A and EXP B, where the trial = 9. The accuracy of EXP A is equal to 73.75% and EXP B is equal to 85%. We can see that EXP B is more accurate than EXP A in any trails that we use.

Figure 7.14: Comparison between the result of experiment A and B

The result of this experiment is shown in Table 7.6 with same set of parameter for each stimulus, sample length, epoch time, duty cycle, intensity and frequency. First from the table 7.6, we compare between MFS and MURS. We can see the accuracy of "WP" in MURS is better than MFS of "WP" in the same row. The accuracy between MFS and MURS of "NT" in the last row of the table, MFS is lower accuracy than MURS. We also found any subject have better accuracy in MURS than MFS of flickering type. We found another thing that is the trials of the experiment. The comparison of accuracy between "WP" in second row and "WP" in tenth row is the accuracy of "WP" in the tenth row is better than in the second row. The main factor is trial that we use in each experiment. We found that when use more trials, the accuracy is increased same as experiment I.

Trial	Total time [s]	Subject	Accuracy of flickering type	
			flickering sequence	Uniform random
3	11	OK	40	50
		WP	40	55
		SS	30	55
		NT	30	60
5	15	OK	45	60
		WP	55	70
		SS	65	65
		NT	55	75
7	19	OK	65	70
		WP	70	75
		SS	70	70
		NT	65	75
9	23	OK	70	85
		WP	80	80
		SS	75	90
		NT	70	85

Table 7.6: Experiment result II

7.4 Experiment III

7.4.1 Experimental Paradigm III

- **Subjects**

  In this experiment, we use 4 subjects. There are SS,OK,WP and NT that is the nickname and firstname of subjects.

Subjects	Age	Sex
SS	22	Male
OK	22	Male
WP	21	Male
NT	21	Male

Table 7.7: Subjects of experiment III

- **Visual Stimulator** In this experiment, we use 1 visual stimulator[LED 1(Y_1)]

- **Stimulus** In this experiment, we separate the stimulus in 2 categories per one trial. First, we obtain the EEG data of the subject to be baseline 6 seconds. In active state, we obtain the EEG of the subject in 14 seconds.

- **Trials** We recorded 20 trials for each set of parameter.
- **Environment** In this experiment, we control the light illuminate value at 37 Lux.
- **Parameters**

  There are 4 parameters. First is frequency, duty cycle, light intensity, and light color.

Frequency(Hz)	**Duty**	**Intensity(%)**	**color**
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17	0.7	50	Green
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			

Table 7.8: Experiment paradigm III

From table 7.8, we set duty cycle = 0.7, light intensity 50%, and light color = "Green". There are some differences in frequencies. We use frequencies from 6Hz to 29Hz and only 1 flicker in this experiment to obtain the EEG signal. The subjects observe the visual stimulator in for 20 trials each subject. Two channels position that we use in our experiment of visual cortex is O_1 and O_2. When EEG signal that we obtained is analyzed, we will calculate the accuracy of the experiment.

From the figure 7.15, we use this method in our experiment. We have 2 states of this experiment. The first state is resting state, we use this state to obtain the EEG of subject to be the baseline. In this state, we obtain the EEG of the subject for 6 seconds. When we have investigated the baseline, we use Fourier transform to obtain the frequency spectrum and use the smoothing filter to get smoothed baseline spectrum. The next state is an active state. In this state, we obtain the EEG of subject for 14 seconds and use the Fourier transform. When we have investigated the EEG of each state, we use the EEG of each state to subtract each other. We use the subtracted EEG to classify by using peak detection algorithm which flicker is fixated.

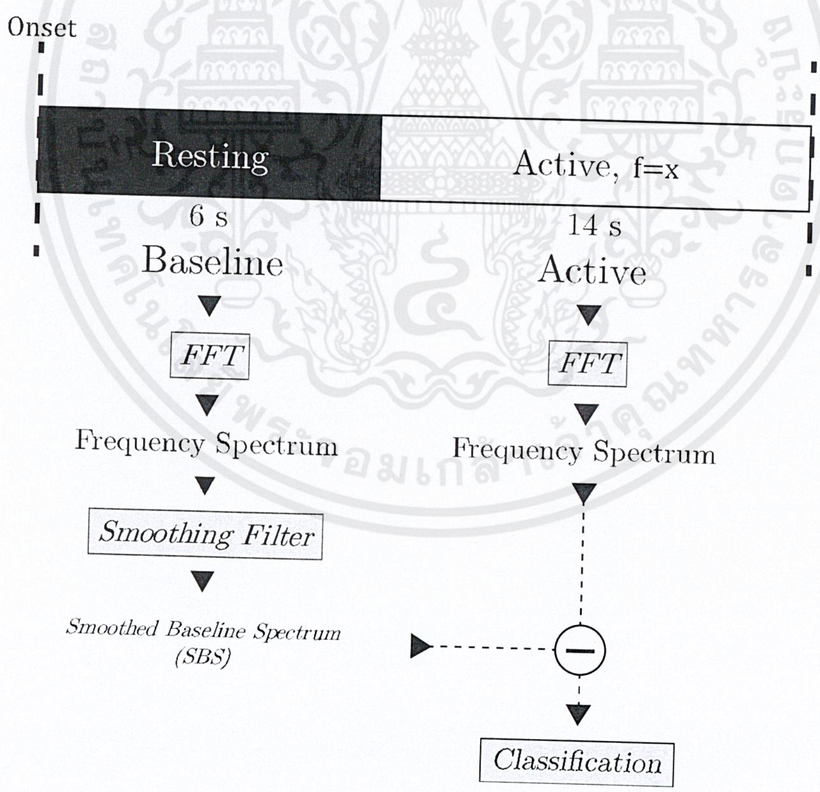

Figure 7.15: Algorithm that we use in this experiment

7.4.2 Experiment result III

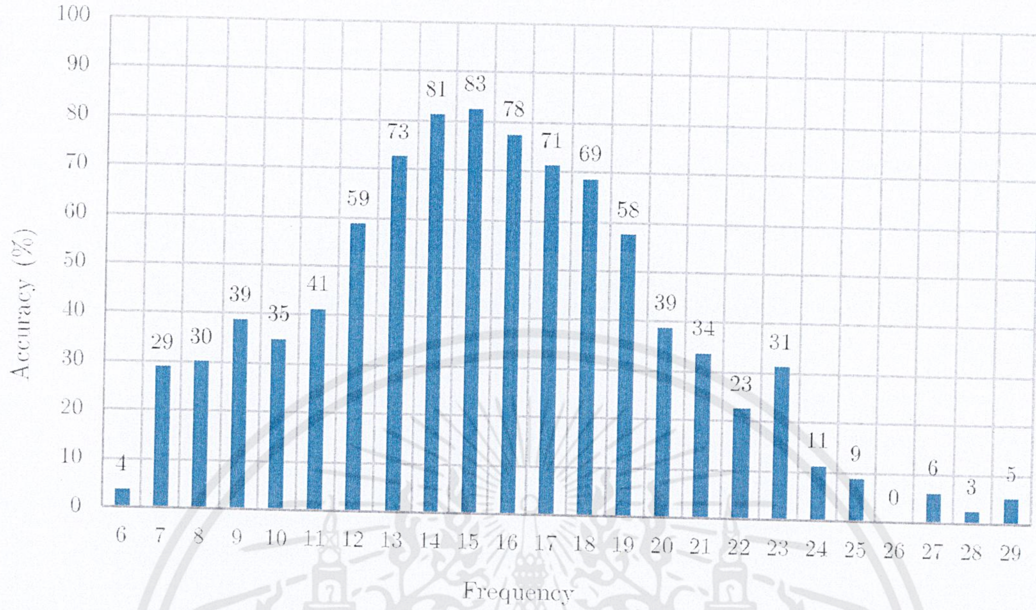

Figure 7.16: The accuracy of all subjects

We use this experiment to find the best accuracy among these frequencies to detect the fittest flicker to be used to control the program. We obtain the raw EEG data from each subject. In one trial, we use windowing function to separate the raw EEG data into segments. We use 512 samples for windowing function. When we get the windowing data. Then, the data will be analyzed by using the Fourier transform. Once the Fourier transform data is obtained, this data will be subtracted from the baseline. We will obtain other data to classify the flickers.The classification algorithm is peak detection. This algorithm is used to find the peak of the EEG data that is already classified, and will be used to calculate the accuracy of this experiment.

Figure 7.16, represents the accuracy value of all subjects which are analyzed by the method mentioned in previous paragraph. The best accuracy is 83% and belongs to the frequency at 15 Hz. The next accuracy is 81$ and belongs to the frequency at 14 Hz. The third highest accuracy value is 78% and belongs to the frequency at 16Hz.

Frequency(Hz)	Subject	Accuracy(%)	Averaged accuracy(%)
11	OK	40	41.25
	WP	35	
	SS	50	
	NT	40	
12	OK	65	58.75
	WP	65	
	SS	60	
	NT	45	
13	OK	80	72.5
	WP	80	
	SS	65	
	NT	65	
14	OK	80	81.25
	WP	85	
	SS	90	
	NT	70	
15	OK	85	82.5
	WP	85	
	SS	80	
	NT	80	
16	OK	80	77.5
	WP	80	
	SS	75	
	NT	75	
17	OK	80	71.25
	WP	70	
	SS	60	
	NT	75	

Table 7.9: Experiment result III

Frequency(Hz)	Subject	Accuracy(%)	Averaged accuracy(%)
18	OK	70	68.75
	WP	65	
	SS	65	
	NT	75	
19	OK	60	57.5
	WP	60	
	SS	55	
	NT	55	
20	OK	50	38.75
	WP	35	
	SS	40	
	NT	30	
21	OK	45	33.75
	WP	20	
	SS	30	
	NT	40	
22	OK	30	22.5
	WP	25	
	SS	20	
	NT	15	
23	OK	30	31.25
	WP	40	
	SS	35	
	NT	20	
24	OK	10	11.25
	WP	15	
	SS	5	
	NT	15	

Table 7.10: Experiment result III

Frequency(Hz)	Subject	Accuracy(%)	Averaged accuracy(%)
25	OK	10	8.75
	WP	15	
	SS	5	
	NT	5	
26	OK	0	0
	WP	0	
	SS	0	
	NT	0	
27	OK	5	6.25
	WP	10	
	SS	5	
	NT	5	
28	OK	0	2.5
	WP	0	
	SS	5	
	NT	5	
29	OK	5	5
	WP	5	
	SS	5	
	NT	5	

Table 7.11: Experiment result III

From table 7.9 and 7.10 display the accuracy of all subjects and the average accuracy of all subjects at each frequency. There are 4 subjects in this experiment, where each subject has different accuracy. For example, subject "OK" at 11 Hz is 40% accurate and at 13Hz, its value doubled to 80%. The subject "WP" at the frequency rate of 11Hz is 35% accurate and at 13 Hz is 80% accurate. We found that there are some frequency ranges that subjects can respond in EEG signal. In this experiment, there are frequencies between 12Hz and 19Hz which is good enough to use.

7.5 Experiment IV

7.5.1 Experimental Paradigm IV

- **Subjects**

  In this experiment, we use 4 subjects. There are SS,OK,WP and NT that is the nickname and firstname of subjects.

Subjects	Age	Sex
SS	22	Male
OK	22	Male
WP	21	Male
NT	21	Male

Table 7.12: Subjects of experiment IV

- **Visual Stimulator** In this experiment, we use 8 visual stimulator[LED 1(Y_1),LED 2(Y_2),LED 3(Y_3),LED 4(Y_4),LED 5(Y_5),LED 6(Y_6)]

- **Stimulus** In this experiment, we separate the stimulus in 2 categories per one trial. First, we obtain the EEG data of the subject to be baseline 6 seconds. In active state, we obtain the EEG of the subject in 14 seconds.

- **Trials** We use only 1 trial to analyze the flicker.

- **Environment** In this experiment, we control the light illuminate value at 37 Lux.

- **Parameters**

  here are 4 parameters. First is frequency, duty cycle, light intensity, and light color.

From table 7.13, we set this experiment to be the same as experiment III. However, we select only the frequency range between 12Hz and 19Hz, because they have high frequency rates. We also conduct only 1 trial to analyze the flicker which the subject fixated and set other parameters to be the same as experiment III.

Frequency(Hz)	**Duty**	**Intensity(%)**	**color**
13	**0.7**	50	Green
14			
15			
16			
17			
18			

Table 7.13: Experiment paradigm IV

At first, we plan to use 8 flickers in this experiment, However, from the experiment III, there are 6 frequencies that are proper to use. Therefore, we change the flickers from 8 to 6.

From the experiment III results, we can calcualte the accuracy of each frequency from the method used in experiment III. The method in this experiment is the same as the experiment III, but we only need to conduct just 1 trial and analyse which flicker is fixated, compared to 20 trials for experiment III. We obtain the EEG signal from two channels of visual cortex. They are O_1 and O_2. When the analysation has finished detecting the flicker, it will control the function commands in the program.

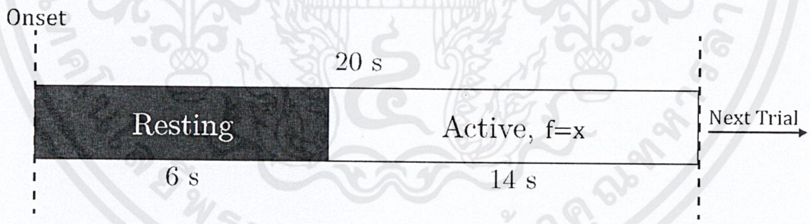

Figure 7.17: Experiment paradigm : duty cycle = 0.5 intensity = 50% color = Green

7.5.2 Experiment result IV

In this experiment, we use the method to calculate the accuracy be the same as the experiment III. We only select the frequencies that have the high accuracy rate to use in this experiment.

From the figure 7.18, There are the accuracy of all subjects in each frequency. The highest accuracy rate is 13Hz frequency, the accuracy rate is 80%. The 16Hz frequency is the 77.5% of accuracy rate which is the second. In this experiment, The lowest accuracy rate is 66.25% that is 18Hz frequency. However, the lowest rate in this experiment is not too low rate to use like the experiment III.

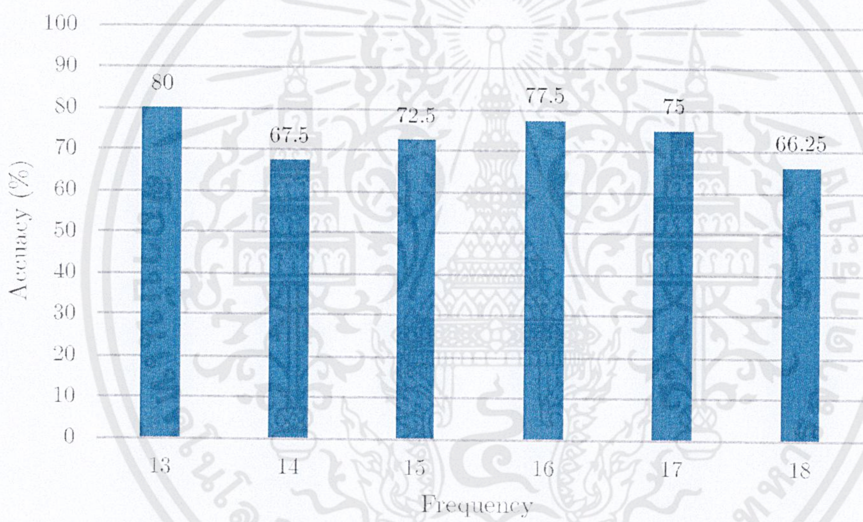

Figure 7.18: The accuracy of all subjects

The result of this experiment is shown in table 7.14, in this table shown all of the accuracy rate of each subject that fixated the flicker in each frequency. The subject "NT" in 13Hz frequency has 85% in accuracy rate but the subject "SS" in the same frequency has only 70% accuracy rate. In frequency is 15Hz, the subject "NT" has only 70% of accuracy rate but the subject "SS" has 75% accuracy rate. From this experiment, we can see each subject can be stimulated in the different frequencies. The accuracy rate can be decreased or increased by this factor.

Frequency(Hz)	Subject	Accuracy(%)
13	OK	85
	WP	80
	SS	70
	NT	85
14	OK	65
	WP	70
	SS	60
	NT	75
15	OK	60
	WP	85
	SS	75
	NT	70
16	OK	75
	WP	70
	SS	80
	NT	85
17	OK	75
	WP	75
	SS	70
	NT	80
18	OK	60
	WP	60
	SS	75
	NT	70

Table 7.14: Experiment result IV

Chapter 8

Conclusion

8.1 Summary of Thesis Achievements

In this project, we have developed the new alternative way to help the disabled people who can not move their part of the body but their brain still is functional by using EEG brain wave to interact with the equipment. We have studied in various techniques to use with ERPs and SSVEP to help the subject interact with the equipment. We have studied about the duty cycle,light intensity,light color and light luminance to use in our project.

We also have developed the hardware which is the visual stimulator combine with the tablet to command the program that we create for the subjects that we have already described in previous chapters. In ERPs experiment, we investigate the EEG data from subjects and use these data to calculate the accuracy. The conclusion of ERPs is when we obtain more trials of subjects , the accuracy rate will increase. In SSVEP experiment, to identify the flicker of visual stimuli we use windows function to separate the EEG data, use Fourier transform and subtract with baseline then use peak detection to determine the flicker and calculate the accuracy of the experiment.

8.2 Problems and obstacles

- Hardware : We use the hardware that we design and create the hardware that uses in our experiment. However, we do not know about how to create this hardware and we use a lot of time to create it. The distance of each flicker can decrease the accuracy rate.

- Environment : In our experiment, we have the chamber to investigate the EEG data of subjects but there is some light through in the chamber that maybe make some mistakes of data. The accuracy rate can be decreased when we use the experiment outside the chamber.

- Algorithm : In this project, we use windows function and FFT algorithm to detect the frequency but it is not too much well-performed to detect the frequency.In our experiment, the lowest accuracy rate is 66.25%. The further solution we plan to change the algorithm in our experiment to acquire good accuracy rate.

8.3 Discussion

From our ERPs experiment, the best accuracy rate is 85% and use 36 seconds to command one function of the program. We suggested this experiment give the high accuracy but it is time-consuming. We suggest the subject should use the previous experiment which uses only 28 seconds and 72.5% accuracy. This can be the general case to use in this ERPs experiment. In SSVEP experiment, we have 2 experiments of SSVEP. The first experiment, we find which frequency is the best accuracy. We found the best accuracy of frequencies is between 13Hz to 18Hz. The 15Hz frequency is the best accuracy which is 83%. The lowest accuracy which chosen is 69% at 18Hz. We suggested that the lowest accuracy is not a bad rate to use in next experiment. The second experiment, we use the result of the previous experiment in visual stimulator device. The best accuracy is 80% at 13 Hz. We suggested that each visual stimuli flickers maybe close with others. The light of each flicker maybe interfere the light of flicker that subject is fixating. We can increase accuracy rate of this experiment, we can enlarge our device to reduce the interference. The accuracy of ERPs is better than SSVEP in our experiment. However, If we use the visual stimuli flickers in the same number for SSVEP and ERPs experiment, The ERPs experiment will take more time than the SSVEP experiment. We can choose to use ERPs or SSVEP in the proper experiment.

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Abbreviations

ADC Analog-to-digital converter

ALS Amyotrophic Lateral Sclerosis

ASPEN American Society for Parenteral and Enteral Nnutrition

BCI Braincomputer interface

c-VEP code-modulated VEP

CMS Common Mode Sense active electrode

DRL Driven Right Leg passive electrode

EEG Electroencephalogram

EPFL Ecole Polytechnique Federale de Lausanne

ERP Event-related Potential

EXP Experiment

FS Flickering Sequence

FFT Fast Fourier transform

GUI Graphic User Interface

ICSP In-Circuit Serial Programming

LED Liquid crystal display

LED light-emitting diode

Li-poly Lithium polymer

NFS Normal Flickering Sequence

MFS Modular Flickering Sequence

MURS Modular Uniform Random based Sequence

SD Standard Deviation

SSVEP Steady state visually evoked potential

UI User Interface

USB Universal Serial Bus

VCC Voltage constant current

VEP Visual evoked potential