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Steady-State Visual Evoked Potential based Brain Computer Interface: Experiment of LED Stimulation in Two-Rooms Condition

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Abstract - The aim of this study is to determine the effect of room's light condition to brain response. Brain response to repetitive visual stimulation is called Steady-State Visual Evoked Potential (SSVEP) based Brain-Computer Interface (BCI). In this study, flickering Light Emitting Diode (LED) is used as visual stimulation. Mostly, brain response is recorded using electroencephalograph (EEG) and recorded in the brain's occipital lobe that is associated with human vision. Welch's method of power spectral estimation is implemented for estimating the power spectral of recorded signal. The result shows that the highest-power of brain response to repetitive visual stimulus can be detected either in the dark-room or in the bright-room.

Keywords—Brain-Computer Interface (BCI), Steady-State Visual Evoked Potential (SSVEP), Power Spectral Estimation, Highest-Power Detection, LED Visual Stimulation.

I. INTRODUCTION

Brain Computer Interface (BCI) is interfacing device communicates human brain to an external device, so called computer system. Pires [1] defines BCI system as a new type interface system that can extend human capabilities, especially for people who suffered from severe motor disabilities.

According to Grainmann's BCI concept map [2], implementation strategy of Steady-State Visual Evoked Potential (SSVEP) is classified as selective attention that use flickering light as external stimulation. SSVEP relies in brain response properties when stimulated with periodic presentation of visual stimulus (such as flickering/blinking light) [3]. When the subject focus on the visual stimulus, then the occipital lobe also resonates at any given frequency of visual stimulus.

Because of its dependencies on ocular muscle SSVEP based BCI is not applicable for people who cannot control the extra ocular muscle. However, compared to another internally driven BCI (i.e.: motor imagery), the number of commands that can be generated using BCI SSVEP are much more than internally driven BCI [4]. The number of electrodes that are used in BCI SSVEP less than another implementation strategy (i.e.: P3000, motor imagery, slow cortical potential).

The aim of this study is to determine the effect of room's light condition to brain response using LED as an external stimulation. This study is a preliminary study towards implementation using computer screen as an external stimulation.

II. METHODS

A. Human Brain Anatomy

The major motor and sensory area of cerebral cortex are frontal lobe, parietal lobe, temporal lobe, and occipital lobe. Each area has its functions. Conscious perception of visual stimulus from the eyes is processed in occipital lobe [5]. Because of its specific function to visual stimulus, in this study we were only monitoring the occipital lobe.

B. Electroencephalograph (EEG) and Visual Stimulator

To monitor and record brain activities, we used Emotiv EEG Neuroheadset [6] as shown in figure 1. EEG records brain's electrical activity by using electrodes. The electrodes are attached to the scalp. Emotiv EEG Neuroheadset is used as data acquisition device in this study. It has been designed for practical research application.

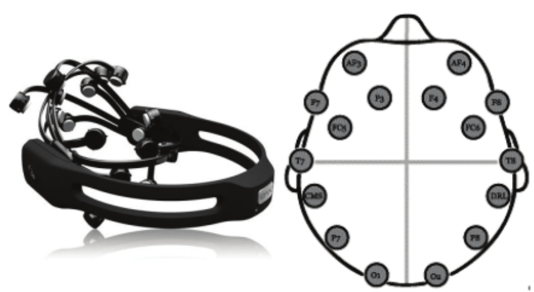

Fig. 1. Emotiv EEG Neuroheadset and electrodes location.

To record brain activity, the Emotiv EEG Neuroheadset uses fourteen electrodes (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4) that need to be wetted with a saline solution. The electrode position use international convention of 10-20 locations [6]. The Emotiv EEG also contains a two-axis gyroscope used to determine the position of the head. It uses proprietary wireless, 2.4GHz band and has 128 samples per second per channel. The ADC is in 14 bits, 1 LSB equals to 0.51 µV.

Sugiarto in [7] mentions that visual stimulus using LED is more flexible to choose the frequency stimulation. Frequency of LED driven stimulus depends on the LED characteristics and the capability of the embedded controller. The side effect of LED-driven stimulus is user fatigue because of its high intensity (>5000 cd/m^2).

We use microcontroller to control LED flickering frequency. The frequency was from 5 Hz up to 38 Hz in 3-Hz step (5 Hz, 8 Hz, 11 Hz, ..., 38 Hz) and the LED color is white.

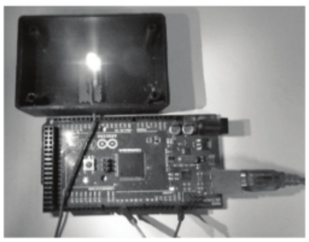

Fig. 2. Implementation of white-colored LED stimulation

C. Welch's Power Spectrum Estimation

Before recorded EEG signals were processed using Welch's power spectrum estimation, the EEG signals were filtered using a 4-40 Hz band pass filter. Welch method is the modification of Bartlett method. The input signals are divided into several overlapped segments. The window function then applied to each segment.

Using this method [8], input signals $x[j]$, $j = 0,1,...,N-1$, divided into several segments. The first input segment is $x_1[j]$ $j = 0,1,...,L-1$. Then,

$$x_1[j] = x[j] \qquad j = 0,1,...,L-1\ , \tag{1}$$

the second segment,

$$x_2[j] = x[j+D] \qquad j = 0,1,...,L-1\ . \tag{2}$$

and finally,

$$x_k[j] = x_k[j+(K-1)D]. \tag{3}$$

K is the number of segmented signals, then $D = \dfrac{N-L}{K-1}$.

Window function of $w[j], j = 0,1,...,L-1$ was applied for each segments with the length of L to compute the periodogram. The result of multiplication each segments with the window function forms a new sequences from $X_1[n]w[j]$ ... $X_k[n]w[j]$. Then, take the Fourier finite transform $A_1[n],...,A_k[n]$ of this sequences using

$$A_k[n] = \frac{1}{L}\sum_{j=1}^{L-1} x_k[j]w[j]e^{-2i\pi jn/L}, \text{ and } i = \sqrt{-1}\ . \tag{4}$$

From these steps, we obtain k modified periodogram,

$$I_k[f_n] = \frac{L}{U}|A_k[n]|^2, \tag{5}$$

where

$$f_n = \frac{n}{L}, \qquad n = 0,...,L/2 \tag{6}$$

and

$$U = \frac{1}{L}\sum_{j=1}^{L-1} w^2[j]. \tag{7}$$

The average of modified periodogram is the spectral estimation:

$$\overline{P}[f_n] = \frac{1}{k}\sum_{k=1}^{k} I_k[f_n]. \tag{8}$$

D. Laboratory Experiment Configuration

The subject was seated in a comfortable chair in front of the LED visual stimulus with a distance of about 40 cm. There are 24 Experiments in total, 12 experiments in dark room condition and 12 experiments in bright-room condition. The duration of each experiment approximately 10 seconds. LED visual stimulus also only flicks for approximately 10 seconds for each experiments. When an experiment is finished, there are no other visual stimulus that given to the subject.

Fig. 3. Experiment in the bright-room condition.

III. RESULT AND DISSCUSION

In this section, we present the result of signal processing in dark and bright-room conditions, and the comparison between the LED visual stimulus frequency and the highest power spectrum estimation detected in frequency domain.

The first experiments were conducted in dark-room condition. The raw EEG signal from channel O1 with 14 Hz visual stimulus frequency is shown in figure 4 and the filtered EEG signal is shown in figure 5. Figure 6 shows power spectrum estimation using Welch method. In this experiments, Welch method uses Hamming as a window function, and 50% overlap. The exact frequency value of highest power detected from figure 6 is 13.88 Hz. It shows that when LED flickers at 14 Hz the brain's occipital lobe mostly resonate at the given frequency.

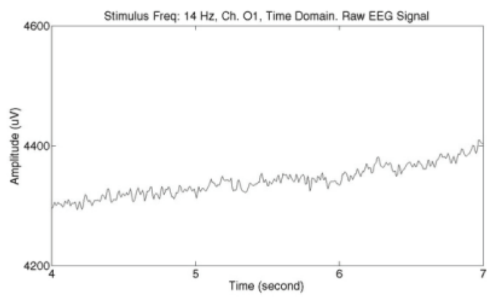

Fig. 4. Raw EEG signal, channel O1, and 14 Hz stimulus frequency

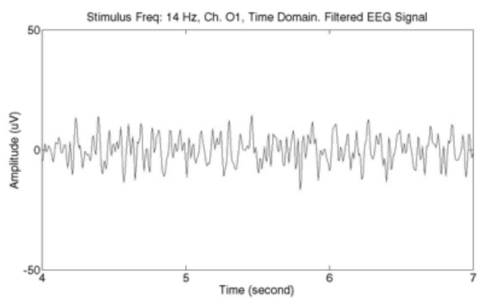

Fig. 5. Filtered EEG signal, channel O1, and 14 Hz stimulus frequency

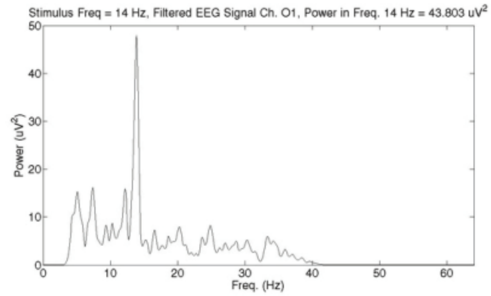

Fig. 6. Welch's power spectrum estimation from filtered EEG signal, channel O1, and 14 Hz stimulus frequency. Dark-room condition.

The second experiments were conducted in bright-room condition. Figure 7 shows power spectrum estimation using Welch method, the exact frequency value of highest power detected from figure 7 is 13.94 Hz.

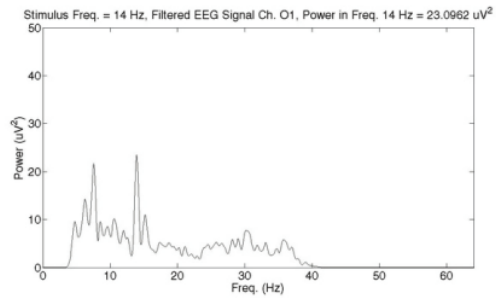

Fig. 7. Welch's power spectrum estimation from filtered EEG signal, channel O1, and 14 Hz stimulus frequency. Bright-room condition.

TABLE I
SUMMARY OF 24 EXPERIMENTS CONDUCTED IN DARK-ROOM AND BRIGHT-ROOM CONDITION

Stimulus Frequency	Dark-Room Condition		Bright-Room Condition	
	Channel O1 Dominant Freq. (Power - μV²)	Channel O2 Dominant Freq. (Power - μV²)	Channel O1 Dominant Freq. (Power - μV²)	Channel O2 Dominant Freq. (Power - μV²)
5 Hz	4.37 Hz (22.61)	5.19 Hz (26.49)	4.81 Hz (17.21)	7.56 Hz (25.23)
8 Hz	6.56 Hz (25.20)	7.88 Hz (28.96)	7.56 Hz (20.39)	11.69 Hz (42.30)
11 Hz	9.50 Hz (21.22)	5.31 Hz (24.45)	9.00 Hz (16.25)	10.31 Hz (29.76)
14 Hz	13.88 Hz (47.96)	13.88 Hz (48.45)	13.94 Hz (23.47)	13.81 Hz (28.25)
17 Hz	16.68 Hz (47.37)	16.69 Hz (44.70)	9.19 Hz (17.30)	9.31 Hz (25.89)
20 Hz	8.18 Hz (24.84)	11.07 Hz (27.07)	19.13 Hz (20.92)	9.56 Hz (24.43)
23 Hz	10.25 Hz (19.25)	10.19 Hz (32.88)	6.94 Hz (25.40)	11.75 Hz (26.08)
26 Hz	5.62 Hz (22.28)	25.07 Hz (21.16)	10.38 Hz (20.79)	11.44 Hz (30.70)
29 Hz	8.18 Hz (27.66)	8.93 Hz (27.60)	4.94 Hz (26.22)	4.94 Hz (39.86)
32 Hz	13.31 Hz (18.48)	7.93 Hz (21.56)	9.69 Hz (18.07)	5.50 Hz (27.68)
35 Hz	5.75 Hz (22.94)	6.93 Hz (24.20)	8.31 Hz (19.21)	14.13 Hz (22.55)
38 Hz	10.37 Hz (23.09)	11.94 Hz (35.66)	9.75 Hz (16.49)	9.69 Hz (30.87)

Table 1 shows the summary of all experiments, in the dark-room condition and bright-room condition. The table shows that if the stimulus frequency is less than or equal to 17 Hz, then the occipital lobe mostly also resonates at any given stimulus frequency either in the dark-room condition or bright-room condition.

Highest power detection at frequency domain gives some false detection. The example of false detection occurs in bright-room condition at channel O2 and 5 Hz stimulation frequency, it is can be caused by the body muscle movement artefact or electrode drift artefact.

When visual stimulus frequency is more than 17 Hz, the highest power detection mostly gives false results. But, at any given stimulus frequency a peak power appeared but its power mostly lower than power in 5 Hz - 17 Hz frequency range. For example is shown in figure 8. When the stimulus frequency is 35 Hz there is a peak power appears in 35.38 Hz, but its power is lower than a power at 5.75 Hz.

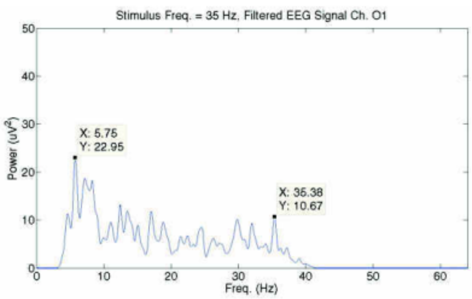

Fig. 8. Welch's power spectrum estimation from filtered EEG signal, channel O1, and 35 Hz stimulus frequency. Dark-room condition.

IV. CONCLUSION

The highest power detection using Welch's power spectrum estimation is more reliable for visual stimulus frequency less than or equal to 17 Hz and the result shows that the highest-power of brain response on frequency domain to repetitive visual stimulus can be detected either in the dark-room or in the bright-room.

Basically, at any given stimulation frequency brain's occipital lobe also resonate at a similar frequency. But, if the stimulation frequency is higher than 17 Hz the power is difficult to be detected. For future work, it needs a method or calculations to compensate the power spectrum estimation.

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