Discriminate the Brain Responses of Multiple Colors Based on Regular/Irregular SSVEP Paradigms

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***Abstract*—Brain-Computer Interface (BCI) system authorizes to controlling and communicates individual peoples with neuromuscular destruction; utilized the brain signals whenever intend to visual stimuli panel. A multi-color stimuli based on Steady-state evoked potential (SSVEP) exiting a pragmatic continuous brain responses. In this experimental study involve the ability of visual stimuli based SSVEP to extract features of human-brain. Distinguish between three-color and different patterns respects to Regular/Irregular paradigms. Utilize Analysis of Variance (ANOVA) to extract the features of each stimulus in agreement with phases and amplitude. The effort of ANOVA is classify the responses effect in each pattern and three color as primary procedure, which exhibit a capability of brain activity based SSVEP paradigms. Outcome results indicate dynamics brainwave (BW) activities, which demonstrate a distinction differences between colors which are effects of brain activity with a significant distinguishable between each others.**

***Index Terms*—Brain-Computer Interface (BCI), Steady-state Evoked Potential (SSVEP), Fast-fourier Transform (FFT), Analysis of Variance (ANOVA), Electroencephalography (EEG)**

I. Introduction

The BCI is novel communication channel technology between human brain and external environment, which construct abilities to control any external electronics device. User Her/his pays attention by stare on stimulus flicker; the commands are expressed to external world based brain activity dependence on stimulus flickers. EEG signals are questing to realize activates which transferred to the real world [1]. Researchers are identified that SSVEPs based BCI don't need training time; and provide a faster response with higher information transfer rate (ITR) [2]-[4]. Advance technology and a high computational signal processing algorithms are given new approach in BCI systems. The new approach allows delve in advance step to understanding brain functions. The brain-wave (BW) is reliable and sufficient to use. Progressing signals towards innovative to understanding the brain-waves (BW) activity concept and requirements. Extent analyses of Digital signal processing (DSP) enables to excitations a particular tasks. Since, the brain-waves (BW) can clarified and transformed into an action, such as robotic-arm movement, a wheelchair control, word-typing-process using a virtual keyboard and e-home. The observation rhythmic of visual stimulus gives a growing oscillatory on EEG signals within several harmonics [5]. The major frequency depends on flicker stimulus. Typically, SSVEP based BCI involve iterative of visual stimuli to procurement brain responses. The iteration on stimulus will translated to the specific control commands or machine instruction by paying attention on visual targets [5]. Interpretations of EEG signals based SSVEP are noisy affect with eye blink artifacts and other external noise such as power-line interference. These noisy signals require efficient strategies to prevention using a specific signal processing techniques which reduce undesired effects; utilize an implement of high precision filter or other techniques [6].

The colors and patterns of Regular/Irregular paradigm of visual stimuli also defined a magnificent elicit affect on SSVEP. Number of BCI studies investigated which paradigms give a strongest SSVEP response. Foremost BCI systems based on SSVEP depended on number of stimuli flickers with strip differences in frequencies or phases, which are exposed brain activities from occipital region of scalp [7]. The motivation in this experimental study is construct a practical BCI system utilize a multi-color stimuli with patterns sequence. SSVEP stimulation panel is set as close-loop system, which responds via embedded microcontroller crossing computer in order to change individual colors and patterns in each light emitted diode (LED). Visual stimulator play an important role that present a flicker within six-patterns by single LED; taking in account the effect of stimulation parameter relying on color and patterns stimuli. Using ANOVA to recognize the different colors respect to Regular/Irregular paradigm according to amplitude and phase shifting. Compared the number of available choices aspect to different phase and amplitude which extend by introducing a multi-patterns and multi-colors targets.

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II. Materials and Methods

A. System Configuration

Differences in Regular/Irregular patterns and colors evoked BCI systems respect to SSVEP stimuli. Fig. 1 illustrates the main block diagram of low-cost SSVEP based on BCI system. In general, the multi-stimulus prototype obtained on LEDs flickering which produce 24 stimuli positions. Evaluate this study, by setting single LED in three colors of (Blue, Red and White); equally distributed distance in between. Controlling on stimuli LEDs are prominent by commands through serial data-bus of computer, according to experiments setup conditions. Commonly, the stimulus LED induced flickering at fixed intervals as Regular/Irregular paradigms toward distinguish brain response. Since, a (single LED $\times$ 3 colors) which are scattered in centre with equally distance in between. Each LED flickered among four phase-shift aspect to $(0^0, 360^0, 720^0 \text{ and } 1080^0)$ respectively according to setup configuration of patterns.

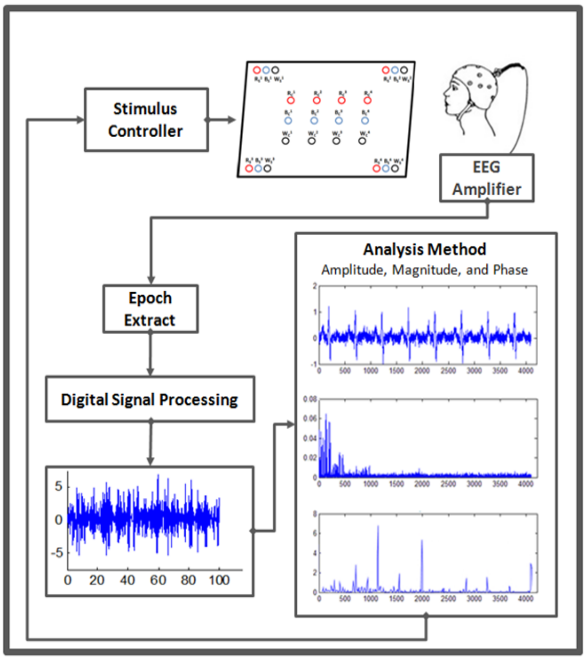

Figure 1. The main block diagram proposed multi-colors LED's stimuli as a low-cost SSVEP based BCI, a stimuli panel content 24 stimulus position; distributed between surround and center; using promote commands to control in each LED positions respect to experiment protocol. Analysis methods extract feature from EEG data base on amplitudes and phases.

A control promotion of stimuli LED is depending on patterns condition setup. The stimuli LEDs are separated into three different colors arranged as (RED_LED, BLUE_LED and WHITE_LED) coordinated on panel as $(R_c^1, B_c^1 \text{ and } W_c^1)$ respectively. EEG signal was measured by single electrode placed at occipital (*Oz*) region, which is exposed a stronger brain activities effect on the scalp [7]. Common mode sense (CMS) activates electrode and drives right leg (DRL) are presenting a passive electrodes which drive the average potential.

B. Visual Stimuli

Consideration the amplitude of lumens in LED that is significant large enough to evoked the SSVEP responses. Different color respect to signal phase are induced in each stimuli which separated into groups of LED. Evaluate all setup condition of this experiment, in order to find out the behavioral and effectuation of brain activity response. Fig. 2 demonstrates the stimulus into five cycles of rhymester on LED as onset of (on / off LED). To induce the stimulus based on SSVEP paradigm depending on flickers beside the phase-shift of each cycle according to [7], [8] in (1):

$$\theta_i = (i-1).90^{\circ} \ ; \ i = 1, 2, \dots, N \qquad (1)$$

The flicker $\mathrm{LED_i}$ is shifted respect to phase angle over full-phase 360°, where $\mathrm{N} = 5$ incremented by 90°.

Considered a pulse trigger in same time event of LED flicker in each cycle, which implies the control delay signal [7], [8] according to (2):

$$t_i = \theta_i / 360^{\circ} \qquad (2)$$

where θ_i is used to anticipated phase delay, and t_i was extract to indicate the flicker and trigger event in time domain.

On other hand, the flickers frequencies depend on θ_i as sequence on LED were t_i present the iteration time requested in (3):

$$T = 1/f \qquad (3)$$

where T is cycle duration, and f is the flicker frequency, indeed setting one or more stimuli frequencies based 5.6Hz and 11.8Hz, which surrounded by Alpha brain response range of (8-13Hz) [9].

Constructed model contained two addition signals present the trigger events in each cycle. First trigger produced in each LED Pulse-On; and second trigger produced in every new cycle sequence which indicates to new stimulus segment. Each stimulus cycle had period in T, comprised by T_{on} and T_{off}. Fig. 2 illustrated one stimulus cycle, since the White-space present (off-time) and Red-blocks present a (stand-on-time); furthermore the Blue-blocks indicate to triggers respect to new cycle-begin and Gray-block indicates which LED is flickering in that time.

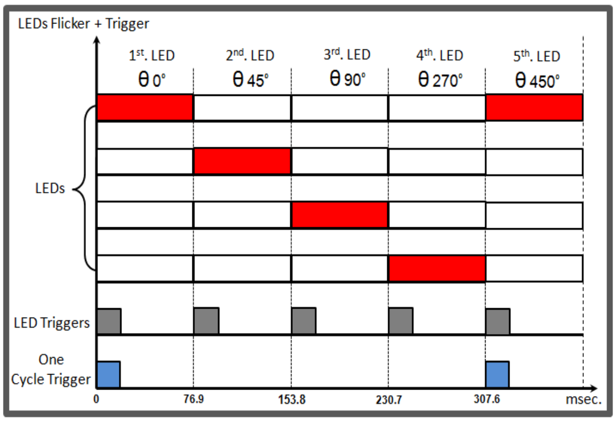

Figure 2. A regular flickering sequences LEDs for five cycles, which include two triggers, first trigger indicate stimulus LED, and second trigger indicate a new cycle [8].

Regulars/Irregular paradigms are regenerate into different phases depend on θ° of (2) as function of stimulus LED. Further evoke high duty cycle on some patterns within same phases to discern the effect and behavioural of brain-wave (BW) activity.

C. Signal Analysis

In this study explore the difference between three colors respect to Regular/Irregular according to high / low flicker frequencies at 5.6Hz and 11.8Hz based on SSVEP. Adopt offline analysis by extraction EEG epochs in each recording level. Analysis of Variance (ANOVA) examines and tests the set of standard effects (e.g. main effects and interactions) [10]. The "Mean-value" of each accumulates trails data of EEG raw respect to color-stimuli of brain response. Influence responses with three different colors of (Blue, Red and White) are accumulated and pre-processing by filtering to extracting feature. Reveal SSVEP amplitude in each color by extract FFT to detect the maximum spectral power [8]. One-way ANOVA is a technique that comparison a significant hypothesis between entire groups. The Mean-value is determined a significant different from each other according to test of null hypothesis H_0 and alternative hypothesis of H_1. Nonetheless, the alternative hypothesis of H_1 presents a not equal entries group; both hypotheses are denoting by (4) and (5):

$$H_0: \mu_1 = \mu_2 = \mu_3 \dots = \mu_k \tag{4}$$

$$H_1: \mu_1 \neq \mu_2 \neq \mu_3 \dots \neq \mu_k \tag{5}$$

Independent groups are normally distributed which compared in one-way ANOVA. However, the different group's values called "Mean Square within groups" denoted by MS_{within}; as well "Mean Square between-groups" denoted by $MS_{between}$ [10]. In general formula requires to finding SS_{within} and $SS_{between}$ values, which are correspond to the "degrees of freedom", according to (6) defined in [10].

$$SS_{\text{within}} = \sum_{j=1}^{n_i} (Y_{ij} - \overline{Y_i})^2, \;\; df_{\text{within}} = n_i - 1 \tag{6}$$

Individual groups of i, where Y_{ij} is observed value for pattern j of group i and $\overline{Y_i}$ is representing the sample means for group i, respect to the estimate δ^2 that of MS_{within} in (7).

$$MS_{\text{within}} = SS_{\text{within}} / df_{\text{within}} \tag{7}$$

Although, $SS_{between}$ presenting the summations of the squared between-group deviations (8), where the deviation is same for all patterns at circumstances at same group [10]:

$$SS_{between} = \sum_{i=1}^{k} n_i (\overline{Y_i} - \overline{\overline{Y_i}})^2 \tag{8}$$

where $\overline{\overline{Y}}$ present the grand "Mean"; since the k is unique deviation [10].

To distinguish a null Hypothesis respect to F statistic ratio tend enough in non-rejection region. In other hand when the alternative hypothesis is true, then a null hypothesis is neglected. Finally prepare the epochs on all collected Data based on flickering onsets to obtain SSVEP responses to discriminate and compare the difference in patterns. Extracting require data of spectral analysis according to the brain activities response of each LED-color groups.

III. Result

The preliminary result of experiment based on SSVEP paradigms of EEG activity which examine and ingesting brain responses. Utilize a One-way ANOVA method for analysis, which indicate a significant difference depending on three-color stimuli; taken in account a preprocessing which performed by implement a low-pass filter (LPF), and high-pass filter (HPF) to remove unwanted signals.

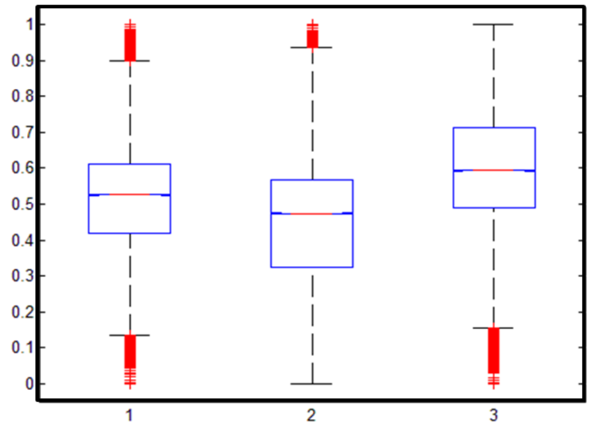

Figure 3. Three LEDs-color stimuli on fixed 11.8Hz frequency, respect to (Blue-Red AND White) of (1, 2 and 3) correspondingly; the mean value in white LED greater than other two stimuli colors.

After recording all scission flickers stimuli that recording as EEG Data which covers all sessions of experiment configuration. Perform average of all accumulative EEG segments under the same stimulus condition.

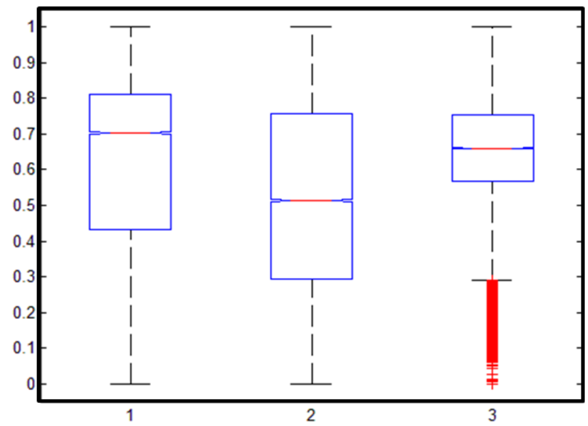

Figure 4. Three LEDs-color stimuli on fixed 5.6Hz frequency is represented respect to (Blue-Red and White) of (1,2 and 3) correspondingly, the mean values in blue and white LED color greater than red LED.

Correspond to the SSVEP response of brain activity recording and signal processing fundamentals of digital filters.

A pre-processing and conducting all EEG epochs, which gathered and filtered by FFT into bands 5.6Hz of low-stimuli and 11.8Hz as high-stimuli; find out the spectral power in each color [8]. A statistical inference of null and alternative hypothesis used to distinguish the difference between three colors within low/high frequencies, from our data-set. Referring to multi-color recognizing based on SSVEP paradigms of stimuli, where the experiment configuration conditions of all sessions are steady and equal, which accept varying frequencies. The schemes in Fig. 3 and Fig. 4 present the SSVEP response that indicates different quantification component according to flicker frequencies. Fig. 3 and Fig. 4 shown results ANOVA in three-color-stimulus categories of brain signal accept in α band brain-wave (BW) frequency that indicates a significant difference in between.

Since, the multi-color stimuli respect the higher flicker frequency at 11.8Hz. Fig. 3 illustrates the White-stimulus is greater than others stimuli by different "Mean-values" estimate the amplitude of SSVEP response. Particular events occurrence according to the influences of brain response, which present a pragmatic different ‘Mean’ in each color stimulus respects to SSVEP response. Analysis begins with a procedure to discriminate of SSVEP respond signal depending on increasing noise signal ration. At the same configuration and conditions of multi-colors stimuli, but in lower flicker frequency within 5.6Hz, the Fig. 4, illustrate a multi-color stimulus, which demonstrate White and Blue-stimuli is bigger than Red stimulus color.

IV. Conclusion

This study was successfully demonstrated with aspect to inquire an offline analysis of SSVEP based BCI system. The present results indicate assessment of three true colors, which are defined by visual stimulus, depends on foundation of SSVEP response paradigms. Structured Regular/Irregular stimuli flicker, using a stimulation panel to evoke. Through experiment preparation employed an ordinary LED to flicker. Concluding offline analysis by One-way ANOVA, which realized the behavioral of brain responses respect to a Three-color stimulus by extracting the FFT to detect the maximum and minimum spectral power in each color. Consequently we found, different influence in SSVEP response respect to brain activity performance such as:

SSVEPs elicited by White-color-stimulus has a highest brain activity in higher stimuli frequency compared with Red and Blue colors, so far the White-color is still the best of encoding, in other hands achieves a highest accuracy. But in lower stimuli frequency we found the White and Blue-colors realized highest brain activity compared with the Red-stimulus.

This could be helpful as new applications to support by increasing BCI control-commands depending on color-stimuli, more attractive with external environment and making objective comparison between BCI systems.

A multi-color is a promising solution for people has problem with motor-disabilities with more attractive external environment.

This will make more objective comparison among BCI systems based multiple colors. Finally this gave us the advantages to exploit this method as a future applications work in SSVEP based on BCI system as online experiments.

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