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Multi-Command SSVEP-based BCI System via Single Flickering Frequency Half-Field Stimulation Pattern

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***Abstract*— This paper proposes a half-field steady state visual evoked potential (SSVEP)-based brain-computer interface (BCI) system to enhance the number of limited commands obtained from the existing SSVEP-based BCI methods. With the theory of vision perception and the concept of the existing half-field SSVEP-based BCI system, we propose the new stimulation pattern that, by using only one frequency, four commands can be generated with the average classification accuracy of approximately 77%. By using only one frequency, eye fatigue can be reduced. Furthermore, this method can be efficiently used to further increase the number of commands for the existing SSVEP-based BCI system.**

I. Introduction

Brain-computer interface (BCI) is the connection between brain signal with computer to restore and enhance a communication or normal activity of persons with disabilities [1, 2]. Among many BCI methods, event related potential (ERP) is one of the popular techniques, especially, visual evoked potential (VEP). VEP technique is widely employed in BCI system. VEP can be grouped into transient visual evoked potential (TVEP) or P300 [3, 4] and steady state visual evoked potential (SSVEP).

In this paper, we will mainly focus on the SSVEP technique. SSVEP is the electroencephalogram (EEG) that changes according to various visual stimulation patterns at some specific frequencies [5]. For SSVEP-based BCI system, flickering stimulator is commonly designed from the light emitting diode LED, liquid crystal display LCD screen and cathode ray tube CRT screen [6].

In order to increase the number of commands, some researchers have allowed subjects to look at the different flickering frequencies over multiple times [1, 2, 5, 7, 8]. A. Materka and M. Byczuk [9] present the technique called half-field SSVEP for BCI system. By letting each eye looks at two different frequencies at the same time, the single and array LEDs at frequency range between 34-40 Hz are investigated. The results illustrate that a good stimulator is an array LEDs. In order to produce multi-command SSVEP based BCI system, Z. Yan, *et al* [10] present the method that utilizes a half-field bilateral flicker stimuli to form each target by a combination of right-and-left frequencies. Even though this paper illustrates the promising results, some subjects still have difficulties looking at two stimuli with two eyes at the same time. Hence, efficient stimulator design is an important problem for a half-field SSVEP system.

In this paper, we propose a new half-field stimulation pattern of the SSVEP. With a single specific frequency, the proposed pattern can lead to four commands. Besides that, by using only one frequency, it is easily to focus with less visual fatigue compared with the existing works.

II. Proposed Method

A human visual field is the area of the vision that human can see the object with the eyes. A normal horizontal visual field is 160 degrees; the nasal direction is 60 degrees and temporal direction is 100 degrees. A normal vertical visual field is 135 degrees. In order to maximize the efficiency of the designed pattern, stimulation pattern is recommended to put in the area of the visual field.

A. Half-Field stimulation pattern

In this paper, our half-field stimulator is designed to match a human visual field. It consists of two black boxes and one Light Emitting Diode LED surface mount matrix for the flicking stimulator. Actually, any frequencies can be used, but for the simplicity on hardware implementation, this paper employed 7 Hz flickering frequency. The location of the designed stimulator is shown in Fig1.

According to the stimulation pattern in Fig.1, with only one frequency in the middle, four commands can be generated by looking at the stimulation according to the focusing method in Fig.2. All four commands can be listed in Tables I and II. According to Table I, four commands come from 1) both eyes looking at the left black box, 2) both eyes looking at the right black box, 3) both eyes looking at the LED box, and 4) both eyes are closed. According to Table II, four commands come from 1) closing right eyes and looking at the LED via left eye, 2) closing left eyes and looking at the LED via right eye, 3) both eyes looking at the LED box, and 4) both eyes are closed.

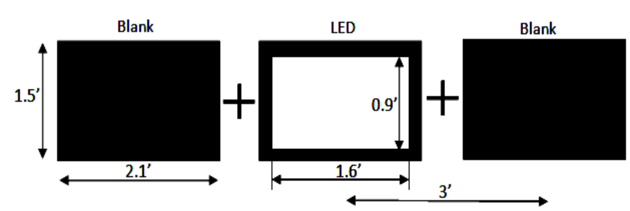

Fig.1 A half field flickering SSVEP based BCI system

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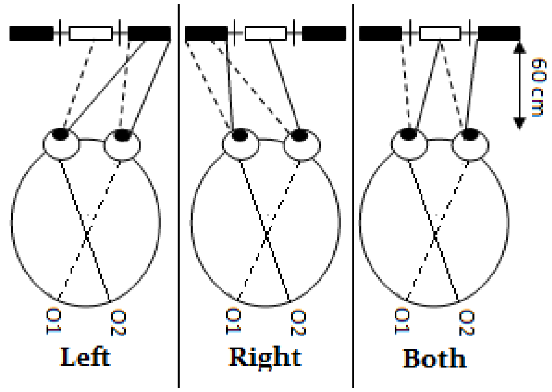

Fig.2 Focusing patterns to stimulator with a half and full visual fields.

B. EEG Acquisition and Real-Time Processing

The lead selection for SSVEP is located on both sides of the occipital region, i.e. O1 and O2. For the reference electrode, in this paper, we will investigate for the suitable one between reference channels from the central lobe C3, C4 and the parietal lobe P3, P4. Reference channel is used for a common mode noise rejection to enhance a SSVEP signal [11]. Two bipolar channels are acquired using the EEG amplifiers BIOPAC^{TM} system. The electrode positions are according to the international 10-20 electrode placement system.

TABLE I
NORMAL FOCUSING PATTERN FOR HALF- FIELD SSVEP

Command	*Target for Focusing*	
	Left eye	*Right eye*
1	LED	Black box
2	Black box	LED
3	LED	LED
4	Close	Close

TABLE II
CLOSING ONE EYE FOCUSING PATTERN FOR HALF-FIELD SSVEP

Command	*Target for Focusing*	
	Left eye	*Right eye*
1	LED	Close
2	Close	LED
3	LED	LED
4	Close	Close

For the preprocessing, the acquired signals are filtered by analog band pass filter with cut off frequencies 1 and 35 Hz. A 50 Hz analog notch filter is also employed to remove a power line noise. The analog to digital A/D, NI USB 6009 multi-function data acquisition card is used for converting those analog signals to digital data with the sampling rate of 128 Hz.

C. Algorithm

In this paper, we also design the algorithms in order to extract the feature that can be simply used to classify SSVEP signal into four commands according to the half visual field stimulation with one flickering frequency at 7 Hz. First and second harmonic frequencies are also used for the response detection [12, 13]. Before using the proposed system, the user needs to perform a three calibration processes as follows:

1) Record a spontaneous EEG baseline values $BL7_{O1}$ and $BL7_{O2}$ that are the maximum magnitudes of power spectrums of channels O1 and O2 among 7, 14 and 21 Hz, i.e.

$$BL7_{O1} = \max(PS_7, PS_{14}, PS_{21}) \quad (1)$$
$$BL7_{O2} = \max(PS_7, PS_{14}, PS_{21}) \quad (2)$$

where PS_i is a magnitude of power spectrum at the frequency *i* Hz calculated from Welch periodogram.

2) Focus at blinking LED with both eyes for 5 seconds and record for the maximum power spectrum of each channel O1 and O2 among 7, 14 and 21 Hz, i.e.

$$Pm7_{O1} = \max(PS_7, PS_{14}, PS_{21}) \quad (3)$$
$$Pm7_{O2} = \max(PS_7, PS_{14}, PS_{21}) \quad (4)$$

Then calculate for the threshold values $T7_{O1}$ and $T7_{O2}$:

$$T7_{O1} = Pm7_{O1} - (Pm7_{O1}/4) \quad \text{where} \quad Pm7_{O1} > BL7_{O1} \quad (5)$$
$$T7_{O2} = Pm7_{O2} - (Pm7_{O2}/4) \quad \text{where} \quad Pm7_{O2} > BL7_{O2} \quad (6)$$

3) Close both eyes and record the maximum power spectrum at O1 among alpha band frequency (8-13 Hz) denoted as P_{max} [14], then calculate for threshold value T_{alpha}:

$$T_{alpha} = P_{max} - (P_{max}/4) \quad (7)$$

The algorithm for half-field SSVEP detection can be summarized followed as

1) Define P_{alpha} as the maximum power spectrum (PS) of O1 channel among alpha band frequency (8-13 Hz).
2) If $P_{alpha} > T_{alpha}$ then make the decision as **command 4** by followed Tables I or II.
3) Define F_{71} as the maximum power spectrum (PS) of O1 channel among 7, 14 and 21 Hz, then calculate Δ_1

$$\Delta_1 = (Pm7_{O1} - F_{71})$$

4) Define F_{72} as the maximum power spectrum (PS) of O2 channel among 7, 14 and 21 Hz, then calculate Δ_2

$$\Delta_2 = (Pm7_{O2} - F_{72})$$

5) If $F_{71} > T7_{O1}$ and $F_{72} > T7_{O2}$ then make the decision as **command 3**.
6) If $\Delta_1 > \Delta_2$ then make the decision as **command 1**.
7) Else if $\Delta_1 < \Delta_2$ then make the decision as **command 2**.
8) In other cases, No command is selected.

III. Testing and Results

There are 4 volunteer subjects to test a performance of our proposed system. Before testing, all subjects are trained to perform the proposed system for 15 minutes. For the experiment, each subject performs 4 trials. A comparison between 2 positions of reference electrode P and C as (O1-P3, O2-P4) and (O1-C3, O2-C4) are also tested. Each position is tested with 2 focusing pattern according to Tables I and II. Each trial contains 10 times of each focusing pattern perform, hence, in total, we have 120 commands per trial. The results are summarized in Table III.

According to Table III, the results of half-field SSVEP for BCI system report the accuracies ranged between 60% to 86.67%. This means that the proposed pattern is likely to be valid to all of the subjects. Increasing more subjects to further verify our claim is listed as our future work. For the reference electrodes comparison, the accuracy using parietal position is higher than using the central position. Furthermore, the results show that normal focusing leads to better performance than trying to close one eye and looking at the stimulation patterns. According to the time consuming, each command consumes the average time of approximately 4 seconds.

IV. Discussions

According to the results, a possible position of reference electrode for our stimulation method should be the one that located near the occipital region. This position will make the reference electrode efficiently reject a common mode noise to enhance a SSVEP response. The performances of the proposed system have the average accuracy ranging between 71.65% - 77.5% by using approximately 15 minutes for the training session. The normal focusing pattern seems to achieve better result than closing one eye. However, subject 1 and subject 4 have ability to perform better via one eye closing. Increasing the training time might lead to higher accuracy.

Regarding the comparison between the previous method and the proposed method, for the proposed method, the worse accuracy that we get is 60% with one eye closing and 66.67% with normal focusing pattern. For the previous method in [10], some subjects could obtain a high accuracy. However, some subjects could not simultaneously focus at the two flickering frequencies which lead to the decreasing in accuracy. Therefore, the proposed stimulation is one possible way to solve the existing half-field SSVEP-based BCI problem.

TABLE III
THE RESULTS OF HALF FIELD SSVEP BASED BCI SYSTEM

Subject	*Focusing Patterns*	*% Average accuracy* (O1-P3) (O2-P4)	*% Average accuracy* (O1-C3) (O2-C4)
1	Normal	66.67	70
	Close one eye	83.3	60
2	Normal	80	76.7
	Close one eye	60	70
3	Normal	83.3	76.7
	Close one eye	73.3	70
4	Normal	80	70
	Closed one eye	70	86.67
Average	Normal	**77.5**	**73.35**
	Close one eye	**71.65**	**71.67**

Regarding the further use of the proposed method, if we add our system to each stimulation frequency of the normal SSVEP-based BCI system, we can get more commands by at least 3 times (excluding closing both eyes, command 4). This is one way to solve the difficulty for increasing the number of commands for the SSVEP-based BCI besides increasing the fundamental frequencies. The GUI and corresponding system for employing and processing the proposed method is also developed as shown in Fig.3(b). Fig.3(a) also demonstrates the experimental setup on employing the proposed system in real-time for turning on/off the selected electrical devices according to four commands with one flickering frequency at 7 Hz.

V. Conclusions

In this paper, we have proposed the new half-field visual stimulation pattern. By employing the proposed pattern, with only one flickering frequency, we can generate 4 commands with the acceptable classification accuracy. Furthermore, possible electrode position regarding the proposed pattern is also investigated. This method can be further applied to increase the number of commands in the normal SSVEP-based BCI system.

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References

[1] G. R. Muller-Putz, and G. Pfurtscheller, Control of an Electrical Prosthesis With an SSVEP-Based BCI. IEEE Transactions on Biomedical Engineering,, 2008. **55**(1), p. 361-364.

[2] R. S. Leow, F. Ibrahim, and M. Moghavvemi, Development of a steady state visual evoked potential (SSVEP)-based brain computer interface (BCI) system. in Intelligent and Advanced Systems, International Conference 2007.

[3] G. M. Pires, Castelo-Branco, and U. Nunes. Visual P300-based BCI to steer a wheelchair: A Bayesian approach. 30th *Ann. Int. Conf.* Engineering in Medicine and Biology Society, *IEEE/EMBS* 2008.

[4] I. Iturrate, et al., A Noninvasive Brain-Actuated Wheelchair Based on a P300 Neurophysiological Protocol and Automated Navigation. *IEEE Trans, Robotics* on, 2009. **25**(3), p. 614-627.

[5] S. Hui, et al., Research on SSVEP-Based Controlling System of Multi-DoF Manipulator, *in Proceedings of the 6th International Symposium on Neural Networks: Advances in Neural Networks - Part III*. 2009, Springer-Verlag: Wuhan, China.

[6] W. Zhenghua, et al., Stimulator selection in SSVEP-based BCI. *Medical engineering & physics*, 2008. **30**(8), p. 1079-1088.

[7] H. Cecotti, I. Volosyak, and A. Graser. Evaluation of an SSVEP based Brain-Computer Interface on the command and application levels. 4th *Int. IEEE/EMBS Conf.* Neural Engineering, NER '09.

[8] I. Sugiarto, B. Allison, and A. Graser. Optimization Strategy for SSVEP-Based BCI in Spelling Program Application. in. *ICCET* '08. *Int. Conf Computer Engineering and Technology*. 2009.

[9] A. Materka and M. Byczuk, Alternate half-field stimulation technique for SSVEP-based brain-computer interfaces. *Electronics Letters*, 2006. **42**(6), p. 321-322.

[10] Y. Zheng, et al. A half-field stimulation pattern for SSVEP-based brain-computer interface. *Ann. Int. Conf. Engineering in Medicine and Biology Society, IEEE /EMBC* 2009.

[11] W. Yijun, et al. Lead selection for SSVEP-based brain-computer interface., 2004. 26th *Ann. Int. Conf. of Engineering in Medicine and Biology Society, IEEE IEMB*S 2004.

[12] D. J. Krusienski, and B.Z. Allison. Harmonic coupling of steady-state visual evoked potentials. 30th *Ann. Int. Conf. of Engineering in Medicine and Biology Society, IEEE/EMB*S 2008.

[13] W. Ruiping, G. Xiaorong, and G. Shangkai. Frequency Selection for SSVEP-based Binocular Rivalry. 2nd *Int. Conf. Proceedings in Neural Engineering. IEEE/EMBS* 2005.

[14] Y. Punsawad, Y. Wongsawat, and M. Parnichkun Hybrid EEG-EOG brain-computer interface system for practical machine control. *Ann. Int. Conf. of in Engineering in Medicine and Biology Society IEEE/EMBC*, 2010

(a)

(b)

Fig.3 (a) The experimental setup and the proposed half-field visual stimulation pattern, (b) GUI and the corresponding system of the proposed method during the real-time processing for turning on/off the selected electrical devices according to 4 commands with one flickering frequency at 7 Hz