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Motion Visual Stimulus for SSVEP-based BCI system

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Abstract— **Steady-state visual evoked potential (SSVEP)-based brain-computer interface (BCI) system is one of the most accurate assistive technologies for the persons with severe disabilities. However, the existing visual stimulation patterns still lead to the eyes fatigue. Therefore, in this paper, we propose a novel visual stimulator using the idea of the motion visual stimulus to reduce the eyes fatigue while maintaining the merit of the SSVEP phenomena. Two corresponding feature extractions, i.e. 1) attention detection and 2) SSVEP detection, are also proposed to capture the phenomena of the proposed motion visual stimulus. Two-class classification accuracy of both features is approximately 80%, where the maximum accuracy using the attention detection is 90%, and the maximum accuracy using the SSVEP detection is 100%.**

I. Introduction

Visual evoked potential is the brain signal occurred from the natural responses to visual stimulations (e.g. light, flash, or checker board patterns) at specific frequencies. SSVEP is generated by stationary localized sources and distributed sources that exhibit characteristics of wave phenomena inside the brain. SSVEP is useful in research because of its excellent signal-to-noise ratio and relatively robust to artifacts. According to BCI researches [1-8], SSVEP-based brain computer interface (BCI) device is one of the most accurate assistive technologies for the persons with severe disabilities.

Regarding the stimulation pattern of SSVEP, there are three main types, flickers as the light-emitting diode (LED), the cathode ray tube of a desktop monitor (CRT), and the liquid crystal display of a laptop screen (LCD). Zhenghua W. *et al* [9] claim that SSVEPs occurred from the LED flicker are significantly larger than those evoked by other flickers. Regarding the lead selection for SSVEP, Yijun W. *et al* [10] improve the applicability of SSVEP-based BCI system by acquiring EEGs over visual cortex between Pz and Oz. To retain SSVEP, the reference channel must have lower amplitude of SSVEP than the signal channel. To reduce background noise, it should have similar background activities with the signal channel. Therefore, the ones close to the signal channel, with lower amplitude of SSVEP, could be the candidates of the reference channel.

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Regarding the SSVEP-based BCI system, in 2008, Muller-Putz G.R. *et al* [3] proposed an asynchronous (self-paced) four-class BCI based on steady-state visual evoked potentials (SSVEPs) used to control two-axis of electrical hand prosthesis. The four LED flicker were 6, 7, 8, and 13 Hz. EEG was recorded bipolarly posterior to electrode positions O1 and O2 according to the international 10–20-electrode system. The ground electrode was placed at position Fz. The results showed the classification rates from 74 to 88%. In 2009, Hui, S. *et al*. [7] presented the SSVEP-based BCI for multi-degree of freedom manipulator control. By using six LEDs flickering (8Hz-20Hz), the results yielded an average accuracy of 72%. In 2010, I. Volosyak and A. Graser [5] introduced the BCI wizard as a system that automatically identifies key parameters to customize the best BCI paradigm for each user and to explore the two most effective BCI based VEP approaches, i.e. SSVEP and P300. The results showed that accuracy and information transfer rate of SSVEP paradigm are higher than P300 paradigm.

Besides the SSVEP, similar idea using the motion onset visual evoked potential (mVEP) was also reported in [6] via the use of N200 signal for the BCI-based spelling system. For further reference on the origin of these signals, the readers could refer to [11] on the study of the functional anatomy and physiology of human visual system from the retina to primary visual cortex.

Even though SSVEP-based BCI yields high accuracy, it usually causes the eyes fatigue problem which can directly affect the long term performance. Meanwhile mVEP can reduce the eyes fatigue, but can achieve lower accuracy than SSVEP. Another thing is most of the existing literatures usually detect mVEP in time dependent way e.g. P300, N200, which might be easily suffered from the artifacts. In this paper, we combine the merit of both SSVEP and mVEP to create the novel visual stimulus as well as to find the efficient features to capture its phenomena.

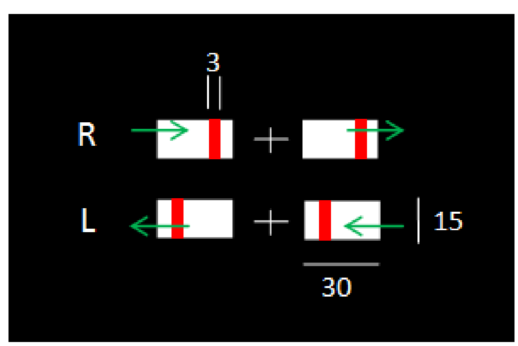

Fig. 1 Motion visual stimulator (Number is in the scale of millimeter)

II. PROPOSED METHODS

In this section, we will illustrate the proposed motion visual stimulator as well two proposed feature extraction methods, i.e. 1) SSVEP detection and 2) Attention detection.

A. Data Acquisition

By following the 10-20 international electrodes placement system, two bipolar-channel EEG signals O1-C3 and O2-C4 are acquired. A1 and A2 are employed as the ground electrodes. EEG amplifier of BIOPAC™ with gain 50,000, analog highpass filter with a cutoff frequency at 0.1 Hz, analog lowpass filter with a cutoff frequency at 35 Hz, and analog notch filter at 50 Hz are used to preprocess the acquired signal. A sampling rate is set to 200 Hz.

B. Visual stimulator

The proposed visual stimulator is designed 1) to reduce the eyes fatigue after the subject takes long time staring at the stimulator, and 2) to make the SSVEP phenomena happen in the occipital lobe of the brain. A motion visual stimulator with the liquid crystal display (LCD) monitor is then proposed as shown in Fig 1. This stimulator can be seen as a motion of vertical strip moving to the left or right direction. In reality, the strip does not move but flash to the left or right with the frequency at 3.5 Hz to make it looks similar to the real motion, hence fatigue can be reduced while SSVEP can still be detected.

For the visual stimulator, there are four pieces of the white rectangles of size 30x15 mm and the red rectangles of the size 3x15 mm. The red one will move along the white one. These rectangles will be located into two rows, left and right sides. In the upper row, the red strips will move to the right while in the lower row, they will move to the left. By staring at the fixation between the two sides, and stay approximately 90 cm apart from the stimulator, the visual stimulator will be ready to use.

C. SSVEP detection from the motion visual stimulus

- **Parameter Calibration**

Before using the proposed system, some baseline parameters need to be acquired as follows:

$$BL_{Oi} = max\,(BL_{3.5}\,,\, BL_7\,,\, BL_{14}) \qquad i = 1, 2 \qquad (1)$$

where BL_n represents the baseline parameter at the frequency n. $BL_{3.5}$, BL_7 , BL_{14} represent the baseline values of three harmonics of the fundamental frequency 3.5. BL_{Oi} are the baseline frequencies at channels O_1 and O_2. BL_n can be calculated as

$$BL_n = mean\,(BL_{n-r}\,,\, BL_n\,,\, BL_{n+r}) \qquad n = 3.5,\ 7 \text{ and } 14 \qquad (2)$$

where r denotes the frequency resolution which depends on the sampling rate and the sample to process in one command.

- **Feature Extraction Process**

The amplitude of the power spectral density f_n obtained from Welch periodogram method is used to extract our feature of interest as the following process:

$$PS_{Oi} = f_{Oi} - BL_{Oi} \qquad i = 1,2 \qquad (3)$$

where PS is the difference of magnitude of PSD between f_{Oi} and $BL_{Oi,}$ f_{Oi} can be calculated as

$$f_{Oi} = max\,(f_{3.5}\,,\, f_7\,,\, f_{14}) \qquad i = 1,2 \qquad (4)$$

where f_n can be calculated as

$$f_n = mean\,(f_{n-r}\,,\, f_n\,,\, f_{n+r}) \qquad n = 3.5,\ 7 \text{ and } 14 \qquad (5)$$

- **Decision Making**

As the feature is carefully selected, the simple decision rule can be used to compare PS_{O1} and PS_{O2}. The decision of two-class classification (Right or Left) can be made according to Table I. For example, if PS_{O1} is higher than PS_{O2} the decision is "Right".

TABLE I
DECISION RULES FOR CLASSIFICATION ACCURACY OF SSVEP DETECTION VIA VISUAL MOTION STIMULUS

Commands	PS_{O1}	PS_{O2}
Right	Higher	Lower
Left	Lower	Higher

D. Attention detection from the motion visual stimulus

Similar to the previous session, attention index is defined as the absolute value of the difference between alpha band power and beta band power of channels O1 and O2, .i.e.

$$\Delta_{O1} = |\,PS_{\text{alpha O1}} - PS_{\text{beta O1}}\,|$$
$$\Delta_{O2} = |\,PS_{\text{alpha O2}} - PS_{\text{beta O2}}\,|$$

The decision rule can be made according to Table II. For example, if the absolute value of Δ_{O1} is lower than Δ_{O2}, then the decision is "Right".

TABLE II
DECISION RULES FOR CLASSIFICATION ACCURACY OF ATTENTION DETECTION VIA VISUAL MOTION STIMULUS

Commands	Δ_{O1}	Δ_{O2}
Right	Lower	Higher
Left	Higher	Lower

III. EXPERIMENTAL RESULTS

There are four volunteer subjects. One is left-handed, the rest of them are right-handed. Each subject needs to stare at the motion visual stimulus. The cue will be randomly asked the subjects to stare at each stimulus (left (lower row) or right (upper row)) for 5 seconds, and then our algorithms will automatically detect and calculate the accuracy. In total each subject will be asked to perform 20 trials (10 trials for left stimulus, and 10 trials for right stimulus). The experimental setup can be seen in Fig.4.

TABLE III
CLASSIFICATION ACCURACY OF BAND POWER TECHNIQUE AND SSVEP TECHNIQUE FOR LEFT/RIGHT DIRECTION OF VISUAL MOTION STIMULUS

Sub ject	*Dom. Hand*	*% Accuracy*				
		Right direction		*Left direction*		*Avg*
		Attention	*SSVEP*	*Attention*	*SSVEP*	
1	Left	90	90	70	90	85
2	Right	90	60	70	70	72.5
3	Right	70	90	80	70	77.5
4	Right	90	100	60	60	77.5
Total		85	85	70	72.5	78.5

According to the experiments three main topics can be discussed, i.e.

1) According to Table III, two-class classification accuracy of both features is approximately 80% where the maximum accuracy using the attention detection is 90%, and the maximum accuracy using the SSVEP detection is 100%.

2) According to Fig.2, the proposed SSVEP detection for motion visual stimulus can efficiently distinguish between the index of channels O1 and O2, which lead to the promising classification accuracy.

3) Amount of band powers of alpha band and beta band activities will be approximately equivalent (at 50% level in Fig.3 for most of the trials) at the occipital lobe of the contralateral side of motion direction. For example, if the motion stimulus is from left to right, the EEG at channel O1 will have approximately equal amount of band powers of alpha band and beta band activities (Fig.3(a)). Similarly, if the motion stimulus is from right to left, the EEG at channel O2 will have approximately equal amount of band powers of alpha band and beta band activities (Fig.3(b)). The investigation for the neuroscience explanation of this observed phenomenon need further study. However, currently, we can say that, we have observed that the moderate attention level would be occurred at the contralateral side of motion direction which could also be used as the feature to efficiently distinguish between channels O1 and O2.

IV. CONCLUSIONS

In this paper, we have presented a novel motion visual stimulus which can reduce the effect of eyes fatigue while maintaining the phenomena of SSVEP. Two corresponding SSVEP detection and attention detection are proposed to capture the phenomena of the proposed stimulus. The proposed method can be efficiently used in BCI. Investigation on combining the two proposed features is listed as our future work.

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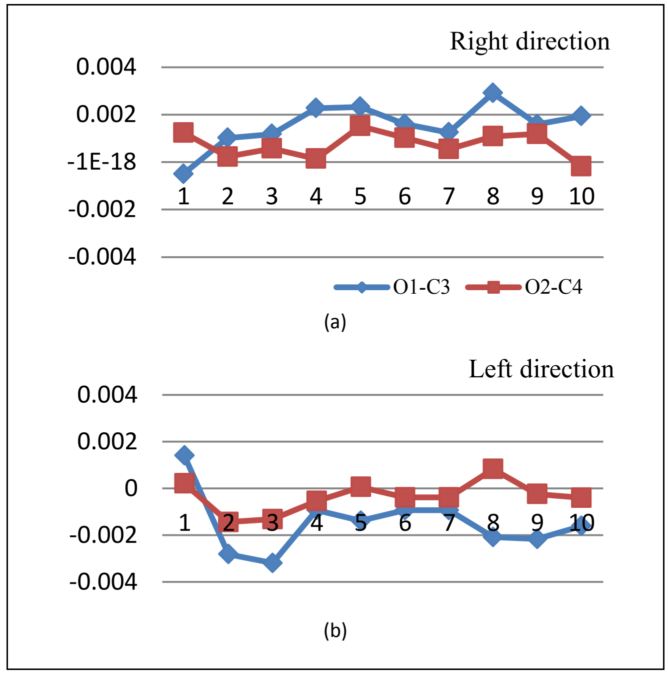

Fig. 2 Example of the results for the proposed SSVEP detection of Subject 1. x-axis represents the number of trials and y-axis represents the SSVEP detection index.

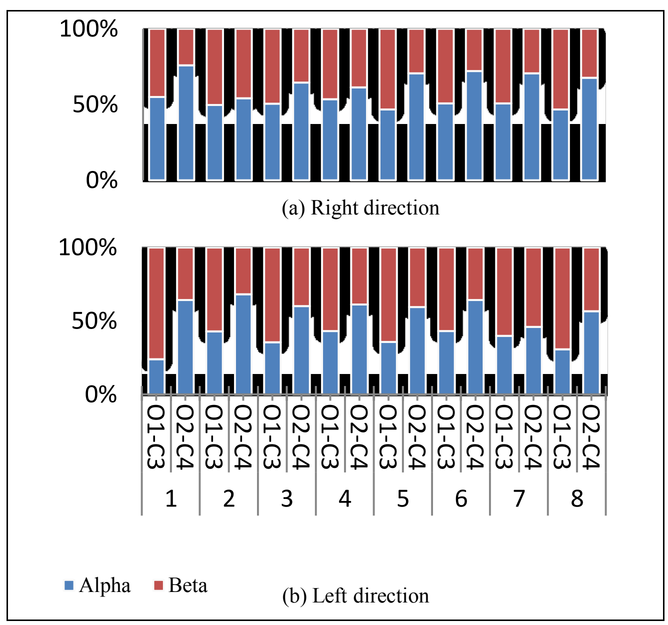

Fig. 3 Example results of the proposed attention index of Subject 1. x-axis represents the number of trials (8 out of 10 trials are shown due to space limitation) and y-axis represents the attention index.

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Fig. 4 Overview of experimental setup