Proceedings of the 6th International Brain-Computer Interface Conference 2014 DOI:10.3217/978-3-85125-378-8-7

Optimization design for the SSVEP brain-computer interface (BCI) system

Erwei Yin[1], Jun Jiang[1], Dewen Hu[1] and Zongtan Zhou[1]

[1]College of Mechatronic Engineering and Automation, National University of Defense Technology, Changsha, Hunan, People's Republic of China
narcz@163.com

Abstract

In this paper, we present a optimized steady-state visually evoked potential (SSVEP) brain-computer interface (BCI) system to enhance the information transfer rate (ITR). First, to increase the number of available items, a two-step paradigm was employed, called row/column (RC) paradigm. Second, to improve accuracy, a new signal processing method (called CCA-RV) and a real-time feedback mechanism were designed. Finally, a fixed optimal approaches for setting the optimal stimulus duration was implemented to reach a reasonable online spelling speed. The experimental results with six subjects suggest that the CCA-RV method and the real-time feedback effectively increased accuracy comparing with CCA and without real-time feedback, respectively. Additionally, the fixed optimal approach achieved reasonable online spelling performance.

1 Introduction

Recently, an increasing number of researchers have focused on steady-state visually evoked potential (SSVEP) brain-computer interface (BCI) systems [1]. Here SSVEP is a periodic neural response located in the subject's central visual field, which is induced by the visual repetitive stimulus [2]. Due to the high information transfer rate (ITR), simple system configuration, and minimal required user training time, the SSVEP BCI has become one of the most promising paradigms for both disabled and healthy participants in practical BCI application. ITR is an important metric to measure the performance of the BCI system [3]. To increase ITR, we first adapted stimulus mechanism with a row/column (RC) paradigm to increase the number of items. Furthermore, we proposed a new signal processing method for reducing the inter-frequency variation in SSVEP responses (called CCA-RV method), and a real-time feedback mechanism to increase the attention on the visual stimuli, thus enhance accuracy. Finally, an optimal approach for setting the stimulus time was implemented for online spelling.

2 Method

2.1 RC paradigm

Because the available frequencies in a SSVEP BCI are often restricted, as the RC paradigm in P300 BCI, the targets in SSVEP BCI system are also detected by their row and column coordinates (see Figure 1). 36 characters arranged in a 6×6 matrix are employed in our paradigm because it includes all the basic items necessary for spelling. Each cell in the proposed SSVEP BCI flickers between white and black at a constant frequency. Furthermore, we employed six frequencies, set at 8.18, 8.97, 9.98, 11.23, 12.85, and 14.99 Hz, in the design of a periodic stimulus mechanism. In Figure 1, the numbers on the top and left sides of the graphical user interface (GUI) denoting the stimulus frequencies. Specifically, to determine the row coordinate

 DOI:10.3217/978-3-85125-378-8-7

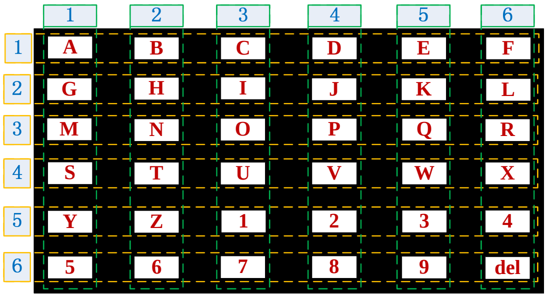

Figure 1: Illustrations for the stimulus configuration of the proposed SSVEP BCI.

of the target, all the items in same row flickered at same frequencies. Subsequently, all items in the same column flickered at same frequencies to detect the target's column coordinate.

2.2 Real-time feedback mechanism

During the spelling process, the subjects might reduce their level of attention on the centre of the SSVEP flicker, thus lead to a decrease in accuracy [4]. To this end, we designed a real-time feedback mechanism to improve the efficiency of the SSVEP speller. Feedback is given in real-time to the subject by changing the color of the current target character to green. Specifically, the system first changes the color of the characters within the selected row, and then changes the color of the character associated with selected row and column coordinates. During the spelling process, if subjects find that the character they are looking at has not changed color, they must increase their focus on the target stimuli.

2.3 CCA-RV method

In our approach, canonical correlation analysis (CCA) was used to calculate the correlation between the stimulus frequency and the multi-channel electroencephalogram (EEG) data. The correlation coefficient of each stimulus frequency is calculated in real-time ($score_i(t)$). Then we obtained the average non-target scores ($score_i^{NT}(t)$) of each frequency associated with different time points following the initial stimulus presentation. Finally, the SSVEP response scores were evaluated in the following manner:

$$Score_i(t) = \frac{score_i(t) - score_i^{NT}(t)}{score_i(t) + score_i^{NT}(t)} \tag{1}$$

2.4 Fixed optimal approach.

We employ the parctical ITR (PITR) proposed by Townsend *et al.* for the optimal spelling time selection, which provides a more realistic estimation of ITR [5]. The time corresponding to maximum PITR is selected as optimal stimulus time. The PITR can be expressed as follows:

$$PITR = \begin{cases} (2P-1)\log_2 N/T, & P > 0.5 \\ 0, & P \leq 0.5 \end{cases} \tag{2}$$

where N is the number of items and P is the spelling accuracy. Here, T is the time interval per selection, which is computed from the following expression:

 DOI:10.3217/978-3-85125-378-8-7

$$T = [(t^{row} + t^{column}) + I]/60 \tag{3}$$

where t^{row} and t^{column} are the row and column stimulus times, respectively, and I is the time between successive selections.

The optimal stimulus time is estimated using calibration data and is fixed prior to online BCI use. During online spelling, the SSVEP speller provides the spelling results once the optimal stimulus time is met. To avoid visual fatigue, we set the maximum stimulus time to 10 s. The peak PITR was taken as a measure of the possible performance of the SSVEP speller.

2.5 Experimental Setup

Six healthy subjects participated in the study. All subjects had normal or corrected-to-normal vision. All subjects signed an informed consent form in accordance with the Declaration of Helsinki. EEG signals were recorded using a BrainAmp DC Amplifier. Nine-channel active electrodes were selected for the SSVEP detection and were placed at Pz, P3, P4, Oz, O1, O2, POz, PO7 and PO8, referenced to P8 and grounded to Fpz. The EEG signals were sampled at 250 Hz and filtered using a 50-Hz notch filter. The experiments were performed in a normal office room. The subjects were seated in a comfortable chair located approximately 70 cm from a 27″ LED monitor. The offline session consisted of two different stimuli conditions - one with real-time feedback and one without. Six runs of each condition were collected. In each run, the subjects were required to input 12 symbols in a random order to avoid adaptation. For each letter selection, the SSVEP stimuli appeared on the screen and remained for 10 s. During online spelling, the subjects were required to spell their own names in Latin letters three times. When an incorrect symbol was detected, the subject had to correct the misspelling by selecting the ‘del’ option located at the bottom right of the matrix, followed by the correct letter.

3 EXPERIMENTAL RESULTS

Figure. 2 presents a comparison of the average classification results achieved using the proposed approaches (CCA-RV and real-time feedback) and traditional SSVEP approaches (CCA and without real-time feedback). The results indicate that the proposed approaches achieved higher average classification accuracy than the traditional SSVEP approaches. The online performance of the proposed SSVEP speller is summarized in Table 1. The average PITR obtained across all subjects using the fixed optimization approach reached 37.59 ± 5.55 bits/min.

Subject	Task Characters	Stimulus Time (s)	Practical Selections	PITR (bits/min)
S1	30	8.24	30	30.29
S2	24	3.92	28	44.91
S3	24	3.92	32	39.30
S4	15	4.48	19	35.59
S5	36	4.72	50	33.24
S6	27	4.40	31	42.21
AVG	26	4.95	31.67	37.59
STD	7.01	1.64	10.13	5.55

Table 1: Online performance of the proposed SSVEP BCI

 DOI:10.3217/978-3-85125-378-8-7

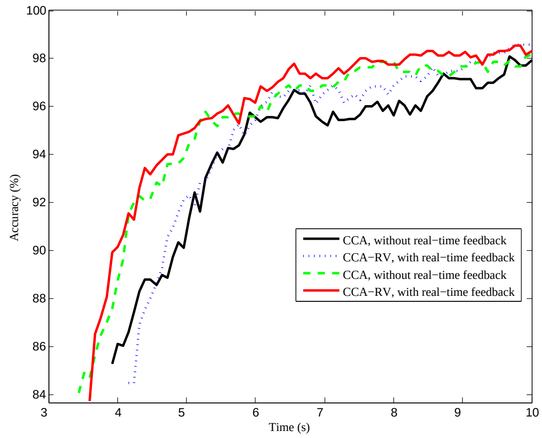

Figure 2: Comparisons of offline results associated with different approaches.

4 Conclusions

In this paper, a optimized SSVEP BCI system was proposed in order to increase ITR. Only six frequencies was used to establish the SSVEP BCI with 36 items. In addition, we proposed the CCA-RV method and the real-time feedback mechanism to enhance the accuracy. To achieve reasonable online performance, we designed a fixed optimal approach for selecting stimulus time. Experimental results suggest that the proposed SSVEP speller can provide improved performance compared to traditional BCI approaches. More specifically, online spelling PITR using the fixed optimization approach achieved 37.59 ± 5.55 bits/min.

5 Acknowledgments

This work was supported in part by the National High-Tech R&D Program of China (863 Program) under Grant 2012AA011601, the National Natural Science Foundation of China under Grant 61375117.

References

[1] H. Cecotti. Spelling with non-invasive brain-computer interfaces-current and future trends. *J. Physiol. - Paris*, vol. 105, pp. 106–114, 2011.

[2] F. Vialatte, M. Maurice, J. Dauwels, and A. Cichocki. Steady-state visually evoked potentials: Focus on essential paradigms and future perspectives. *Prog. Neurobiol.*, vol. 90, pp. 418–438, 2010.

[3] J. R. Wolpaw, D. J. M. N. Birbaumer, P. G, and T. M. Vaughan. Brain-computer interfaces for communication and control. *Clin. Neurophysiol.*, vol. 113, no. 6, pp. 767–791, 2002.

[4] S. Kelly, E. Lalor, C. Finucane, R. Reilly, and J. Foxe. Visual spatial attention tracking using high-density SSVEP data for independent brain-computer communication. *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 13, no. 2, pp. 172–178, 2005.

[5] G. Townsend, B. K. LaPallo, C. B. Boulay, D. J. Krusienski, G. E. Frye, C. K. Hauser, N. E. Schwartz, T. M. Vaughan, J. R. Wolpaw, and E. W. Sellers. A novel P300-based brain-computer interface stimulus presentation paradigm: moving beyond rows and columns. *Clin. Neurophysiol.*, vol. 121, no. 7, pp. 1109–1120, 2010.