BCI Using Space-Time-Frequency Coding Protocol

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Abstract. Many recent studies introduced some novel protocols for achieving further improvements in brain-computer interface (BCI). We argued that BCI protocol, one of the most significant issues in BCI study, should adopt the strategy of space-time-frequency (STF) coding which would highly enhance its efficiency. In this paper, we presented our work on the parallel BCIs which is the preliminary stage of STF coding applied in BCI. Two P300+SSVEP-B sub-systems with different frequency codes shared the same time code in the proposed BCI. Four subjects participated in this study and performed the offline experiment. The result showed the highest information transfer rate (ITR) of 139 bit/min with an average of 95.65 bit/min. It demonstrated that the parallel BCIs were effective in boosting bit rate, and the STF coding protocol was a promising approach to improve BCI communication.

Keywords: Brain-Computer Interface, BCI Protocol, Space-time-frequency coding, P300, SSVEP-B

1. Introduction

Recently, brain-computer interfaces (BCIs) have got tremendous progress in mental control. The achievements are mainly based on the conventional BCI protocols, i.e., P300, SSVEP and Motor imagery. However, these BCI protocols have almost reached their limits in communication ability by current technology [Ahi et al., 2011; Volosyak, 2011], although efforts are being made from different aspects, such as hardware and algorithms [Nicolas-Alonso and Gomez-Gil, 2012]. Therefore, researchers begin designing novel BCI protocols for further progress. For reactive BCIs, the coding method is the first reason determining the accessible bandwidth of communication. In this paper, we review BCI protocols and argue that the space-time-frequency (STF) coding is a promising protocol to boost ITR of BCI.

Currently, most BCI protocols adopt either time or frequency strategy. The time coding strategy discriminates the commands by coding the epoch of stimuli, such as P300, cVEP [Bin et al., 2011] and mVEP [Guo et al., 2008], while the frequency coding strategy uses orthogonal frequencies to code commands, such as SSVEP and SSmVEP [Xie et al., 2012]. In addition, the space coding strategy has been proved to be available in BCI system [Andersson et al., 2012; Treder et al., 2011]. However, so far there is no report on joint coding strategy over space, time and frequency for BCI protocol.

STF coding, as a potent approach for high speed communication, is considered to jointly use of space, time and frequency coding strategies [Liu et al., 2002]. To approach STF coding of BCI, we first develop a novel BCI system called the parallel BCIs which are based on the time-frequency coding protocol. The parallel BCIs consist of two independent P300+SSVEP-B subsystems [Xu et al., 2013]. Frequency codes are different with both subsystems but the same for characters in each, while time codes are the same for subsystems but different with characters in each. Therefore, each character has a specific code different with others.

2. Material and Methods

In this study, two independent P300+SSVEP-B spellers of different flicker frequencies (15 Hz and 17 Hz) are built by LED stimulators and a FPGA control. Each speller has the same screen consisting of 3 by 3 red light LEDs between which the horizontal and vertical distances are 3.2 cm. The two horizontal screens are 8.3 cm apart and controlled by the FPGA which sends different frequency codes but the same pseudorandom sequence of oddball stimuli to them. LEDs in each speller are extinguished individually with the duration of 200 ms and the ISI was 0ms. Characters are pasted on each LED to make difference.

Four right-handed healthy subjects (23-26 years of age; 2 females) participated in this study. All subjects gave written informed consent. In the experiment, all subjects sat in front of the screens with a distance of 70 cm. They were required to focus on a specified character and to silently count the number of times that the target character was interrupted, until a new character was specified for next selection. All characters would be interrupted once in a stimuli round and five rounds composed a stimuli block. 18 blocks were conducted for each subject. EEG was recorded by 32 electrodes whose location follows 10-20 system. Data were down sampled at 200 Hz for SSVEP classification and 40 Hz for ERP.

3. Results and Discussion

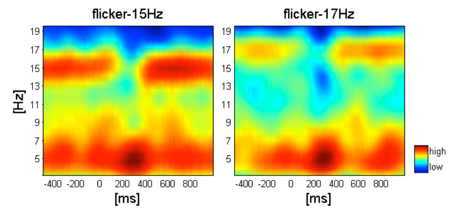

Figure 1. *Typical responses of Oz to different spellers are displayed with time-frequency energy distribution.*

Fig. 1 presents the features of SSVEP-B and ERP by time-frequency analysis. It is obvious that the frequencies of SSVEP and its blocking changes with the flicker frequency while ERPs are relatively steady. The canonical correlation analysis (CCA) was used to discriminate the intent screen by addressing SSVEPs, while stepwise linear discriminant analysis (SWLDA) was adopted to select the attentive character by finding ERPs. To validate the improvement of parallel BCIs, we investigate the accuracy and Wolpaw's ITR in this study. The results show that the average accuracy reaches 87.5% after 1 round and 98.6% after 5 rounds, and the ITR reaches the maximum of 139 bit/min with an average of 95.65 bit/min.

In this study, we investigate the performance of parallel BCIs which code the command set through time and frequency lattice. The results have demonstrated the effectiveness of parallel BCIs in boosting ITR. As there are only two frequency codes used in this work, which may limit the ITR enhancement, more benefits will be obtained by increasing frequency codes.

STF coding is a promising strategy to enhance the BCI communication ability through giving more bandwidth, which has the advantage of single coding strategy used in previous studies. Therefore, designing a proper STF coding strategy is a significant issue in BCI research. And it is also a considerable topic in constructing hybrid BCIs.

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