Brain-Computer Interface Using Chromatic Transient Visual Stimulus Array

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Abstract. Transient chromatic circle was proposed to be a safer and more comfortable stimulation method for brain-computer interface (BCI). This study further developed a chromatic array to elicit chromatic transient visual evoked potentials (CTVEP). This paper introduces a novel encoding/decoding approach using pseudo random sequences in order to increase the number of inputs of the system. The preliminary experiment was carried out using pseudo random gold sequences of length 127, and showed promising results with accuracy of BCI from 96% to 100%. It suggests the potential use of CTVEPs in a practical BCI system.

Keywords: VEP, CTVEP, Pseudo random sequences, BCI

1. Introduction

It is a popular and successful protocol to apply visual evoked potential (VEP) for practical brain-computer interfaces (BCIs), e.g. steady-state visual evoked potentials (SSVEPs) [Parini et al., 2009] or flash onset and offset visual evoked potential (FVEP)-based BCIs [Lee et al., 2008]. However, rapidly flashing stimuli (5-60 Hz) may elicit epileptic seizures, and fast-varying luminance of stimuli may easily fatigue and exhaust users.

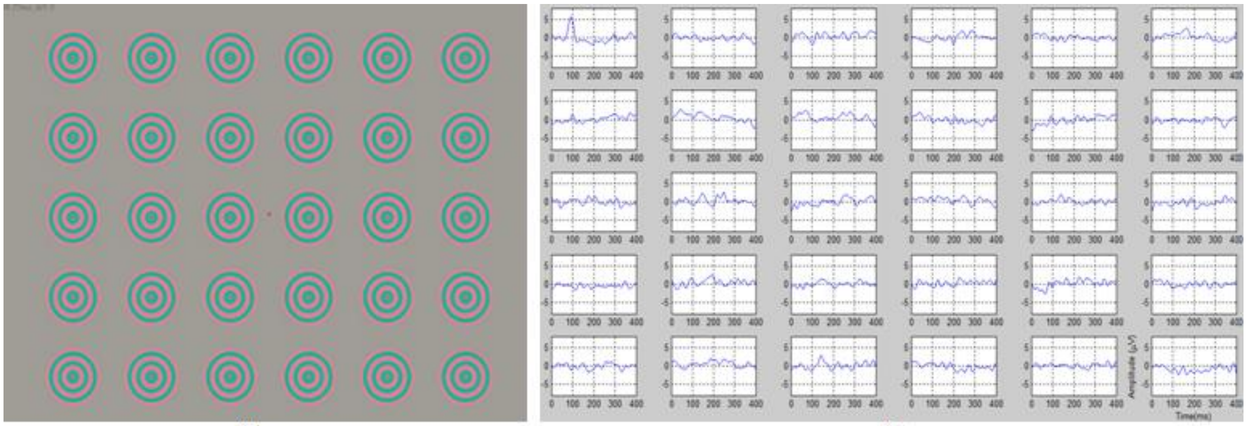
In a previous work [Lai et al., 2011], we proposed a visual stimulation as input for a BCI system, named chromatic transient visual evoked potential (CTVEP) based BCI. This stimulus provides a safer and more comfortable stimulation method than those in the conventional VEP-based BCIs. However, the maximal input number of our previous preliminary CTVEP-based BCI system is only seven. It is necessary to increase the number of commands in practical BCI systems. In the present study, we further develop the CTVEP-based BCI system by exploiting a novel encoding/decoding approach using pseudo random sequences.

2. Material and Methods

A practical panel with thirty visual field circles was presented in a 5 by 6 array on a color monitor. The onset visual stimulation of each visual field location is modulated with a pseudo random Gold sequence of length 127, and the Gold sequences of these locations are pair-wise uncorrelated in order to reduce the inter-location interference in the decoding. All visual field locations are stimulated in parallel with their own individual modulation Gold sequence. Based on color opponent theory, we select a double opponent cell: red-green on and red-green off [Gerth et al., 2003; Tobimatsu et al., 1996]. Fig. 1a shows the locations of 30 visual fields. In onset/offset pattern presentation for the experiments, stimuli were turned on for 33 ms and turned off for 67 ms, resulting in a duty cycle of 33%. Two stimuli states, ‘light’ and ‘dark’, were represented as ‘1’ and ‘0’ in the binary sequence, respectively. The time to present one stimulus cycle is 12.7 s.

Three male subjects (22-30 years) with no previous experience of BCIs participated in the study. Visual acuity was normal in all subjects. One subject was asked to repeat the experiment several days later. Electroencephalography (EEG) was recorded binocularly using a SynAmps2 128 Channel Quik-Cap electrode placement system with 2 electrodes (Cz and Oz for active recording, GND for grounding, M1 and M2 for referencing). The subject was asked to focus on one visual field location (randomly selected) in each experiment. Before the experiment, the subject was requested to focus on a specific visual field (with its pre-determined Gold sequence), so that a VEP template could be obtained through a decoding using the known Gold sequence. Since the Gold sequences are uncorrelated with each other, a decoding by correlation can provide an estimate of the response signal for the stimulation in any specific visual field as long as the Gold sequence for this known specific visual field is used as the decoding code, similar to the CDMA wireless communication system.

All zeros from the binary code were converted into '-1' in order to comply with the balanced property of Gold sequences, but also to help in the amplification of the signal-to-noise ratio. The VEP template is used as a matched filter in the command detection step in BCI, after the pseudo random sequence decoding. Before any decoding and matched filtering, the collected EEG signals were first filtered through a 1-30 Hz band-pass filter to reduce some interference out of our interest. Subject can make one selection after one stimulus cycle (12.7 s).



(a) (b)

Fig 1. (a) Thirty visual locations in 5 by 6 array. (b) Results of the decoding process where the first Gold sequence in this case was identified as the stimulating sequence while x-axis is in time (ms) and y-axis in amplitude (μV).

3. Results

As an example shown in Fig. 1b, the decoding by sequence 1 that modulates the stimulation of the focused visual field provides a clear VEP response, while the other sequences decode only background noise, and the difference is made more apparent after matched filtering using the VEP template obtained using the method described in Section 2. All subjects' accuracy is over 96% with mean 98.34% accuracy, leading to a quite reliable and much more efficient BCI system as compared to our previous work [Lai et al., 2011].

4. Discussion

The novel encoding/decoding scheme using pseudo random sequences has been demonstrated with promising results for the CTVEP-based BCI system in order to increase the number of commands, and this BCI solution can get a very high off-line performance. These preliminary results are based on an on-going project, while this paper presented only three subjects. More inputs and higher ITR with high accuracy performance can be achieved based on our solution. We are further improving the encoding/decoding scheme and will build a real-time BCI system with the proposed chromatic transient visual stimulus array.

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