3D Image Control System based on Phase-coding BCI

Qiuling Yang, Pingdong Wu

Abstract—**In this paper, we describe an optimized proposal for brain-computer interface (BCI) based on steady-state visual evoked potential (SSVEP), especially in 3D image control system application. In this application, there are four components for implementing a complete BCI application: stimulator, signal acquisition, signal processing and classifying, and application (3D image control system). Ideally, integrating stimulator and 3D image display on the same screen gives advantages, but in order to obtain optimum performance, visual stimulation and 3D display device should independently run on different units. To achieve that purpose, we need optimize two components: stimulator and 3D image display. On the one hand, we use phase coding visual stimulus and the corresponding signal analysis method in order to obtain a good stimuli effect and to allow more flexibility in system design. On the other hand, we apply 3D image control to BCI system, not only to expand the BCIs' application, but also to promote the induced electrical brain signals. Six volunteers (four men and two women), from 24 to 30 years old, participated in the experiment. The average accuracy information transfer rate and phase deviation over the seven subjects were 779.83% and 30.74bits/min, respectively. The proposed system can provide a reliable channel for severely disabled patients to communicate with external environments..**

Index Terms—**BCI, SSVEP, phase-coding, 3D image control system**

I. Introduction

BRAIN computer interface (BCI), as an extended communication method without the brain's normal output pathways of peripheral nerves and muscles[1], allows a direct connection between brain and external world, and provides a selective communication way to people with severe motor disability. Steady-state evoked visual potential (SSVEP), which is induced by repetitive visual stimuli, with its advantages of higher signal-to-noise ratio (SNR) and minimal training to enable a person to operate the BCI[2], become an excellent paradigm for BCIs. SSVEP based BCIs will be the most likely to be deployed in the consumer's market in the near future.

In a SSVEP based BCI system, the user needs to face an external visual stimuli device and gaze at a selected stimulus; his or her attention of the choosing stimulus can be detected by examining the features of the recorded EEG. Therefore, in order to extract the appropriate signal in the SSVEP based BCI system, a suitable stimulus is required. According to published literature, most SSVEP based BCIs adopt stimulus flickering at different frequencies and identify user's intention by examining the frequency spectra of the recorded SSVEP for peaks in amplitude at the corresponding flashing rate. SSVEP can also be excited by stimulus flickering at different phases for a single frequency, because fundamental frequency components extracted from short-time data segments in the same flickering state should have similar phase due to the phase feature of SSVEP. The latter one is called phase-coding mode in some literature; accordingly, the former is defined as frequency-coding one. Here, I follow the naming way. SSVEP based BCIs will obtain some good aspects by using phase-coding mode. First, it greatly increases the number of effectively stimulates. Second, noise is not phased locked and can be reduced to the in-phase component, thus making it possible to significantly improve the SNR [3].

In my application, signals with different phases at one frequency, are classified and then translated into commands using a general purpose computer for controlling a 3D image on the display screen. 3D image displays provide a very friendly, motivating and safe feedback, leading to higher user acceptance. It was shown in several studies that 3D image feedback can enhance performance of SSVEP based BCIs [4]. In this application, we will present we use parallax 3D display, a real 3D image display, to get a better sense of immersion and improve the system's stability.

This paper will be presented in the following outline. At the beginning, system architecture will be presented and followed by its optimization strategies, such as stimulator, signal processing and classifying, and application. Then, the system experiment result will be presented and discussed.

II. MATERIALS AND METHODS

A. System Architecture

In this 3D image control system application, there are at least four components for implementing a complete BCI application: stimulator, signal acquisition, signal processing and classifying, and application (3D image control system), as depicted below:

Ideally, integrating stimulator and 3D image display on the same screen gives advantages, but in order to obtain optimum performance visual stimulation and 3D display device should independently run on different units. Although signal acquisition is part of the BCI system, but these are not

Manuscript received January 3, 2014; revised February 12, 2014. This work was supported in part by the National Natural Science Foundation of China.

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modified in this work and are not mentioned further here.

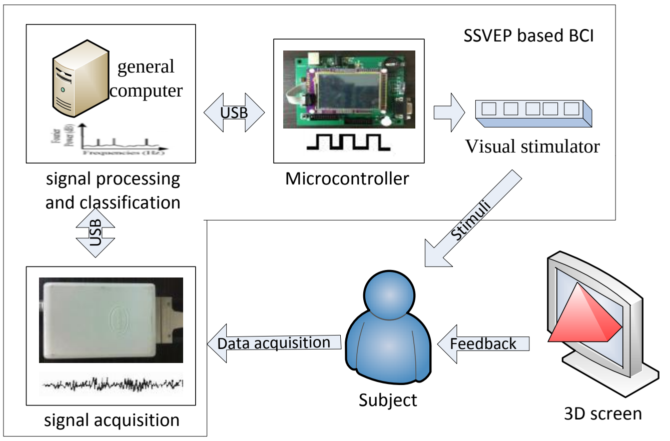

Fig. 1. 3D image control system application based on phase coding BCI.

B. Stimulator

Because SSVEP is phase-locked to the stimulus onset, a method of phase coding visual stimulator for SSVEP based BCIs is proposed here. There are two types of stimuli frequently used: one is using the display as stimulation, such as LCD [4], CRT [5] and TFT [6]; the other is using the LED as stimulation [7]. The advantage of the former is adjusting parameters easily; the disadvantage is flashing effected by monitor refresh rate and is difficult to achieve portability and miniaturization. The advantage of the latter is stable performance, good flicker effect and low cost; the disadvantage is poor versatility since it is applicable to a particular design. We use micro-controller (MCU) in order to drive peripheral circuits (including keyboard, LCD and LED driver) and communicate with the host computer (using USB interface). The entire device is integrated in a circuit board, flexible and easy to operate. Its size is small and has portability and versatility. Micro-controller function block diagram is as following.

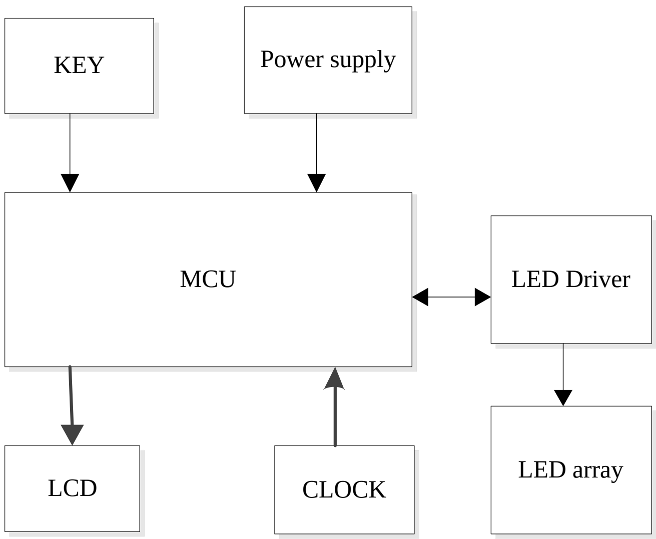

Fig. 2. Micro-controller function block diagram.

Each stimulus is composed of 6 × 10 arranged LEDs, covered with thin white paper diffusers, each of which respectively depicted symbols ↑, ↓, →, ←, ○ and represent the 3D image moving up, down, left, right, rotation (clockwise). It is more intuitive and easily accepted by the user that arrow identification on the paper instead of number.

The only frequency f is defined as 25Hz, which was proved to be the better effect in previous experiments. Then the cycle duration is T = 1/f. Every stimulus begin with different delay time t_i, corresponding to different phase θ_i, $i = 1, \ldots, 5$. The equation is as following:

$$t_i = \frac{\theta_i}{360°} \times T \tag{1}$$

The phase for LED1 to LED5 were 0°, 72°, 144°, 216° and 288°, respectively, corresponding to time delays of 0, 8, 16, 24, 32ms.

C. Signal Processing and Classifying

The phase analysis was performed in the following way. First, the instantaneous phases of signals were obtained by means of the Wavelet Transform. Next, one signal was taken as the reference one, and phase locking between this one and all others was studied the phase difference between the two. Function convolution of signal and wavelet as follow:

$$\begin{aligned} W_x(t) &= (\omega * x)(t) \\ &= \int \psi(\tau)x(\tau - t)d\tau = A_x^w(t)e^{i\theta_x^W(t)} \end{aligned} \tag{2}$$

D. Application

We created three programs to make the system work. The first program, which is called the Stimuli Program, is responsible for displaying LED flashing and controlling of stimulus. The second program, which is called the Signal Processing and Classifying Program, is responsible for signal analysis, feature extraction and classification, and command generation. The third program, which is called the 3D Display Program, is responsible for displaying 3D image. Commands generated by the second program will be sent to the third program through program interface. The first program and the second program can be connected and communication via USB interfaces. The 3D image can be moved up, down, left, right, or clockwise rotating according to the command interpreted by the Signal Processing and Classifying Program from user' s SSVEP signals. The first program is written in C and the others are written in C++. The following diagram shows the three programs architecture.

The 3D image control system application also provides visual feedback to the subjects. The observation in some literatures supported that the more realistic visual feedback, the better performance subjects played [9]–[11].

III. EXPERIMENT AND RESULTS

Six volunteers (four men and two women), from 24 to 30 years old, sitting in a comfortable armchair in the dim lighting room. Each subject has been corrected to normal vision, no clinical history of eye disease. Subjects sat in front of the stimulate and screen, 70cm away from the screen. Detection electrodes placed on O1 and O2, reference electrode placed on ears, and ground (GND) placed on Cz. The application task requested subjects to fulfill a predefined command sequence. The sampling frequency is 1000Hz. The information transfer rates (ITRs) is computed as(3).

$$ITR = s[\log_2(N) + P\log_2(P) + (1-P)\times\log_2(\frac{1-P}{K-1})] \quad (3)$$

Which has s commands per minute with the same probability p, N is the total number of LED flickers (K = 5) [8].

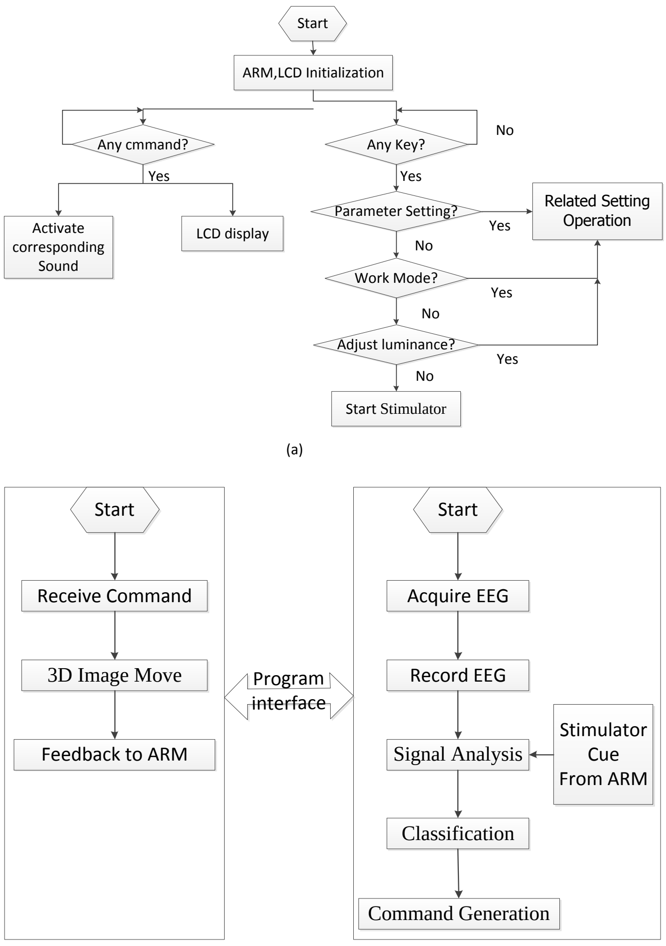

Fig. 3. (a) Stimuli Program and (b) PC program, including Signal Processing and Classifying Program (right) and 3D Display Program (left). Stimuli Program and PC program are communicated with USB.

IV. CONCLUSION

This work proposes an optimized proposal for brain-computer interface (BCI) based on steady-state visual evoked potential (SSVEP), especially in 3D image control system application. This system has the advantages of: (1) We use phase coding visual stimulus and the corresponding signal analysis method in order to obtain a good stimuli effect and to allow more flexibility in system design; (2) We apply 3D image control to BCI system, not only to expand the BCIs' application, but also to promote the induced electrical brain signals. The average accuracy information transfer rate and phase deviation over the seven subjects were 79.83% and 30.74bits/min, respectively. The 3D Image Control System based on Phase-coding BCI provides entertainment for both disable people and healthy people.

TABLE I
EXPERIMENT RESULTS

Subject	Accuracy (N correct/N total)(%)	information transfer rate (ITR)
FXA	78	34.10
SXZ	81	26.90
TT	69	28.12
YQL	73	38.74
WCE	90	36.71
TR	88	19.88
BLZ	79.83	30.74

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