Brain-Computer Interface with High Transfer Rates*
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Abstract
This paper presents a brain-computer interface (BCI) based on steady-state visual evoked potential (SSVEP) with high transfer rates. The system serves for a phone dial using 12 virtual buttons on the screen of a computer monitor. The test results for most testees are encouraging. The maximum information transfer rate is 44bits/min. Frequency resolution and spatial resolution of SSVEP is discussed in detail.

1 Introduction
Over the past decade, many laboratories have begun to explore BCI as a new augmentative communication technology to individuals with motor impairments, and have built some prototype systems that can demonstrate the techniques in laboratories. The input signals of present BCI’s could be either endogenous or exogenous. Electrodes can be placed on either scalp or cortex. Typical BCI applications contain cursor movement, letter or icon selection, or device controls. Currently, these systems are relatively low bandwidth devices, offering maximum information transfer rates of 5–25 bits/min at best [1].

Our interest concentrates on SSVEP recorded on scalp. SSVEP emerges at specific scalp location, i.e., occipital over visual cortex. It is the physiological response of visual system under external stimulation, and the subjects are not required to have extensive training. The salient feature of SSVEP-based BCI’s is the requirement for a stereotyped stimulus. This feature requires an intact visual system, and it will be wholly or in part devoted to EEG-based communication. In contrast, endogenous BCI’s provide users direct control over the environment, but this kind of BCI’s often require extensive training.

We have explored SSVEP-based BCI to control cursor movements [2]. Four buttons blinking at different frequencies represent four directions; users can move the cursor to different directions simply by looking at the corresponding buttons. Multiple SSVER’s have also been employed in the Air Force Research Laboratory [3]. Only two virtual buttons were displayed in their experiments, modulated at relative high frequencies, i.e., 17.56 Hz and 23.42 Hz.

One approach to improve the information transfer rates of SSVEP-based BCI is to use more blinking buttons. But more buttons need more space area. Furthermore, only limited frequency band is favorable for SSVEP induction. In this paper, we will introduce an SSVEP-based BCI with high transfer rates, and discuss the frequency resolution and spatial resolution of the system in detail.

2 Methods
Bit rate was used as the performance measure of the BCI system in many experiments. It depends on both speed and accuracy. If a trial has N selections, and the selection accuracy (the probability that the desired selection will actually be selected) is P, then bit rate, or bits/trial (B) is

$$B = \log_2 N + P \log_2 P + (1 - P) \log_2 \frac{(1 - P) / (N - 1)}{(N - 2)}$$

(1)

More details about equation (1) can be found in [1].

Our system was designed to serve for a phone dial. Twelve buttons blinking at different frequencies were displayed on the screen of a computer monitor, representing 0-9 ten numerals, BACKSPACE and ENTER (Fig.1). Users could input phone number to computer and correct input errors via looking at these buttons. Computer was connected to telephone network by MODEM. The phone dial would be finally realized by selecting ENTER when number input was finished.

![Fig.1 Twelve buttons on the monitor](image)

The buttons were distributed on the screen sparsely. Each button was a 2 by 2.8 cm rectangle. If the buttons were viewed at a distance of 60 cm, the visual angles would be 1.9
degrees in horizontal and 2.7 degrees in vertical. The intervals between neighboring buttons were 5.5 cm in horizontal and 7 cm in vertical.

Subjects were seated comfortably in front of the monitor. Two channel EEG signals were recorded at O1 and O2 according to the international 10-20 system and referred to left and right lobe respectively. The electronic circuits fulfilled signal amplification, A/D conversion (sample rate = 200 Hz) and signal transmission. Computer got the data by a receiver connected to the serial port. Computer analyzed the EEG signals and decided which button subject was looking at. The results were sent to MODEM and monitor as a feedback.

Amplitude spectrum of each channel was calculated with a frequency resolution of 0.195 Hz. If the amplitude at some stimulus frequency was prominently greater than the mean value of several neighboring frequency components and lasted an enough long time, a selection was made.

Considering the low refreshing frequency of CRT monitor, the stimulus frequencies were selected within the frequency band between 6 Hz and 14 Hz. Furthermore, all of the stimulus frequencies were integer multiples of the frequency resolution. The minimal difference between stimulus frequencies was twice of the frequency resolution, i.e., 0.39 Hz.

3 Results

Five volunteers with normal or corrected normal vision participated in the experiments. Their average age was 28 (range 24 to 36) year’s old. They were asked to input a telephone number (11 numerals long) without training. If a wrong selection was taken, they should delete it via BACKSPACE and input again until the number was correctly input. The number was sent out by selecting ENTER when input was finished. Four of the testees finished the work successfully, only one of them could not fit the work in the case.

To calculate the information transfer rates, the testees were asked to input 20 numerals with no error correcting. These numerals included ten Arabic numerals from 0 to 9 and each numeral appeared twice, i.e., possible selections N=10. The results can be classified into three grades.

Good: Two testees could input all numerals with no errors, so input accuracy P=100%. The average time for one selection was 4.5 seconds. Information transfer rates were 3.32 bits/trial or 44.29 bits/min.

Moderate: Two testees input 18 and 14 numerals correctly, and the input accuracy P was 90% and 70% respectively. The average time for one selection was 6.0 seconds and 7.2 seconds. Information transfer rates were 25.36 bits/min and 12.41 bits/min respectively.

Bad: One testee’s performance was unacceptable. All of his inputs were wrong. The Information transfer rates were zero.

4 Discussion

(1) Frequency resolution: As described above, the frequency resolution of 0.195 Hz can be reached in the system. Considering the system reliability, we took 0.39 Hz as the minimum difference between two adjacent stimulus frequencies. The appropriate frequency band for SSVEP induction is about 6 to 24 Hz, so \((24 - 6) / 0.39 \approx 46\) objects can be identified in principle. As the results shown above, the Good and Moderate testees give terrific results.

(2) Spatial resolution: The blinking buttons show on Fig.1 can also be replaced as Fig.3. Twelve blinking buttons were displayed on the screen without block spacing between them. The size of these buttons hasn’t been changed. As the result, those Good testees still can identify the objects very well.

(3) Training requirements: The photic following of SSVEP is the response of the cerebral cortex. So the testees in our experiments don’t need any training and it also doesn’t matter whether they have glasses on nose or not.

(4) Individual difference: To find the reason for that failed
test, the cerebral structure MRI images of the testee’s with good and bad transfer rate were taken for comparison. The differences in anatomy between them were found obvious. When we replaced the electrodes for that testee with zero transfer rate the situation was getting better.

![Diagram of buttons](image)

Fig.3 Twelve buttons on the monitor without gaps between them

5 Conclusion

This paper presents a SSVEP based BCI system with high transfer rates. The system is noninvasive and has no requirement of training. The test results of most testees are encouraging. Future study is needed to further improve the performance of the system and to make the applicable devices to serve the people with motor impairments.

References