# An Online SSVEP-based Chatting System

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*Abstract*—**This paper presents a steady-state visual evoked potential (SSVEP) based online brain-computer interface (BCI) chatting system. In this application, it helps disable subjects to chat by means of their brain signal activities. Stimuli illuminated at different frequencies are displayed on liquid crystal display (LCD) screen. The BCI system implements a chatting interface programmed in Java, and it provides a convenient and high efficient communication platform for paralyzed patients. A novel idle state detection is introduced in this proposed system, and a high transfer rate of 63.54 bits/min and 92% idle state detection accuracy are achieved.**

*Keywords*—**brain computer interface (BCI), speller, steady state visual evoked potential (SSVEP), canonical correlation analysis (CCA).**

## I. INTRODUCTION

A brain–computer interface (BCI) is a system that allows people to communicate through direct measurements of cortical activity. BCIs are move beyond communication tools for people who cannot otherwise communicate. Such an interface would increase an individual's independence, leading to an improved quality of life and reduced social costs. A BCI system detects the presence of specific pattern in a person's ongoing brain activity that relates to the person's intention to initiate control. Current interest in BCI development comes mainly from the hope that this technology could be a valuable new augmentative technology, all of which require some voluntary muscle control [1-3].

Nowadays, non-invasive scalp electroencephalogram (EEG) measurements have become a popular solution in BCI research, which is widely used in BCI systems due to few of patient agree to use subdural electrodes [5]. In recent years, there has been increasing interest in using SSVEP in BCI systems. SSVEP is a resonance phenomenon arising mainly in the visual cortex when subject is focusing the visual attention on a light source flickering with a frequency above 4 Hz [4]. Recorded from the surface of scalp over the visual cortex, the SSVEP response is composed of a number of discrete frequency components. Considering its short training time as well as high information transfer rate (ITR), SSVEP-based BCI has become one of the most promising modalities for a practical non-invasive BCI system [6].

With the SSVEP-based BCIs discussed above, many studies have been performed to implement applications, which including environment control (switch, TV, volume) [7], [9], [10], assistant device (wheelchair, computer, robot, speller) [8], [11], neural prosthesis, entertainment (racing game) [12]. To our best knowledge, however, there is no publication on chatting system based on the SSVEP. On the other hand, for those paralyzed patient who have no other means to communicate with the external world, it is necessary to provides them a convenient communication tool. The motivation of this paper is mainly to establish SSVEP-based BCI chatting system to help the people without motor abilities on communication through the visual responses.

The paper is organized as follows: the section two presents methods employed in generation of reliable frequencies on liquid crystal display (LCD)/ cathode ray tube (CRT) screen for SSVEP based BCI system, Java interface description, signal analysis, and control strategy. The experimental protocol, offline analysis, online experiment setup, results analysis and discussion are presented in the section three, followed by conclusion in the section four.

## II. METHOD

### A. *Visual Stimulator*

For an SSVEP-based BCI chat application, larger numbers of targets are required to be presented on the visual stimulator. Stimuli can be generated by using light-emitting diode (LED) or LCD/CRT. LEDs aren't adopted in our system because it needs extra elaborate hardware and inconvenient to configured. However, the commonly used approach to generate stable stimuli in LCD/CRT monitor is traditional frame based methods [13]. While the frequency of visual stimuli based on this approach is limited by the refresh rate of the LCD/CRT monitor. For a monitor with 60Hz refresh rate, visual stimulator with the frequency of 6.67Hz, 7.5Hz, 8.57Hz, 10Hz, 12Hz, 15Hz or 20Hz can be applied in practical application. However, it is still far from enough to implement a speller. In the proposed system, a frame-based encoding method [14] is used to solve the problem mentioned above. In particular, a 60Hz refresh rate monitor has 60 frames in one second and the number of frames in each cycle is a constant. For 10Hz flicker, the stimulus reverses between black and white every three frames; a 12 Hz flicker states in black for three frames and reverses to white for two frames. The frame-based encoding method combines sequences of two frequencies into a single sequence to approximate 10.5Hz, 11Hz and 11.5Hz with a varying number of frames in each cycle. Therefore, frame based encoding method can be used to generate stimuli in this application. For more see [14].

For the spelling interface, Microsoft Visual C++ 6.0 and DirectX DirectDraw 7 are used for programming for the visual



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stimulator. 42 characters as it shown in Fig. 1(26 English letters: "A-Z", 10 digits: "0-9", 4 common symbols, 2 special symbols: "$" representing sending the words; "#" representing canceling backward). Three pages are prepared for users to "click" through visual stimulation. On every page, 16 buttons are presented on the screen and there exist 2 buttons available to help users turn over the page. The frequencies of those buttons in one page vary with an equal difference of 0.5Hz from 8Hz to 15.5Hz.

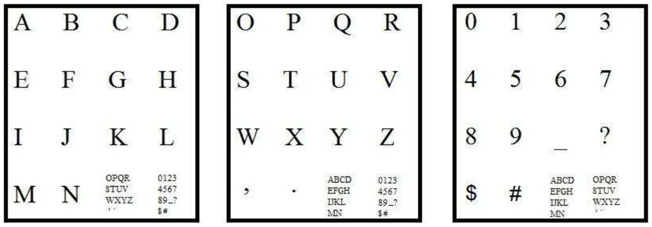



Figure 1. Graphical user interface of SSVEP based BCI speller.

### B. Chatting System

This chatting interface is programmed in Java environment. The Java SE Development Kit 6u24 is suggested to be installed. The entrance page of the chatting system is shown in Fig. 2a, and chatting interfaces of master and guest are shown in Fig. 2b, respectively. The button "Master" must be selected before the button "Guest" is selected because "Master" should host a chatting room at first. "Master" can be user of BCI system or keyboard. When two users join in chatting system, a dialog box is displayed in a window as shown in Fig. 2b, respectively, the dialog can be started. The words can be sent if the symbol"$" is selected by the user and the character will be cancelled if the symbol "#" is selected by the user.

### C. Canonical Correlation Analysis (CCA)

In the multivariable statistical analysis, CCA is widely applied in a variety of engineering fields for finding the underlying and obscure correlation between two given sets of data. The objective of CCA is to find a pair of linear combinations, for two sets, where the correlation between two canonical variables is maximized.

Consider two multidimensional random variables $X$, $Y$ and their linear combinations $x = X^T W_x$, $y = Y^T W_y$, respectively. CCA find the optimal weights vector, $W_x$ and $W_y$, which maximize the correlation between $x$ and $y$, as shown in (1),

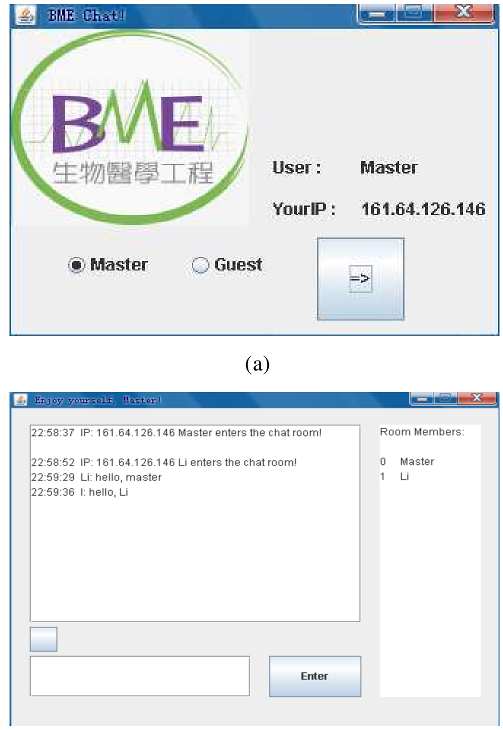
$$\max_{W_x, W_y} \rho(x, y) = E[x^T y] / \sqrt{E[x^T x] E[y^T y]} \quad (1)$$

$$= E[W_x^T X Y^T W_y] / \sqrt{E[W_x^T X X^T W_x] E[W_y^T Y Y^T W_y]}$$

where $\rho$ is called correlation coefficient.

Then, the command

$$C = \arg\max_i \rho_i \quad (i = 1, 2, \ldots, k) \quad (2)$$




(a)

(b)

Figure 2. Java communications interface (a) Entrance page (B) Dialog box

Command $C$ is used to make a determination, for more details refer to [5].

### D. Idle State Detection

In asynchronous systems, BCI do not give any orders in idle states. Only when non idle states are detected, the system begins to perform target recognition and give orders. For BCI system, it is a very important step to realize the accurate detection of idle state. In our experiment, a novel idle state detection is used. CCA is employed to extract feature parameter of SSVEP component from EEG recordings. The correlation coefficient of CCA is important parameter used to detect the idle state. Based on our rule of thumb, the higher correlation coefficient may obtained when subject is in non-idle state and the relative smaller one may produced when subject is in idle state. In particular, the correlation coefficient distribution of two states has a distinct boundary. Hence we set a threshold to discriminate two states and it achieves a good performance in our experiment. During the processing, five sequential correlation coefficients are calculated, and then decide if the mean of those correlation coefficient is large than the threshold value or not. If so, this segment of data would be regarded as work state, otherwise the system would consider the period as idle state and wait for the next window length.

### E. Control Strategy

In the experiment, when work state is detected, system begins to count the total number of the selected correlation coefficient $\rho_i$, and the corresponding command $C$ will be chosen to be final result if more than certain command labels are same. The initial time window length $T$ used to calculate the CCA coefficient is 1second. And then apply CCA approach for each window length step with a time interval 0.2s. Therefore, 5 correlation coefficients will be obtained in a gazing time interval. If more than 2 command labels of them are same, the corresponding value will be selected, otherwise the EEGs should be detected again. The whole process is shown in Fig 3.

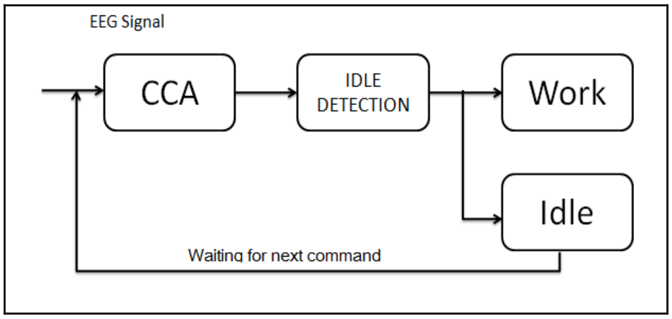



Figure 3. Control strategy

## III. EXPERIMENT ANALYSIS

### A. *Experiment Setup*

In this experiment, our visual stimulator was a LCD monitor (ViewSonic 22”, refresh rate 60Hz, 1680 × 1080 pixel resolution). Six standard EEG electrodes were connected to corresponding positions $PO_z$, P3, P4, $O_z$, O1, and O2 as input channels. An amplifier (g.USBamp, Guger Technologies, Graz, Austria) collected EEG signals. Online data was processed by Matlab Simulink. For those specific parameter setup, we chosen the dominant frequency was detected every 0.2s, and selected the threshold value of CCA equal to 0.24. All signals were filtered by 0.5Hz to 60Hz band-pass filter and sampling rate was 256Hz. Two 24 years old subjects with normal eyesight with participated in this experiment, and both of them had BCI experience. In the process of this experiment, monitor had three-second flickering to keep the subject of gazing at one target each time, and the subject can take a rest in the following two second.

### B. *Offline Analysis*

Before online experiment, the offline analysis was performed for two subjects to identify which stimulus frequencies would have better SSVEP responses with high amplitude. Select the frequency of 7.5Hz, 8.67Hz, 10Hz, 12Hz, 15Hz and 20Hz to detect the SSVEP response of subject, Record down EEG signal and operate FFT analysis. As it is shown in Fig 4, *X* axis presents response frequency and *Y* axis presents magnitude. The higher magnitude, the better response it is. Hence subject had good performance in 8.67Hz, 10Hz, 12Hz and 15Hz, in the other hand, magnitude of FFT in Frequency of 7.5Hz and 20Hz is chaos and it is hard to recognize dominant frequency. Finally we selected stimuli frequency from 8Hz to 15Hz. The idle detection experiment was designed under these three conditions, the stimulus, of only one frequency, was on for 5s and then off for 5s. This process lasted for 80s, and each subject completed two trails. The frequency used is the same as mentioned above. The signal was digitized with a sampling rate of 256Hz, and then bandpass filtered with cutoff frequency of 0.5Hz and 45Hz. From Fig.5, it was correlation coefficient distribution of two subjects in frequency of 8.67Hz, 10Hz and 12Hz. The grey circle presents work state, the black block presents idle state, and dotted line is the threshold value which is utilized to discriminate two different states. Both threshold values are 0.24. Based on offline analysis, the average idle state accuracy is nearly 92%. Fig 5(a) and Fig 5(b) have a distinct discrimination between idle state and work state. It proved our imagines that the higher correlation coefficient was produced by work state was detected and the smaller correlation coefficient was obtained when idle state was detected.

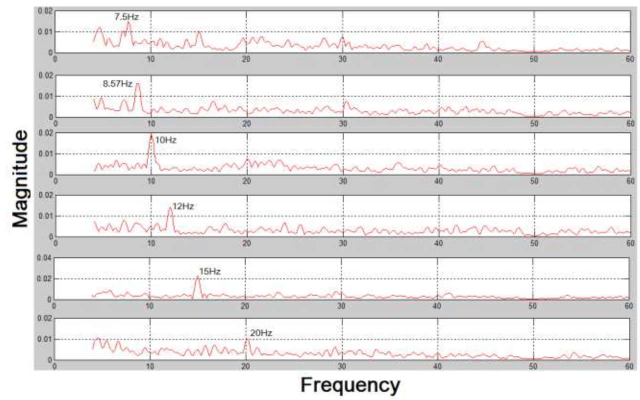
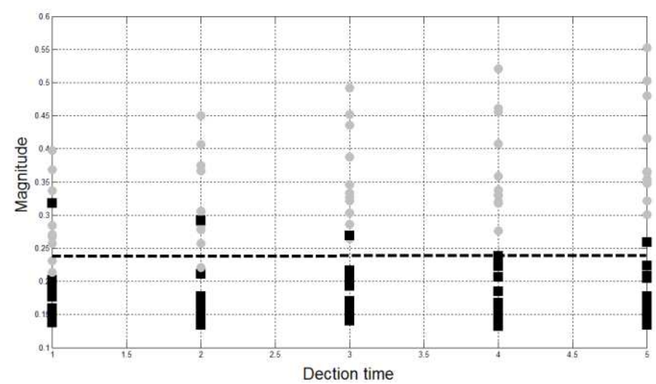
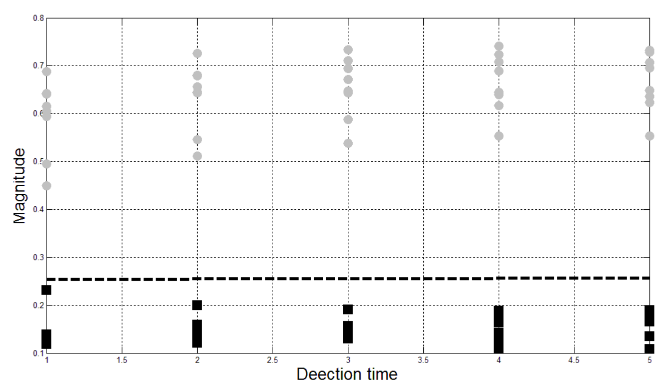



Figure 4. FFT analysis of different frequencies




(a)




(b)

Figure 5. Idle state detection based on correlation coefficient distribution. (a)S1’s result (b) S2’s result

### *C. Online operation*

In the first step, one subject started the server of the chatting system. Then this subject established a chatting room, and the other subject entered into this established chatting room subsequently. One subject inputted some characters through BCI system and then every character were displayed in the dialog box. Once the subject discovered the mistaken characters, he or she could select the button "#" to cancel the character. The whole sentence of words would be sent to the chatting board of the other subject until the subject gazed the symbol "$" which means to send message. This experiment stimulated patient chatting with normal person, each group consisted of two subjects, S1 played patient who used BCI system to input character and chatted with S2, which used keyboard normally. Next time, they changed the role. The experiment required subject to spell a sentence "how are you" at first and "Fine. Thank you" after normal person responded. As a standard measure of communication system, ITR means bits per minute, which is expressed as

$$ITR = \frac{60}{S} \times \left[ \log_2 N + p \log_2 p + (1-p) \log_2 \left( \frac{1-p}{N-1} \right) \right] \tag{3}$$

where $S$ is regarded as the time to finish total tasks over the total number of the detection. $p$ is the accuracy to detect commands and $N$ is 42 which means number of characters. As the experiment required, total task included 26 character inputs.

TABLE 1. RESULT OF CHART SOFTWARE EXPERIMENT FOR TWO SUBJECT

| SUBJECT | TIME | TOTAL /WRONG | ITR(BITS/M) | ACCURACY |
|---|---|---|---|---|
| S1 | 135s | 26/0 | 62.31 | 100% |
| S2 | 130s | 26/0 | 64.71 | 100% |

According to table I, it presents total time consumed for each one, input result, ITR and accuracy. The average ITR was 63.54 bits/min. The result from two subjects depicts that they could input characters without error in the work state and it is important as a chatting application.

## IV. CONCLUSION

A BCI chatting system based on SSVEP with high performance is presented in this paper. Frame-based encoding method [14] is used to generate stimuli in LCD monitor and CCA method is employed to extract of frequency information. Stimulus frequencies for each subject are specified in offline analysis. Moreover, we also develop a novel idle state detection is introduced, and the experiment results show that the idle state can be determined with an accuracy of 92%. In online experiment, the proposed system achieves a good performance. A high ITR of 63.54 bits/min was achieved.

As an application of chatting tool, this software is aimed at applying BCI into real life and improving life quality for those paralyzed patients. The further work may focus on the optimization of detailed functions and interface of the chatting system. For instance, adding some remind button to keep subject pay attention to other's response. In addition, typing accuracy and typing speed are both planning to be improved. For more practical application, it is impossible to determine at which threshold value the detection result is most suitable, hence it is crucial to explore the more complete selection approaches of the threshold parameters to promote the efficiency of this system.

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