E-book Retrieval and Reading System Based on Brain-Computer Interface

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Abstract. In this paper, we propose a real-time Brain-computer interface (BCI) system that enables paralyzed patients to read e-books on the website autonomously according to their intentions. The system uses EMOTIV EPOC+ to acquire the user's electroencephalography (EEG) signals and decodes them to analyze the user's real intention when reading e-books on the website, including selecting and reading operations. The system uses the VRPN communication protocol to transmit the EEG data processing results to the PC to realize the corresponding operations on the web page. To verify its performance, we have carried out experiments on 5 subjects. And the result shows that after short-term training, the accuracy of the system can reach more than 90%.

1. Introduction
There are currently about 25 million people worldwide who suffer from severe spinal cord injuries. They lose the ability to sense and move, because the nerve signals can no longer pass through the nerves in the spine to reach the edges of the body. The disease has a great impact on the lives of its victims.

BCI providing an alternative pathway for patients to communicate with the environment does not rely on the peripheral nervous system and muscle tissue. There have been some researchers successfully applied BCI systems for paralyzed patients. Michael Bensch[1-2], first provided ALS patients with a BCI system. Further studies developing different BCI systems, such as sensory-motor EEG rhythms (SMR)[3], P300 evoked potentials[4] and Steady-State Visual Evoked Potentials (SSVEP)[5].

Here we introduce a retrieval and reading system based on SSVEP. The new BCI system can discriminate people's intention by detecting the EEG signal of the occipital lobe visual area. Severely paralyzed patients can read e-books by themselves in this way, which can greatly improve their quality of life.

2. The structure of BCI system
The system is made up of a 14-channel device for acquisition EEG signals, a visual stimulation, a web analyzer[6], an EEG signal analysis module and data transmission module. Figure 1 shows the structure of e-book retrieval and reading system.
Fig. 1 Diagram of e-book retrieval and reading system based on BCI

The implementation process of the system includes the following parts. Web analyzer, first obtain the position of e-books on the website then send it to the visual stimulation. When receiving the information from the visual stimulation, it will generate flickering pictures of different frequencies next to the e-books on the website. These flickering pictures are used to evoke EEG signals. Once subjects finds a book they want to read while browsing the web, they focus their attention on the flickering pictures. Meanwhile, the EEG signal is recorded in real time by Emotiv EPOC+. The EEG signal analysing and processing module extracts the features of the signals and classifies them. The result of feature classification is sent to the web analyzer through the VRPN communication module. After receiving the peak frequency information, the web analyzer will confirm which frequency flicking picture the user is staring at and perform operations on the corresponding books. Wireless serial port permits to communicate between the BCI headset and the computer, and TCP network protocol communicating within software. Both of the communication ways make the system have a good compatibility.

3. The design of visual stimulation

We introduce flickering-based stimulus patterns. This pattern uses a standard LCD screen to display stimuli. The resolution of the screen is 1024 H×768 V pixels, refreshing 60 frames per second[7-8]. The stimulus flicker control program is written using Windows pycharm. We designed a total of 6 stimuli: 11Hz, 13Hz, 15Hz, 17Hz, 19Hz and 23Hz[9], which represent 6 different control commands for the book. The pixels of each stimulus are 50×50 pixels, and the spacing between stimuli is 100 pixels. The location of the flickering pictures on the e-books website is shown in Figure 2. The two pictures on the right control the page scrolling up and down, and the four pictures on the left mark the book in the first row. After a pull-down operation, the scintillation block is moved down one line to mark the e-book in the second row, as shown in Figure 3.
It facilitates the subject to focus attention on the fixation target by displaying the stimulus scintillation picture and the fixation target together, which avoids the problem of switching back and forth between target and stimulus that existing SSVEP BCIs. This method can improve the efficiency and flexibility of the system. According to the test, the average time for the five subjects from staring at the target to choosing the corresponding e-book was 12 seconds.
BCI systems based on SSVEP usually use frequency to encode information. SSVEP is difficult to detect the characteristics of EEG signals induced in the time domain, but can be clearly captured in the frequency domain. We can see from figure 4, when subject focuses on a certain frequency stimulation, EEG signals related to its frequency will be generated in the occipital region of the brain. The frequency-domain analysis shows that the energy value of the evoked EEG signals at the stimulation frequency is significantly higher than that at other frequencies.

4. EEG data acquisition system

In this system, a low-cost commercial wireless Emotiv EPOC+ EEG acquisition device is used to collect EEG signals. The device based on International 10–20 locations records from 14 channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4)[10]. Two additional electrodes (P3, P4) were used as reference. In order to reduce interference, we choose four channels (P7, O1, O2, F4, F8, T7 ,T8 and P8) in the occipital lobe of the cerebral cortex were used to collect EEG data. Data were digitized at 128 Hz sampling rate and sent to the computer via Bluetooth wireless serial port.

The EEG acquisition device is connected to the computer via the TCP/IP protocol, which provides a reliable data stream service. In this experiment, the collector is the client and the computer is the server, they establish TCP connection based on "three handshakes" mechanism. Clients and servers are uniquely identified by IP addresses and port addresses. In this experiment, the port is set to 5555 and the IP address is set to 127.0.0.1. The collected EEG data are shown in Figure 5.
5. EEG processing
Electroencephalogram (EEG) is a low-frequency bioelectrical signal ranging from 5 to 100 μV that requires amplification for displaying and processing. In the EEG signal analysis and processing and feature recognition system, in order to correctly identify the EEG signal, the signal processing mainly includes the following three parts: data preprocessing, feature selection and extraction, feature classification. Signal preprocessing can remove the interference of low frequency noise, such as eye electricity, electromyography, etc. The purpose of feature extraction and selection is to reduce the dimensions of EEG signals and extract the features related to classification. Feature classification mainly uses the classification algorithm to classify the extracted features. There are two steps: firstly, the model is trained by using the characteristics of training samples to obtain classification parameters; then, the trained classifier is used to obtain the categories of the characteristics of the test samples.

5.1. Pre-processing
The bandpass filter can effectively remove the noise signals of unneeded frequency bands in EEG signals[11]. In the system, the band pass filter is \( f_{\text{low}} = 5 \text{Hz}, f_{\text{up}} = 30 \text{Hz} \). After the EEG signal is filtered by a bandpass filter, the components related to the evoked EEG are preserved.

5.2. Feature selection and extraction

5.2.1. Common spatial pattern (CSP). After filtering through a band-pass filter, we spatially filter the EEG signal to maximize the weight of the relevant information contained in the channel while reducing other irrelevant information.

5.2.2. FFT combined with weighted spectral signal-to-noise ratio. In this system, Fourier Transform (FFT) first perform on the EEG signal of each channel. After the signal is mapped to the frequency domain, the formula (1) calculates the frequency domain signal-to-noise ratio (SNR), and then
combines the weighting factor function to obtain the weighting factor. The EEG signal is multiplied by the weighting factor to obtain the weighted value and averaged to obtain the weighted spectral signal-to-noise ratio.

$$SNR = 20 \log_{10} \left( \frac{y(f)}{\sum_{k=1}^{K} [a(k)y(f-k) + a(k)y(f+k)]} \right)$$

(1)

Where $y(f)$ is the amplitude of the EEG signals at the f-th frequency point after FFT transformation, and $a(k)$ is the first N coefficients of a 2N-order FIR filter. The denominator in Equation is a weighted average of the neighbor frequency points of the f frequency point as the noise estimate.

We compared the method of with spectral amplitude method. Figures 6 and 7 demonstrate that the SNR method can reduce the influence of spontaneous EEG signals. It effectively solves the problem of high energy in the low frequency part of the EEG signal and low energy in the high frequency part, so it can optimize the extraction of features. It is more conducive to extracting effective frequency features in EEG than the second method.

![Fig. 6 Frequency energy spectrum](image)

![Fig. 7 Weighted spectral signal-to-noise ratio](image)
5.3. Feature classification
The support vector machine (SVM) is employed to identify the user's intention in the system. Firstly, the system trains the SVM offline to obtain the trained classifier, and then perform real-time classification on EEG, so as to judge the user's reading intention. SVM maps the feature data to a high-dimensional linear separable feature space by kernel function and makes the nearest distance of different samples maximized, that is, the operation from feature space to type space. The feature vectors extracted from the EEG signals are classified and recognized according to different classifier rules. When a length of EEG data is recognized, the decoding algorithm can dynamically update its parameters according to the recognition results, so as to further improve the accuracy of subsequent recognition. The iterative updating method can realize the real-time optimization of EEG features.

5.4. Data transmission
The data transfer module is the last part of the software platform design. The module outputs the control instructions or feedback information after classifying the modes. In order to meet the requirements of real-time data and good compatibility of brain-computer interface system, this part uses VRPN communication protocol to complete real-time data transmission. The classified EEG data is sent to the web content analyzer.

6. Experiments and Results
At present, the information transmission rate (ITR) is usually used as the main evaluation index of the BCI system[8], which reflects the total amount of effective data that the BCI system can transmit in a unit time. ITR is mainly determined by three parameters: recognition accuracy, number of targets and response time. The higher the information transmission rate of the BCI system, the more data the system can transmit per unit time. The higher the average recognition accuracy, the more the number of replacement targets and the shorter the response time of the command, which is more conducive to the improvement of control efficiency.

We recorded the experimental data of 5 subjects to verify the actual control effect of SSVEP-BCI and evaluate the performance of the algorithm. All online experiments are conducted in a quiet and comfortable laboratory. Each subject performed five experiments, and the accuracy of the system can be calculated from the recorded results. The experimental results are shown in Table 1.

| The experimenter | Numbers of test | Exact number of commands | Accuracy rate | Average accuracy | ITR (bit/min) | Average ITR (bit/min) |
|------------------|-----------------|--------------------------|---------------|------------------|---------------|-----------------------|
| S1               | 6               | 180                      | 95.6%         |                  | 2.97          |                       |
| S2               | 6               | 180                      | 87.5%         |                  | 2.23          |                       |
| S3               | 6               | 180                      | 96.7%         | 93.3%            | 3.21          | 2.76                  |
| S4               | 6               | 180                      | 92.2%         |                  | 2.66          |                       |
| S5               | 6               | 180                      | 94.4%         |                  | 2.74          |                       |

7. Discussion and Conclusion
In this paper, we introduce a real-time BCI system that enables paralyzed patients to read e-books on a website by their intention. The patients can enrich their spiritual world without the help of their families by using the e-book BCLs, which provides a pathway for them to communicate with the external environment. The system uses bluetooth wireless serial port to realize the communication
between hardware and software. As can be seen from the experimental results, the accuracy of each subject is different, this is because EEG signal is very complex and highly sensitive to the state of the experimenter and ambient noise. The helmet testing phase can produce a variety of disturbances, which can be: environment noise, helmet errors, improper use of sensors and incorrect contact or oxidized scalp sensors. Therefore, it is very necessary to ensure a controlled environment to effectively reduce the interference of noise signals.

The experiment still has some limitations that the age of the subjects is mainly between 25 and 30 years old. However, the performance of BCI is also affected by age to a certain extent, and the information transfer rate (ITR) of the elderly may decrease[5]. Therefore, in further research, we will expand the age range of subjects. On the other hand, in order to make the system more convenient and accurate, the next research is to optimize the noise model and improve the accuracy of the EEG signal.

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