Brain-Machine Interface Training System of Motor Imagery Based on Virtual Reality

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ABSTRACT

This paper aims to study the brain-computer interface (BCI) training system for motor imagery (MI) based on virtual reality. In this paper, the MI-BCI software was designed and implemented by using C# and MATLAB mixed programming method, besides, three types of EEG signal pre-processing algorithms, five feature extraction algorithms, and two classification recognition algorithms were integrated to provide off-line analysis, on-line analysis, and adaptive algorithm selection. The results show that by automatically selecting the optimal combination of algorithms for the subjects, the integration degree between the BCI system and the subjects, and the universality of the BCI system are improved. The test objects can all complete the roaming test by constantly adjusting their state of mind under the feedback of virtual reality. The designed training system in this paper can improve the MI ability of subjects.

Key Words: Brain-Computer Interface (BCI), Motor Imagery (MI), Virtual Reality

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Introduction

The 21st century is considered to be "Era of Brain Science". The research on brain science has also become the important part in the "International Frontier Science Program". In 2007, the European Union increased its investment in brain science research; in 2001, China officially joined the "Human Brain Project" and initiated the research on neuro-informatics (Yamazaki *et al.*, 2005). The main purpose of brain science research is to "understand the brain, protect the brain, and apply the brain". The brain-computer interface (BCI) technology is the most direct application of brain science research, and has a wide application prospects in the medical, rehabilitation, military, and entertainment fields etc. It is the hot spot of brain science research worldwide.

The BCI serves as a new channel for information exchange and control between the brain and the computer and its peripheral devices, esp. the MI-BCI is used as an autonomous BCI mode. It is undoubtedly a great boon for those incapacitated patients with normal thinking due to diseases, accidents or natural disasters, because BCI is of great significance for their personal physical rehabilitation and improvement of their quality of life, and also can reduce the economic and labour burden of their families (Fichtlscherer *et al.*, 2000). For decades of research, great progress has been made for the research on MI-BCI, but there still exist some problems as follows: (1) There is a big difference in the subject's motor imagery ability, and then for the same BCI system, the different subjects vary in the manipulative ability; (2) When different subjects make the same mental task, the activity areas of their brain also differ, and different EEG lead need to be selected; (3) When different subjects do the same thinking task, their EEG characteristics are not the same, and it is necessary to select the optimal feature extraction algorithm; (4) Training has a greater impact on

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the subject's motor imagery ability, so, much training is required for the subject in order to improve their manipulative ability (Wilmore, 1991). Therefore, it has been the voice of all researchers to develop one MI-BCI system with universality and robustness that can achieve rapid training of subjects, quick recognition of brain electrical signal and be suitable for all kinds of individuals.

By combining the virtual reality with BCI technology, this paper designs one virtual reality MI-BCI system that integrates the function of the rapid training of subjects, BCI system lead optimization selection, adaptive selection of optimal algorithm, and real-time control of peripheral device etc. together. First, in order to shorten the training period of subjects and improve the R&D and service efficiency of BCI, VR technology was integrated into the BCI study. A 3D simulation scenario designed by computer graphics technology was used to simulate the effects of the real environment, bringing the user the immersive real-time perception and experience. VR technology was also used to realize the information feedback of BCI system. Compared with traditional simple feedbacks such as colour bars and arrows etc., VR can provide more abundant and motivational feedback; using VR's interactivity to better mobilize the training enthusiasm of the subjects or patients, and also increasing the fun of training could be conductive to better learning and adaptation to BCI systems and control applications by (Su *et al.*, 2004). Then, according to the natural phenomenon that the EEG characteristics of different subjects are not the same when doing the same mental task, the optimal algorithm combination scheme was provided by building one self-adaptive optimal algorithm-based BCI software system platform and 3D virtual reality training and control system for different subjects. It aims to improve the versatility of motor imagery BCI system. Finally, the subject training and test platform for MI was designed through VR technology.; the online analysis results of BCI system were used to control the virtual human in the virtual reality environment; the new interactive technology was used to improve the training efficiency of the subjects (Geal-Dor *et al.*, 1993).

Methods

In the MI-BMI system, there exist the problems with individual differences, e.g. different active cortical area when different subjects are doing the same mental task, different characteristics of the EEG signals for different subjects when they are doing the same task, and different manipulative ability of different subjects for the same BCI system. In addition, the MI training has a great influence on the subjects' EEG separability and the manipulative ability for the BCI system. In order to improve the subject's handling ability of the BCI system and the universal applicability of the BCI system, an adaptive algorithm-based MI-BCI software system should be designed to provide optimal algorithm combinations for different subjects, and also one good-interacted and strongly-immersed MI training scene is required to shorten the training period and improve the manipulative ability of the BCI system.

Based on the analysis above, this paper aims to design one common set of MI-BCI data analysis system and virtual reality training system to solve the problems of large individual differences of subjects, long training period, and unobvious training effect. The MI-BCI system is used to parse the EEG signals, identify the thinking tasks, convert the recognition result codes into control instructions and then transfer them to the VR system to realize the virtual reality control.

Results and discussion

LAN setting of BCI training system

C# network communication uses two namespaces system: Net and System.Net.Socket to implement the class call. The most commonly used solution in network programming is the C/S (client/server) model. In this model, the client and server refer to two application processes respectively, where the client sends a service request to the server and then the server responds.

The TCP/IP protocol is the basis of network communication. It is divided into four layers: network interface layer, network layer, transport layer, and application layer. The TCP/IP model defines two protocols at the transport layer: the transmission control protocol (TCP) and the user datagram protocol (UDP). UDP protocol is a connectionless and unreliable transmission protocol, while the TCP protocol is a reliable connection-oriented protocol. Socket exists as the middleware for application program communication, and is used to manage the creation, monitoring, connection, and data transmission of communication port, so it is widely used in network communication program development (Fig.1). Using Socket to access

TCP/IP can quickly and efficiently establish a reliable point-to-point network connection (Eggermont, 1992). There are three types of sockets: stream sockets, datagram sockets, and raw sockets. In this paper, the stream socket-type communication is used to implement data exchange between systems.

Figure 1. Socket location during communication

EEG signal processing algorithm

Baseline drift is mainly caused by changes in the interface impedance between the electrode and the scalp due to the subject's breathing, and head movement etc. Its frequency is around 0.05-1.5Hz, as a low-frequency signal, which has much impact on the correct detection of multi-task EEG signals and mode, thus, this interference must be removed during pre-processing. In this paper, the baseline shifting interference is removed using the de-averaging method. Assuming that the number of leads is M, there are T trials in each experiment, and there are N valid data points in each trial. Then, all leads were selected to calculate mean value of data at the 100ms before each lead stimulus. Finally, the lead average was subtracted from the amplitude of all sampling points in a single trial. Fig.2 and 3 depicts the comparison chart before and after the baseline correction.

The study showed that in the analysis of MI-EEG signals, when one imagined unilateral hand movement, the cortical mu rhythm and beta rhythm energy of the corresponding primary sensory motions at the opposite side of the brain were significantly reduced, indicating the event-related desynchronization. The mu-rhythm and beta-rhythm amplitudes of the primary sensorimotor cortex at the same side were significantly increased, which was characterized by event-related synchronization. This phenomenon is the basis for the classification and recognition of ME-EEG signals. In the process of MI-EEG analysis, the ERD and ERS are used to realize the classification and recognition.

In this paper, Burg method was used to calculate the power spectrum density (PSD) of each segment of MI-EEG data. 10-12Hz power spectrum data was selected to make sum calculation as the feature value of the MI EEG signal. For the selected N-lead EEG data, the PCD algorithm was used to calculate the sum of the power spectral densities of the 10-12 Hz signals of each lead (where each lead is used as a dimension) so as to form the feature vector. If there are num trials in one experiment, one left-hand or one right hand MI is taken as one trial, and there are n trials in left and right hand respectively, then the characteristic dimension of PSD in one experiment is D=num*N. Wavelet transform (WT) was used to extract the features of the three types of MI-EEG signals, as shown in Figure 4.

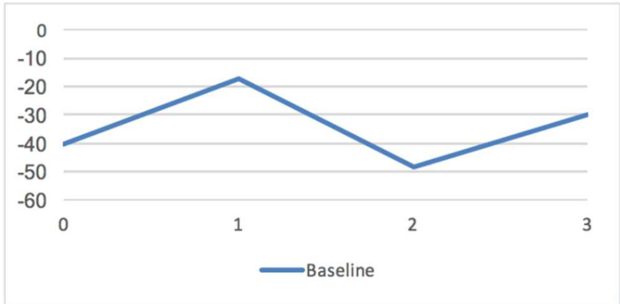

Figure 2. Baseline correction chart

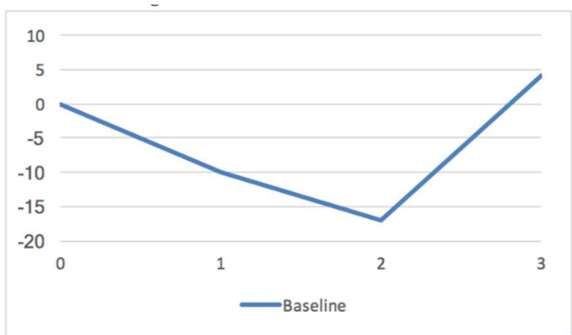

Figure 3. Baseline after change chart

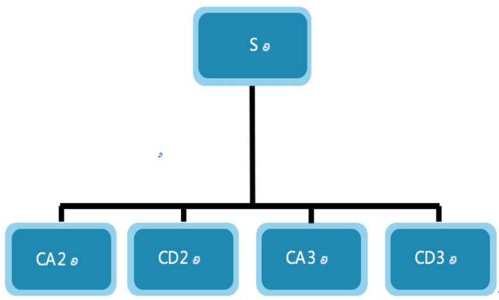

Figure 4. Wavelet decomposition tree

Wavelet packet decomposition (WPD) is an extension of wavelet transform. It decomposes the low-frequency part and the high-frequency

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part of the signal to the uniform and fine frequency band at the same time. Compared with the WT, the time-frequency resolution is improved and the decomposed signals show more distinguished characteristics at different frequency bands in WPD (Kraus *et al.*, 1990). In the experiment, the MI-EEG signal was down-sampled to 128Hz, and then the down-sampled EEG signal was decomposed and reconstructed by three-layer wavelet packets; the selected wavelet was db4, and the frequency band width was 8Hz. Table 1 lists the frequency band range of effective nodes after the wavelet packet decomposition.

Table 1. Wavelet packet decomposition layer 3 effective node corresponding band range

Decomposition signal	Frequency range/Hz
d(3,0)	0-8
d(3,1)	8-16
d(3,2)	24-32
d(3,3)	16-24

The terrain in Unity 3D refers to the terrain landform and other factors in the virtual reality scene. The design quality of terrain directly affects the fidelity of the virtual reality system, as shown in Figure 5.

Figure 5. Unity scene setup

Experiment results of VR roaming test

Table 2 lists the test results of four subjects.

Table 2. Virtual reality roaming test results

Test	Success times	Average time/s
A1	8	85
A3	7	103
A4	7	92
A6	3	115

In the VR roaming test, the subjects adjusted their thinking based on the degree of deviation between the virtual person and the target, and brought the virtual person closer to the target, gradually increasing the control effect. The results in the above table show that the four subjects can complete the roaming test by continuously adjusting their state of mind under the feedback of virtual reality. The single best result of the subject is 64s in the experiment. Although the experimental results are not ideal, the subjects trained in virtual reality have significantly better results in the roaming experiments than those who weren't trained in the virtual reality system. It shows that through training, the subject is expected to produce the best EEG signal.

Conclusion and outlook

Thanks to the fast and efficient processing ability of MATLAB and the object-oriented programming design advantages of C#'s, the efficiency of system development was improved, and the system algorithms were updated and maintained. Through the friendly human-computer interaction interface, the efficiency of EEG signal analysis and processing was improved for the BCI researchers; this system realized the multi-algorithm adaptive selection function, aiming at the differences between the individual subjects, and by comparing different algorithms, the algorithm combinations suitable for each subject were selected respectively to obtain the best classification result, thereby improving the universality of the BCI system for the subject (Rogers *et al.*, 1989). Besides, the Unity3D engine was applied in this paper to design a virtual reality software system, providing the first perspective and the third perspective to increase the diversity of the system.

Then, this paper analysed the results of both synchronous online experiments and virtual reality online roaming for the four subjects. The results show that the training system designed in this paper can improve the subject's motor imagery ability, which verifies the effectiveness, reasonableness and feasibility of this system design.

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