NAO Robot Walking Control System Based on Motor Imagery

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Abstract. Brain-computer interface (BCI) technology refers to the spontaneous imagination of a certain mode of movement in the brain to communicate with the computer or control external equipment. This technology helps the limb rehabilitation of paralysed and stroke patients. BCI system will fix electrodes on the experimenter's brain. This paper designs a brain-computer interface system based on motor imagery, and uses it to control the movement of NAO robot. The system is mainly divided into three modules: signal acquisition, signal processing and robot control. In the aspect of signal acquisition, EEG cap, conductive paste, EEG amplifier and the designed upper computer software system are used to realize the design. Computer storage and processing of data. In signal processing, this paper designs a signal feature method based on Common Spatial Pattern (CSP) and Local Characteristic Scale Decomposition (LCD), and then classifies the features into commands to control NAO robots. In the aspect of communication control, the instruction coding is set in advance, and the classification result is set as the instruction to control the different actions of the robot. Socket communication is carried out by client-server mode using UDP protocol. The experimental results of the study also obtained a high accuracy.

1. Introduction
According to the 2018 national economic and social development statistics bulletin issued by the national bureau of statistics, by the end of 2018, the population aged 65 or above in China had reached 137.55 million, accounting for 10.1%, exceeding 10% for the first time, and is expected to rise to 25.4% in 2033[1]. According to the international consensus, this means that China has entered an aging society, the proportion of the elderly population will continue to increase, and the incidence of stroke and other cerebrovascular diseases and disability will continue to increase[2]. At present, physical disability is very common among the elderly over 60 years old in China. The consequences of physical disability are very serious, causing great pain and even the loss of walking or labor force. In order to solve the social phenomenon, the paper combining with the imagination based on movement (Motor imagery, MI) of brain-computer interface (brain computer interface, BCI) technology and the equipment, NAO robot real-time interactive system[3], let the disabled or elderly through the device to communicate with the outside world, to the greatest extent improve the ability of independent life of these patients with movement disorders and social participation ability, to restore and improve the Motor function of patients.
2. Experiment setup and methods

2.1. Experiment Setup
The human brain is the most important organ of the human body, and all kinds of human physiological activities such as thinking, limb movement and so on need the participation of the brain to complete. When the human brain is working, tens of billions of neurons in the brain are working at the same time[4]. They transmit neurotransmitters in nerve fibers to achieve the purpose of transmitting information. At the same time, micro-current will be generated in the process. Different brain states of thinking produce different sizes of micro-currents, so the electroencephalogram signals detected by electrodes are also different. Everyone's brain waves are different, but they are all in a certain frequency range, so according to the different frequency range, they can be divided into several kinds: alpha wave, beta wave, theta wave, delta wave and mu wave.

The BCI system based on motor imagery is the most widely studied one. When people exercise or imagine in a waking state, there will be event-related de-synchronization or synchronization of beta and mu rhythms in the motor cortex (ERD/ERS) [5] [6]. That is to say, the energy of these two kinds of motor rhythms will change to a certain extent. ERD-based BCI system based on motor imagery is the suppression of rhythm amplitude. ERS is the enhancement of rhythm amplitude, which is the physiological basis of BCI system based on motor imagery. This process is carried out in human imagination without external stimulation or obvious limb movements. It is precisely because the process of motor imagery only needs to be completed in the human brain, so this method has the advantages of easy implementation, but it also has some disadvantages. For example, it can only detect the changes of beta and Mu rhythmic energy to determine whether the experimenter has the behavior of motor imagery, but it cannot determine the specific behavior of motor imagery, which leads to the essence of this system. The accuracy cannot be very high.

Subjects sat in quiet, soft lighting environment to reduce environmental factors and psychological stress or muscle tension interference. Before the experiment, training experiments are needed to obtain the classification model of the subject's motor imagery[7]. In this study, left-hand, right-hand, bipedal and tongue thinking were used. As an experimental paradigm, tasks correspond to the motion instructions of the left, right, back and front tasks of the robot. Subjects need to perform corresponding motion image tasks according to the robot's motion path. The signal processing module converts the motion image results into motion intentions in real time and sends them to the shared control system for the motion control of the robot.

2.2. Motor imagery classification
When the user performs imagery exercise, it activates the cortex of the corresponding motor sensory area of the brain, increases metabolism and blood flow, and decreases the amplitudes of the mu-rhythm (about 8-13 Hz) and the beta-rhythm (about 14-30 Hz), which is described in Table 1[8]. This is called event-related desynchronization (ERD), which is called event-related synchronization (ERS) when it comes to the increase of Mu and beta rhythms. Therefore, in order to improve the signal-to-noise ratio, this paper chooses Butterworth filter to filter EEG signal, because this kind of filter can effectively reduce the degree of distortion.

| EEG | description |
|-----|-------------|
| α-rhythm | Frequency ranges from 8 to 13 Hz. When people are awake and relaxed, their attention is easy to concentrate. |
| β-rhythm | Frequency ranges from 14 to 30 HZ. This rhythm occurs when a person's mind is in a state of tension. |
| θ-rhythm | Frequency range is 4 to 8 Hz, when theta-rhythm appears, people are generally in a state of depression or deep relaxation. |
| δ-rhythm | Frequency ranges from 0.5 to 4 Hz, usually during sleep or deep sleep. |
| µ-rhythm | Frequency band is similar to alpha-rhythm and closely related to beta-rhythm. Both µ--rhythm and beta--rhythm are related to motion, which is usually called mu/beta rhythm. |
2.2.1. **Preprocessing.** When the user performs imagery exercise, it activates the cortex of the corresponding motor sensory area of the brain, increases metabolism and blood flow, and decreases the amplitudes of the mu-rhythm (about 8-13 Hz) and the beta-rhythm (about 14-30 Hz) [9]. This is called event-related desynchronization (ERD), which is called event-related synchronization (ERS) when it comes to the increase of Mu and beta rhythms. Therefore, in order to improve the signal-to-noise ratio, this paper chooses Butterworth filter to filter EEG signal, because this kind of filter can effectively reduce the degree of distortion.

2.2.2. **Feature extraction method.** Because there are more than two kinds of tasks in this paper, CSP needs to be extended. This paper chooses one-to-many CSP mode. OVR-CSP is a common method to extend CSP to multi-class classification. First, any class is taken as one input of binary CSP algorithm, and the remaining classes are merged into another input of binary CSP algorithm. A spatial filter belonging to this class is constructed by binary CSP algorithm to extract all kinds of features. Because of the lack of time-frequency domain information in CSP, local Characteristic-scale Decomposition (LCD) is introduced. LCD defines the intrinsic scale component (ISC), which refers to the instantaneous frequency of a signal. Therefore, LCD can decompose a signal into several ISC components, and then observe the characteristics of these components to get the original information. The characteristics of time-frequency domain. LCD has some advantages in many aspects, such as computing speed and the ability to decompose signals[10].

2.2.3. **Signal classification.** Before classification, MCFS is used to sort the features of the special signals extracted before, and then the classification method of Spectral Regression Discriminant Analysis (SRDA) is used to classify them. SRDA classifies feature data without resolving feature vectors, thus greatly reducing classification time and storage. Compared with all other methods, SRDA does not involve dense matrix feature combination or SVD decomposition location. Using spectral analysis, SRDA transforms discriminant analysis into regression framework to facilitate the use of effective computing and regularization techniques. It can classify feature data by solving a series of regularized least squares problems, which can be easily extended to large data sets, thus greatly saving classification time and storage[11] [12]. After the study, the final classification results of the experiment are shown in Figure 3.3. The experiment currently tests 25 groups of imagined motor movements, totaling 100 groups of experiments. Finally, the correct classification rate can be calculated to be 0.875.

2.3. **NAO Robot Control**

This project uses the wireless LAN technology which is widely used at present to connect the robot into the wireless LAN. At the same time, the EEG acquisition and processing equipment mentioned above is also in the same LAN. The processing results are sent to the terminal equipment in real time. Through the pre-set instruction translation, the real-time interactive effect can be achieved. By
comparing the results of several experiments, it can be concluded that the method in this paper has the best classification results on the tongue. This means that other tasks are more likely to be considered tongue MI tasks. Therefore, in order to obtain better experimental results, four kinds of motion imagery tasks, left-handed, right-handed, biped and tongue, are used as experimental paradigms, corresponding to the robot motion commands of left-turn, right-turn, backward and forward tasks[13].

Four kinds of motion imagination are designed here, namely, biped, tongue, left hand and right hand, which correspond to the walking process of the robot in front, back, left and right. The robot is tentatively controlled to walk on a pre-planned route. The control instructions of the robot terminal are marked as "0", "1", "2", "3", "5" and "6". "0", "1", "2" and "3" correspond to four different types of motion imagery respectively, and correspond to four directions of walking around the robot; "5" is defined as that the subjects' motion imagery does not correspond to the planned path behavior at this time, i.e., the wrong state; "6" is defined as the unaccepted data.

In the control process, the command flag corresponding to the real-time motion imagery classification results is sent to the server through UDP Socket. Each time the server receives a status value, it creates a TXT file with the number of times it receives the data, and writes the status value into the TXT file[14].

In the project, the robot is controlled by Python API of the robot control software, and the script reads the txt file newly written to the specified folder. When the command sign is read as "5" or "6", the robot is not controlled to do any operation. When the command sign is "0", "1", "2" and "3", the robot is controlled to move forward, backward, left and right respectively. In order to achieve better brain-computer synchronization and real-time performance, when the classification results are "0", "1", "2", "3" four kinds of RMS, the thread of EEG acquisition terminal enters the delayed state, and the delayed time is the same as that of the robot.

3. Experiment and results discussion

3.1. System design
Firstly, in the off-line training stage, the experimenter imagines the movement through a specific experimental paradigm, and stores the results on the computer. After the training, the off-line data are processed, and the MATLAB program is run on the computer. First, the projection matrix of each experimenter's specific spatial filter is obtained, and then the classification model of each experimenter is calculated. After a large number of training, real-time control of terminal equipment can be started. The whole system flow chat is showed in Figure 2.

3.2. Acquisition of EEG signals
In the acquisition of EEG signal, this paper uses portable EEG signal acquisition device to lighten the EEG acquisition device, without losing its acquisition accuracy. Before the experiment, users should wear EEG caps and sit in quiet and soft light environment to reduce the interference of environmental factors, psychological pressure or muscle tension. In order to achieve better signal extraction, conductive glue can be coated. The EEG acquisition device locates the electrodes on the scalp to extract weak EEG signals. The differential signal extraction module with high gain and input impedance is used and pre-amplified. At the same time[1], the EEG signals are filtered and artifacts are removed. Finally, the better EEG signals are obtained by A/D conversion and stored on the computer.
3.3. Experiment results discussion
Because each person's thinking state is different, the micro-current in the brain will also be different, so there are individual differences, but the overall difference is not obvious. The effect of feature selection affects the accuracy of the classification results. At the same time, the longer processing time of MI signal will result in a larger control delay and reduce the control effect. Aiming at the problem that the calculation of LCD is large, the three channels of C3, C4 and Cz with the largest contribution to motor imagery are selected to extract frequency domain features.

4. Conclusion
Based on the background of rehabilitation robot and brain-computer interface based on motion imagination, this paper constructs a complete BCI system to realize the control of NAO robot. After
the overall design and testing of the experimental system, in the model training, feedback training, robot control and other links have basically reached expectations, in terms of accuracy and real-time also achieved a certain effect. The main work and innovations in this paper are as follows:

- In the pre-processing stage of EEG signal, Butterworth filter carries out band-pass filtering, which not only guarantees the quality of EEG signal, but also improves the signal-to-noise ratio of EEG signal.

- In the feature extraction stage of EEG signal, LCD is introduced because of the lack of frequency domain information in CSP. The channel of motion imagery signal is decomposed by LCD to obtain the ISC component, and the frequency domain features are extracted. Then the ISC component and the original signal are filtered by CSP to obtain the spatial domain features.

- In the stage of feature classification, spectral regression discriminant analysis (SRDA) classifier is used in this paper. By classifying feature data without solving feature vectors, the time of classification and storage are greatly reduced.

- In the communication stage, the robot is connected to the wireless local area network. At the same time, the EEG acquisition and processing equipment mentioned above is also in the same local area network, and the processing results are sent to the terminal equipment in real time. Real-time interaction effect can be achieved through pre-set command translation. UDP Socket is used for client-server communication, UDP protocol is used for datagram socket, and connectionless data transmission service is provided. Because this project is set up for data transmission in local wireless local area network, and the amount of data transmitted is small, UDP Socket is lightweight and easy to implement, which is very suitable for communication between devices in this project.

- In the upper computer interface, this paper uses JAVA to write a game program to control the robot movement, so that the experimenter can control the robot more conveniently and quickly through the motion imagination.

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