Study on Brain Computer Interface based on Motor Imagery

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Abstract

Directly from the brain thinking activity signals to communicate with the outside world, to achieve the heart and heart communication, achieve control of the surrounding environment, even is the dream of human beings since the ancient times is the pursuit of. Brain-computer Interface (Brian - Computer Interface: BCI) this novel human-computer interaction mode provides the scientific way to realize this dream. People hope that the new communication technology can be used in traffic tools, weapons, and other auxiliary control system, especially for those neuromuscular damage, cannot use the conventional methods of communication disability patients provides another way to communicate with the outside world. Exercise imagination refers to through the brain consciously simulate a certain action, but without obvious physical activity. In the human brain has a corresponding motor cortex area, when people have limbs activities, the motor cortex area is active. In imagine movement, although physical activity, but has remained active in the areas of the brain's corresponding motor cortex, the brain also sends out the corresponding EEG signals, so that there will be movement similar brain electrical signal, but due to the body don't exercise, avoid the my electricity interference, using the movement of the thought mainly, participants imagine left and right hand movement, or don't want to, the need to constantly training, participants learn to imagine the essence of sport, to avoid other distractions. So-called brain-computer interface, it is an organization that does not depend on peripheral nerves and muscles, etc. Usually the brain output channel of communication system. In recent five years, the research of this field gradually formed a hotspot; dozens of research team in the world have developed various forms of BCI experiment system. This research mainly based on multiple electrodes EEG recording, for a variety of brain stimulation mode is intended to explore the spatial and temporal variations of electrical signals. Applied to the second-order blind identification, phase synchronization and energy entropy of the signal analysis methods to analyze imagine movement EEG signals processing, extracting its features, and USES the BP neural network and support vector machine (SVM) classification method for different types of EEG classification is imagine movement, won a higher classification accuracy and designed a BCI system based on motion imagination, through this system, participants can more freely to imagine to control the mouse movement or virtual car movement to the left or right. The innovation of this study is to imagine the movement of brain electrical signal as input signal of the brain-computer interface system, imagination is a very complicated process, and the brain electrical signal characteristic is not obvious, so higher requirements for feature extraction and classification algorithm.

Keywords: *EEG (electroencephalogram); Brain Computer Interface (BCI); BP network; Motor Imagery*

1. Introduction

Directly from the brain thinking activity signals to communicate with the outside, or even the control system for the surrounding environment, are the dream of human beings since the ancient times is the pursuit of. Today, in science highly developed, it is a kind of dream? Whether there is a kind of technology can realize this dream?

In 1929, Hans Berger had mark to record the first time evidence of brain activity, electroencephalogram (EEG) [1-3], people started to use electroencephalography (EEG), and analysis of brain activity, subsequently brain-computer interface technology arises at the historic moment, people gradually found that the dream is slowly becoming a reality.

Brain-computer Interface (BCI, Brain Computer Interface) is a new way of human-computer interaction, it through the EEG acquisition equipment acquisition corresponding EEG signals, extract the features are classified, and then different thinking and different instructions (such as the mouse moves up and down, *etc*.,) together, realize the human Brain and external devices of the communication, such as typing, lights, drive in the wheelchair.

BCI systems [4-6] generally have signal collection, signal analysis and controller of three functional modules, which is just as Figure 1.

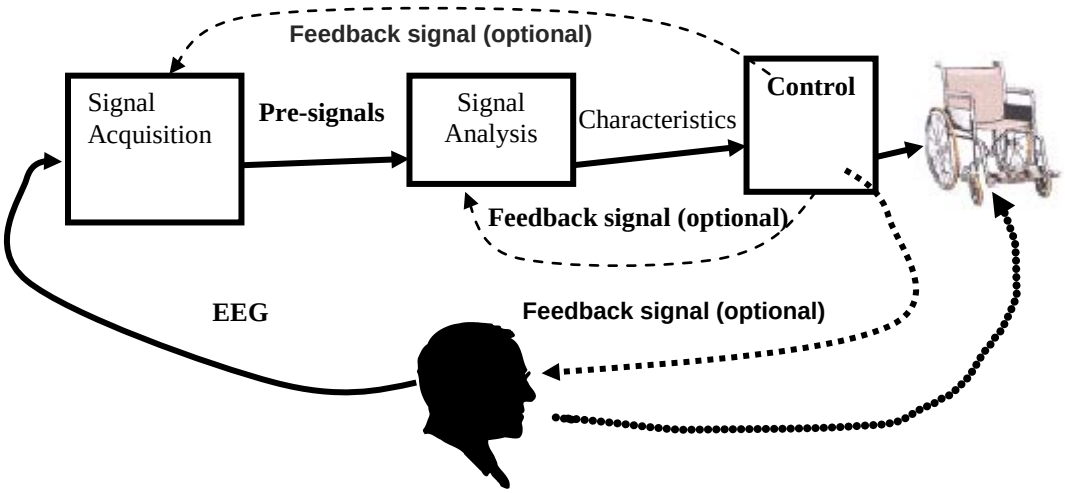

Figure 1. BCI System Basic Structure

2. Data Description

This dataset of Graz-BCI was provided by Graz University of Technology, which has K3b, K6b and L1b of Data IIIa in our work. The subject sat in a relaxing chair with armrests. The task was to perform imagery left hand or right hand movements according to a cue. The order of cues was random. The experiment consists of several runs (>= 6)) with 40 trials each after each; after trial begin, the first 2s were quite, at t=2s an acoustic stimulus indicated the beginning of the trial, and a cross "+" is displayed; then from t=3s an arrow to the left or right was displayed for 1s; at the same time the subject was asked to imagine a left hand or right hand, respectively, until the cross disappeared at t=7s(see Figure1). Each of the 2 cues was displayed 10 times within each run in a randomized order.

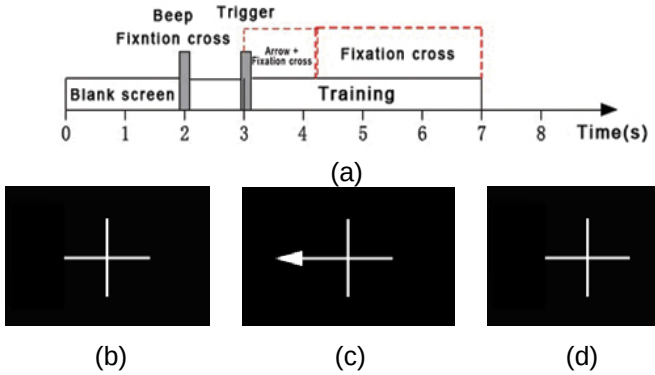

Figure 2. Stimulation Paradigm of the Motor Imagery

According to data preprocessing analysis in the first section, the experimental data were filtered between 8 and 30 Hz by a band pass digital filter. Previous knowledge tell us that C3, CZ, C4 electrode and the Central region play an important characteristic in motor imagery. So, in order to find the differences of motor imagery in phase synchronization, The C3-FCz, C4-FCz electrode pairs were calculated.

To further analyze the role and the feature of phase synchronization for motor imagery. According to Figure 3, the electrode pairs selected were calculated. This way, 10 different electrode pairs can be constructed. The number of electrodes was reduced from 22 to these 5 channels located in the frontal, central, parietal, and occipital regions. In order to find an optimal feature set, PLV of electrode pairs that have significant difference were selected as feature. Finally, the support vector machine is used for classification of the motor imagery in different time windows.

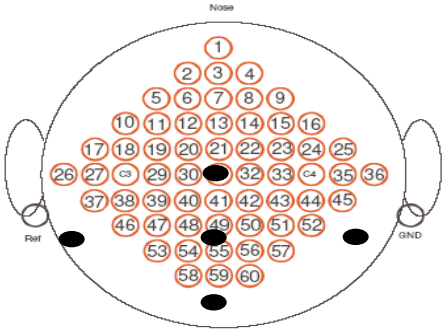

Figure 3. Selections of Electrodes

3. Feature Extraction of Motor Imagery EEG signals in the Time-Frequency Domain [7-16]

3.1. Theory

The original EEG (EEG) signal, the design of classification method is as follows:

(1) Hjort Data Conversion

In order to reduce the electrode around the real signal interference, before data analysis, need to the original data to convert the Hjort, conversion method is as follows:

$$C_i^H = c_i - \frac{1}{8}\sum_{j \in S_i} c_j \qquad (1)$$

C_i^H of which is the convert back electric data, ci is the original EEG data, S is ci around eight electrodes, including 8 electrode raw EEG data.

Raw data is through collecting 64 guide 10/20 accords with international standard EEG amplifier, the sampling rate of 250 Hz, with left and right mastoid as the reference electrode, band-pass filter pass band is 1-50 Hz.

(2) STFT Transformation

Original EEG is the signal on the time domain, scattered energy distribution, the characteristic signal submerged in noise, in order to better to extract features, we transform the original time domain signal in frequency domain, then in the 64 derivative according to the analysis, we found that around imagine movement characteristics are mainly concentrated in C3, C4 on the electrode, but especially of C3 and C4. Figure 4 is in the data set K3b electrode C3, C4 signal time-frequency transition diagram.

Time domain signal into frequency signal, the most commonly used method is to use the short time Fourier transform (STFT), USES A Spectrogram method in Matlab toolbox, signal conversion from the beginning of the stimulus, can be seen from the figure 4, the signal energy is concentrated mainly in 8-13 Hz (color in red), mainly, the second is 18-30 Hz (beige color), mainly is the band.

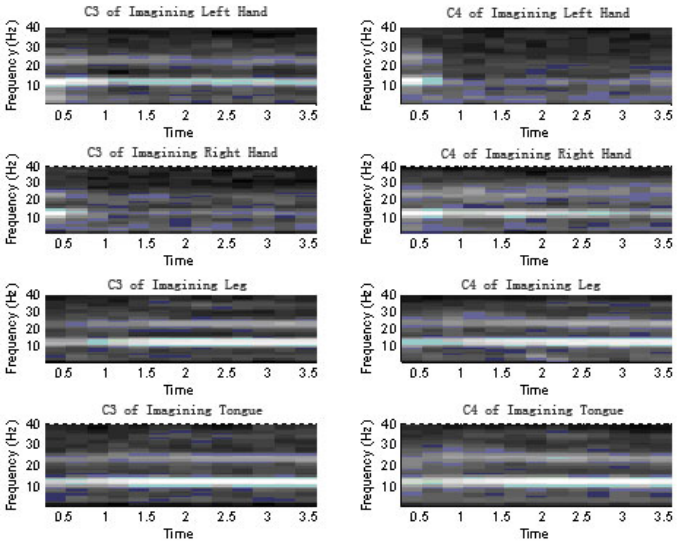

Figure 4. Time and Frequency Domain of C3, C4 Electrode EEG Signals

Because of C3, C4 electrode signal strength is different, before further processing analysis, has carried on the data since the conversion we pair frequency signal, conversion formula is as follows (frequency I said sample label, j, k said time window, n is total number of samples, same below) :

$$P(i, j, k) = \frac{P'(i, j, k)}{C(i, a, b)} \qquad (2)$$

$P'(i,j,k)$ is the STFT signal data, $P(i,j,k)$ is for the transformed data, $C(i,a,b)$ is extracted from the STFT signal data and is used as a reference data transformation, a is the selected frequency, b says time window (according to the experiment, this paper set a=44, b= 4). The following data have been used for the conversion.

(3) Calculating Fisher Distance between types

In order to better for feature extraction, we first Fisher distance computed in the STFT signal the data section, Fisher distance according to the size of the contribution of the data segments as features for classification. Fisher distance calculation steps are as follows:

1) Computing STFT between C3 and C4 sample electrode signal data

Can be seen from Figure 4, in different motion picture signal between C3 and C4 electrode synchronization and synchronization characteristics, in order to extract relevant features, let's plan the C3, C4 electrode STFT signal data, the difference between computation formula is as follows:

$$Q(i,j,k) = P_3(i,j,k) - P_4(i,j,k) \qquad (3)$$

Q is as sample difference matrix, P3, P4, C3, C4 electrodes respectively STFT signal data matrix.

2) Computing STFT data signal average data, computation formula is as follows:

$$\mu(j,k) = \sum_{i=1}^{n} Q(i,j,k)/n \qquad (4)$$

And μ is the mean for each frequency and time window of data.

3) Computing STFT data signal data section of the standard deviation, formula is as follows:

$$\sigma(j,k) = \sqrt{\frac{\sum_{i=1}^{n}(Q(i,j.k) - \mu(j,k))^2}{n-1}} \qquad (5)$$

And σ is standard deviation.

4) Fisher matrix calculation, formula is as follows

$$F(j,k) = \frac{(\mu_1(j,k) - \mu_2(j,k))^2}{\sigma_1(j,k)^2 + \sigma_2\ (j,k)^2} \qquad (6)$$

And F is said Fisher Distance Matrix.

3.2. Feature Extraction

Fisher, the size of the distance, said the data segment size to distinguish between the two types of degrees. Feature extraction to extract in the STFT matrix can distinguish between sample types of data. Is different to different people, the following data set K3b, for example, has 93 samples, the experimental data to test the results, we put the total sample is divided into two sets, learning sample set L) (60 sample and testing sample set T (33 samples). Feature extraction steps as follows:

1) As learning sample set L as an example calculation Fisher distance matrix;

2) The Fisher distance matrix according to descending order;

3) According to the sort of Fisher distance matrix, before ordering Fisher distance matrix of k, the composition characteristics of the alternative collections Ch1 {};

4) For Fisher distance learning sample set classification line;

Computation formula is as follows:

$$y = \frac{\sum_{j=1}^{k} P_{ia} - \sum_{j=1}^{k} Q_{ib}}{2} \qquad (7)$$

Y is the classification of thread, Pia is 1 type (movement to the left to imagine), Qib is 2 types (movement to the right imagine) characteristic collection; K number was characterized.

5) Select Ch1 {}, the first element in the Ch {} to join feature set, and delete the elements in the Ch1, through the classification line calculation test sample set classification recognition rate;

6) Repeat the above steps, and recognition rate/biggest characteristic values.

3.4. Theory of BP Network

In order to confirm the input num of each layer by wavelet, for example, EEG can be decomposed into 16 layers by wavelet. If the num of BP network can be ensured with three participators, the output layer of BP network will be confirmed as M Hidden layer will be confirmed with $H = \sqrt{N + M} + l$. Therefore, H is the num of Hidden layer, l is the num between 1 to 10.According to Figure 5, three layers will be modeled with BP network, which is group of Input layer, hidden layer and output layer.

1) Input node i (i = 1, 2, ..., n), output O_i is, $O_i = x_i$, and the control variable has been transferred into the second layer..

2) Hidden layer j (j = 1, 2, ..., p), input I_j is:

$$I_j = \sum_{i=1}^{n} \omega_{ji} o_i + \theta_j \qquad (8)$$

$$O_j = f(I_j) = 1/[1 + \exp(-I_j)] \qquad (9)$$

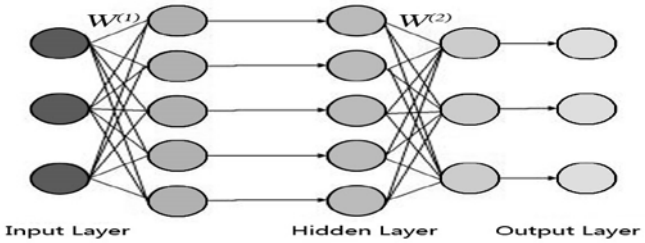

Figure 5. Model of Neural Networks based on BP Arithmetic

ω_{ji} is connective power between i and j .and θ_j is the partial of j , f is function of Sigmoid, $f(x) = 1/[1+\exp(-x)]$. (6)

3) Output layer k (k = 1, 2, ..., m), Input I_k, output layer y_k are defined as

$$I_k = \sum_{j=1}^{p} \omega_{kj} O_j + \theta_k \quad (10)$$

$$y_k = f(I_k) = 1/[1+\exp(-I_k)] \quad (11)$$

Set ω_{jk} is connection of output k and hidden j , θ_k is threshold of k . Flow chart of sample training is Figure 6.

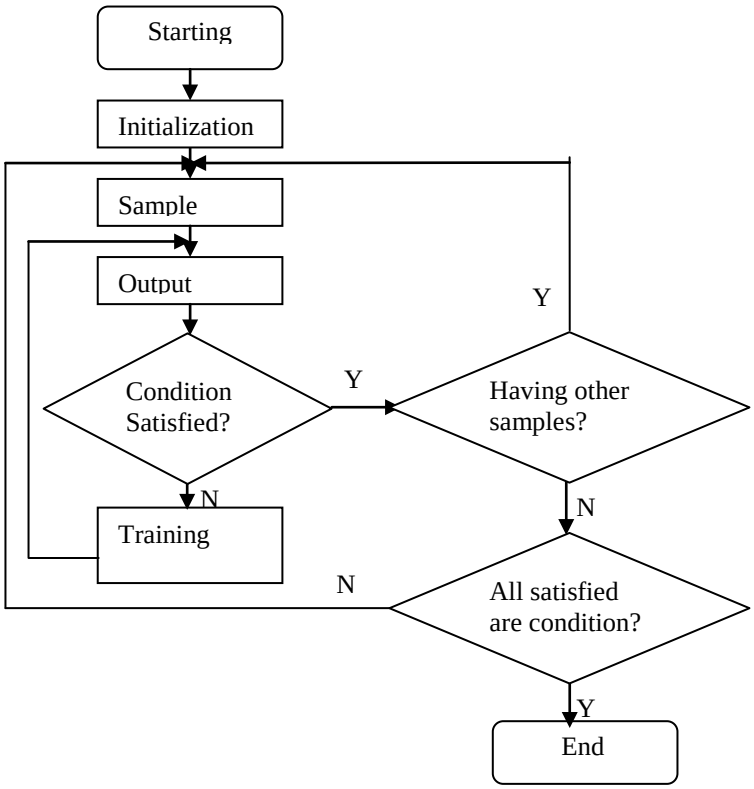

Figure 6. Flow Chart of Sample Training

4. Results

Can be seen from the experiments, the real mind imagine data begins with 3 s, so the intercept each test data of 3 s-7 s data processing. First according to the data after pretreatment, the experiment according to the instantaneous phase calculation method, the formula is adopted to C3-FCz, C4-FCz phase locking value calculated, for each category of 36 subjects PLV test data calculation. Its left and right movement consciousness imagination PLV value (see Figure 7), can be seen from the figure in the left and right movement consciousness imagined phase synchronization has the obvious difference, this means that phase synchronization is fit for classification of sports consciousness imagination.

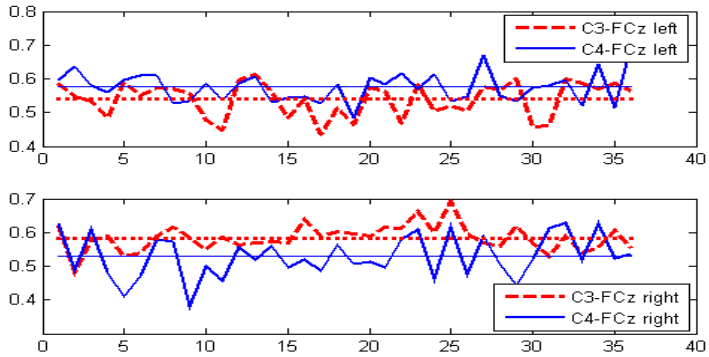

Figure 7. PLV Values of C3-FCz and C4-FCz Electrode for Motor Imagery

In order to further understand the phase synchronization of sports consciousness imagine classification performance, the data window have been adjusted, and the phase synchronization analysis under the condition of different time window size calculation influence on recognition rate, so the calculation under different time window C3-FCz, C4-FCz matching electrodes PLV values. The result is shown in figure 8. Order of the end time of each test data (the length from 3 s moment began to the moment of data), Y sit said the PLV values.

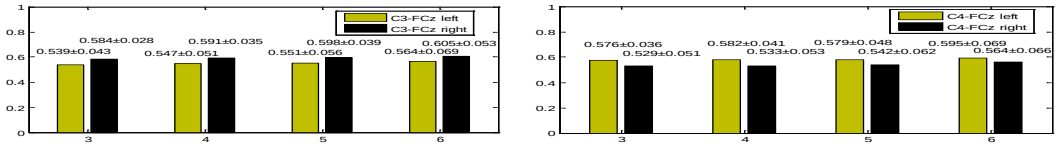

Figure 8. C3-CFz, C4-CFz Left and Right Movement Consciousness Imagination under Different Time Window of PLV Average Value and Variance

According to above you can see, you can see left and right to imagine the PLV has the obvious difference, but under the same type in different time Windows of the mean difference is not big, but mainly on the PLV value of the variance. In order to further improve the classification accuracy and the classification effects analysis under different time window, using Section 2.3 describes the matching calculation of, again with a different time window, the classification based on support vector machine, horizontal axis in the below time window of data since data 3 s time points, starting at 100 points. Ordinate represents the starting point for the data, the time window size. The classification result is shown in Figure 9.

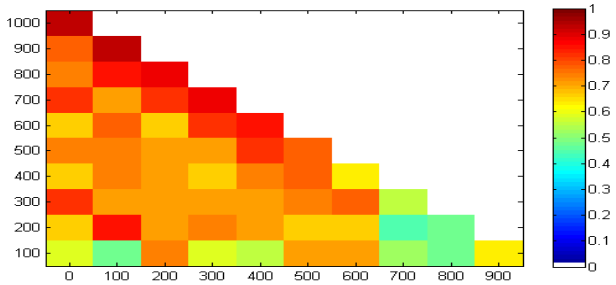

Figure 9. Classification Accuracy under the Different Starting Time in Different Time Windows

As can be seen from the above, the classification accuracy with the increase of starting time, classification accuracy rate is declining. Under the same start time, the longer time window, and the classification for higher rates. Also shows that phase synchronization phase locking value with the starting time and data length is connected. Based on the analysis of data, for each test data with 2-4 Hz segment filtering phase (PLV) phase locking value calculation, its classification effect is poorer.

5. Discussion

Over the past decade, the BCI research and development is very rapid, the current BCI research primarily for some patients (generally refers to normal thinking, but patients with dyskinesia) provides a means of communication with the outside world or to control the outside world and help them to recovery. With more clear understanding of human brain structure and function, improvement of extracting EEG technology, the advent of the computer as well as high efficiency, low cost, BCI researchers will study the "faster, more accurate, more" BCI technology. Of course, there are still many challenges in the development of BCI. For example, there is no a BCI system can both accurate and can realize rapid control; haven't really the commercialization of the product.

Anyhow, BCI research has a broad prospect, not only to strengthen the understanding of people themselves, but also will change the human way of life.

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