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BCI-based Electric Cars Controlling System

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Abstract

The so-called brain machine interface (BCI) is a use of peripheral nerves and muscles the brain's normal output channels of communication system. People hope that this new communication technology can be used for auxiliary control of vehicle, weapons and other systems, especially for those people with damaged nerves and muscles, providing another way to communicate with the outside world because disabled patients cannot use conventional means of communication. In this paper, we use the BCI technology to build a control system to assist the electric vehicle operation. The control system is based on BCI and vehicle control technology research and development. The system can make the disabled persons control the electric vehicle operation after training, so as to improve the life quality of the handicapped.

Keywords: BRAIN-COMPUTER INTERFACE (BCI); ELECTRIC CARS; ELECTROENCEPHALOGRAPH (EEG).

1. Introduction

In 1929, Hans Berger, firstly recorded electroencephalograph (EEG) brain activity of human, then, people began to use EEG, analysis brain activity, and the brain computer interface (BCI) technology emerge as the times require[1]. People gradually found that this dream is slowly become a reality.

Brain computer interface (BCI) is a new way of human-computer interaction, it is through the EEG acquisition equipment collecting corresponding EEG

signals, feature extraction, and classifying different brain activities and different emotions (such as the mouse moves up and down etc.), then realizing the communication of human brain and the external equipment, such as computer, lights, wheelchair, mobile phone, vehicle etc.

In 1991, JR Wolpaw and DJ McFarland began using EEG to study brain computer interface system[2], at this time the brain computer interface system is mainly to control the cursor moving 1D.

With the progress of technology and the development of the times, people are increasingly aware of the importance of study of brain machine interface system. Since the 90's of the last century, in USA human brain project funds support, the research of BCI has gradually become hotter. Article entitled "Real Brains for Real Robots" published in NATURE magazine [3], reported that nerve signal obtained from the cerebral cortex of the monkey, control a robot thousands of miles away, and finally met realization of the "Monkey Think, Robot Do".

Invasive-free BCI system, according to the application purpose, may be divided into neural repair system, information communication system and the environmental control system etc. Information carrier using the steady-state visual evoked potential (SSVEP), slow cortical potential (SCP), P300 and frequency, rhythm etc. Due to the adoption of electrodes on the scalp recorded EEG signals as the communication carrier, the utility model has the advantages of simple implementation is lossless, brain computer interface, is easy to be accepted by the user. The disadvantage is the signal ambiguity, signal-to-noise ratio is small, less information, affected by the environment impact of the larger, improving the accuracy and high speed communication has become the main challenge.

In 2000, Pfurtscheller et al introduced a brain independent thinking control cursor movement experiment [5]. E Donchin used P300 to create a character input system for [6]. In addition, there are people using steady-state visual evoked potential (SSVEP) implementation of the screen menu selection. In 2002, Tsinghua University Professor Gao SHANGKAI et al developed an implementation of the [7] experimental system for telephone dialling by SSVEP, in 2003 it was realized by using the BCI control of [8] on such as lights, TV, telephone and other indoor environment. In 2006, Tsinghua University successfully used EEG control machine dog play football.

The most challenging thing in these applications is to control cars by human's EEG. A few of research has been performed on create information chain from brain to cars by BCI system. DuanFeng and his research team of Nankai university implements communication between auto control system and the EEG signals, the equipment can control the car by thoughts of human.

Although some progress has been made in this area, at least two major obstacles must be overcome before BCI technology has begun to develop commercial applications. Firstly, most of BCI systems were achieved under laboratory conditions, lack of flexibility, scalability, and availability. Secondly, full

set of BCI system equipment was both complex and expensive, and the related applications were difficult to promotion. The above difficulties are real challenges faced by researchers attempting to develop. In recent years, with the popularity of electric cars, more and more people choose to use it as transportation. At the same time it also has the advantages of simple operation, energy conservation and environmental protection. The brain-machine interface technology used in electric vehicle drive control system, will make it easier for action of persons with disabilities to travel alone to become a possibility.

The goal of this paper is to develop a system for controlling electric car on real-time BCI system that includes physiological signal acquisition, EEG transmission, and a mobile devices which be used to analyze and process EEG and then control cars.

2. Methods

2.1 Signal acquisition

The EEG signals are recorded by the NeuroScan, which is a 64 channel EEG amplifier. It uses the left mastoid as reference electrode. EEG sampling frequency is 250 Hz signal notch filtering between 1 and 50Hz. EEG channel is arranged according to the recording scheme in Figure 1.

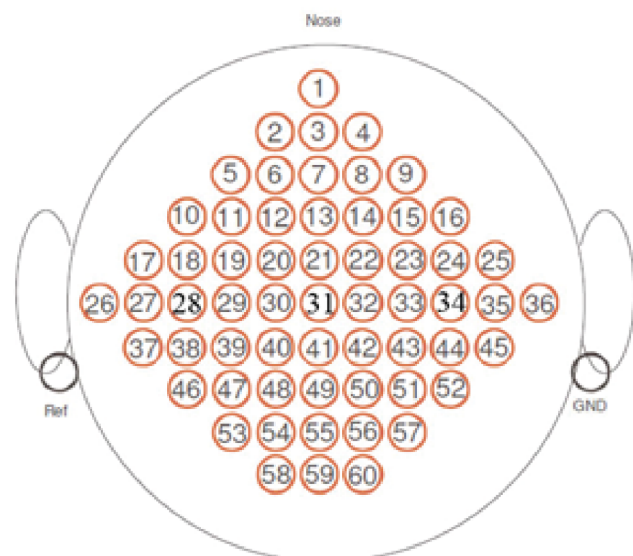


Figure 1. Position of EEG electrodes

Subjects first need to exercise the imagination of EEG training experiment. As Figure 2 shows, the subjects were asked to perform an imagination of left (L) or right (R) index finger movement according to the experimental paradigm shows that the task is complete image of the left hand, right hand according to the prompt. experiment includes several operation (≥ 6) 40 test; at the start of the experiment, when the first phase 2S that represents the beginning of the trial at $t = 2S$ sound stimulation, display and a cross "+"; and then from the $T = 3S$ left arrow, right, such as the

display is 1; at the same time, the subjects were asked to imagine the left hand, right hand, respectively, until the cross disappear.

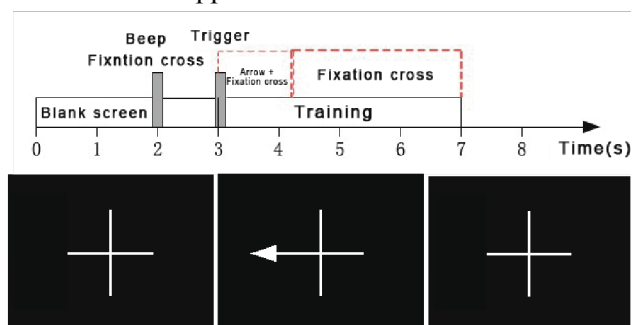


Figure 2. Timing of the paradigm

In training subjects EEG data analysis results as input parameters, according to the system data flow model, classification algorithm in each calculation, 3 s data. As shown in Figure 2, due to determine the characteristics of EEG appear time cannot be imagined movement, therefore using sliding time window way, each read 3 s EEG signal, time window every 1 s forward sliding grid, each grid are stored in the EEG data of 1 s.

2.2 Signal analysis algorithm

EEG signal is a weak signal, the useful elements of EEG signal will be submerged in the noise data in all of the many cases, so in order to better highlight the characteristics of EEG, it is necessary to analyze the EEG signals, to extract the useful signal which, which involves signal conversion. Due to the complexity of EEG signals, in order to better highlight the characteristics of EEG, we use the AR method to the signal in time domain to frequency conversion, which can extract the feature of EEG signals from the frequency, below is the brain electrical signal after conversion by using the principle of AR, the signal is divided into the left hand, right hand, imagine legs and imagine tongue, four kinds of motor imagery.

In order to extract the feature of EEG signal better, the author tried to use a variety of ways, such as time-frequency transform, two order blind identification, wavelet entropy, phase transition and a variety of ways, and with the Austria Graz University of number of a group of Graz-BCI Technology biomedical research project reported for inspection, the results show that, in the offline data analysis on the above method, can imagine movement EEG feature prominent, and in the subsequent EEG classification in the EEG recognition rate to a higher level of [11], however, in reference to online EEG signal analysis and classification, the classification efficiency is not high, the analysis shows that, the main reason is because the algorithms are too complex, too long the

operation time, therefore the re-introduction of the maximum entropy spectral estimation of EEG signal analysis. Maximum entropy spectrum estimation is a modern spectrum analysis method proposed by Burg. This method can be used to predict the data outside the observation area, so as to solve the classical spectrum estimation window brings lower resolution algorithm problem. Due to a series of advantages of the maximum entropy method, it become a field of very active in modern spectrum analysis in recent ten years, and is widely used in communication, chemistry, medicine and other fields. In this experiment, by using Burg algorithm in AR model reference motor imagery classification, according to event related synchronization and desynchronization theory, feature extraction of related frequency. The Burg algorithm is described as follows: the Burg algorithm by making before, after the average power to the minimum prediction error to calculate the reflection coefficient, based on Levinson-Durbin recursive as constraint conditions, calculate the signal power spectrum. The specific steps are as follows:

The calculation of the initial value

$$e_0(n) = b_0(n) = x(n) \quad (1)$$

$$e_0(n) = b_0(n) = x(n) \quad (2)$$

To $p=1$, find the reflection coefficient

$$K_p = - \frac{2 \sum_{n=p}^{N-1} e_{p-1}(n) b_{p-1}(n)}{\sum_{n=p}^N [e_{p-1}^2(n) + b_{p-1}^2]} \quad (3)$$

$$e_p(n) = e_{p-1}(n) + k_p b_{p-1}(n-1) \quad (4)$$

By the following formula to calculate

$$e_p(n) = e_{p-1}(n) + k_p b_{p-1}(n-1) \quad (5)$$

$$b_p(n) = b_{p-1}(n-1) + K_p e_{p-1}(n) \quad (6)$$

Then by the formula (3) estimate K_2 .

Modeled on the $a_{pk} = a_{p-1,k} + K_p a_{p-1,p-k}$ and $p=2$ Levinson recursion relation, calculate $p=2, a_{21}, \sigma_2^2, \sigma_2^2$.

Repeat this process until P is equal to the desired order of AR model, calculated AR model parameter alpha PK all, then the following formula to calculate the power spectrum density:

$$P_{Burg}(w) = \frac{\sigma_p^2}{|1 + \sum_{k=1}^p a_{pk} e^{-jw(k)}|} \quad (7)$$

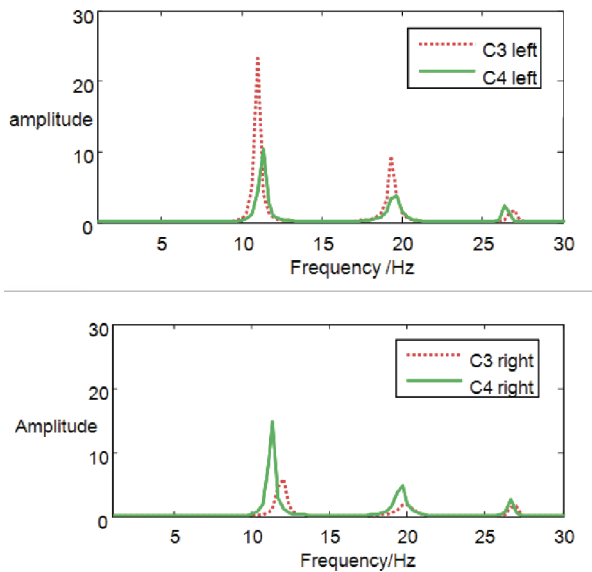


Figure 3. Motor imaginary power spectrum

The system uses P=6B order AR model of Burg algorithm is about motor imagery analysis as shown in figure 3. It can be seen from the figure in the power spectrum analysis, can see the characteristic difference in the 10~14 Hz and 16~21 Hz between.

As you can see in Figure 8-2, motor imagery EEG signal in 10~15 Hz (alpha band), 16~23 Hz (beta band) and 25~28Hz (gamma band) direct continuous appeared 3 peak, in the imagination of left brain waves, for alpha and beta band peak band of C3 EEG signal energy, total body more than C4 electrode, and for the right to imagine the opposite. This difference is the recognition of hand based, is also a game player by brain waves to the basic principle of controlling the game.

3. System Design

3.1 System Architecture

The Architecture diagram of the Pocket PC game based BCI system is shown in Fig. 4, which includes four units: Dedicated EEG Cap; signal acquisition and amplification unit; Signal Processing module and controller. The four units and driver constitute a complete data chain.

There are four steps in this data cycle. 1) Human's thinking activity will make the changes in cortical potentials. This change can be acquisition by The EEG cap which can acquire this change by high sensitivity electrode. 2) This signal is send to Signal acquisition and amplification unit by data cable of EEG cap. The device supports 8 analog input channels digitized at 16 bit resolution and sampled at a fixed 256 Hz sampling rate. 3) By Signal acquisition and amplification unit, the original signal is transform to formatted data like a huge data matrix. 4) The main function

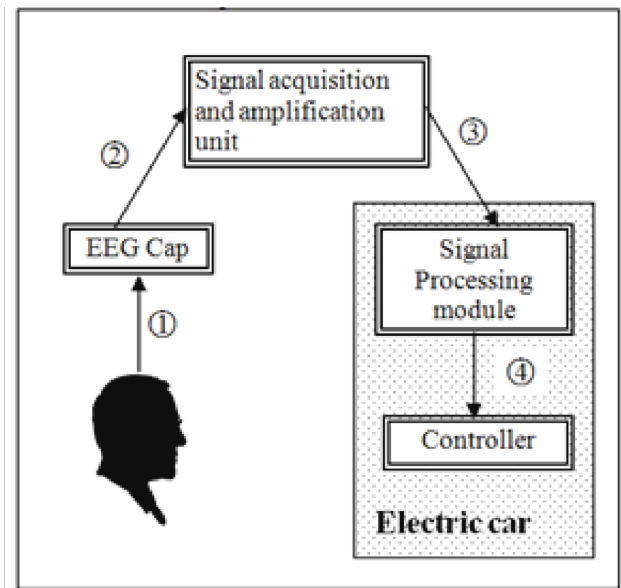


Figure 4. Architecture of electric car BCI System

of this unit is to transform pretreatment EEG signal into control signal like turn left, turn right, forward, backward, stop etc. The driver will get feedback by the car's movement.

3.2 Requirements Analysis

The first things we need to do is the requirements analysis before the software developing, UML as a common modelling tools have many types of diagrams. One of the most important UML diagrams is use case diagram. The following figure 5 is the use case diagram of BCI system for electric car:

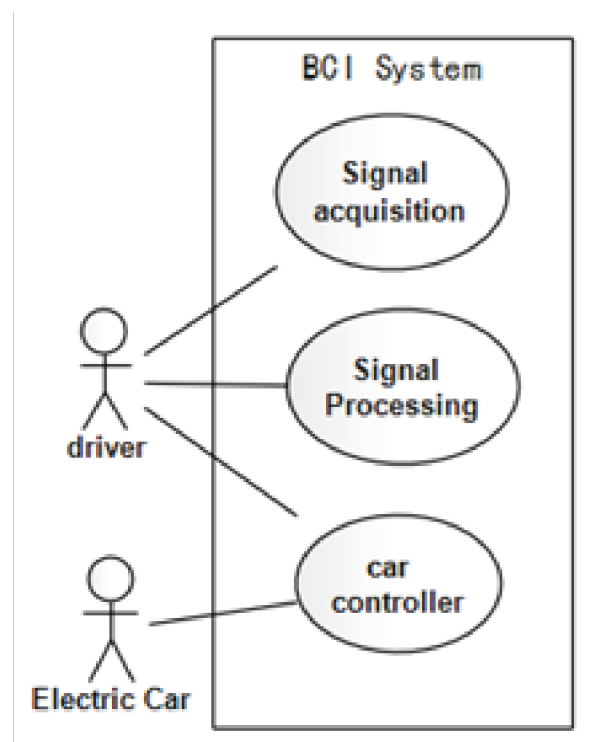


Figure 5. Use case diagram of electric car BCI System

As figure 5 shows, there are three main use cases, signal acquisition, signal processing and car controller. Signal acquisition use case is responsible for read EEG data packets from EEG acquisition device by Bluetooth port, and then send to signal processing module after data formatting. Signal processing use case is responsible for analysis and processing EEG-data from the signal analysis modules, the last results

will be sent to car controller. Finally car controller produce control signals to control the movement direction of the electric car and speed. The two roles in the figure are the driver and electric car.

Figure 6 and figure 7 are two activity diagrams of signal acquisition use case and signal processing use cases.

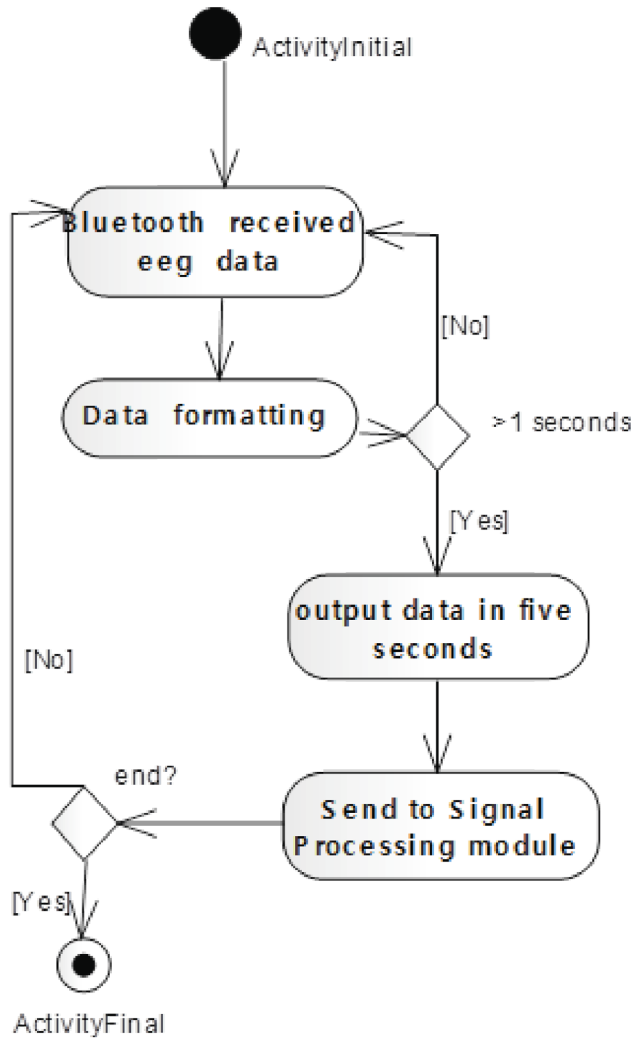


Figure 6. Activity diagram of signal acquisition

It can be seen from figure 6 that system receive the EEG data via Bluetooth port firstly, and then storage data after formatting, the next step it determine whether more than one second, if there is no more than one second continues to read the data, if more than one second it will output EEG data collected in five seconds, and finally sent it to the signal processing module.

From figure 7 we can see that the system will receive the formatted EEG data sent from acquisition module. And then system through four steps such as signal pre-processing, feature extraction, feature selection, classification. If certain classification results

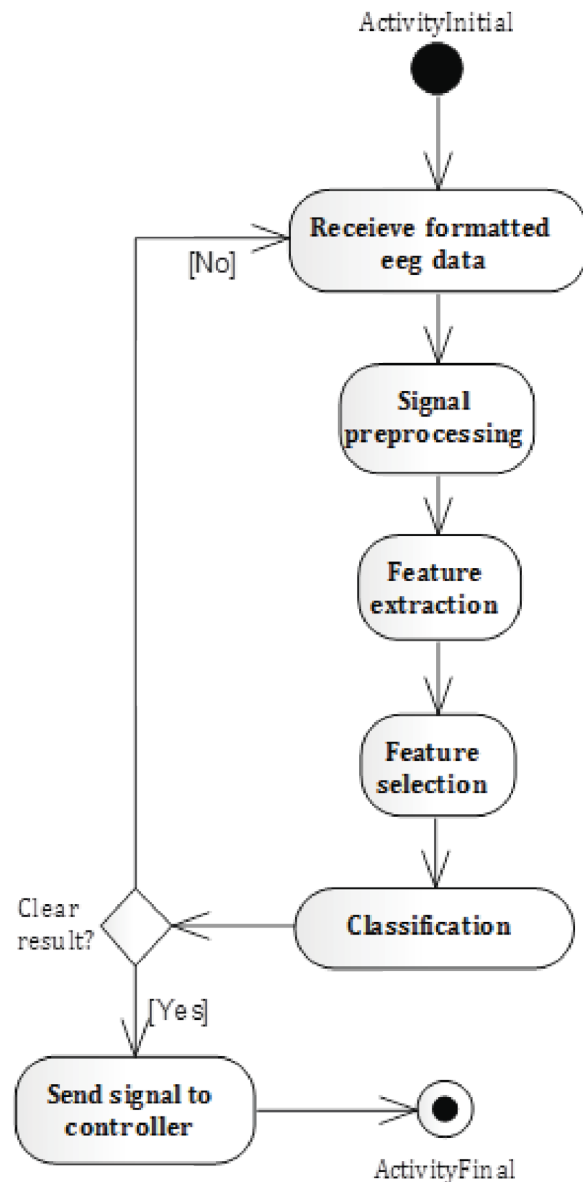


Figure 7. Activity diagram of signal processing

were obtained the system will send signals to the controller, or to give up the analysis results, continue to the next data analysis.

As figure 8 shows, this is a sequence diagram of the main operation flow in this system. Participate in the role graph of drivers, including EEG acquisition device and electric vehicles, and its participation in class includes Analysis and Controller.

First by the driver through the motor imagery EEG signals to produce EEG acquisition equipment, EEG acquisition equipment the collected data format, standard EEG data generated by asynchronous send to analysis classes, analysis through data pre-processing and feature recognition process recognition result, the recognition results are sent to the control class. Finally the control class recognition results will be trans-

formed into vehicle control signal sent to the electric car, in order to control brain waves on vehicle driving process. The main signal transmission in the figure are the asynchronous operation, which makes the between each module can run independently, reduce the waiting time of the system, thereby greatly improving the operating efficiency of the system.

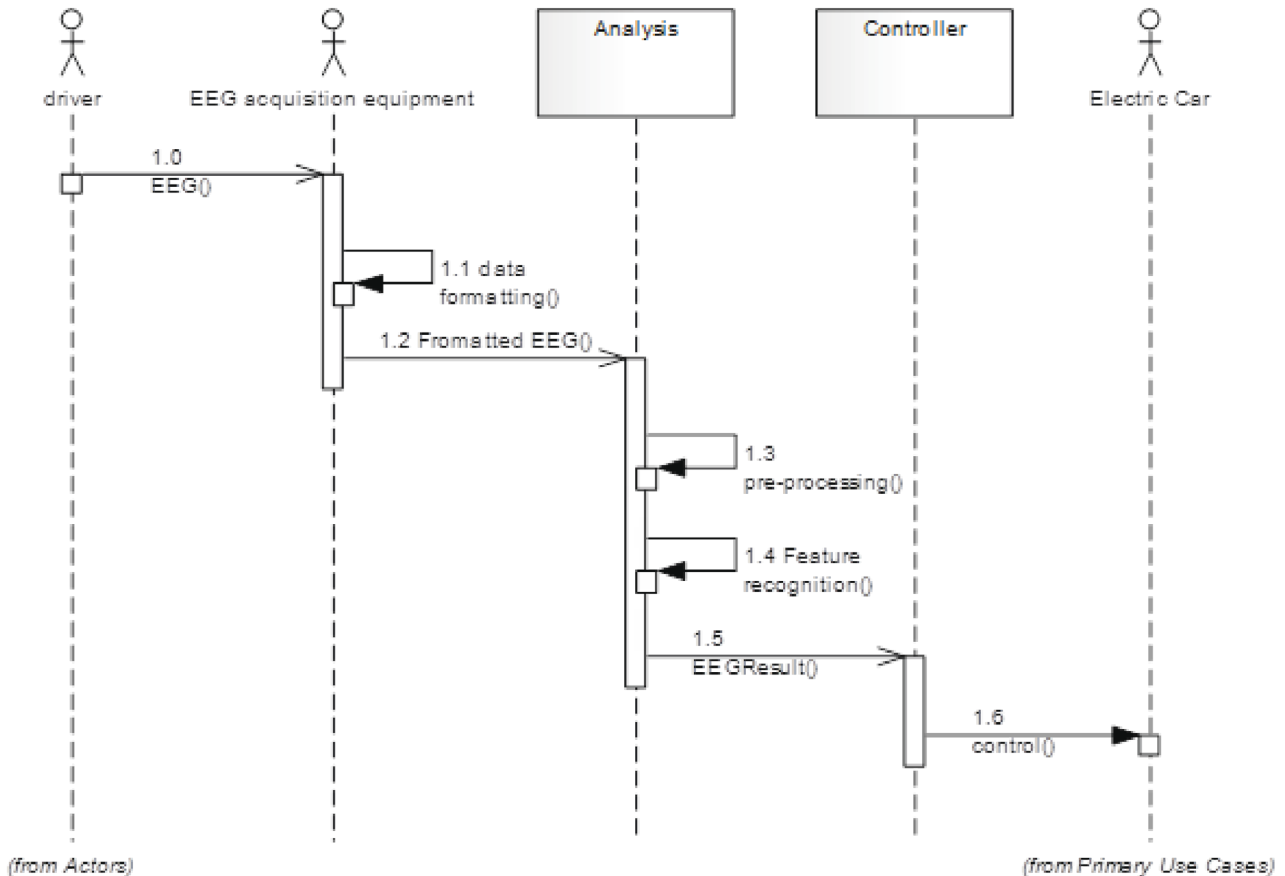


Figure 8. Sequence diagram of main activity

3.3 Framework Architecture

When developing the software architecture for the interaction framework, we tried to adhere to a simple class structure. The Class diagram captures the logical structure of the system: the Classes - including Active and Parameterized Classes - and things that make up the model. It is a static model, describing what exists and what attributes and behaviour it has, rather than how something is done. Class diagrams are most useful to illustrate relationships between Classes and Interfaces. The class structure of electric car BCI system can be found in Fig. 9.

In the figure there are three data entity classes including EEGStream, EEGMatrix, EEGResult. EEGStream class is responsible for electrical streaming data storage and management, EEGMatrix class is responsible for electrical matrix data storage and

management, this is the standard format of EEG data, while EEGResult class is responsible for the storage of non-standard matrix data format of the identification results of all kinds of intermediate results and final. Action classes contain Bluetooth, Analysis, and the Controller, etc. Bluetooth class is responsible for communication with Bluetooth port and management, Analysis class is responsible for all kinds of signal Analysis and processing method calls and management, the classification of the Controller class will receive the results into a control signal is sent to the electric car, it has two subclasses, respectively is Direction Controller class and Speed Controller class. All the operation process be unified managed by manager class.

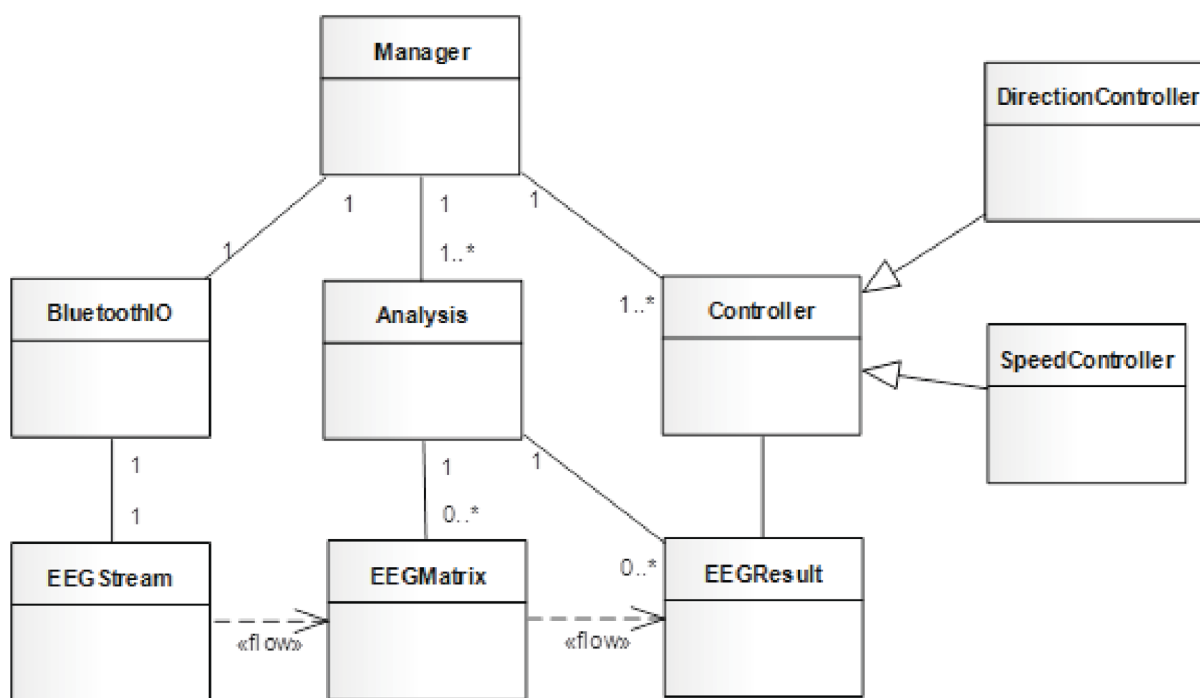


Figure 9. Architecture of electric car BCI System

4. Implementation

Different classification accuracy has been obtained with different training sets for each subject. The range in classification accuracy across training sets was relatively large in subject 2 (89.25% to 92.25%) and 3 (87.3% to 94.0%) (Figure 10), which means larger error, because of the less trials number of subject 2 and 3 than subject 1.

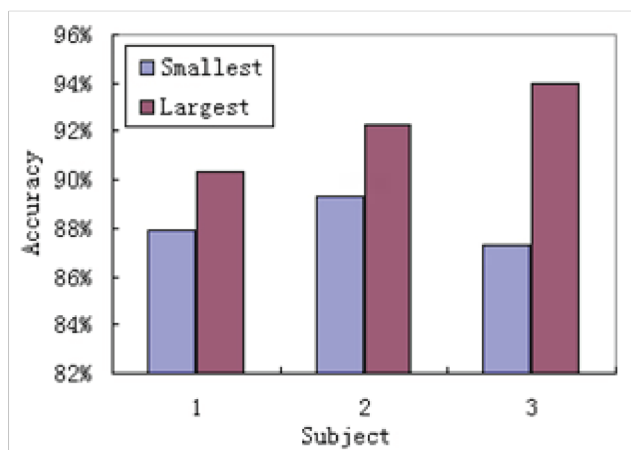


Figure 10. The largest and smallest classification accuracy.

Classification accuracy of different time windows is presented in Figure 11. For subject 1 and 3, the classification accuracy became larger and larger with the time window became longer and longer. It shows that the features of signal equally distributing on the time of 3-7th second.

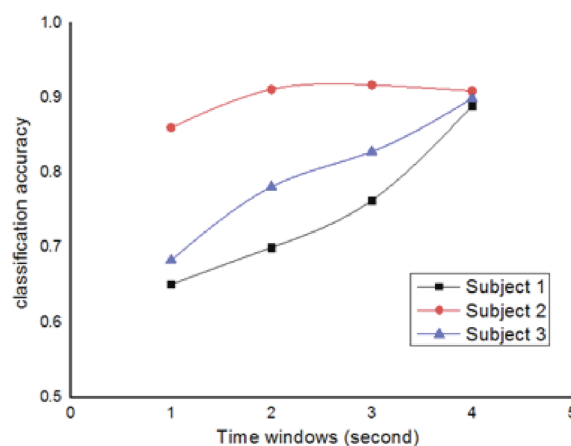


Figure 11. Different time windows classification accuracy

Before the real vehicle experiment, participants must accept the laboratory motor imagery control force test. The test by a motor imagery based on BCI Tetris game to.

The subjects control the movement of Tetris leftward or rightward movement and deformation through their own imagination. When the game player Tetris fall at the bottom of the screen, a new Russian box will appear at the top of the screen (the box on the left random graph). The right part of figure is the real-time display of the original EEG data and related parameters setting. As shown in the figure, motor imagery EEG signal acquisition, BCI only need C3 CZ, C4 three electrodes. Analysis of the module

Automatization

call signal module according to the returned result to determine the Tetris is left or right movement or deformation. Each 6S is a round, determine an imaginary type, a total of every imagination calculate 4 classification results using the most simple way, optimal,

ultimately determine the imagination type, if imagine types were not, does the deformation processing. The experimentally measured system response speed is 10 bit/min, the online EEG classification accuracy can basically stable at 90%~95%.



Figure 12. EEG training module

And then the real vehicle experiment, the system software interface as shown below:

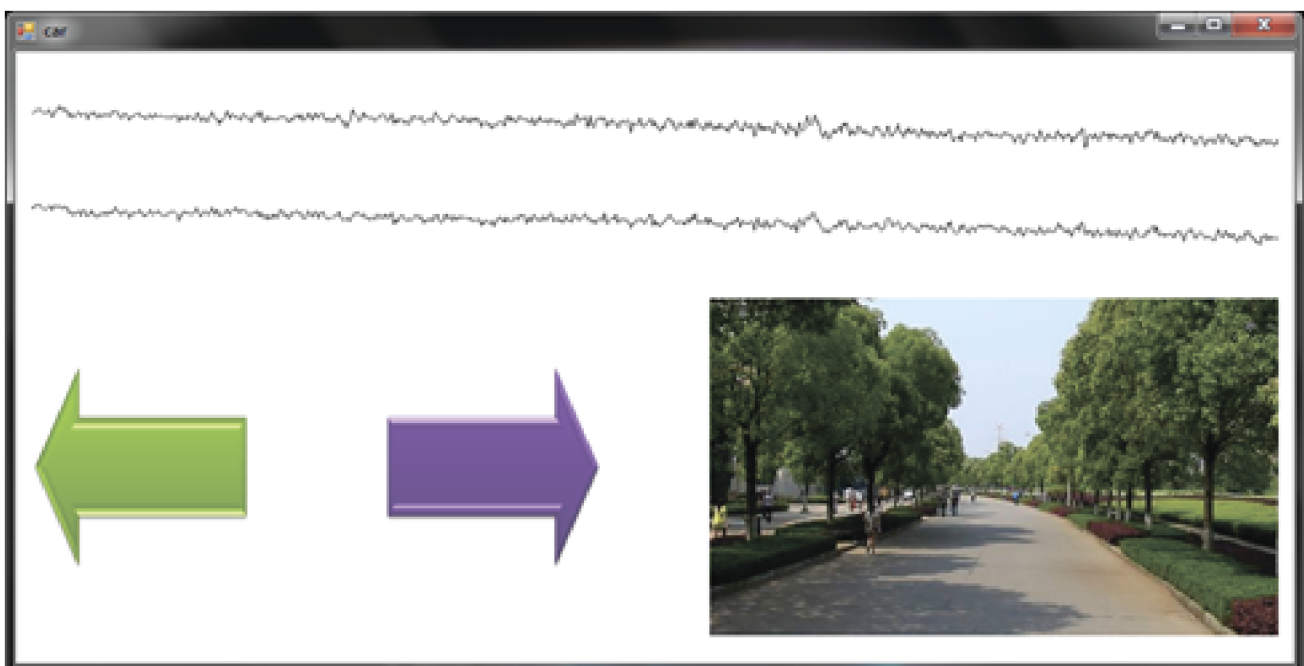


Figure 13. The running interface of BCI system

The top part of the interface is the EEG in real time, the left part of the following is the direction of the recognition results, and the right part is the front of the vehicle current view scene graph.

5. Discussion

This paper has demonstrated the development of

a new BCI-based electric cars controlling system. We proposed that the EEG recordings can be transformed to represent control signal, including four type of motor imagery: Left hand, right hand, legs and tongue. Sensor condition and adjustments of the EEG headset were critically important for successful system usage.

As the system presented in this project is BCI-based, it is especially suited for disable person, but a healthy person can use the system to intellectual exercise or entertainment. Based on our experience and feedback from the subjects we have tested, the control ability of the BCI system varies from subject to subject and some people finds it relatively uncomfortable to use the system for a longer period of time.

Compared with ordinary cars, the control of electric cars is relatively simple, only need about the direction and forward and stop the four variables. It needs neither the accelerator is not need to shift, not ordinary cars so complicated driving method. Considering the security related issues and brain machine interface response speed, we think the low-speed electric vehicles are more suitable to use brain machine interface to control. The main problems to be solved in the next step will be to improve the system for different subjects of adaptability and signal analysis and pattern recognition, anti-interference ability, shorten the user of the EEG samples learning time, reduce the external interference effects on brain electrical signal recognition accuracy at the same time, improve the stability of the whole BCI system.

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