Design and Experimental Research on EEG Control System of Unmanned Vehicle Based on Brain-Computer Technology

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ABSTRACT

The study on brain-computer interface technology to achieve the automatic control of unmanned vehicles can help people with disabilities to realize self-service travel, thus attracting more and more attention from scholars and manufacturers. In this paper, the visual evoked potentials of human brain are extracted by visual stimulator of FPGA, and the evoked potential vector by waveform matching recognition algorithm on Labview platform, which are used as the control signals of brain-computer interface to realize automatic control of unmanned vehicle. The article explains the basis of related technologies, based on which, the signal processing flow of unmanned vehicle control system is introduced. Finally, experiment on the automatic system control of unmanned vehicle based on visual evoked potentials is designed. The experiment shows that the average time for sending instructions is less than 3s, and the average correct recognition rate of instructions is higher than 90%. The present research has opened up the research on the brain-computer interface controlled unmanned vehicle field, and will have a positive effect for the ultimate realization of autonomous travel for patients with limited mobility.

Key Words: Brain-computer Interface, Unmanned Vehicle, Visual Evoked Potentials, FPGA, Labview

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Introduction

Statistics show that there are currently 16 million cerebral palsy brain atrophy patients worldwide, 5 million spinal cord injury patients, and 10 million patients with total paralysis caused by brain stem problems. At present, neuromuscular diseases such as stroke, muscle atrophy and amyotrophic lateral sclerosis, have shown an increasing trend of occurrence and have brought an adverse impact on people's lives. Due to the loss of brain's direct control over the muscles, the patient with brain or nerve injury have lost his functional abilities in language, walking, and regular movement, which has brought heavy burden for the patient himself and the society. In view of this, it is particularly important as how to help patients to realize autonomous travel.

At present, in the field of medical rehabilitation, the employment of brain-computer interface technology to effectively assist patients to communicate with the outside world and realize the ability of autonomous movement has become the focus of researches. In addition, the application value of brain-computer interface technology in other fields is also being explored, such as in surgical operation, remote military vehicle or aircraft control, games, human brain cognition, etc (Hoffmann *et al.*, 2008).

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In fact, the key of brain-computer interface technology is to realize the recognition and extraction of brain wave signals.But there are many kinds of brain waves, including brain wave potentials such as vision, hearing, touch, smell, etc., in which visual evoked potentials are the brain wave signals that are relatively easy to recognize (Blankertz *et al.,* 2007). VEP (Visual Evoked Potential) is the electrical response of the occipital cortex of the cerebral cortex to visual stimulation, and the change of the electroencephalogram potential generated by the retina receiving stimulation. SSVEP (Steady State Visual Evoked Potential) has the advantages of high information transmission rate, short training time and easy extraction, which is widely used in the input signals of human-computer interaction system (Nijboer *et al.,* 2008).

In this paper, SSVEP is extracted by visual stimulator of FPGA, the SSVEP feature extracted based on the transformation of waveform matching recognition algorithm, and the signal feature extracted on Labview, which has realized the transition from brain wave signals to digital signals of computer input (Di *et al.,* 2002; Li *et al.,* 2015). The unmanned vehicle control module can achieve the signal reception, wireless transmission and control, so that finally human brain can realize the direct control over the unmanned vehicle. Finally, the feasibility and stability of the automatic control system of unmanned vehicle are verified through experiments. The present research has opened up the research on the brain-computer interface controlled unmanned vehicle field, and will have a positive effect for the ultimate realization of autonomous travel for patients with limited mobility.

Theoretical basis

Brain-computer interface technology

Brain-computer interface refers to the pathway of communication and action control of “thinking into action” information established by human brain, computer or other electromechanical devices by means of computer engineering rather than going through the conventional brain information output path. There are two necessary conditions for the success of BCI technology, 1. The signal reflecting the state of human brain; 2. real-time or short-time signal classification and extraction (Qiu *et al*., 2014; Sellers *et al*., 2006; Wang *et al*., 2015).

The working principle of the brain-computer interface technology is to get the brain electrophysiological signals through various means, from which the data signal are obtained through amplification, filtering and analog-to-digital conversion, and then the characteristic quantity which reflects the user's intention is extracted through the correlation algorithm, and finally the characteristic quantity is converted into the external control command of the computer. The feedback link can provide the user with instructions to improve the accuracy of signal transmission and transmission speed (Santhanam *et al.,* 2006).

As shown in the structure diagram of BCI in Figure 1, the human brain’s control over automatic devices such as the external machines is realized through three main parts, including signal acquisition, signal analysis and controller, and feedback signals.

FPGA and Labview

(1)FPGA

FPGA, Field — Programmable Gate Array, is developed on various kinds of editor, which solves limitations of custom circuit and limited number of programmable logic gates. FPGA is a kind of semi-custom circuit with strong online modification ability, whose function is decided by the program of configuration. Different programming data of FPGA can produce different circuit functions, thus the design can be modified at any time without changing the hardware circuit (Cummings and Haruyama, 1999; Li *et al.,* 2016).

At present, there are many kinds of FPGAs, among which XC series of XILNX, TPC series of TI company and FIEX series of Altera company are the most commonly used. With the development of microelectronic technology, the cost of FPGA is more and more economical and the performance more and more superior. With high flexibility, programmability, reprogrammability and repeated operation, it is convenient for design, development and verification (Naouar *et al.,* 2007).

The research focus of this paper is the application and development of brain-computer interface, in which FPGA plays a key role. On the one hand, FPGA needs to import signals into Labview template to extract and feedback. On the other hand, FPGA provides a suitable signal processing algorithm to extract weak visual evoked potentials from EEG signals. Generally speaking, FPGA technology is the key to unmanned vehicle control system based on brain-computer interface technology.

(2) Labview

Labview, a software product of National Instruments in USA, has been a graphical and standardized platform for researchers in the design, virtual instrumentation, measurement, test and control industries since its founding in 1986. Labview has the following advantages.

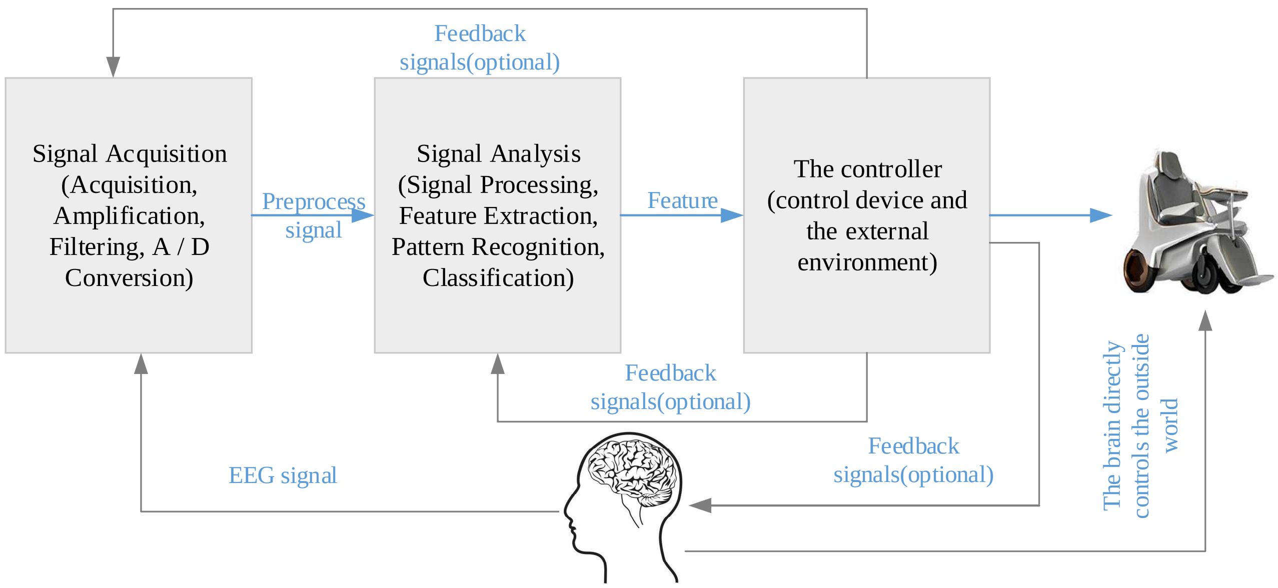

Figure 1. The structure diagram of BCI

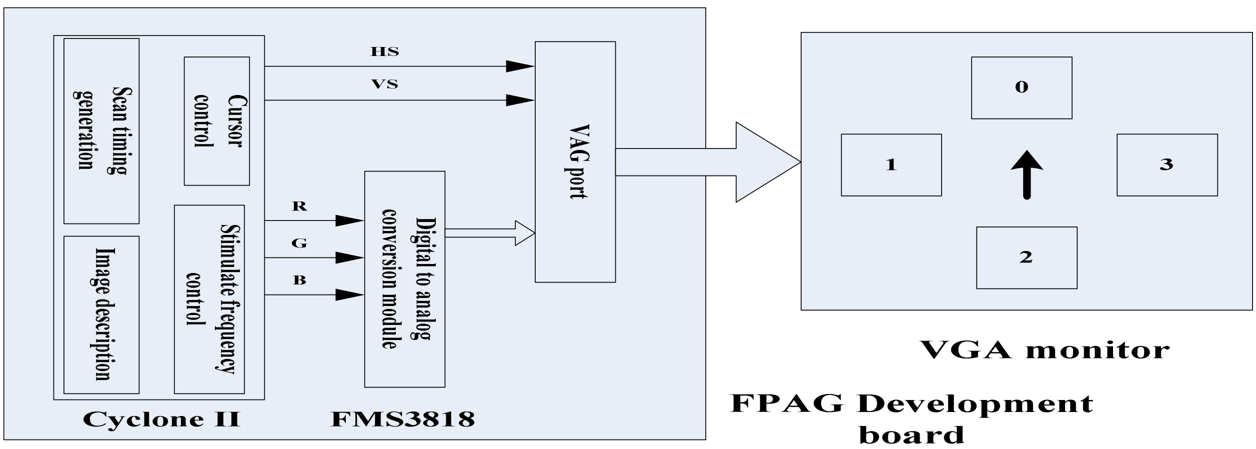

Figure 2. Diagram of VGA visual stimulator based on FPGA

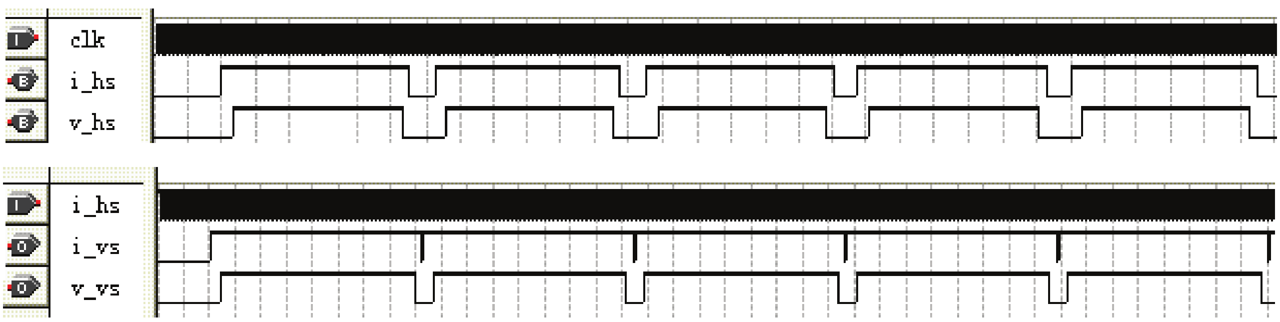

Figure 3. Stimulation figure of horizontal scan and vertical scan

1)It is intuitionistic, easy to learn and easy to use. Labview does not use the programming language code in the form of text, but uses the graphical G language to write the program, and replaces the traditional program code with the block diagram (Horng, 2008).

2) It is a universal program system. Although Labview uses a graphical programming mode, it still has the characteristics of a universal programming system. It has a large library of functions, where data acquisition, display, analysis, storage, GPB, serial control and other content can be called. In addition, Labview can continuously and dynamically track data changes, making it more efficient than other language environments.

3)Modularity. The basic nodes and functions of Labview all exist in the form of small modules. The program that it writes is a virtual instrument module, which can run independently or can be a subroutine of other programs.

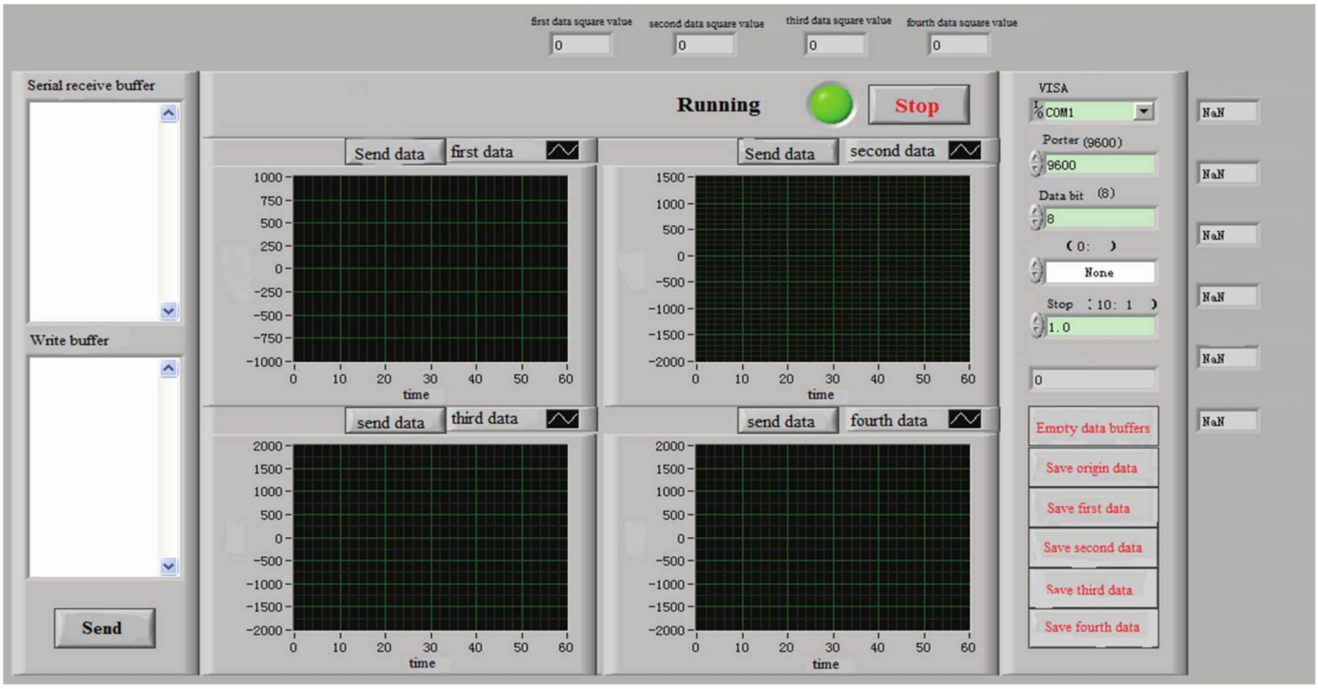

Figure 5. Example figure of real-time extraction template based on Labview

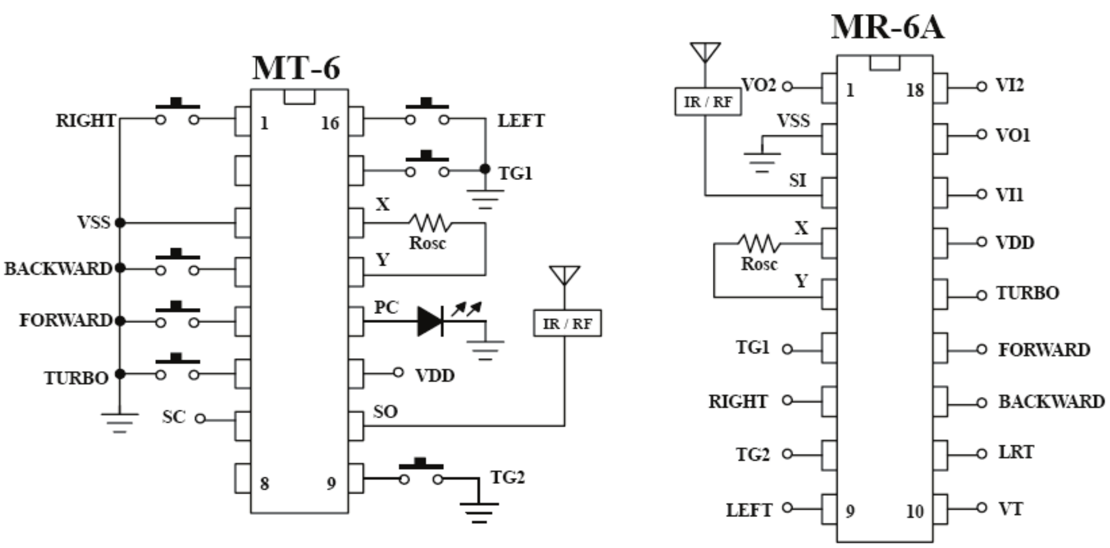

Figure 6. Circuit of MT-6 and MR-6A

Owing to these advantages, Labview has been widely used in design, production and control of aerospace, aviation, automobile, communication, semiconductor, electronics, biomedical and other fields.

Acquisition and Processing of Visual Evoked Points

Visual signal acquisition based on FPGA

With VGA liquid crystal display as visual stimulator, FPGA realizes the control over line synchronization signal and field synchronization signal through RGB signal synchronization. VHDL programming can generate visual stimulation signals.

As shown in the figure, four squares and one square mark form the stimulation graphics on the VGA display. The four squares respectively represent the front, back, left and right directions of the display, and the selected results are fed back through the movement of the cursor to the observed square (Imrek *et al.,* 2006). The VGA controller is composed of frequency division module, scanning timing generation module, image description module, stimulation frequency control module and cursor control module. Its basic steps are as follows:

(1) The scan timing generation module performs line scan and field scan to obtain a scan frequency of 59.94 Hz. As shown in Figure 3, the module includes i_hs line synchronization signal, v_hs line blanking signal, i_vs field synchronization signal and v_vs field blanking signal.

(2) The image description module produces stimulation graphics, checkerboard squares and directional arrows in four directions from top to bottom and from left to right of the screen. The square realizes the stimulation target of multiple target selection, and the cursor feeds back the selection result. The position and size of the square and arrow are described by line coordinates and field coordinates. Squares are marked with arrows to distinguish from each other. The change or movement of the graphics can cause an effective evoked potential, so the color of the squares is alternately changing between black and white (Robson *et al.,* 2006).

(3) The stimulator adopts the same frequency compound stimulation mode, thus the square is black when the clock is low level, and white when the clock is high level. The trigger signal is generated during the process of stimulating the module to change from black to white.

(4) The cursor control module describes the graphics of the cursor and controls its movement.

The FPGA-based VGA visual stimulator adopts synchronous timing control to design the VGA display control with low cost, easy modification and strong controllability, which realizes the collection of visual evoked potentials of human brain.

Visual signal processing based on Labview and waveform matching algorithm

(1) Model extraction of brain-computer interface based on Labview

1) Template extraction procedure

Wearing an electrode cap, the brain-computer experimenter is 65cm away from the VAG screen, with eyes staring at the center of the visual stimulator. The stimulator works simultaneously with the EEG acquisition circuit. After AD conversion, it is transmitted to FPGA, and then four sets of template data are obtained after accumulative averaging and FIR filtering. Virtual machine, Labview, extracts data templates in real time and feeds them back to FPGA in real time.

2) Design principles

With graphics extraction capabilities, and signal acquisition, data analysis, data display and other built-in functions, Labview can realize the communication between host computer and slave computer through VISA sub-module. In FPGA, the data template is introduced to the host computer, after being programmed by Labview, the data is received and processed by VISA serial port, and then returned to the FPGA as a discrimination template.

3) Labview real-time selection template interface

As shown in the figure, the real-time template selection interface based on Labview is divided into four parts, A: serial port receiving and sending buffer; B: waveform real-time display; C: data storage; D: correlation coefficient calculation (Yu *et al.,* 2017).

Labview integrates the EEG signal acquisition, data analysis, data processing and data functions, which has high processing efficiency and improves the real-time performance of the brain-computer interface application system, laying a foundation for the data processing of unmanned vehicles.

(2) Waveform matching recognition algorithm
In order to effectively recognize and discriminate the visual evoked potentials (VEP) from the EEG signals, the signal highly matching with the standard visual evoked potential is selected as the discrimination signal, as the higher the similarity is, the more probably the potentials will be evoked (Qiu *et al.,* 2002).

The vectors of the model to be identified X and the standard VEP sample, M, are set as follows.

$$X = \{x_1, x_2, \dots, x_n,\} \quad (1)$$

$$M = \{m_1, m_2, \dots, m_n,\} \quad (2)$$

The correlation coefficient, ρ_{xy} may also be referred to as similarity, and the closer its value is to 1, the more similar the two models will be. The calculation method of the correlation coefficient is as shown in Formula 3(Hou and Bose, 2002).

$$\rho_{XM} = \frac{cov(X,M)}{\sqrt{D(X)}\cdot\sqrt{D(M)}} \quad (3)$$

Set the constant σ as a threshold value, and 0<σ < 1. It is determined that the model X to be recognized may be an evoked potential signal only when ρ_{XM} is greater than the threshold value, and otherwise it is not, and will not be processed.

The correlation coefficient is discretized and then introduced into FPGA for implementation. Calculation method for discrete sequence correlation coefficient is as shown in Formula 4.

$$\rho = \frac{cov(X,M)\sum(x-\bar{x})(m-\bar{m})}{\sqrt{\sum(x-\bar{x})^2}\cdot\sqrt{\sum(m-\bar{m})^2}} \quad (4)$$

x is the data obtained in real-time processing, and m the template data, and $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $\bar{m} = \frac{1}{n}\sum_{i=1}^{n} m_i$. First calculate the value of m-$\bar{m}$ and store it in RAM; And calculate the value of $\sqrt{\sum(m-\bar{m})^2}$, and deliver it to the divider. Only a MAC multiply adder is needed for calculating $\sum(m-\bar{m})^2$ and $\sum(x-\bar{x})(m-\bar{m})$.

Algorithm flow. FPGA conducts time domain feature search on the input of a group of EEG waveform data that is to search for specific peaks and troughs. First, the minimum value and the maximum value are obtained to determine whether the peaks and troughs are in a specific domain. If they are, that is, when the time-domain feature is in the incubation period (the minimum value is [20,35] and the maximum value [30,50]), the output discrimination signal will be high level. If they are not, the data are not determined as VEP signals. If they are in the specific domain, they are discriminated in parallel with the calculated correlation coefficient, when the correlation coefficient is greater than the set threshold value and the time domain discrimination signal is high level, then they will be judged as a VEP signal; otherwise, they are not(Wang *et al.,* 2010). The corresponding control command output upon the EEG signals, control the display cursor, and at the same time, FPGA output control signals control the movement of the carriage in the corresponding direction.

Implementation and Experimental Analysis of EEG Signal Control

Implementation of brain-computer interface control

Since wireless remote control is required between the computer and the unmanned vehicle, wireless remote control technology shall be needed to receive signals from the FPGA via the integrated circuit board. MT6 is chosen as the signal encoder of FPGA, MR-06A as the decoder of unmanned vehicle, and their circuit diagram is shown in Figure 6.

For example, when the value of the pattern recognition Vga _ sel after recognition and signal processing by FPGA waveform matching algorithm is 000, it indicates that the experimenter looks at the first target module; when its value is 001, the experimenter looks at the second target module; when its value is 010, the experimenter looks at the third target module; when its value is 011, the experimenter looks at the fourth target module; when its value is 111, it means annotation mode. These numerical information generate the control level for controlling the unmanned vehicle through the encoding module, and its corresponding high-low level signal output is Vga _ sel: 001 = 11111010, 010 = 11111100, 011 = 11011101, and 111 = 111111111, in which 11011011 controls the forward movement of the unmanned vehicle, 11111100 the rightward movement, 11011101 the backward movement, and 11111111 indicates that the unmanned vehicle does not move.

Experimental analysis of brain-computer interface

The brain-computer interface control system based on FPGA has been constructed

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theoretically, but its feasibility needs to be verified through experiments.

(1) Experimental purpose

The experiment mainly purports to verify whether the evoked potential produced by visual stimulator is obvious, the real-time property of Labview in extraction and processing signal, and the success rate of controlling the output and reception of signals.

(2) Experimental design

Five students aged from 23 to 26 were selected as experimental subjects, including 2 males and 3 females. The experimenter installed EEG signal according to international standard for potential acquisition in front of VGA liquid crystal display. Each of the 5 subjects was tested 4 times, and each time the subject gazed at the display target 4 times, with a total of 16 times.

(3) Analysis of experimental results

Table 1 shows the experimental results of controlling the unmanned vehicle by obtaining the visual evoked potentials of the VGA stimulator that performs the cumulative evaluation 20 times.

As shown in Table 1, the average success rate of 5 subjects' instructions being sent is higher than 90%, and the average time for acquiring, processing, transmission and controlling of EEG signals is less than 3 seconds. The experiment shows that the visual evoked potential of EEG collected by VAG stimulator has a high recognition rate, and the signal extracted and processed by Labview template has a better real-time performance. In addition, the average success rate of EEG control for unmanned vehicle control is higher than 90%. That the design of the system meets the requirements of real-time and accuracy, is beneficial to the practical application of brain-computer technology.

Table 1. The experiment results of brain-computer interface experiment

Subjects Name	Cumulative average number=20		Accuracy	Instruction Sending time
	Correct judgments	Incorrect judgments		
Liuxiaoping	15	1	93.75%	2.1s
Fangfang	14	2	87.50%	2.4s
Yangyu	15	1	93.75%	2.5s
Zhaoyi	14	2	87.50%	2.7s
Huzhaoyang	15	1	93.75%	2.6s

Conclusions

Brain-computer interface technology is about direct interaction between the human brain and the machine, which has been gradually applied in medical rehabilitation, military, aviation unmanned fields and other fields. This article aims to study the control of unmanned vehicles through brain-computer technology. In the paper, the application of computer technology and research background are firstly introduced, then the procedure and principles of acquisition, processing and control of EEG are analyzed in detail, and finally, the effect of brain computer technology is verified through experiments. The main contents and significance of this article are as follows:

(1) Adopting steady-state visual trigger signal as EEG control signals has improved the success rate of EEG signal extraction.

(2) The use of FPGA and Labview enhances the speed and accuracy of signal processing, and the rate of brain signal filtering is improved through waveform recognition algorithm. Experimental results show that EEG control signal controlling unmanned vehicle has a high success rate and timeliness.

(3) The research in this paper provides practical guidance for the application of brain-computer technology in the field of actual unmanned control, and has positive significance for promoting the popularization and development of brain-computer technology in China.

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