



# Design and Implementation of Real-time Brain-computer Interface System Based on LabVIEW

Chang Liu

## ABSTRACT

Brain-computer interface (BCI) is a newly developed man-machine interface method that is applied in the field of brain science, rehabilitation engineering, biomedical engineering and human-machine automatic control. Under the LabVIEW environment of virtual instrument graphical programming language, this paper improves the program of Active One, a physiological signal acquisition system. The off-line processing system of electroencephalogram (EEG) is improved to a real-time processing system and a real-time feedback BCI experiment system is established based on visual evoked potential (VEP). The cumulative average method combined with the FIR filter method was used to extract the VEP signal and form a closed-loop BCI. Real-time feedback of the BCI system was realized and the VEP signal was automatically identified. Using the proposed method of this paper to implement BCI can achieve a higher accuracy with certain practicality and feasibility.

**Key Words:** Brain-computer interface (BCI), Visual evoked potentials (VEP), LabVIEW, Signal Processing

**DOI Number:** 10.14704/nq.2018.16.3.1200

**NeuroQuantology 2018; 16(3):97-104**

97

## Introduction

The brain-computer interface (BCI) is a direct connection between a human or animal brain (or culture of brain cells) and external devices, which can directly conduct some external activities according to the signals from the brain. Prior to this, a research team at Tsinghua University developed a series of internationally advanced methods for signal processing and pattern classification, they used this series of methods to successfully implement the BCI for real-time brain activity cortical signal interpretation (Mohy *et al.*, 2011; Andruseac *et al.*, 2016; Kotchetkov *et al.*, 2010; Qiu *et al.*, 2014). This technology will greatly expand the ability of people to control the exchange of information from the outside world and thus lead to the revolution of the traditional information exchange means between the human brain and the outside world (Kübler, 2013; Reilly *et al.*, 2008). At present, the research of BCI is still in developing, its application in practice is still

facing some problems. For example, the identification accuracy and speed needs further improvement, the signal acquisition and processing methods also need to be further improved, the instantaneity, stability, flexibility and usability needs to be further optimized. This paper's design is based on the LabVIEW-based real-time BCI system; it can solve the above problems to a certain extent and promote the development of the potential application value of the technology.

## Related theoretical research

### *Brain-computer interface concept*

The Brain-computer interface (BCI) is a completely new way of human-machine interfaces. It is defined as follows: it is a brain-computer (computer or other equipment) communication system with no relation to the normal brain output channels (peripheral nervous system and muscle tissue) (Zhong *et al.*,

**Corresponding author:** Chang Liu

**Address:** College of Electrical and Information, Heilongjiang Bayi Agricultural University, Daqing 163319, China

**e-mail** ✉ beginthd@163.com

**Relevant conflicts of interest/financial disclosures:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Received:** 1 February 2018; **Accepted:** 25 February 2018



2008; Faraco and Gabriele, 2007; Kullmann *et al.*, 2004). The implementation conditions are: (1) It need relevant signals to represent the thinking of the brain; (2) The signal acquisition needs to be real-time and has high efficiency; (3) The signal can be effectively classified.

### Virtual Instrument - Features and Applications of LabVIEW

Virtual Instrument is a data acquisition system. It is computer-based and can be reasonably organized according to the actual situation of the instrument, which is based on the theory of computer information collection and digital signal processing (Chouder *et al.*, 2013; Salehi and Brandt, 2006; Dierick *et al.*, 2004). What's currently widely used is the laboratory virtual instrument integration environment, namely the Laboratory Virtual Instrument Engineering Workbench, or LabVIEW for short, which is a graphical programming language that can be viewed as a standardized data acquisition and instrument control software. LabVIEW relies on visualization technology (WYSIWYG, what you see is what you get) for human-machine interfaces. Users can directly invoke internal functions libraries, run 32-bit programs based on a compiled model which is compatible with several system platforms, in structure, LabVIEW exhibits hierarchical features (Pfurtscheller *et al.*, 2008; Russo *et al.*, 2002) and is widely used in many areas to ensure development efficiency.

### Visual evoked potentials (VEP)

When BCI is studied based on VEP, the VEP signals can be obtained from background EEG signals by signal processing.

#### (1) Evoked potential signal extraction method

In this paper, we process the evoked potential signals by the cumulative average method, matching with the narrowband FIR filter, which can both improve SNR(Signal to Noise Ratio) and avoid multiple cumulative average, so that all aspects of BCI system (communication speed, accuracy) would be guaranteed.

Narrowband FIR filter enables fast downsampling and interpolation (Jansen and Rit, 1995; Clark and Hillyard, 1996). The system given in Figure 1 cascades the M-times downsampling with the interpolation.

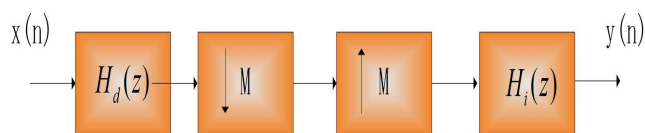


Figure 1. The filter based on downsampling and interpolation

We can easily obtain the relation between the Fourier transform of  $y(n)$  and  $x(n)$  as:

$$Y(e^{j\omega}) = \frac{H_i(e^{j\omega})}{M} \left\{ \sum_{k=0}^{M-1} X(e^{j(2-2\pi\frac{k}{M})}) H_d(e^{j(2-2\pi\frac{k}{M})}) \right\} \quad (1)$$

Assuming that the downsampling filter  $H_d(z)$  and interpolation filter  $H_i(z)$  are properly designed so that the spectral continuations in the above formulas cancel each other out, then we get:

$$\frac{Y(e^{j\omega})}{X(e^{j\omega})} = \frac{H_d(e^{j\omega}) H_i(e^{j\omega})}{M} = H(e^{j\omega}) \quad (2)$$

According to the equation, when both filter bandwidths of interpolation and downsampling are lower than  $\pi/M$ , then the cascaded system in Figure 1 is equivalent to the two filter cascades. This structure can significantly reduce the using frequency of multiplier.

#### (2) VEP identification method

From the perspective of BCI application, in order to ensure the normal communication and control of human brain and outside world, it is necessary to convert the EEG signals into a plurality of control commands. In other words, EEG signal patterns need to be identified and classified to obtain control instructions. For visual evoked signals, since using template matching method cannot complete the pattern identification, we select an identification method based on time domain waves.

Assuming a to-be-identified pattern X, and a standard VEP sample vector M are:

$$\begin{aligned} X &= \{x_1, x_2, \dots, x_n\} \\ M &= \{m_1, m_2, \dots, m_n\} \end{aligned} \quad (3)$$

The correlation coefficient  $\rho_{xy}$  is a quantity value, which can accurately represent the waveform similarity between different signals. It's normal value interval is:  $|\rho_{xy}| \leq 1$ . The related algorithm is as follows:

$$\rho_{XM} = \frac{\text{cov}(X, M)}{\sqrt{D(X)} \cdot \sqrt{D(Y)}} \quad (4)$$

Where  $\text{cov}(X, M) = E[(X - E(X))[M - E(M)]]$ ,  $\text{cov}(X, M)$  is the covariance of X and M,  $D(X) = E[X - E(X)]^2$ ,  $D(M) = E[M - E(M)]^2$ , are the variance of X and M, respectively.

The discriminant function is:

$$g(x) = \rho_{XM} - \sigma \quad (5)$$

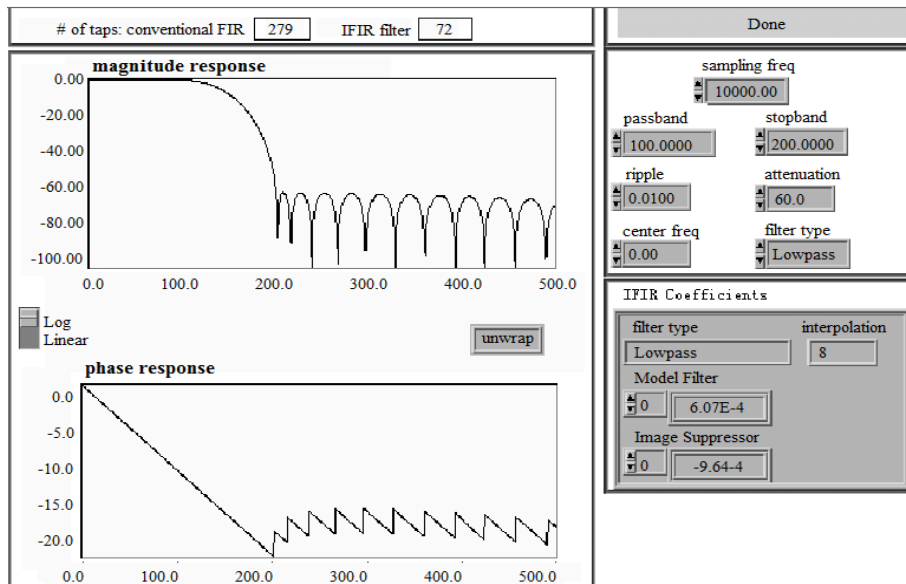
The above equation is a linear discriminant function, where  $\sigma$  represents a threshold constant.

When  $g(x) \leq 0$ , the to-be-recognized pattern X is not a VEP signal;  $g(x) > 0$ , the to-be-recognized pattern X may be a VEP signal.

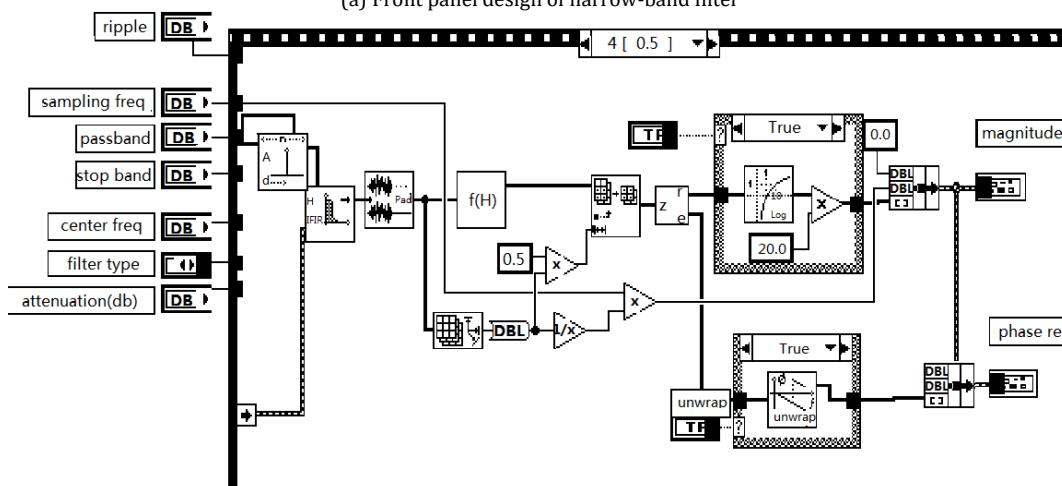
According to the time-domain waveform correlation coefficient method, the discrimination is easy and the operation is convenient, just in line with the real-time BCI system pattern identification requirements.

### Implementation of filter design in LabVIEW

To design real-time BCI system based on LabVIEW, we must first design the key parts, namely using LabVIEW to build the filter. According to the requirement, we choose FIR narrow-band filter and input the pulse sequence. Details are in Figure 2:



(a) Front panel design of narrow-band filter



(b) Rear panel design of narrow-band filter

Figure 2. The design of FIR narrowband

Front panel provides filter parameters, traditional and narrowband FIR filter order and other information under the same situation; the rear panel provides the design code. During practical operation, we should pay full attention to the following parameters to ensure these are reasonable parameters, detail description is as follows:

Ripple (rp): Passband Ripple (maximum attenuation), the normal default value is 0.01dB.

Sampling freq (fs): sampling frequency, should be  $\leq 0$ . The normal default is 1.0Hz. If  $\leq 0$ , the IFIR coefficients are empty and provide invalid information.

Stopband (fstop): stopband cut-off frequency, the normal default value is 0.02Hz.

Center freq (fc): Center frequency, the normal default generally takes 0.01Hz.

X: target signal sequence (should be filtered).

Filtered X: Filter sample output array.

Error: Generate VI errors and warnings.

When the technical indicators are unified, the filter lengths of the traditional filter and the narrow-band FIR filter are 279, 72 respectively. On the one hand, it can bring more reliable EEG signals to the BCI signal processing, on the other hand, it can save signal filtering time and ensure the efficiency. Moreover, introducing existing digital filter subroutine directly into LabVIEW can both simplify the filter design process and improve work efficiency, which is of great significance.

### Real-time feedback BCI system construction

In the past, the signal acquisition system could only process EEG off-line, but the result could not be sent to the subject in real time. Designing a closed-loop system to satisfy real-time processing needs while providing the results to the subjects at the same time, we must take the BCI application system as the prerequisite, then perfect and strengthen it via various optimization.

### Human-machine interface (HMI)-visual stimulator design

Using LabVIEW software programming and combining BCI application requirement and user-related issues, we designed the visual simulator as follows, details are in Figure 3:

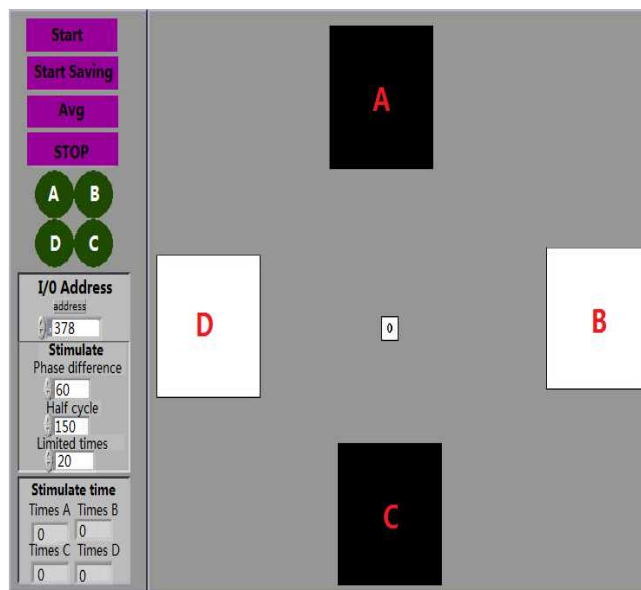


Figure 3. The front panel of visual stimulator

On the screen, A, B, C, and D modules are all the subjects' choices, which causes the visual stimuli by constantly blinking. To distinguish the stimuli brought by each target, there are obvious differences in the blinking moment of the module, the whole process relies on the same frequency compound stimulus (with a fixed sequence). Taking into account the BCI experiment standards, parameters can be adjusted on the stimulus interface. According to relevant requirements, the unit time as a prerequisite to determine the number of flashes, the module color and so on.

For a dual computer system, a single computer system needs to be properly optimized to facilitate normal communication between the two programs of signal acquisition processing and visual stimulation. The latter is defined as a HMI, which not only can effectively control the acquisition program, but also can directly transfer the results to the stimulus interface.

In the rear panel block diagram program of the visual stimulator, there are following LabVIEW applications:

(1) Parallel mechanism: LabVIEW relies directly on the data stream to call programs. In short, in order to ensure the stable operation of function nodes, various data needs to be obtained, and the flickering of different modules depends on the parallel structure, the blinking of each module does not affect each other, and they always have a fixed sequence.

(2) Timing function: LabVIEW brings a series of time function nodes based on Time &

Dialog, such as Wait (ms), Wait Until Next ms Multiple, etc., 1ms precision can be achieved.

(3) Parallel output: for LabVIEW 7.1 function panel, the “Advanced” and “Port I/O” option panel have two node functions (“In Port” and “Out Port”), which can be used to access the Windows bottom port address, in this premise, it can also complete related operations of computer parallel ports.

*Design of real-time processing physiological acquisition measurement system*

During the operation of the BCI system, signal processing can be completed and feedbacked to the subjects in a corresponding manner so as to establish a closed-loop system and improve the response ability of the subjects. To achieve this goal, we need to equipped with a corresponding acquisition system so as to satisfy signal real-time processing requirement. In this paper, we adjusted the program of the Active One physiological signal acquisition system, after effective adjustment, it can both process real-time signals and feedback the results to the subjects. Compared with early off-line processing model, the effect is more significant, and it can be used in more fields. After the adjustment we can get following system block diagram as shown in Figure.

To ensure the EEG signals are processed in real-time, a stable differentiation of evoked potential signals should be achieved through long data. Therefore, for real-time processing program, we can use the cache to obtain a long data, the cache is often set according to demand, and it can be called directly as a subroutine. See Figure 5 for single cache implementation codes.

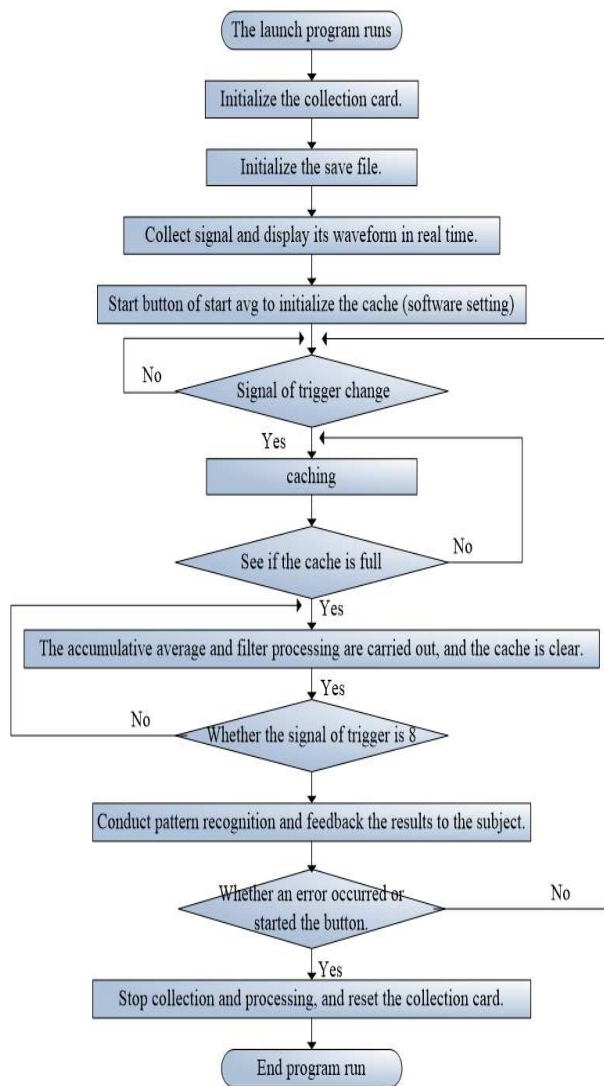


Figure 4. The diagram of the real-time feedback Active One

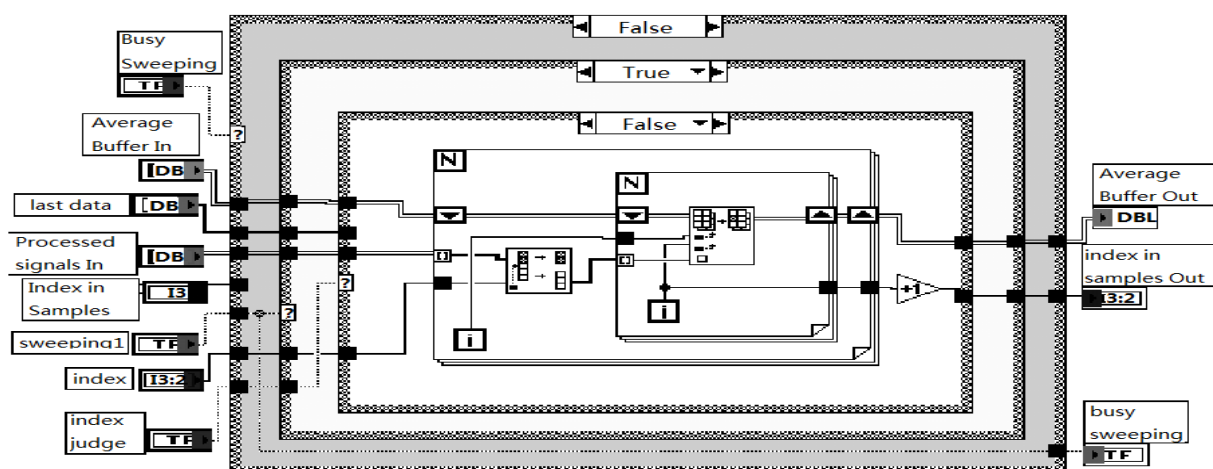


Figure 5. The code of data buffer



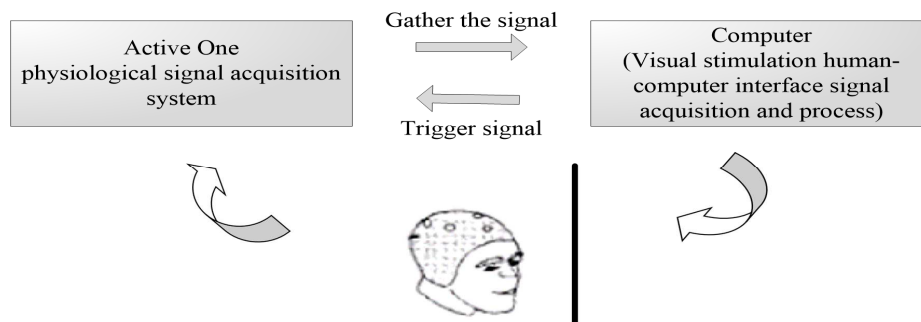


Figure 6. The diagram of the experiment system

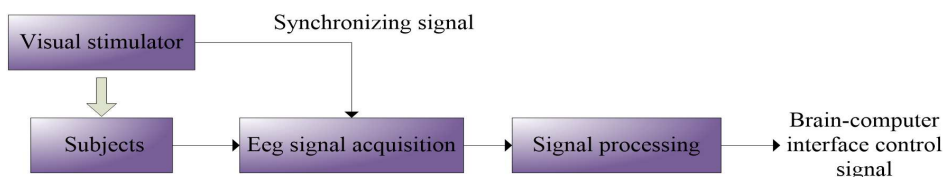


Figure 7. The diagram of BCI experiment

When subjects were observing visual stimuli interface modules, there will be EEG signals. But the trigger signal is different, it needs to take the moment of stimulation modules turning white as the prerequisite, and can be obtained only when using the visual stimulus program related modules to write data for the computer parallel ports. When triggering the signal judgment procedure, we must follow below criteria to determine whether there's new states: if a data is different from the data in the previous bit, and is the same with data in the next bit, then the trigger signal changes the state, and a new state appears, then input this bit of data, and determine the cache that need to be run. If the trigger signal state corresponding to the number of the module blinking that need to perform, and we can write data to the computer parallel port, in this case, the pattern identification of the EEG (with repeated accumulative averaging and filtering) can be realized to confirm the target of the subject, and then the results are transmitted to the visual stimuli interface.

**Real-time feedback of BCI experiment system construction**

In this paper, Active One physiological signal acquisition system (which can meet the real-time processing requirements of EEG signals) is combined with a computer to obtain real-time feedback BCI experiment system.

Basic functions of the computer are as follows: First of all, it can provide BCI visual stimulator, through software programming, we can get the required series of visual stimulation mode; Second, the signal acquisition and processing, for the acquisition system, the receiver, interface board, and software were all setup into the computer.

To dynamically record the visual stimulus trigger time, the parallel outputs and the Active One trigger inputs must be linked together. In this case, the EEG signals and trigger events can be recorded together. If we implement the visual stimulator basing on LabVIEW to setup the single computer system, in this case, the number of devices will be streamlined accordingly, thus further reducing the experimental complexity.

**BCI experimental research**

By constructing BCI experimental system and discussing VEP extraction and identification method, in these premises, we need to conduct visual stimulus and BCI experiment, use experiments to comprehensively analyze BCI communication speed, accuracy and other relevant factors, then achieve the research purpose and complete the study and discussion according to the results.

9 subjects (7 males and 7 females) were selected as experimental targets and were aged from 24 to 45 years old. See Figure 7 for details.



**Table 1.** Results of the BCI experiments

Subject	The cumulative average=25		The cumulative average=18	
	Number of correct judgments	Number of correct judgments	Number of correct judgments	Number of correct judgments
	Look at target	Ignore the target	Look at target	Ignore the target
Q	12	6	10	6
S	12	6	10	6
H	11	6	10	6
F	10	6	9	6
X	10	6	9	6
W	8	5	7	6
L	7	6	7	6
Y	7	6	6	6
Z	2	6	2	5
Subject	The cumulative average=13		The cumulative average=9	
	Number of correct judgments	Number of correct judgments	Number of correct judgments	Number of correct judgments
	Look at target	Ignore the target	Look at target	Ignore the target
Q	10	6	10	6
S	10	6	10	6
H	10	6	8	6
F	7	6	4	6
X	6	6	4	6
W	6	6	4	6
L	4	5	3	6
Y	4	6	2	6
Z	1	6	0	6

This study completes a series of BCI experiments, during which there are "A", "B", "C" and "D", four stimulation modules in the visual stimulation interface, all cycles are 300ms. The subjects can visualize the specific stimuli in the screen according to the experimental conditions or personal preference, and observe the corresponding time, when the beep sounds, an experiment is over. Then wait for about 2 seconds, the subject can continue to observe next stimulation target. According to above procedure, the subject directly observes the selected target and continuously output the control command by BCI system, thereby changing the corresponding state of the external device.

According to the results, when there are four modules appear on the screen at the same time, the VEP signal is generated regardless of which module the subject observes. If there is only one single stimulation module (the same size) on the screen, the VEP signal can also be obtained, but by comparison, the latter case gets a larger signal.

Table 1 shows the experimental results of BCI. There are 9 subjects in total. During the whole process, the blinking period of visual module is 300ms. During the signal processing, the cumulative average successively selects 25, 18, 13 and 9 times. According to the resolution accuracy, the experimental results can be divided into three categories: good, average, bad. Combining with the data provided in the table we

can see that the first five results are good, if the cumulative average is 25 times, the BCI control accuracy is more than 80%, the results of the 6th and 7th and 8th were average, and the correct rate of control reached over 50%; the result of the 9th was bad and the correct rate of control is less than 20%.

It can be seen that the main factors that affect the experimental results of BCI are: (1) the design of BCI experimental system and signal processing algorithm; (2) the ability of subjects to use the BCI; (3) the mental state of subjects.

**Table 2.** Information transfer rate in the BCI experiments (bit/min)

Subject\Average time	N=25	N=18	N=13	N=9
Q	16.00	12.07	16.71	24.13
S	16.00	12.07	16.71	24.13
H	11.64	12.07	16.71	12.22
F	8.80	8.81	5.69	0.66
X	8.80	6.11	3.23	0.66
W	4.40	4.11	3.23	0.66
L	3.00	4.11	0.46	0
Y	3.00	2.33	0.46	0
Z	0	0	0	0

After calculating the number of single-trial bits of the BCI, the theoretical value of the communication rate (the number of bits per minute) can be obtained according to the blinking period of the module and the accumulated average value. For details, see Table 2, where N represents the accumulated average number of times.

According to the results of bit rate calculation, it is not difficult to find that when the subjects such as (Q, S, H) conduct experiments,



the communication rate is obviously higher if the cumulative average number of times is very small. From the majority of subjects' perspective, if the cumulative average is 25 or 18, the communication rate can be guaranteed to achieve the desired level. Taking multiple factors into consideration, we can get following conclusion that if most subjects' average cumulative number are 18, it not only can ensure the BCI communication rate to meet the requirements, but also can promote more reliable BCI, and the effect is quite significant.

### Conclusion

(1) In this paper, a computer monitor is used as a visual stimulator to generate graphical stimuli signals through LabVIEW software programming, which can flexibly generate different stimulation modes for modification and upgrading, and can simplify the previous dual computer experiment system into a single computer experiment system. (2) This paper uses a cumulative average method combining with the FIR filter method to extract the VEP signal, which effectively improves the signal to noise ratio, reduces the cumulative average number of times, thus improves the communication rate and accuracy of the BCI system. (3) The physiological signal measuring system was improved to achieve the real-time processing acquisition system, and the result of discrimination was fed back to the subject, which realized real-time feedback of BCI system. (4) The BCI experiment results of the 9 subjects showed that the BCI proposed in this paper can achieve a high accuracy. Experiments show that the BCI visual stimulator and the design of the experiment do have certain practicality and feasibility.

### Acknowledgement

The work was supported by projects of Heilongjiang Bayi Agricultural University "XDB2014-18" and "NDJY15Z13".

### References

Andruseac GG, Paturca SV, Banica CK, Costea IM, Rotariu C. A novel method of teaching information technology

- applied in health monitoring. *Journal of Biotechnology* 2016; 239: 1-3.
- Chouder A, Silvestre S, Taghezouit B, Karatepe E. Monitoring, modelling and simulation of pv systems using labview. *Solar Energy* 2013; 91(3): 337-49.
- Clark VP, Hillyard SA. Spatial selective attention affects early extrastriate but not striate components of the visual evoked potential. *Journal of Cognitive Neuroscience* 1996; 8(5): 387-402.
- Di Russo F, Martínez A, Sereno MI, Pitzalis S, Hillyard SA. Cortical sources of the early components of the visual evoked potential. *Human Brain Mapping* 2002; 15(2): 95-111.
- Dierick M, Masschaele B, Van Hoorebeke L. Octopus, a fast and user-friendly tomographic reconstruction package developed in labview. *Measurement Science & Technology* 2004; 15(7): 1366-1370.
- Faraco G, Gabriele L. Using labview for applying mathematical models in representing phenomena. *Computers & Education* 2007; 49(3): 856-72.
- Jansen BH, Rit VG. Electroencephalogram and visual evoked potential generation in a mathematical model of coupled cortical columns. *Biological Cybernetics* 1995; 73(4): 357-66.
- Kotchetkov IS, Hwang BY, Appelboom G, Kellner CP, Jr CE. Brain-computer interfaces: military, neurosurgical, and ethical perspective. *Neurosurgical Focus* 2010; 28(5): E25: 1-6.
- Kübler A. Brain-computer interfacing: science fiction has come true. *Brain* 2013; 136(6): 2001-04.
- Kullmann PH, Wheeler DW, Beacom J, Horn JP. Implementation of a fast 16-bit dynamic clamp using LabVIEW-RT. *Journal of Neurophysiology* 2004; 91(1): 542-54.
- Mohy-Ud-Din Z, Sang HW, Lee JH, Lee MG, Kim JH, Jin HC. Pleasure detection by online brain-computer interface. *Measurement* 2011; 44(1): 121-28.
- Pfurtscheller G, Mllerputz GR, Scherer R, Neuper C. Rehabilitation with brain-computer interface systems. *Computer* 2008; 41(10): 58-65.
- Qiu ZC, Zhang WM, Guo Y, Qin F, Yue MM. Effect of external field on the variation of magnetic memory signals, *Mathematical Modelling of Engineering Problems* 2014; 1(1): 1-4.
- Reilly RB, Reilly RB, Leeb R, Hirose M, Slater M. Brain-computer interfaces, virtual reality, and videogames. *Computer* 2008; 41(10): 66-72.
- Salehi D, Brandt M. Melt pool temperature control using LabVIEW in Nd: YAG laser blown powder cladding process. *International Journal of Advanced Manufacturing Technology* 2006; 29(3-4): 273-78.
- Zhong M, Lotte F, Girolami M, Lécuyer A. Classifying EEG for brain computer interfaces using gaussian processes. *Pattern Recognition Letters* 2008; 29(3): 354-59.

