Psychological Test System and Signal Processing Algorithm for Intelligent Wheelchair

Binfeng Xu¹,* and Yarong Hu¹
¹Guangdong food and drug vocational college, Guangzhou, China

*Corresponding author e-mail: xubf@gdyzy.edu.cn

Abstract. Intelligent wheelchair based on BCI is a hot spot in recent research, and brain activity is actually a reflection of psychological activity. Completing the design of psychological test system is the key to BCI. ERP reflects the psychological activity of the brain, is a psychological test good tools such as cognitive neuroscience research. And there is psychological test system is mostly based on the traditional theory of external behavior inference, unable to objectively evaluate people's psychological activity. In the study of psychological tests and event related potential theory, the article improved FastICA algorithm, and applied to feature extraction of ERP. Eventually set up a complete set of psychological test system. Experiments show that the system can effectively detect the ERP feature extraction, and faster, better than other conventional psychological test system. So as to lay the foundation for the completion of the design of Intelligent wheelchair.

Keyword: Intelligent Wheelchair, BCI, Fastica, Psychological Test

1. Introduction
The aging of the global population and some new diseases have caused more and more people to lose their ability to walk on their own. Smart wheelchair is a service robot that can be used as a mobility tool for the elderly and disabled. After research, it is feasible to use EEG to operate smart wheelchairs, and brain activity is actually a reflection of psychological activity. Human psychological phenomena are one of the most complex and subtle phenomena in the universe. Brain cognition is the science of studying psychological phenomena. Psychological testing and brain function evaluation have applications in many aspects, such as brain disease diagnosis, drug treatment effect evaluation, and children's intelligence evaluation. Psychological testing also provides a reference method for brain cognitive assessment [1].

Based on the test theory of event-related potential (ERP), this paper designs a more complete psychological test system. In the design and research of the system, we optimized the FastICA algorithm and obtained an improved algorithm, which reduced the sensitivity to the initial weights and the number of iterations, thereby increasing the convergence speed of the algorithm. In the experimental application stage, we try to test the psychological system with traffic lights and voice, which can effectively generate characteristic waveforms, which will help the design of intelligent wheelchair systems.
2. System Design
In a general sense, ERP is the addition of a specific stimulus that acts on a certain part of the sensory system or the brain. When a stimulus is given or withdrawn, the potential change in the brain area is caused. A complete ERP-based psychological test system must first contain two aspects, one is the stimulation system, and the other is the signal analysis and processing system. The stimulus system is responsible for generating a variety of specific stimuli (sound, image, etc.), while the analysis system mainly completes the collection, storage, and analysis of the original EEG, and extracts the ERP and finally gives the conclusion. Figure 1 shows the system block diagram of the psychological test system [2].

![Diagram of the psychological test system based on ERP](image1)

**Figure 1**. Diagram of the psychological test system based on ERP

2.1. Stimulation System Design
The use of Single-modal ERP (SERP) to study the cognitive process in a complex sensory stimulation environment is often inadequate, and Cross-modal ERP (CERP) has gradually become a modern cognitive psychology, Psychophysiology and other subject research hotspots, so the stimulation system we developed can fully meet the research requirements of compound mode event related potential. As shown in Figure 2 for the main functional module structure [3].

![Stimulation system main function modules](image2)

**Figure 2**. Stimulation system main function modules

2.2. Signal Processing System Design
The signal processing system consists of two parts: data acquisition and data analysis. The task completed by the data acquisition part is mainly to collect brain waves from the brain area and then send it to the PC. The data analysis part is responsible for receiving data from the brain electrical amplifier, extracting the ERP signal using signal processing methods, and performing analysis processing to obtain the final result [4].

2.2.1. Hardware Design
The event-related potential is very weak (the amplitude is 0-30μV) and is often submerged in the background noise. The EEG signal amplification detection circuit is mainly composed of a buffer stage, a pre-differential amplification circuit, a 50Hz power frequency notch circuit, a voltage amplification circuit, a filter circuit, a linear optical coupling circuit, and an A / D conversion circuit. Finally, the EEG signal is sent to the PC through the USB interface.

2.2.2. Analysis System Design
The analysis system development platform is similar to the stimulation system. According to the principle of top-down project development of software engineering, a prototype for analyzing software system structure is proposed. As shown in Figure 3. The software system consists of 5 subsystems.

![Figure 3. The analysis of system structure model](image)

2.2.3. Signal Matching Between Stimulation System And Signal Processing System
From the basic concept of ERP, we can know that the ERP experiment requires the participation of the subjects and the precise recording of the stimulation time in order to correspond to the EEG signal in real time, so as to accurately extract the corresponding ERP signal. Here, we use radio frequency transmission to complete the connection between the stimulation system and the data acquisition and analysis system, that is, the stimulation system records the moment of stimulation, and transmits it to the analysis and processing system through the network. The corresponding position of the EEG signal will be used as a reference in the ERP extraction processing algorithm in the future.

3. Algorithm Design

3.1. Signal Preprocessing
For signal preprocessing, we use the method of wavelet analysis to achieve. Denoising is done using the wavelet threshold method. Select a threshold, perform threshold processing on the discrete details of each scale after the wavelet transform of the signal, and then reconstruct the signal by the discrete approximation signal and the processed discrete details through the inverse wavelet transform to achieve the purpose of signal denoising [5].

3.2. Event-Related Potential Extraction
ICA is a new multi-channel signal processing method developed along with blind source separation. It is based on the principle of statistical independence to decompose multi-channel observation signals into several independent components through optimization algorithms. The ERP signal measured from
the scalp electrode can be considered as a linear superposition of the signals generated by several independent signal sources, which provides the premise for applying the ICA method to it. The FastICA algorithm, also known as the fixed-point algorithm, is a fast-iterative independent component analysis algorithm that can simultaneously separate hidden super-Gaussian and sub-Gaussian sources from multiple input observation signals. However, the original fast algorithm FastICA does have some very obvious shortcomings, and its iteration depends on the initial weights. The improper use of initial weights may cause the algorithm to fail to converge. In order to improve the requirements of the ICA algorithm for initial weights, it was decided to introduce a relaxation factor in the FastICA iteration formula [6]. The iteration formula is as follows:

\[
    w_{p+1} = w_p - \alpha_p \frac{[E\{xg(w_p^T x)\} - \beta w_p]}{[E\{g'(w_p^T x)\} - \beta]}
\]  

(1)

By introducing a relaxation factor, it is guaranteed that a certain \( w_k \) will enter the convergence area of the Newton iteration method, so that the algorithm can achieve the convergence effect in any case. From multivariate differentials, the direction of the negative gradient is the direction in which the function value decreases the fastest, so we can choose to use the gradient as the relaxation factor. Then we calculate the gradient of \( E\{xg(w_p^T x)\} \) in the position of \( w \), as follow:

\[
    \alpha = \begin{bmatrix}
        \frac{\partial E[xg(w_p^T x)]}{\partial w_i} & 0 \\
        0 & \frac{\partial E[xg(w_p^T x)]}{\partial w_p} 
    \end{bmatrix}^{-1}
\]

(2)

Where \( \frac{\partial E[xg(w_p^T x)]}{\partial w_p} = E[\int g'(w_p^T z)] \), we adjust the formula of iteration, improved algorithm as follows:

\[
    \begin{align*}
    w_i' & \leftarrow E[g(w_i^T z)] + \alpha E[g'(w_i^T z)]w \\
    w_i'' & \leftarrow E[g(w_i^T z)] + E[g'(w_i^T z)]w \\
    w_i & \leftarrow w_i'' / |w_i''|
    \end{align*}
\]

(3)

The updating process for improved FastICA can be summarized as follows:
Step 1: \( \bar{X} = x - E[x] \);
Step 2: \( \tilde{X} = E\Lambda^{-1/2}E^T \bar{X} \);
Step 3: Initialize random vector \( w_0 \), set the error of convergence \( 0 < \varepsilon < 1 \);
Step 4: According to the formula (14), we could calculate loose gene \( \alpha \);
Step 5: According to the formula (15) adjust \( w_{p+1} \), calculate \( w_{p+1} \), and normalizing;
Step 6: If \( |w_{p+1} - w_p| < \varepsilon \), then make Algorithm converged; estimate independent component. Else repeat (5), (6);
Step 7: Get all the estimate $y'_p$ of source signal by the separated matrix, Output signal $y$.

4. Psychological Test Based On Intelligent Wheelchair

After the design of the system is completed, the project team uses traditional pictures and sound target stimulation methods to conduct experiments, which can produce effective event-related potentials. In order to verify whether this system can be applied to smart wheelchairs, combined with the actual traffic situation, we use traffic lights and traffic prompts to stimulate the subjects[7].

4.1. Experimental Design

The designed experimental method is as follows: using many different traffic light pictures and different traffic reminder sounds as the original material of the stimulus, presented in a variety of ways, allowing the subjects to confirm the key presses for different stimulus scenarios. The subjects of this experiment are mainly selected from the students of Guangdong Food and Drug Vocational College. There are 4 boys and 4 girls, 19 ~ 21 years old, average 20.6 years old.

Several different traffic light pictures (red light, green light, yellow light) were selected for the experimental materials. Different traffic lights and corresponding voice prompts are played at the same time. According to different sources of stimulus materials, the stimuli are still divided into 3 categories. Presentation, the experiment presents a total of 180 pictures and voice stimulation scenes. The stimulation is presented until the subject presses the button response. In order to eliminate the fixed response, the stimulation interval is between 0.5s and 1.5s, which is randomly selected by the computer.

4.2. Experimental Results

4.2.1. Behavioral Data Analysis

According to the research purpose of this experiment, statistical analysis was conducted on the response rate of the subjects and the response time of the correct response. As shown in Table 1, in the traffic light pictures, the recognition accuracy of the green light is significantly lower than the red-light picture, and the response rate is significantly higher than the red-light picture. This shows that the respondent's response to the green light is low. In each experimental task, the correct rate of the red-light picture is higher than the green light picture, and the response rate is significantly lower than the green light picture. This may indicate that the perception of the green light picture is harder than the red-light picture. The subjects' resolution of red and yellow light pictures is relatively stable, while the recognition of green light pictures requires more time and the accuracy is lower.

| Test type          | Accuracy (%) | Average response time (ms) |
|--------------------|--------------|----------------------------|
| Red light          | 98%          | 499                        |
| Green light        | 95%          | 530                        |
| Yellow light       | 97%          | 443                        |

4.2.2. ERP Data Analysis

Analysis of the data shows that all three stimulation modes can have a significant N400 on the parietal lobe electrode. From all the electrodes distributed throughout the cortex, the N400 amplitude at the parietal lobe is the largest. Therefore, when we analyze the waveform, select Pz and Cz for analysis. Table 2 shows the amplitude and latency of N400 at two points, Pz and Cz. Figures 4 and 5 show the results of ERP signals at Pz and Cz respectively.

From the analysis of the results in Figures 4, 5 and Table 2, it can be seen that the red light, yellow light, and green light can trigger N400 with an amplitude of 0-30μv, but the red light amplitude is
significantly higher than the two outside, indicating that the red light is the warning effect is higher than the other two, and it can be used in a smart wheelchair system.

Table 2. Pz, Cz point amplitude and latency of the table

| Test type | Incubation period (ms) | Pz Amplitude (μV) | Incubation period (ms) | Cz Amplitude (μV) |
|-----------|------------------------|-------------------|------------------------|-------------------|
| Red light | 450                    | 34                | 455                    | 20                |
| Yellow light | 460                   | 26                | 456                    | 20                |
| Green light | 490                   | 10                | 495                    | 16                |

Figure 4. Pz (Red, Yellow, Green)

Figure 5. Cz (Red, Yellow, Green)

5. Conclusion
The ICA algorithm can effectively separate the independent source components hidden in multiple EEG signals, including some non-neural electrical activities (such as ophthalmic electromyography and myoelectric interference) generated from other organs and tissues of the human body. Using this feature, the interference components in the EEG signal can be effectively eliminated, and the useful EEG information is almost not destroyed, so that the ERP signal is extracted quite accurately. In this subject, we built a psychological test system, using independent component analysis algorithm as the core algorithm of ERP feature extraction, made a series of improvements to FastICA Newton iterative algorithm, introduced a relaxation factor in the iterative process, and used the gradient algorithm to determine Value, which not only improves the convergence performance, but also reduces the dependence of the algorithm on the initial value, realizes a wide range of convergence, and greatly improves the processing speed. At the same time, according to the actual research situation, a reasonable experimental method was designed to prove that the psychological test system can be used in the control system of intelligent wheelchairs, laying a foundation for later research.

Acknowledgments
This work was financially supported by Guangdong Medical Research Fund, project number A2017556.

Reference
[1] Md Fahim Ansari, Damodar Reddy Edla, Shubham Dodia, Venkataanareshbabu Kuppili, Brain-Computer Interface for wheelchair control operations: An approach based on Fast Fourier Transform and On-Line Sequential Extreme Learning Machine, Clinical Epidemiology and Global Health 7(2019)274-278.

[2] S. P. Liburkina, A. N. Vasilyev, L. V. Yakovlev, S. Yu. Gordleeva, A. Ya. Kaplan, A Motor Imagery-Based Brain–Computer Interface with Vibrotactile Stimuli, Neuroscience and Behavioral Physiology, Vol. 48, No. 9, November, 2018.

[3] Andrea Kübler, The history of BCI: From a vision for the future to real support for personhood in people with locked-in syndrome, https://link.springer.com/article/10.1007/s12152-019-09409-4

[4] Javeria Khan, Muhammad Hamza Bhatti, Usman Ghani Khan and Razi Iqbal, Multiclass EEG motor-imagery classification with sub-band common spatial patterns, EURASIP Journal on Wireless Communications and Networking (2019) 2019:174.

[5] Binfeng Xu, Haoyu Jin, Xin Tan, Yarong Hu, Extracting Fetal Electrocardiogram based on A Modified Fast Independent Component Analysis, 2012 9th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD 2012)

[6] FastICA, http://www.cis.hut.fi/projects/ica/fastica/

[7] Yimin Hou and Shuaiqi Chen, Distinguishing Different Emotions Evoked by Music via Electroencephalographic Signals, Computational Intelligence and Neuroscience Volume 2019.