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Enhanced BCI Intelligent Wheelchair System Based on Alpha Wave and SSVEP EEG Signals

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ABSTRACT: Intelligent wheelchair System research based on Brain Computer Interface (BCI) is a cross-disciplinary and futuristic research in brain science, information science and control science. It is expected to provide a new channel for patients with severe sports disabilities to communicate with external devices. Several kinds of brain-computer interface (BCI) systems have been proposed to make up for the absence of clinical innovation for helping patients who lost the the ability to use motor functions to communicate with the outside world. However, most of the proposed systems are limited by their non-portability and inconvenience. In this paper, a BCI intelligent wheelchair system based on Steady State Visual Evoked Potential (SSVEP) and Alpha wave is proposed. This BCI wheelchair uses the fusion of SSVEP and Alpha wave to realize the asynchronous control, uses the Mecanum wheel accomplish the omni-directional movement and group task-related component analysis (gTRCA) algorithm achieve multi-frequencies EEG signal analysis. In order to detect the proposed system's efficiency and effectiveness, five subjects conducted corresponding wheelchair control experiments. The corresponding experiment results show that the proposed system can accomplish the wheelchair's asynchronous control and omni-directional movement with high accuracy and high Information Transfer Rate (ITR).

KEYWORDS: Brain- computer interface; steady -state visual evoked potential; alpha wave; intelligent wheelchair; asynchronous control introduction, group task-related component analysis.

I. INTRODUCTION

Many diseases affect the patients physical activity, which limits their autonomy and communication skills. Brain-Computer Interface (BCI) is a technique that helps patients with severe motor dysfunction to communicate with or control external devices using EEG signals.

Brain Computer Interfaces (BCIs) tends to measure brain activities, extract features from these activity and convert them into outputs that improves human functions.

BCIs may replace lost functions, such as speaking or moving. They may restore the ability to control the body, such as by stimulating nerves or muscles that move the hand. BCIs have also been used to improve functions, such as training users to improve the remaining function of damaged pathways required to grasp. BCIs can also enhance function, like warning a sleepy driver to wakeup.

Different techniques are used to measure brain activity for BCIs. Most BCIs have used electrical signals that are detected using electrodes placed invasively within or on the surface of the cortex, or noninvasively on the surface of the scalp [electroencephalography (EEG)]. Some BCIs have been based on metabolic activity that is measured noninvasively, such as through functional magnetic resonance imaging (fMRI).

This chapter is focused on providing an overview of non-invasive BCIs. After a brief review of the relevant aspects of EEG and fMRI, each of the subsequent sections is dedicated to one of the four different purposes that a BCI may serve and that have been realized as of this writing.

The idea of interfacing minds with machines has long captured the human imagination over a period of time. Recent studies have showed advancement in neuroscience and engineering that are making this idea a reality, opening the door to restoring and potentially augmenting human physical and mental capabilities. Medical applications such as cochlear implants for the deaf and deep brain stimulation for Parkinson's disease are fastly becoming commonplace.

Brain computer interfaces (also known as brain-machine interfaces) related technologies are now being explored in applications as diverse as security, lie detection, alertness monitoring, telepresence, gaming, education, art, and human augmentation. This introduction to this field is designed as a textbook for upper-level undergraduate and first-year graduate courses in neural engineering or brain-computer interfacing for students from a wide range of disciplines. Italso be used for self-study and as a reference by neuroscientists, computer scientists, engineers, and medical practitioners

II. RELATED WORK

Since the emergence of BCI technology in the 1970s, many experts and scholars have carried out related research works and achieved rich scientific results. In 2005, Japanese scholar Tanaka et al successfully used EEG signals to control the direction of the electric wheelchair (left or right), but the accuracy was not stable. The Millan team has intensively studied the asynchronous brain-computer interface based on spontaneous EEG. Users provided specific thinking tasks (usually imagination left-hand movement, word association and relaxation) to generate specific EEG signals. The system converted the EEG signals into corresponding control instructions in real time, and realized the operation control of wheelchair or remote robot. In 2007, the brain-computer research team at the Graz University of Technology demonstrated for the first time that quadriplegia can use brain waves to control the movement of wheelchairs in virtual reality (VR). Each subject participated in the experiment with an average correct rate of 90%. In 2012, Tongji University of China proposed an effective and low-latency asynchronous SSVEP-BCI system for practical wheelchair control. The accuracy of the system is about 87%. In 2016, Lopes et al. proposed a paradigm of using a self-paced P300-based BCI to manipulate wheelchairs in real office scenes. Recently, Yang Yu's team of National Defense University of Science and Technology developed a Mecanum wheelchair, which combines motion imagery (MI) and P300 hybrid brain-computer interface. It controls the direction and speed of the wheelchair with high accuracy, but the time used to classify EEG signals is slightly longer. In 2018, the Álvaro Fernández-Rodríguez team at the University of Málaga used the sensory motor rhythm (SMR) modulated by the right-handed motor imaginary task to study the feasibility of the continuous and switch-controlled mode of the brain-controlled wheelchair (BCW). The results show that the best system for a particular user depends on his/her ability and preferences, but the switch control mode has higher accuracy. Although many achievements have been made in Brain-Computer wheelchair technology, it still faces many challenges. At present, the application of brain-computer interface in intelligent wheelchair still has a series of problems, such as long analysis time, difficult to control wheelchair according to user's own rhythm, low recognition rate, low information transmission rate and poor control of turning angle. To solve the above problems, the purpose of this paper is to design a hybrid BCI Wheelchair Based on Mecanum wheels, improve the accuracy of BCI intelligent wheelchair, shorten the time window for issuing orders, and enable users to control wheelchair movement more efficiently according to their own rhythm. The experimental results show that the intelligent wheelchair system can achieve asynchronous control and arbitrary motion, with high accuracy and responsespeed.

III. PROPOSED SYSTEM

The overall structure of the proposed wheelchair system is shown in Figure below. The system consists of four parts: EEG Acquisition System, Visual Stimulation module, EEG Analysis Program and Wheelchair Control System. The visual stimulation module produces different frequency stimuli. The signal acquisition system completes the acquisition and amplification of the user's EEG signals. The signal processing module performs feature extraction and classification of the SSVEP signal and the Alpha wave signal. The wheelchair control system performs the control of the Mecanum wheelchair. Every module is described in detail in the followingparts.

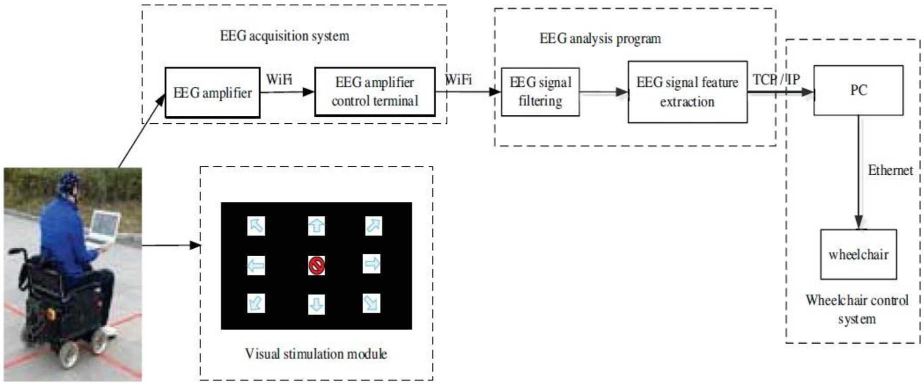


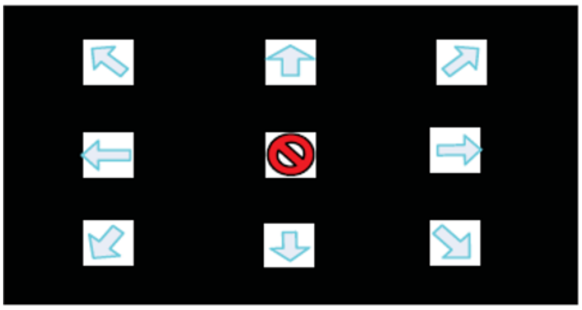
Figure 1.The structural diagram of the proposed BCI wheelchair system.

The various modules of BCI Wheelchair System are as follows:

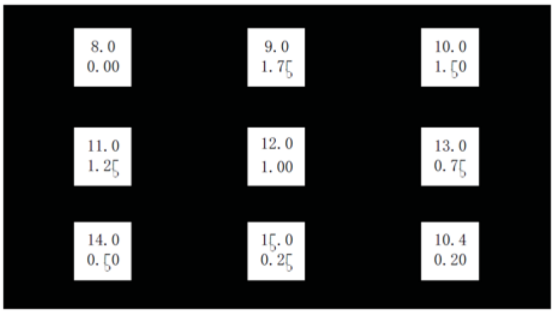
A. Visual StimulationModule:

The visual stimulation module of this study is implemented by **MATLAB's Psychtoolbox 3 2020** (PTB), which solves the problem of limited LCD refresh rate. The visual stimulation module uses a liquid crystal display with a refresh rate of 60 frames per second and a resolution of 1366 x 768 (pixels). Using sine wave sampling stimulation, the visual stimulus on a

23.6-inch liquid crystal display (LCD) display is encoded by the JFPM (joint frequency-phase modulation) method. Keeping track of previously used paths. The stimulus target consists of 9 white squares of size 150 x 150 (pixels), including forward, backward, left, right, left rear45, left front45, right rear45, right front45 and stop. Fig. 2 (a) shows the visual stimulus interface of the proposed system and Fig. 2(b) is the corresponding frequencies and phases of the function blocks. The frequencies and phases of the nine function blocks are set to be 8.0Hz/0.00, 9.0Hz/1.75,10.0Hz/1.50,11.0Hz/1.25,12.0Hz/1.0,13.0Hz/0.75,14.0Hz/0.50,15.0Hz/0.25and10.4Hz/0.20,from left to right and top to bottom.



(a)



(b)

Figure 2. (a) Visualstimulationinterface 2. (b) Frequencies and phases of each functionblock.

B. EEG AcquisitionSystem:

The EEG signal acquisition device used in this system is a 32-channel wireless EEG acquisition system from Neuracle, which includes a: 32 strips-electrode cap, a wireless brain power amplifier, and a wireless router. The EEG signal is generated by the user, collected by the electrode cap, and transmitted by the wireless Wifi to the EEG wireless brain electrical amplifier terminal. The EEG signal is amplified and transmitted to the subsequent EEG signal processing module for signal analysis.

Figure 3. EEG Aquistion System

C. EEG Analysis Program:

Alpha waves are rhythmic brain waves with frequencies between 8-12Hz. Studies show that alpha wave appears when eyes closed and disappear when eyes opened or the brain is thinking. Therefore the detection of the alpha wave can help to realize the asynchrnismof the system.When the subject wants to control the movement of the wheelchair: He/she can close his/her eyes quietly. Once the system detect the appears of the Alpha wave then the system will give the subject a beep hint, which means the subject and the system can switch into the work state. The subject need to fix his/her eyes on the function blocks of the visual stimulation interface and the system need to detect the subject’s SSVEP signal and make the corresponding control command. The EEG signal is generated by the user, collected by the electrode cap, and transmitted by the wireless Wifi to the EEG wireless brain electrical amplifier terminal. The EEG signal is amplified and transmitted to the subsequent EEG signal processing module for signalanalysis.

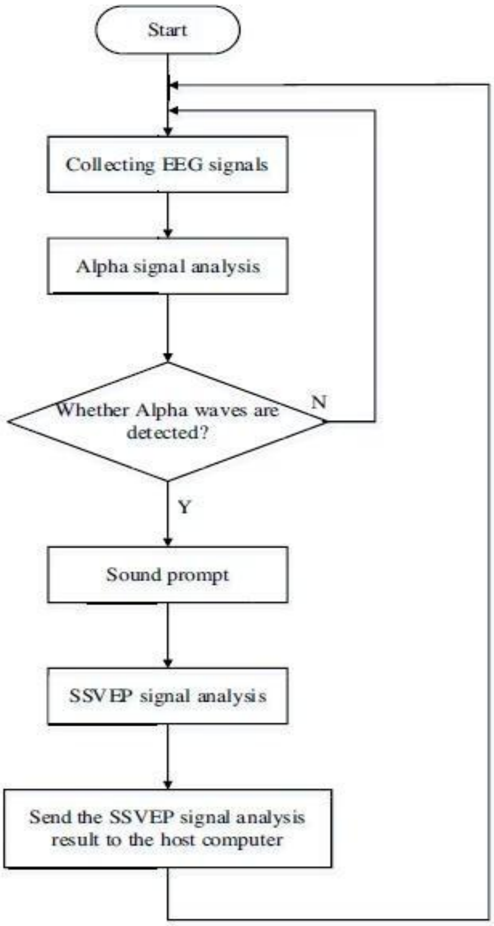


Figure 4.Asynchronized BCI Wheelchair Flowchart

D. Wheelchair ControlSystem:

The wheelchair control system is based Trio control system.The characteristic of Trio motion controller is that some simple instructions can complete complex multi-axis coordinated motion.In order to solve the wheelchair’s turning angle problem, the system uses Mecanumwheel.TheMecanum wheel consists of a hub and an unpowered roller mounted on the outer edge of the hub at an angle to the hub axis.The rim of Mecanum wheel is composed of rollers. In order to ensure the smooth movement of Mecanum wheel, the envelope of each roll is a complete circle.The non-power rollers can not only rotate around the hub axis, but also rotate around their respective supporting mandrels under the action of ground friction.

Figure 5. Typical structure of the Mecanum wheel

IV. EXPERIMENT SETUP ANDRESULTS

A. Establishment of ClassificationModel

Five healthy subjects aged 18 to 24, including three males and two females, were selected for the offline and online experiments in a quiet environment with slightly low light intensity. Subjects were asked to avoid blinking during the time of the stimulus, and their eyes were about 0.5 m from the visual stimulation module. The experiments uses the visual stimulation interface of Fig. 2. Before the online experiment, each subject first carried out 5 rounds (each round containing 9 trials) experiments to collect SSVEP signals to establish the classification model. In each round, all the function blocks were flashed for 5 seconds and then stopped for 1 second. The subjects looked at nine function blocks in turn, each round lasted 54 seconds. Offline experimental time procedure for one round is shown in Fig. 6. Five rounds EEG data from every subject were used to establish classification models based onTRCA.

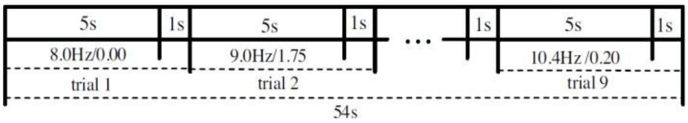


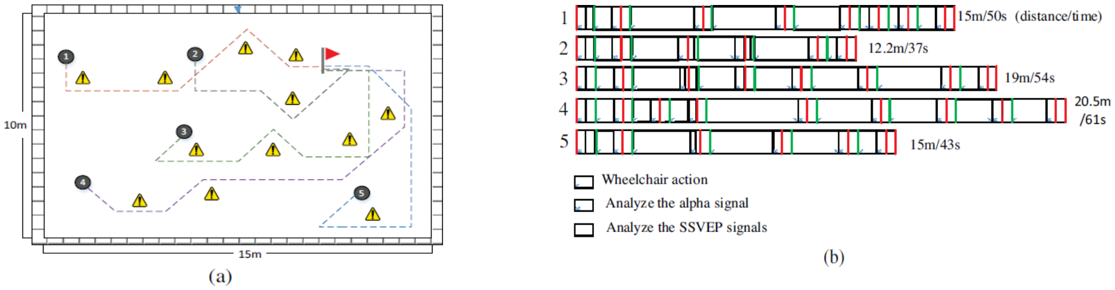
Figure 6. Offline experimental time procedure

B. Online ExperimentSetup

The experiment ground is showed in Fig. 7(a). It is a 10m×15m flat ground. Five numbers (from 1 to 5) represent the start point for five subjects, the triangular red flag is the destination point for the five subjects and the yellow triangles are obstacles in the ground. The subject’s task is to control the BCI based wheelchair from the start point to the destination point without touch the obstacles with minimum time.

C. ExperimentResults

Fig.7(a) depicts the experimental roadmap of subject A in five experiments and Fig. 7. (b) describes the real-time status of subject A in five online experiments. In Fig. 7.(b), the green vertical line indicates that the wheelchair is starting to move, and the red vertical line indicates that the wheelchair is stopped.



(a) (b)

Figure 7. (a) Brain computer interface wheelchair experiment path arrangement (b) Subject's real-time status

TABLE I. EXPERIMENTAL RESULT

subjects	Starting point	T(s)	Ac(%)	Distance/m	ITR (b/min)
A	1	50	87.5	15.0	175.09
	2	37	100.0	12.2	170.20
	3	54	94.0	19.0	172.20
	4	61	93.0	20.5	176.20
	5	43	100.0	15.0	174.20
B	1	45	100.0	14.3	171.20
	2	42	87.5	13.5	173.09
	3	63	90.0	20.3	172.06

	4	72	90.9	21.3	171.43
	5	54	92.5	16.5	173.09
C	1	49	87.7	14.7	172.09
	2	36	100.0	12.1	173.20
	3	55	100.0	19.3	171.20
	4	74	90.9	21.6	170.43
	5	55	87.5	16.8	172.09
D	1	52	89.5	15.5	173.09
	2	43	87.5	13.5	172.09
	3	65	90.0	20.5	171.06
	4	73	90.9	21.5	172.43
	5	44	100.0	15.2	170.20
E	1	41	100.0	14.0	175.20
	2	35	100.0	12.3	174.20
	3	64	90.0	20.4	170.06
	4	60	90.0	20.3	171.20
	5	45	100.0	15.3	172.20

Table I lists all the experimental results, including duration time, accuracy (Ac), distance and ITR. The accuracy in Table 1 is calculated as below:

$$accuracy = \frac{correct\ command\ number}{total\ command\ number} \times 100\%$$

And the ITR is calculated as below:

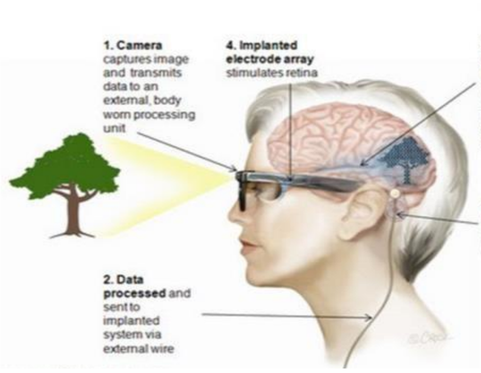
$$ITR = (\log_2 Nf + Ac \log_2 Ac$$
$$+(1-Ac) \bullet \log_2 (\frac{1-Ac}{Nf-1})) \times 60 / T$$

where Ac denotes accuracy, Nfis the number of stimuli, and T is the time taken to complete the output of an SSVEP signal. Table I shows that five subjects can control the operation and stop of the wheelchair at their own pace, and realize the asynchronous control of the wheelchair. In the five experiments, subjects A and E completed the task perfectly four times without any mistakes, and the classification accuracy of all the five subjects was above 92%, and it takes about 2 seconds for the system to generate a control command. The ITR of the system was above 72 b/min. The system collects EEG signals almost without delay, and takes an average of 1 second to process SSVEP signals. This result shows that the SSVEP and alpha wave based brain-computer interface analysis program of this project has higher accuracy, faster analysis speed and higher information transmission rate. At the same time, the wheelchair based on the Mecanum wheel can move directly from the starting point to any position in the plane without considering the turningproblems.

V. CONCLUSION AND FUTUREWORK

This paper presents the overall design scheme of Intelligent Wheelchair Based on SSVEP and Alpha brain- computer interface, and verifies the feasibility and effectiveness of proposed system through online experiments. In order to improve the practicability and flexibility of the intelligent wheelchair, this paper chooses the wheelchair with Mecanum wheel, and installs obstacle avoidance sensor on the wheelchair. The experimental results show that the subject can control the intelligent wheelchair movement system based on the hybrid brain-computer interface according to his own rhythm, and realize the asynchronous control of the intelligent wheelchair. The system can accurately analyze the control commands that the user wants to send and has a high information transmission rate. It can move the intelligent wheelchair to any position in the plane according to the user's intention without considering the turning and turning angle, which provides an effective solution for the movement of the intelligent wheelchair.

Although the intelligent wheelchair proposed in this paper achieves asynchronous control, high analysis accuracy and omni-directional movement, it still needs to be further improved in the following aspect of a blind person controlling the wheelchair. Therefore we can merge the Australian Bayonic Eye Concept with the BCI WheelChair Concept where an invasive electrode is inserted inside the grey matter of the brain from where signals can be extracted to directly control wheelchair instead of using MatlabPsychoToolbox-3.



With the continuous development of brain-computer interface technology and in-depth research of scientific researchers, the intelligent wheelchair system based on BCI will be gradually improved, and have a broader application prospect in various fields.

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