A Human Computer Interface Using SSVEP-Based BCI Technology

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Abstract. To address the issue of system simplicity and subject applicability, a brain controlled HCI system derived from steady state visual evoked potential (SSVEP) based brain computer interface (BCI) is proposed in this paper. Aiming at an external input device for personal computer, key issues of hardware and software design for better performance and user-friendly interface are introduced systematically. With proper parameter customization for each individual, an average information transfer rate of 46bits/min was achieved in the operation of dialing a phone number. With encouraging online performance and advantages of system simplicity, the proposed HCI using SSVEP-based BCI technology is promising for a substitute of standard computer input device for both health and disabled computer users.

Keywords: brain-computer interface (BCI); steady state visual evoked potential (SSVEP); input device.

1 Introduction

Much effort has been made to develop various forms of augmented device for those computer users with motor impairments. Besides traditional technologies, such as voice recognition, eye-tracker and breath controller [1], brain-computer interfaces (BCI) has been adopted as a new media to facilitate the human computer interaction in recent years. BCI translates the human intents encoded in the brain signal into control commands of computer or devices. Because of its non-invasive operation and easy system implementation, electroencephalogram (EEG) recorded on the surface of human head are widely used for BCI clinical trials [2].

Currently there are several types of EEG signal, such as motor related μ rhythm, visual evoked potential, slow cortical potential, P300, can be modulated by user's intent and/or attention and act as neural media in the brain controlled HCI system [2]. However, with its limitation of poor subject applicability (only intensively trained user can operate the system easily), low information transfer rate (usually lower than 25bits/min) and high system complexity (typically with tens of EEG electrodes), the current brain controlled HCI systems are far from user friendly.

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Based on our prototype BCI system [3][4][5], a novel design and implementation of the brain controlled HCI is introduced in this paper. Aiming at a brain controlled input device for personal computer, key issues of hardware and software optimization for better performance and user-friendly interface are addressed systematically.

2 System Design and Implementation

2.1 System Configuration

Our HCI system is composed of visual stimulation and feedback unit (VSFU), EEG Data Acquisition Unit (EDAU) and personal computer (Fig.1a). In the VSFU, compact LED modules flicking at predefined frequency bands were employed as visual stimulator. For a typical setting, 12 LEDs in a 4 by 3 array formed an external number pad with numbers 0-9, ‘Backspace’ and ‘Enter’ key (Fig.1b). When the user focused his/her visual attention on the flickering LED labeled with the number that he/she wanted to input, the EDAU and software running on PC identified the desired number by analyzing the EEG signal recorded from the user’s head surface. By this means, the computer user was able to input number 0-9 and other characters with proper design of the input method. In the mode of mouse cursor control, 4 of the keys were assigned as UP, DOWN, LEFT and RIGHT movement of the cursor. Real-time feedback of input characters was provided by means of visual display and voice prompts.

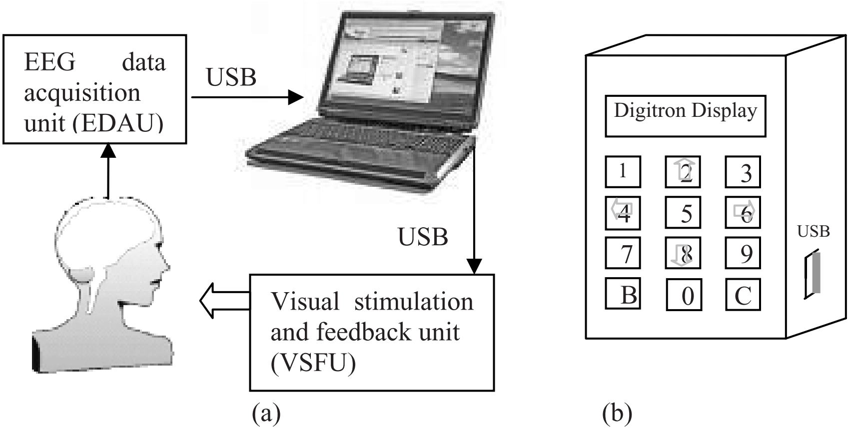

Fig. 1. Brain controlled HCI system using SSVEP. (a) System configuration and main components; (b) External number pad for visual stimulation and feedback.

2.2 Hardware Implementation

Aiming at a PC peripheral device with standard interface, the hardware of our brain controlled HCI system was designed and implemented as a compact box containing both EEG data acquisition unit and visual stimulation and feedback unit. Two USB ports are used for real-time data streaming from EDAU and online control of VSFU respectively.

EEG Data Acquisition Unit. In the EDAU, a pair of bipolar Ag/AgCl electrode was placed over the user's occipital region. A tennis headband was modified to harness the electrodes on the head surface.The EEG signal was amplified by a customized amplifier and digitized at a sampling rate of 256Hz. After a 50Hz notch filtering to remove the power line interference, the digital EEG data were streamed to PC memory buffer through USB port.

Visual Stimulation and Feedback Unit. As shown in Fig.2, for the precision of frequency control, the periodical flickering of each LED was controlled by a separate lighting module, which downloads the frequency setting from the PC through master MCU.

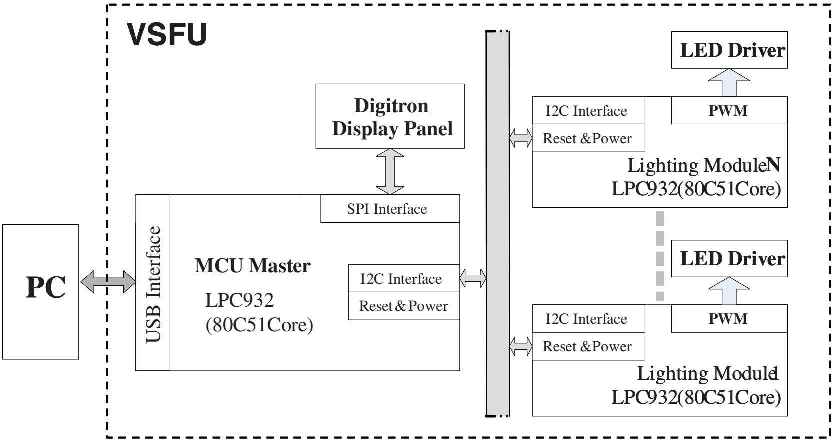

Fig. 2. Schematic diagram of visual stimulation and feedback unit

In one of the application, our brain controlled HCI system was used for dialing a phone number. In that case, a local telephone line was connected to the RJ11 port of internal modem of the personal computer.

2.3 Software and Algorithm

The main software running on the PC consists of key parts of the EEG translation algorithm, including signal enhancing, feature extraction and pattern classification. The following algorithms were implemented in Microsoft Visual C/C++ and compiled into a stand alone program. The real time EEG data steaming was achieved by using a customized dynamic link library (DLL).

In the paradigm of SSVEP, the target LED evokes a peak in the amplitude spectrum at the flickering frequency. After a band filtering of 4-35Hz, fast Fourier transform (FFT) was applied on the ongoing EEG data segments to obtain the running power spectrum. If a peak value was detected over the frequency band (4-35Hz), the frequency corresponding to the peak was selected as the candidate of target frequency. To avoid a high false positive rate, a crucial step was to make sure that the amplitude of candidate frequency was higher enough than the mean power of the whole band. Herein, the ratio between the peak power and the mean power was defined as:

$$Q = P_{peak}/P_{mean}. \tag{1}$$

Basically, if the power ratio Q was high than the predefined threshold T (T>2), the peak power was considered as significant. For each individual, the threshold T was estimated beforehand in the parameter customization phase. The optimal selection of the threshold made a tradeoff between the speed and accuracy of the HCI operating. Detail explanation of this power spectrum threshold method can be found in our previous study[4][5].

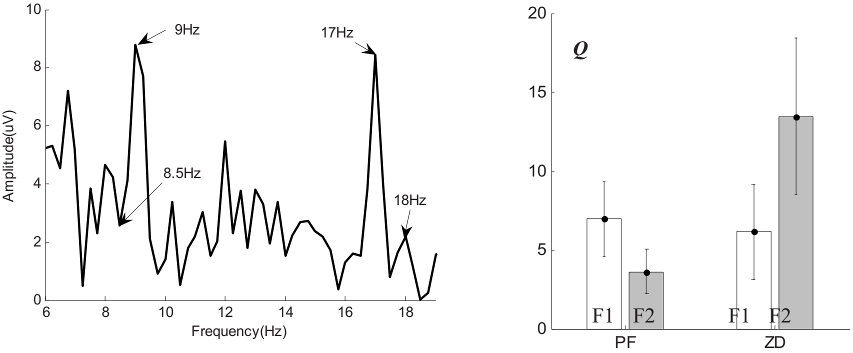

Fig. 3. SSVEP response at fundamental frequency and second harmonic frequency. (a) An instance of user ZD's power spectrum with a prominent peak in second harmonic frequency F2 (b) Comparison of Q value at F1 and F2 for subject PF and ZD, in which the Q value at 27 frequencies between 6-19Hz (0.5Hz spacing) was averaged.

During the algorithm testing and verifying, we notice that the fundamental target frequency F1 of some users does not give a prominent response, while the second harmonic frequency F2 (F2=2F1) displays more significant peak power. As shown in Fig.3a, for the user ZD and the target frequency 8.5Hz, the power of fundamental frequency is lower than the neighboring peak frequency 9Hz, which misled the algorithm. It can be easily found that, if the power at second harmonic frequency (17Hz) were taken into account, the situation would changed a lot. The further comparison of Q value between fundamental frequency and second harmonic frequency gives us a clear idea as shown in Fig.3b. For the user PF, the fundamental frequency F1 is a better feature to detect the target frequency, while the user ZD prefers the second harmonic F2. For this reason, we further improved the algorithm by incorporating the power value at the second harmonic frequency and the P_{peak} in Eq.1 was substituted by the linear combination of power amplitude at F1 and F2.

$$P_{peak} = \alpha P_{F1} + (1-\alpha) P_{F2} \tag{2}$$

The weight coefficient α was optimally predefined in the parameter customization phase. Basically, for users like ZD, weight coefficient α should be set lower than that of users like PF.

2.4 Parameter Customization

To address the issue of individual diversity and to improve the subject applicability, a procedure of parameter customization was conducted before the HCI operating. Our previous study suggests that the crucial system parameters include EEG electrode location, visual stimulus frequency band, and threshold (*T*) for target frequency determination [5]. To maintain the simplicity of operation and efficiency of parameter selection, a standard procedure was designed to help the system customization, which consists of the following steps:

Step1 - Frequency Scan. 27 frequencies in the range of 6-19Hz (0.5Hz spacing) were randomly divided into 3 groups and the 9 frequencies in each group were randomly assigned to number 1-9 on the aforementioned LED number pad. Then the frequency scan was conducted by presenting the number 1-9 on the digitron display one by one and each for 7 seconds. During this time period, the user was asked to gaze at the LED number pad corresponding to the presented number. This kind of scan was repeated for 3 groups containing all 27 frequencies. There was 2 seconds of resting period between each numbers and 1 minutes of resting between groups. It took about 8 minutes for a complete frequency scan. The 7-second SSVEP response during each frequency stimulus was saved for the following offline analysis. In the procedure of frequency scan, the bipolar EEG electrodes were placed at Oz (center of the occipital region) and one of its surrounding sites (3cm apart on the left or right side). According to our previous study[6], this electrode configuration was the typical one for most of the users.

Step2 - Simulation of Online Operating. The saved EEG segments were analyzed using FFT to find the optimal frequency band with relatively high *Q* values. The suitable value of the threshold *T* and the weight coefficients α were estimated in a simulation of online HCI operating, in which the saved EEG data were fed into the algorithm in a stream.

Step3 -Electrode Position Optimization. For some of the subjects, when the above two steps do not provide a reasonable performance, the advanced method using independent component analysis was employed to find the optimal position of EEG electrodes. The best electrode pair for bipolar recording with highest signal-to-noise ratio was selected by mapping the EEG signal and noise amplitude over all possible electrodes[6].

3 Result

Ten subjects participated in the online experiment of dialing a telephone number and all of them succeeded in the operation. As shown in Fig.4, the brain controlled BCI box acts as an external input device of a laptop computer. With only two EEG electrodes attached on the surface of the head, the HCI user could obtain an easy control of number inputting through directing his/her gaze on the external flickering number pad.

Fig. 4. The brain controlled HCI box in the operation of dialing a cell phone number

Table 1. Online operation performance of 5 subjects with parameter optimization

Subject	Time/selection (seconds)	Accuracy (%)	ITR (bits/min)
ZD	2.7	93	66.7
SY	3.5	100	61.5
PF	4.6	100	46.8
XH	5.0	88	31.9
JC	6.8	93	26.5
Average	4.52	94.8	46.68

With optimized system parameters for 5 participants, an average information transfer rate (ITR) of 46.68bits/min and an average accuracy of 94.8% were achieved. The best performance was the 93% accuracy at an ITR of 66.7bits/min (Table 1). In another testing of operating Microsoft Internet Explorer, 8 of the participants were able to implement the task of opening a target web link.

4 Conclusion

To address the issue of system simplicity and subject applicability, a SSVEP-based brain controlled HCI system was proposed in this paper. Comparing with other brain controlled HCI systems, it bears the following major characteristics: 1) non-invasive harnessing; 2) PC compatible operating; 3) few EEG electrodes without using EEG cap; 4) little training and setting; 5) high information transfer rate; 6) low cost of the system hardware.

With encouraging online performance and advantages of system simplicity, the proposed HCI using SSVEP-based BCI technology is promising not only for the prosthetics of the disabled people, but also for a substitute of standard computer input device in the case of inconvenient use of one or both hands of the health people[5][7], such as the situation of using a cell phone or other handheld devices.

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