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# An SSVEP-Based BCI System with SOPC Platform for Electric Wheelchairs

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***Abstract***

In this paper, the purpose is to design a Brain-Computer-Interface (BCI) based system with a System on a Programmable Chip (SOPC) platform by using of the Steady-State Visually Evoked Potentials (SSVEP) through a Bluetooth interface that can aid the Amyotrophic Lateral Sclerosis (ALS) or other paralyzed patients to easily control an electric wheelchair in their lives. The EEG signals may be detected by electrodes and signal extracting chip. Then these signals can be transmitted to the electric wheelchair by using of Bluetooth interface. Finally, the electric wheelchair can be moved smoothly in accordance with the EEG signal in frequency domain transferred from time domain. The experimental results had shown that the proposed system can easily control electric wheelchair.

***Keywords: EEG; SSVEP; BCI; Bluetooth; Electric Wheelchair***

## 1 INTRODUCTION

People's behaviors and activities are always controlled by signals in the brain. The signals are then delivered to the entire body via the nervous system. Some people can't control hands and bodies but their brains are still operating like a normal person such as amyotrophic lateral sclerosis (ALS), muscular dystrophy, and severe cerebral palsy that is also referred to as motor neuron disease. The electric wheelchair has been considered as one of important mobility aids for the elderly as well as the physically impaired patients. Including paralyzed patients, approximately 50% of patients cannot be able to control an electric wheelchair by conventional methods in the clinicians report. Especially, people can only use eyes and brain to exercise their willpower if they got motor neuron disease motor neuron disease (MND).

Brain computer interface (BCI) is a system so that people can directly communicate with the external device through the neuromuscular pathway [1-3]. In some researches, BCI system is a promising tool can help the paralyzed people such as medical assistant devices. The BCI system contains the acquisition of electroencephalography (EEG) signal, signal processing, and an application. The signal processing includes preprocessing, feature extraction, and classification.

In the past two decades, different EEG signal characteristics such as mu / beta rhythm, the P300 event-related potentials and visual evoked potential (VEP) have been widely used in the field of BCI. The VEP system has its advantages including higher information transfer rate (ITR), small amount of training samples, low user variable and easily use.

The SSVEP signal that is natural responses to visual stimulation at particular frequencies ranging from 3.5 Hz to 75 Hz [4-6], when the eyes are excited by a visual stimulus signal and the brain then generates same reaction at the same frequency of the visual stimulation signal. The characteristic of the SSVEP is that it can detect and measure SSVEP stimulation frequencies when the amplitude of the stimulation frequency is increased. Frequency coding method has been widely used in the SSVEP-based BCI systems. In such a system, each visual target is flickering at a frequency. The system can identify the primary frequency of SSVEP for the subject's gaze target. To design a practical BCI system needs to address the following issues: 1) ease of use, 2) a reliable system performance, and 3) low-cost

hardware and software. In recent years, with the biomedical sciences and electronics technology, mobile and online BCI's development have been proposed and set on the schedule. SSVEP has been widely used in EEG visual research as a test task, because it does not require special training. It also has a very high information transmission rate (ITR).

For the electric wheelchairs in references [7-10], they did not use any wireless interface in their system. The author [11-12] also proposed EEG-based electric wheelchairs with microprocessor-based and FPGA-based through wireless interface. Although references [11] and [12] can simplify and downsize the system with wireless and FPGA manner, the speed of electric wheelchair was limited since the "attention" signal is only one command to control electric wheelchair. In order to speed up the movement and occupy more commands to control an electric wheelchair, a SSVEP technique was used to extract brain signal on the occipital in this paper. The study also focused on paralyzed patients who can only use eyes and brain to exercise their willpower.

## 2 SYSTEM ARCHITECTURES

FIG. 1 shows the architecture of the proposed SSVEP-based EEG system with an SOPC platform through Bluetooth interface for electric wheelchair that includes a stimulating platform, EEG signal acquisition unit, signal processing unit, and electric wheelchair with SOPC platform. In the stimulating platform, three arrows, indicated moving ahead, turning left, and turning right for electric wheelchair, were flickered with different frequencies such as 9 Hz, 11 Hz, and 13 Hz on the LED screen of ASUS PadFone. Then, a patient gazes flickering target arrow to generate the correspondence frequency on his/her occipital. In this system, electrodes are attached on point FP2 of forehead for eyes winking and point Oz of occipital for stimulated frequencies. In the EEG acquisition unit, the EEG or eye winking signal was extracted and processed by a NeuroSky EEG chip. Then, these signals were transmitted through a Bluetooth transmitter to a Bluetooth receiver in the signal processing unit on the platform of ASUS PadFone. In addition to the Bluetooth receiver, the signal processing unit occupied FFT module to transfer EEG signal from spatial domain to frequency domain for recognizing frequencies or an eye winking signal detected on point FP2 with a peak pulse on spatial domain. When a suitable frequency or eye-winking pulse was detected, then they would be transformed into a correspondence commend and transmitted to the SOPC platform on the electric wheelchair through another Bluetooth interface. In the electric wheelchair with SOPC platform, a Bluetooth receiver to receive a command and 4-set ultrasound modules to detect obstacles are mounted through Universal Asynchronous Receiver/Transmitter (UART) interface. Then, these signals are converted by a Digital to Analog Converter (DAC) and transmitted by a General Purpose Input Output (GPIO) interface on the SOPC to control DC motors on the electric wheelchair.

### *2.1 EEG Acquisition Unit*

The EEG acquisition unit is shown as in FIG. 2. The brain wave is extracted by using of an acquisition chip produced by NeuroSky corporation and named TGAM1. The Bluetooth wireless module HL-MR08R-C2A serves as a data transmitter. HL-MR08R-C2A was selected because it has low-power consumption, supports many interface protocols (SPP, SDP, GAP, L2CAP, and RFCOMM), and can be designed a wireless interface with a simple manner. In order to effectively acquire the suitable EEG signals, 2-channel electrodes were bounded on the point FP2 of forehead, point Oz of occipital, and grounding electrode was tied on one's ear. The International 10-20 system is a reference to apply the locations of scalp electrodes for EEG extraction. The proposed system uses a set of channel for acquiring the wave signals. We used FP2 and Oz as the point of interception. A1 and A2 on the earlobes are set as the EEG reference points. The wet electrodes are placed on the occipital lobe of the scalp as shown as in FIG. 3.

FIG. 4 (a) is the NeuroSky EEG chip that works in voltage 3.3 V with 57600 transmission baud rate. The EEG are classified into five types in the TGAM1 including Signal quality, Attention, Meditation, Raw EEG, and Long EEG. The size of Raw EEG is 2 bytes. The size of Long EEG is 24 bytes including Delta, Theta, Low Alpha, High Alpha, Low Beta, High Beta, Low Gamma, and Mid Gamma. FIG. 4 (b) shows the Bluetooth module named HL-MD08R-C2A. In this paper, Raw EEG was used for detecting different frequencies from occipital lobe and extracted eyes-winking signal from forehead. It is used as transmitter in the EEG acquisition device. The transferred rate is 3 Mbit/s as well as the data transferred band is 2.4 GHz. The operating voltage is 3.3 V. In this paper the ASUS PadFone was

selected for the development platform.

### *2.2 Signal Processing Units*

In this paper, the EEG signals were transformed by the Fast Fourier Transform (FFT) into frequency domain. The FFT and its inverse manner are defined as Eqs. (1) and (2), in which the signals are transformed between spatial domain and frequency domain.

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{j2n\pi k / N} \tag{1}$$

$$x(n) = \sum_{k=0}^{N-1} X(k) e^{-j2n\pi k / N} \tag{2}$$

FFT is an efficient processing approach to compute the discrete Fourier Transform (DFT) of a digital signal to convert spatial signal into frequency domain. FFT reduces the number of computations needed for N points from $2N^2$ to $2N \log_2 N$. Therefore, EEG signal extracted from location Oz within 1 second in spatial domain is shown as in FIG. 5 (a). In FIG. 5 (a), we obtained 512–point amplitudes during a second with a 512 Hz sampling frequency. FIG. 5 (b) shows the frequency spectrum transferred from FIG. 5 (a) with FFT in Eq. (1).

The eye winking signal, being a high-voltage pulse shown as in FIG. 6, was used as "stop" command to force electric wheelchair stop movement while frequencies 9 Hz (arrow left), 11 Hz (arrow right), and 13 Hz (arrow ahead) were detected to transform to force electric wheelchair turn left, turn right, and move ahead.

### *2.3 Electric Wheelchair with SOPC Platform*

In the Electric Wheelchair with SOPC Platform, the commands were received from the Bluetooth interface and transmitted to the SOPC platform through an UART interface. The signals, detected by the 4-set ultrasound modules to detect obstacles at left, right, left front, and right front, were also sent to the SOPC module by an UART.

We utilized a 32-bit Redundancy Instruct Set computer (RISC) SOPC platform, built in XILINX SPARTAN-3 (SP3) XC3S500E-PQ208, as a processing unit for commands and ultrasound signals. These signals were implemented by using of C language in order to transform the commands and obstacle signals into 4-set D/A converters by a GPIO interface. The 4-set D/A converters convert digital signals, transmitted by GPIO, to several analog signals to drive DC motors on the electric wheelchair. The SP3 FPGA occupies 500 K system gates equivalent a number of 10476 logic cells. It uses eight independent I/O banks to support 24 different single-ended and differential I/O standards and allows us to easily migrate different densities across multiple packages. The SP3 SOPC platform integrates many Silicon Intellectual Property (SIP) modules, including the RS-232, RJ-45, USB, expand I/O pin, etc. The processing of commands and ultrasound signals can be developed by the Xilinx Embedded Development Kit (EDK), in which the Platform Studio (XPS) and IP cores (including a 32-bit soft-RISC-CPU MicroBlaze) are supported. In addition, we organized off-chip memory with a 16-mB SDARM as well as a hyper terminal through an internal IP named UART Lite.

The 4-set D/A converters, were used to generate different voltages to mount on the connecter to replace the joystick module of the VR2 wheelchair control system (PG Drivers Technology). The electric wheelchair, control by VR2, is shown as in Figure 7.

## 3 EXPERIMENTAL RESULTS

The experimental environment is also to refer the scenario in the reference [11]. The length of travel path for the electric wheelchair from start point and bypassing two tables then going back to original point is about 24 meters. We also selected seven healthy young people. Everyone must test 3 times. The experimental results for the consuming time are shown as in TABLE I. From TABLE I, we can find that the average consume time of the proposed SSVEP-based electric wheelchair (03:34) is faster than the system in reference [11] (07:14) over two times. The maximum consuming time for the proposed system were less than 5 minutes and 30 seconds while the maximum consuming time is 12 minutes and 52 seconds for the reference [11]. From the experimental results,

promising results can be obtained by the proposed electric wheelchair.

TABLE 1 CONSUMING TIME FOR DIFFERENT SUBJECTS

| Subject # | Consuming Time (min:sec) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Test 1* | | *Test 2* | | *Test 3* | | *Average time* | |
| | [11] | Proposed | [11] | Proposed | [11] | Proposed | [11] | Proposed |
| 1 | 04.08 | 03:38 | 03:48 | 03:07 | 04:15 | 03:32 | 04:04 | 03:26 |
| 2 | 07:07 | 03:06 | 07:11 | 03:09 | 05:47 | 03:07 | 06:42 | 03:07 |
| 3 | 07:59 | 02:58 | 06:31 | 02:50 | 06:42 | 03:00 | 07:04 | 03:00 |
| 4 | 04:46 | 03:39 | 03:42 | 03:00 | 05:16 | 03:12 | 04:35 | 03:12 |
| 5 | 07:24 | 05:20 | 06:56 | 05:12 | 07:45 | 05:09 | 07:22 | 05:09 |
| 6 | 08:48 | 03:57 | 07:28 | 03:48 | 10:25 | 03:57 | 08:54 | 03:57 |
| 7 | 10:34 | 03:20 | 12:52 | 02:58 | 12:22 | 03:06 | 11:56 | 03:06 |
| ***Average time*** | **07:14** | **03:34** | | | | | | |

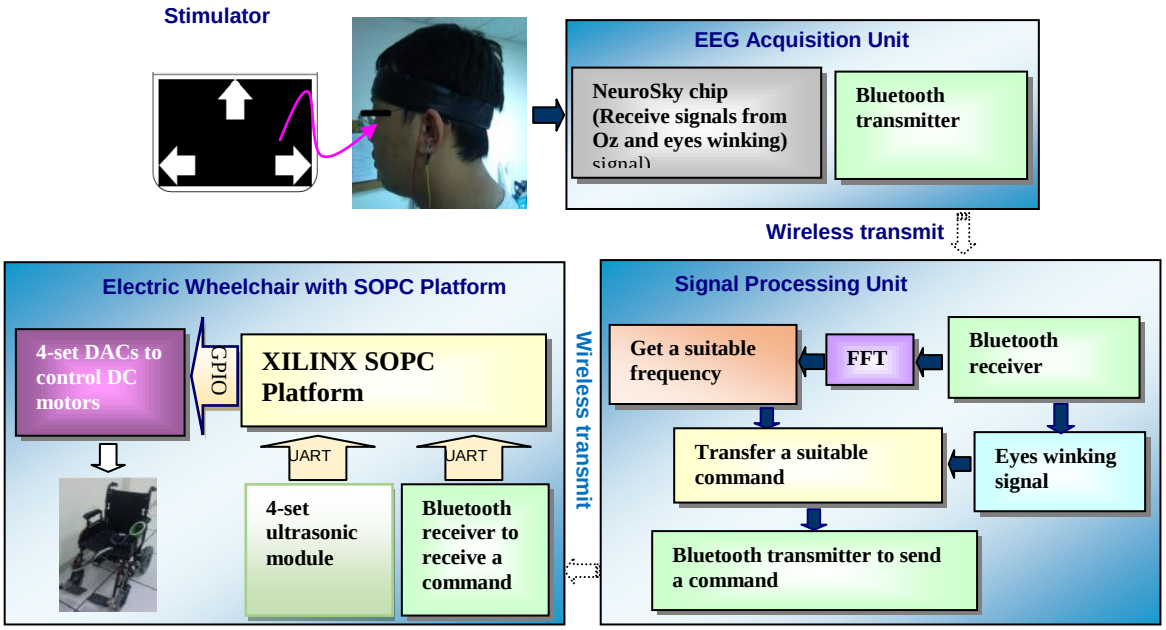



FIG. 1 SYSTEM ARCHITECTURE OF AN SVEP-BASED ELECTRIC WHEELCHAIR



FIG. 2 THE EEG ACQUISITION DEVICE. (A) EEG CAPS; (B) ELECTRODE PADS; (C) NEUROSKY CHIP; (D) BLUETOOTH MODULE; (E) POWER SUPPLY

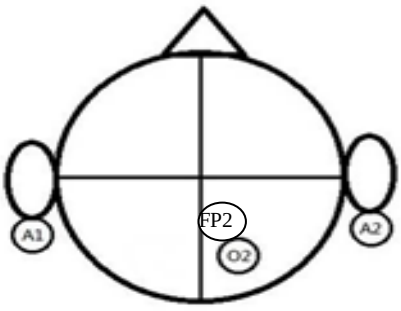
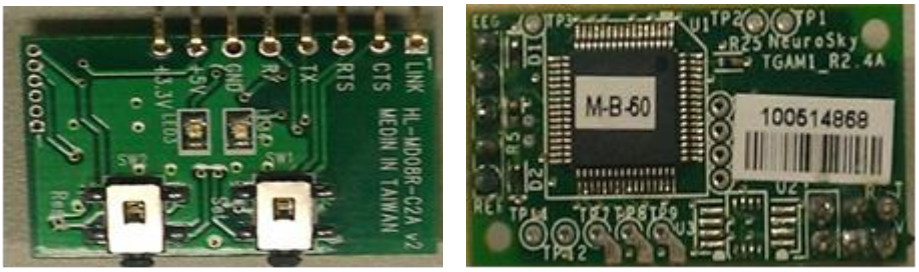
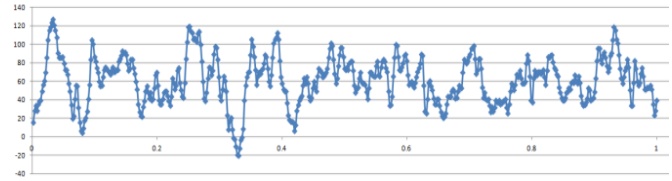



FIG. 3 THE ELECTRODE LOCATIONS ON OCCIPITAL LOBE

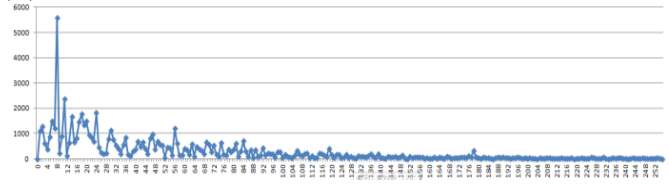



(A) (B)

FIG. 4. ACQUISITION MODULES: (A) NEUROSKY EEG MODULE; (B) BLUETOOTH MODULE



(A) EEG SIGNALS DURING 1 SECOND ON SPATIAL DOMAIN



(B) SPECTRUM ON FREQUENCY DOMAIN FROM 0 TO 255 HZ

FIG. 5. EEG SIGNALS: (A) EEG SIGNAL ON SPATIAL DOMAIN, (B) SPECTRUM ON FREQUENCY DOMAIN

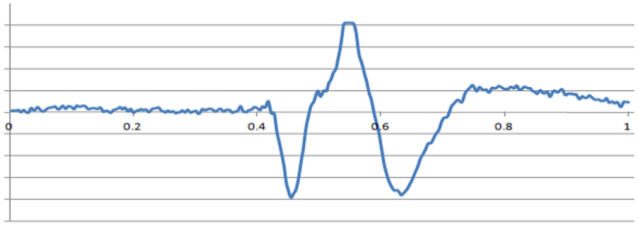



FIG. 6. EYE-WINKING PULSE

## 4 CONCLUSIONS

In this paper, SSVEP-based EEG signal on the occipital lobe Oz and eye-winking signal on the forehead FP2 through a BCI interface for electric wheelchair with wireless scheme was proposed. In the proposed system, the patients just gaze the winking target to select different directions to force an electric wheelchair move ahead, turn left or right. The eye-winking detected from FP2 was used to enforce wheelchair stop. 4-set ultrasound modules were to detect the obstacles around the wheelchair. From the experimental results, the proposed SSVEP-based electric wheelchair is low cost and easier control for the patients.




FIG. 7. VR2-CONTROLLED ELECTRIC WHEELCHAIR

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## REFERENCES

[1] Cabrera F., Nascimento O. F. do, Farina D., and Dremstrup K. "Brain-Computer Interfacing: How to Control Computers with Thoughts," 1st International Symposium on Applied Sciences on Biomedical and Communication Technologies, (2008):1-4

[2] Wolpae J. R., Birbaumer N., McFarland D. J., Pfurtscheller G., and Vaughan T. M. "Brain-Computer Interfaces for Communication and Control," Clin. Neurophsiol, 113 (2002): 767-91

[3] Fabiani G. E., McFarland D J., Wolpaw J. R., and Pfurtscheller G. "Conversion of EEG activity into cursor movement by a brain-computer interface (BCI)," IEEE Trans. on Neural Systems and Rehabilitation Eng., 12 (2004): 331-38

[4] Nawrocka A., and Holewa K. "Brain - Computer Interface based on Steady – State Visual Evoked Potentials (SSVEP)," 14th International Carpathian Control Conference (2013): 251-254

[5] Bi L., Li Y., Jie K., and Fan X., "A New SSVEP Brain-computer Interface Based on a Head Up Display," International Conference on Complex Medical Engineering, Beijing, China, (2013): 201-204

[6] Kelly S. P., Lalor E. C., Reilly R. B., and Foxe J. J., "Visual Spatial Attention Tracking Using High-Density SSVEP Data for Independent Brain–Computer Communication," IEEE Trans. on Neural Systems and Rehabilitation Engineering, 13(2005): 172-78

[7] Montesano L., Diaz M., Bhaskar S., and Minguez J., "Towards an Intelligent Wheelchair System for Users with Cerebral Palsy Users," IEEE Transactions on Neural Systems and Rehabilitation Engineering, 18 (2010): 193-202

[8] Tanaka, K. Matsunaga K., and Wang H. O., "Electroencephalogram-Based Control of an Electric Wheelchair," IEEE Trans. on Robotics, 21 (2005): 762-66

[9] Gal án F., Nuttin M., Lew E., Ferrez P. W., Vanacker G., Philips J., and Mill án J. d. R., "Abrain-Actuated Wheelchair: Asynchronous and Non-invasive Brain-Computer Interfaces for Continuous Control of Robots," Clinical Neurophysiology, 119 (2008): 2159-2169

[10] Cho S-.Y., Vinod A. P., and Cheng K. W. E., "Towards a Brain-Computer Interface Based Control for Next Generation Electric Wheelchairs," Int. Conf. on Power Electronics Systems and Applications, (2009): 1-5

[11] Lin J.-S., and Yang W.-C., "Wireless Brain-Computer Interface for Electric Wheelchairs with EEG and Eye-Blinking signals," Int. J. of Innovative Computing, Information and Control, 4 (2012): 2973-80

[12] Lin J. -S., and Huang S. -M., "An FPGA-Based Brain-Computer Interface for Wireless Electric Wheelchairs," Applied Mechanics and Materials 284-287 (2013): 1616-21

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