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大專學生參與專題研究計畫研究成果報告

* 計畫 *
* : 以腦波控制外骨骼機器人之研究 *
* 名稱 An EEG-based Approach for Exoskeleton Control *

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Abstract

For people suffered from spinal cord injury or stroke, since the connections between the cerebral cortex and the muscles were interrupted, the motor function of the patients is damaged and not able to restore. However, with the advance in the research of brain-computer interface (BCI), it is possible to develop a brain-actuated prosthetic or exoskeleton to compensate the inconvenience.

In this paper, a noninvasive brain-actuated robot system was developed. Using commercial BCI device, the human electroencephalogram (EEG) was recorded and processed in real-time. The analyzed results were mapped to corresponding commands to control robot. The system developed was able to distinguish 2 different mental states, in addition to neutral. To validate the results, an experiment was performed to compare mental control and manual control on the same task, the result showed that the average error between mental and manual control is less than 1.5 seconds.

Keywords: exoskeleton; brain-computer interface; electroencephalogram; robot

1. Introduction

The idea of controlling apparatus simply by thinking has been dreamed by scientists, engineers, and science-fiction authors for decades. With the advance in neuroscience, electromechanical engineering and information technologies, the development of BCI is coming to its prime time for application.

The method to control outer actuator via brain activity can be categorized as invasive and noninvasive, respectively. For invasive approach, it is relied on intracranial electrodes implanted in the motor cortex of subjects, and is currently accomplished by animal experiments, such as rats and monkeys [1]-[3]. However, noninvasive technique is more preferable for human, since it does not need surgery to implant electrodes. To measure brain activity noninvasively, both EEG and functional magnetic resonance imaging (fMRI) are considered. Among them, using fMRI to measure brain activities is accurate and able to produce detail map of brain in any plane desired [4]. Nevertheless, the large size and the powerful magnetic field generated by the fMRI scanner confined the application of the device to medical inspection solely [5]. On the other hand, EEG-based brain-machine interface is portable, easy to use, and able to acquire signals in real-time, which is feasible to achieve brain-actuated control of the robot. The drawback of EEG-based brain-machine interface is that the EEG signals are suffered from reduced in special resolution. Therefore, rather than detecting motor activities in the motor cortex, EEG signals only provide mental states caused by millions of neurons under the scalp [4]. However, the mental states acquired through EEG are sufficient to develop brain-actuated devices [6]-[8].

Although it is appropriate to develop brain-machine interface via EEG-based BCI, the typical costs of the machines are expensive since they are targeted to medical use. Recently, some companies are dedicating to commercialize the BCI devices in lower cost and are currently available in the market. In this paper, a brain-actuated robot system was proposed by utilizing the commercial BCI device. The experiment results show that the proposed system has feasible mental control compared to manual control for the same task.

2. Materials and Methods

2.1. Materials

The hardware setup includes a commercial BCI device, *Emotiv EPOC*, a *LEGO Mindstorms NXT* robot, an exoskeleton for upper limb, and a personal computer.

The *Emotiv EPOC* headset (Fig. 1) was used to acquire EEG signals, and the data was transferred wirelessly to personal computer. The headset was accompanied with the self-development kit (SDK) for software development.



Fig. 1 *Emotiv EPOC* headset.

The headset has 14 electrodes, which were located on AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 based on the 10% electrode positions. These positions are standardized by American EEG Society, as shown in Fig. 2 [9].

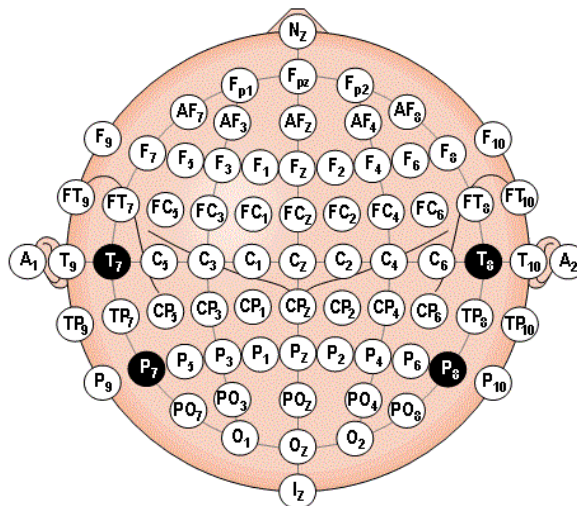


Fig. 2 10% electrode positions [9].

The *LEGO Mindstorms NXT* was used to construct a dual wheels robot (Fig. 3) in order to test the program before applying to the exoskeleton. *LEGO Mindstorms NXT* is one of the most popular platforms for robot education. The set include a programmable brick, *NXT*, which is support by almost all programming languages available. The program can be executed by either the brick independently or via computer as the host, depend on the

programming tool used. In this study, the program was executed on the computer, and the brick was connected to the computer wirelessly through Bluetooth.



Fig.3 *LEGO Mindstorms NXT*, which was used to verify the program.

The exoskeleton has two degree of freedom since two electrical drives were used. The axes were located on elbow and shoulder joints, respectively, as shown in Fig. 4. The exoskeleton is the property of the bio-photonics and bio-imaging laboratory, bio-industrial mechatronics engineering department, National Taiwan University.

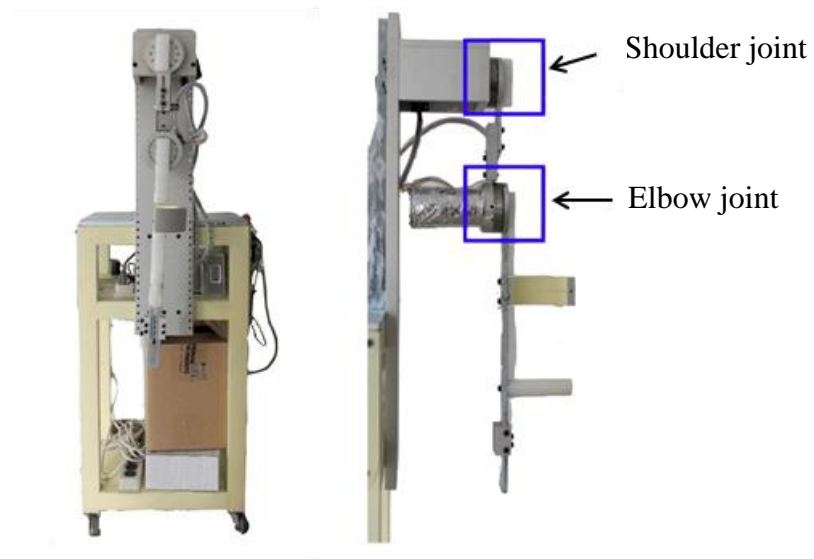


Fig. 4 An two degree of freedom exoskeleton for upper limb.

The personal computer consists of Intel Core2 Duo CPU 3.0GHz, 4GB RAM, and ATI Radeon HD 4670 Graphics Card. The operation system is Microsoft Windows 7 Enterprise edition. The software development environment was Visual Studio 2008, using C++ language. The dynamic link libraries (DLLs) provided by *Emotiv* were used to analyzed EEG signals.

The system architecture is illustrated in Fig. 5. The *Emotiv EPOC* send EEG data wirelessly to personal for real-time analysis, the result was then mapped to the event that the robot would actuate. Either *LEGO NXT* robot or the exoskeleton can be control. For

LEGO robot, the command was sent from personal computer to *NXT* via Bluetooth, and for exoskeleton, the command was sent via physical wire, which signal type is RS-232.

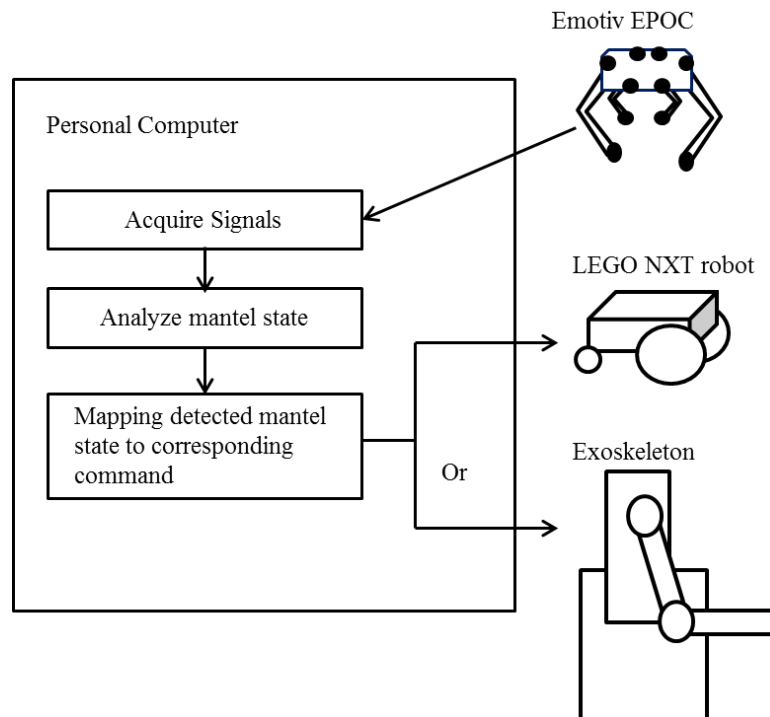


Fig. 5 Architecture of the system.

2.2 Signal Acquisition and Analysis

The system acquires 14 channels of EEG signals from the headset, and sends the data to personal computer under user datagram protocol (UDP) rather than transmission control protocol (TCP) in order to achieve real-time transmission, since the UDP does not spend time on checking packets' loss or error. Prior to the experiment, the subject need to establish a profile for specific mental states, this can be accomplished by the SDK provided from *Emotiv*. During the training process, the subject was first told to remain neutral for 8 seconds, and then focus on a specific event, such as push or turn right, for another 8 seconds. The recorded patterns were stored and can be called from the program. The SDK has the capability to store up to 4 different mental states (neutral state is not count). However, in this study, only two mental states are sufficient. Furthermore, the SDK also provide sufficient application programming interfaces (API) for software development. The *Emotiv* API is exposed as an ANSI C interface that is declared in 3 header files and implemented in 2 Windows DLLs [10]. With the API functions provided, the EEG signals can be analyze in real-time. The outputs of the analysis contain two arguments: mental state and the consistency of the state, where the consistency of the state can be consider as power. The procedure can be figured as Fig. 6, where *state_1* and *state_2* is the specific mental states that were trained.

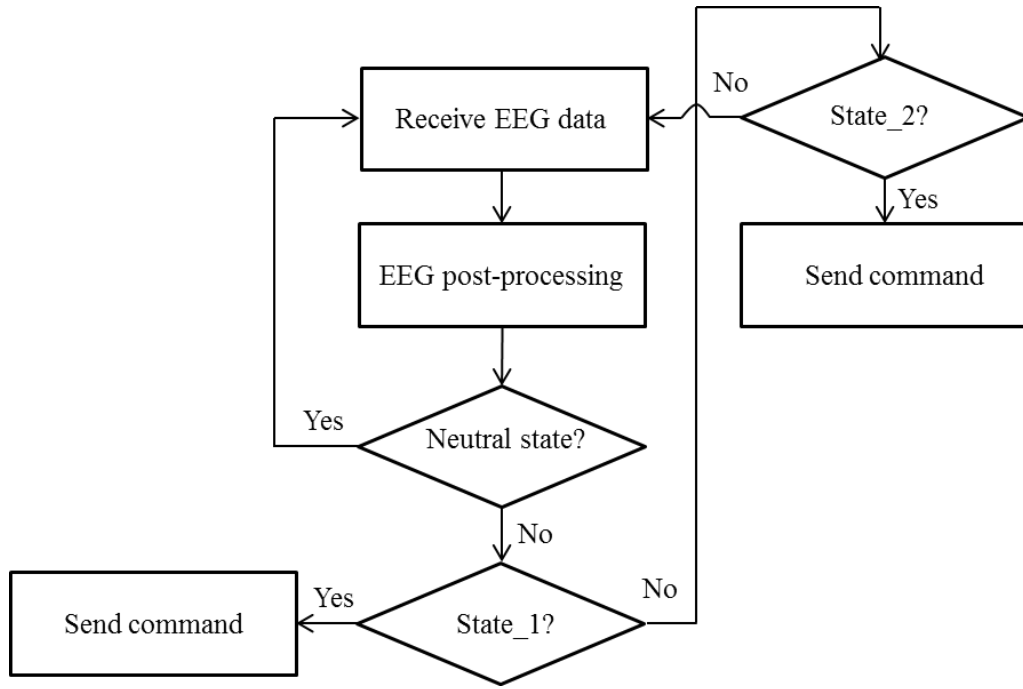


Fig. 6 Block diagram of the analysis procedure.

2.3 Control Strategies

After calling the API function, the return values can be utilized immediately. For controlling *NXT* robot, the mental states returned were used to decide the behaviors of the robot. Addition to the neutral state, there were two more mental states trained, push and turn. If the mental state is neutral, the two motors of the robot will break; if the mental state is push, the robot will drive forward; and if the mental state is turn, the robot will turn clockwise. The speeds of the motors are decided by the consistency of the state, and if the state is turn, the motors will drive in opposite direction.

The control strategy for exoskeleton is different from the *NXT* robot. Since the exoskeleton is for rehabilitation, the speeds of the motor drives are constant. Further, a threshold value, TH_{act} , was defined to control whether the exoskeleton should actuate or not based on the consistency level returned by the API function, as shown in (1):

$$TH_{act} = \begin{cases} 1 & \text{if } E(n) > \text{Max}(E'(n)) - 3\sigma_E \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

In (1), $E(n)$ is the function of the consistency level returned by the API function during the trial; $E'(n)$ is the function of the consistency level that obtained before the trial; σ_E is the standard deviation of $E'(n)$. Applying (1) during the trial can ensure that the mental state of the subject is stable.

3. Results and Discussion

3.1 Experimental Setup

The EEG of one healthy subject (male, 22 years old) was measured and analyzed. The subject was told to sit still during the measuring process, since any movement, especially facial movements, will cause order types of signals, such as electromyography (EMG) that will interfere the EEG signals. The subject had trained an individual profile containing one mental state, push, in addition to neutral state. During the experiment, the subject was told to remain neutral for a period of time and think push for about 5 seconds. Meanwhile, when thinking about push, the subject was told to press a button on keyboard by hand simultaneously. Therefore, the mental control and the manual control of the same task can be compared. The data was saved as text files for further analysis.

3.2 Control of Robot

To control *LEGO NXT* robot, once the mental state detected, the computer will send command to the robot via Bluetooth connection. For neutral state, the break command will send, making the robot to stop, and for push state, the move command will send, making the robot to go straight. Adapting the strategy proposed in (1), the control for the exoskeleton required stable mental state to operate and the commands were sent by RS-232 cable. In the experiment, the manual control did not affect the operation of the robots, and was recorded only for validation purpose.

Table 1 Time in seconds for ten different trials.

Trial number	Mental start	Manual start	Error	Mental stop	Manual stop	Error
1	21.5185	18.5159	3.0026	26.5228	25.5219	1.0009
2	35.7808	34.5297	1.2511	43.037	42.9119	0.1251
3	35.0622	35.0614	0.0008	43.3185	42.3176	1.0009
4	68.8091	67.5581	1.251	74.5641	73.0628	1.5013
5	79.6309	79.5058	0.1251	84.7603	83.7595	1.0008
6	43.5687	43.0683	0.5004	54.8284	54.0777	0.7507
7	14.575	13.4491	1.1259	19.7044	19.204	0.5004
8	58.2141	54.7111	3.503	62.9682	63.0933	-0.1251
9	14.9816	15.3569	-0.3753	29.369	25.2404	4.1286
10	26.4602	25.4594	1.0008	35.2178	34.9676	0.2502
Mean			1.13854			1.01338
Standard Deviation			1.188709			1.137669

The errors between mental and manual control are shown in Table 1. The first column indicates the trial numbers. There were 10 trials in total for one subject for the same task. For each trial, the table shows the time pasted that the event occurred after the experiment started. Since the start time and stop time were not limited and was depend on the subject, therefore the average and standard deviation were not reported. From Table 1, it can be observed that the mental control shared an average error about 1 second lag than manual control. The delay of the mental control is reasonable and can be referred to the processing time of the program. However, there were also a few data indicated that the mental control was prior then manual control. Since the program needs time to detect the mental state, the manual control must be lead to mental control Therefore, the lead of the mental control can be referred to the subject changed the mental state earlier then pressing the button.

4. Conclusion

The system proposed utilized the commercial BCI device and successfully developed a brain-machine interface that is able to operate by user in real-time wirelessly. The system developed only require two mental states in addition to neutral state and is therefore easy to achieve accuracy as long as the subject is well trained and is familiar to maintain the mental state consistently. However, as the mental states increase, it will be much difficult to achieve accuracy and will need more time for users to train. Furthermore, EEG signals can be interfered by other type of signal easily, such as EMG and electrooculography (EOG). According to the observation from the raw data, the facial movements have the strongest influence to EEG signals, since the facial movements will affect scalp movement. Therefore, the users need to eliminate the muscle content while using the device.

The experimental results showed that the errors between the manual control and mental control are less than 1.5 seconds in average. For practical applications that do not need fast respond, the errors are acceptable. For future works, the further research will take advantage on raw EEG data to seek a solution to eliminate the effect of the signals other than EEG so that the users can operate the devices in more convenient way.

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