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Towards a Brain-Computer Interface Based Control for Next Generation Electric Wheelchairs

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Abstract–This paper presents an idea of building a Brain-Computer Interface (BCI) based control for next generation electric wheelchairs. The aim is to explore the area of research on BCI based control to potentially develop a next generation of electric wheelchair which is able to benefit to paralyzed patients. This EEG interfacing development controls a wheel chair through a skid steering method. The mechanical part including the conventional steering can be eliminated. It also uses differential speed that controls the propulsion and turning. The system is neat, low cost and high dynamic performance; it can be used for stoke patent or disabled patents.

Keywords–Brain-Computer interface, signal processing, next generation electric wheelchairs, skid steering.

I. INTRODUCTION

An electroencephalogram (EEG) is a recording of the electrical potentials generated by the brain on the scalp. Due to the relative simpler technology and smaller time constants when compared to other noninvasive methods such as MEG, PET and fMRI, EEG has become a powerful means for monitoring brain activity in therapeutic and neurophysiologic research. It is known that observable changes occur in EEG depending on the mental task performed by a subject [1]. Based on this fact, a new communication system between brain and a computer has evolved, in which the information support is the EEG pattern, voluntarily generated by the user and independent of any muscular activity. EEG biofeedback has been used in the viable alternative treatment for Attention Deficit Hyperactivity Disorder (ADHD) successfully [2]. Users that receive the neurofeedback show greater attention and less hyperactive and impulsive behaviours. The EEG biofeedback therapy (EGT) play a major therapeutic role in many different areas. The application of the EEG for machine interfacing is now a rehabilitation research area. Such a system that allows us to translate in real-time the electrical activity of the brain in commands to control devices is called a Brain-Computer Interface (BCI) [3].

BCIs provide communication and control for people with severe motor disabilities (Amyotrophic lateral sclerosis (ALS), brainstem stroke, brain or spinal cord injury, cerebral palsy, muscular dystrophies etc.). The immediate goal of BMI is to provide these users, who may be completely paralyzed, with basic communication capabilities so that they can express their wishes to caregivers, or even operate switches, word processing programs, and move artificial limbs. It has been shown that locked-in patients are able to achieve EEG-controlled cursor movement and patients have successfully communicated by means of a BCI [4].

There is a rising trend in the growing recognition needs of BCI system. This is due to the potentials of people with disabilities, the leading advancement of low-cost computer equipment and better understanding of brain function. These existing BCI systems focus on developing new improved control and communication technology for those with severe neuromuscular disorders. The main concern is to provide these users who may be completely paralyzed with basic communication capabilities so that they can express their wishes to caregivers or even operate word processing programs.

In this paper, we propose a potential technology to incorporate interactivity value in a BCI system to control the next generation of electric wheelchair. Currently, the scope of this work is to build a BCI system that allows communication between human and machine and to provide real-time translation of electrical activity of the brain into command to control the wheelchair.

II. BACKGROUND OF BRAIN-COMPUTER INTERFACE

A Brain-Computer Interface (BCI) is a communication system that allows users to communicate without movement with the external world [3]. For individual with neuromuscular disabilities, they are unable to deliver commands or messages through the brain's normal output pathways of peripheral nerves and muscles. Instead, BCIs are the only means to infer user intent through direct measures of brain activity, usually via EEG signals. A BCI replaces the disabled nerves and muscles by translating EEG signals from a reflection of brain activity into user action through the system's hardware and software. One major concern is how well a BCI system reacts toward the user's brain activity. Hence, an excellent BCI must response to the user's feedback and vary to adapt in a fast and dynamic fashion. This implies the smooth translation of the user's intention is to depend on the interaction of the two adaptive controllers: the user's brain and the BCI system itself.

Similar to any communication and control system, a BCI consists of an input channel (i.e., brain signal from user), output channel (i.e., device command) and a translator that does the classification. The translator is governed by a protocol that determines the degree of adaption and timing constraints of the BCI operation. Thus, all BCI should be made up of at least four components [5]. These components are signal acquisition, feature extraction, signal classification and the operating environment. Figure 1 shows these components and their interaction between each other in a BCI system.

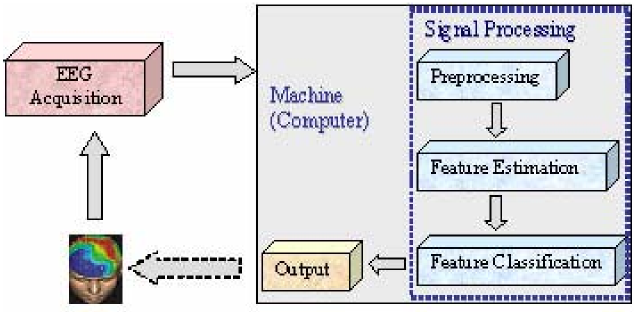


Fig. 1: Basic Design and Operation of a BCI System

1. Signal Acquisition

BCI system can be grouped into non-invasive (e.g. EEG) or invasive (e.g. intracortical) methodology for the signal acquisition [1]. The system can also be categorized by whether the system draws on impulsive or evoked inputs. Impulsive inputs (e.g. EEG rhythms over sensorimotor cortex) are independent inputs that do not generated from any stimulation. Evoked inputs (e.g. EEG produced by flashing letters) are those signals that resulted from artificial sensory stimulation provided by the BCI. During the signal acquisition of the BCI operation, the user performs a task that has a distinctive EEG signature. As the user is executing the action, the electrodes attached onto the user's scalp record the necessary brain signal. Subsequently, the input signal is being amplified and digitized before sending the signal for processing.

2. Signal Processing: Feature Extraction

During this part of BCI operation, the digitized signals are to undergo either a single or combination of feature extraction procedures. The procedures that can be used consist of spectral analyses, single-neuron separation, spatial filtering or voltage amplitude measurements. These processing procedures will extract the specific signal features of the digitized signals. Subsequently, the signal features in the frequency or time domain are used to aid in the encoding of the user's intent. For existing BCI system, most of the used signal features reflect particular brain events such as the rhythmic synaptic activation in sensorimotor cortex that produces a Mu rhythm or the firing of a specific cortical neuron. In addition, knowledge of the correlation between the brain events and the signal features can benefit and help to guide development in BCI system.

3. Signal Processing: Signal Classification

The BCI depends on its classification algorithm to encode the extracted signal features for interpreting the user's intent into device commands. The algorithm used is to translate independent variable (e.g. signal features) into dependent variables (e.g. device commands). This mapping relationship allows the system to work out the user's intent easily. The effectiveness of a classification algorithm depends on the level of adaption. The first level is the initial adaptation to the individual user. Next, the second level is the spontaneous adaptation to continuous and sudden changes in the user's performance. Finally, the third level of adaptation is the most effective but difficult of all level. It involves the interaction of the two adaptive controllers, the BCI system and the user's brain.

III. OUR BRAIN-COMPUTER INTERFACE SYSTEM

The BCI data acquisition software is developed based on a software module namely, ACQUIRE, which is a fast and flexible tool for dependable EMG/EEG signal acquisition. The module is able to record continuous, averaged and epoched EMG/EEG data up to 64 channels with the SCAN 4.3 system. Using the data acquired from the NuAmps, SynAmps or SynAmps2 amplifiers, the module can perform various techniques of online signal processing on those data. Generally, there are three main steps to obtain EMG/EEG data with ACQUIRE software. The first step is to either create a new setup file or load an existing one to configure the system. Then, the second step is to enter the subject's information. Lastly, the final step is to run the program to acquire and record down the data.

Figure 2 and 3 show to illustrate the position of the sensor on the headband and the equipment used in the data acquisition process. When the user has worn the equipment and the amplifier is connected to the computer, the next thing is to verify the connection and impendence. Ensure that the reference for the signal is setup by selecting A1 as the reference. Lastly, verify that the impendence for the sensors should be at least in the middle or lower range.

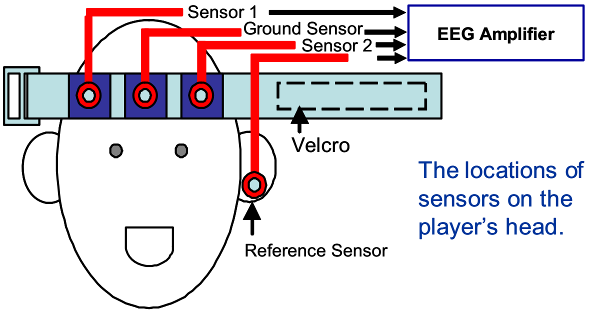


Fig. 2: Location of Sensors on a Subject's Headband

Fig. 3: Equipment used for the Data Acquisition Process

In this research, the acquired brain signal is processed and classified to interpret the subject's intention for next generation electric wheelchairs. Based on the classified signal (i.e., left, right, go forward or go backward), the system uses the signal for controlling the wheelchair's movement.

The design goal of the research is to provide interactivity and rehabilitation values in BCI system. Generally, the project can be broken down into two main layers. The two layers are namely the data acquisition layer and the user interface layer. Together with the two layers' functionality, it seems rather similar to the two-tier architecture. Hence, the proposed software architecture to be used for the system is the two-tier architecture.

For this project, the user interface and data acquisition layers respectively will be the presentation and data tiers. Firstly, the data tier acquires data from the subject and classifies them into category. Then, the presentation tier does the job of presenting the results to the user. The advantages of using this approach are that applications are easy to manage and any modifications to the tier can be controlled effortlessly. The two-tier approach also provides better performance in terms of overall efficiency, reusability and maintainability of the system.

IV. SIMULATION

The simulations performed for the proposed BCI system are by integrating with a simple soccer game in which the user is supposed to control the goalkeeper to catch the incoming ball kicking by the striker which is controlled by the computer. Several test cases are carried out to test out the functionality of those required features in data acquiring and user interface modules. Below are the test cases involved in the functional test.

- Test Case 1
  The aim is to verify that the data acquisition module is able to perform the acquiring and classification of data to the subject in real-time. During the testing, the system performs data acquisition and classification on the data. The console displays output with the value of either -100, 0 or +100 at the speed of the sampling rate.

- Test Case 2
  The aim is to verify that the user interface module is able to update the image of the form using the classified data from the data acquiring module. During the testing, the form displays the corresponding movement of the image based on the classification of the data, either -100, 0 or +100 at the speed of the sampling rate.

V. NEXT GENERATION OF ELECTRIC WHEELCHAIRS

The basic idea of the BCI based control for next generation of electric wheelchairs is shown in Figure 4. Signals from the brain are acquired by electrodes on the scalp or in the head and processed to extract specific signal features (e.g. amplitudes of evoked potentials or sensorimotor cortex rhythms, firing rates of cortical neurons) that reflect the user's intent. These features are translated into commands that operate a wheelchair. Success depends on the interaction of two adaptive controllers, user and system. The user must develop and maintain good correlation between his or her intent and the signal features employed by the BCI; and the BCI must select and extract features that the user can control and must translate those features into device commands correctly and efficiently.

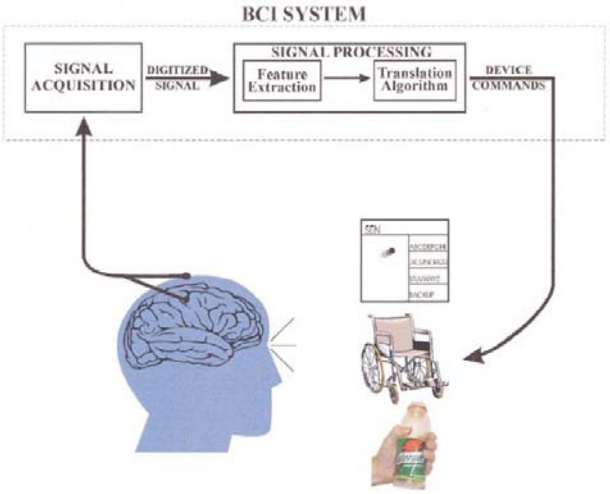


Fig. 4: A basic idea of BCI based control for next generation electric wheelchair (adopted from [3])

VI. INTERFACING TO MOTOR DRIVES

The motion control of electric wheelchair is through a motor drive to a motor. There are several selection of the motor. As the wheel chair is a DC operated, the use of a DC based motor is used. There are two low cost and high performance motor can be used. They are the conventional DC motor [6], DC brushless motor [7] and the switched reluctance motor[8]. Other motors such as the induction motor and AC synchronous are not suitable because their voltage is usually biased to high voltage. For low cost solution, conventional DC motor is used. For higher performance, the DC brushless motor or switched-reluctance motor is used because of their brushless and higher dynamic feature. Fig 5 shows the base view of the system. Two motors are used to provide both the propulsion and the steering. The steering is based in skid steering as in a tank [8]. No angle steering is needed. The controller is a motor drive that provides the power signal to the motor. The CCU is the central control unit that contains all the control electronics and algorithms. It accepts user's input to provide the wheel chair.

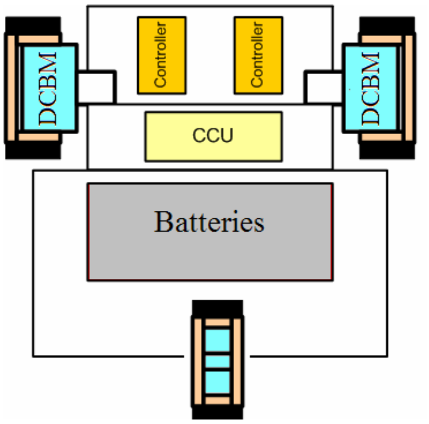
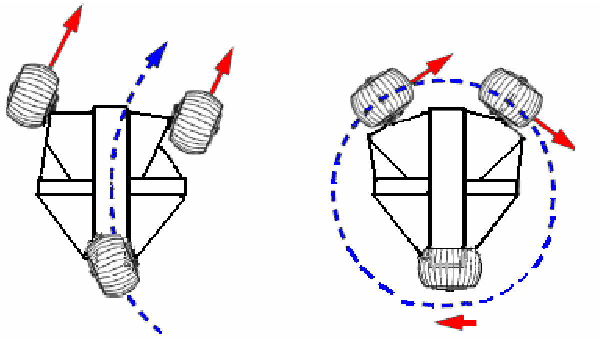


Fig 5: Base view of the wheel-chair system

The control diagram is shown in Fig 6. The BCI is to provide the command signal to the CCU and it therefore provides the speed and torque control of each of the wheel. The differential speed being zero means straight ahead. The differential speed of +ve or –ve controls the left and right turning respectively.

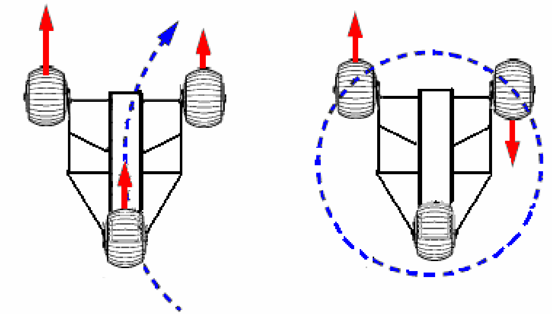
VII. STEERING CONTROL ELECTRIC WHEELCHAIRS

The conventional explicit steering is using the angle turning on the wheel. Fig 6 shows the angle tuning on the front wheel of the wheel chair. The requirement of the mechanical subsystem is significant and it requires significant maintenance and has higher material cost. The dynamic response is slow. High dynamic response is needed in order to compensate for the slow response of certain patents or users. This is especially important for road users or used in areas with a lot of traffic or pedestrians. Using the differential speed on the front wheel and the rear wheel is free-running, the skid steering can be realized. Fig 7 shows the mechanism. It can be seen that for large radius of angle, the speed between two front wheels is small. The base panel or the chassis can be a fixed structure rather than in explicit steering, the wheel alignment and steering axis design are more complicated. When a sharp turning is needed, the two wheels will be in different rotational directions. The differential speed is then maximum.



(a) Right turn (b) Point or sharp right turn

Fig 6: Angle turning for the explicit steering



(a) Right turn (b) Point or sharp right turn

Fig 7: Skid steering using differential speed

VII. TORQUE AND STEERING CONTROL

When the wheelchair is driven in a straight line, the torque is given by:

$$T = F_f + F_w + m \cdot a_x \tag{1}$$

where a_x is longitudinal acceleration, { EMBED Equation.3 } is wind block force and { EMBED Equation.3 } is roll resistance force. They are usually small for slow motion of the wheel chair. The sum of the inner wheel torque and the outer wheel torque,

$$T_{inner} + T_{outer} = 2T \tag{2}$$

The torque of each motor is controlled in order to give direct torque and delicate motion control during the turning. The skid steering model is shown in Fig 8. From proportional relationship of similar triangles, the desired turn radius{ EMBED Equation.3 } and the desired yaw rate{ EMBED Equation.3 } are calculated below.

$$R_{desired} = \frac{v_o + v_i}{v_o - v_i} \cdot \frac{d}{2} \tag{3}$$

$$\gamma_{desired} = \frac{v_o - v_i}{d} \tag{4}$$

where v_o and v_i denote the desired outer wheel speed and the inner wheel speed respectively, v_{actual} the actual vehicle speed, and{ EMBED Equation.3 } represents the distance between the left and the right wheels.

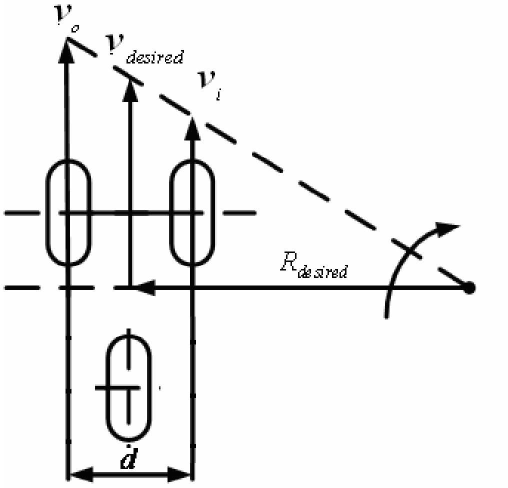


Fig 8: Skid steering model

The reference yaw rate can be calculated from the following equation

$$\gamma_{desired} = \frac{v_o + v_i}{2R_{desired}} = \frac{v_{actual}}{R_{desired}} \tag{5}$$

The CCU is to control the yaw rate to be zero for straight ahead, positive for right turn and negative for left turn. This will control differential speed of the two wheels.

VIII. ELECTRICAL PERFORMANCE

The wheel chair is powered by a motor and its energy source is through the battery. Fig 9 shows the block representation. The battery set is a lead-acid or lithium–ion battery that depends on the cost specification by the users. The cost for each is different by 5 times. Two 12V 17Ahr batteries are used that provide 24V for the whole system. The 24V is directly connected to the controller of the motor to support the main power. Another DC-DC converter is used to give low voltage 5V/12V to the CCU and BCI. They are small power consumption for less than 30W.

The motor is a DC brushless motor of peak 300W. The total power needed is 600W. The nominal power for flat road is only less than 100W. The energy storage for the battery is around 400Whr that can provide a travelling distance 20km that is suitable for a user of one week travelling. The charging system is a plug-in to AC mains that can charge the battery in 4 hours using a high power battery charger system that provide 3-stages of charging method.

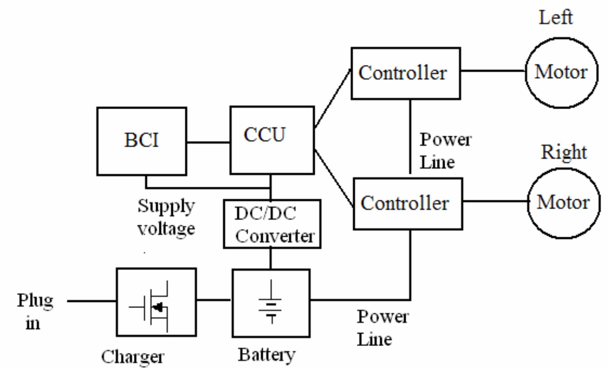


Fig 9: System diagram

IX. CONCLUSION

An EEG signal with BCI is developed to control a wheel chair. The total design is based on all electric and to eliminate most of the mechanical parts. The conventional steering system that requires the user to control by hand is eliminated. The explicit steering is replaced by skid steering that is based on differential speed or yaw rate control to two motors and each controls the left and right wheels This is a 2-wheel drive control and works well with the BCI. The system is low cost, easy to control, and powered by Brushless DC motor and high performance battery system. Electronic medication has demonstrated a wide spectrum of efficacy using BCI and power electronics driven machine. It is now universally accepted and widely used.

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REFERENCES

[1] Z. A. Keirn and J. I. Aunon, “A new mode of communication between man and his surroundings,” IEEE Trans. Biomed. Eng., vol. 37, Dec. 1990, pp. 1209-1214.
[2] D.J.Fox, D.F.Thapr and L.C.Fox, “Neurofeedback: An Alternative and Efficacious Treatmentfor Attention Deficit Hyperactivity Disorder”, Applied Psychophysiology and Biofeedback, Vol. 30, No. 4, December 2005, pp.365-373.
[3] J. R. Wolpaw, N. Birbaumer, D. J. McFarland, G. Pfurtscheller, and T. M. Vaughan, “Brain-computer interfaces for communication and control,” Clinical Neurophysiology, 2002, vol. 113, pp. 767-791.
[4] G. E. Fabiani, D. J. McFarland, J. R. Wolpaw, and G. Pfurtscheller “Conversion of EEG activity into cursor movement by a brain-computer interface (BCI), IEEE Trans. on Neural Systems and Rehabilitation Engg., vol. 12, no. 3, pp. 331-338, Sep. 2004.
[5] B. Allison, Brain Computer Interface Systems: Progress and Opportunities [Online] Available: http://www.researchchannel.org/prog/displayevent.aspx?rID=4931
[6] J.Y.M.Cheung, K.W.E.Cheng and A.S.Kamal, `Motor speed control by using fuzzy logic model reference adaptive controller', IEE 6th Int. Conference Power Electronics and Variable Speed Drives, 1996, pp. 430-435.
[7] S.L.Ho, M.N.Fei, K.W.E.Cheng, H.C.Wong, “A Novel auto-tuning algorithm for the integrated RBF network of brushless D.C. motor”, IEEE Trans on Magnetics, Volume: 40 , Issue: 2 , March 2004, pp. 1168 – 1171.
[8] X.D. Xue, K.W.E. Cheng and S.L. Ho, “Influences of output and Control Parameters on Power Factor of Switched Reluctance Motor Drive Systems”, Electric Power Components and Systems, Dec 2004, Vol. 32, No. 12, pp. 1207-1223.
[9] Gao Shuang, Norbert C. Cheung, K. W. Eric Cheng, Dong Lei, Liao Xiaozhong, “Skid Steering in 4-Wheel-Drive Electric Vehicle”, IEEE PEDS, Bangkok, Nov 27-30 2007.
[10] Cheung T. K., Cheng K. W. E., Chan H. L., Ho Y. L., Chung H. S., Tai K., “Maintenance techniques for rechargeable battery using pulse charging”, PESA 2006, 12-14 Nov 2006, pp. 205-208.