Real-Time Two-Dimensional Asynchronous Control of a Remote Controlled Car Using a Single Electroencephalographic Electrode

César Márquez-Chin, Ph.D.(c)[1,2,3], Egor Sanin, M.A.Sc.(c)[4], Jorge Silva, Ph.D.[5], and Milos R. Popovic,Ph.D.[1,2]

[1] Rehabilitation Engineering Laboratory, Toronto Rehabilitation Institute Lyndhurst Centre
520 Sutherland Drive, Toronto Ontario, M4G 3V9, Toronto, Canada.
[2] Institute of Biomaterials and Biomedical Engineering, University of Toronto
164 College Street, Toronto, Ontario, M5S 3G9, Canada.
[3] iDAPT Technology R&D, Toronto Rehabilitation Institute
180 Elm Street, Toronto, Ontario, M5T 3M4, Canada.
[4] Department of Mechanical and Industrial Engineering, University of Toronto
5 King's College Road, Toronto, ON, M5S 3G8, Canada.
[5] Adaptive Technology Resource Centre, University of Toronto
130 St. George Street, Toronto, Ontario, M5S 3G9, Canada.

Running Title: EEG 2D Asynchronous Control

January 26, 2009

Corresponding Author:
César Márquez-Chin
iDAPT Technology R&D
Toronto Rehabilitation Institute
180 Elm Street
Toronto, Ontario M5T 3M4
CANADA.
Phone: (416) 849-4340 Ext. 224
Fax: (647) 438-7150
Email: marquez.cesar@torontorehab.on.ca

ACKNOWLEDGEMENTS

This project received financial assistance from the Toronto Rehabilitation Institute Student Scholarship Fund, Ontario Graduate Scholarships in Science and Technology, University of Toronto Open Fellowship, Natural Sciences and Engineering Research Council of Canada (#249669), Canadian Fund for Innovation (#7313), Ontario Innovation Trust (#7313), and Ontario Ministry of Health and Long-Term Care.

ABSTRACT

A brain-machine interface (BMI) can generate control commands using signals from the brain. These devices have a great potential to assist individuals with severe mobility impairments. Despite enormous advances in this field, most BMI systems have restricted information transfer rates limiting the potential applications that this technology may have. A defining factor for this limited information transfer rate is a synchronous (cue-based) mode of operation, currently used by most BMI systems. We present a novel approach for using electroencephalographic signals from a single electroencephalographic (EEG) electrode to control asynchronously a remote controlled vehicle moving in two dimensions.

Keywords: Brain-Machine Interface, Asynchronous Control, Assistive Technology

INTRODUCTION

A brain-machine interface (BMI) uses signals from the brain to control electronic devices. A BMI system has three fundamental components: an input (i.e., a signal from the brain), an output (i.e., a command that controls an external device), and an intermediate translation state that transforms the input into the output. This technology has great potential to assist individuals with severe mobility impairments, especially those who have lost all ability to move voluntarily and communicate.

In the last decade researchers around the world have created numerous BMI systems. The majority of these devices use electrical recordings acquired from the brain in a non-invasive way using electroencephalographic (EEG) techniques. To operate, these EEG-based BMI systems require that the user adopts different mental states, which are detected by specific temporal or frequency changes in the brain activities. Some of the features that have been used to detect different mental states include slow cortical potentials (SCP) [1-3], P300 potential [4, 5], and changes in power (amplitude) of oscillatory rhythms [6]. When a change in the brain activity is detected, it is then possible to trigger a specific action effectively producing the interface between the brain and an external device. EEG-based BMIs have been used successfully to assist the communication of individuals who have lost all ability to perform voluntary movement (locked-in syndrome [1]).

Despite tremendous advances in the development of EEG-based BMI technology most of these devices suffer from a limited communication rate (information throughput). This has restricted the number of applications that could take advantage of EEG-based BMI technology. An increase in communication rate would likely expand the population that can benefit from these devices. In fact, it has recently become evident that this technology may also benefit individuals with spinal cord injury [7-11]. An important challenge for researches in the field of BMI is therefore to increase the communication rate of this technology.

One factor with a negative impact on the communication rate of BMIs is the use of synchronous modes of operation. With this style of interaction between the user and the BMI, used by the majority of current EEG-based BMIs, a person can issue commands (i.e., adopt a particular brain state) only during specific time instances determined by the BMI itself and not by the user. In turn, this mode of interaction to a large extent determines the rate at which commands can be generated. Most of the existing work on EEG-based BMIs uses a synchronous mode of operation.

To create practical BMIs that can be used outside a laboratory setting it is necessary to implement asynchronous systems that would allow the user to generate commands at any given time. Such a device could potentially allow for a more natural and faster way of interaction with the user. The implementation of an asynchronous BMI is a challenging problem as it requires that the brain activity be monitored constantly to identify specific EEG patterns indicating that a user wishes to generate a command. While only a few research groups have tried to address this problem in the past [7-9] there has been a recent increase in the creation of asynchronous BMIs. The application of asynchronous EEG-based BMIs have included control of functional electrical stimulation systems [7-10], virtual and simulated wheelchair navigation [11,12], upper limb prosthesis [13], and a virtual keyboard [14].

We present here a proof of concept study were we use a single EEG electrode to perform asynchronous control of a miniature remote control vehicle moving in two dimensions. The proposed method operates on the identification of a single mental state used to create a "brain-switch". This work is the implementation of the work presented by Silva et al. [21] within the context of BMI.

MATERIALS AND METHODS

Participants

There was a single participant in this proof of concept study. The subject was a 24 year old man with no neurological disorders. He gave informed written consent to participate in this study and had no previous experience using a BMI.

Experimental Setup

EEG was recorded from the subject using a single EEG electrode placed at C3 according to the 10-20 reference system. The signals were band-limited between 0.5 Hz and 30 Hz and amplified using a dedicated EEG amplifier (IP511, GRASS Technologies, West Warwick, U.S.A.). The amplified signals were then digitized using a portable USB data acquisition system (NI-DAQPad-6016, National Instruments, Texas, U.S.A.).

A real-time "brain-switch" was implemented to create the BMI. This was done by first filtering the digitized signals between 7 Hz and 13 Hz [20]. The absolute value of a 250 msec segment was integrated twice and the mean value of this segment was then used to calculate a moving average with the last 5 estimated mean values. Whenever the value of this moving average decreased and remained below an experimentally determined threshold for a pre-specified duration, the switch would be considered activated (closed). The threshold value as well as the amount of time in which the signal had to remain under the threshold could be changed at any point during the operation of the BMI.

The brain-switch was then used as an input to a control strategy that allowed the control of two-dimensional movements with a single switch [20]. With this strategy, rather than using a single switch to indicate a desired behavior from an object under control, the activation of the switch is used to indicate that the current behavior of the device under control is not the desired one.

To operate the remote controlled car the subject activated the switch repeatedly. Each time the switch was activated the behavior of the device under control (e.g., the direction of the object moving in two dimensions) changed randomly. At the same time each time the device changed its behavior, the control system eliminated the rejected behavior (direction) temporarily so that it was not selected again in subsequent switch activations. This ensured that the control system would ultimately converge to the direction desired by the user.

Formally, each switch activation *n* changed the direction

(2)

The weighing factor

We defined the following states as the set from which the control system could select a behavior: 1) move forward, 2) move backward, 3) move forward right, 4) move forward left, 5) move backward right, 6) move forward left, and 7) stop. The control strategy was used to command a miniature remote control car (ZipZaps ®, The Source, Canada) (Figure 1). This car was modified so that it could receive digital control input signals making it possible to operate it with a personal computer. The actual control signals were delivered to the remote control car using the same data acquisition system used to collect the EEG signals.

Participant Training

The participant of this study received training lasting 5 days. During this training time the user first became familiar with the single-switch control strategy. He was instructed on how to operate the single switch interface and asked to control the remote controlled car by activating an actual switch.

The training time also allowed the person to learn how to induce changes in their brain oscillations in the selected frequency band (7 Hz – 13 Hz). The initial attempts to achieve this self-regulation of EEG signals were done using motor imagery of the right hand. The participant was shown the moving average of the processed EEG signal as a continuous graph displayed on a computer screen as well as a visual indicator that was turned on whenever the brain switch had been activated. The user was given the opportunity to ask for adjustments in the threshold value (increase or decrease) and the time duration (shorter or longer) during which the EEG signal had to be sustained below the threshold level for the “brain-switch” to be activated

Experimental Tasks

The participant was asked to control the remote control car from an initial point to a final point. To do this, three targets were marked on the floor, which indicated the possible starting and ending points. The targets were arranged in the manner displayed in Figure 2. The data collected for these experiments included 1) number of activations required to complete the task, and 2) the time required to move from one target to another.

RESULTS

The EEG signals revealed changes in power in the selected frequency bandwidth (7 Hz to 13 Hz). Subject 1 was able to gain control over the power of his brain oscillations after three days of training. He was able to drive the remote control car successfully for 11 minutes during which he drove the car to **7** targets. The average time required to move between targets was 90.71 seconds (±85.28) with an average of 13.85 switch activations (± 13.33).

CONCLUSIONS AND DISCUSSION

We presented a methodology for two-dimensional asynchronous control using a single EEG electrode. We believe that the work presented here proposes a simple approach to BMI implementation in which the user is capable of issuing commands at any given time to control a two-dimensional task.

One factor that limits the communication rate of BMI devices include a small number of brain states that these devices can identify. With one identifiable brain-state it is possible to generate one command, which is ideal for controlling devices that offer only two possible outcomes/states (e.g., a light that can be turned on or off) or to answer YES or NO questions. Therefore, one of the methods used to increase the information throughput of BMIs has been enhanced by increasing the number of brain-states that the BMI can identify. Today it is possible to find BMIs that recognize up to four different mental states [22]. This recognition of multiple brain states has been possible through the use of sophisticated computational methods [17] and/or by increasing the features in brain signals that a person can control voluntarily [23].

A different approach to increase the communication rate of the BMIs has concentrated on identifying and using different neural signals with richer information content. Examples of this approach include BMI systems that record the activity of the brain directly from small populations of individual neurons acquired with invasive techniques (i.e., intracortical electrodes). Using this approach, it has been possible to control computer cursors in two dimensions, robotic arms, and assistive devices. However, the stability and long-term viability of these highly invasive systems still needs to be investigated.

The approaches taken to increase the communication rate of the BMI systems also increase the demands placed upon the user as well as increase the complexity of the BMI systems. This can result in systems that are: 1) difficult to use, or 2) require extensive training, or 3) are not suitable for applications outside a laboratory.

The approach that we present in this article uses self-regulation of oscillatory rhythms of the motor cortex and identifies moments when this activity is above or below predefined threshold level. This application of the EEG signals has a proven track record in the field of BMI applications. What is unique about our method is that it uses this very simple EEG signal processing technique and integrates it with new real-time two-dimensional asynchronous control technique proposed by Silva et al.[21]. This new control technique allowed us to create a sophisticated control tool that was able to regulate movement of the remote controlled toy car in two-dimensional space using simple EEG threshold detection approach. We believe that this BMI system gives users more time to concentrate on the task they need to perform instead of focusing their attention on operating the BMI system itself.

The system presented here can be improved by increasing the speed at which the user can change direction. In our work, this is not dependent on the control mechanism presented here but rather on the EEG feature detection, and methods to extract them as a prerequisite for the BMI. The use of other feature identification and extraction approaches will likely result in an increase in the overall operational speed of the system. It is also highly probable that the speed of the system will increase as the user gains more experience with the proposed BMI system.

Our future directions include the exploration of the control methodology presented here for the control of three-dimensional movements. In parallel we will also focus on identifying new features that can be used to create a brain-switch as well as the techniques required to extract and process these features.

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FIGURE CAPTIONS

Figure 1. Remote controlled car used to conduct this study. Custom modifications to the car and the controller box made it possible to operate it through a personal computer. The direction of the car was controlled using a novel single-switch asynchronous access method[21] Source: Author.

Figure 2. Experimental targets. The participant was asked to drive a remote controlled car between three targets by regulating the amplitude of his brain oscillations (7 Hz to 13 Hz). The targets were marked on the floor and separated by a distance of 200 cm. Source: Author.

FIGURES

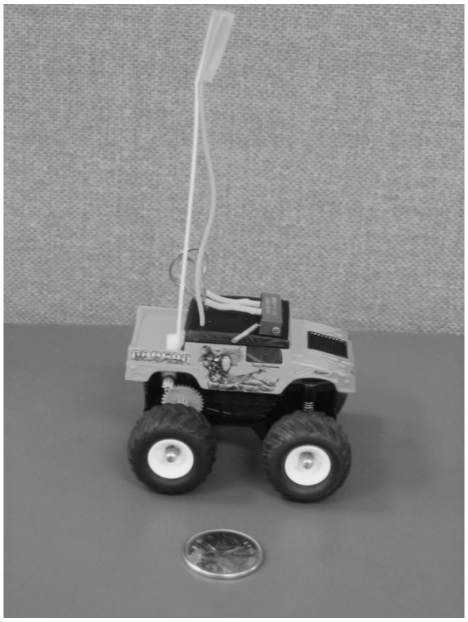

Figure 1

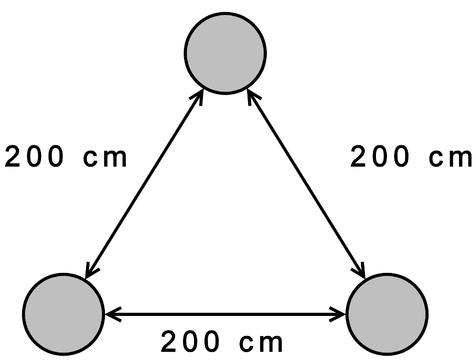

Figure 2