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Original article

Command of a simulated wheelchair on a virtual environment using a brain-computer interface

Commande d'un fauteuil roulant simulé sur un environnement virtuel en utilisant une interface cerveau-ordinateur

G.G. Gentiletti [a,b,*], J.G. Gebhart [b], R.C. Acevedo [b], O. Yáñez-Suárez [a], V. Medina-Bañuelos [a]

[a] *Neuro-imaging Research Laboratory (LINI), Universidad Autónoma Metropolitana, Iztapalapa, Mexico*
[b] *Rehabilitation Engineering and Neuromuscular and Sensorial Research Laboratory (LIRINS), Universidad Nacional de Entre Ríos, Entre Ríos, Argentina*

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Abstract

Objective. – The goal of this research was to design, set up, use and evaluate a realistic simulation platform that could host real-time simulated robotics applications controlled with a brain-computer interface based on an event-related potential paradigm.
Materials and methods. – The platform is composed of the following modules: (i) six band-limited channels of electroencephalographic signal acquisition; (ii) signal processing and classification with the BCI2000 software platform; (iii) stimulus presentation and (iv) robotics simulation. A modified Donchin speller matrix that uses iconic elements to indicate diverse navigational commands was implemented as the stimuli for the brain-computer interface, and an alternative interface was also included for independent manual navigation. A physically realistic wheelchair model with both autonomous and user control was used as the robotic element in the system.
Results. – Two healthy subjects were asked to perform a given navigation task throughout a simulated home environment using both navigational interfaces. For each task, each subject drove the wheelchair along similar paths and distances. The task execution time was greater when using the brain-computer interface, but both subjects were successful in adequately driving the wheelchair with the BCI.
Discussion. – The wheelchair model within the simulation and control platform serves as a proof of purpose of the proposed system and demonstrates its potential. Further tests and experiments are needed, along with the definition of adequate metrics to characterize the entire user-controller-robot-task ensemble.
Conclusions. – With the developed platform, evaluation of prospective brain-computer interfaces can go beyond classical measurements of error and bit transfer rates, to include metrics accounting for the integrated system.

Keywords: Brain computer interface; Electroencephalography; Robotics simulation; Smart wheelchair; Virtual environment

Résumé

Objectif. – Le but de cette recherche était de concevoir, installer, utiliser et valider une plateforme réaliste de simulation pouvant accueillir des applications de robotique simulées en temps réel et commandées avec une interface cerveau-ordinateur basée sur un paradigme de potentiels liés aux événements.
Matériel et méthodes. – La plateforme est composée des modules suivants : (i) six canaux limités en bande pour la saisie des signaux électroencephalographiques ; (ii) traitement et classification des signaux avec le logiciel BCI2000 ; (iii) présentation de stimulus et (iv) simulation robotique. Une matrice de Donchin modifiée, qui emploie des éléments iconiques pour indiquer des commandes de navigation diverses, a été mise en application en tant que stimulus pour l'interface cerveau-ordinateur, tandis qu'une autre interface alternative a été également incluse pour la navigation manuelle indépendante. Un modèle physiquement réaliste de fauteuil roulant a été employé comme élément robotique dans le système.

* Corresponding author.
E-mail address: gentiletti@gmail.com (G.G. Gentiletti).

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Résultats. – Deux sujets ont effectué une tâche de navigation dans une chambre simulée en utilisant les deux interfaces de navigation. Pour chaque tâche, chaque sujet a conduit la chaise roulante sur des voies et des distances similaires. Le temps de navigation avec l'interface cerveau-ordinateur a été plus long, toutefois, les deux sujets ont réussi à bien conduire le fauteuil roulant avec la BCI.
Discussion. – Le modèle de fauteuil roulant dans la plateforme de simulation et de commande sert de « preuve de but » du système proposé, prouvant ainsi son potentiel. D'autres essais et expériences seront nécessaires, avec la définition des métriques appropriées pour caractériser l'ensemble utilisateur-contrôleur-robot-tâche.
Conclusion. – Avec la plateforme développée, l'évaluation des interfaces cerveau-ordinateur peut aller au-delà des mesures classiques comme le taux de classification ou la vitesse de transfert d'information, pour inclure des métriques qui expliquent le système intégré.

Mots clés : Interface cerveau-ordinateur ; Électroencéphalographie ; Simulation robotique ; Fauteuil roulant intelligent ; Environnement virtuel

1. Introduction

The first research works aimed at establishing a direct communication channel between a person's brain activity and a computer can be traced back to J. Vidal works in the early 1970s [1]. However, it is over the last 2 decades that this research area has experimented an outstanding growth. A key event in this research community was the First International Meeting on Brain Computer Interface technology, held in Albany, N.Y. in 1999, where 22 labs and about 50 researchers gathered to explore future directions in the field [2]. Throughout that meeting, a general agreement was established about a definition for a Brain–Computer Interface (BCI) that stands until today: "*A BCI is a communication system that does not depend on the brain's normal output pathways of peripheral nerves and muscles*." This definition also reflects the principal reason of interest in BCI development, the possibilities it offers for providing new augmentative communication technology for those who are paralyzed or have other severe motor deficits. This definition discards all other augmentative communication technologies that require some level of muscle control, and thus would not be useful for those with the most severe motor disabilities, such as late-stage amyotrophic lateral sclerosis, a brainstem stroke, severe cerebral palsy, or the "locked-in" syndrome.

Nowadays, there are many research groups working in the BCI area, and a first major classification of the most used approach could be done in terms of "invasive" (microelectrodes are implanted into the subject's brain to measure the activity of specific neural populations) and "non-invasive" (i.e., the brain electrical activity is recorded from electrodes or other sensors placed on the scalp) BCI systems.

Depending on the signal and the information that will be used to establish a communication between the brain and the computer, different paradigms of non-invasive BCI can be defined. Within these, we can mention those based on the transient and steady state visual evoked potentials (SSVEP), slow cortical potentials (SCP), mental tasks (MT), event related synchronization (ERS)/desynchronization (ERD) of EEG motor rhythms and event related potentials (ERP).

The Transient Visual Evoked Potentials (TVEP) are generated in response to a visual stimulus and are used to estimate the direction of the gaze of a person, thereby controlling a device such as a cursor on screen [1]. When the stimulation frequency is higher than 6 Hz, the SSVEP are obtained, which consist of a periodic signal containing harmonic components of the stimulation frequency. The basic theory of operation of this BCI paradigm is to put multiple targets on a screen flickering with different frequencies. When a person pays attention at a particular target, a SSVEP is generated whose fundamental frequency is equal to the flickering frequency of the attended target [3]. The SCP are potentials of low-frequency (0.1 to 2.0 Hz) generated in the cerebral cortex. Elbert et al. have shown that a person can learn to control their SCP and thus control the movement of an object on a computer screen [4]. In the MT paradigm, the decisions of the BCI are based on the classification of patterns found in the recordings of the spontaneous EEG into a predefined number of different MT. A particular case of MT is the phenomenon called ERD that appears when the execution of movements or their mental preparation decreases the activity of mu and beta brain rhythms. After a movement, the opposite phenomenon, known as ERS is produced. However, the most important characteristic to implement a BCI is that the ERD and ERS do not requires an actual movement, but also occur with the imagination of movements [5].

The ERP are evoked potential with latencies greater than 100 ms and wave shapes dependent on psychological and behavioral processes. For example, when a rare visual stimulus (that is nonetheless particularly significant) is mixed with frequent or routine stimuli, a potential on the parietal cortex with a positive peak around 300 ms, called P300, is generated. Farwell and Donchin [6] were the first to use the P300 in a BCI with visual stimuli over a 6×6 character matrix using randon intensifications of matrix rows and columns. The most relevant advantage of this technique is that it requires little or no training on the side of the user [7], allowing the performance of target-based tasks in a natural way (spelling words, selecting an address or menu, etc). Its main disadvantage is the need of visual attention from the user, which is an obstacle in subjects with visual impairments [8]. These potentials and their BCI application are the subject of this communication.

In recent years, several investigations on BCI have been directed towards applications that go beyond the interface with computers [9] [10] (see [11] for a review of application areas targeted in BCI). Within these applications, some of them are making use of robotic technologies trying to provide the user not only with possibilities for communication but also with a direct physical interaction and/or navigation over his environment [12] [13].

However, these new BCI applications imply new challenges and problems [14] [15]. Among them, three relevant aspects that