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BCI-controlled Wheelchair; Audio-cued Motor Imagery-based Paradigm

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Abstract

In this study we present a control paradigm that enables subjects to drive a real wheelchair using four navigation commands. The control is achieved through the discrimination of two mental tasks (relaxed state versus one active Motor Imagery task), in order to reduce the risk of misclassification. After a short training, the paradigm becomes only audio-cued, thus avoiding the need of a graphical interface that could distract subjects' attention.

1 Introduction

A brain-computer interface (BCI) is based on analysis of the brain activity, recorded during certain mental activities, in order to control an external device. It helps to establish a communication and control channel for people with serious motor function problems but without cognitive function disorder (Wolpaw, Birbaumer, McFarland, Pfurtscheller & Vaughan, 2002). Amyotrophic lateral sclerosis (ALS), brain or spinal cord injury, cerebral palsy and numerous other diseases impair the neural pathways that control muscles or impair the muscles themselves. Among others ways to control such a system, Sensorimotor rhythm-based BCIs (SMR-BCI) are based on the changes of μ and β rhythms. These rhythms correspond to specific features of the EEG signals characterized by their frequencies that can be modified by voluntary thoughts: when a person performs a movement (or imagines it), it causes a synchronization/desynchronization in this activity (event-related synchronization/desynchronization, ERS/ERD) which involves a rhythm amplitude change (Neuper & Pfurtscheller, 1999).

Recently, a survey on BCI-controlled devices has been published (Bi, Fan, & Liu, 2013) which shows a wide variety of systems controlling wheelchairs or mobile robots. Most of the SMR-BCI there reported match the number of commands to the number of mental tasks. However, incrementing the number of mental tasks can reduce the classification performance (Kronegg, Chanel, Voloshynovskiy & Pun, 2007; Obermaier, Neuper, Guger, & Pfurtscheller, 2001). In order to provide different commands without making the BCI performance worse, our group proposed a paradigm based on the discrimination of only two classes (one active mental task versus any other mental activity), which enabled the selection of four navigation commands (Ron-Angevin, Díaz-Estrella & Velasco-Álvarez, 2009). The evolution of this paradigm included its adaptation to a self-paced BCI enabling a Non-Control (NC) state (Velasco-Álvarez & Ron-Angevin, 2009), the support for continuous movements (Velasco-Álvarez, Ron-Angevin & Blanca-Mena, 2010) or its conversion into an audio-cued paradigm (Velasco-Álvarez, Ron-Angevin, da Silva-Sauer, Sancha-Ros & Blanca-

Mena, 2011). This control paradigm has already been tested for virtual and real environments (Velasco-Álvarez, Ron-Angevin, da Silva-Sauer & Sancha-Ros, 2013); once it has proved to be valid for controlling a virtual wheelchair or a mobile robot, our aim is to adapt it to the use of a real wheelchair. The use of an audio-cued paradigm is important, as a graphical interface could limit the subjects' field of view and, at the same time, distract them from the task of controlling the wheelchair by requiring them to look at the computer screen. Furthermore, for disabled people without gaze control a graphical interface may not be useful.

2 Methods

2.1 Data Acquisition, Initial Training and Signal Processing

In our system, the EEG is recorded from ten active electrodes, combined to result two laplacian channels around C3 and C4 positions (right and left hand sensorimotor area, respectively) according to the 10/20 international system. The ground electrode is placed at the FPz position. Signals are amplified and digitized at 200 Hz by an actiCHamp amplifier (Brain Products GmbH, Munich, Germany).

Subjects have to follow an initial training that consists of two sessions: a first one without feedback and a second one providing continuous feedback. These two training sessions are used for calibration purposes. The training is the same as the one used in (Ron-Angevin, 2009) and is based on the paradigm proposed by the Graz group (Leeb, Settgast, Fellner & Pfurtscheller, 2007). It consists of a virtual car that dodges a water puddle in the road, by moving left or right according to the mental task carried out (relaxed state or right hand MI). An offline processing of the first session determines the parameters for the feedback session. The same parameters are used to calibrate the system for the navigation sessions. This processing is based on the procedure detailed in (Guger, Edlinger, Harkam, Niedermayer & Pfurtscheller, 2003), and consists of estimating the average band power of each channel in predefined, subject-specific reactive frequency (manually selected) bands at intervals of 500 ms. In the feedback session, the movement of the car is computed on-line every 25 ms as a result of a Linear Discriminant Analysis (LDA) classification. The trial paradigm and all the algorithms used in the signal processing are implemented in MATLAB 2013b (The MathWorks Inc., Massachusetts, USA).

2.2 Navigation Paradigm

The training procedure to control the paradigm consists of a first navigation session in which subjects control a virtual device with the help a graphical interface showed simultaneously with presence of the audio cues. Once the users become familiar with it, it is replaced by an only audio-cued interface.

The procedure to control the device is similar to the one used in (Velasco-Álvarez et al., 2013): the system waits in a NC state in which an NC interface is shown: a semi-transparent vertical blue bar placed in the centre of the screen. By extending the bar carrying out the MI task (above a subject-dependant selection threshold for a given selection time), subjects can switch to the Intentional Control (IC) state, where the control is achieved through the IC interface. The IC interface consists of a circle divided into 4 parts, which correspond to the possible navigation commands (move forward/backward, turn right/left), with a bar placed in the centre of the circle that is continuously rotating clockwise. The subject can extend the bar by carrying out the MI task in order to select a command when the bar is pointing at it (same selection threshold and time). Subjects receive audio cues while they interact with the system. When the state switches from IC to NC (which occurs when

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the rotating bar completes two turns without selecting any command), they hear the Spanish word for "wait"; the reverse switch is indicated with "forward", since it is the first available command in the IC state. Finally, every time the bar points to a different command, they can hear the correspondent word ("forward", "right", "back" or "left").

2.3 Robotic Wheelchair

We customized a robotic Invacare Mistral Plus electric wheelchair. The wheelchair is modified in such a manner that its direction and speed can be controlled with a computer, and sensors are included that give the software information about the wheelchair's status and environment.

A custom electronic board that emulates an analog 2-axis joystick is needed, which is attached to the wheelchair control board replacing its actual joystick. Via a USB/Bluetooth interface, an external computer can communicate with that board and set the virtual joystick position in real time. Besides, the board includes an IIC bus that allows a number of sensors, such as a magnetometer, an accelerometer and a set of sonars, to be attached to the main system. The status of these sensors can also be read from the USB/Bluetooth interface.

This board is controlled by an application (running on the same computer that processed the EEG signal, or on a different one connected via TCP). This application is responsible for translating high-level navigation commands from the BCI interface (move forward, turn right, etc.) into virtual joystick positions, which in turn makes the wheelchair move. The attached sensors allow for safe and reliable navigation. After an initial calibration stage, the magnetometer can be used as a digital compass which the application use to instantly correct small variations of the direction when moving the wheelchair forward or backwards, or to perform discrete turns to a specific angle. The accelerometer, for its part, is used to detect steep slopes and reduce the wheelchair speed, or to stop it when a potentially dangerous tilt was reached.

The set of sonars allow to create an estimated real-time map of the environment. The application keeps a discrete grid which describes the likelihood of a certain small area around the wheelchair being occupied. When one of the sonars detects an obstacle at a given distance, all the grid cells within its detection cone are updated according to a model of the sensor.

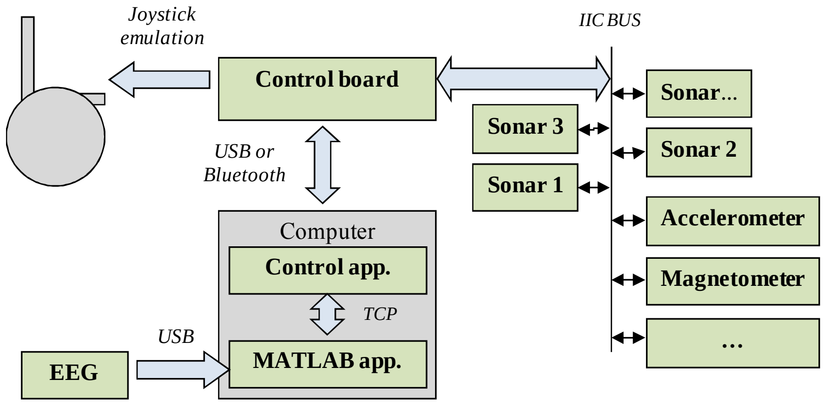

Figure 1: Module distribution for the BCI-controlled wheelchair

3 Work in Progress

Our group is nowadays preparing experiments to test the viability of the proposed system, so the given description of the system corresponds to a work in progress. As long as the navigation paradigm has already been validated, we expect that, with the proper training and adaptation sessions, the change from a mobile robot to a real wheelchair will not severely affect the performance.

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