RobChair: Experiments Evaluating Brain-Computer Interface to Steer a Semi-autonomous Wheelchair

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Abstract—Experiments with a semi-autonomous wheelchair controlled by means of a Brain-Computer Interface (BCI) are presented. The navigation system, having at its core a collaborative controller, performs smooth and safe manoeuvres following sparse steering commands provided by the user. The user intents are decoded from electroencephalographic signals evoked by a visual P300-based paradigm. Experiments have been performed by several able-bodied users and motor disabled participants, showing the effectiveness of the approach.

I. INTRODUCTION

RobChair [1], [2], is a robotic wheelchair (RW) being developed at the Institute for Systems and Robotics, University of Coimbra. This video shows the latest results with RobChair, related to the evaluation of its driving through a brain-computer interface (BCI). These experiments are being developed in collaboration with the Cerebral Palsy Association of Coimbra (APPC).

People with severe motor disorders, such as cerebral palsy, persons, are unable or have great difficulty in using conventional Human-Machine Interfaces (HMI). Non invasive BCI is emerging as a promising HMI alternative for these users. This type of interface offers a communication channel independent of muscular activity, and therefore it can be used by people with their motor functions severely affected [3]. However, the development of a robotic system guided by BCI is full of challenging issues. BCI offers a low information transfer rate associated with a non-negligible error rate. In other words, the user will be able to provide only sparse commands in time and some of them may be unreliable. To effectively use such type of HMI, an assistive navigation system able to predict and execute user navigation goals with minimum commands is required. We proposed in [4] a P300-based BCI [5] that allows the selection of brain-actuated commands to steer a RW. To alleviate user effort, low-level commands are only issued when there are dynamic changes of the environment or when ambiguous situations occur. In recent years different semi-autonomous controllers were developed for applications in the field of assistive robotics and, in particular, intelligent wheelchairs [1], [6]. Brain-actuated wheelchairs have been researched by other research groups pursuing the same goals [7]–[9].

We present the actual stage of RobChair navigation system, in which users are able to steer the wheelchair using a P300-based BCI. Two different experimental scenarios are presented to assess the performance of the navigation system based on BCI. The first scenario is a Structured Known Environment (SKE), and the second one is a Structured Unknown Environment (SUE) with the presence of new static and moving obstacles (e.g. pedestrians). Experiments in both scenarios were carried out with ten able-bodied participants and a participant with cerebral palsy and motor impairment. Figure 1 presents a scene of the RobChair being brain-guided by the cerebral palsy participant with motor disabilities. For this user, tests were performed remotely since RobChair is not equipped with accessory equipment necessary to ensure the safety and welfare of users with severe motor disabilities.

II. SYSTEM DESCRIPTION

An overview of the Assistive Navigation System (ANS) is shown in Fig. 2. This architecture is structured in five levels: HMI, global motion planning, local motion planning, motion tracking, and motion control. This architecture has been tested in a player/stage simulation environment and with RobChair [4], [2]. As HMI, a P300-based BCI is used to provide the user intent, which consists in steering commands issued sparsely. The EEG acquisition is made by a gtec gUSBamp system. Signals are recorded from 12 electrode channels, labeled as Fz, Cz, C3, C4, CPz, Pz, P3, P4, O7, O8, POz and Oz according to the extended international 10-20 standard system. The P300-BCI consists of an oddball
paradigm, which elicits P300 components according to the relevance of the visual events. The proposed P300-BCI paradigm is shown in Fig. 1. The paradigm consists of a set of flashing symbols that represent low-level steering commands, namely FORWARD, RIGHT45, RIGHT90, BACKWARD, LEFT45, LEFT90 and STOP. Each symbol flashes during 100 ms with an inter-stimulus interval of 75 ms. At each moment, the relevant event is the one mentally selected by the user, which corresponds to the desired direction that the user wants to follow.

After a BCI offline calibration, each participant was asked to carry out the experimental real-time navigation tasks in the wheelchair, in two scenarios: SKE and SUE. All participants were able to use the ANS with relative ease. When compared with able-bodied users performance, it was possible to observe that the cerebral palsy participant presented a similar performance. The quantitative results obtained from these experiments can be found in [2]. Since the user can not be continuously issuing commands because it would be tiresome, the ANS was designed to reduce the user effort. The navigation module considers the BCI input commands if the following situations occur: multiple possible directions due to a bifurcation; multiple possible directions due to new obstacles in the environment; moving backwards due to deadlock situation; and performing pure rotations due to deadlock situations. The first two situations were experimentally tested in a structured environment, and results showed that the navigation system was robust. The RW stops when a object is too close, and waits till it is safe to continue its path again. Pure rotations, and moving backwards to solve deadlocks are only implemented and tested in simulation environment. At the present stage, the RW stops if a deadlock situation occurs. In a multiple direction situation caused by new obstacles in the environment, the navigation system waits for the user’s BCI command. The final steering is determined by a two-layer collaborative controller, which uses the information provided by machine and human agents. The proposed collaborative controller includes a virtual-constraint layer and an intent-matching layer. The former is responsible for enabling/disabling user commands, as a function of certain criteria, and the latter determines the suitable manoeuvres, taking into account her/his steering competence.

III. CONCLUSION AND FUTURE WORK

An assistive navigation architecture based on collaborative control, and using P300-based BCI paradigm allows the selection of brain-actuated commands provided by users. Experiments showed that participants, with and without motor disabilities, were able to safely steer the RW using BCI, in different test scenarios, with relative ease. Currently, the BCI commands are not issued in a self-paced manner by the user. This topic is being researched to allow the user to issue commands only when he/she desires. A new dynamic local planner that takes into account robot geometry to plan more efficient obstacle avoidance manoeuvres, and that can be able to effectively avoid slow dynamic obstacles, such as people and other moving objects is also being pursued. The shared-controller is also being extended to include information regarding user state of mind (such as stress, focus and attention).

REFERENCES