User-Tailored Shared Autonomy by a Robotic Wheelchair with Multimodal Interface
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Abstract—The aim of this research consists in the development of an autonomous wheelchair capable to avoid obstacles, self-localize and explore indoor environments in a safe way. To meet disabled people requirements, we have designed the user interface to the autonomous wheelchair in such a way that it can be simply modified and adapted to the users needs. In particular, the user has the opportunity to choose among several autonomy levels (from simple obstacle avoidance to complete autonomous navigation) and different interfaces: a classical joystick, a touch-screen, an electro miographic interface, and a brain-computer interface (BCI), i.e. a system that allows the user to convey her intention by analyzing her brain signals.

I. INTRODUCTION
The possibility of moving in an autonomous way gives individuals a remarkable physical and psychological sense of well-being. Robotic wheelchairs are usually driven by a joystick and are addressed to those people that are not able to apply the necessary force to move a manual wheelchair. They often are people with low vision, visual field reduction, spasticity, tremors, or cognitive deficits. In order to give these people a higher degree of autonomy, and also to lighten the duties of those who assist them, a large number of solutions have been studied by researchers since the 1980s, by using technologies originally developed for mobile robots to create the so called “smart wheelchairs”.

A smart wheelchair, or autonomous wheelchair, typically consists of either a standard powered wheelchair to which a computer and a collection of sensors has been added or a mobile robot base to which a seat has been attached. One of the first examples of autonomous wheelchairs was proposed in (Madarasz et al. 1986), who equipped a wheelchair with sonars and a vision system to identify landmarks and correct its trajectory in hallways. Another solution was presented in (Levine et al.1999) with NavChair, an electric wheelchair provided with an obstacle avoidance algorithm and multiple task-behaviors to control the movements through doorways or to avoid collision with walls. A more sophisticated solution was Rolland III, proposed by Mandel et al. (2005): a semi-autonomous wheelchair, equipped with laser range finders, encoders and a camera, that is able to set the appropriate speed in the presence of obstacles and avoid them. Montesano et al. (2006) presented an autonomous wheelchair for cognitive-disabled children in narrow doors, and cluttered scenarios.

In this work we present the LURCH (Let Unleashed Robots Crawl the House) project aimed at the development of an autonomous wheelchair able to avoid obstacles, self-localize and explore indoor environments in a safe way. The user can either control the wheelchair through analog interfaces (e.g., joystick or special controls) or issue high level commands such as “go to the kitchen”. In both situations the smart wheelchair is capable to deal with unforeseen obstacles, avoiding them, and in the latter it can plan and execute autonomously the movement.

In order to meet the variable requirements of disabled people, we have designed our system in such a way that it can be simply modified and adapted to user needs. The typical control system used by smart wheelchairs, based on the use of a joystick, is not suitable for totally paralyzed persons. For instance, millions of people in the world suffer from several diseases (e.g., amyotrophic lateral sclerosis — ALS, multiple sclerosis, cerebral paralysis, etc.) that destroy the neuromuscular channels used by the brain to communicate and control body movements. This calls for the development of a flexible system, able to adapt also to the necessity of completely locked-in individuals. In LURCH, the user has the opportunity to choose among several autonomy levels, ranging from simple obstacle avoidance to full autonomy, and different interfaces: a classical joystick, a touch-screen, an electro miographic interface, and a brain-computer interface (BCI), i.e. a system that allows the user to convey her intention by analyzing her brain signals (Wolpaw et al. 2005).
II. AUTONOMOUS WHEELCHAIR DESIGN

The smart wheelchairs described in this paper have been designed to provide navigation assistance in a number of different ways, such as assuring collision-free travel, aiding in the performance of specific tasks (e.g., passing through doorways), and autonomously transporting the user between locations. Our aim is to reduce as much as possible the cost of the whole system (the total cost of the framework proposed for indoor environment, wheelchair not included, is less than five thousands of euros, which is cheap with respect to other works) and provide different kinds of interfaces (e.g., the BCI, see the next section for more details), in order to fulfill the needs of people with different disabilities, and to allow users to set the desired level of autonomy.

The LURCH system was designed to be easily adaptable to different kinds of electric wheelchairs. Fig. 2 outlines a scheme of LURCH. As it is possible to notice from the image, our system is completely separated from the wheelchair, and the only gateway between LURCH and the vehicle is represented by an electronic board that intercepts the analog signals coming from the joystick potentiometers and generates new analog signals to simulate a real joystick and drive the joystick electronics. In other words, we do not integrate our system with the wheelchair at the digital control bus level, but instead we rely on the simulation of the signals from the joystick in the analogue domain. Though this choice could seem awkward, its motivations are twofold: first of all, it is often hard to obtain the proprietary communication protocols of the wheelchair controllers, or to understand how they exchange data with the motors and interfaces; second, this solution improves the portability, since it avoids a direct interaction with the internal communication bus of the wheelchair. LURCH was designed by adopting the modular approach proposed by Bonarini et al. (2007):

- localization module: it estimates the robot pose with respect to a global reference frame from sensor data, using a map of the environment;
- planning module: using knowledge about the environment and the robot, this module selects the most appropriate actions to reach the given goals, while respecting task constraints;
- controlling module: it contains all the primitive actions, typically implemented as reactive behaviors that can be executed by the robot.

A. Localization module

The localization algorithm operates using a video camera and some passive markers. These are placed on the ceiling of the environment, since this allows to avoid occlusions, and provide accurate and robust pose estimation (see Fig. 3). This restricts LURCH to indoor environments.

Fig. 2. The LURCH architecture; the control system is independent from the wheelchair, and the gateway between LURCH and the vehicle is represented by an electronic board that intercepts the analog signals coming from the joystick potentiometers and generates new analog signals to the wheelchair.

Usually, a fiducial marker is a planar patch with a known shape that contains some encoded information. In this work we decided to use the ARToolKitPlus (Wagner and Schmalstieg 2007) system, where the markers are squares with a black border, and the information is encoded in a black and white image represented in the square. The marker identification process is defined by three steps: identification of possible markers in the image captured by the camera, rectification of the image, and comparison of the information represented in the markers with the database of known landmarks. If a marker is recognized, with the knowledge of its dimension, it is possible to estimate its 6 DoF position and orientation in the camera reference. Since the position and the orientation of the markers in the environment w.r.t. the absolute frame and also the position and the orientation of the camera w.r.t. the wheelchair are known, the system can estimate the pose of the wheelchair w.r.t. the world frame every time it is able to detect a marker. In indoor environments, it is generally sufficient to know the 3 DoF pose of the wheelchair; thus, we decided to simplify the problem, improving in this way the robustness and the accuracy of the localization algorithm.
Fig. 3. A set of ARToolKitPlus passive markers is placed in the environment to provide a global localization system.

B. Planning module

The trajectory planning is obtained by SPIKE (Spike Plans In Known Environments), a fast planner based on a geometrical representation of static and dynamic objects in an environment modeled as a 2D space (Bonarini et al. 2007). The wheelchair is considered as a point with no orientation, and static obstacles are described by using basic geometric primitives such as points, segments and circles. SPIKE exploits a multi-resolution grid over the environment representation to build a proper path, using an adapted A* algorithm, from a starting position to the requested goal; this path is finally represented as a polyline that does not intersect obstacles. Moving objects in the environment can be easily introduced in the SPIKE representation of the environment as soon as they are detected, and they can be considered while planning. Finally, doors or small (w.r.t. the grid resolution) passages can be managed by the specification of links in the static description of the environment.

C. Controlling Module

To implement trajectory following and obstacle avoidance (Fig. 4), we used MrBRIAN (Multilevel Ruling BRIAN) (Bonarini et al. 2004), a fuzzy behavior management system, where behaviors are implemented as a set of fuzzy rules. Antecedents match context predicates, and consequents define actions to be executed. Behavioral modules are activated according to the conditions defined for each of them as fuzzy predicates, and actions are proposed with a weight depending on degree of matching.

Fig. 4. By the use of a set of fuzzy rules it is possible to implement avoid strategies when facing unexpected obstacle.

III. MULTIMODAL WHEELCHAIR INTERFACE

In LURCH, to deal with different user capabilities, a multimodal interface has been implemented. Commands can be issued to the autonomous wheelchair at different level of abstraction, from simple “turn right” or “go straight” to complex task such as “bring me to the kitchen”. The user has thus the opportunity to choose among several autonomy levels, ranging from simple obstacle avoidance to full autonomy, and different interfaces: a classical joystick, a touch-screen, an electro miographic interface, and a brain-computer interface (BCI).

A. Joystick Interface

The most common interface mounted on electric powered wheelchairs is a joystick; in this case the user performs a direct control of LURCH movements as if it was a standard electric powered wheelchair. When the user has difficulties in fine control, obstacle avoidance capability is in charge of super-imposing ad-hoc maneuvers to avoid unforeseen objects. This intervention has been designed in such a way that it slows down the wheelchair up to its complete stop when the user is directly aiming at the obstacle (e.g., when pointing directly to a person the driver wants to talk with), while it deviates from the original path to circumvent the obstacle if this is approached from a lateral direction.

B. Touch-screen Interface

When only limited motion capability is available to the user a higher level of autonomy is needed from the wheelchair. In this case a touch-screen based interface has been designed with easy to select buttons. Each button is configured with an action (e.g., forward, right left, stop, etc.) or target destination (e.g., kitchen, bathroom, garden, etc.) and the user has only to select the desired option to be executed by the wheelchair. When an action is selected this is implemented by the wheelchair as if it was issued by the joystick; when the selection regards a target destination the planning module figures out the best trajectory to get there and the control module follows the trajectory by taking care of obstacle avoidance.

C. Electro-miography Interface

The touch-screen based interface has been extended with a selection mechanism to implement a low-cost electro miographic interface based on the NIA (Neural Impulse Actuator) gaming device by OCZ (see Fig. 5). In this
interface an automatic selection mechanism performs a sequential scan of selections, i.e., available actions or target destinations, and the user has to activate her muscles to confirm the actual selection. Being able to capture several electrical sources on the forehead the NIA device can be actuated by raising eyebrows, by moving eyes, or by activating jaw muscles.

D. Brain-Computer Interface

When no muscular activity is possible for the user an alternative way to communicate her intent to the autonomous wheelchair is to use a Brain-Computer Interface. In this context, brain activity, as measured from a suitable device such as an electroencephalograph (EEG), can be used to infer user intent and thus her will. Some BCIs detect the involuntary brain activity in response to stimuli associated with possible commands in order to infer the command intended by the user (event-related potentials). Others analyze components of brain signals that can be controlled voluntary by the user. Although the latter may feel somewhat more natural to the user, as they do not need external stimulation, they need cumbersome training from the user. To reduce this training effort, in LURCH, we have implemented a BCI based on P300 and ErrP event-related potentials.

The P300 is an event-related potential (ERP) which can be recorded via EEG as a positive deflection in voltage at a latency of roughly 300 ms in the EEG after a defined stimulus. It follows unexpected, rare, or particularly informative stimuli, and it is usually stronger in the parietal area. Our P300 BCI presents the user with the action/destination choices, one at a time; when it detects a P300 potential, it selects the associated choice. The user is normally asked to count the number of times the choice of interest is presented, so as to remain concentrated on the task. As the P300 is an innate response, it does not require training on part of the user.

Real BCIs sometimes misclassify user intent, and much research is devoted to improving BCI classification ability in order to increase their performance. Another way to face the issue is, as previously mentioned, to repeat the process more than once until a sufficient confidence is reached. Another possibility is, finally, to ask directly the user to confirm his/her choice, by adding another interactive interface.

In our work we adopted an alternative way to improve BCI performance, i.e., the early identification of errors and their automatic correction. It is known from the literature that user’s and BCI errors elicit error potentials (ErrP), a particular kind of potentials that occurs in the EEG when a subject makes a mistake or, more relevant to BCI applications, when the machine the subject is interacting with does not behave as the user expects. Thus, the detection of ErrPs could be a viable way to improve BCI performance and to increase its reliability, without making the interaction with the user heavier (Dal Seno et al. 2007).

IV. Conclusion

This paper has presented an overview of our research on the user centered design of a technological aid for the mobility of disabled people.

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REFERENCES