Introducing LURCH: a Shared Autonomy Robotic Wheelchair with Multimodal Interfaces

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***Abstract*— The LURCH project aims at the development of an autonomous wheelchair capable of avoiding 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 intentions by analyzing brain signals.**

I. Introduction

The possibility of moving in an autonomous way gives individuals a remarkable physical and psychological sense of well-being. Electric 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. However, often they cannot be used by people with low vision, visual field reduction, spasticity, tremors, or cognitive deficits. In order to give also to these people a higher degree of autonomy, and 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 [1], who equipped a wheelchair with sonars and a vision system to identify landmarks and correct its trajectory in hallways. Another solution was presented in [2] 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 in [3]: 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. In [4] authors presented an

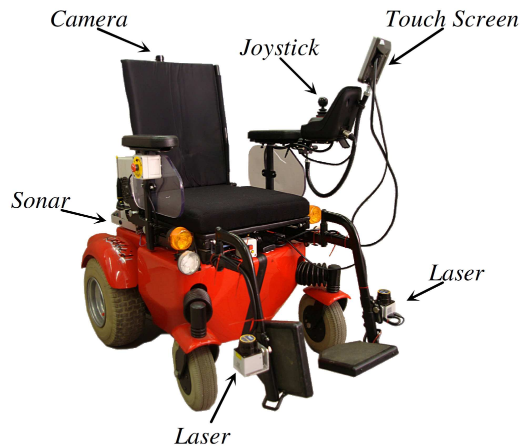

Fig. 1. The LURCH autonomous wheelchair equipped with sensors for autonomous navigation and the touch-screen interface.

autonomous wheelchair for cognitive-disabled children in narrow doors, and cluttered scenarios. These are just few examples of projects and the interested reader can look at [5], and [6].

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

*This work has been partially supported by the PRIN 2009 project “ROAMFREE: Robust Odometry Applying Multi-Sensor Fusion to Reduce Estimation Errors” from the MIUR (Itailan Ministry of University and Research).

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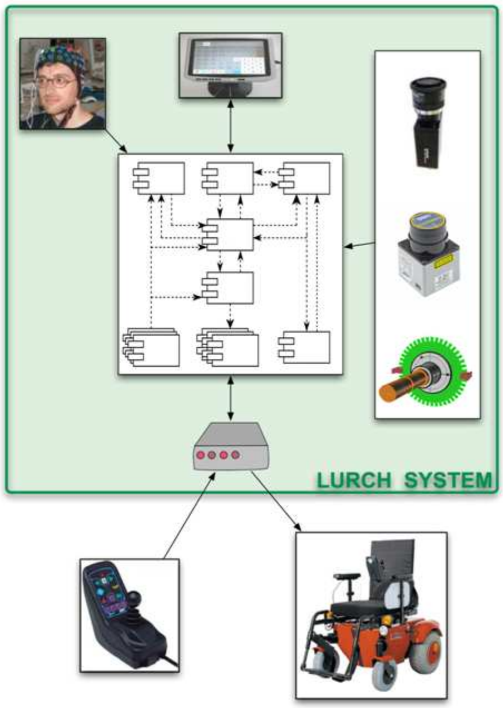

Fig. 2. The LURCH architecture; the control system is independent from the wheelchair, and the gateway between LURCH and the vehicle is represented by an electronic board that intercepts the analog signals coming from the joystick potentiometers and generates new analog signals to the wheelchair. Sensors used by LURCH are low-cost laser range finders, wheel encoders, and an upward looking camera.

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 intentions by analyzing brain signals [7].

II. AUTONOMOUS WHEELCHAIR DESIGN

The smart wheelchairs described in this paper has been designed to provide navigation assistance in a number of different ways, such as assuring collision-free travel, aiding in 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 and EEG amplifier not included, is less then five thousands of Euros, which is cheap with respect to other works) and provides different kinds of interfaces (see the next section for more details), in order to fulfil 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. Figure 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 in [8]:

- *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;
- *controll module*: it contains all the primitive actions, typically implemented as reactive behaviors that can be executed by the robot.

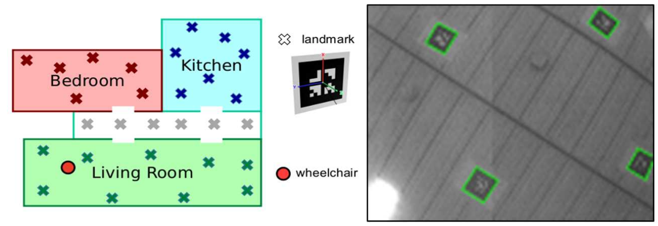

Fig. 3. A set of passive markers (in the middle) is placed on the ceiling of the environment to provide a global localization system (on the left) through the upward looking vision system (on the right).

According to the level of autonomy desired/required by the specific user, only few of these modules need to be deployed on the wheelchair; in the following we give a description of each of them together with the mechanism to integrate their functionality with the user intent.

A. Localization Module

The localization module operates using a video camera and some passive markers placed in the environment. Indoor, these markers are usually placed on the ceiling, avoiding in this way occlusions due to surrounding objects or people (see Figure 3). The use of known passive markers placed on the ceiling, although only feasible in indoor environments, provides an accurate and robust global localization system, i.e., the equivalent to what a GPS provides in outdoor environments, at the cost of just the upward looking low cost camera, (e.g., a consumer webcam). We have mounted a pair of custom encoders on the wheelchair; this allowes the use of a limited number of markers since we can use differential drive odometry for short paths and correct the cumulated error each time a marker is in the field of view of the camera.

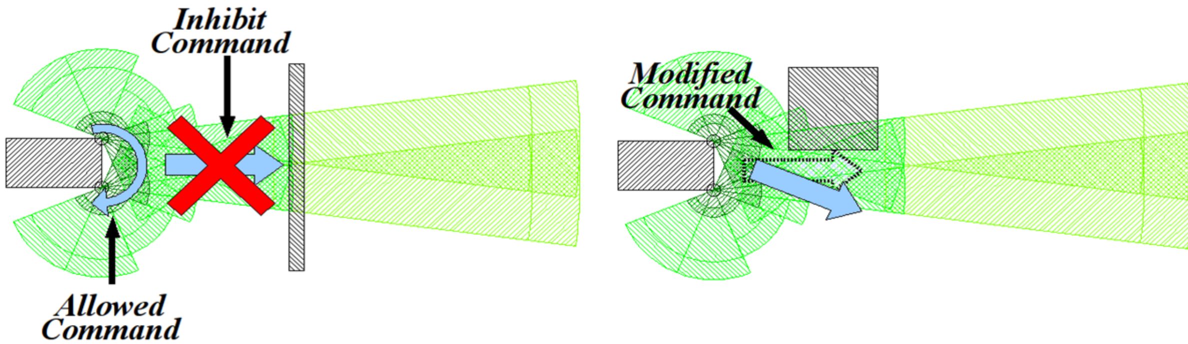

Fig. 4. By the use of a set of fuzzy rules it is possible to implement avoid strategies when facing unexpected obstacle.

A passive marker, in this context, is a planar image with a known shape that contains some encoded information. In particular, we used the ARToolKitPlus system [9], 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, implemented by the ARToolKitPlus library, 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 Degree of Freedom (DoF) position and its orientation in the camera reference frame. Since the position and the orientation of the markers in the environment w.r.t. the absolute frame (i.e., the environment map) and also the position and the orientation of the camera w.r.t. the wheelchair (i.e., camera extrinsic parameters) are known, the system can estimate the pose of the wheelchair w.r.t. the world frame each time it is able to detect one or more markers in the field of view of the camera. In indoor environments, it is generally sufficient to know the 3 DoF pose of the wheelchair; thus, we simplified through this assumption the localization problem, improving in this way the robustness and the accuracy of the localization algorithm.

B. Planning Module

The planning module is in charge of defining the trajectory LURCH should follow when moving from the actual position, as determined by the localization module, to the desired destination (selected by the user through one of the available interfaces). Such trajectory is obtained by using SPIKE (Spike Plans In Known Environments), a simple and fast planner based on a geometrical representation of static and dynamic objects in an environment modeled as a 2D space [8]. In SPIKE, 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.

It should be noticed that this kind of planner does not take into account few relevant aspects, and significant improvements are ongoing in this direction. First of all, a path planner for an autonomous wheelchair should take into account the footprint of the wheelchair and the fact that the center of the wheels baseline is not necessarily in the center of the footprint; by taking this into account, together with the dynamics of the vehicle, accurate paths in cluttered environments could be planned. A second issue that should be taken into account is the user preference; for instance, a classic path planner for a differential drive robot does not make any difference between forward movements and backward movements, this does not hold for the user on top of a wheelchair and forward movements should be favoured as well as smooth accelerations and decelerations.

C. Controlling Module

To implement trajectory following and obstacle avoidance (see Figure 4), we used MrBRIAN (Multilevel Ruling BRIAN) [10], a fuzzy behavior management system, where behaviors are implemented as a set of fuzzy rules. The antecedents of these rules 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 (for details refer to [10]).

In particular, we have defined two sets of rules: one implementing trajectory following and one implementing obstacle avoidance. The former set is enabled only when autonomous navigation is required by the user, while the latter is enabled both when the wheelchair is moving autonomously and when the user is driving the wheelchair. In this second case the obstacle avoidance corrects involuntary user mistakes and inaccurate commands, inhibiting dangerous commands and

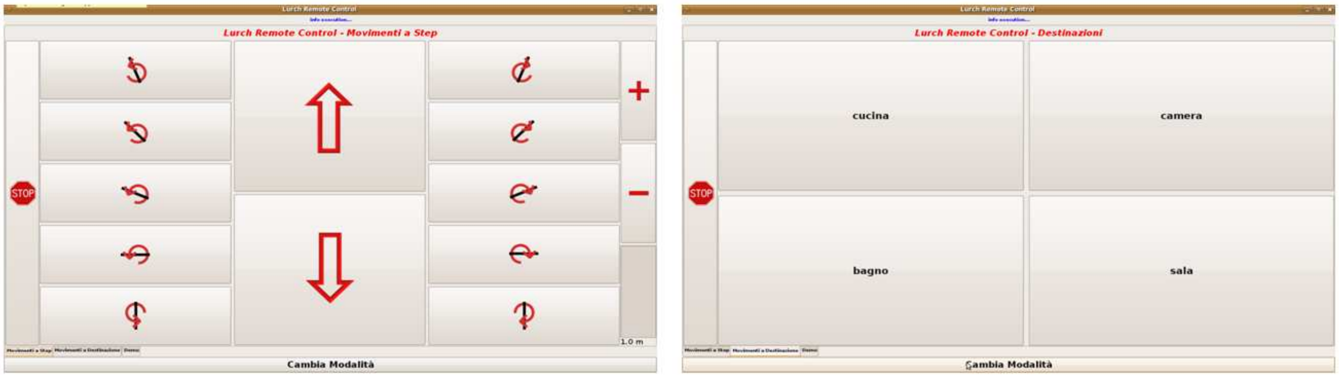

Fig. 5. The two modalities for the touch-screen interface: command mode (on the left) and destination mode (on the right).

modifying the trajectory of the wheelchair when and obstacle is obstructing the way, as depicted in Figure 4.

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 fitted to electric powered wheelchairs is the joystick; if this is the 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 can be enabled to integrate the user intent by superimposing 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 in front of the driver), while it deviates from the original path to circumvent the obstacle if this is not approached directly. By integrating obstacle avoidance with the classical manual control of a wheelchair, LURCH can safely be used by people with low vision or poor visual motor coordination. This widening of the user base in comparison to conventional electric wheelchairs becomes more evident when different analog devices, such as chin or sip-and-puff controllers [11], are used.

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 (see Figure 5). 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.

Fig. 6. The electro miographic interface based on the NIA gaming device.

C. Electro Miographic Interface

In LURCH, 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, depicted in Figure 6. 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. After an action has been selected, the wheelchair keeps performing it at least for the duration of a whole scan cycle of the available choices.

Fig. 7. The Brain-Computer Interface setting on the LURCH autonomous wheelchair; on the left the electrodes setup, on the right the acquisition of brain signals.

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 [12]. 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 [13].

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 (see Figure 7 for a sample setup). As the P300 is an innate response, it does not require training on part of the user. In our implementation, the P300 detection is obtained by a fast and robust logistic regression classifier trained on features extracted by a genetic algorithm [14].

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 users 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 [15].

IV. Field Tests

LURCH has been tested in several real world contexts, in order to evaluate its capability to correctly react to dynamic environments and to provide a satisfactory user experience. In particular, AIRLab collaborated with Simpatia (http://www.sim-patia.it), an Italian association promoting the use of high technology to improve the life of disabled people. In the context of this collaboration, actual everyday users of conventional electric wheelchairs have been asked to test an early version of the system at the associations premises, and their feedback has been incorporated into subsequent evolutions of LURCH. Additionally, all operative modes of LURCH have been successfully tested not only in the laboratory, but also in other environments not explicitly designed for robots.

Especially significant, from this point of view, is the successful demonstration of LURCH (in fully autonomous mode) at the Robotica 2010 fair in Milan (November 2010). A virtual home environment was defined over an open public area, by providing LURCH with a map describing the area as subdivided into a set of rooms connected by (fictitious, but spatially specified) doors. The autonomous wheelchair was required to continuously move around the “home”, going from “room” to “room” passing through the “doors”. Being the ceiling of the fairground too far to be accessible, for this test the markers used by LURCH for self localization were fitted instead to the floor.

The “virtual home” area was populated by visitors of the fair, coming and going while they visited the stands: LURCH had to detect them as obstacles and avoid collisions, modifying its course dynamically without interrupting it. The

Fig. 8. LURCH at Robotica 2010. From left to right: typical crowded moment, with LURCH moving among visitors; LURCH modifying its trajectory to avoid a fast moving passer by; back view of LURCH, showing the special configuration used for the fair (downward looking camera, self localization markers fitted to the floor).

system has been in continuous operation at Robotica 2010 for three full days. Notwithstanding the particularly challenging nature of the test, not a single incident occured. See Figure 8 for some snapshot taken during the event.

V. Conclusion

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

Despite the quite high number of research projects and investment, still no autonomous wheelchair is on the market, possibly due to problems of matching real user needs, reliability, and cost. The first issue can be faced by developing a methodology to evaluate the needs and abilities of single users, and by applying it to define the specifications for modules and interfaces bringing the required functionalities. Works in this directions have been done, including also robotic companions not necessarily dedicated to support mobility, also within funded projects [16].

The reliability issue depends on technology and design of the system, and needs to be certified in order to guarantee quality for a product that should go on the market. Steps in this direction have been done, for instance, by [4]. Given that the market for autonomous wheelchairs is large, but possibly not enough, and that it could prove not enough standardizable to support large scale economy, one path to cost reduction would be the modularization of the systems, so to give the possibility to re-use modules to produce personalized products at an acceptable cost. In any case, the fact that ISO has recently issue a first standards for care robots (ISO 13482) will probably aid the birth of markets for such devices, including autonomous wheelchairs.

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