Assistive Robot for Mobility Enhancement of Impaired Students for Barrier-Free Education: A Proof of Concept

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Abstract Smart wheelchairs are in the category of assistive robots, which interact physically and/or non-physically with people with physical disabilities to extend their autonomy. Smart wheelchairs are assistive robots that enhance mobility, and can be especially useful for improving access to university premises. This paper proposes a smart wheelchair that can be integrated with an academic management system to enable students who have serious leg problems and cannot walk on their own to reach any academic building or room on a university campus autonomously. The proposed smart wheelchair receives information from the academic management system about the spaces on campus, the lesson schedule, the office hours of lecturers, and so on. Students can select the desired task from the user interface. The smart wheelchair can then guide the student autonomously to the desired point of interest, while planning the best barrier-free route inside the campus/building and, simultaneously, avoiding fixed and moving obstacles. The assistive robot has localization and navigation capabilities, which allow students to move about campus freely and autonomously, and benefit from a barrier-free education.

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1 Introduction

Assistive technology is a broad and active field of research [1], which has been experiencing a noticeable growth in recent years, thanks to massive economic investments from both the private and the public sectors. As a result of these investments, the gap between the current and potential market share of assistive technologies is gradually narrowing [2, 3]. Traditional wheelchairs are among the most common assistive devices, and represent one of the first solutions to the problem of mobility for impaired users [4]. Recently, electric wheelchairs have been turned into smart wheelchairs with integrated sensors and computational capabilities [5]. The market currently offers smart wheelchairs with several functionalities, such as, autonomous behaviors, interaction with domestic environments and parameter measurement, just to name a few [6, 7].

This paper proposes a smart wheelchair for use as a semi-autonomous mobility support for students who have serious leg problems and cannot walk on their own. The assistive robot has localization and navigation capabilities and, thanks to an integrated academic management system, it can guide the user between locations on a university campus, making it easier for them to attend lectures and reach common spaces, such as cafeterias and toilets.

2 Architecture

The proposed integrated system is mainly composed of the following elements:

1. smart wheelchair;
2. database containing information about the university campus.

2.1 The Smart Wheelchair

The smart wheelchair is based on a commercial electric powered wheelchair, namely the Quickie Salsa R2 produced by Sunrise Medical. This wheelchair has integrated sensors and computational power, which permit semi-autonomous navigation in partially-known environments. Its compact size and its low seat-to-floor height (starting from 42 cm) gives it flexibility and easy access under tables, making it suitable for indoor settings. The mechanical system is composed of two rear driving wheels and two forward caster wheels. The latter are not actuated wheels, but are able to rotate around a vertical axis. The wheelchair is equipped with an internal control module, the OMNI interface device, manufactured by PG Drivers Technology. This controller has the ability to receive input from different SIDs (standard input devices) and convert them to specific output commands compatible with the R-net control system. In addition, an Arduino MEGA 2560 microcontroller, a Microstrain 3DM-GX3-25 inertial measurement unit, two Sicod F3-1200-824-BZ-K-CV-01 encoders, a Hokuyo URG-04LX laser scanner and a Logitech C270 webcam make up the remaining equipment of the smart wheelchair. The encoders, inertial measurement unit and the OMNI are connected to the microcontroller, while the microcontroller itself and the other sensors are connected via USB to a computer running ROS (robot operating system). Signals from the Sicod and Microstrain devices are converted by the Arduino and sent to the ROS localization module. The information provided by the Hokuyo is used by the mapping module and by the path planning module for obstacle avoidance. Once a waypoint is chosen by the user, the path planning module creates the predefined path.

The smart wheelchair is navigated in three different steps [8–10]: localization, map building and path planning. The steps are described as follows:

- *Mapping*: representation of the environment where the robot is operating, which should contain enough information to enable the robot to accomplish its task; it mainly relies on the laser rangefinder, which can measure distances in the space.
- *Localization*: estimation of the robot's current position in the setting; the localization method is based on AMCL (adaptive Monte Carlo localization), which exploits recursive Bayesian estimation and a particle filter to determine the actual robot position.
- *Path Planning*: choosing the route to a desired goal location from the robot's position; this takes into account possible obstacles detected by the laser rangefinder.

All the steps described above are performed via ROS modules. The wheelchair software is essentially composed of ROS packages and nodes, which acquire data from the sensor sets, elaborate the information and command the wheels accordingly. A description of these functionalities can be found in [11], and Fig. 1 illustrates the working prototype under development in our laboratory.

(a) Overall view (b) Topside view (c) Backside view

Fig. 1 Smart wheelchair test setup

2.2 The Database

The database is the second key part of the system. It contains all the relevant information about the university and is responsible for making the smart wheelchair adapt to the specific environment. In detail, the database contains:

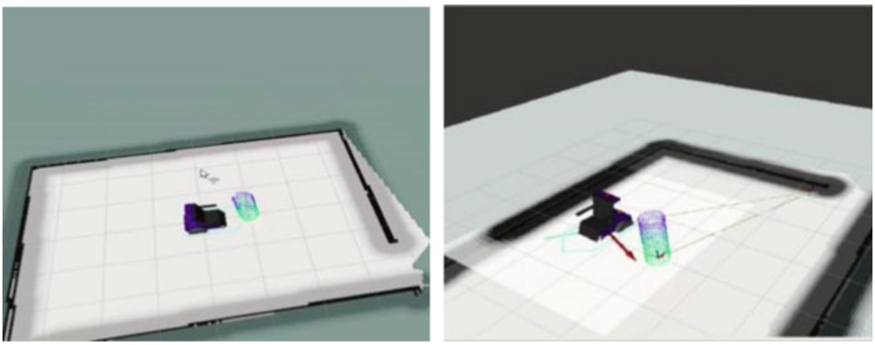
Maps—Maps of the entire campus must be captured digitally, measured by laser and catalogued by floor.

Course Program—All available lessons must be included in the database, together with the timetable and the room where the lesson is to take place.

The user can simply choose the place or the lesson on a graphical user interface, and the wheelchair will take her/him straight to the desired location, choosing the shortest available route and guaranteeing obstacle avoidance.

3 Simulation Testing

Both the environment and the smart wheelchair, including its sensors, have been simulated in Gazebo. A "virtual user" was positioned in front of a computer running the simulator and chose an end point (i.e., a new classroom, or a space on the campus). After the path was generated, additional obstacles were positioned on the screen to simulate an obstacle avoidance situation. During path planning, once the laser scanner detected the presence of an obstacle, the wheelchair's speed was automatically decreased by the system, and eventually set to zero to give it time to select a new path (see Fig. 2). The simulation was repeated with different "virtual users" and "obstacles" in order to test the capabilities of the path planning algorithm.



(a) Wheelchair with an obstacle in its way

(b) Wheelchair plansa new path to avoid the obstacle.

Fig. 2 The first image shows a new cylindrical obstacle. After it is identified, a new path is planned to avoid the obstacle

4 Conclusions

This paper has explored a solution that provides support to students with physical disabilities in the form of a smart wheelchair with an integrated academic management system containing relevant information about the university. This integrated solution allows the student to move through different areas of the campus. The algorithms related to the wheelchair for localization, mapping and path planning have been tested in a Gazebo simulator environment and performed well when it came to reaching the point selected on the map. A preliminary version of the database was organized by separating the information section about the maps and different sites on campus (e.g., classrooms, auditorium) from the course program and the schedule of lessons or particular events.

5 Future Works

Various aspects relating to navigation, interaction with the mobile robot and the user interface still need improvement to increase the smart wheelchair's functionalities. First, if there is an elevator on the planned route, the mobile robot could communicate with the elevator system and require the highest priority. This would avoid wait times for impaired students. Also, the wheelchair could be fitted with a system to recognize that people are moving around it, to avoid collisions and autonomously modulate the speed of the mobile robot in crowded spaces. The user interface is under development, and should provide an overall view of all possible actions. Finally, the possibility of integrating the smart wheelchair with the database and the management system is currently under investigation, as it is a key step in getting from simulation to real-life validation.

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