Development of an Automatically Guided Wheelchair Using Robot Operating System

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Abstract

We developed a wheelchair that could automatically take users to their destination, even for their first visit to a facility, to reduce their particular mental stress. The automatically guided (AG) wheelchair was developed based on open-source tools such as the Robot Operating Systems (ROS), which provided various useful and convenient libraries and tools. The AG wheelchair consisted of three functions: map detection, control and simultaneous localization and mapping (SLAM), and communication between a robot model created in Navigation Stack and the AG wheelchair. The map was successfully created with errors of ± 7 cm, which was not considered a problem for actual use. Additionally, the AG wheelchair successfully took a user to a destination designated on a map under automatic operation. The AG wheelchair avoided not only the walls and pillars but also the obstacles that were excluded from the map information, with 30 cm of avoidance distance (i.e., safety margin). We achieved cost savings for all parts of the AG wheelchair, except the laser sensor. Because safety is the most important factor for actual use, the obstacle avoidance function must be improved in future works. Additionally, users' evaluation should be examined by visual-analog-scale and measuring their physiological parameters, e.g., brain activities and autonomic nervous system activities.

Keywords: Automatic operation, Wheelchair, ROS (Robot Operating System).

1. Introduction

The number of people that require care assistance has been increasing since statistics have been kept, and the number of wheelchair users has been increasing^(1,2). These people would very much like to go out by themselves, something that was confirmed by a questionnaire administered at the Japan Assistive Technology Forum 2018 in Hakodate (unpublished data). However, although barrier freedom has been positively promoted for relatively large facilities (e.g., public offices, large department stores, stadiums, and educational facilities), we believe that it is not widespread enough for wheelchair users to utilize or enjoy many facilities by themselves. In fact, respondents answered that they felt mental and physical stress when leaving the house without an assisting person. On their first visit to a facility, they wondered if there were enough ramps for wheelchair users and if the floor areas of elevators were adequately wide, and they did not immediately know where such services were located even if the building had them. Wheelchair users also experience this problem even when they are accompanied by an assisting person. Certainly, a large facility can provide them with an assistance service; however, they tend prefer to move by themselves because they are sometimes bothered by their conscience or hesitant to ask the helper. Additionally, some of them occasionally feel anxious or are afraid of a helper who is not used to assisting them.

On the other hand, because the Olympics and

Paralympics will be held in Tokyo in 2020, the opportunity for wheelchair users to go out by themselves must improve. In this study, to assist wheelchair users' easy outing, we attempted to develop a wheelchair that could automatically take them to their destination, even for their first visit to a facility.

2. Development of the AG wheelchair

2.1 Developmental Concept

Recently, various companies (e.g., Panasonic Co.) have attempted to develop automatically operated wheelchairs with significant high-tech functions. However, such wheelchairs are very expensive, which means that they are difficult to obtain for average wheelchair users, even if the users receive welfare subsidies. Therefore, we attempted to develop an affordable wheelchair with automatic guidance and operating functions. Our aims were the following: 1) to add parts to an ordinary commercial wheelchair to reduce costs and 2) to use open-source technology to familiarize general users with this wheelchair. In this paper, we call this wheelchair the “automatically guided (AG) wheelchair.”

First, the AG wheelchair was driven to create the map data for a facility; it was not in automatic operation for this part of the research. Then, after the user pointed out the destination (e.g., an elevator, cash desk, or lavatory) on the map of the tablet/laptop PC created in the first step, the AG wheelchair took the user to the goal point under automatic operation. An announcement function to the user by sounds or voice was not installed at that time.

2.2 Systems

Development of automatic operation was attempted using Navigation Stack, provided by the Robot Operating System (ROS). The ROS is a set of open project tools that is currently developed by the Open Source Robotics Foundation Inc. It provides various libraries and tools (e.g., communication library, recognition library, control library, and visualization tools) for robot developers. The ROS might not be a novel technology in 2018; however, it has become explosively popular in robot engineering, mainly in the American and European robot communities because it gives the robot engineer various advantages⁽³⁻⁵⁾. For instance, Dr. Okada said that he felt that the (robotics) world was drastically changed after the ROS was developed. He also said that he had never seen such useful software before

Fig. 1. Schematic diagram of Navigation Stack.

that⁽³⁾ (Actually, his comment was described in Japanese. The above English comment was translated by the authors).

Navigation Stack, which is one of the tools of ROS, mainly provided localization and navigation functions. The adaptive Monte Carlo localization (AMCL) package localized the object using map information from map_server, and the move_base package planned the route to the destination and then navigated the object to the goal point, which achieved the automatic operation function. The map_server received the map information created by the simultaneous localization and mapping (SLAM) function using various sensing values^(e.g.,6,7). The move_base sent the navigation information to the base_controller to move the robot. The schematic diagram is shown as Fig.1. The developed AG wheelchair was divided into three systems, i.e., the map detection system, control and SLAM systems, and a communication system between the created robot model and the AG wheelchair.

2.3 Map creation

Map_server receives the map information and provides it to Navigation Stack. In this study, a map was created using Google Cartographer. Cartographer is the package that creates the surrounding map and estimates self-localization with an input of the laser sensor and the Inertial Measurement Unit (IMU). We selected the UST-10LX (Hokuyou Automatic Co., Ltd.) as the laser sensor and the 9DOF Razor SFE-SEN-10736 (Spark Fun Inc., Ltd.) as the IMU.

Figure 2 shows an example of the UST-10LX laser sensor and its driven result on the ROS. A circular object (in the red circle) and two small dolls (in the blue circle) were located directly in front of the laser sensor and diagonally forward and to the right of it as obstacles, respectively (Fig. 2, top image). These obstacles were detected by the laser sensor (Fig. 2, bottom image). Here, the solid yellow circle at the center of the bottom image in

Fig. 2 is the laser sensor.

Fig. 2. Object detection by the UST-10LX laser sensor.

Fig. 3. Detection of 3D coordinates by the inertial measurement unit (IMU).

Figure 3 shows an example of detection of three-dimensional coordinates by the IMU on the ROS. The direction of the IMU (red board) in front of the laser was accurately detected and was displayed in three dimensions (x, y, and z) on the monitor.

Figure 4 shows an example of the mapping result by Cartographer using the laser sensor and IMU on the third floor of the National Institute of Technology (NIT), Hakodate College, building C. The black part indicates occupancy by an object, the white part represents open space, and the grayish color means “unknown.” The small map at the top left is the actual map. The mapping of Fig. 4 was performed manually instead of automatic driving. The actual walls and pillars are displayed as black areas, whereas the actual open spaces were shown as white areas, indicating that the created map was reliable for the navigation system. However, several spaces (grayish area indicated by the arrow) are displayed as unknown points, although those places were measured by the laser sensor.

Table 1 shows the actual and detected sizes of several objects and spaces. The error was not greater than ± 7 cm.

Fig. 4. Example of mapping results by Cartographer using the laser sensor and IMU on the third floor of the NIT, Hakodate College, building C.

Table 1. Accuracy of the created map.

Locations / Subjects	Size from the measured map (m)	Actual size (m)	Error (m)
Width of locker	2.77	2.70	0.07
Distance between pillars	3.38	3.36	0.02
Width of corrido	2.30	2.37	-0.07
Width of toilet entrance	0.75	0.80	-0.05

Fig. 5. Velocity control of the wheelchair.

We assume that the reason for detection of the unknown points and the measurement error is that the laser sensor was displaced by vibration caused by movement of the wheelchair. We supposed that the location of the wheelchair in this study was inside the building and the wheelchair maintained a certain distance from obstacles for the users' safety, which indicated that the accuracy of the map was suitable for actual use. It should be noted that only one laser sensor was mounted on the wheelchair for this study; therefore, we expect these detection errors to be improved using multiple laser sensors.

2.4 Velocity control of the wheelchair

When the wheelchair was operated, the base controller controlled its velocity based on a target velocity sent from move_base in Navigation Stack. The velocity of the wheelchair was controlled by a proportional, integral, and differential (PID) controller as a feedback value with self-velocity, which was measured by an encoder on one wheel[e.g., 8].

Figure 5 shows the velocity of the AG wheelchair V_{forward} m/s with a target velocity of 0.4 m/s. The velocity of the AG wheelchair reached the target velocity in approximately 0.5 s (0.5 to 1.0 s). Overshoots of up to 7.5% of the target velocity (0.4 m/s) occurred.

3. Result of Automatic Operation

After the systems described in the above section were installed on the wheelchair, we conducted a test drive of the automatic operation. Here, the map data made by Cartographer were input to the map_server of Navigation

Stack. The wheelchair model designed by 3D CAD was displayed on the map. Then, the coordinates of the destination and the entering direction of the wheelchair were set by the arrow (Fig. 6A). The red object at the center of Fig. 6A is the wheelchair model, and the green arrow at the center right of Fig. 6A indicates the direction forward to the goal point. Finally, the systems displayed real-time conditions, and the AG wheelchair took the user to the goal point, as shown in Fig. 6B.

The AG wheelchair successfully took the user to the destination designated on the map under automatic operation (Fig. 7). For the safety of users, which is the most important factor, obstacle detection and avoidance algorithms using simultaneous real-time laser sensor and map information were installed on the AG wheelchair.

As the avoidance distance (i.e., safety margin), a 30-cm distance between the AG wheelchair and obstacles was maintained during automatic operation. The AG wheelchair

Fig. 6. Input of the destination and an example of real-time conditions.

Fig. 7. The AG wheelchair is taking a user to the destination designated on the map under automatic operation.

avoided not only the wall and pillars on the map_server but also the obstacles that were placed by us. However, when the obstacles were placed on a narrow-width floor, the AG wheelchair was occasionally stopped because the algorithm selected “unavoidable”.

4. Conclusion

In order to promote an opportunity of wheelchair users' easy outing, we developed a wheelchair that could automatically take them to their destinations even on their first visit to a facility. Table 2 summarizes the results of this study. The errors between the map created by the ROS (including Navigation Stack) tools and actual map did not exceed ± 7 cm. In actual operation, because the AG wheelchair utilized the created map information as well as real-time obstacle detection, we believe that this level of error is not a significant problem. However, in this research,

the map was not created automatically, which means that staff had to have previously operated the AG wheelchair to create the map information for their facility before providing it to users. To alleviate this prerequisite task, automated map creation should be required as a next step. For instance, this activity should be conducted during times when the facility is closed.

The velocity V_{forward} of the AG wheelchair fluctuated because of repeated overshoots around the set value owing to the limited resolution of pulse width modulation control. When the V_{forward} was set to 0.4 m/s, overshoots of up to approximately 7.5% of the target value occurred. We would like to investigate whether this velocity fluctuation affects the users' comfort.

The AG wheelchair successfully took the user to the destination designated on the map under automatic operation. However, the AG wheelchair was occasionally stopped because of the “unavoidable” condition. Although this could have been improved by reducing the avoidance distance (i.e., safety margin), it would have meant increasing the risk of collision with obstacles (particularly moving obstacles such as people). Indeed, in the obstacle avoidance trial with a safety distance of less than 30 cm, the AG wheelchair occasionally contacted an obstacle owing to missed avoidance. If users felt any anxiety and/or fear, user could stop the automatic operation of the wheelchair, and it can be manually controlled by themselves. However, safety remains the most important factor for actual use. Therefore, in future works, the obstacle avoidance function must be improved, e.g., using small cameras and image processing. Additionally, for instance, although we set the safety margin at about 30 cm, whether this distance is suitable or not for users' stress was not investigated yet in this study. It (i.e., sensibility estimation) should be examined by visual-analog-scale and measuring their physiological parameters, e.g., brain activities and autonomic nervous system activities.

As an estimate of the development cost, we developed this AG wheelchair with low costs, except for the laser sensor (UST-10LX, approx. 150,000 yen) and personnel expenses. The ROS, which was the core technology of this research, is an open-source tool. The tablet/laptop PC costs 35,000–60,000 yen, the IMU board was ~15,000 yen, and some aluminum and acryl plate materials were required. Because two or more laser sensors would be used for safer driving in future works, we should attempt to equip this wheelchair with other low-cost distance sensors.

Table 2. Summary of the results

Aim / Function	Results
Automatic operation	Achieved on flat floor
Sensing and map creation	Maximum error of 7 cm
Velocity control	Overshoots within 7.5% of target velocity
Obstacle avoidance	With safety margin of 30 cm
Cost	Low cost except the laser sensor
Users' evaluation	To be investigated

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