Indoor Autonomous Navigation using a ROS-Generated Map via Cartographer SLAM

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I. INTRODUCTION

The need for autonomous navigation systems in indoor environments has grown due to the increasing demand for efficient and reliable robotic applications. In the modern world, the integration of robotics extends across various fields, from healthcare to artificial intelligence. To address this escalating demand, the Robot Operating System (ROS) provides a technical foundation for the real-time handling of sensors and actuators, offering open-source codes for implementation.

The development of this paper presents an advancement in the field of robotic navigation within indoor environments. Through the amalgamation of the ROS framework and Cartographer SLAM, this research seeks to delve into the effectiveness of autonomous navigation for indoor applications. By harnessing sensors and mapping algorithms, robots can meticulously chart their surroundings, continually vigilant of dynamic environmental changes. This implementation of SLAM in ROS offers a robust platform for autonomous navigation, ensuring precise positioning and streamlined navigation within indoor spaces.

II. Background of the Problem

The problem of indoor autonomous navigation has gained significant attention due to the rapid advancements in Simultaneous Localization and Mapping (SLAM) algorithms and robotics technology. With the integration of the Robot Operating System (ROS) framework and SLAM algorithms, robots are now capable of effectively navigating and mapping previously unknown indoor environments. This has opened up possibilities for a wide range of applications, including automated delivery systems, inventory tracking, and security monitoring.

The research papers cited in this work have thoroughly explored the utilization SLAM algorithms, such as GMapping, HectorSLAM, and Cartographer, for achieving autonomous navigation in indoor environments. These algorithms provide an effective solution for mapping and localization, enabling robots to navigate autonomously while avoiding obstacles, as evidenced in studies of Thale et al. (2020) and Megalingam et al. (2018). The essential components for this implementation include the use of laser data and odometry information, which, in conjunction with SLAM algorithms, facilitate the generation of accurate 2D occupancy grid maps crucial for enabling seamless and safe autonomous navigation (Shankar & Shivakumar, 2023).

III. OBJECTIVES

1. Develop a ROS-generated map of an indoor environment using the LiDAR sensor via Cartographer SLAM
2. Integrate the ROS-generated map into a program for the autonomous mobility of a robot

IV. RELATED STUDIES

In 2019, a study conducted by Moriya et al., used an open-source software like Robot Operating System (ROS) to create an autonomously guided (AG) wheelchair. This study focuses on the use of functions in the wheelchair for the development of an automatic map. It provided various useful and convenient libraries and tools. Map detection, control and using cartographer algorithm as its simultaneous localization and mapping (SLAM), and communication were the three functions AG wheelchair have. By the use of the Cartographer SLAM, the map was successfully created with errors of±7 cm, which was not considered a problem for actual use. With a 30 cm avoidance distance (i.e. safety margin), the AG wheelchair avoided not only the walls and pillars but also the obstacles that were not indicated on the map, it successfully took the user to the destination designated on the map by the use of Cartographer algorithm [1].

In 2019, Megalingam et al. conducted a study where they test the flexibility of a SLAM based mobile robot to map and navigate in an indoor environment based on the Robot Operating System (ROS) framework. The mapping process is done by using the GMapping algorithm, which is an open-source algorithm. By the use of ROS and SLAM based GMapping and navigation, they were able to create specific environments. In each environment, different parameters like how well the SLAM generated maps represent reality, the time it took for the robot to reach the given destination. They also placed dynamic obstacles in the robot's navigation path to test the amount of time that is required for the robot to reroute itself to another path. They considered 10 trials to obtain the average travel time in the environment, with and without obstacle. It is observed that the robot gives a good response time and also it takes only reasonable time to cover the distance from the source to destination. In the case of a map with obstacles, the robot will find the shortest path. And if an extra obstacle is introduced the robot will stop and recalculate the new path. [2]

In 2023, Shivakumar et al. conducted a comprehensive study on the development and implementation of a multi robot system for mapping and autonomous navigation within indoor environments. They used the Robot Operating System (ROS) platform and LIDAR sensors. The ROS framework serves as the foundation for this endeavor, allowing seamless integration of sensor data, robot control, and high-level navigation algorithms. They selected the Gazebo simulation platform for validating robot mapping and navigation. Methods such as Gmapping, Cartographer, and Hector slam were implemented on single robot equipped with LIDAR. To generate the map, the robot is driven manually in the environment. All the mapping methods were implemented on the same environment. They conducted simulation experiments within the Gazebo platform on Ubuntu 18.04 and ROS Melodic systems to assess the mapping accuracy. Once the global map is generated, it's been shared among the robots for autonomous navigation. Each robot then uses the global map generated in the multi-robot system to independently navigate to the destination. The 2D pos estimate button in the Rviz tool is used initially to locate the robot, which internally runs the AMCL algorithm to know where it is inside the map. The target is set by using a 2D nav goal key, which intern uses the A* path planning algorithms to plan the route from the starting point to the target destination. The work reveals that efficient and safe solution for navigation through unknown indoor environment can be provided by mapping and autonomous navigation using LIDAR and ROS. The system provided a promising result in obstacle detection and avoidance. [3]

V. METHODOLOGY

A. Block Diagram

The block diagram shown in Figure 1 presents the development of an indoor autonomous navigation for wheelchair control. It consisted of 2D-RPLiDAR and IMU sensors to map specific essential locations based on the collected data points of the mapped environment. Once the essential locations have been mapped, it was employed as indoor destinations wherein the user can select to move the wheelchair, respectively. Additionally, the study included ultrasonic sensors to further improve the accuracy of obstacle detection and avoidance.

Fig. 1. Block Diagram

B. Gathering of mapping data

The design incorporated an RP 2D-LiDAR and IMU (Inertial Measurement Unit) sensor mounted on the wheelchair to collect data points on the mapped interior environment. The LiDAR sensor was strategically placed beside the left handle of the wheelchair as it is in close proximity to the center of the wheelchair, wherein this can accurately represent its location during localization and data collection. The data collection is the extraction of certain aspects of the mapped interior environment. The 2D-RPLiDAR sensor gathered data by sending laser beams to the environment and the time it takes by the beam to return to the sensor upon reflecting on a surface was used to calculate the distance between the sensor and its surroundings. The map that was produced using SLAM is simultaneously graphically presented in Rviz. Each point on the generated map represents x, y and z coordinates which were used to represent specific goal locations that the user can navigate towards to.

C. Programming of the auto-navigation

For the auto-navigation system, the Cartographer SLAM algorithm was used to validate the localization and the mapped construction of the indoor environment. Based on a prior study which compared three different SLAM techniques namely Hector, Gmapping and Cartographer (Shivakumar et al.), Cartographer has the advantage in terms of constructing precise 2D maps and navigating unknown environments. Once the gathered data points have been finalized, the Robot Operating System (ROS) was used to run the SLAM algorithm and monitor its output including the chosen locations on the environment using the gathered sensor data and estimated position of the wheelchair. The collected data were processed for mapping and localization using built-in ROS packages. Additionally, ROS visualization (RViz) was used to visualize, as well as to modify and interact with the mapped environment in real time.

D. Initial Testing

After the gathering of data points for the IMU and LiDAR sensors, the researchers conducted initial testing of the programmed auto-navigation and obstacle avoidance system. In addition to the sensors, three ultrasonic sensors were also incorporated in the obstacle avoidance system. These systems were implemented directly onto the wheelchair, to check the validity and reliability of both systems. RViz was used to visualize obstacle data coming from the LiDAR and ultrasonic sensor, while IMU was used to determine the orientation. To verify the reliability of obstacle avoidance, navigation was tested using RViz by setting a goal location on the map. Successful navigation was determined if the wheelchair reached the destination without any collisions, indicating that the obstacle avoidance system was functioning correctly.

VI. RESULTS AND DISCUSSION

Based on obtained results from the functionality and field testing shown from Figure 2, the data from one of the researchers attained an acceptable accuracy rate of 79%, as summarized from Tables 1 to 8.

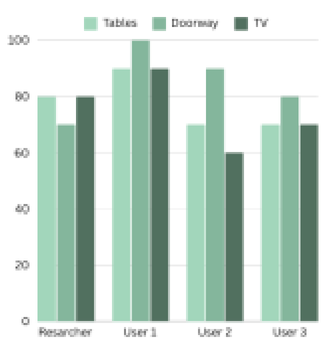

Figure 2. Field Testing Results of Autonomous Navigation

Table 1. Confusion Matrix in Autonomous Mode Testing of One Member of the Researchers

Researcher			
		Goal Reached in Map	**Goal not Reached in Map**
Arrived at Actual Destination within 1 minute	A/Tables	7	0
	B/Doorway	7	0
	C/TV	7	0
Did not arrive at actual destination within 1 minute	A/Tables	2	1
	B/Doorway	3	0
	C/TV	2	1

Table 2. Summary of Confusion Matrix Metrics in Autonomous Mode of One Member of the Researchers

Researcher				
30 Trials	**Metrics**			
Auto navigation locations	**Accuracy**	**Precision**	**Recall**	**F1-score**
A/Tables	80 %	77.778 %	100 %	87.5 %
B/Doorway	70 %	70 %	100 %	82.353 %
C/TV	80 %	77.778 %	100 %	87.5 %

Table 3. Confusion Matrix in Autonomous Mode Testing of User No. 1 from Young Focus

User no. 1			
		Goal Reached in Map	**Goal not Reached in Map**
Arrived at Actual Destination within 1 minute	A/Tables	9	0
	B/Doorway	10	0
	C/TV	5	0
Did not arrive at actual destination within 1 minute	A/Tables	1	0
	B/Doorway	0	0
	C/TV	1	4

Table 4. Summary of Confusion Matrix Metrics in Autonomous Mode of User No. 1 from Young Focus

User no. 1				
30 Trials	**Metrics**			
Auto navigation locations	**Accuracy**	**Precision**	**Recall**	**F1-score**
A/Tables	90 %	90 %	100 %	94.737 %
B/Doorway	100 %	100 %	100 %	100 %
C/TV	90 %	83.333 %	100 %	90.909 %

Table 5. Confusion Matrix in Autonomous mode Testing of User No. 2 from Young Focus

User no. 2			
		Goal Reached in Map	**Goal not Reached in Map**
Arrived at Actual Destination within 1 minute	A/Tables	6	0
	B/Doorway	9	0
	C/TV	6	0
Did not arrive at actual destination within 1 minute	A/Tables	3	1
	B/Doorway	1	0
	C/TV	4	0

Table 6. Summary of Confusion Matrix Metrics in Autonomous Mode of User No. 2 from Young Focus

User no. 2				
30 Trials	**Metrics**			
Auto navigation locations	**Accuracy**	**Precision**	**Recall**	**F1-score**
A/Tables	70 %	66.667 %	100 %	80 %
B/Doorway	90 %	90 %	100 %	94.737 %
C/TV	60 %	60 %	100 %	75 %

Table 7. Confusion Matrix in Autonomous mode Testing of User No. 3 from Young Focus

User no. 3			
		Goal Reached in Map	**Goal not Reached in Map**
Arrived at Actual Destination within 1 minute	A/Tables	5	0
	B/Doorway	8	0
	C/TV	6	0
Did not arrive at actual destination within 1 minute	A/Tables	3	2
	B/Doorway	2	0
	C/TV	3	1

Table 8. Summary of Confusion Matrix Metrics in Autonomous Mode of User No. 3 from Young Focus

User no. 3				
30 Trials	**Metrics**			
Auto navigation locations	**Accuracy**	**Precision**	**Recall**	**F1-score**
A/Tables	70 %	62.5 %	100 %	76.923 %
B/Doorway	80 %	80 %	100 %	88.889 %
C/TV	70 %	66.667 %	100 %	80 %

VII. CONCLUSION

The researchers successfully developed an indoor auto-navigation system which utilized the ROS-generated map from Cartographer SLAM. The implemented SLAM algorithm was able to construct a map of the mapped environment and identify available paths the wheelchair can take to reach its destination predetermined by the user. In addition to that, the proposed auto-navigation system demonstrated satisfactory results, indicating its potential to for further improvement. Lastly, the obtained results from the field-testing together with actual users proved that the proposed system could cater to the specific needs of a quadriplegic patient or individuals with limb impairments.

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