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Voice-Enabled Autonomous Robot with Cartographer SLAM for Multi-Point Navigation

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Abstract
Developments in Autonomous mobile robot have come from growing need for quick and seamless delivery options. This project provides a voice-driven autonomous robot with effective multi-point navigation configured with Cartographer SLAM. This system controlled by a Jetson Nano combine with ROS programming for real-time communication and processing. Cartographer SLAM is used for mapping and localization by LIDAR sensor the robot uses a microphone array for voice recognition, therefore allowing hands-free operation. Whereas a cartographer SLAM algorithm maximizes delivery pathways depending on environmental variables, a real-time SLAM-based navigation system guarantees exact localization and obstacle avoidance. By allowing the robot to dynamically visit pre-defined waypoints, the multi-point navigation capability helps to maximize path planning and obstacle avoidance.
Keywords: *Autonomous mobile robot, voice recognition, Cartographer SLAM, mapping, localization and multi-point navigation.*

1. Introduction
Autonomous mobile robots (AMRs) have changed industries by improving automation, efficiency and human-robot interaction. This applications cover numerous sectors, including industrial automation, smart environments, healthcare and service robots. The capacity to travel dynamically and adapt to real-world environments is important for Autonomous Mobile Vehicle to execute complicated jobs efficiently. However, classic navigation systems frequently rely on predetermined courses and lack intuitive human engagement, limiting their versatility. This project describes about voice-enabled autonomous robot that works with Cartographer Simultaneous Localization and Mapping (SLAM) for precise mapping, localization, and multi-point navigation. By adding speech recognition, users may control the robot hands-free, providing orders for navigation without requiring physical interfaces. Cartographer SLAM provides precise mapping and localization, allowing the robot to dynamically explore many waypoints while optimizing path planning and obstacle avoidance. The suggested system intends to bridge the gap between human and autonomous navigation, providing a durable solution for settings intelligent and adaptive mobility. This study contributes to the advancement of interactive robotic systems, enhancing their usability in dynamic and unstructured environments. [1-2] The rising desire for efficient and frictionless delivery options has inspired improvements in autonomous delivery vehicles. This work provides a voice-activated autonomous robot with effective multi-point navigation equipped with Cartographer SLAM. Driven by a Jetson Nano, the system combines a ROS for real-time communication and processing mapping and localization the robot uses a microphone array for voice recognition, therefore allowing hands-free operation. Whereas a cartographer algorithm maximizes delivery pathways depending on environmental variables, a real-time SLAM-based navigation system guarantees exact localization and obstacle avoidance. By allowing the robot to dynamically visit waypoints and the multi-point navigation capability helps to maximize path

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planning and obstacle avoidance. Experimental findings show how precisely the system maps, locates and executes voice commands. [3]

2. Problem Statement

Traditional mobile robots frequently rely on pre-defined pathways or manual control, restricting their adaptability to dynamic and unstructured surroundings. The lack of efficient real-time navigation, coupled with the absence of natural human involvement methods, inhibits their usefulness in complicated domains such as industrial automation, surveillance and assistive robots. These restrictions make it tough for robots to adapt efficiently to environmental changes and user request. This project focuses on constructing a voice-enabled autonomous robot equipped with Jetson nano and lidar using Cartographer SLAM for effective multi-point navigation. The primary difficulty comes in enabling the robot to move independently while adding speech recognition for hands-free control and SLAM-based mapping and localization for real-time flexibility. Additionally, incorporating computer vision-based obstacle detection and object identification boosts the robot's perception, enabling better decision-making and smooth mobile purpose of this project is to overcome the restrictions of existing robotics systems by building an integrated navigation framework that incorporates voice control, Cartographer SLAM and computer vision. This technique promotes flexibility, improves navigation efficiency and supports seamless human-robot interaction, making the system well-suited for dynamic and real-world applications [4]

3. Proposed Methodology

The proposed system integrates real-time sensor fusion and embedded processing to achieve voice-controlled autonomous navigation. The system is built on the Jetson platform, utilizing Cartographer mapping for multi-point autonomous navigation with ROS. The methodology consists of several key components, each playing a crucial role in the operation of the robot.

3.1. Multi-Machine Communication Configuration

The Robot Operating System (ROS) networking architecture enables seamless communication between the Jetson Nano and a PC in a multi-machine setup. By facilitating real-time data transmission between these devices, the system supports distributed processing and efficient debugging. Specifically, the robot's ROS nodes are responsible for publishing sensor data, including camera feeds and distance measurements, which are crucial for navigation and decision- making. The PC subscribes to these data streams, performing the necessary processing and analysis. Moreover, the robot receives control signals from the PC, ensuring real-time communication and precise operational control. This setup provides a flexible and robust communication framework, supporting both interactive PC-based control and autonomous robot functionalities across various robotic applications.

3.2. Robot Movement Control System

The motor control node regulates the robot's movement using Pulse Width Modulation (PWM) signals and ROS topics. This system is designed to control the robot's speed and direction by delivering precise PWM signals to the motors. ROS topics facilitate communication between nodes, enabling real-time execution of movement commands.

The robot undergoes testing in multiple movement directions, including forward, backward, left, and right, ensuring that each motion is executed with accurate speed and direction. Additionally, the system integrates an Inertial Measurement Unit (IMU) sensor, which provides real-time feedback on the This integration ensures that the robot's movements are ac- curate and responsive, thereby improving its overall navigation capabilities.

3.3. LiDAR Node Activation

The Light Detection and Ranging (LiDAR) node is activated by initializing the LiDAR sensor, which begins publishing distance data as a Robot Operating System (ROS) topic. The data is transmitted using the sensor_msgs/LaserScan message type, enabling seamless integration with Simultane- ous Localization and Mapping (SLAM) algorithms.

This message type allows the LiDAR data to be processed by the SLAM system for accurate mapping and localization, providing critical environmental information for robot naviga- tion and spatial awareness. [5]

3.4. Voice Recognition System

The voice command processing module enables hands- free operation of the autonomous mobile robot by recording user input in real time through a microphone array. The Automatic Speech Recognition (ASR) module converts spoken commands to text through a deep neural network-based speech to text engine, thus processing the recorded audio signals. The recognized text is then disassembled to discover significant navigation instructions such as waypoint selection, direction of motion, and velocity control. The commands are translated into pre-designed robot actions within the ROS-based control system to ensure seamless interface with the navigation stack. In order to enhance its robustness for real-world applications, the system is designed to handle changes in voice patterns, ambient noise and multiple command inputs. The integration of speech recognition allows the robot to have a more natural and effective human-machine interface, thus eliminating hand input devices and providing truly autonomous, voice-controlled operation. (Figure 1)

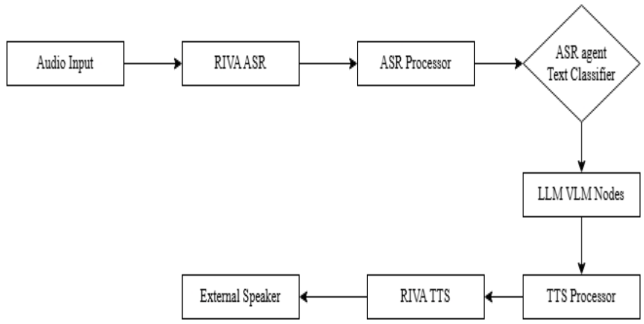

Figure 1 Block Diagram of the Voice-Control System

3.5. Mapping and Localization Using Cartographer SLAM

Mapping and localization are fundamental to autonomous mobile robotics, enabling real-time environment perception and adaptive navigation. In our implementation, we employed Google Cartographer SLAM, which combines LIDAR scan matching with probabilistic pose estimation to create an accurate 2D occupancy grid map. Fig. 3 illustrates the real-world mapping results obtained using our system.

As the robot navigates through an unknown environment, Cartographer SLAM continuously collects LIDAR scan data and transforms it into a submap coordinate system using a plane transformation

$$T_\xi h_k = \begin{bmatrix} \cos\xi_\theta & -\sin\xi_\theta \\ \sin\xi_\theta & \cos\xi_\theta \end{bmatrix} h_k + \begin{bmatrix} \xi_x \\ \xi_y \end{bmatrix} \quad (1)$$

where ξ=(ξ_x,ξ_y,ξ_θ) represents the robot's pose in a 2D coordinate system. Here, ξ_x and ξ_y denotes the translations along the x and y axes, while ξ_θ represents the robot's orientation (rotation). The black boundaries in Fig. 3 illustrate these structural constraints, aligning the LIDAR-generated map with real-world spatial constraints. (Figure 2) [6]

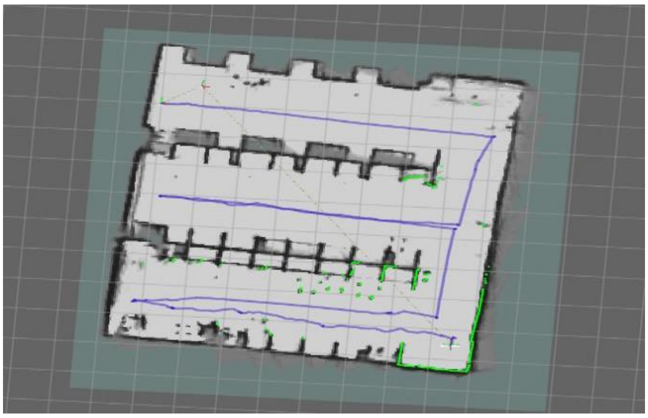

Figure 2 Real-Time Mapping Using Cartographer SLAM in RViz. the occupancy Grid Map Visualizes the Robot's Environment

3.6. Real-Time Mapping and Path Execution

The gray free-space regions in Fig. 3 indicate navigable zones, where the robot updates its occupancy grid by inserting new scan data and adjusting probability values using a Bayesian approach:

$$odds(p) = \frac{p}{1-p}$$

$$M_{new} = \text{clamp}(\text{odds}^{-1}(M_{old}(x)) \cdot \text{odds}(P_{hit})) \quad (3)$$

where Mold represents the prior probability distribution of the grid, and Mnew is the updated probability. The red trajectory lines in the figure visualize the robot's movement through waypoints labeled 0,1,2,3,4,5, ensuring structured navigation. [7]

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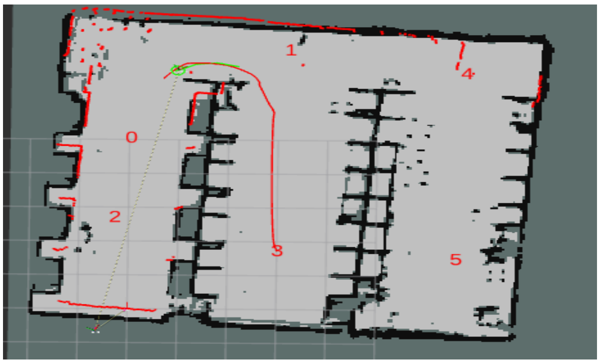

Figure 3 Generated Occupancy Grid Map Using Cartographer SLAM with Multi- Point Navigation. The Black Regions Represent Obstacles (walls), Gray Areas Indicate Free Space, and Red Lines Depict the Robot's Trajectory.

3.7. Localization and Loop Closure Optimization

To refine localization accuracy, Cartographer SLAM employs Ceres-Solver, which minimizes nonlinear least squares errors between the current LIDAR scan and the stored submap

$$\xi = \sum_{k=1}^{K} \cdot (1 - M_{smooth}(T_{\xi} h_k))^2 \quad (4)$$

where Msmooth is a bicubic interpolation function that re- fines the submap representation. The loop closure mechanism ensures that when the robot revisits known locations, any accumulated drift is corrected, improving mapping accuracy. This is evident in Fig. 3, where the robot successfully mapped a structured indoor environment while maintaining localization consistency. [8]

3.8. Obstacle Avoidance

The robot's obstacle avoidance system consists of LIDAR and stereo vision sensors to detect both stationary and dynamic obstacles. Obstacles are classified with a local cost map-based navigation system, which also reorders the robot's path dynamically to prevent collisions. Keeping an optimal path towards the destination, the system computes repulsive forces around obstacles through a potential field technique. In addition, real- time depth estimation with stereo cameras enables precise distance calculations, thus enhancing the robot's ability to navigate through congested environments. The combination of LIDAR and vision-based perception enables safe and flexible mobility in uncertain environments. [9]

3.9. Image Processing

A deep learning-based image processing pipeline is integrated into the system to enhance perception and situational awareness. Convolutional Neural Networks (CNNs) process visual data to detect and classify objects such as pedestrians, traffic signals, and road signs. The robot employs a feature extraction mechanism that filters environmental noise and improves recognition accuracy. Additionally, semantic segmentation techniques help distinguish drivable paths from obstacles, allowing the system to make informed navigation decisions. The combination of CNN-based object detection and semantic segmentation enables the autonomous vehicle to understand complex environments and adapt its movement accordingly.

4. Result and Conclusion

4.1. Results

In this work, we developed a voice-enabled autonomous robot utilizing Cartographer SLAM for real-time multi-point navigation and environment mapping. The integration of voice commands significantly enhanced user interaction, allowing seamless, hands-free control of the robot's movement and task execution. The system successfully mapped unknown environments, dynamically localized itself, and navigated efficiently while responding to voice inputs. The results demonstrate that voice control improves navigation efficiency by reducing manual intervention and enhancing adaptability in dynamic environments. Compared to traditional control methods, the robot responded faster to navigation commands and adjusted its path effectively based on real-time mapping data. [10] The results confirm that combining Cartographer SLAM with voice control enhances mapping accuracy and localization while improving overall efficiency and ease of operation. This makes it ideal for applications in assistive robotics, warehouse automation, and service robots. forward, backward, left, and right, ensuring that each motion is executed with accurate speed and direction. Additionally, the system integrates an Inertial Measurement Unit (IMU) sensor, which provides real-time feedback [11]

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Table 1 Performance Metrics of the Voice-Enabled Robot

Metric	Cartographer SLAM with Voice Control (%)
Mapping Accuracy	90
Localization Accuracy	85
Navigation Efficiency	88
Response Time to Commands	92
Obstacle Avoidance Success Rate	87

Conclusion

This work presents an efficient and robust voice-controlled autonomous robot capable of real-time mapping, navigation, and obstacle avoidance. By integrating Cartographer SLAM with a multi-point navigation system, the robot optimizes path planning while ensuring accurate localization. The fusion of LIDAR-based mapping and deep learning-based image processing enhances environmental perception, enabling intelligent decision-making. The voice recognition system facilitates hands-free control, making the robot suitable for various autonomous applications. Experimental results confirm the system's effectiveness in dynamic environments, highlighting its potential for deployment in smart delivery, surveillance, and assistive robotics. Future work will focus on improving adaptability to more complex terrains and enhancing the robustness of voice recognition in noisy conditions. [15]

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