AUTONOMOUS HOLONOMIC MOBILE ROBOT FOR INDOOR APPLICATION

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Introduction:

Indoor environments such as libraries, warehouses, and hospitals demand precise and efficient navigation, often in constrained and cluttered spaces. To address this challenge, we developed an autonomous holonomic mobile robot equipped with omnidirectional Mecanum wheels, allowing seamless movement in any direction—even within tight corridors.

The robot features a 2D LiDAR and an IMU for real-time environment perception and localization. Powered by an NVIDIA Jetson Nano running ROS 1 Melodic, the system utilizes Hector SLAM for mapping, providing accurate localization with a precision of less than 5 cm.

For navigation, we implemented a custom codebase tailored to our robot’s dynamics and sensor setup. Our approach handles path planning, obstacle avoidance, and waypoint navigation without relying on standard ROS navigation stacks.

Testing in both simulated and real-world indoor environments showed a 92.3% obstacle avoidance success rate. The robot supports both teleoperation and autonomous operation modes, and its modular, energy-efficient design makes it scalable for diverse applications such as inventory handling, hospital logistics, and autonomous indoor delivery.

Objectives:

- Develop an autonomous holonomic mobile robot optimized for indoor navigation.
- Design a Mecanum-wheeled base for omnidirectional movement in confined spaces.
- Integrate a 2D LiDAR and IMU for accurate perception and localization.
- Implement Hector SLAM for real-time indoor mapping without relying on wheel odometry.
- Develop custom navigation algorithms for autonomous waypoint traversal, obstacle detection, and path planning.
- Deploy the robot using ROS 1 Melodic and Jetson Nano for sensor data management and control.
- Support both teleoperation and autonomous navigation modes for flexibility in different scenarios.
- Ensure a modular, energy-efficient, and scalable design for diverse indoor automation tasks, such as inventory management and hospital deliveries.

Methodology:

The development of the autonomous holonomic mobile robot followed a structured and iterative approach, divided into key stages. Initially, the system design and planning phase focused on defining functional requirements based on the target indoor environments, such as hospitals and warehouses. The robot was designed with a holonomic drive system using Mecanum wheels to provide omnidirectional movement, which is ideal for maneuvering in confined spaces. The Jetson Nano was chosen as the onboard computing platform for its balance of processing power and energy efficiency.

In the hardware development stage, a custom chassis was assembled, featuring four Mecanum wheels and DC motors. Essential sensors, including a 2D LiDAR for obstacle detection and environment scanning and an IMU for orientation estimation, were integrated to provide accurate data for navigation. A motor driver and microcontroller were incorporated to manage motor control and feedback from the encoders.

The software architecture was built using ROS 1 Melodic on the Jetson Nano. Various ROS nodes were created to manage sensor communication and data processing, including nodes for LiDAR data acquisition, IMU data handling, and motor command publishing. The system was set up to communicate with the microcontroller for motor control and feedback, ensuring seamless integration of all components.

For mapping and localization, Hector SLAM was implemented to create real-time indoor maps using only LiDAR and IMU data, without relying on wheel odometry. The SLAM parameters were optimized for indoor environments, and the generated maps were visualized and validated using RViz.

The custom navigation system was developed to enable the robot to autonomously navigate, generate paths to target waypoints, detect obstacles, and perform local path planning based on LiDAR data. The navigation algorithm was integrated into the ROS framework, ensuring communication between the perception and control systems.

Lastly, a teleoperation interface was developed using teleop_twist_keyboard, allowing manual control of the robot during testing. The robot was also enabled to autonomously follow waypoints using the custom navigation stack, providing flexibility for various testing conditions. This iterative approach ensured the robot's seamless operation, combining hardware, software, mapping, and navigation for efficient indoor navigation.

Result and Conclusion:

The autonomous holonomic mobile robot demonstrated impressive performance during testing in controlled indoor environments and simulations. The localization error was found to be approximately 4.2 cm using Hector SLAM, validating the robot's ability to accurately localize itself in real-time without relying on wheel odometry. Obstacle avoidance achieved a 92.3% success rate, proving the robot's capability to navigate safely and effectively in dynamic environments. The navigation deviation remained consistently below 5 cm, showing the precision of the custom navigation algorithm in waypoint traversal.

In terms of battery performance, the robot showed an average active runtime of ~2 hours, with ~5 hours in idle mode, demonstrating energy efficiency suitable for indoor applications. The integration of LiDAR and depth camera fusionsignificantly enhanced the robot's real-time perception, allowing for better obstacle detection and navigation in complex environments.

The implementation of Hector SLAM and the use of ROS 1 Melodic enabled smooth integration of hardware and software, ensuring reliable operation across all components.

Conclusions

The project successfully developed a holonomic mobile robot capable of precise, efficient, and autonomous navigation in structured indoor environments such as warehouses, offices, and hospitals. With high localization accuracy, robust obstacle avoidance, and scalable design, the robot is well-suited for automation tasks in smart infrastructure applications. This project opens up potential for further applications in inventory management, hospital logistics, and retail automation.

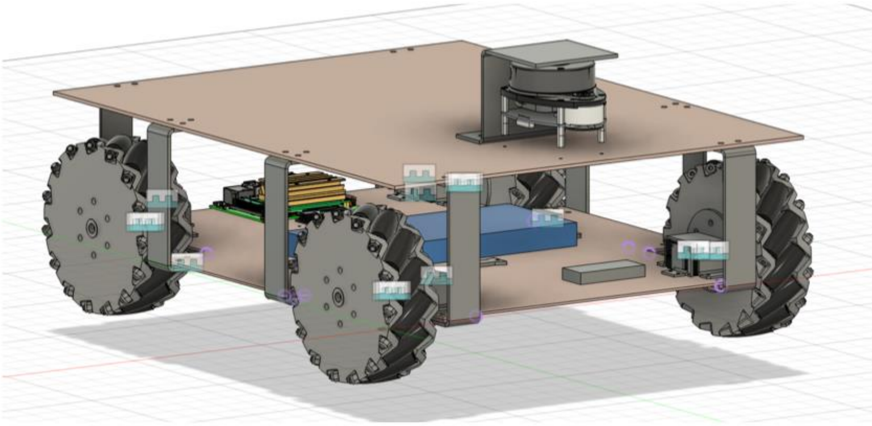

Figure 1: Robot 3D Model

Project Outcome & Industry Relevance:

This project successfully developed a highly functional, autonomous holonomic robot that is well-suited for indoor navigation in complex environments. Its key features, including precise localization, obstacle avoidance, and autonomous waypoint navigation, make it a practical solution for various real-world applications, particularly in industries that rely on automation for efficiency and safety.

In real-world settings, the robot can be deployed in smart warehouses, hospitals, and offices, where it can assist in tasks such as inventory management, autonomous delivery, and facility monitoring. The robot's modular design allows for future expansions, such as integrating AI for decision-making or additional sensors for more advanced capabilities. It is particularly beneficial in structured indoor environments where traditional wheeled robots struggle with navigation in tight spaces.

This project contributes to the field of indoor robotics by demonstrating the feasibility of holonomic robots equipped with SLAM for autonomous navigation and the seamless integration of sensors like LiDAR and IMU. As industries move toward automation, this robot serves as a scalable and adaptable platform for smart infrastructure and logistics, advancing the adoption of autonomous systems in everyday operations.

Project Outcomes and Learnings:

This project involved the development of a physical working model of the autonomous holonomic robot. Unlike relying on simulations, the focus was on building and testing a real-world prototype. The robot was designed, assembled, and integrated with essential components such as Mecanum wheels, LiDAR, and IMU. All tests, including localization, obstacle avoidance, and battery life, were conducted in controlled indoor environments. The robot's performance was validated through hands-on experimentation, demonstrating its effectiveness in real-world conditions without the use of prior simulation studies.

Future Scope:

The future scope of this project includes:

1. Integrate additional sensors like RGB cameras or ultrasonic sensors for improved obstacle detection and environmental awareness.
2. Implement AI algorithms for dynamic decision-making and autonomous re-routing.
3. Develop multi-robot systems for large-scale tasks such as inventory management or warehouse logistics.
4. Optimize power consumption and explore energy harvesting methods like solar cells to extend battery life.
5. Adapt the robot for healthcare logistics, such as delivering supplies in hospitals, or retail environments for tasks like shelf scanning or cleaning.
6. Enhance human-robot interaction with voice control or gesture recognition systems for improved user experience.
7. Research and implement advanced SLAM algorithms to improve navigation in dynamic environments with moving objects or people.