Ros-Slam Powered Autonomous Vacuum Cleaner

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Abstract:
The increasing need for autonomous home cleaning technology requires robotic vacuum technology advancements. This paper introduces a ROS-SLAM- driven autonomous vacuum cleaner for accurate navigation and enhanced cleaning efficiency. In contrast to conventional models with random or pre-programmed navigation, this system employs LiDAR-based SLAM for real-time mapping, optimal path planning, and dynamic obstacle avoidance.
The system, which is based on ROS 2 Humble, is modular in nature and includes an ESP32-CAM for object identification, an Arduino Nano, a Raspberry Pi 4, and LiDAR. The Nav2 stack increases coverage while removing redundancy to discover the best paths. Gazebo simulations and experiments conducted in real-world situations verify the system's effectiveness, adaptability, and improved obstacle management. The work serves as an example of how ROS and SLAM might be used to promote smart home robotics. Keywords: ROS , SLAM, Nav2 stack, Gazebo.

1. INTRODUCTION

With growing demands for smart home automation, autonomous vacuum cleaners are becoming new household appliances for increased efficiency and decreased human input in cleaning activities. The previous robotic vacuum cleaners relied on pre-defined navigation patterns or random movement algorithms, leading to low efficiency cleaning coverage, redundant motion, and poor obstacle handling. It is crucial to design dynamic, intelligent, and adaptable technologies that can significantly alter a changing environment while enhancing cleaning performance.
This paper develops and applies an autonomous vacuum cleaner powered by ROS-SLAM, in order to provide simultaneous localization and mapping in an attempt to attain a real-time environment perception, localization, and path planning. The employed system, in this case, is LiDAR-based SLAM to build up accurate maps around the environment so as to make intelligent decision making for navigation and obstacle avoidance..
This flexible and modular ROS-2 Humble integration would allow the smooth interaction between the hardware components: Raspberry Pi 4, Arduino UNO, LiDAR sensors, and the motor-driven cleaning mechanism.
Key functionalities of the proposed system include:LiDAR-based SLAM real-time mapping and localization

- Dynamic obstacle avoidance with the ROS Nav2 stack- based path planning

- Optimized autonomous cleaning mechanisms for coverage
- Simulation and testing on Gazebo and real-world environments

Compared to the traditional robotic vacuum cleaners, it can improve navigation accuracy and obstacle handling at run time and also guarantees efficiency in coverage. This stands as a viable approach for modern home automation. The rest of the paper details the system architecture, hardware and software integration, experimental validation, and evaluation of the proposed system.

2. TECHNOLOGY AREAS ADDRESSED IN THE PROJECT

A. Robotics

The proposed system is designed as an autonomous mobile robot that is capable of self-navigation and intelligent cleaning. It integrates LiDAR-based perception, motor-driven cleaning mechanisms, and real-time decision-making algorithms to improve operational efficiency.

B. Automation

It uses pre-programmed algorithms and real-time sensor feedback to ensure full autonomy of navigation and cleaning. The system adapts the path planning and strategies for avoiding obstacles based on the changes in the environment.

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C. SLAM

It allows a real-time map to be generated during the localization using the robot as it moves in unknown and even known terrains. The model of the environment is updated to enable adaptive navigation in the optimized path of cleaning.

D. ROS

The system is based on ROS-2 Humble, providing a flexible and modular development framework. The ROS Nav2 stack is used for efficient path planning with sensor data fusion to improve cleaning coverage and obstacle detection.

E. Machine Learning

Machine learning-based algorithms are further evolved for better object detection

F. Embedded Systems The hardware implementation uses Raspberry Pi 4, Arduino uno, and ESP-32 CAM in real- time processing and motor control.

3. METHODOLOGY

The development of the proposed autonomous vacuum cleaner involves several key steps: system design, hardware integration, software implementation, and testing. The methodology is divided into the following phases:

System Design: The system is designed to integrate SLAM for real-time mapping and navigation. The hardware components include a Raspberry Pi 4 for processing, an Arduino Uno for motor control, a LiDAR sensor for environment mapping, and motor-driven cleaning mechanisms.

Hardware Integration: The hardware components are interconnected using ROS 2 Humble, which provides a modular framework for seamless integration. The Raspberry Pi 4 serves as the central processing unit, while the Arduino Uno controls the motors and cleaning mechanisms. The LiDAR sensor is used for environment sensing and mapping.

Software Implementation: The software stack is built on ROS 2 Humble, with the Nav2 stack employed for navigation and path planning. SLAM is implemented using LiDAR data to generate real-time maps, enabling the robot to navigate efficiently and avoid obstacles dynamically. Testing and Validation: The system is tested through simulations in Gazebo and real-world experiments. The performance is evaluated based on cleaning efficiency, obstacle handling, and spatial coverage.

4. SYSTEM ARCHITECTURE

The system architecture is divided into hardware and software components .

A. Hardware Architecture

Raspberry Pi 4: Acts as the central processing unit, running ROS 2 Humble and handling SLAM computations.
Arduino Uno: Controls the motor-driven cleaning mechanisms and interfaces with the Raspberry Pi.
LiDAR Sensor: Provides real-time environment mapping and obstacle detection.
Motor-Driven Cleaning Mechanisms: Enable the robot to perform cleaning tasks efficiently.

B. Software Architecture

ROS 2 Humble: Provides a modular framework for integrating hardware and software components.
Nav2 Stack: Handles navigation, path planning, and obstacle avoidance.
SLAM Algorithm: Generates real-time maps using
LiDAR data for precise navigation.

5. OBJECTIVES

- To Design and Develop an Autonomous Vacuum Cleaner
- Design a robotic system capable of autonomous
- navigation and cleaning using modular hardware components such as Raspberry Pi 4, Arduino Uno, LiDAR, and motor-driven cleaning mechanisms.
- To Implement SLAM for Real-Time Environment Mapping
- Integrate LiDAR-based SLAM to generate real-
- time maps of the environment, enabling the robot to localize itself and navigate efficiently.
- To Achieve Optimal Path Planning and Navigation
- Utilize the Nav2 stack in ROS 2 Humble for intelligent route optimization, minimizing redundant cleaning and ensuring complete spatial coverage.
- To Enable Dynamic Obstacle Avoidance
- Implement algorithms for real-time obstacle detection and avoidance, allowing the robot to adapt to dynamic environments.
- To Validate System Performance Through Simulation and Real-World Testing Conduct thorough testing using Gazebo simulations and real-world experiments to evaluate the system's efficiency, obstacle handling, and advancing research in smart home robotics.

6. PROPOSED SYSTEM DESIGN

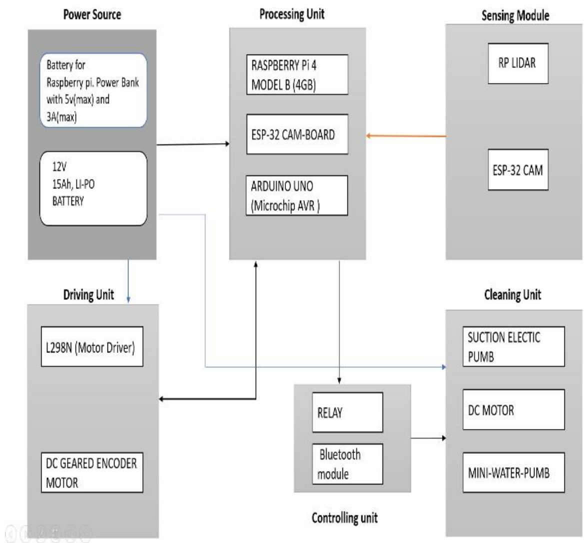

Fig. 1 System level Architecture Diagram.

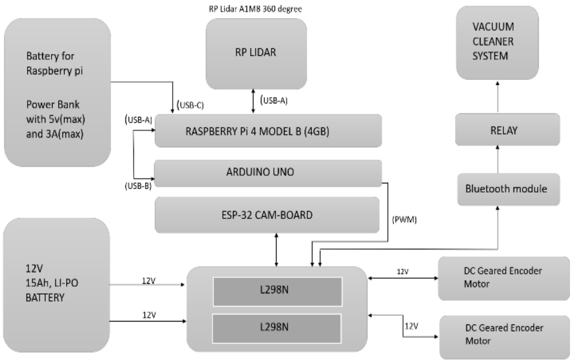

Fig. 2 Block diagram of the hardware

The proposed system integrates a Raspberry Pi 4 Model B (4GB) as the central processing unit, interfaced with an RP Lidar A1M8 360-degree LiDAR sensor for real-time environment mapping and navigation. The Raspberry Pi communicates with an Arduino Uno via a Bluetooth module for motor control and PWM (Pulse Width Modulation) signals. The motor driver L298N is utilized to control two DC geared encoder motors, enabling precise movement and navigation. A 12V, 15Ah Li-Po battery powers the system, ensuring sufficient operational time. The vacuum cleaner system is activated through a relay module, which is controlled by the Arduino Uno. This modular design ensures seamless integration of hardware components, facilitating efficient autonomous navigation and cleaning.

VII. ALGORITHM

1. Initialize System:

- Power on the system components (Raspberry Pi, LiDAR, motors, etc.).
- Load ROS environment and configure required nodes (SLAM, navigation, and sensor drivers).

2. Environment Scanning:

- Activate LiDAR to start scanning the environment.
- Collect real-time data from sensors.
- Initiate mapping and localization process using SLAM algorithm.

3. Map Generation and Localization:
- Create an initial map of the environment using SLAM.
- Continuously update the map with new data as the vacuum cleaner moves.
- Calculate the robot's position in the environment relative to the map.

4. Path Planning:
- Generate a cleaning route using ROS Navigation stack(Nav-2 Stack).
- Consider obstacles and dynamic changes in the environment to optimize the path.
- Adjust route in real-time based on sensor feedback (LiDAR).

5. Vacuum Operation:
- Turn on the vacuum system.
- Follow the pre-planned cleaning route, ensuring obstacle avoidance and efficient coverage.

6. Dynamic Obstacle Handling:
- Detect any obstacles or changes in the environment (e.g., new furniture or moving objects).
- Modify the cleaning route dynamically using real- time sensor data and SLAM updates.

7. Software Requirements

ROS-2(Humble)

ROS-2 serves as the foundational framework for communication between robot components, enabling modular development and integration.

Operating System

Ubuntu 22.04 LTS will be used as the OS for Raspberry Pi.

SLAM (Simultaneous Localization And Mapping) LiDAR-based SLAM method to create and update maps, enabling the robot to navigate accurately and adapt to changes in the warehouse environment.

Gazebo and Rviz

Gazebo as a simulation environment will allow us to realistic test and validate the robot's behaviour before deployment in a physical warehouse setting.Rviz provides a real-time visualization interface, aiding in debugging and monitoring robot data during development.

SolidWorks

CAD software used for designing the robot's mechanical structure.

Arduino IDE

Used to write the computer code and upload this code to the physical board.

8. RESULTS

The proposed system was tested through simulations in Gazebo and real-world experiments. The results demonstrate significant improvements in cleaning efficiency, obstacle handling, and spatial coverage compared to traditional robotic vacuum cleaners. Key findings include:

Efficiency: The system reduces redundant cleaning by optimizing paths using SLAM and the Nav2 stack.

Obstacle Handling: The robot dynamically avoids obstacles in real-time, ensuring smooth navigation.

Spatial Coverage: The system achieves near- complete coverage of the cleaning area, minimizing missed spots.

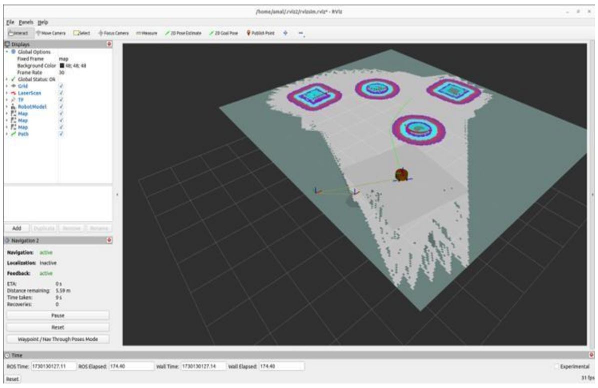

Fig.3 Real-time Mapping in RViz

SLAM successfully created real-time maps in Gazebo and RViz.. Provided high-quality localization, but mapping in highly dynamic environments may need refinement.

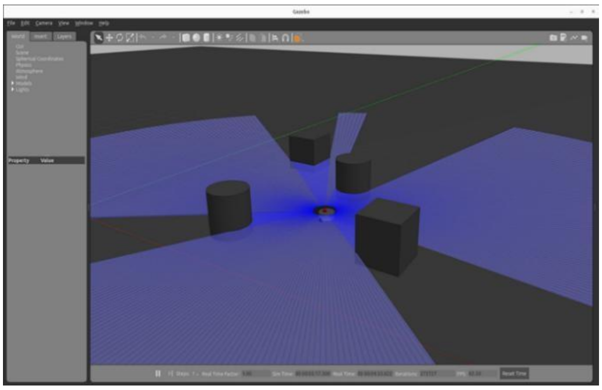

Fig.4 Real-time Mapping in Gazebo

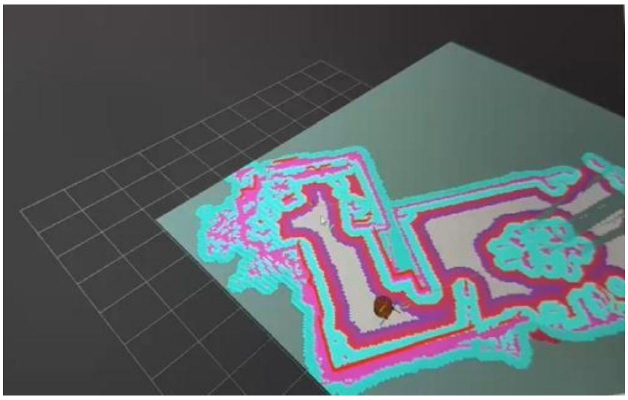

Fig.5 Real-time Mapping

Nav2 path planner efficiently generated routes, dynamically adjusting to obstacles detected. Some latency observed in real-time re-routing, suggesting areas for software optimization.

9. CONCLUSION

This paper details the design and development of an autonomous vacuum cleaner with SLAM powered by ROS. With LiDAR-based SLAM combined with ROS 2 Humble, it will be possible to achieve the goals of precise navigation, dynamic obstacle avoidance, and enhanced cleaning efficiency while showing robust performance and adaptability in a dynamic environment based on evidence from simulations and real-world testing. Compared to the conventional robotic vacuum cleaners, such proposed system has tremendous improvements in terms of efficiency, obstacle handling, and coverage. Therefore, this work will be contributing to the field of smart home robotics as it demonstrates how ROS and SLAM can be applied in the development of intelligent and autonomous cleaning solutions.

10. ACKNOWLEDGMENT

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