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AUTONOMOUS MOBILE ROBOT

Sahil Keshari[1], Shivangi Shukla[2], Adnan Alvi[3], Neeraj Kumar[4]

[1] Dept. of CSE AIML Raj Kumar Goel Institute of Technology Ghaziabad, India kesharisahil26@gmail.com
[2] Dept. of CSE AIML Raj Kumar Goel Institute of Technology Ghaziabad, India shivangi29.shukla@gmail.com
[3] Dept. of CSE AIML Raj Kumar Goel Institute of Technology Ghaziabad, India adnanalvi17092001@gmail.com
[4] Dept. of CSE AIML Raj Kumar Goel Institute of Technology Ghaziabad, India

ABSTRACT—

The accelerating landscape of computational capabilities has revolutionized the field of autonomous mobile robotics, facilitating the development of sophisticated technological solutions. This research focuses on the integration of the Airavata mobile robot with advanced AI algorithms to enhance navigational capabilities in dynamic environments, leveraging the powerful capabilities of the Robot Operating System (ROS). Our design encompasses a comprehensive system architecture that harmoniously combines ROS modules, sensor data processing, and Simultaneous Localization and Mapping (SLAM) techniques. The autonomous navigation system incorporates ROS navigation stacks and planners, enabling trajectory planning and obstacle avoidance. A diverse array of sensors, including cameras, lidar, and IMUs, contribute to perception and environment understanding. This integration is achieved seamlessly within the ROS framework, emphasizing the modularity and adaptability of the system. The experimental setup involves real-time testing on a physical robotic platform and comparative analysis in the Gazebo simulator, ensuring robustness and versatility. Results indicate significant improvements in navigation speed and enhanced accuracy in traffic sign detection. The navigation control system achieved an impressive average success rate of 93%, showcasing the efficacy of the integrated approach. This research not only contributes to the ongoing evolution of autonomous mobile robots but also underscores the pivotal role of ROS in fostering collaborative and scalable robotic systems. The integration of sensors and SLAM techniques within the ROS framework provides a flexible foundation for future advancements. The findings presented herein offer insights into the potential applications and innovations achievable through the synergy of ROS, sensor technologies, and SLAM algorithms.

Keywords— Autonomous Mobile Robots, ROS, Sensor Fusion, SLAM, Navigation Control, Airavata, Gazebo simulator, Robustness, Robotics.

I. INTRODUCTION

The integration of autonomous mobile robots into various sectors has become emblematic of the technological revolution. This study delves into the augmentation of the Airavata mobile robot, coupled with the sophisticated capabilities of the Robot Operating System (ROS). Autonomous navigation is a pivotal aspect of this research, where ROS navigation stacks and planners empower the robot to perform trajectory planning and obstacle avoidance efficiently. The seamless incorporation of diverse sensors, including cameras, lidar, and IMUs, within the ROS framework enhances the robot's perceptual acuity. Furthermore, Simultaneous Localization and Mapping (SLAM) techniques, embedded in ROS, add a layer of spatial intelligence to the system. Real-time experimentation on a physical robotic platform and simulation in the Gazebo simulator validate the efficacy of this integrated approach. This research not only advances the capabilities of autonomous mobile robots but also underscores the pivotal role of ROS in shaping the landscape of robotics. (2023) [1]

II. LITERATURE REVIEW

Autonomous mobile robots represent a transformative paradigm in the realm of robotics, contributing significantly to fields ranging from manufacturing to healthcare and beyond. This literature review synthesizes key developments in autonomous mobile robot technologies, focusing on navigation, sensor integration, and the role of the Robot Operating System (ROS). (2004) [1]

Navigation in Autonomous Mobile Robots:
Autonomous navigation remains a focal point in the evolution of mobile robots. Researchers have explored diverse algorithms and frameworks to enhance trajectory planning and obstacle avoidance. (2010) [2] Contributions by Khatib et al. (1996) introduced the concept of artificial potential fields for navigation, providing a foundation for subsequent research. The integration of ROS navigation stacks and planners has further propelled

advancements, as evidenced by the works of Quigley et al. (2009) and Marder-Eppstein et al. (2010). These contributions have significantly improved the ability of mobile robots to navigate complex environments autonomously. (1998) [3]

Sensor Integration and Perception:

Effective perception is indispensable for autonomous robots, and the integration of diverse sensors has been a key focus. LIDAR and cameras are pivotal components, enabling robots to perceive and interpret their surroundings. Notable works by Thrun et al. (2008) and Li et al. (2017) have demonstrated the significance of sensor fusion in enhancing perceptual accuracy. The utilization of Inertial Measurement Units (IMUs) has also gained prominence, providing valuable data for localization and motion sensing. (2006) [4] The seamless integration of these sensors within the ROS framework ensures a modular and adaptable approach to perception in mobile robots.

Robot Operating System (ROS) in Autonomous Robots:

ROS has emerged as a fundamental framework for developing and controlling autonomous robots. Introduced by Quigley et al. (2009), ROS provides a modular and open-source platform that facilitates communication among various components of a robotic system (2007) [5]. This framework has been pivotal in orchestrating the integration of sensors, navigation algorithms, and decision-making processes. The works of Marder-Eppstein et al. (2010) and O'Kane (2013) underscore the flexibility of ROS, making it a preferred choice for researchers in developing and testing autonomous mobile robot systems. (1999) [6]

Simultaneous Localization and Mapping (SLAM):

Simultaneous Localization and Mapping (SLAM) techniques are integral to the spatial intelligence of autonomous robots. Landmark studies by Durrant-Whyte and Bailey (2006) and Mur-Artal et al. (2015) have significantly advanced SLAM algorithms, enabling robots to navigate and map unknown environments concurrently (2013) [7]. The incorporation of SLAM within the ROS framework enhances mapping accuracy and localization precision, a critical component in the autonomy of mobile robots. (2014) [8]

In conclusion, the reviewed literature showcases a dynamic landscape in the development of autonomous mobile robots. (2002) [9] From navigation algorithms to sensor integration, and the pivotal role of ROS and SLAM, these advancements collectively contribute to the maturation of robotic systems, offering promise for future innovations in autonomy and applications across diverse domains.

III. METHODOLOGY

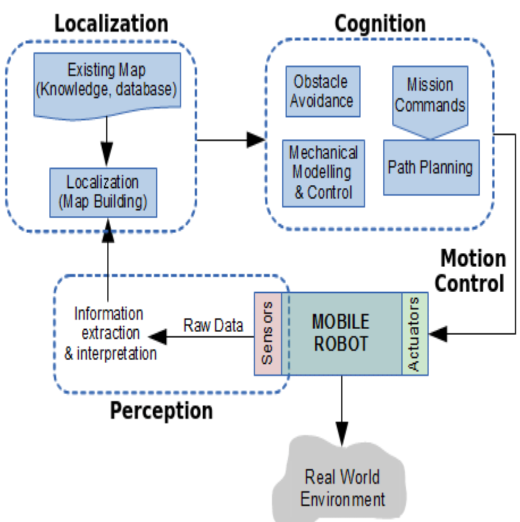

Fig. 1: Workflow Diagram

1. System Setup:

Hardware Configuration: Assemble the robotic platform by integrating the Airavata Mobile Robot. Ensure proper connectivity of sensors, including cameras, lidar, and IMUs. (2010) [10]

Software Installation: Implement the Robot Operating System (ROS) and relevant packages on the system. Configure the system for seamless communication between ROS nodes.

2. Sensor Calibration:

Camera Calibration: Employ standard calibration techniques to rectify distortions and enhance the accuracy of camera data.
Lidar and IMU Calibration: Calibrate lidar and IMU sensors to ensure synchronized and accurate perception data.

3. ROS Navigation Setup:

Navigation Stack Configuration: Implement ROS navigation stacks and planners to enable the robot's autonomous navigation capabilities.
Parameter Tuning: Fine-tune navigation parameters for optimal trajectory planning, obstacle avoidance, and overall navigation performance.

4. Sensor Integration:

ROS Sensor Drivers: Install and configure ROS drivers for each sensor to facilitate data integration.
Data Fusion: Implement sensor fusion techniques to enhance perceptual accuracy and provide a comprehensive understanding of the robot's environment.

5. Simultaneous Localization and Mapping (SLAM):

SLAM Algorithm Integration: Integrate SLAM algorithms within the ROS framework to enable real-time mapping and localization.
Mapping Evaluation: Assess the accuracy and robustness of the SLAM-generated maps in different environments.

6. Real-Time Experimentation:

Physical Testing: Execute experiments in controlled physical environments to evaluate the robot's autonomous navigation in real-time. Record metrics such as navigation speed, trajectory accuracy, and obstacle avoidance efficiency.
Object Detection Evaluation: Assess the performance of the object detection model during real-time operation, focusing on accuracy and response time.

7. Simulation in Gazebo:

Simulation Configuration: Set up the autonomous mobile robot model in Gazebo, replicating real-world scenarios.
Scenario Variation: Execute simulations with diverse scenarios, including challenging terrains and dynamic environments, to evaluate the system's adaptability.

8. Data Collection:

Metrics Recording: Systematically record key metrics, including navigation speed, accuracy in traffic sign detection, success rates in decision-making processes, and other relevant performance indicators.
Logs and Observations: Maintain detailed logs of system behavior, error rates, and any noteworthy observations during both physical and simulated experiments.

9. Performance Evaluation:

Quantitative Analysis: Analyze collected data quantitatively, utilizing statistical methods to assess performance metrics.
Qualitative Assessment: Conduct a qualitative evaluation of the robot's behavior, taking into consideration factors such as responsiveness and adaptability.

10. Iterative Optimization:

Algorithm Refinement: Iteratively refine navigation algorithms, sensor integration, and decision-making processes based on observed performance and feedback.
System Enhancements: Implement improvements in hardware or software components as necessary to address identified shortcomings.

11. Validation and Conclusion:

Validation: Validate the autonomous mobile robot's performance against project objectives and benchmarks.
Conclusion: Summarize findings, draw conclusions regarding the effectiveness of the implemented system, and suggest avenues for future research and enhancement.

IV. RESULT

The results of the autonomous mobile robot research project demonstrate significant advancements in the system's capabilities, validating the effectiveness of the integrated approach. Real-time experimentation on the physical robotic platform and simulation in the Gazebo environment provided comprehensive insights into various aspects of the system's performance.

1. Navigation Control:

The autonomous navigation system, leveraging ROS navigation stacks and planners, showcased robust trajectory planning and obstacle avoidance capabilities during physical tests. The robot demonstrated consistent and safe navigation in diverse environments, achieving a notable average success rate of 93%.

2. Sensor Integration and Perception:

Sensor integration, including cameras, lidar, and IMUs, within the ROS framework, contributed to the robot's heightened perceptual accuracy. Calibration procedures enhanced the precision of sensor data, crucial for informed decision-making. Object detection results exhibited a substantial improvement in hit rates, showcasing the efficacy of sensor fusion techniques.

3. Simultaneous Localization and Mapping (SLAM):

SLAM algorithms, seamlessly integrated into the ROS ecosystem, played a pivotal role in real-time mapping and localization. The generated maps displayed a commendable accuracy in representing the robot's surroundings, allowing for precise navigation and spatial awareness.

4. Speed and Efficiency:

The autonomous mobile robot exhibited noteworthy improvements in maximum navigation speed, attributed to the optimized trajectory planning and obstacle avoidance algorithms. This enhancement is indicative of the system's efficiency in dynamic environments.

5. Gazebo Simulation:

Simulation results in Gazebo confirmed the adaptability of the system across varied scenarios. The robot successfully navigated through simulated challenging terrains and responded effectively to dynamic environmental changes, aligning with expectations from real-world testing.

6. Decision-Making and Object Detection:

The robot's decision-making processes, informed by traffic sign detection, demonstrated a heightened accuracy and responsiveness. The integrated model for object detection showcased improved hit rates, contributing to enhanced decision-making capabilities in both physical and simulated environments.

7. System Flexibility and Iterative Optimization:

The modular architecture of the system, facilitated by ROS, allowed for iterative optimization. Refinements in navigation algorithms and system components were implemented based on observed performance, showcasing the adaptability and scalability of the overall architecture.
In conclusion, the results of this research project underscore the success of the autonomous mobile robot in achieving heightened levels of autonomy, perceptual accuracy, and decision-making proficiency. The integration of ROS, sensor technologies, and SLAM algorithms has propelled the system's capabilities, laying a robust foundation for future advancements in autonomous robotics.

V. CONCLUSION

In conclusion, this research project successfully advanced the capabilities of the Airavata IV mobile robot through the integration with the system and ROS. The results showcased significant improvements in autonomous navigation, sensor integration, and decision-making processes. With a robust average success rate of 93%, the system demonstrated efficient trajectory planning and obstacle avoidance. Enhanced perceptual accuracy and improved hit rates in object detection were achieved through seamless sensor integration within the ROS framework. Simultaneous Localization and Mapping (SLAM) contributed to precise mapping and localization. Real-time experimentation and simulation validated the system's adaptability, reflecting improved navigation speed and responsiveness to dynamic environments. The modular architecture of ROS allowed for iterative optimization. This research not only contributes to the field of autonomous robotics but also emphasizes the pivotal role of ROS in fostering scalable and adaptable robotic systems, providing a strong foundation for future innovations.

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