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ENHANCING ROBOTICS EDUCATION: DEVELOPMENT OF AN AI-DRIVEN AUTONOMOUS NAVIGATION SYSTEM USING LIDAR SLAM FOR ROBOTIC WAITERS IN RESTAURANT ENVIRONMENTS

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Abstract:

This research into autonomous mobile robots introduces an innovative, educational approach using artificial intelligence (AI) and advanced navigation technologies to enhance learning in robotics, engineering, and computer science. The study focuses on developing an intelligent navigation system for robotic waiters that can operate independently in complex, dynamic environments like restaurants. Through this project, students gain insights into real-world applications of AI in robotics, particularly in employing LiDAR-based Simultaneous Localization and Mapping (SLAM) for precise navigation. Key to this system is the use of LiDAR sensors, which emit laser pulses to create detailed maps, enabling the robot to navigate effectively even in challenging lighting conditions. The Nvidia Jetson Nano, a powerful compact computer, functions as the robot's "brain," controlling its movements and processing navigation data in real time. This aspect of the project offers hands-on learning in embedded systems, giving students practical experience with computing hardware and data handling. Beyond technical skills, this research encourages students to consider the broader impacts of AI and robotics in hospitality. By exploring how autonomous robots can safely navigate and serve in crowded spaces, students engage with both engineering challenges and the transformative potential of AI in service industries. This initiative provides a holistic, hands-on educational experience aligned with cutting-edge developments in robotics, preparing students with vital skills for a technology-driven future.

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***JEL classification**: Classify your work using the suitable JEL codes. E.g. G12, G14*

Keywords:

Robotic Education; STEM; Mechatronics; Autonomous Robot

Introduction

This research into service robots emphasizes the potential of integrating advanced robotic systems into educational settings to enhance learning and research in robotics, engineering, and service innovation. Service robots, as defined by Wirtz et al. (2018), are adaptable, autonomous systems that interact with and deliver services to customers within various organizational contexts. With service industries increasingly adopting technologies for efficiency and customer satisfaction, educational institutions have unique opportunities to explore these developments and their educational impact (Ali, 2021; Yin, Luo, Yan, & Zhuang, 2022; He, Teo, & Moey, 2024). Leveraging service robots in an academic environment can offer students hands-on experience with cutting-edge robotic technologies, preparing them for a workforce that is ever-more reliant on automation and AI advancements.

In the manufacturing sector, robotic process automation (RPA) has become a common tool, automating tasks such as parts handling and quality inspections, particularly in automotive production. This application of robotics in controlled, industrial settings demonstrates efficiency gains and serves as a foundation for educational research (Gumus, Topaloglu, & Ozcelik, 2016; Malik, 2023; Kocić, Jovičić, & Drndarević, 2018). However, deploying service robots in customer-facing environments—such as in hospitality settings—introduces unique challenges that educational research can address, especially within fields like computer science, engineering, and vocational training (Sulistijono, Rois, Yuniawan, & Binugroho, 2021). These scenarios allow institutions to analyze the contrasting demands of industrial versus customer-service applications of robots, enriching educational curricula with real-world insights.

Existing service robots in hospitality often rely on basic line-following techniques for navigation, which, while useful in structured environments, lack adaptability for dynamic settings (Mishraa, Goyal, & Sharma, 2018; N. P. R., Naveenkumar, & W. S., 2023; Zhou, Feng, Di, & Zhou, 2023). Studies reveal significant limitations, including path interruptions and safety vulnerabilities, that hinder effective robot deployment in public spaces. These challenges point to a strong need for research-driven innovations in navigation technologies, such as LiDAR-based Simultaneous Localization and Mapping (SLAM) and artificial intelligence (Khan et al., 2021; Yue, Zhang, & He, 2023; Li, Lin, Zha, Jiang, & Sun, 2021). Such advancements could improve robot versatility and adaptability in complex, unstructured environments, making them more suitable for public-facing applications.

This research project proposes an enhanced navigation system aimed at improving service robots' performance and safety in complex environments, with benefits for both the service industry and educational programs. By providing students and researchers with hands-on experience in developing and testing AI-driven navigation solutions, this study fosters critical skills in problem-solving and innovation. The project's focus on real-world applications of robotics aligns educational objectives with industry needs, preparing future professionals to

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drive advancements in robotics and AI across various sectors (Tompa, Hurgoiu, Neamtu, & Popescu, 2012; Belzunce, Li, & Handroos, 2016; Pütz, Santos Simón, & Hertzberg, 2018). Through this approach, educational institutions can produce graduates equipped to contribute meaningfully to the evolving fields of robotics and automation.

Methodology

This research aims to develop an autonomous navigation system optimized for educational use in teaching robotics and AI, particularly in the context of a restaurant service robot. The project is designed to provide students with hands-on experience in building and programming a robot that can autonomously navigate to destinations while avoiding obstacles, simulating a real-world application in the hospitality industry. Core components, including a Jetson computer, Arduino Mega microcontroller, Brushless DC (BLDC) motor, LiDAR, and motor drivers, are utilized to give students practical exposure to integrated robotics systems. By implementing a LiDAR-based Simultaneous Localization and Mapping (SLAM) system, the project enables students to understand complex mapping and navigation technologies.

Currently in the early testing phase, this project builds on prior student work where the robot body and components were selected and assembled. However, the robot is not yet operational. This phase of development involves teleoperated control via keyboard inputs, allowing students to configure, test, and collect essential data on motor speed and turning angles—foundational data for designing an effective autonomous navigation system. This teleoperation step ensures a comprehensive understanding of component functions and captures critical performance data for subsequent navigation programming.

The robot's BLDC motor speed is regulated by an Arduino microcontroller, providing students with insights into embedded systems and feedback control processes. The Arduino continuously adjusts the motor speed to maintain synchronization with the programmed ROS (Robot Operating System) commands, demonstrating key concepts in robotics control systems. By manually configuring and fine-tuning the system before implementing autonomous control, students gain a thorough grounding in troubleshooting and data-driven design in robotics.

The autonomous navigation system in this project aims to provide an educational framework for teaching advanced robotics and navigation systems, specifically utilizing LiDAR-SLAM. Designed to foster hands-on learning, this system immerses students in critical technologies used in autonomous robots, which are essential for robotics, engineering, and computer science education. Based on a literature review, LiDAR-SLAM (Simultaneous Localization and Mapping) has been identified as the optimal method for autonomous navigation due to its precise mapping capabilities and is implemented here through the ROS (Robot Operating System) platform, a prominent tool in robotics development.

Written in Python within the ROS environment, the navigation system code uses ROS Core—a collection of nodes and programs critical for managing an ROS-based system. With SLAM techniques integrated into ROS, the robot can simultaneously map its surroundings and track its position within that environment, crucial for autonomous operation [9]. This project incorporates the Intel LiDAR L515 sensor for 3D obstacle detection and RP-LiDAR for mapping, enabling the creation of detailed 3D point clouds for spatial awareness. The robot leverages LiDAR's light-pulsing technology to detect and measure distances, which provides students with a tangible understanding of LiDAR-based navigation.

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Addressing real-world challenges in LiDAR-SLAM, the project exposes students to common obstacles in autonomous navigation, such as sensor calibration issues and environmental variability. Calibrating the LiDAR sensor to establish precise reference points and applying filtering techniques to reduce noise are essential steps in achieving reliable navigation. Additionally, algorithms are used to detect, track, and predict the movement of dynamic obstacles, equipping students with strategies for safe navigation in environments with moving objects.

By working through these steps, students develop critical skills in programming, data processing, and real-time problem-solving, all foundational for roles in robotics, AI, and automation industries. This project thus supports educational outcomes aligned with industry demands, preparing students to contribute to advancements in robotics and AI-driven technologies.

This research project serves as a robust educational tool, merging theoretical learning with hands-on experimentation. By engaging in each development stage, students acquire invaluable skills in robotics, embedded systems, and AI-driven navigation—skills directly applicable to real-world challenges in the rapidly advancing fields of robotics and automation.

This research project introduces a dual-microcontroller system that leverages both C++ and Python programming languages, offering a rich educational platform for students to understand cross-platform integration and microcontroller coordination. The Arduino microcontroller, which controls the robot's motor system, uses C++ for motor control and sensor data processing, while the Nvidia Jetson, which serves as the central processing unit, utilizes Python for higher-level functionalities, such as running ROS (Robot Operating System) nodes and performing autonomous navigation tasks. By managing both programming languages, students gain insights into embedded systems, real-time data handling, and the complexities of integrating separate platforms in robotics.

The Arduino-based robot is designed to estimate its orientation and position using a gyroscope and an MPU6050 accelerometer, which introduces students to fundamental sensor processing. The robot, equipped with two wheels, two motors, and encoders, relies on a PID (Proportional-Integral-Derivative) controller in C++ to maintain stable movement and manage the motor speeds based on desired velocity and orientation. This control mechanism gives students hands-on experience with PID tuning and real-time control, essential skills for robotics engineering.

In the Arduino setup, necessary libraries such as Arduino Wire, ROS, and MPU6050 are incorporated. Constants like PID gains, base length, and wheel radius are defined, and the system initiates the ROS node, configuring the pins for motors, encoders, and sensors. By working with this setup, students develop essential skills in initializing hardware and configuring real-time systems, gaining an understanding of the intricate requirements of sensor integration and data synchronization.

The robot’s loop function operates at a frequency of 10 Hz, calculating the robot’s orientation (theta) and position (x, y) and updating these parameters at regular intervals. Students learn about frequency constraints, sensor sampling, and data consistency through this process, especially as it computes wheel velocities using encoder data and adjusts motor speeds to maintain desired velocity and orientation. The robot's pose is published to the ROS topic,

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enhancing student familiarity with ROS topic publishing and real-time data communication in robotics.

For motor control, the system applies a PID controller to determine the Pulse-Width Modulation (PWM) values required to adjust motor speeds. Through this process, students learn to apply control theory principles, reducing velocity errors and achieving smooth and accurate movement, crucial in robotics navigation. This dual-microcontroller setup presents an ideal educational project, allowing students to experiment with cross-platform development, learn ROS integration, and gain experience with real-time control algorithms in an accessible, hands-on context.

Enhancing Robotics Education through ROS Implementation and Teleoperation Testing
This study explores the implementation of code directly onto hardware as an essential step in achieving robust robot functionality, particularly within an educational setting. The project utilizes the Robot Operating System (ROS) terminal to execute the roscore command, which initiates ROS core. ROS core functions as the communication backbone, enabling nodes on a Jetson device to communicate and share data effectively, forming a foundation for practical learning and robot application development. This setup is valuable for students learning ROS as it provides an integrated environment for real-world robotic control and inter-system communication.

Running roscore on a Jetson device with a desktop interface allows seamless integration between ROS and Arduino, facilitated by the rosserial library. This connection bridges ROS applications and Arduino-based hardware, enabling effective data sharing from sensors and actuators with ROS nodes. This dual-platform communication is particularly useful for students to grasp how embedded systems interface with ROS, thus applying theory in practical scenarios.

In the teleoperation stage, ROS's teleop_twist_keyboard script allows for keyboard-based robot control. For example, pressing the "I" key generates a command for forward movement, translated into a geometry_msgs/Twist message—a standard ROS message type for linear and angular velocity data. This command is then published to the cmd_vel topic, where other nodes subscribed to it execute the movement instructions. This hands-on practice in teleoperation demonstrates the fundamental concepts of ROS messaging and node interaction, equipping students with essential skills in robotics software development.

During initial tests, a teleoperated system was used to manually guide the robot, allowing data collection on movement characteristics and speed, essential for tuning the autonomous system. This method ensures that unsuitable speeds or maneuvers are identified early, mitigating risks such as unpredictable movement or accidents during autonomous operation. Testing on varied surfaces, such as tile floors, helps students analyze and calibrate speed control to achieve precise navigation, an exercise that solidifies their understanding of the critical relationship between programming, testing, and hardware.

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(a) (b)

Figure 1: (a) Robot Initial Position; (b) Robot End Position

Through these phases, the research integrates theoretical learning with hands-on experimentation, guiding students in applying coding skills, understanding hardware constraints, and analyzing control dynamics. This combination of ROS implementation and teleoperation testing provides a structured pathway for students to gain proficiency in programming, control theory, and robotics—all critical competencies in engineering education.

In the context of robotics education, the process of mapping and navigating environments is crucial for developing a deep understanding of both hardware and software integration. This project leverages ROS (Robot Operating System) and RViz, a 3D visualization tool, to guide students in implementing real-world robotics systems. RViz provides a visual interface that helps students understand and debug the robot's perception of its environment, making it an invaluable tool for learning and troubleshooting robot navigation systems.

The mapping process begins by launching RPLiDAR from the ROS terminal, followed by initiating RViz to visualize the data captured by the LiDAR sensor. To ensure that the LiDAR data aligns accurately with the robot's sensor, students must set the Fixed Frame in RViz to "laser" – the reference point for the LiDAR's measurements. By adding the LaserScan display type and adjusting the size for clarity, students are able to see the real-time point cloud that represents the surrounding environment. This exercise introduces students to important concepts in sensor data visualization, critical for understanding how robots perceive their surroundings.

The mapping is performed by moving the LiDAR sensor slowly around the room to collect high-quality environmental data. The slower movement allows the system to generate precise 3D maps that are essential for accurate navigation. This task emphasizes the importance of sensor placement and the effects of sensor mobility on data quality, providing students with hands-on experience in fine-tuning sensor operations for optimal performance.

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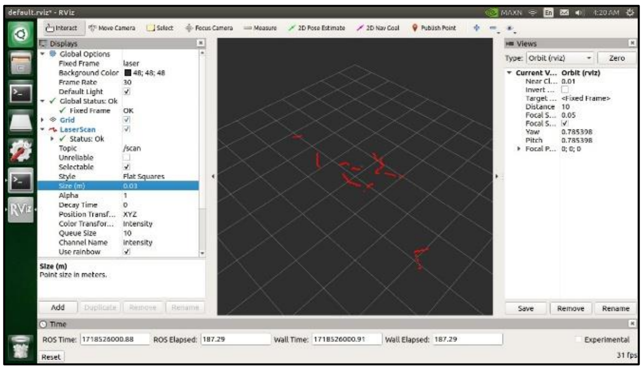

Figure 2: RViz GUI

However, the project also highlights several engineering challenges that are crucial for students to address. During robot maneuver tests, errors arose due to the robot's weight distribution, leading to torque overload and occasional stalling of the motors. This issue caused the robot to fail in navigating the path effectively, interrupting the overall system performance. By introducing odometry sensors, specifically the RealSense T265, the project solved these issues, enhancing the mapping and navigation accuracy. This integration underscores the importance of sensor fusion in robotics, offering students a chance to understand how multiple sensor types can complement each other for better performance.

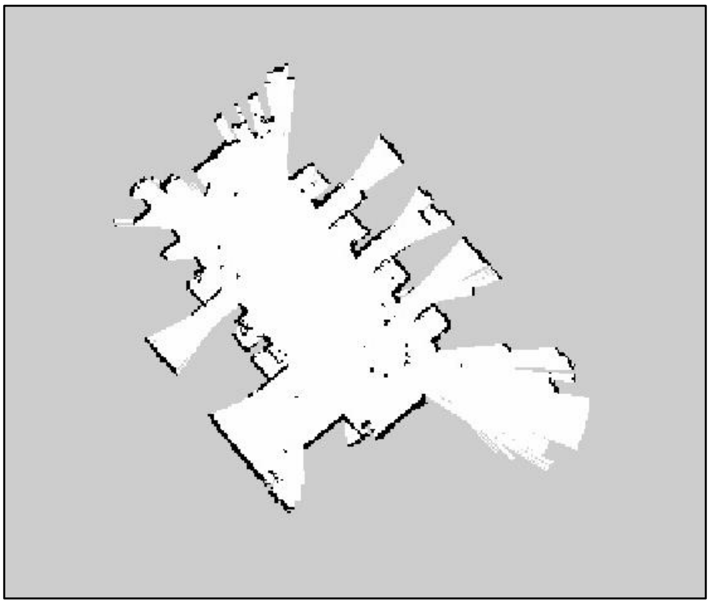

Figure 3: Mapping Result

Another challenge encountered during the testing phase was finding the optimal speed for the robot's movement. Too low a speed caused the robot to fail to move, while higher speeds resulted in erratic motion. Manual tuning of the robot’s speed allowed students to fine-tune motor control algorithms and understand how speed affects the overall performance and safety of robotic systems. This iterative process teaches students about the practical application of control systems in robotics.

In addition to these technical challenges, the project also exposed safety concerns, such as sparking when connecting the robot's battery. This issue highlighted the importance of implementing proper safety measures during robotics experiments. Teaching students about battery safety and ensuring proper voltage and current levels, using LIPO batteries, is a crucial aspect of building reliable and safe robotic systems. This hands-on experience reinforces the significance of electrical engineering principles in robotics education, emphasizing safety and precision in component selection and testing.

Through these stages of mapping, sensor integration, and troubleshooting, the project provides students with a comprehensive educational experience in robotics, from theory to practical implementation. By engaging with real-world challenges and solutions, students gain valuable insights into the complexities of autonomous systems and their applications in various fields of robotics.

Conclusion

This research underscores the critical role of hands-on, practical learning in robotics education, highlighting the integration of advanced technologies such as LiDAR, odometry sensors, and motor control systems within a Robot Operating System (ROS) framework. By utilizing tools like RViz for sensor visualization and engaging in real-world challenges such as optimizing motor speeds and sensor calibration, students are provided with invaluable insights into the complexities of autonomous navigation systems. These practical exercises not only foster a deeper understanding of robotics principles but also help students develop problem-solving skills necessary for real-world applications.

The project's design and development stages also emphasize the importance of interdisciplinary knowledge, combining elements of software development, sensor technology, control systems, and electrical engineering. Through iterative testing, troubleshooting, and optimization, students learn how to balance theoretical concepts with hands-on experimentation. Furthermore, challenges such as managing motor torque, sensor calibration, and battery safety provide students with essential safety and engineering practices, preparing them for future careers in robotics and automation.

Ultimately, this project contributes to the field of education by offering a structured approach to teaching robotics, combining theoretical knowledge with practical applications. It encourages critical thinking, innovation, and collaboration, making it an excellent model for developing educational frameworks that bridge the gap between classroom learning and real-world robotics engineering. As robotics continues to evolve, projects like this will play a crucial role in shaping the next generation of engineers and researchers equipped to tackle the challenges of tomorrow's autonomous systems.

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