MCT443

Design of Autonomous Systems

Project Report

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ABSTRACT

This technical project report presents the development and implementation of an autonomous robot with forward steering and backward driving wheels. The robot utilizes a Raspberry Pi 4 for processing and communication, an ultrasonic sensor for obstacle detection, an IMU for heading calculation, and optical encoders for distance measurement. The project includes two phases: straight-line movement and obstacle avoidance. The robot uses the IMU and encoders to maintain its position within the lane during straight-line movement, and the ultrasonic sensor to detect obstacles and perform lane changes during obstacle avoidance. The report discusses the methodology, results, and potential future upgrades for the autonomous robot, including the integration of Kalman filtering and SLAM techniques.

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1. Introduction

The field of autonomous robotics has witnessed significant advancements in recent years. This technical project report presents the development and successful implementation of an autonomous robot with forward steering and backward driving wheels. The objective of the project is to design a robot capable of moving in a straight line inside its lane using an IMU for heading calculation, optical encoders for distance measurement, and obstacle avoidance capabilities using an ultrasonic sensor. The integration of a Raspberry Pi 4 and an Arduino Uno within the ROS framework enables seamless communication and coordination between the various components of the robot system.

2. System Overview

The autonomous robot system comprises several key components that work together to enable its autonomous functionalities. The system architecture includes a Raspberry Pi 4, an ultrasonic sensor, an IMU, optical encoders, and an Arduino Uno connected to an H-bridge.

The Raspberry Pi 4 serves as the central processing unit and is responsible for coordinating the various subsystems of the robot. It runs the ROS (Robot Operating System) framework, which facilitates communication and data exchange between the different components of the system.

The ultrasonic sensor plays a crucial role in obstacle detection. It emits ultrasonic waves and measures the time it takes for the waves to bounce back after hitting an obstacle. This information allows the robot to determine the distance between itself and the obstacle.

The IMU (Inertial Measurement Unit) includes sensors such as accelerometers and gyroscopes. These sensors provide data on the robot's orientation, angular velocity, and acceleration. By fusing this data, the IMU enables accurate heading calculation, which is essential for maintaining the robot's straight-line movement within its lane.

To measure the distance traveled by the robot, two optical encoders are employed. Each encoder is connected to a backward driving wheel and provides feedback on the wheel's rotation. By monitoring the encoder readings, the robot can calculate the distance it has moved with high precision.

The Arduino Uno, connected to the H-bridge, controls the steering motor and the driving motor. It receives commands from the Raspberry Pi and adjusts the motors accordingly to achieve the desired steering angle and wheel rotation.

The integration of these components within the ROS framework ensures seamless communication and coordination between the Raspberry Pi and the Arduino, allowing for effective control and execution of autonomous behaviors.

3. Methodology

3.1. Phase 1: Straight Line Movement (Lane Keeping)

The first phase of the project focuses on achieving straight-line movement. The IMU with gyroscope data fusion accurately calculates the robot's heading and detects any drifting. By analyzing the heading information, the robot identifies deviations and adjusts the steering angle using the Arduino and H-bridge. The optical encoders provide precise distance measurements, enabling the robot to monitor its progress and stop after reaching a predefined distance [3][6].

3.2. Phase 2: Obstacle Avoidance (Lane Shift)

The second phase enhances the robot's capabilities with obstacle avoidance functionalities. The integration of the ultrasonic sensor allows the robot to detect obstacles in real-time. When an obstacle is detected at approximately 50cm, the robot initiates a lane change maneuver to avoid it. The obstacle detection and decision-making algorithms are crucial for determining the appropriate action to take based on the sensor data [2]. Upon initial start movement and reaching first obstacle after traveling 4 meters, the robot employs the ultrasonic sensor to identify its presence. Based on the sensor readings, the robot decides to turn left, enter the adjacent lane, and continue moving forward. After an additional 4 meters, a similar obstacle detection process occurs, and the robot chooses to turn right, re-entering its initial lane. Finally, the robot moves forward for 2 meters before coming to a stop.

4. Results and Discussion

The results obtained from both phases of the project demonstrate the successful implementation of the autonomous robot's functionalities. In the straight-line movement phase, the robot exhibits accurate heading calculation, efficient steering adjustments, and precise distance measurement. The obstacle avoidance phase showcases the robot's ability to detect obstacles, make appropriate decisions based on sensor data, execute lane change maneuvers smoothly, and navigate the desired path. The integration of the ROS framework ensures effective communication and coordination between the Raspberry Pi and the Arduino.

5. Future Upgrades

5.1. Incorporating Kalman Filtering

One potential future upgrade for the autonomous robot system is to incorporate Kalman filtering techniques. Kalman filters are widely used in robotics and can significantly improve the accuracy and reliability of sensor data fusion and state estimation. In the current system, the IMU provides heading information, and the encoders measure the distance traveled. However, these measurements may contain noise and errors. By integrating Kalman filtering, the robot can take advantage of the filtering algorithm to better estimate its position, velocity, and orientation, even in the presence of noisy sensor data [4][7].

Kalman filters are particularly beneficial when dealing with non-linear systems, as they can handle non-linearities and provide more accurate estimations. Since the autonomous robot's dynamics and sensor measurements are non-linear, implementing a Kalman filter would be advantageous. The filter would fuse the information from the IMU, encoders, and any other relevant sensors, considering their respective error characteristics. By continuously updating the robot's estimated state based on the current measurements and previous estimations, the Kalman filter can provide more robust and accurate information about the robot's position and orientation, allowing for improved control and decision-making.

5.2. Integrating SLAM

Another significant upgrade to consider is integrating Simultaneous Localization and Mapping (SLAM) techniques into the autonomous robot system. SLAM addresses the challenge of simultaneously building a map of the robot's environment while estimating the robot's own position within that map. By combining sensor measurements, such as from the IMU, encoders, and additional sensors like cameras or LIDAR, SLAM algorithms enable the robot to create a coherent and accurate representation of its surroundings, even in unknown or dynamic environments [1][5].

The integration of SLAM would provide the robot with a comprehensive understanding of its environment, allowing for improved navigation and path planning. With a map of the environment and the ability to localize itself within that map, the robot can make more informed decisions about its actions, considering obstacles, landmarks, and other relevant features. This enhanced spatial awareness would enable the robot to navigate more efficiently, avoid collisions, and potentially perform tasks that require knowledge of the environment.

By incorporating SLAM techniques, the autonomous robot could expand its capabilities beyond simple obstacle avoidance, enabling it to explore and map unknown areas, handle complex environments, and potentially interact with objects or perform tasks based on its understanding of the surroundings.

Overall, the integration of Kalman filtering and SLAM techniques would significantly enhance the autonomy and performance of the robot, improving its ability to estimate its state, navigate in complex environments, and make informed decisions based on a more accurate representation of its surroundings.

6. Conclusion

In conclusion, this project has successfully designed and implemented an autonomous robot capable of executing straight-line movement and obstacle avoidance tasks. By leveraging principles from behavior-based robotics, control algorithms, and the ROS framework, the robot demonstrates accurate heading calculation, efficient steering adjustments, precise distance measurement, and effective obstacle detection. The project's outcomes highlight the potential for further enhancements and advancements in autonomous robotics.

7. References

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