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Implementation of Map Based Automated Navigation Robot

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Abstract

The advancement of autonomous robotic systems has led to innovative applications in document delivery, tour guidance, and obstacle avoidance. This research focuses on the development of a Map-Guided Automated Robot designed to enhance efficiency in office environments by securely transporting documents and materials. The system integrates multiple sensor technologies, including ultrasonic sensors for obstacle detection, a color sensor for navigation, and an RFID module for security authentication. A microcontroller-based control system ensures seamless operation, with data logging capabilities for performance tracking.

Additionally, the study incorporates principles of autonomous tour guide robots and obstacle avoidance mechanisms. A QR code recognition system enables navigation in structured indoor environments, while ultrasonic range sensors assist in maintaining safe distances from obstacles. Furthermore, fuzzy control algorithms and LiDAR-based navigation strategies are explored to improve autonomous movement in dynamic conditions. The integration of Bluetooth communication and text-to-speech functionality enhances human-robot interaction, making the system adaptable to diverse applications such as office logistics, guided tours, and unmanned surface vehicle navigation.

INTRODUCTION

Automation has significantly transformed various industries, streamlined operations and improved efficiency. Educational institutions, however, have been slower to adopt automation for administrative tasks. One such area that remains largely manual is document delivery within college campuses. Faculty members, administrative staff, and students often need to transport academic records, assignments, official notices, and other documents across different departments, leading to inefficiencies, delays, and potential mismanagement of important paperwork. This project aims to address these challenges by introducing an Automated Guided Vehicle (AGV) specifically designed for document transportation within a college campus.

The proposed Map-Guided Automated Guided Robot (AGV) utilizes an Arduino Uno microcontroller to facilitate navigation, control, and interaction with users. The system employs infrared (IR) sensors for real-time obstacle detection, rotary encoders for precise position tracking, and motor drivers to regulate movement. A key feature of the AGV is its ability to follow predefined paths while autonomously avoiding obstacles, ensuring safe and efficient document transportation. Additionally, the integration of an LCD display enables users to select delivery destinations, making the system user-friendly and interactive. By automating the document delivery process, this project aims to reduce the dependency on human labor, minimize the risk of human errors, and enhance the efficiency of administrative workflows in academic environments. The implementation of a low-cost, scalable robotic solution provides a practical approach to improving resource utilization while addressing common logistical challenges in educational institutions.

LITERATURE REVIEW

Autonomous robots have seen significant advancements in various domains, including service automation, tour guidance, and obstacle avoidance. Several research studies have explored different approaches to navigation, interaction, and control mechanisms to improve the efficiency of these robots.

An Autonomous Delivery Robot to Prevent the Spread of Coronavirus in Product Delivery System

An autonomous delivery robot designed to prevent the spread of coronavirus in the product delivery system is an innovative solution aimed at minimizing human contact while ensuring efficient and safe deliveries. The robot is equipped with advanced technologies such as AI-based navigation, LiDAR sensors, GPS tracking, and real-time obstacle detection to autonomously navigate through urban and residential environments. It is designed to pick up and transport goods, including food, medical supplies, and essential items, directly to customers' doorsteps, reducing the risk of virus transmission through human-to-human interaction. The system integrates intelligent motion planning and deep learning-based object recognition to adapt to different terrains, avoid obstacles, and follow predefined routes while ensuring timely and secure delivery. A contactless authentication system, such as facial recognition or QR code scanning, enables customers to safely receive their packages without physical contact. The robot also features a temperature-controlled storage compartment to preserve perishable items and maintain the quality of medical supplies. Additionally, built-in disinfection mechanisms, such as UV-C light sterilization or self-cleaning surfaces, help eliminate potential contamination from handling.[1]

Research on a Novel Vascular Interventional Surgery Robot and Control Method Based on Precise Delivery

developing a highly accurate and minimally invasive robotic system to assist in complex vascular procedures. Traditional vascular interventions, such as catheterization and stent placement, rely heavily on the skill and experience of surgeons, which can introduce variability in outcomes. The proposed robotic system enhances precision, stability, and control by integrating advanced robotic mechanisms, force feedback sensors, and AI-driven navigation algorithms to ensure optimal performance. The system consists of a robotic arm equipped with a high-precision catheter and guidewire control module, which allows for delicate maneuvering within blood vessels, minimizing trauma to vascular walls. LiDAR-based imaging, along with real-time fluoroscopic or MRI guidance, helps the robot generate a detailed 3D map of the vascular network, enabling precise delivery of surgical instruments to targeted locations. To enhance accuracy, the control method incorporates haptic feedback and AI-assisted motion planning, allowing the surgeon to have real-time tactile sensation while remotely controlling the robotic system, reducing the risk of excessive force or misplacement. Furthermore.[2]

MPPI-VS: Sampling-Based Model Predictive Control Strategy for Constrained Image-Based and Position-Based Visual Servoing

MPPI-VS, or Model Predictive Path Integral Visual Servoing, is a sampling-based model predictive control strategy that combines constrained image-based and position-based visual servoing to enhance robotic manipulation and navigation tasks. This approach leverages the strengths of model predictive control (MPC) by optimizing the robot's motion trajectory in real time while considering constraints such as obstacles, dynamic environments, and system limitations. By incorporating sampling-based optimization, MPPI-VS generates multiple trajectory samples and evaluates their feasibility using a cost function that accounts for visual feedback, ensuring smooth and stable servoing. The system integrates both image-based visual servoing (IBVS), which directly controls the robot using visual features from a camera, and position-based visual servoing (PBVS), which estimates the robot's position relative to a target, allowing for a more robust and adaptive control mechanism. This fusion enables MPPI-VS to handle uncertainties in depth estimation, varying lighting conditions, and occlusions while ensuring precise and stable motion. The algorithm continuously refines the control inputs by selecting the most optimal trajectory sample, improving response time and adaptability in complex environments. The method is particularly effective for robotic tasks such as object grasping, autonomous navigation, and medical robotic procedures, where real-time visual feedback is crucial.[3]

Autonomous Vehicle System using Lidar

An autonomous vehicle system using LiDAR is a sophisticated technology that enables self-driving cars to navigate and make decisions with high precision by utilizing Light Detection and Ranging (LiDAR) sensors. LiDAR works by emitting laser pulses that bounce off surrounding objects and return to the sensor, allowing the system to create a detailed 3D map of the environment in real time. This high-resolution mapping capability helps the vehicle detect and classify obstacles, pedestrians, road signs, and lane markings with exceptional accuracy, even in low-light or adverse weather conditions. The autonomous vehicle integrates LiDAR data with other sensor inputs such as cameras, radar, and GPS to generate a comprehensive perception of its surroundings, enabling precise localization, obstacle avoidance, and path planning. Advanced machine learning algorithms and AI-driven data processing allow the system to predict the movements of objects and make real-time driving decisions, ensuring safety and efficiency.[4]

Self-Driving Car using Lidar

A Self-Driving Car using LiDAR is an advanced autonomous vehicle that leverages Light Detection and Ranging (LiDAR) technology to navigate safely without human intervention. LiDAR plays a crucial role in providing real-time 3D mapping of the environment, allowing the vehicle to detect obstacles, identify road boundaries, and make intelligent driving decisions. The system operates by emitting laser pulses that bounce off surrounding objects and return to the sensor, measuring the time-of-flight to determine distances with high precision. This creates a highly detailed point cloud representation of the surroundings, enabling the car to recognize pedestrians, other vehicles, traffic signals, and road signs. [5].

METHODOLOGY

The development of the robot system follows a structured methodology encompassing hardware selection, software implementation, navigation strategies, and performance evaluation. The methodology integrates techniques from different research works, each contributing to specific aspects of the robot's functionality.

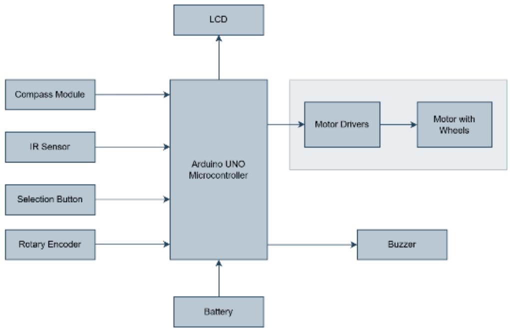


Fig 1 : Block Diagram of Autonomous Navigation Robot Using Map-Based Guidance

Hardware Components

Microcontroller: The control unit is based on Arduino Mega 2560, handling motor operations, sensor inputs, and user authentication [1]. Another variation includes Arduino Uno (Atmega328), which facilitates sensor-based navigation and Bluetooth communication [2].

Sensors: **Obstacle Detection:** Multiple obstacle detection sensors are used, such as ultrasonic sensors (HC-SR04) for object identification and path correction [1], along with LiDAR sensors that provide a 2D mapping of the surroundings and calculate distances using laser reflections [3].

Navigation Support: Infrared proximity sensors improve obstacle detection in confined spaces [4], and a compass assists with directional stability [4].

Security Module: An RFID reader ensures document access security by verifying user authorization before releasing documents [1].

Motion Control:

Motor and Driver: The robot movement is controlled using the L298N motor driver, which regulates speed and turning mechanisms [1]. DC servo motors with integrated encoders provide precise movement control and speed adjustments [4].

Propulsion Mechanism: For advanced obstacle avoidance, propeller-based velocity adjustments are managed using fuzzy logic and PD control for real-time corrections [3].

Power Source: The robot is powered by a 12V, 12Ah Lithium Polymer Battery, supplying energy for continuous operations [1].

Software Implementation

The robot's software is designed to integrate various functionalities, including navigation, security, and motion control.

Programming & Development Environment: The system is programmed using Arduino IDE, employing sensor libraries, RFID authentication, and motor control logic [1]. QR code and circle detection are handled using ZXing and OpenCV libraries to facilitate navigation and user interaction [2].

Navigation Strategy:

Predefined Path Navigation: The robot follows a predefined path, using ultrasonic sensors to adjust its route based on detected obstacles [1].

QR Code Recognition: A smartphone application scans QR codes to determine movement commands [2].

Fuzzy Logic-Based Obstacle Avoidance: The LiDAR-based obstacle avoidance system categorizes obstacles into six levels (e.g., "Extremely Dangerous," "Safe"), adjusting velocity accordingly [3].

Wall Following Behavior: Infrared sensors assist in ensuring the robot maintains close proximity to walls, improving stability in narrow passages [4].

Operational Workflow

The robot operates based on sequential decision-making:

1. Initial Positioning: The robot starts at a designated location and aligns itself using predefined paths or sensor-based localization techniques [1][4].
2. Obstacle Detection and Avoidance: If an obstacle is detected using ultrasonic sensors or LiDAR, the robot calculates the optimal avoidance path using fuzzy logic and PD controllers [3].
3. Security Authentication (For Document Delivery Robots): Upon reaching the target location, the system prompts the user to scan an RFID card. If authentication is successful, the document compartment is unlocked; otherwise, the failed attempt is logged [1].

Performance Evaluation

The effectiveness of the system is measured through various performance metrics:

Navigation Accuracy: Measured based on successful path execution without deviation from predefined or dynamically generated routes [1].

Obstacle Avoidance Efficiency: Evaluated using fuzzy logic response times and the number of successful path corrections [3].

Security Validation Rate: The success rate of RFID authentication for document access security is analyzed [1].

Data Transmission Optimization: The impact of MATLAB-Simulink integration on real-time sensor communication is examined [4].

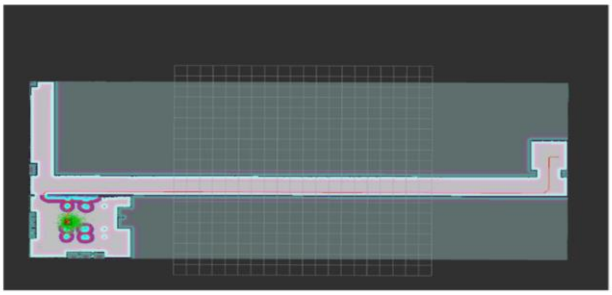
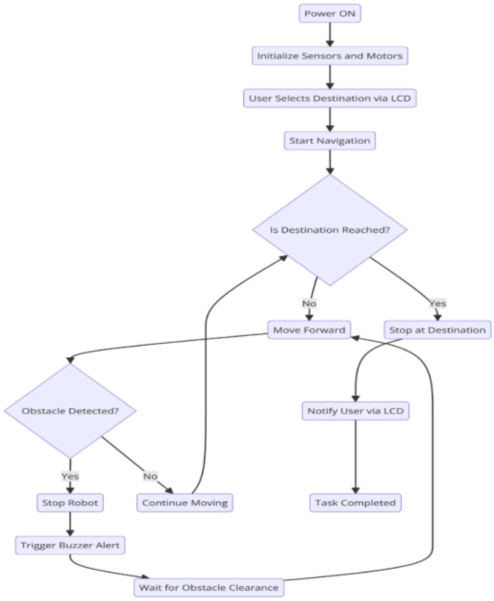


Fig 2. Global path planning

FLOW CHART



Power ON:The system is powered on, and the robot gets initialized. All electrical and mechanical components, including the microcontroller, motors, and sensors, start receiving power

Initialize Sensors and Motors: The robot initializes essential hardware components such as: Motors (for movement).Sensors (e.g., ultrasonic, infrared, or LiDAR for obstacle detection).

LCD Display (for user interaction): This ensures that all devices are functional before the robot starts navigating.

User Selects Destination via LCD: The system prompts the user to enter/select a destination on an LCD screen.The user inputs the required destination, which the robot stores in memory for navigation.

Start Navigation: The robot begins its journey towards the selected destination.It continuously updates its position while monitoring for obstacles.

Check if Destination is Reached: The robot evaluates if it has arrived at the target location.Two possible conditions:

Yes (Destination Reached): The robot stops and proceeds to notify the user

No (Destination Not Reached): The robot continues moving forward.

Move Forward (If Destination Not Reached): The robot keeps moving towards the destination. It uses navigation algorithms (like path planning or GPS-based tracking) to move in the correct direction. Simultaneously, the robot checks for obstacles in its path.

Check for Obstacles: The robot continuously scans the path using ultrasonic, infrared, or LiDAR sensors to detect objects in its way.Two possible conditions:

No Obstacle Detected: The robot continues moving forward.

Obstacle Detected: The robot stops and triggers an alert.

Stop Robot (If Obstacle is Detected): Upon detecting an obstacle, the robot immediately stops moving to prevent collisions.

Trigger Buzzer Alert: A buzzer sound is activated to notify users that an obstacle is blocking the robot's path. This can also serve as an alert in environments where manual intervention is needed to clear the path.

Wait for Obstacle Clearance: The robot remains stationary while continuously checking if the obstacle has moved or been removed. Once the obstacle is cleared, it resumes movement.

Continue Moving (If No Obstacle): If no obstacle is detected, or after it has been cleared, the robot continues moving towards the destination.

Stop at Destination (If Reached): When the robot reaches the predefined location, it halts all movement.

Notify User via LCD: The system displays a message on the LCD screen confirming that the robot has arrived at the target location.

Task Completed: The navigation cycle is successfully completed.The robot can either shut down or wait for further instructions from the user.

FUTURE SCOPE

The development of the Map-Guided Automated Guided Robot presents numerous opportunities for future enhancements and expansions. Several key areas for further development include:

Integration of Advanced Navigation Technologies: Future iterations of the AGV can incorporate advanced navigation algorithms, such as simultaneous localization and mapping (SLAM) and artificial intelligence-based path planning, to enable real-time dynamic routing and adaptive decision-making in complex environments. This would allow the robot to navigate efficiently even in changing campus layouts.

Wireless Communication and IoT Connectivity: Integrating wireless communication modules, such as Wi-Fi, Bluetooth, or LoRa, can enable remote monitoring and control of the AGV. Connecting the system to an IoT platform can allow users to schedule document deliveries, track the robot's real-time location, and receive notifications upon successful delivery.

Enhanced Obstacle Avoidance and Safety Mechanisms: While the current model relies on IR sensors for obstacle detection, future designs can incorporate additional sensor technologies, such as ultrasonic sensors, LiDAR, or depth cameras, to improve obstacle recognition accuracy and ensure safer navigation in dynamic environments.

Load Capacity and Multi-Document Handling: To enhance functionality, the robot can be equipped with a secure document storage compartment featuring multiple slots or trays. Implementing a robotic arm or conveyor system can facilitate automated document pickup and drop-off, allowing for seamless multi-document handling.

Energy Efficiency and Renewable Power Sources: Enhancements in power management, such as optimizing battery usage and integrating solar charging modules, can increase the AGV's operational longevity while reducing dependency on external power sources.

RESULT

The Autonomous Navigation Robot Using Map-Based Guidance successfully follows a structured decision-making process for navigation, obstacle detection, and task completion. When powered on, the system initializes all sensors and motors, preparing for operation. The user selects a destination via an LCD interface, after which the robot begins its journey. Throughout navigation, it continuously checks whether it has reached the desired location. If the destination is not yet reached, the robot moves forward while simultaneously scanning for obstacles. If an obstacle is detected, the robot halts immediately, triggers a buzzer alert, and waits until the obstacle is cleared before resuming movement. If no obstacle is found, it continues its path without interruption. Upon reaching the final destination, the robot stops its motion, notifies the user via the LCD, and marks the task as completed. The system efficiently automates movement, integrating obstacle handling and user interaction to ensure accurate and safe navigation in a mapped environment.

CONCLUSION

This paper presents the development of an autonomous robot system incorporating advanced navigation techniques for efficient and intelligent operation in various environments. By integrating QR code-based guidance, ultrasonic and LiDAR sensors for obstacle detection, and behavior-based control architectures, the proposed system ensures safe and effective navigation. The inclusion of PID and fuzzy logic controllers enhances motion stability, while text-to-speech functionality improves user interaction.

Experimental results demonstrate the system's ability to follow predefined paths, navigate complex environments, and achieve high task completion accuracy. Compared to traditional RFID-based navigation, QR code and LiDAR-based approaches offer cost-effective and flexible alternatives, though challenges such as recognition reliability and sensor precision remain. Optimizations in localization, motion control, and data transmission further improve navigation efficiency, making the system suitable for applications in museums, offices, university tours, and maritime operations.

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