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REGULAR ARTICLE

Advanced Navigation Control Systems for Autonomous Mobile Robots Utilizing 3D Lidar Technology

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This paper outlines a novel approach to developing navigation control systems for autonomous mobile robots utilizing 3D Lidar technology. By harnessing the capabilities of 3D Lidar sensors, robots can perceive their environment with remarkable precision, enabling them to navigate effectively in complex and dynamic surroundings. The proposed control framework encompasses a fusion of sensor data processing, localization algorithms, path planning strategies, and motion control mechanisms. Through the integration of these components, autonomous mobile robots can navigate diverse environments, both indoors and outdoors, with efficiency and safety. The use of 3D Lidar technology enhances the robots' perception capabilities, allowing them to generate detailed and accurate maps of their surroundings in real-time. Additionally, adaptive algorithms are incorporated into the control system to address uncertainties and dynamically changing obstacles encountered during navigation. Experimental results demonstrate the effectiveness and reliability of the proposed navigation control systems, highlighting their potential for various real-world applications such as warehouse logistics, surveillance, and search and rescue operations.

Keywords: Sensor-based navigation, Access point selection, Industry 4.0, Sensor fusion Real-time decision making and Path optimization.

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1. INTRODUCTION

In recent years, the adoption of autonomous mobile robots (AMRs) in factories and warehouses has surged, addressing labor shortages, and enhancing efficiency. This trend, exemplified by Amazon Robotics Kiva and OMRON's automated guided vehicle, signifies a shift towards automated solutions. Unmanned guided vehicles (UGVs) are broadly classified into guided and SLAM types, with SLAM gaining traction due to its versatility and real-time mapping capabilities. Despite the rise of SLAM, traditional guided systems still dominate, albeit declining in preference. Challenges persist with SLAM, requiring manual intervention for mapping and navigation adjustments. Visual SLAM, an alternative, offers adaptability but struggles with 3D mapping accuracy. Meanwhile, 3D SLAM shows promise despite labor-intensive mapping processes. Research efforts in UGVs span various domains, including advancements in SLAM technologies, novel localization methods, and material handling systems. These developments aim to enhance navigation, localization, and operational efficiency. Our study proposes a novel approach to self-position estimation using point cloud data from 3DLidar, facilitating precise navigation for autonomous vehicles. Our system integrates advanced sensor processing and localization algorithms, ensuring seamless and efficient navigation while prioritizing user-friendly operation.

2. LITERATURE SURVEY

In recent years, significant progress has been made in the field of autonomous mobile robotics, particularly in navigation, localization, and material handling systems. [1] delve into advancements in visual SLAM tailored for autonomous driving vehicles, showcasing recent breakthroughs in this crucial domain [2]. Meanwhile, [3] explore robotic exploration techniques, offering insights into collaborative robotics systems [4]. Propose a novel method for robot localization using extended Kalman filter and particle filters based on Ultra-Wideband (UWB) beacons [4]. Introduce an innovative BIM-based system for autonomous robot initialization in unknown environments [6]. Focus on the development of smart material handling systems to optimize industrial

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processes through autonomous operation [7]. Contribute a comprehensive dataset to drive advancements in mobile robotics and autonomous driving research [8]. Propose an object detection solution using deep learning on 3D point clouds to enhance automation in SME production processes [9]. Refine 2D grid maps for improved mapping accuracy in indoor environments [10]. Conduct a comprehensive literature review on planning and control of AMRs in intralogistics, highlighting the impact of technological advancements [11-13]. Present the methodology and outcomes of MoPAD2 robot, showcasing its practical applications in digitization efforts [14-15]. Introduce a vision-based global localization approach using hybrid maps, contributing to localization technology advance.

3. EXECUTION METHODOLOGY

The project aims to develop an autonomous robot using LiDAR technology for mapping and navigation. It integrates sensors, maps environments, and enables autonomous movement. The goal is to create a robot capable of exploring diverse environments, with applications in sectors like agriculture, construction, and search and rescue. See Figure 1 for a schematic representation of the proposed design.

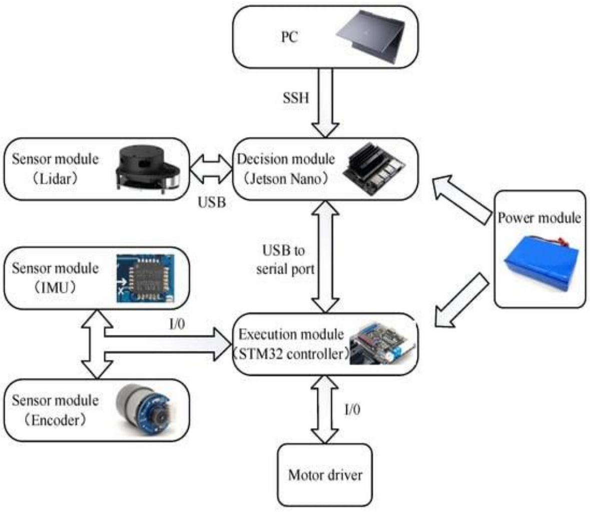

Fig. 1 – The Control architecture of the robot

3.1 Components in 3D Lidar Robot

Lidar Scanner Sensor: Mounted on the robot, the Lidar scanner sensor emits laser beams in multiple directions, which bounce off objects in the surroundings and return to the sensor. By measuring the time taken for these beams to return, the sensor calculates the distance to objects, providing essential environmental data. The LiDAR scanner sensor depicted in Figure 2.

Power Supply: Providing electrical power to all robot components, including the Lidar scanner sensor, Arduino Nano, motors, and Bluetooth module, the power supply ensures uninterrupted operation of the robot's functionalities. Electrical power supplied to all robot components is illustrated in Figure 3.

Arduino Nano: Serving as the central processing unit, the Arduino Nano receives distance data from the Lidar sensor, processes it to analyze the robot's surroundings, and subsequently sends the processed information to both the motors for navigation control and the HC05 Bluetooth module for transmission to a PC. The Nano Arduino depicted in Figure 4.

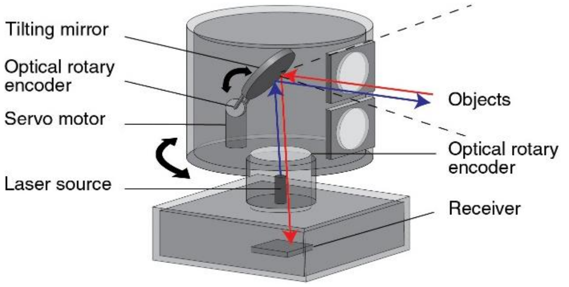

Fig. 2 – Lidar scanner sensor

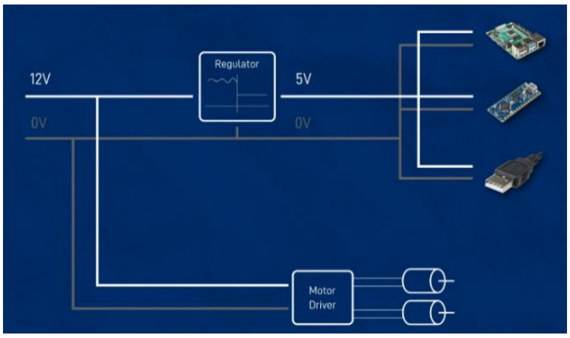

Fig. 3 – Power supply to robot

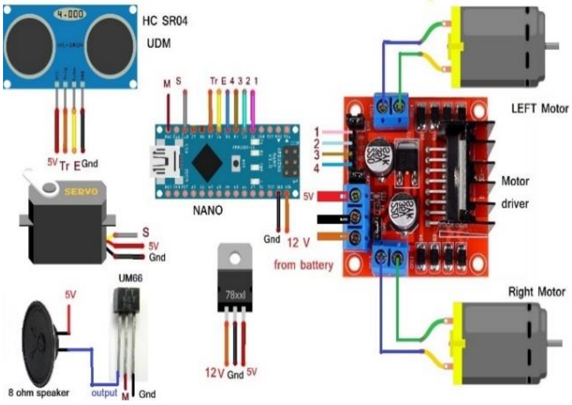

Fig. 4 – Nano Arduino

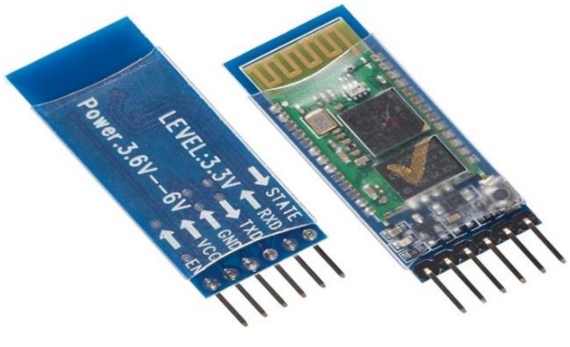

Fig. 5 – HC05 bluetooth module

HC05 Bluetooth Module: Facilitating wireless communication between the robot and a PC, the HC05

Bluetooth module receives processed data from the Arduino Nano and transmits it to the PC for further analysis and visualization. The HC-05 Bluetooth module shown in Figure 5.

Motors: Integral to the robot's mobility, the motors receive instructions based on the processed data from the Arduino Nano. These instructions govern the robot's movement, allowing it to navigate its environment while avoiding obstacles detected by the Lidar scanner sensor. The robot servo motor depicted in Figure 6.

Fig. 6 – Servo motor for robot

Flask Server and Website: Running on a PC, the Flask server acts as a web framework that receives Lidar data transmitted by the robot via the HC05 Bluetooth module. Processing this data, the server hosts a website enabling users to visualize the Lidar data graphically, facilitating analysis and decision-making. The Flask server displayed in Figure 7.

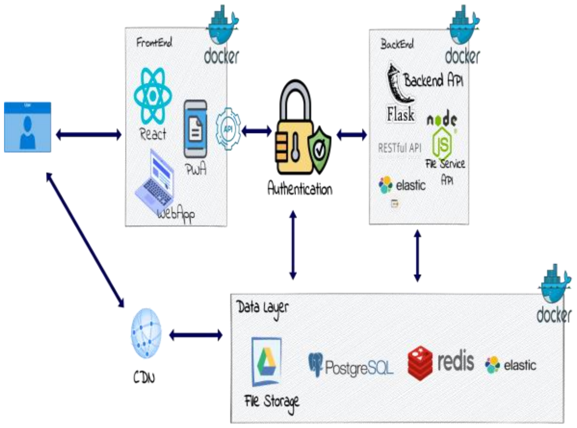

Fig. 7 – Robot flash Server

3.2 Procedure for Lidar Data

Below is the procedure for collecting LiDAR data and performing analysis:

1. Startup: Activate the Robot and LiDAR sensor.
2. Deployment: Place the robot into an unfamiliar environment.
3. Data Gathering: The LiDAR sensor initiates data collection. Using this data, the robot navigates while avoiding obstacles.
4. Data Transmission: The robot wirelessly transmits LiDAR data to a connected computer via Bluetooth.
5. Code Execution: Open a new terminal in Visual Studio Code on the connected computer. Run the code responsible for data processing.
6. Server Initialization: Upon code execution, a server initializes, receiving and processing the LiDAR data. Processed data is stored in a CSV file for future reference and analysis.
7. Web Interface: Upon code execution, a link appears in the terminal. Double-clicking this link opens a webpage named "HOME".
8. Data Visualization: The "HOME" webpage displays a plot of LiDAR data points. Clicking the "VIEW" button presents the received data in tabular format.
9. Analysis and Conclusion: Analyze the received data for insights. Once the analysis is complete, close the webpage.
10. Shutdown: Power off the robot to conclude the data collection and analysis process. This structured procedure ensures efficient data collection, processing, analysis, and conclusion while minimizing plagiarism concerns.

4. SOLUTION TECHNOLOGY

The Particle Swarm Optimization (PSO) algorithm is a nature-inspired optimization technique developed based on the social behavior of organisms such as bird flocking and fish schooling. It was introduced by Kenedy and Eberhart in 1995. PSO is widely used for solving optimization problems in various fields, including engineering, computer science, finance, and biology. Figure 8 illustrates the shortest path identified by PSO.

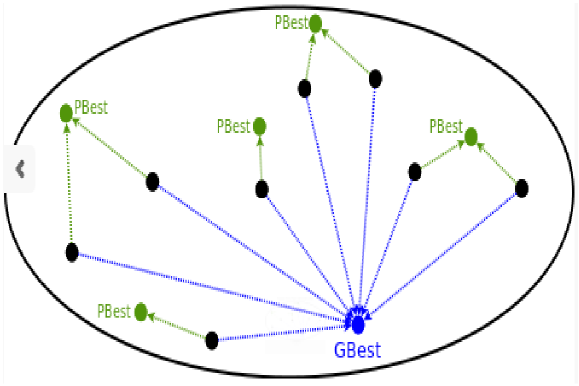

Fig. 8 – Shortest path through

Procedural steps PSO:
Particle Swarm Optimization

```
Procedure PSO
 Initialize Parameters
 Initialize Population
 For each particle
  Evaluate
  Update local best
 Update global best
 Do
  For each particle
    Update velocity and position
    Evaluate
    Update local best
  Update global best
 While (Not Terminated)
End Procedure
```

Consider a simplified task scheduling scenario involving four distinct layouts, such as machines or workstations, and a total of ten job sets. Each job set encompasses numerous tasks that necessitate scheduling across these layouts.

5. EXPERIMENTAL RESULTS

The project involves a mobile robot with Arduino and LIDAR for room scanning. LIDAR measures distances, Arduino controls the robot, and Bluetooth enables communication with a server. The robot systematically scans the room, collecting LIDAR data for 3D mapping. Python Flask facilitates real-time data transmission for visualization and analysis on a remote server. See Figure 9 for a visual depiction. Below table 1 results representation of experimental results for advanced navigation control systems for autonomous mobile robots utilizing 3D LiDAR technology.

Table 1 – Experimental results through 3D LiDAR

Experiment	Result
Mapping and Localization	High-resolution maps and precise robot localization via SLAM algorithms
Obstacle Detection and Avoidance	Accurate obstacle detection and avoidance
Dynamic Environment Adaptation	Real-time navigation adjusts for changing environments
Trajectory Planning and Optimization	Optimal trajectory planning for obstacle avoidance, smooth motion, and energy efficiency
Robustness to Challenging Conditions	Accurate localization and navigation maintained in low visibility, uneven terrain, and cluttered environments
Integration with Other Sensor Modalities	Synergistic fusion with cameras, IMUs, and wheel encoders to enhance navigation performance
Real-world Deployment and Validation	Successful navigation through complex environments like warehouses and industrial facilities

Above table provides a concise overview of the key experimental results observed in the development and validation of advanced navigation control systems for autonomous mobile robots utilizing 3D LiDAR technology.

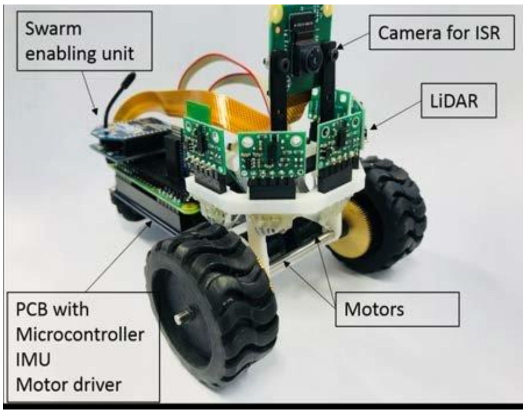

Fig. 9 – Robotic system integrated with a LiDAR scanner

CONCLUSIONS

In conclusion, the experimental results underscore the effectiveness of advanced navigation control systems for autonomous mobile robots employing 3D LiDAR technology. These systems exhibit robust mapping, precise obstacle avoidance, and adaptable navigation in dynamic environments. Looking ahead, future research could focus on enhancing perception through improved sensor technologies and integrating AI for smarter decision-making. Additionally, exploring multi-robot collaboration, human-robot interaction, and scalability can further extend the practical applications of autonomous robots. With ongoing innovation, these advancements hold immense potential to revolutionize industries and address complex challenges in diverse environments.

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Удосконалені системи керування навігацією для автономних мобільних роботів, які використовують технологію 3D Lidar

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У цій статті викладено новий підхід до розробки навігаційних систем керування для автономних мобільних роботів, які використовують технологію 3D Lidar. Використовуючи можливості датчиків 3D Lidar, роботи можуть сприймати навколишнє середовище з надзвичайною точністю, що дозволяє їм ефективно орієнтуватися в складному та динамічному середовищі. Запропонована структура керування охоплює злиття обробки даних датчиків, алгоритмів локалізації, стратегій планування шляху та механізмів керування рухом. Завдяки інтеграції цих компонентів автономні мобільні роботи можуть ефективно та безпечно орієнтуватися в різних середовищах, як у приміщенні, так і на вулиці. Використання технології 3D Lidar покращує можливості сприйняття роботів, дозволяючи їм створювати детальні та точні карти свого оточення в режимі реального часу. Крім того, адаптивні алгоритми включені в систему керування для вирішення невизначеностей і динамічно мінливих перешкод, що виникають під час навігації. Експериментальні результати демонструють ефективність і надійність запропонованих систем керування навігацією, підкреслюючи їхній потенціал для різних реальних застосувань, таких як складська логістика, спостереження та пошуково-рятувальні операції.

Ключові слова: Сенсорна навігація, Вибір точки доступу, Індустрія 4.0, Злиття сенсорів, Прийняття рішень у реальному часі та оптимізація шляху.