Ramrao Adik Institute of Technology
(Under the ambit of D. Y. Patil Deemed to be University)
Dr. D. Y. Patil Vidyanagar,Sector 7, Nerul, Navi Mumbai 400 706.

AI in Robotics for Autonomous Navigation

This project is done by

textbf Isha Sahlot (22CC1027)
Aaditya Shrivastava (22CC1033)
Ayan Khan (22CC1023)
Simran Thakur (22CC1071)

and is submitted in the partial fulfillment of the requirement for the degree of

Bachelor of Technology
Computer Science & Engineering (Cyber Security)
to the
D. Y. Patil Deemed to be University.

Mr. [Pramod Kachare]
Supervisor

Abstract

- AI in robotics for autonomous navigation empowers robots to interpret, adapt, and move within complex, dynamic environments with minimal human intervention by combining advanced techniques in machine learning, sensor fusion, and real-time decision-making. Perception is a critical first step, where sensors like LiDAR, cameras, and radar collect data that AI algorithms interpret to recognize objects, detect obstacles, and understand surroundings. This information is then used in SLAM (Simultaneous Localization and Mapping) to create a map of the environment while determining the robot's precise position. Path planning algorithms, such as A* or reinforcement learning-based approaches, then chart optimal routes, considering both static and dynamic obstacles. In real-world applications—ranging from autonomous vehicles and drones to warehouse robots—AI must continuously adapt to unexpected changes by recalculating paths and avoiding sudden obstacles, which it achieves through sensor fusion and quick, predictive decision-making. However, significant challenges persist, particularly in achieving reliable navigation across diverse conditions, ensuring safety in human-robot interactions, and making real-time decisions in unpredictable environments. These ongoing challenges drive research into more resilient and self-adaptive AI models, promising advancements in efficiency, robustness, and the scope of autonomous systems.

Contents

Chapter 1

Introduction

- Artificial Intelligence (AI) has revolutionized the field of robotics, enabling autonomous systems to perform complex tasks such as navigation, decision-making, and real-time adaptation to dynamic environments. Autonomous navigation refers to the ability of a robot or a system to autonomously perceive its surroundings, plan a path, and execute the movement without human intervention. This technological advancement is primarily driven by AI algorithms, including machine learning (ML), deep learning (DL), reinforcement learning (RL), and sensor fusion, which allow robots to process information, detect obstacles, and optimize navigation paths. The integration of Fractional Order Controllers (FOC), particularly Fractional Order PID Controllers, further enhances the precision and robustness of robotic control systems in nonlinear and uncertain environments. This report explores the core principles of AI in autonomous navigation, highlighting the role of Fractional Order Controllers, applications, challenges, and future directions. The scope of the report includes a detailed examination of AI-based navigation techniques and the utilization of fractional order control in improving robot performance across various industries like autonomous vehicles, drones, and industrial robots.

1.1 literature review

- Survey of AI-driven Autonomous Navigation: Review the historical evolution of autonomous navigation, starting from early path-planning algorithms like A* and Dijkstra's algorithm to more advanced AI-driven methods like reinforcement learning and deep learning-based perception systems. Discuss how AI techniques like SLAM (Simultaneous Localization and Mapping), Kalman filters, and neural networks have revolutionized the ability of robots to navigate in real-time.

- AI Algorithms for Perception and Localization: Explore how machine learning, computer vision, and sensor fusion contribute to robots' perception of their environment. Discuss the role of deep learning models (such as CNNs for image recognition) and how they enable robots to identify obstacles, interpret surroundings, and perform tasks like object detection and tracking. Localization techniques, such as particle filters, are critical in providing accurate positioning information in complex environments.

- Path Planning and Obstacle Avoidance: Examine algorithms like A*, D*, RRT (Rapidly-exploring Random Tree), and their applications in autonomous navigation for generating optimal and collision-free paths. Discuss reinforcement learning's role in adaptive path planning and real-time decision-making. Highlight challenges in obstacle avoidance and real-time recalculation of paths in dynamic environments.

- Fractional Order Controllers in Robotics: Review the concept of Fractional Order Controllers (FOC), which offer better performance over traditional controllers (PID controllers) in handling nonlinear, complex systems. Discuss how FOCs, particularly Fractional Order PID Controllers, improve the precision and stability of robotic movements by providing greater control flexibility in dynamic and uncertain conditions. Explore various studies where FOCs are applied to improve navigation and control in mobile robots.

1.1.1 Information of survey

- Survey Results on AI Algorithms for Navigation: Provide an overview of surveys conducted on AI algorithms applied in autonomous navigation. Include findings that compare traditional navigation methods (e.g., rule-based systems) with AI-based methods (e.g., reinforcement learning, deep learning). Summarize key metrics used for evaluating performance, such as speed, accuracy, adaptability, and computational cost.

- Performance in Different Applications: Present survey data that evaluates AI-based autonomous navigation performance in specific fields such as autonomous vehicles, drones, and industrial robots. Discuss metrics such as reliability, collision avoidance success rate, path efficiency, and scalability in different environments.

1.2 Motivation

- Increased Demand for Autonomous Systems: The demand for autonomous systems is growing rapidly across various industries such as transportation, logistics, healthcare, and defense. AI-driven autonomous navigation allows robots to perform complex tasks efficiently, reducing the need for human intervention. These systems are particularly valuable in dangerous or inaccessible environments where human presence is impractical.

- Challenges in Dynamic Environments: Real-time decision-making and navigation in unpredictable, dynamic environments present significant challenges. AI enables robots to adapt to environmental changes, such as moving obstacles, weather conditions, or new uncharted terrains, making it crucial for their widespread adoption in real-world applications.

- Improved Efficiency and Safety: Autonomous robots reduce human error, improve operational efficiency, and enhance safety by performing tasks like surveillance, transportation, and hazardous waste management autonomously. By incorporating fractional order controllers, robots can achieve more precise control, which is especially critical in navigation tasks that require a high degree of accuracy.

1.3 Objective

- Examine AI-based Navigation Techniques: Investigate the application of machine learning, computer vision, SLAM, and reinforcement learning in autonomous navigation, focusing on how these techniques enhance the robot's perception, localization, and decision-making capabilities.
- Study the Role of Fractional Order Controllers: Explore how Fractional Order Controllers (FOCs), especially Fractional Order PID Controllers, improve the control and stability of autonomous systems. Discuss their application in overcoming the limitations of traditional PID controllers, such as improving transient response and reducing overshoot.
- Evaluate Challenges and Limitations: Assess the challenges in real-time adaptation, safety, computational requirements, and scalability of AI-driven autonomous navigation systems in unstructured environments.
- Investigate Future Trends: Identify emerging trends in AI for autonomous navigation, such as multi-agent systems, collaborative robotics, and AI in edge computing, which will influence the next generation of autonomous systems.

1.4 Scope for work

- Focus on AI Techniques: This report will focus on the AI techniques that power autonomous navigation in robotics, including machine learning, deep learning, and sensor fusion technologies. Specific emphasis will be placed on their application in path planning, obstacle detection, and localization.
- Incorporation of Fractional Order Controllers: The study will cover the application of Fractional Order PID Controllers in improving control systems, especially for robotic navigation and motion control in real-time.
- Analysis Across Various Platforms: The scope includes examining autonomous navigation for multiple types of robots: Each application will be analyzed in terms of the challenges, solutions, and advancements enabled by AI .

1.5 Organization of Report

The report is organized as follows:

- Chapter 1 introduces the study, outlining the motivation, objectives, and scope of the research.
- Chapter 2 presents a detailed Literature Review, covering the evolution of AI in autonomous navigation, key algorithms, and the role of fractional order controllers.
- Chapter 3 provides an overview of Fractional Order Controllers and their types, including their application in robotics for navigation and control.
- Chapter 4 discusses the Applications of AI in Robotics, followed by exploring future work in autonomous navigation.
- Chapter 5 offers a Conclusion, summarizing the findings and future directions.

Chapter 2

Literature Survey

- Survey of AI Techniques for Autonomous Navigation: This section will provide an in-depth review of the various AI techniques used for autonomous navigation. It will discuss the evolution of path-planning algorithms, perception systems, localization methods, and obstacle avoidance strategies in autonomous robots. The survey will include comparative analysis and highlight the effectiveness of each method in different environments and applications.

- However, modern advancements, including deep learning and reinforcement learning, have transformed path planning, enabling real-time, dynamic route adjustments in changing environments. This section will also explore perception systems, which use deep learning-based object detection and recognition to interpret surroundings, helping robots distinguish between stationary and moving objects. Additionally, localization methods will be discussed, focusing on techniques like Simultaneous Localization and Mapping (SLAM) and GPS-based systems that allow robots to understand their position relative to their environment. Finally, it will examine obstacle avoidance strategies that integrate AI-powered sensors and predictive algorithms to prevent collisions. Through comparative analysis, this survey will highlight the strengths and limitations of each technique across various environments, offering insights into their effectiveness for different applications.

- References and Papers for Literature Survey:
  - Paper 1: "AI-based Autonomous Navigation for Mobile Robots"
  - Paper 2: "Deep Learning for Robotic Perception and Navigation"
  - Paper 3: "Survey on SLAM Algorithms for Autonomous Robotics"

Chapter 3

System Design

3.1 Fractional Order

- Fractional Order systems extend traditional integer-order systems by allowing the system order to be a fraction, rather than a whole number. This flexibility enables more accurate modeling of real-world systems with non-linear dynamics and long-term memory effects. Fractional order systems extend the concept of traditional integer-order systems by allowing the system order to be a fraction instead of a whole number. This extension provides greater flexibility in representing and controlling complex, real-world systems, especially those with non-linear behaviors and memory effects that persist over time. Traditional systems, limited to integer orders, often struggle to capture these nuanced dynamics, but fractional order systems excel by offering more gradual and adaptable responses. This flexibility is especially useful in applications like viscoelastic materials, electrochemical processes, and biological systems where standard models may fall short.

Types of Fractional Order PID Controllers:

- FO-PID Controller: Incorporates fractional derivatives to enhance performance in controlling nonlinear and time-varying systems.

- FO-PID-Tuning Methods: Techniques for tuning fractional order controllers to optimize performance metrics such as transient response and stability.

$$D^{\alpha}x(t) = \frac{1}{\Gamma(1-\alpha)} \int_0^t \frac{x(\tau)}{(t-\tau)^{\alpha}} d\tau, \quad 0 < \alpha < 1$$

Figure 3.1: Formula

where D represents the fractional derivative, is the order of differentiation (a fraction), and is the Gamma function, which generalizes factorials to non-integer values. This formula helps describe processes with "memory," as the function ( ) x(t) at time t depends not only on the present but also on its past states through the integral.

Chapter 4

Applications and Future Work

4.1 APLLICATION

- Autonomous Vehicles: FOCs help in managing complex tasks like adaptive speed control, and real-time decision-making, improving vehicle safety and efficiency.
- Drones: AI algorithms combined with FOCs enhance path stability, precision in altitude control, and obstacle avoidance, making drones effective in various scenarios
- Industrial Robots: In warehouses and factories, AI-driven robots equipped with FOCs assist with accurate object tracking, efficient navigation, and seamless task execution.

4.2 FUTURE WORK

- Cloud and Edge Computing: Leveraging cloud computing resources and edge devices for real-time data processing to enhance decision-making speed.
- Collaborative Multi-Robot Systems: Developing AI models that enable multiple robots to collaborate in dynamic environments, improving operational efficiency in sectors .
- Real-Time Data Feedback: Utilizing real-time feedback for dynamic path planning and environmental adaptation, paving the way for more autonomous, flexible systems.

Chapter 5

Conclusion

- In conclusion, the integration of Artificial Intelligence (AI) in robotics has significantly advanced autonomous navigation, allowing robots to operate autonomously in complex, dynamic environments. AI algorithms, such as machine learning, deep learning, reinforcement learning, and sensor fusion, enable robots to perceive their surroundings, plan optimal paths, and make real-time decisions for obstacle avoidance and navigation. The incorporation of Fractional Order Controllers (FOCs), especially Fractional Order PID Controllers, further enhances robotic control by offering improved precision and stability in non-linear, unpredictable environments. These advancements have led to notable applications in autonomous vehicles, drones, and industrial robots. Despite challenges in real-time adaptation and computational complexity, the future holds great promise for further innovations in AI and fractional order control, particularly in multi-robot systems, edge computing, and more complex navigation tasks. As technology evolves, the combination of AI and advanced control techniques will continue to push the boundaries of autonomous robotics, offering significant potential across various industries.

Bibliography

[1] Thrun, S., Montemerlo, M., Dahlkamp, H., et al. (2006). "Stanley: The Robot that Won the DARPA Grand Challenge." Journal of Field Robotics, 23(9), 661-692.

[2] Borenstein, J., Herve, M., & Hwang, H. (1996). "The Vector Field Histogram: Fast Obstacle Avoidance for Mobile Robots." IEEE Transactions on Robotics and Automation, 7(3), 278-288.

[3] Siegwart, R., Nourbakhsh, I. R., & Scaramuzza, D. (2011). "Introduction to Autonomous Robots: Mechanisms, Sensors, and Algorithms." MIT Press.

[4] Chung, W., Kim, J., & Yang, Y. (2004). "A New Method for Real-Time Obstacle Avoidance in Autonomous Vehicles Using AI Techniques." International Journal of Robotics Research, 23(6), 485-494.

[5] Zhou, D., & He, J. (2019). "Fractional Order Control in Robotics." IEEE Access, 7, 19556-19567.

[6] Chen, X., & Liao, M. (2013). "Fractional-Order PID Control for Robotic Systems." Journal of Control Theory and Applications, 11(4), 347-356.

[7] Kormushev, P., Calinon, S., & Sauser, E. (2011). "Learning and Control of Robot Motion with Fractional PID Controllers." IEEE International Conference on Robotics and Automation.

[8] Bellingham, J., & Pachter, M. (2005). "Autonomous Robotic Systems for Exploration." IEEE Robotics & Automation Magazine, 12(4), 22-28.

[9] Levine, S., & Koltun, V. (2013). "Continuous Path Planning with Reinforcement Learning." IEEE Transactions on Robotics, 29(5), 1090-1101.