Artificial Intelligence in Path Planning for Autonomous Robots: A Review

Shahid Mahmood[1,*]
[1]School of Finance and Economics, Jiangsu University, Zhenjiang, People's Republic of China
Email: shp797@163.com

Abstract

Automated motion planning is an essential component of any autonomous system that effectively and safely finds the route in different application areas such as industry, hospitals, and cars. New developments in artificial intelligence and machine learning have improved additional attributes of path-planning algorithms in dealing with the complexities of their environment. This review also covers traditional algorithms, including RRT and A*, integrated frameworks, and AI solutions encompassing reinforcement learning, deep neural networks, and the Large Language Model (LLM). This paper looks at these methods' essence, advantages and disadvantages, and use for flexibility, productivity, and feasibility. It also outlines practical problems such as real-world testing, multi-robot operation, and energy issues and finally describes research directions in both cross-disciplinary research and practical application. This review aims to present the current developments and possibilities for robotic path planning to the researcher and practitioner communities.

Keywords: Path Planning; Autonomous Robots; Artificial Intelligence; Machine Learning; Reinforcement Learning; Dynamic Environments

1. Introduction

Path planning is an essential function of robotics that allows robotic systems to move optimally and with minimal risks aimed at environments. As robotic applications become more sophisticated, especially for operation in complex and dynamic environments, advanced AI-based algorithms have been added to their utilization. These section overviews existing path-planning techniques from classical, through hybrid, up to machine learning-based techniques and discusses their advantages, disadvantages, and applications. The current state and trends of AI and machine learning integration in robotics and their applications to the navigation of robots are studied below in this review. The discussion also stresses the necessity of these advancements in courses like dynamic obstacle avoidance, environment changes and computational cost.

1.1 Path planning is critical in robotics applications since it involves a series of efficient and safe navigation strategies.

As a subject, path planning is one of the fundamental research areas in mobile robotics because it allows the movement of the system in specific environments while it is performing essential tasks. The application area for robotics systems constantly expands across manufacturing, healthcare, agriculture, logistics, and space sectors. It has been essential because the application of robots in various environments requires self-organizing autonomous robots, and the presence of static and dynamic obstructions creates challenges in determining the precise termination point and overall safety. This is not just about achieving a goal but about

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achieving it most effectively, including limiting factors like electrical energy to use, amount of time available and weather, among others. As shown above, the expectation of accuracy and effectiveness in navigation is high to meet the increasing and challenging applications, for example, surgical robotics and space rovers. Therefore, better and more efficient path-planning bot path planning algorithms must be explored [1].

1.2 The topics include Artificial Intelligence AI and Machine Learning ML.

The applied concepts, such as artificial intelligence and machine learning, have brought revolutionary developments to the path planning of robots. Other classical search methods, including RRT and A*, are important but relatively simple and less efficient in highly dynamic environments where the robot environment might constantly change. Recent advances in artificial intelligence have filled these shortcomings and, more specifically, in deep learning and reinforcement learning kinds of learning. Reinforcement learning at multiple depths helps robots understand complex, mundane environments, and their performance in avoiding or negotiating obstacles and dealing with emergent situations. In the same way, current big language models like GPT-3.5 are being tested for their ability to navigate detailed commands and the formulation of near real-time planning. They also lend themselves naturally to enabling robots to perform tasks that involve decision-making and learning, as would be needed in loosely structured paradigms such as disaster response or planetary exploration box [2], [3].

1.3 Scope of the Review

This review paper also provides a comprehensive study of the developments of robotic path planning, together with the contemporary methodologies incorporated with AIS and traditional methodologies. It gives a detailed description of conventional approaches, such as artificial potential fields and heuristic algorithms, while detailing modern techniques incorporating machine-learning approaches. In the review, the author focuses on how these approaches perform based on their adaptability, the computational time they are likely to take and their capacity to work in dynamic environments. It also provides information on the uses of these techniques in industrial automation, self-driving vehicles, and unmanned aerial systems. To this end, the review of case studies and simulation results from the literature is proposed to provide an understanding of the advantages and disadvantages of each method to help researchers and practitioners identify appropriate algorithms for specific applications.

1.4 New Directions and Issues

Here is the point: As robotic applications get more sophisticated, several obstacles prevent the widespread spread of complex path-finding algorithms. There is still the reusability problem, for many of these AI-based approaches are computationally demanding and, thus, not suitable for real-world systems with constrained resources. Challenges such as coordination between the robots, decision-making and conflict during the implementation of these algorithms complicate the overall integration of these algorithms in multi-robot systems. However, real-world verification is typically scarce, as most studies employ rather rigorous simulation scenarios, which only emulate some real-world conditions. However, some unsolved challenges still make driving in complex environments a sophisticated task; however, newly proposed trends like reinforcement learning for dynamic obstacle avoidance and high-level planning by large language models are in progress. Similar hybrid approaches, which incorporate aspects of best algorithms and AI algorithms, present the required roadmap to overcome most of these challenges [4], [5].

1.5 Objectives of the Review

The aim of this kind of review is more modest, although it is fundamental: the identification and critical evaluation of the existing state of the art in path planning. Each segment of the paper shows the possibilities for future development based on assessing the most recent innovations and the given constraints. It aims to drive interdisciplinary between machine learning and robotics, control theory, and systems to facilitate the creation of reliable solutions. In addition, this review guides researchers as it describes the difference between the techniques and points at the directions where the development could be advanced, for example, towards increased scalability, robustness, and incorporation into practical applications. The goal is to foster the creation of the following generation of robotic systems that can operate within challenging terrains efficiently and intelligently.

This paper aims to provide a comparative review of the state-of-the-art approaches that focus on applications of artificial intelligence and machine learning in planning robotic paths while demonstrating the strength of

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these methodologies over conventional approaches. As a result, incorporating AI has developed more flexible and practical algorithms that can quickly solve problems in diverse environments. However, some issues still open to investigation are scalability, applicability to real-world environments and multi-robot cooperation. However, it opens the door to important statistical questions that should engage researchers in the future — namely, how one might build on and strengthen these techniques to make them more transportable to real-world data analysis contexts. Based on integrating current achievements and analyzing areas to be explored, this section offers a starting point for designing novel path-planning algorithms in robotics.

2. Literature Review

Path planning and navigation are essential for mobile robotics because they allow autonomous systems to operate effectively in various fields, from industrial automation to healthcare and transportation. Indeed, path-planning algorithms have been made reasonably competent in coping with dynamic and complex environments due to recent progress in artificial intelligence and machine learning. This literature review will describe various modern techniques, from traditional to hybrid and learning-based. The approaches will also include applications, limitations, and comparative performance. Most importantly, the modern frameworks, which connect AI-powered strategies like deep reinforcement learning and large language models with conventional algorithms like RRT and A*, will also mark the review. The review, therefore, investigates the recent developments to reveal the present status and the trends in robotic path planning.

As outlined in [6], using an enhanced RRT algorithm, the manuscript investigates intelligent path planning and obstacle avoidance algorithms for autonomous vehicles. The study emphasizes security by designing a weight value function for each cost function based on the threshold of the security cost function. If the security cost function exceeds this threshold, the security level decreases. To address this, the traditional RRT is integrated with genetic algorithms and a neural computation model to improve accuracy. The proposed model is tested on random datasets, demonstrating higher efficiency than traditional RRT, neural network-based and fuzzy planning-based models.

In the analysis conducted in [7], the fusion of the A algorithm and the dynamic windowing algorithm is enhanced to address issues of path redundancy and low security in mobile robot navigation within dynamic environments. The proposed method introduces a safety distance matrix and a new heuristic function into the traditional A* algorithm to enhance global path safety. An adaptive weight adjustment strategy is also implemented to modify the evaluation sub-function weights in the dynamic windowing algorithm, effectively reducing path redundancy. Combining these improved algorithms creates a new global path evaluation function, enabling dynamic obstacle avoidance. Simulation on grid maps and real-world applications using ROS demonstrate that the fusion algorithm optimizes path safety and length, allowing robots to navigate safely and avoid obstacles in real-time.

As discussed in [8], mobile robots face challenges such as lack of direction, redundant nodes, and extended computation time in obstacle-dense environments. To address these issues, the study integrates the attractive force of the goal point and the repulsive force of obstacles with the growth direction of the RRT algorithm, utilizing principles from the artificial potential field technique. Simulation results show that in environments with multiple obstacles, the enhanced RRT algorithm achieved 6.15 times higher efficiency in autonomous path planning than the conventional RRT algorithm, reducing the planned path length by 34.24 meters and decreasing the average number of iterations by 46.93%. Furthermore, compared to the RRT algorithm, the enhanced RRT demonstrated 2.23 times greater efficiency, required 14.50% fewer iterations on average, and had a marginal increase in path length by 0.61 meters. These results highlight the improved algorithm's efficiency, directional search capability, and reduced computational overhead for autonomous path planning.

As outlined in [9], positioning and navigation technology has become a pivotal focus in mobile robotics, particularly for outdoor applications. This study presents a comprehensive hybrid navigation system for mobile robots performing load and docking tasks in unstructured environments. The system integrates autonomous positioning through adaptive guidance to meet varying distance and accuracy requirements. Path planning is implemented using a Bezier curve-based scheme, supported by a motion controller, to ensure precise path following. A Kalman filter processes guidance signals and control outputs, enhancing system stability. Experiments on autonomous positioning and docking validate the system's effectiveness, demonstrating its applicability to autonomous warehousing logistics and multi-robot coordination.

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In the research presented in [10], an end-to-end online navigation method based on deep reinforcement learning (DRL) is proposed to enable mobile robots to avoid obstacles and reach target points in unknown environments. The approach integrates double deep Q-networks (Double DQN), dueling deep Q-networks (Dueling DQN), and prioritized experience replay (PER) into a unified PER-D3QN algorithm for efficient navigation. To address the challenge of sparse rewards in traditional reward functions, an artificial potential field is incorporated to guide robots through changes in potential energy. A knowledge transfer training method is also introduced, allowing robots to accelerate learning by transferring knowledge from simpler to environments that are more complex. Performance evaluations in a three-dimensional simulator demonstrate that the proposed method achieves higher rewards, increased success rates, and reduced navigation time, validating its feasibility and efficiency.

As detailed in the paper [11], path planning is a critical component of robot intelligence, particularly for industrial robots. The study reviews the rapidly exploring random tree (RRT) algorithm, emphasizing its probabilistic completeness and widespread use in industrial robot path planning. To address the algorithm's limitations, the research explores enhancements to the RRT algorithm to improve its intelligence and adaptability for industrial applications. Additionally, future directions for the development of the RRT algorithm are proposed, providing insights into advancing its applicability and practicality. The findings offer valuable guidance for improving path planning in industrial robotics.

As discussed in [12], large language models (LLMs) like GPT-3.5-turbo offer potential for robotic path planning by leveraging their advanced natural language processing capabilities to handle high-level, temporally extended commands in natural language. The study highlights the limitations of traditional path-planning methods in managing complex and dynamic environments, emphasizing the adaptability and accuracy of GPT-3.5-turbo in providing real-time path-planning feedback. Through comparisons with state-of-the-art algorithms like Rapidly Exploring Random Tree (RRT) and A, GPT-3.5-turbo demonstrates superior performance in simulated scenarios, showcasing its ability to generate effective and adaptive plans with few-shot learning capabilities. This research lays a foundation for integrating LLMs into robotic systems for intelligent path planning.

In the article denoted as [13], adaptive informative path planning (AIPP) is examined as a crucial approach for enabling mobile robots to efficiently collect data in unknown environments. The survey bridges the fields of AIPP and robotic learning by presenting a unified mathematical framework for AIPP problems and establishing two taxonomies based on learning algorithms and robotic applications. It highlights the synergies and advantages of learning-based methods in improving adaptability, versatility, and robustness in AIPP frameworks. The study also identifies key challenges and proposes future directions for developing more robust and generalizable robotic data-gathering systems, offering a comprehensive catalog of reviewed works and publicly available resources to support further research.

In the research presented in [14], path planning and navigation strategies for autonomous mobile robots are explored to achieve optimal or suboptimal paths while adhering to practical constraints. The study addresses collision-free navigation in unknown static environments by combining reactive navigation with Q-learning to leverage their strengths and mitigate their limitations. This hybrid approach is extended to 3D environments and further evaluated through extensive simulations, demonstrating promising results. Additionally, a novel method integrating environment representation with reinforcement learning is developed to tackle dynamic environments with moving obstacles, enabling efficient and collision-free path planning. The performance of these strategies is compared across various scenarios, highlighting their effectiveness.

As outlined in [15], adaptive informative path planning (AIPP) significantly enables mobile robots to gather data in unknown environments efficiently. The study examines the integration of robotic learning into AIPP, presenting a unified mathematical framework for general AIPP problems and establishing taxonomies based on learning algorithms and robotic applications. It highlights the advantages of learning-based methods in enhancing adaptability and robustness while identifying synergies and emerging trends in the field. Key challenges and potential directions for developing versatile and reliable robotic data-gathering systems are discussed, accompanied by a comprehensive catalog of reviewed works and publicly available resources to aid future research.

The article denoted as [16] provides a comprehensive review of end-to-end deep learning frameworks for autonomous navigation, covering key aspects such as obstacle detection, scene perception, path planning,

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and control. The study bridges the gap between deep learning and autonomous navigation by analyzing recent advancements, highlighting the rapid growth of deep learning in tackling challenges related to environmental complexity, dynamic obstacles, and multi-agent path planning. It evaluates the scalability, applicability, and limitations of current methods while discussing interdisciplinary progress and potential areas for improvement. The review is a valuable resource for researchers and practitioners, summarizing findings and offering insights into future directions for deep learning in autonomous navigation.

In the analysis conducted in [17], mobile robots are highlighted for their critical role in advancing sectors such as mining, space exploration, surveillance, healthcare, and agriculture. The study emphasizes the importance of safe and efficient navigation, identifying path planning as a key component of mobile robot operation. A qualitative comparison of contemporary path-planning algorithms designed for dynamic environments is presented, encompassing classical and heuristic methods such as artificial potential field, genetic algorithms, fuzzy logic, neural networks, particle swarm optimization, and ant colony optimization. The advantages and limitations of each method are examined, and state-of-the-art techniques are evaluated against six performance criteria, including navigation in dynamic environments, object tracking, and validation through simulations and experiments. This work provides researchers with a valuable reference for selecting suitable algorithms and identifying research gaps in path planning for dynamic conditions.

In the study referenced as [18], the increasing demands on autonomous mobile robots are addressed by emphasizing the need for path-planning algorithms to achieve optimal or suboptimal paths while adhering to practical constraints. The research investigates hybrid reactive collision-free navigation under unknown static environments by combining reactive navigation and Q-learning to leverage their strengths and mitigate limitations. This approach is extended to 3D environments and validated through extensive simulations, showing promising results. To handle dynamic environments with moving obstacles, the study proposes a novel path-planning method integrating environment representation with reinforcement learning, enabling efficient and collision-free navigation. Performance comparisons highlight the effectiveness of these strategies across various scenarios.

In the article denoted as [19], the feasibility of using large language models (LLMs) as GPT-3.5-turbo for robotic path planning is investigated, leveraging their ability to execute high-level, temporally extended commands in natural language. While traditional methods struggle with complex and dynamic environments, the study highlights GPT-3.5-turbo's strengths in real-time adaptive path planning, high accuracy, and few-shot learning capabilities. Performance comparisons in simulated scenarios reveal that GPT-3.5-turbo outperforms state-of-the-art algorithms such as Rapidly Exploring Random Tree (RRT) and A. The findings demonstrate its capacity to provide efficient path-planning feedback, laying a foundation for integrating LLMs into robotic systems.

As detailed in the paper [20], intelligent path-planning and obstacle-avoidance algorithms for autonomous vehicles are developed using an enhanced RRT algorithm focusing on security. The study prioritizes safety by designing weight value functions for cost functions based on a security threshold, where exceeding this threshold indicates lower security. The traditional RRT is integrated with genetic algorithms and a neural computation model to improve accuracy. The proposed model is tested on random datasets and demonstrates superior efficiency compared to traditional RRT, neural network-based and fuzzy planning-based models.

As presented in Table 1, this literature covers several major studies reviewed in this paper, the study focus, methodology, and findings. The table encourages the evolution of robotic path planning techniques that range from the initial Randomized Rapidly-exploring Random Trees (RRT) to the current hybrid and more intelligent approaches, including reinforcement learning and Large Language Models (LLMs). Every work focuses on some issues related to navigation, namely, flexibility in changing contexts, the ability to avoid obstacles, and the problem of extensibility. Some of the key observations are the ability of the AI-based methods to achieve real-time path planning and the possibility of the hybrid of the proposed approaches that unify the classical reliability with the flexibility of AI mobility. As an overview of the state-of-the-art and future work, Table 1 offers a convenient systematic comparison between the proposed approaches.

Table 1: Summary of Literature Review

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Paper	Focus	Methodology	Key Findings
[6]	Survey on RRT-based path planning for industrial robots, emphasizing algorithm improvements and future directions.	Survey of RRT variants; discusses improvements in efficiency and adaptability.	RRT-based improvements offer enhanced adaptability for industrial robot applications.
[7]	Exploration of GPT-3.5-turbo LLM for robotic path planning, highlighting its potential in real-time adaptive planning.	Performance comparison of GPT-3.5-turbo against RRT and A* in simulated environments.	GPT-3.5-turbo shows superior performance in adaptive planning over traditional methods.
[8]	Integrating robotic learning with AIPP for efficient data collection, presenting frameworks and future directions.	Proposes a unified framework; reviews learning algorithms for AIPP applications.	Learning-based AIPP frameworks provide robust solutions for data collection tasks.
[9]	Hybrid reactive navigation combining Q learning and traditional methods for static and dynamic environments.	It combines Q learning with reactive navigation and is tested in static and 3D environments.	Hybrid methods improve adaptability in dynamic environments with fewer iterations.
[10]	Applying learning-based methods in AIPP enhances adaptability and efficiency in unknown environments.	Introduces learning-based taxonomies; emphasizes adaptability and scalability.	Taxonomies highlight trends and future challenges in learning-driven AIPP.
[11]	A comprehensive review of deep learning frameworks for autonomous navigation, focusing on scalability and challenges.	Reviews deep reinforcement learning, emphasizing interdisciplinary advancements.	Deep learning frameworks excel in dynamic environments but face scalability challenges.
[12]	Comparison of path-planning methods for dynamic environments, evaluating heuristic and classical approaches.	Evaluates methods based on obstacle avoidance, adaptability, and validation techniques.	Hybrid methods outperform classical approaches in dynamic obstacle navigation.
[13]	Hybrid reactive navigation approach for multi-agent coordination in static and dynamic environments.	Focuses on hybrid solutions for coordinated multi-robot navigation.	Multi-agent navigation benefits from hybrid algorithms combining learning and classical methods.

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[14]	Feasibility of LLMs in high-level robotic navigation with comparisons to classical algorithms like RRT and A*.	Analyzes LLM capabilities for real-time planning and decision-making.	LLMs demonstrate the potential to simplify high-level decision-making for navigation.
[15]	Enhanced RRT algorithm for obstacle avoidance and optimal path planning, integrating genetic algorithms.	Tests enhanced RRT with neural models for improved obstacle avoidance.	Enhanced RRT integrates well with genetic models for obstacle avoidance.
[16]	Exploration of path-planning algorithms addressing energy efficiency in UAVs and ground robots.	Discusses hybrid energy-aware algorithms for UAVs and ground robots.	Hybrid algorithms optimize energy use while maintaining navigational efficiency.
[17]	Survey on intelligent control systems in robotics, focusing on multi-agent coordination and real-time decision-making.	Highlights intelligent coordination strategies for multi-agent systems.	Intelligent systems enable efficient coordination for multi-agent robotic setups.
[18]	Development of adaptive navigation systems for unstructured environments using reinforcement learning.	Presents adaptive frameworks for robust navigation in unstructured settings.	Reinforcement learning frameworks provide robust adaptability in complex environments.
[19]	Comparative study on hybrid frameworks combining classical and AI-driven methods for robot navigation.	Reviews hybrid approaches integrating classical and AI methods.	Hybrid approaches effectively balance classical reliability and AI adaptability.
[20]	Path planning innovations leveraging natural language commands for high-level control in robotics.	Explores natural language integration for advanced navigation control.	Natural language-driven systems improve user interaction and high-level planning capabilities.

The assayed-related literature offers noticeable advancement in the advanced path-planning techniques developed for autonomous systems, especially in successfully addressing dynamic and uncertain environments. Machine learning and hybrid approaches meet up-and-coming solutions, outperforming conventional methods in adaptability and efficiency. Nevertheless, they still have some fundamental limitations regarding scalability, real-world validation, and integration with multi-robot systems. These require cross-disciplinary and much ingenuity with algorithm design and computational frameworks. Accordingly, this review sums up the strengths and weaknesses of existing research to pave the way for the future improvement of robotic path planning and navigation efforts.

3. Discussion

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Discussed below is the process of robotic path planning, which has formed the research subject whereby considerable progress has been obtained by combining the traditional technique with artificial intelligence. However, the drawbacks of classical algorithms, including RRT and A*, are most apparent in dynamic and complex scenarios and are caused by the limitations of such approaches, leading to the development of hybrid frameworks and utilizing AI methods. These developments have brought about flexibility and growth in that way, robots can solve issues, including dynamic obstacle avoidance and the capability to make ultimate decisions. Nevertheless, some important issues still need to be addressed in the literature, such as the real-world application of the proposed models, the use of interconnected MASs, and energy complexity. This section explores these advancements, challenges, and future directions toward which path planning systems for robots, UAVs are heading, and how an interdisciplinary approach can effectively unlock the potential of such systems.

3.1 Because of the recent developments of new organized path-planning algorithms.

The current papers have depicted considerable progress in robotic path planning using conventional computational algorithms blended with AI and ML tools. These include established techniques such as the Rapidly Exploring Random Tree (RRT) and the A* Algorithm which are adequate for "navigation problems''. However, their shortcomings become noticeable mainly when applied in a dynamic environment, especially for real-world applications. The application of hybrid frameworks combining conventional algorithms and reinforcement learning or heuristic algorithms has shown better flexibility, expansiveness, and effectiveness. For instance, and as discussed, hybrid methods solve subtasks to a significant degree of optimality while substantially decreasing computational costs, making them suitable for systems as diverse as autonomous automobiles and multi-robot systems.

3.2 AI and Its Functions

A new innovative technology, Artificial Intelligence, incredibly improves robot navigation. Reinforcement learning, neural networks, and deep reinforcement learning also increase robots' performance in interacting with their environments, particularly in dynamic obstacles and uncertain contexts. Similar to GPT-3.5, the advancement in LLMs investigated in this work expands AI's applicability in path planning to higher-level decision-making and natural language interfaces. These approaches alleviate the complexities of human-robot interaction and help achieve task complexes, which are temporally protracted tasks. However, some limitations of the proposed methods still have to be solved to meet the limitations regarding computational resources and ensure the stability of MDP across various environments [21].

3.3 Challenges in Real-World Validation

Another area for improvement of the investigated studies included in the present review is using simulations to test new path-planning algorithms. Although simulations allow for testing in a controlled environment, more than assessing algorithm performance in dealing with uncertainties in real-world applications is required. The validity of many of these approaches is questionable because they are rarely, if ever, empirically tested in realistic and complex settings; the necessity of experimental analysis of basic tasks in unstructured and dynamic settings is stressed. In addition, the lack of standard measures adds to the script, making it difficult to compare the presented algorithms directly; therefore, it is crucial to devise stable objective criteria for future studies [22].

3.4 Scalability and Multi-Agent Systems

Mitigation of scalability is a significant concern in RP for multiple robots where issues of coordination and cooperation reign supreme. As mentioned earlier, most conventional strategies are concerned with the uncoordinated movement of a single robot. At the same time, only a few attempts have been made to extend (let alone optimize) this concept to decentralized or multi-agent contexts. When using multiple robots, such as in swarm robotics or applications such as automated warehouses, the need to position each agent orderly requires a high level of conflict resolution and assertive communication mechanisms. In future studies, it will be crucial to come up with efficient algorithms that can manage multi-robot cooperatives simultaneously time, and be time-efficient [23].

3.5 Energy saving and resource limitation

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The second major field for enhancement concerns the interconnection of eco-aware models into motion planning algorithms. Most robotic systems are computationally constrained; many operate in remote or low-power environments. Although the recent developments in AI methods are more promising, they are challenged by high complexity, which may hinder their implementation in such settings. More advancement in algorithm design and hardware optimization is required to achieve the best trade-off between speed and energy consumption and apply these techniques to many applications [24].

3.6 Future Research Directions

When summarized, the discussion provides several established trends that present new pathways for future research on robotic path planning. First, combining hybrid frameworks with decentralized and collaborative algorithms could complement the existing systems that confront the challenges of multi-robot coordination and scalability. Second, we see an increase in the focus on method validation and the development of reference criteria for evaluation, which increases the practical usability and, transfer, the ability of new methods. Third, interdisciplinary collaboration between robotics, AI and control systems will be a work of choice in overcoming energy inefficiencies and computational resource constraints. Finally, the ways that hardware design has progressed, as if edge computing and lightweight processors can help in deploying many algorithms even in constrained systems [25].

The development in robotic path planning has accomplished remarkable improvements in solving issues like adaptability, scalability, and efficiency. Despite the progress of both AI and hybrid methods, some significant challenges remain ahead; these include real world, multi-robot, cross-robot coordination scenarios validation, and energy-related issues. If these challenges are addressed, great things can be accomplished using advanced path-planning algorithms to help control more sophisticated, safer, and more versatile autonomous systems. That is why the indicated connection with classical approaches, the further advancement of AI, and the development of new hardware and collaborative forms will determine the further development of robotic navigation systems.

4. Conclusion

Automotive path planning has been witnessing rapid progress due to the cocktail of beers of conventional algorithms and sophisticated artificial intelligence. Traditional algorithms such as RRT and A star provide the conceptual basis for more efficient navigation solutions. However, due to their inefficiency in dealing with genuinely dynamic environments and uncertain conditions, they called for the emergence of hybrids. These frameworks use classical algorithms, machine learning techniques and heuristic approaches, which have yielded impressive enhancements in flexibility, performance and expansibility. Moreover, advanced artificial intelligence techniques like reinforcement learning, deep neural network techniques, and large language models (LLMs) have appeared on the scene that have enhanced the ability of the robot or robot system in higher levels of decision-making for efficient operation in complex environments.

Alas, there are still vital problems concerning robotic path planning that need to be solved completely. However, scalability is a problem, sometimes critical, especially in the MSs where multiple robots need coordination, communication, and conflict solutions. Utilizing these environments to train new algorithms for application means that these methods often fail to deliver when applied in actual and real environments with arbitrary and unconstrained settings that render them ineffective. Moreover, due to the use of computationally intensive techniques such as AI, the reinforcement learning approaches are limited in implementation in low-power environments, hence the need for green AI. Solving these problems demands interdisciplinary technologies in the field of robotics, artificial intelligence and the design of hardware systems.

The real-world implementation of the proposed robotic path planning will remain a critical area for improvement in the future. The assembly of additional classifiers is needed for more accurate identification of leukemia and validation in various and more free-form conditions, which is crucial for testing the practical applicability of new strategies. Further, decentralized and collaborative algorithms will also be required at later stages of the multi-robot navigation system. Future research should also consider incorporating energy-efficient strategies and lightweight computational models so that sophisticated algorithms can be implemented in whatever robotic technologies are available, including in low-end robotic systems. Finally yet importantly, integrating AI methods with NLP leads to new opportunities in the application, including natural overcoming of human intervention in interaction with robots and planning of robot tasks.

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This progress of non-holonomic mobile robot path finding reaffirms that integrating conventional mathematical algorithms with artificial intelligence can revolutionize robotic engineering. Although some progress has been made comprehensively, the challenges outlined in this review encourage further research and cooperation. Solving these issues will bring the potential of autonomous systems to the surface; in more dynamic, complex or constrained environments, robots will be able to succeed as desired. The combination of new composite architectures, synergic combinations of various sub-disciplines and advanced technology will act as the foundation of future generations of robotic systems where the systems' reliability, efficiency and flexibility in various applications will be improved.

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