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REVIEW ARTICLE

# Artificial Intelligence in Path Planning for Autonomous Robots: A Review

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## 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 covers traditional algorithms, including RRT and A*, integrated frameworks, and AI solutions encompassing reinforcement learning, deep neural networks, and Large Language Models (LLMs). 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 cross-disciplinary research and practical application. This review aims to present current developments and possibilities for robotic path planning to 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 in their operating environments. As robotic applications become more sophisticated, especially in complex and dynamic environments, advanced AI-based algorithms have increasingly been added to navigation systems. This review overviews existing path-planning techniques from classical, through hybrid, 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 robot navigation, are studied in this review. The discussion also stresses the necessity of these advancements for dynamic obstacle avoidance, environmental change, and computational cost.

### 1.1 Path Planning in Robotics Applications

Path planning is one of the fundamental research areas in mobile robotics because it allows a system to move through specific environments while performing essential tasks. The application area for robotic systems is constantly expanding across manufacturing, healthcare, agriculture, logistics, and space sectors. This expansion has made autonomous and self-organizing robots essential, while static and dynamic obstructions create challenges in determining precise termination points and maintaining safety. Path planning is not only about achieving a goal, but about achieving it effectively while considering limiting factors such as electrical energy use, available time, and weather. The expectation of accuracy and effectiveness in navigation is high in challenging applications such as surgical robotics and space rovers; therefore, better and more efficient path-planning algorithms must be explored [1].

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### 1.2 Artificial Intelligence and Machine Learning

Artificial intelligence and machine learning have brought revolutionary developments to robot path planning. Classical search methods, including RRT and A*, remain important but can be less efficient in highly dynamic environments where the robot environment changes constantly. Recent advances in artificial intelligence, especially deep learning and reinforcement learning, have addressed these shortcomings. Reinforcement learning helps robots understand complex environments and improve obstacle avoidance and negotiation. Current large language models, such as GPT-3.5, are also being tested for their ability to process detailed commands and formulate near real-time plans. These capabilities enable robots to perform tasks that involve decision-making and learning in loosely structured paradigms such as disaster response or planetary exploration [2, 3].

### 1.3 Scope of the Review

This review provides a comprehensive study of developments in robotic path planning together with contemporary AI-based methodologies and traditional methodologies. It describes conventional approaches such as artificial potential fields and heuristic algorithms, while detailing modern techniques incorporating machine-learning approaches. The review focuses on adaptability, expected computational time, and the capacity of these approaches to handle real-world uncertainty. It also considers issues such as scalability, validation in real environments, multi-robot operation, energy consumption, and resource limitations.

### 1.4 New Directions and Issues

The increasing capability of robotics systems has created new research directions in hybrid planning, learning-based planning, and natural-language-guided planning. AI-enhanced models offer flexibility, improved response to dynamic changes, and better decision-making under uncertainty. However, these benefits introduce challenges in verification, interpretability, computational cost, and transfer from simulation to physical systems. These issues are central when robots operate in safety-critical settings.

### 1.5 Objectives of the Review

The objective of this paper is to provide a comparative review of state-of-the-art approaches that apply artificial intelligence and machine learning to robotic path planning while demonstrating their strengths over conventional approaches. The review identifies research gaps in scalability, real-world applicability, multi-robot cooperation, energy efficiency, and robust validation. By integrating current achievements and analyzing areas to be explored, the paper 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 fields ranging from industrial automation to healthcare and transportation. Recent progress in artificial intelligence and machine learning has made path-planning algorithms increasingly capable of coping with dynamic and complex environments. This literature review describes modern techniques from traditional to hybrid and learning-based approaches, including applications, limitations, and comparative performance.

Ren et al. [6] investigated intelligent path planning and obstacle avoidance for autonomous vehicles using an enhanced RRT algorithm. The study emphasized security by designing a weight value function for each cost function based on a security threshold. If the security cost function exceeds this threshold, the security level decreases. To address this, traditional RRT was integrated with genetic algorithms and a neural computation model to improve accuracy. Tests on random datasets showed higher efficiency than traditional RRT, neural-network-based, and fuzzy-planning-based models.

Zhai et al. [7] enhanced the fusion of the A* algorithm and the dynamic window algorithm to address path redundancy and low security in mobile robot navigation in dynamic environments. The proposed method introduced a safety distance matrix and a new heuristic function into traditional A* to enhance global path safety. An adaptive weight adjustment strategy was implemented to modify evaluation sub-function weights in the dynamic window algorithm, reducing path redundancy and enabling dynamic obstacle avoidance. Simulations on grid maps and real-world applications using ROS showed improved path safety and length.

Du et al. [8] addressed the lack of direction, redundant nodes, and long computation time faced by mobile robots in obstacle-dense environments. The study integrated attractive force from the goal point and repulsive force from obstacles with the growth direction of RRT using artificial potential field principles. Simulations showed that, in multiple-obstacle environments, the enhanced RRT achieved substantially higher efficiency in autonomous path planning, reduced planned path length, and decreased the average number of iterations.

Shentu et al. [9] presented a hybrid navigation system for mobile robots performing load and docking tasks in unstructured environments. The system integrated autonomous positioning through adaptive guidance to meet varying distance and accuracy requirements. Path planning used a Bezier-curve-based scheme supported by a motion controller, while a Kalman filter processed guidance signals and control outputs to improve stability. Experiments on autonomous positioning and docking validated the system's applicability to warehousing logistics and multi-robot coordination.

Li et al. [10] proposed an end-to-end online navigation method based on deep reinforcement learning to enable mobile robots to avoid obstacles and reach target points in unknown environments. The approach integrated Double DQN, Dueling DQN, and prioritized experience replay into a PER-D3QN algorithm. To address sparse rewards, an artificial potential field was incorporated to guide robots through changes in potential energy. A knowledge-transfer training method accelerated learning by transferring knowledge from simpler to more complex environments.

Luo et al. [11] reviewed RRT-based path planning for industrial robots. The study emphasized probabilistic completeness and the widespread use of RRT in industrial robot path planning. It also explored enhancements that improve intelligence and adaptability for industrial applications, while proposing future directions for advancing RRT applicability and practi-

cality.

Latif [3] discussed the use of large language models, such as GPT-3.5-turbo, for robotic path planning. LLMs can handle high-level, temporally extended commands in natural language and provide real-time path-planning feedback. Comparisons with methods such as RRT and A* in simulated scenarios indicated that GPT-3.5-turbo can generate effective and adaptive plans with few-shot learning capabilities, laying a foundation for integrating LLMs into robotic systems.

Popovic et al. [4] examined adaptive informative path planning (AIPP) as a crucial approach for enabling mobile robots to collect data efficiently in unknown environments. Their survey bridged AIPP and robotic learning by presenting a unified mathematical framework and taxonomies based on learning algorithms and robotic applications. The study highlighted the advantages of learning-based methods in improving adaptability, versatility, and robustness.

Zhang [2] explored AI-based path planning and navigation strategies for autonomous mobile robots. The study addressed collision-free navigation in unknown static environments by combining reactive navigation with Q-learning. This hybrid approach was extended to 3D environments and evaluated through simulations. A method integrating environment representation with reinforcement learning was also developed for dynamic environments with moving obstacles.

Golroudbari and Sabour [5] reviewed end-to-end deep learning frameworks for autonomous navigation, covering obstacle detection, scene perception, path planning, and control. Their work bridged deep learning and autonomous navigation by analyzing advancements related to environmental complexity, dynamic obstacles, and multi-agent path planning. The review evaluated scalability, applicability, and limitations while discussing interdisciplinary progress.

Hewawasam et al. [1] compared contemporary path-planning algorithms for dynamic environments, including artificial potential fields, genetic algorithms, fuzzy logic, neural networks, particle swarm optimization, and ant colony optimization. Their review evaluated methods against performance criteria including navigation in dynamic environments, object tracking, and validation through simulations and experiments.

Table 1 summarizes major studies reviewed in this paper. The literature demonstrates the evolution of robotic path planning from early RRT approaches to hybrid and intelligent approaches, including reinforcement learning and LLMs. Key observations include the capability of AI-based methods to support real-time path planning and the potential of hybrid methods to combine classical reliability with adaptive intelligence.

## 3. DISCUSSION

The reviewed studies demonstrate a continuous shift from purely deterministic and heuristic methods toward hybrid and learning-based robotic path-planning methods. Classical approaches remain important because they provide conceptual clarity, predictable behavior, and established baselines. However, the demands of complex and dynamic environments require algorithms that can adapt, learn, and reason under uncertainty.

### 3.1 Recent Developments in Organized Path-Planning Algorithms

Recent developments in organized path-planning algorithms show that hybrid approaches are especially valuable. Enhanced RRT variants, A*-based approaches, and dynamic window methods improve performance by incorporating safety distance, artificial potential fields, adaptive weights, and learning strategies. These developments reduce redundant paths, improve obstacle avoidance, and support real-time navigation. Nevertheless, many algorithms still require careful tuning, and their performance can vary with environmental complexity.

### 3.2 AI and Its Functions

AI supports path planning by enabling perception, prediction, learning, and decision-making. Reinforcement learning allows robots to improve through trial and reward, while deep neural networks support feature extraction and decision-making from high-dimensional sensory data. LLM-based systems introduce another possibility: high-level natural-language interpretation and task-level reasoning. These tools can simplify human–robot interaction and help robots produce flexible plans from abstract instructions. However, AI methods also introduce concerns about reliability, explainability, and computational demand.

### 3.3 Challenges in Real-World Validation

A major limitation of current path-planning research is the gap between simulation and real-world validation. Many proposed methods perform well in controlled simulators but face difficulties in physical environments with sensor noise, unpredictable obstacles, imperfect maps, and hardware constraints. Robust validation requires standardized benchmarks, reproducible experimental protocols, and testing across varied environmental conditions. Without such validation, it is difficult to assess whether an algorithm can be deployed safely in real applications.

### 3.4 Scalability and Multi-Agent Systems

Scalability is a critical issue for robotic path planning. Traditional strategies often focus on uncoordinated motion of a single robot, while fewer studies optimize decentralized or multi-agent contexts. Multi-robot systems, including swarm robotics and automated warehouses, require conflict resolution, communication, coordination, and efficient allocation of shared space. Future studies must develop algorithms that manage multi-robot cooperation simultaneously while remaining computationally efficient [1, 4].

### 3.5 Energy Saving and Resource Limitation

Another important research direction is the incorporation of energy-aware models into motion-planning algorithms. Many robotic systems are computationally constrained or operate in remote and low-power environments. Although AI methods are promising, their high computational complexity may hinder deployment in these settings. Further advancement in algorithm design and hardware optimization is required to achieve an effective trade-off between speed, accuracy, and energy consumption [4, 5].

**Table 1.** Summary of Literature Review

| Paper | Focus | Methodology | Key Findings |
|---|---|---|---|
| [11] | 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. |
| [3] | Exploration of GPT-3.5-turbo LLM for robotic path planning and real-time adaptive planning. | Performance comparison against RRT and A* in simulated environments. | LLMs show strong potential in adaptive planning over traditional methods. |
| [4] | Integrating robotic learning with AIPP for efficient data collection. | Unified framework and review of learning algorithms for AIPP. | Learning-based AIPP frameworks provide robust solutions for data collection tasks. |
| [2] | Hybrid reactive navigation combining Q-learning and traditional methods. | Combines Q-learning with reactive navigation in static, dynamic, and 3D environments. | Hybrid methods improve adaptability in dynamic environments with fewer iterations. |
| [5] | Review of deep learning frameworks for autonomous navigation. | Reviews deep reinforcement learning and interdisciplinary advances. | Deep learning excels in dynamic environments but faces scalability challenges. |
| [1] | Comparison of path-planning methods for dynamic environments. | Evaluates obstacle avoidance, adaptability, and validation techniques. | Hybrid methods outperform classical approaches in dynamic obstacle navigation. |
| [6] | Enhanced RRT for obstacle avoidance and optimal path planning. | Integrates RRT with genetic algorithms and neural models. | Enhanced RRT improves safety, accuracy, and obstacle-avoidance efficiency. |
| [7] | Real-time mobile robot path planning using safety distance and adaptive weights. | Combines A* improvements with dynamic window optimization. | Improves global path safety and real-time obstacle avoidance. |
| [8] | Autonomous path planning in multi-obstacle environments. | Integrates RRT with artificial potential field principles. | Improves search direction, reduces iterations, and decreases path length. |
| [9] | Hybrid navigation for autonomous positioning and docking. | Uses adaptive guidance, Bezier-curve path planning, and Kalman filtering. | Effective for warehousing logistics and multi-robot coordination. |

### 3.6 Future Research Directions

Several trends present new pathways for future research on robotic path planning. First, combining hybrid frameworks with decentralized and collaborative algorithms can address multi-robot coordination and scalability. Second, greater focus on validation methods and reference criteria can improve practical usability and transferability. Third, interdisciplinary collaboration among robotics, AI, control systems, and hardware design will help overcome energy inefficiencies and resource constraints. Finally, advances in edge computing and lightweight processors can help deploy advanced algorithms in constrained systems.

The development of robotic path planning has achieved significant improvements in adaptability, scalability, and efficiency. Despite progress in AI and hybrid methods, challenges remain in real-world validation, multi-robot coordination, cross-robot transfer, and energy-related issues. Addressing these challenges will enable advanced path-planning algorithms to control more sophisticated, safer, and more versatile autonomous systems.

## 4. CONCLUSION

Autonomous path planning has witnessed rapid progress due to the combination of conventional algorithms and sophisticated artificial intelligence. Traditional algorithms such as RRT and A* provide the conceptual basis for efficient navigation solutions. However, their limitations in genuinely dynamic and uncertain environments have encouraged the emergence of hybrid frameworks. These frameworks combine classical algorithms, machine-learning techniques, and heuristic approaches to improve flexibility, performance, and scalability. Advanced artificial intelligence techniques, including reinforcement learning, deep neural networks, and large language models, have enhanced robot decision-making and enabled more efficient operation in complex environments.

Important problems in robotic path planning still require further research. Scalability remains difficult, especially where multiple robots require coordination, communication, and conflict resolution. Algorithms trained or validated only in simplified environments often fail when applied to real environments with arbitrary and unconstrained settings. Furthermore, computationally intensive AI and reinforcement-learning approaches can be difficult to deploy in low-power environments, increasing the need for energy-efficient AI.

Future work should emphasize real-world implementation, decentralized and collaborative algorithms for multi-robot navigation, energy-efficient strategies, and lightweight computational models. Integrating AI methods with natural language processing also opens new opportunities for human–robot interaction and task planning. Continued collaboration between robotics, artificial intelligence, control systems, and hardware design will determine the next stage of intelligent robotic navigation systems.

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