Journal of Artificial Intelligence Practice (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/jaip.2024.070417
ISSN 2371-8412 Vol. 7 Num. 4

Literature Review of Path Planning Algorithms for Mobile Robots

Leiwen Yuan[1,a,*]

[1]Yunnan Normal University, Kunming, China
[a]704447795@qq.com
[*]Corresponding author

Keywords: Path Planning, Mobile Robots, RRT, Sampling Planning, DWA

Abstract: Path planning is a very important part of the working process of mobile robots, and quickly and efficiently planning a feasible path is currently a research focus. Excellent path planning algorithms can save a lot of time and economic costs. To comprehensively understand the development of mobile robot path planning technology, this article elaborates on the classic global path planning algorithms and local path planning algorithms both domestically and internationally. According to the properties of mobile robot path planning algorithms, they are divided into global path planning algorithms and local path planning algorithms. The global path planning is further divided into sampling based, search based, and biomimetic based planning algorithms, and the development of various algorithms is introduced. The current status of mobile robot path planning algorithms is summarized, and the future prospects are also discussed.

1. Introduction

With the continuous advancement of technology and the improvement of people's living standards, the demand for intelligent and information-based devices is increasing day by day. In 2015, China released the "Made in China 2025" strategy, aimed at enhancing the innovation capability and informatization level of the domestic manufacturing industry. Among them, the robotics industry has been identified as one of the key areas for development, and the strategy clearly proposes to focus on the application of industrial robots in industries such as automobiles, machinery, dangerous goods manufacturing, national defense and military industry, as well as the demand for service robots in medical, home services, education and entertainment, and promote the widespread application of robotics[1] technology. With the rapid development of robot technology, path planning[2], as one of the key technologies for autonomous navigation and action of robots, has become a research hot spot in both academia and industry. The core task of robot path planning is to provide an effective path for the robot to move from the starting point to the target position in the environment, while avoiding collisions with obstacles in the environment. This technology has broad application prospects in many fields such as automation, intelligent manufacturing, autonomous driving[3], medical care, and search[4] and rescue. The research purpose of robot path planning is to achieve autonomous navigation of robots, improve the efficiency, accuracy, and intelligence level of robot autonomous actions.

2. Path planning

Path planning solves the problem of "how to go" for robots, and is divided into global path planning and local path planning. Global path planning is a static planning based on prior information, and the results of its planning can provide guidance for local path planning; Local path planning is dynamic programming based on global path planning, which can avoid collisions with newly added or dynamic obstacles in the environment in real time. Traditional global path planning algorithms can be roughly divided into sampling based, search based, and biomimetic based algorithms. The commonly used local path algorithms include DWA dynamic window method, APF artificial potential field method, TEB time elastic band method, and so on.

2.1. Global Path Planning

Global path planning for robots refers to the process of finding an optimal or feasible path between a starting point and a target point in a known environmental map or workspace. This process typically relies on the robot's positioning system, environmental perception system, and path planning algorithm for decision-making and computation.

2.1.1. Sampling based algorithm

The probability landmark method PRM[5] and the fast exploration random tree method RRT[6] and their variants have been popular research directions for sampling algorithms in recent years. In the 1990s, M.H. Overmars et al. first proposed the Probabilistic Roadmap Method (PRM), a path planning algorithm based on random sampling. This algorithm randomly scatters points in the configuration space, removes points that overlap with obstacles, connects each sampling point with points in a certain area nearby, removes the lines that collide with obstacles, forms a connected graph, and finally uses a search algorithm to find the best path. PRM is probabilistic complete, but it requires a large amount of computation and has low efficiency.

The RRT (Rapidly Exploring Random Tree) algorithm proposed by LaValle et al. takes the starting point as the root node, randomly samples in space, and adds the nearest and collision free node as a child node to grow a randomly expanded tree. When the randomly generated node already includes the target node or is within the range of the target node, a path from the starting point to the endpoint can be found. If a feasible path is not found within the specified number of sampling times, it indicates that the path is unreachable. This algorithm has probabilistic completeness, but the final result is often not the optimal path. The RRT*[7] algorithm optimizes the reselection of parent nodes and rewiring based on the RRT algorithm to find local minima within a certain range, reducing the cost of the path. RRT* can obtain the optimal value after countless iterations, but its convergence speed is slow and the search method is still global random search. Kuffner et al. proposed the RRT Connect algorithm[8], which generates two random trees based on the starting and target points as root nodes, improving search efficiency. However, the final planned path cannot be improved.

Gammell et al. proposed Informed RRT*[9], which to some extent solves the problems of slow convergence speed and inability to change paths. The Informed RRT* algorithm optimizes the sampling process of RRT*. After obtaining a reachable path in RRT*, it generates an elliptical sampling area to replace global sampling, limiting the sampling range and improving sampling efficiency. It also reduces the area of the ellipse after finding a lower cost reachable path, further improving sampling efficiency.

2.1.2. Search based algorithm

Search based path planning algorithm is a widely used and mature planning method, developed in 1959 W. Dijkstra proposed the Dijkstra algorithm[10], also known as the Dijkstra algorithm. The core idea of this algorithm is to use breadth first search to solve the shortest path problem of weighted graphs. In 1968, Hart et al. published the A*[11] algorithm, which introduced heuristic functions based on Dijkstra's algorithm as follows :Where is the actual distance from the starting point to the current node , and is the minimum distance estimate from node to the endpoint. The algorithm prioritizes the search direction towards the target point during the search process, calculates the value of each child node, selects the node with the smallest value as the next target node, and repeats this process until the endpoint is found.

2.1.3. Biomimetic based algorithms

Biomimetic algorithm is an intelligent computing method that simulates the collective intelligent behavior, biological evolution, or ecological mechanisms of organisms in natural environments. Its calculation method is simple and clear, and it has high robustness to the environment. It can also improve efficiency through adaptive or learning methods. The commonly used biomimetic algorithms include ant colony algorithm, particle swarm algorithm, genetic algorithm, etc.

Ant Colony Optimization (ACO)[12] was first proposed by Dorigo et al. in 1991. It simulates the process of ants foraging in nature, and ant colonies release pheromones along the way while searching for food. Ants usually choose a path with a higher concentration of pheromones and continue to release pheromones to enhance the concentration of pheromones on this path, thus forming a positive feedback mechanism. Miao[19] introduced angle guidance factor and obstacle removal factor in the transition probability of ant colony algorithm to shorten the planning time. Liu proposed a probability based random walk strategy, which generates the step size of random walks by alternately using Gaussian distribution and Cauchy distribution, instead of using only Gaussian distribution to construct new solutions.

Particle Swarm Optimization (PSO)[13] was proposed by Eberhart and Kennedy in 1995, inspired by the foraging behavior of bird flocks. The algorithm simulates the process of bird flocks flying and foraging, where each bird imagines itself as a "particle" with velocity and direction. They can remember the best position they have searched for, and each particle is judged by its fitness function to determine its position. It can dynamically adjust based on its own and its companions' flight experience. The particles find the optimal solution through cooperation and information sharing between groups.

Genetic Algorithm (GA)[14] was proposed by Holland in 1962. Its main idea is derived from the evolutionary laws of "survival of the fittest" and "natural selection" in nature. Through selection, crossover, and mutation operations, multiple solutions are obtained, and unsuitable solutions are eliminated. After iterative evolution, the optimal solution is obtained.

2.2. Local path planning

Local path planning refers to the real-time planning of an effective path by a robot based on the current location information and target requirements, in order to avoid obstacles and complete tasks, based on a known environment. This is different from global path planning, which typically involves calculating the global path across the entire environmental map, with the aim of finding the optimal path between the starting point and the target point; Local path planning mainly involves real-time response to changes and obstacles in dynamic and local environments.

2.2.1. Dynamic Window Approach

The Dynamic Window Approach (DWA) [15] is a local path planning algorithm proposed by Dieter Fox et al. in 1997. The core idea of the algorithm is to sample the current state of the robot based on hardware constraints, calculate the motion trajectory of the robot in the sampled state for a certain period of time, and then use an evaluation function to obtain the optimal trajectory as the linear velocity and angular velocity of the robot.

2.2.2. Time Elastic Band

In 1993, Sean Quinlan et al. proposed the Elastic Band algorithm[16] (EB), which considers the robot's path as an elastic band, with adjacent path points forming internal tension. The robot uses sensors to detect surrounding obstacles while moving. The obstacle exerts external force on the elastic band, changing the robot's movement path. However, this algorithm does not take into account the kinematic constraints of the robot and cannot run well in practical environments. Therefore, in 2012, Christoph Rosmann et al. proposed the Time Elastic Band (TEB)[17] algorithm based on the rubber band algorithm. The TEB algorithm not only considers the kinematic constraints of the robot, but also takes into account the dynamic constraints, resulting in smoother and safer paths.

2.2.3. Artificial Potential Field

In 1986, Khatib first proposed the Artificial Potential Field (APF) method. The main idea of this algorithm is to construct an artificial potential field with virtual forces in the robot's workspace, where obstacles exert a "repulsive force" on the robot and target points exert a "gravitational force" on the robot. Their combined force is the direction of the robot's motion, and the magnitude is the robot's velocity. The path generated by the artificial potential field method is relatively smooth and safe, but it is prone to getting stuck in local minima, and when passing through narrow passages, it is easy to encounter situations where the target point cannot be reached. Huang Xiaowen proposed the APF-RRT fusion algorithm, which incorporates the idea of gravitational attraction between target points and random trees during random tree growth, solving the problem of blind search in RRT. Chen proposed a drone trajectory planning algorithm based on APF-RRT, which incorporates an improved APF into RRT to solve the problem of unreachable targets. Although these improved algorithms have improved search efficiency, the RRT algorithm still has significant randomness.

3. Conclusion

The research on path planning has not only promoted the advancement of robotics technology, but also been widely applied in multiple fields such as unmanned driving, automated production, and drone flight. The following is a summary of the development of path planning, covering the main research progress, technological evolution, and application areas. Although path planning technology has made significant progress, it still faces several challenges. The environment in reality is often dynamically changing, and how to ensure the effectiveness of the robot's path in the constantly changing environment has become an important issue. The errors of sensors, dynamic obstacles, and uncertainty of motion models in actual environments all pose challenges to path planning. How to ensure the safety and effectiveness of the path even in the presence of uncertainty is an important direction of current research. Especially in high-dimensional space, path planning algorithms have high computational complexity, and how to improve path planning efficiency and reduce computation time remains a challenge. In some application scenarios, it is not only necessary to consider the shortest path, but also other factors such as energy consumption, time constraints, obstacle avoidance, etc. How to balance and optimize among multiple objectives has become an important topic.[18]

4. Prospects

The development of future path planning will rely more on intelligence and adaptability. Path planning will pay more attention to the autonomous learning and adaptive capabilities of robots, which can cope with more complex and dynamic environments, and even perform path planning without complete map information. By combining deep learning and big data analysis, path planning will be able to predict environmental changes more accurately, improving the decision-making ability and response speed of robots. Multi robot systems will collaborate together for path planning, especially in scenarios such as industrial automation and post disaster rescue. How to coordinate multi robot collaborative work, avoid conflicts, and optimize the overall path will be a key research direction in the future. With the improvement of distributed processing capability of computing resources, edge computing will play an increasingly important role in path planning, enabling robots to calculate and execute path planning tasks in real-time on edge devices.

Overall, path planning technology is developing towards a more intelligent, efficient, and flexible direction, and is constantly expanding into new application scenarios. With the continuous advancement of technologies such as artificial intelligence and machine learning, future path planning will become more precise and efficient, driving further development of robotics technology and automation applications.

References

[1] Touzani H, Hadj-Abdelkader H, Séguy N, et al. Multi-robot task sequencing & automatic path planning for cycle time optimization: Application for car production line[J]. IEEE Robotics and Automation Letters, 2021, 6(2): 1335-1342.

[2] Vougioukas S. Annual review of control, robotics, and autonomous systems[J]. Agricultural robotics, 2019, 2(1): 365-392.

[3] Wang M, Zhang L, Wang Z, et al. A real-time dynamic trajectory planning for autonomous driving vehicles[C]// 2019 3rd Conference on Vehicle Control and Intelligence (CVCI). IEEE, 2019: 1-6.

[4] Quan L, Han L, Zhou B, et al. Survey of UAV motion planning[J]. IET Cyber-systems and Robotics, 2020, 2(1): 14-21.

[5] Geraerts R, Overmars M H. A comparative study of probabilistic roadmap planners[M]//Algorithmic foundations of robotics V. Berlin, Heidelberg: Springer Berlin Heidelberg, 2004: 43-57.

[6] LaValle S M, Kuffner Jr J J. Randomized kinodynamic planning[J]. The international journal of robotics research, 2001, 20(5): 378-400.

[7] Karaman S, Frazzoli E. Sampling-based algorithms for optimal motion planning[J]. The international journal of robotics research, 2011, 30(7): 846-894.

[8] Kuffner J J, LaValle S M. RRT-connect: An efficient approach to single-query path planning[C]//Proceedings 2000 ICRA. Millennium Conference. IEEE International Conference on Robotics and Automation. Symposia Proceedings (Cat. No. 00CH37065). IEEE, 2000, 2: 995-1001.

[9] Gammell J D, Srinivasa S S, Barfoot T D. Informed RRT: Optimal sampling-based path planning focused via direct sampling of an admissible ellipsoidal heuristic[C]//2014 IEEE/RSJ international conference on intelligent robots and systems. IEEE, 2014: 2997-3004.*

[10] Dijkstra E W. A note on two problems in connexion with graphs[M]//Edsger Wybe Dijkstra: his life, work, and legacy. 2022: 287-290.

[11] Hart P E, Nilsson N J, Raphael B. A formal basis for the heuristic determination of minimum cost paths[J]. IEEE transactions on Systems Science and Cybernetics, 1968, 4(2): 100-107.

[12] Kennedy J, Eberhart R. Particle swarm optimization[C]//Proceedings of ICNN'95-international conference on neural networks. ieee, 1995, 4: 1942-1948.

[13] Holland J H. Outline for a logical theory of adaptive systems[J]. Journal of the ACM (JACM), 1962, 9(3): 297-314.

[14] Fox D, Burgard W, Thrun S. The dynamic window approach to collision avoidance[J]. IEEE Robotics &

Automation Magazine, 1997, 4(1): 23-33.
[15] Quinlan S, Khatib O. Elastic bands: Connecting path planning and control[C]//[1993] Proceedings IEEE International Conference on Robotics and Automation. IEEE, 1993: 802-807.
[16] Rösmann C, Feiten W, Wösch T, et al. Trajectory modification considering dynamic constraints of autonomous robots[C]//ROBOTIK 2012; 7th German Conference on Robotics. VDE, 2012: 1-6.
[17] Khatib O. Real-time obstacle avoidance for manipulators and mobile robots[J]. The international journal of robotics research, 1986, 5(1): 90-98.
[18] Miao C, Chen G, Yan C, et al. Path planning optimization of indoor mobile robot based on adaptive ant colony algorithm[J]. Computers & Industrial Engineering, 2021, 156: 107230.
[19] Liu J, Anavatti S, Garratt M, et al. Modified continuous ant colony optimisation for multiple unmanned ground vehicle path planning[J]. Expert Systems with Applications, 2022, 196: 116605.