Path planning

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***Abstract*—This paper explains what happens in Path planning and its types and local planner and global planner and challenges and future trends in path planning**

***Index Terms*—Path planning , autonomous , robotics**

I. Introduction

PATH planning is a fundamental problem in robotics and computer science that involves finding an optimal or feasible path between two or more locations in a given environment. It is a crucial task for various applications, including autonomous vehicles, mobile robotics, computer-aided design, and even video games.

The goal of path planning is to determine a sequence of actions or waypoints that an agent or a robot should follow to navigate from a starting point to a desired goal while avoiding obstacles or constraints. The environment in which the path planning is performed can be represented as a grid, a graph, or a continuous space, depending on the specific problem and application.

Path planning algorithms typically take into account various factors such as the geometry of the environment, the presence of obstacles, the agent's capabilities and limitations, and any specified constraints or objectives. The algorithms often aim to optimize certain criteria, such as minimizing the path length, minimizing the time taken, or maximizing safety.

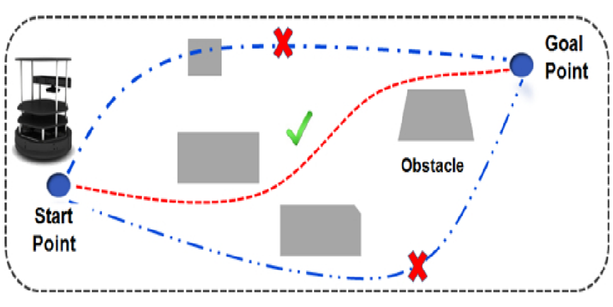

Figure 1: Path Planning

II. Types of Path Planning Algorithm

There are several types of path planning algorithms used to solve the problem of finding optimal or feasible paths in various environments. Here are some common types:

1. Graph Search Algorithms: These algorithms operate on a graph representation of the environment, where nodes represent locations, and edges represent connections between locations. Examples of graph search algorithms include Depth-First Search (DFS), Breadth-First Search (BFS), Dijkstra's algorithm, and A* search. Graph search algorithms explore the graph to find the optimal path based on certain criteria like distance or cost.

2. Sampling-Based Algorithms: These algorithms generate a set of samples or configurations in the environment and attempt to connect them to form a path. The most well-known sampling-based algorithms are Rapidly-exploring Random Trees (RRT) and Probabilistic Roadmaps (PRM). RRT explores the configuration space by randomly growing a tree, while PRM constructs a graph by connecting randomly sampled configurations.

3. Potential Field Algorithms: These algorithms treat the environment as a potential field, where the agent is attracted to the goal and repelled by obstacles. The agent moves along the steepest descent of the potential field to navigate. Potential field algorithms include Artificial Potential Fields (APF), which calculate attractive and repulsive forces to guide the agent towards the goal while avoiding obstacles.

4. Optimization-Based Algorithms: These algorithms formulate the path planning problem as an optimization task and find the optimal path by minimizing or maximizing a specific objective function. They often consider constraints and objectives such as minimizing path length, minimizing time, maximizing safety, or minimizing energy consumption. Examples include Rapidly-exploring Random Tree-Star (RRT*), D* algorithms, and algorithms based on mathematical optimization techniques like quadratic programming.

5. Cell Decomposition Algorithms: These algorithms divide the environment into cells or regions and generate a path by connecting cells in a meaningful way. Common cell decomposition methods include Voronoi diagrams and grid-based methods. Voronoi diagrams divide the space based on proximity to obstacles, while grid-based methods divide the environment into a grid of cells and use techniques like BFS or A* search to find the optimal path.

6. Hybrid Algorithms: These algorithms combine multiple approaches to leverage their strengths and overcome limitations. Hybrid algorithms often integrate graph search algorithms, sampling-based algorithms, or potential field methods to create effective path planning solutions. They may use graph search algorithms to find an initial path and then refine it using sampling-based or optimization-based methods.

It's important to note that each algorithm type has its own advantages and drawbacks, and the choice of algorithm depends on factors such as the complexity of the environment, computational resources, real-time requirements, and specific objectives of the path planning task.

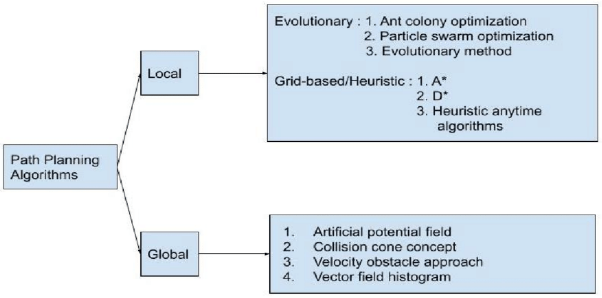

Figure 2: Types of Path Planning Algorithm

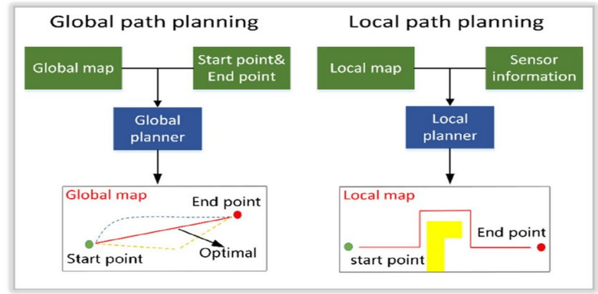

Figure 3: Local planner and Global planner

III. Local planner and Global planner

In the context of path planning, local planners and global planners are two components that work together to find feasible paths for an agent or robot in an environment.

1. Global Planner: The global planner is responsible for determining the high-level path from the starting point to the goal. It takes into account the overall environment, including obstacles, terrain, and any specified constraints or objectives. The global planner generates a global path that connects the start and goal locations, often using algorithms like A* search, Dijkstra's algorithm, or potential field methods. The global planner focuses on finding an overall optimal or feasible path based on global information.

2. Local Planner: The local planner operates at a lower level and is responsible for navigating the agent or robot along the global path generated by the global planner. It takes into account the current state of the agent, such as its position, orientation, and sensor readings. The local planner considers the immediate surroundings and makes decisions on how to move from one point to the next on the global path. It takes into account local obstacles, dynamic obstacles, and other factors that may affect the immediate movement of the agent. The local planner uses techniques like obstacle avoidance algorithms, feedback control, or trajectory planning to ensure safe and smooth navigation.

The interaction between the global planner and local planner is iterative. The global planner generates the initial global path based on the overall environment, and then the local planner navigates the agent along that path, taking into account the immediate surroundings. As the agent progresses, the local planner continuously updates the agent's trajectory based on real-time information, such as sensor data or changes in the environment. If the local planner encounters obstacles or other unexpected conditions that make the global path infeasible, it may request the global planner to compute a new global path.

In summary, the global planner determines the high-level path from start to goal, considering the overall environment, while the local planner focuses on the immediate navigation of the agent along the global path, considering the local situation and obstacles. The combination of these two components enables efficient and safe path planning for agents or robots in complex environments.

IV. Challenges and Future Trends in Path Planning

Path planning is a complex and challenging problem, and researchers continue to explore new techniques and approaches to address its limitations. Here are some challenges and future trends in path planning:

1. High-Dimensional and Continuous Spaces: Many real-world environments involve high-dimensional and continuous spaces, such as those encountered in autonomous driving or robotic manipulation. Traditional path planning algorithms struggle with such spaces due to the curse of dimensionality. Future advancements will focus on developing efficient algorithms that can handle high-dimensional and continuous spaces effectively.

2. Dynamic Environments: In dynamic environments, the presence of moving obstacles or uncertain target positions adds complexity to path planning. Future path planning algorithms will need to integrate real-time perception and prediction capabilities to account for dynamic obstacles and plan paths that are adaptable and responsive to changes in the environment.

3. Real-Time and Online Planning: Real-time path planning is crucial in applications where decisions need to be made quickly, such as autonomous vehicles or drones. Future trends will involve developing algorithms that can plan paths in real-time, considering time constraints, computational efficiency, and the ability to react to unforeseen events.

4. Multi-Agent and Cooperative Planning: Path planning for multiple agents or robots operating in the same environment requires coordination and cooperation to avoid collisions and conflicts. Future research will focus on developing cooperative path planning algorithms that enable efficient and collision-free navigation of multiple agents.

5. Uncertainty and Risk-aware Planning: Path planning algorithms often assume a deterministic environment. However, real-world environments are inherently uncertain, and uncertainties need to be considered to ensure safe and robust path planning. Future trends will involve incorporating uncertainty models and risk-aware planning techniques to handle uncertain and dynamic environments.

6. Learning-based Approaches: Machine learning and artificial intelligence techniques have shown promise in path planning. Future research will explore the use of learning-based approaches to improve path planning performance, such as training neural networks or reinforcement learning agents to learn from experience and adapt to different environments.

7. Human-Robot Interaction: In scenarios where robots operate in shared spaces with humans, path planning should consider human preferences, safety, and social norms. Future trends will involve developing path planning algorithms that can reason about human intentions, preferences, and social behaviors to enable natural and socially acceptable interactions between humans and robots.

8. Explainability and Interpretability: As path planning algorithms become more complex and autonomous, there is a growing need for interpretability and explainability. Future research will focus on developing techniques to provide explanations and insights into the decision-making process of path planning algorithms, enhancing transparency, trust, and accountability.

These challenges and future trends highlight the ongoing efforts to enhance path planning algorithms, making them more robust, efficient, adaptable, and capable of handling real-world complexities and requirements.

V. Practical Applications of Path Planning

Path planning has numerous practical applications across various domains. Here are some of the key areas where path planning techniques are extensively used:

1. Autonomous Vehicles: Path planning is crucial for autonomous vehicles, including self-driving cars, drones, and robotic vehicles. It enables them to navigate safely and efficiently in complex urban environments, considering factors like traffic, obstacles, traffic rules, and pedestrian interactions.

2. Robotics: Path planning plays a vital role in robotic systems, enabling robots to navigate through cluttered environments, avoid obstacles, and reach desired locations. It finds applications in industrial automation, warehouse logistics, robotic manipulation, and mobile robotics.

3. Video Games and Virtual Environments: Path planning algorithms are used in video games and virtual environments to control non-player characters (NPCs) and simulate realistic movement. They generate paths for NPCs to navigate in dynamic and interactive game environments.

4. Computer-Aided Design (CAD): In CAD systems, path planning is used to generate tool paths for CNC machines and robotic arms. It ensures efficient and collision-free movement of the tools during manufacturing processes, such as milling, cutting, or 3D printing.

5. Network Routing: Path planning algorithms are employed in network routing protocols to find the most efficient paths for data packets to travel through communication networks. They optimize factors such as latency, bandwidth utilization, and network congestion.

6. Search and Rescue Operations: In search and rescue missions, path planning is used to guide autonomous or remote-controlled robots through disaster-affected areas, helping them navigate complex terrains, avoid hazards, and locate survivors.

7. Supply Chain and Logistics: Path planning is essential in optimizing supply chain and logistics operations. It helps in determining efficient routes for transportation vehicles, minimizing travel distances and costs, and ensuring timely delivery of goods.

8. Urban Planning and Infrastructure Design: Path planning algorithms aid urban planners in designing efficient transportation networks, road networks, and pedestrian walkways. They assist in optimizing traffic flow, reducing congestion, and enhancing the overall accessibility and safety of cities.

9. Medical Robotics: Path planning techniques are applied in surgical robotics to plan safe and precise paths for surgical instruments or robotic arms during minimally invasive procedures. They are also used in the navigation of medical robots within the human body for targeted interventions.

10. Virtual Reality (VR) and Augmented Reality (AR): In VR and AR applications, path planning algorithms are employed to enable virtual avatars or augmented objects to move realistically in virtual or augmented environments, enhancing the immersive experience for users.

These are just a few examples of the practical applications of path planning. The versatility of path planning algorithms allows them to be adapted to various domains where navigation and efficient movement are crucial.

VI. Conclusion and Resources

In conclusion, path planning is a fundamental problem in robotics, autonomous systems, and various other fields. It involves finding optimal or feasible paths for agents or robots to navigate in complex environments while considering obstacles, constraints, and objectives. Path planning algorithms, such as graph search algorithms, sampling-based methods, potential field approaches, and optimization-based techniques, play a crucial role in addressing this problem.

The challenges and future trends in path planning focus on handling high-dimensional spaces, dynamic environments, real-time planning, multi-agent scenarios, uncertainty, learning-based approaches, human-robot interaction, and explainability. Ongoing research aims to enhance the performance, adaptability, and safety of path planning algorithms in practical applications.

If you're interested in diving deeper into path planning, here are some resources to explore:

1. "Principles of Robot Motion: Theory, Algorithms, and Implementations" by Howie Choset et al. 2. "Robot Motion Planning and Control" by Jean-Paul Laumond. 3. "Planning Algorithms" by Steven M. LaValle. 4. "Path Planning for Vehicles in Unknown Semi-structured Environments" by Zongqing Lu and Jie Bao. 5. "Path Planning and Navigation for Autonomous Vehicles" by Juan Cortés et al. 6. "Path Planning: Principles and Practice" by Paolo Salaris. 7. "Introduction to Autonomous Robots: Path Planning, Sensing, Localization, and Control" by Nikolaus Correll et al. 8. Research papers and articles in journals and conferences like IEEE Transactions on Robotics, Robotics and Autonomous Systems, and International Conference on Robotics and Automation (ICRA).

These resources provide in-depth insights into path planning algorithms, techniques, and their applications in various domains.