TASK 6.3

Path planning

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1 Introduction to Path Planning

1.1 Introduction

Path planning plays a crucial role in the navigation and autonomy of mobile robots and remotely operated vehicles (ROVs). It involves determining an optimal or feasible path for a robot to navigate from its current location to a desired goal while avoiding obstacles and adhering to certain constraints. Path planning algorithms are essential for enabling mobile robots and ROVs to autonomously navigate in complex and dynamic environments, including indoor spaces, outdoor terrains, and underwater environments. With advancements in robotics, sensing technologies, and computational power, path planning for mobile robots and ROVs continues to evolve. Researchers and engineers are constantly developing new algorithms and techniques to enhance the autonomy and efficiency of these robotic systems in navigating complex environments. The ability to plan optimal paths is pivotal in enabling mobile robots and ROVs to operate effectively, accomplish tasks, and overcome challenges in a wide range of applications.

1.2 Robots

For mobile robots, such as autonomous ground vehicles or aerial drones, path planning algorithms enable them to efficiently navigate through cluttered environments, avoid collisions with obstacles, and reach their destinations in a safe and timely manner. These algorithms take into account various factors, including the robot's dynamics and kinematics, environment maps or sensor data, obstacle avoidance, and optimization objectives such as minimizing travel time or energy consumption.

1.3 ROVs

In the case of ROVs, which are remotely operated underwater vehicles, path planning is critical for performing tasks in underwater environments with limited visibility and complex terrain. ROVs are used in various applications, such as underwater exploration, marine research, offshore inspections, and underwater infrastructure maintenance. Path planning algorithms for ROVs need to consider factors such as ocean currents, sensor limitations, underwater obstacles, and the unique dynamics of underwater vehicles.

2 Types of Path Planning Algorithm

2.1 Introduction

Path planning algorithms for both mobile robots and ROVs can employ different techniques, including graph-based algorithms (e.g., Dijkstra's algorithm, A* algorithm), sampling-based algorithms (e.g., Rapidly-exploring Random Trees, Probabilistic Roadmaps), potential field methods, and machine learning-based approaches. These algorithms aim to find a path that optimizes criteria such as efficiency, safety, obstacle avoidance, smoothness, or mission-specific objectives.

2.2 Dijkstra

1. Dijkstra's Algorithm: Dijkstra's algorithm is a graph-based path planning algorithm that finds the shortest path between a start node and all other nodes in a weighted graph. It works by iteratively selecting the node with the smallest distance and expanding its neighbors until the goal node is reached. It guarantees optimality but can be computationally expensive for large-scale environments.

2.3 A* Algorithm

2. A* Algorithm: A* is a heuristic search algorithm that combines the advantages of Dijkstra's algorithm and greedy best-first search. It uses an admissible heuristic function to estimate the cost from a node to the goal, guiding the search towards the most promising paths. By considering both the actual cost and the estimated cost, A* is efficient and often finds the optimal path.

2.4 Rapidly-exploring Random Trees (RRT)

3. Rapidly-exploring Random Trees (RRT): RRT is a sampling-based algorithm suitable for high-dimensional configuration spaces. It incrementally builds a tree by randomly sampling the space and expanding towards unexplored areas. RRT is effective in exploring and finding feasible paths in complex and dynamically changing environments, but it does not guarantee optimality.

2.5 Probabilistic Roadmaps (PRM)

4. Probabilistic Roadmaps (PRM): PRM is another sampling-based algorithm that constructs a graph connecting randomly sampled configurations in the space. It precomputes a roadmap of feasible paths and uses graph-search techniques to find the path between the start and goal configurations. PRM is efficient for high-dimensional spaces and can handle complex obstacles, but optimality is not guaranteed.

2.6 Potential Field Methods

5. Potential Field Methods: Potential field methods utilize artificial potential fields to guide the robot towards the goal while avoiding obstacles. The robot is attracted to the goal and repelled by obstacles based on attractive and repulsive forces. These methods are

computationally efficient and can handle dynamic environments but may suffer from local minima and can result in suboptimal paths.

2.7 Machine Learning-based Approaches

6. Machine Learning-based Approaches: Machine learning techniques, such as reinforcement learning and neural networks, are increasingly used for path planning. These methods learn from data and experience to generate policies or value functions that guide the robot's decision-making process. Machine learning-based approaches have the potential to adapt to complex environments and improve path planning performance but require extensive training and may lack interpretability.

2.8 Overview

Each algorithm has its strengths and weaknesses, and their suitability depends on the specific requirements of the application, the environment, and the available computational resources. Choosing the right algorithm involves considering factors such as optimality, computational efficiency, scalability, obstacle avoidance capabilities, and the specific constraints and objectives of the robot or vehicle.

3 Local planner and Global planner

3.1 Introduction

The local planner focuses on short-term navigation, obstacle avoidance, and real-time adjustments, while the global planner focuses on long-term route planning, optimization, and high-level decision-making. These two planners often work in conjunction to provide a comprehensive path planning solution for robots and vehicles, combining real-time responsiveness with strategic path determination.

3.2 Local Planner

A local planner, also known as a local path planner or local motion planner, is responsible for generating a feasible and collision-free path for a robot or vehicle in real-time. It operates within a short-term planning horizon and focuses on immediate obstacles and constraints present in the robot's immediate vicinity. The local planner takes into account the robot's dynamics, sensor information, and environmental data to navigate around obstacles and reach the next waypoint or goal. It typically employs reactive or real-time planning algorithms that can quickly respond to changes in the environment and make necessary adjustments to the robot's trajectory. Local planners are crucial for ensuring the safety and agility of a robot during its navigation and play a significant role in obstacle avoidance and trajectory tracking.

3.3 Global Planner

A global planner, also known as a global path planner or long-term planner, is responsible for finding an optimal or near-optimal path from a start location to a goal location in a given environment. Unlike the local planner, the global planner operates on a larger planning horizon and considers the overall structure of the environment and the desired goal. It typically utilizes high-level planning algorithms that explore the environment, evaluate different paths, and make strategic decisions to find the best route. Global planners take into account factors such as distance, accessibility, and any additional constraints or objectives specified by the application. They may use algorithms like Dijkstra's algorithm, A* algorithm, or sampling-based methods to search for the optimal path. Once the global planner determines the path, it provides the waypoints or intermediate goals to the local planner for execution. Global planners are essential for long-range planning, mission planning, and overall navigation strategy.

4 Challenges and Future Trends in Path Planning

4.1 Introduction

Path planning continues to evolve to address the challenges posed by dynamic environments, high-dimensional spaces, real-time requirements, uncertainty, and multi-objective optimization. Future trends focus on adaptive and reactive planning, advanced optimization techniques, incorporating human factors, leveraging learning-based approaches, and addressing the unique requirements of multi-robot systems. These advancements will enhance the autonomy, efficiency, and reliability of path planning algorithms and enable their application in a wide range of robotic systems and environments.

4.2 Challenges and Future Trends in Path Planning

4.2.1 Dynamic Environments

Path planning algorithms face challenges in dealing with dynamic environments where obstacles, terrain conditions, or other factors can change over time. Future trends focus on developing adaptive and reactive path planning techniques that can quickly respond to environmental changes and adjust the robot's trajectory accordingly.

4.2.2 High-dimensional Spaces

Path planning becomes more complex in high-dimensional configuration spaces, such as those encountered in robotic arms or multi-robot systems. Advanced sampling-based algorithms, machine learning approaches, or hybrid methods that combine different planning techniques are being explored to address the challenges of high-dimensional path planning.

4.2.3 Real-time Performance

Real-time path planning is crucial for robotics applications that require rapid decision-making and responsiveness. Future trends involve optimizing path planning algorithms for faster computation, leveraging parallel processing, and incorporating efficient data structures to enhance the real-time performance of the planners.

4.2.4 Uncertainty and Sensing Limitations

Path planning algorithms need to account for uncertainty in sensor measurements, localization errors, and incomplete information about the environment. Techniques such as probabilistic planning, uncertainty-aware planners, and sensor fusion methods are being developed to handle uncertainty and improve the reliability of path planning in uncertain or partially observable environments.

4.2.5 Multi-objective Optimization

Path planning often involves multiple conflicting objectives, such as minimizing travel time, energy consumption, or risk while maximizing coverage or robustness. Future trends focus on multi-objective optimization algorithms that can generate a set of Pareto-optimal paths, allowing decision-makers to select the most suitable path based on their preferences and priorities.

4.2.6 Human-Robot Interaction

As robots increasingly operate in shared spaces with humans, path planning algorithms need to consider human preferences, safety constraints, and social norms. Future trends involve integrating human factors into path planning, considering factors such as human comfort, predictability, and natural interaction to enable safe and socially acceptable robot navigation.

4.2.7 Learning-based Approaches

Machine learning techniques, such as reinforcement learning, deep learning, and imitation learning, are being applied to path planning. These approaches aim to learn from data, experience, or human demonstrations to improve the performance and adaptability of path planning algorithms. Learning-based approaches have the potential to handle complex environments, generalize across different scenarios, and optimize path planning based on specific application requirements.

4.2.8 Cooperative and Swarm Path Planning

Path planning for multi-robot systems or swarms introduces additional challenges, such as coordination, communication, and collision avoidance among multiple robots. Future trends involve developing cooperative path planning algorithms that enable efficient and safe navigation of multiple robots, leveraging techniques like decentralized planning, consensus algorithms, and information sharing.

5 Practical Applications of Path Planning

5.1 Introduction

Path planning algorithms find applications in various domains where autonomous navigation and efficient trajectory planning are essential. Some practical applications of path planning include:

5.2 Autonomous Vehicles

Path planning plays a crucial role in autonomous driving, enabling vehicles to navigate complex road networks, avoid obstacles, and reach destinations safely and efficiently. It involves real-time decision-making for lane changing, merging, intersection crossing, and adapting to dynamic traffic conditions.

5.3 Robotics

Path planning is fundamental in robotics for tasks such as autonomous mobile robots, robotic arms, and drones. It enables robots to navigate through cluttered environments, avoid obstacles, and reach target locations. Path planning is used in warehouse automation, industrial automation, logistics, and search and rescue missions.

5.4 Unmanned Aerial Vehicles (UAVs)

Path planning is applied to UAVs for tasks like surveillance, aerial mapping, package delivery, and agriculture. It enables UAVs to plan optimal routes, avoid restricted areas, and navigate efficiently in three-dimensional space while considering obstacles, wind conditions, and energy constraints.

5.5 Underwater Robotics

Path planning is crucial for underwater vehicles, such as ROVs, AUVs (Autonomous Underwater Vehicles), and submarines. It enables them to navigate through underwater environments, avoiding obstacles, mapping the seabed, conducting scientific surveys, and performing inspections of underwater infrastructure.

5.6 Virtual Reality and Gaming

Path planning algorithms are utilized in virtual reality (VR) environments and video games to enable realistic and intelligent movement of virtual characters or non-player characters (NPCs). They determine the paths for NPCs to follow, avoid collisions, and simulate realistic behaviors in virtual environments.

5.7 Urban Planning and Infrastructure Design

Path planning algorithms are used in urban planning to optimize transportation networks, traffic flow, and public transit routes. They assist in designing efficient road networks, determining optimal locations for infrastructure, and improving urban mobility.

5.8 Medical Robotics

Path planning is applied in medical robotics for procedures such as robot-assisted surgery, rehabilitation robotics, and medical imaging. It helps in planning safe and accurate paths for surgical instruments, guiding robot-assisted rehabilitation exercises, and optimizing medical imaging trajectories.

5.9 Autonomous Drones and Robotics Competitions

Path planning algorithms are utilized in autonomous drone races and robotics competitions. These algorithms enable drones and robots to navigate challenging courses, avoid obstacles, and complete tasks in the shortest time possible.

6 Conclusion and Resources

6.1 Conclusion

In conclusion, path planning is a fundamental aspect of autonomous navigation and efficient trajectory planning in various domains. It enables robots, autonomous vehicles, drones, and other autonomous systems to navigate through complex environments, avoid obstacles, and reach their goals safely and efficiently. Path planning algorithms continue to evolve to address challenges such as dynamic environments, high-dimensional spaces, real-time requirements, and uncertainty. Future trends include adaptive and reactive planning, multi-objective optimization, human-robot interaction, learning-based approaches, and cooperative path planning for multi-robot systems.

6.2 Resources

If you're interested in further exploring path planning, here are some resources you may find helpful:

1. "Connected papers: Influential academic papers". - It uses similarity to identify related papers based on one paper that you have already identified. Connected Papers also provides features such as "Prior Works" (references) and "Derivative Works" (papers that cited the original article) to further assist in literature exploration and review..

2. "Principles of Robot Motion: Theory, Algorithms, and Implementations" by Choset, et al. - This comprehensive book covers the principles, algorithms, and implementations of robot motion planning, including path planning. It provides a thorough understanding of the underlying concepts and techniques.

3. "Robot Motion Planning and Control" by Jean-Paul Laumond. - This book offers a detailed introduction to robot motion planning, covering various algorithms and techniques. It provides insights into both classical and advanced approaches to path planning.

4. "Planning Algorithms" by Steven M. LaValle. - This resource is freely available online as an open-access textbook. It covers a wide range of planning algorithms, including path planning, and provides detailed explanations, pseudocode, and examples.

5. "Motion Planning for Intelligent Transportation Systems" edited by Weixiong Zhang and Jing Zhao. - This book focuses on motion planning algorithms specifically designed for intelligent transportation systems, including autonomous vehicles. It covers topics such as traffic simulation, cooperative planning, and multi-agent systems.

6. Research Papers and Conference Proceedings: - Exploring research papers and conference proceedings in the field of robotics, artificial intelligence, and autonomous systems can provide insights into the latest advancements and cutting-edge techniques in path planning.