PATH PLANNING SYSTEM

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September 2023

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1 Introduction to Path Planning

Path planning is the most critical issue in-vehicle navigation. It is defined as finding a geometrical path from the current location of the vehicle to a target location such that it avoids obstacles. This path must be navigable by the vehicle and optimal in terms of at least one variable so that it can be considered a suitable path. For different target distance situations, the smoothest path, the shortest path, or the path along which the vehicle can move with the highest speed can become the most important path. In other words, the optimal path is determined concerning these characteristics.

2 Types of Path Planning Algorithm

Path planning algorithms are used in various fields such as robotics, computer graphics, and transportation to find an optimal or feasible path from a starting point to a goal point while avoiding obstacles. Here are some commonly used types of path planning algorithms.

2.1 Dijkstra's Algorithm

Dijkstra's algorithm is a popular algorithm for finding the shortest path in a graph. It explores the graph in a breadth-first manner, assigning tentative distances to nodes and updating them if shorter paths are found.

2.2 A* Algorithm

The A* (A-star) algorithm is an extension of Dijkstra's algorithm that incorporates heuristics to guide the search towards the goal more efficiently. It uses a combination of the actual cost to reach a node and an estimate of the remaining cost to the goal to determine the best path.

2.3 Rapidly Exploring Random Trees (RRT)

RRT is a sampling-based algorithm commonly used in robotics. It incrementally builds a tree of randomly sampled configurations from the configuration space. RRT explores the space by extending the tree towards unexplored regions, gradually growing towards the goal.

2.4 Probabilistic Roadmap (PRM)

PRM is another sampling-based algorithm that constructs a graph-based representation of the configuration space. It samples random configurations and connects them to nearby configurations, creating a roadmap. The roadmap is then used to find a path between the start and goal configurations.

2.5 Potential Fields

Potential fields use the concept of attractive and repulsive forces to guide a robot or object through a space. The goal location exerts an attractive force, while obstacles exert repulsive forces. The robot navigates by following the resulting gradient of the potential field.

2.6 Wavefront Expansion

Wavefront expansion, also known as breadth-first search, explores the environment by expanding in all directions from the starting point. It assigns values (wavefronts) to each cell or node, representing the distance from the starting point. It can be used in grid-based environments.

2.7 Genetic Algorithms

Genetic algorithms use principles inspired by biological evolution to search for optimal solutions. Paths are encoded as chromosomes, and genetic operators such as mutation and crossover are applied to generate new paths. Fitness functions evaluate the quality of each path, and evolution takes place over multiple generations.

2.8 Visibility Graphs

Visibility graphs construct a graph by connecting nodes representing key points in the environment that have a clear line of sight to each other. The resulting graph is used to find a path by traversing the edges that connect the start and goal nodes.

3 Local planner and Global planner

In the context of path planning, local planners and global planners are two components often used together to navigate a robot or vehicle through an environment.

3.1 Global Planner

- The global planner is responsible for generating a high-level plan or a global path from the starting point to the goal. It considers the entire environment and typically operates on a higher-level representation, such as a map or a graph. The global planner takes into account factors like obstacles, terrain, and desired objectives, and it aims to find the optimal or near-optimal path.

- The global planner considers the overall structure of the environment and plans the route accordingly. It may use algorithms like Dijkstra's algorithm, A* algorithm, RRT, or PRM to search for a path while avoiding obstacles. The output of the global planner is a sequence of waypoints or key poses that form the desired trajectory.

3.2 Local Planner

- The local planner, also known as the reactive or low-level planner, operates at a lower level of control and is responsible for navigating the robot or vehicle in real time based on the global path provided by the global planner. Its primary objective is to handle local obstacles, dynamic changes in the environment, and ensure smooth and safe navigation.

- The local planner takes into account the current state of the robot, such as its pose and velocity, and the sensory information from onboard sensors (e.g., lidar, cameras) to make real-time decisions. It adjusts the robot's trajectory or motion commands to handle immediate obstacles or changes in the environment. The local planner may use algorithms like potential fields, dynamic window approach, or model predictive control (MPC) to generate feasible and collision-free trajectories.

The interaction between the global and local planners is iterative. The global planner generates the initial global path, and the local planner executes it while handling local obstacles. If the local planner encounters an unexpected obstacle or the environment changes significantly, it may request a new global path from the global planner to update the trajectory.

By combining global and local planners, a robot or vehicle can effectively navigate through complex environments, taking into account both long-term objectives and short-term obstacle avoidance. The global planner provides a high-level plan, while the local planner handles real-time navigation and adaptation to the local environment.

4 Challenges and Future Trends in Path Planning

Path planning is a fundamental task in various industries and fields, and it continues to face several challenges while striving to incorporate emerging trends. Here are some challenges and future trends in path planning.

4.1 Challenges in Path Planning

- **Complex and Dynamic Environments:** Path planning algorithms need to handle increasingly complex and dynamic environments. This includes accounting for moving obstacles, dynamic changes in the environment, and uncertain or incomplete information. Future path-planning algorithms will need to improve their ability to adapt and handle such complexities.

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- **Real-Time Performance:** Many applications require real-time path planning, especially in robotics and autonomous systems. It is crucial to develop efficient algorithms that can generate paths quickly, allowing robots to navigate dynamically changing environments in real time.

- **Uncertainty and Risk-aware Planning:** Path planning algorithms often assume deterministic environments, but in reality, uncertainties exist. Future trends involve incorporating uncertainty modeling and risk-aware planning techniques into path planning algorithms. This includes considering probabilistic models, sensor uncertainties, and expected outcomes to make more informed decisions.

- **High-Dimensional Spaces:** Path planning becomes more challenging in high-dimensional spaces, such as those encountered in multi-robot systems or high-dimensional configuration spaces. Future path-planning algorithms will need to address the curse of dimensionality and find efficient ways to search and explore such spaces.

4.2 Future Trends in Path Planning

- **Edge and Cloud Computing:** As the demand for more computational power grows, path planning algorithms can benefit from edge and cloud computing. Offloading computationally intensive tasks to edge devices or cloud servers can enhance the performance and scalability of path-planning algorithms, enabling them to handle larger-scale environments and more complex scenarios.

- **Machine Learning and Data-driven Approaches:** Machine learning techniques, such as deep learning and reinforcement learning, are increasingly being integrated into path planning algorithms. By leveraging large amounts of data, these approaches can learn complex patterns and make more informed decisions. They enable path planners to adapt to specific environments, handle uncertainties, and optimize performance based on learned experiences.

- **Probabilistic and Uncertainty-aware Planning:** Traditional path planning algorithms often assume deterministic environments, but future trends involve incorporating probabilistic models and uncertainty-aware planning techniques. These methods account for uncertainties in sensor measurements, dynamic changes in the environment, and incorporate probabilistic reasoning to make more robust decisions.

- **Multi-Agent and Cooperative Planning:** With the rise of multi-robot systems and collaborative environments, there is an increasing need for path-planning algorithms that can handle multiple agents and coordinate their actions. Future trends involve developing cooperative planning algorithms that enable agents to collaborate, share information, and optimize their paths collectively, promoting efficiency and avoiding conflicts.

- **Human-Centric Path Planning:** As robots and autonomous systems interact more closely with humans, path planning algorithms need to consider human preferences, safety, and social conventions. Future trends involve developing human-centric path planning algorithms that take into account human intentions, preferences, and ensure safe and socially acceptable navigation in human-populated spaces.

5 Practical Applications of Path Planning

- **Robotics and Autonomous Vehicles**: Path planning is essential for autonomous robots and self-driving vehicles to navigate through complex environments, avoiding obstacles and reaching their destinations safely.
- **Aerospace**: In the aerospace industry, path planning is crucial for flight route optimization, collision avoidance, and trajectory planning for spacecraft, drones, and aircraft.
- **Manufacturing**: Path planning plays a vital role in industrial automation, guiding robotic arms in manufacturing processes such as welding, assembly, and material handling.
- **Logistics and Supply Chain**: It is used in optimizing the paths of autonomous delivery robots and drones, improving the efficiency of logistics and supply chain operations.
- **Healthcare**: Surgical robots use path planning to assist surgeons during minimally invasive procedures, ensuring precise movements and reducing patient trauma.
- **Agriculture**: Autonomous agricultural machinery uses path planning to optimize planting, harvesting, and crop management tasks, increasing agricultural efficiency.
- **Mining and Exploration**: Path planning is employed in autonomous mining vehicles and exploration robots to navigate challenging terrains and locate resources.
- **Search and Rescue**: Drones and robots equipped with path-planning capabilities are used in search and rescue operations to access remote or hazardous locations.
- **Environmental Monitoring**: Autonomous underwater and aerial vehicles are deployed for environmental monitoring, and path planning helps them cover large areas efficiently.

- **Video Games and Simulations**: Path planning algorithms are used in video games to control non-player characters (NPCs) and create realistic virtual environments.
- **Smart Cities**: Path planning is applied to optimize traffic flow, reduce congestion, and improve transportation systems in smart cities.
- **Security and Surveillance**: Drones and surveillance systems use path planning to monitor and secure critical infrastructure and public spaces.
- **Virtual Reality and Augmented Reality**: Path planning is used to simulate realistic movements of virtual entities within virtual and augmented reality environments.

6 Conclusion and Resources

6.1 Conclusion

In conclusion, path planning is a critical task in various fields, including robotics, transportation, and computer graphics. It involves finding an optimal or feasible path from a starting point to a goal while avoiding obstacles. Different types of path planning algorithms exist, such as Dijkstra's algorithm, A* algorithm, Rapidly Exploring Random Trees (RRT), Probabilistic Roadmap (PRM), and potential fields, each with its own strengths and applications.

Path planning consists of two main components: the global planner and the local planner. The global planner generates a high-level plan or global path considering the entire environment and factors like obstacles and terrain. It aims to find the optimal or near-optimal path using algorithms like Dijkstra's algorithm, A* algorithm, or sampling-based approaches like RRT and PRM. On the other hand, the local planner operates at a lower level and focuses on real-time navigation, handling local obstacles, and ensuring smooth and safe movement. It adjusts the robot's trajectory based on the global path and sensory information from onboard sensors.

Path planning faces several challenges, including complex and dynamic environments, real-time performance requirements, uncertainty and risk-aware planning, and high-dimensional spaces. To address these challenges, future trends in path planning involve incorporating edge and cloud computing for enhanced performance, utilizing machine learning and data-driven approaches to learn complex patterns, integrating probabilistic and uncertainty-aware planning techniques, developing cooperative planning algorithms for multi-agent systems, and considering human-centric factors in path planning.

Path planning finds practical applications in various industries, including robotics and autonomous vehicles, aerospace, manufacturing, logistics and supply chain, healthcare, agriculture, mining and exploration, search and rescue, environmental monitoring, video games and simulations, smart cities, security and surveillance, and virtual reality and augmented reality.

Overall, path planning is a dynamic and evolving field that plays a crucial role in enabling efficient and safe navigation in complex and diverse environments, and it continues to advance with the integration of new technologies and approaches.

6.2 Resources

- `https://link.springer.com/article/10.1007/s11227-023-05305-0`
- `https://link.springer.com/article/10.1007/s11227-023-05554-z`
- `https://iopscience.iop.org/article/10.1088/1742-6596/1213/3/032006`
- `https://dl.acm.org/doi/10.1145/3583136`
- `https://ieeexplore.ieee.org/document/9534409`