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ROUTE PLANNING FOR A MOBILE ROBOT IN 3D SPACE BASED ON AN ALGORITHM PROBABILISTIC ROADMAP

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ABSTRACT:

This article discusses route planning for a mobile robot in three-dimensional space using the Probabilistic Roadmap (PRM) algorithm. The mathematical apparatus of PRM allows you to build a state graph for the robot's movement space, taking into account obstacles and environmental features. The developed Python program includes an implementation of the PRM algorithm to find the optimal path in 3D space. Experiments on route generation in various environments were conducted to demonstrate the effectiveness and accuracy of the proposed approach. The results obtained confirm the applicability of the PRM algorithm for route planning of mobile robots in complex 3D environments.

Key words: Industry 5.0, Computer Vision Systems, Mobile Robots, Work zone, Manufacturing Innovation, Industrial Innovation

INTRODUCTION

In the modern world, autonomous mobile robots are playing an increasingly important role in various fields, including manufacturing, logistics, medicine, and more [1]-[17]. For such robots to function effectively, it is necessary to have effective route planning algorithms [18]-[23], especially in three-dimensional space, which takes into account not only the plane of motion, but also vertical obstacles and environmental conditions. Various methods, approaches, and ideas can be used here [24]-[33]. One of

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the promising methods for planning routes for mobile robots in 3D space is the Probabilistic Roadmap (PRM) algorithm, which allows you to generate routes taking into account complex 3D obstacles and environmental features.

However, to effectively implement a PRM algorithm, it is important to consider a number of features and challenges. First, it is necessary to correctly select the algorithm parameters, such as the number of generated points and the radius of the search for nearest neighbors, to ensure optimality and speed of route construction. Secondly, computational complexity must be taken into account, especially when working with large amounts of data in 3D space.

Thus, the implementation of route planning for a mobile robot in 3D space based on the PRM algorithm is an urgent task, ensuring efficient and accurate movement of robots in complex three-dimensional conditions. Research in this area will allow the development of new methods and technologies to improve the navigation of autonomous systems and their application in various fields of industry and science.

Related works

Modern trends in path finding for a mobile robot involve the use of various algorithms. Among them we can highlight Probabilistic Roadmap (PRM) algorithm. It is considered for path planning by plenty of scientists in their researches. Let us look at some recent works on this topic.

Let us begin from the fact, that path planning and navigation is a very important problem in robotics, especially for mobile robots operating in complex environments [34]. An improved sampling-based path planning method for mobile robot navigation is proposed in [34]. The proposed method uses a layered hybrid Probabilistic Roadmap and the Artificial Potential Field (APF) method for global planning.

Paper [35] presents a new path planning algorithm based on the probabilistic roadmaps method, in order to effectively solve the autonomous path planning of mobile robots in complex environments with multiple narrow channels. The improved PRM algorithm mainly improves the density and distribution of sampling points in the narrow channel, through a combination of the learning process of the PRM algorithm and the APF algorithm.

Authors in [36] try to develop a new path planning algorithm that can guarantee the optimal path solution. Their method hybridizes the Probabilistic Road Map (PRM) algorithm with the Information Search Algorithm.

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Probabilistic Roadmap algorithm is also used for cable harness route planning. A novel multi-branch cable harness layout design method is presented in [37], which unites the probabilistic roadmap method and the genetic algorithm.

Researchers in [38] present Temporal-PRM, a novel sampling-based path-planning algorithm that performs obstacle avoidance in dynamic environments. They show that their algorithm can run onboard a flying robot, performing obstacle avoidance in real time.

The study [39] proposes an improved probabilistic roadmap planning method for safe indoor flights based on the assumption of a quadrotor model UAV. The results showed that our method ensures safe indoor UAV flights while significantly improving computational efficiency.

Scientists in [40] developed a novel probabilistic roadmap algorithm, or node reduction-based search algorithm. They try to reduce the shortcomings of conventional algorithms in mobile robot path planning, such as long paths, random sampling and high collision risk.

Thus, we see that this algorithm is widely used to create various paths in a wide variety of areas. Next, we will consider the use of this algorithm to select the path of a mobile robot

Mathematical description of the Probabilistic Roadmap algorithm for planning the route for a mobile robot

The PRM (Probabilistic Roadmap) algorithm is a powerful method for planning routes for mobile robots in 3D space. Its main advantage is that it allows paths to be built in complex and dynamic environments, taking into account various constraints and obstacles. The way the algorithm works is that it creates a graph where the vertices represent valid positions for the robot, and the edges represent valid paths between these positions.

One of the key stages of the algorithm is the generation of random points in space, which can be used as potential vertices of the graph. Then, for each point, its connection to other points is checked through an obstacle collision check. If two points can be connected, then an edge is added to the graph between them.

One of the disadvantages of the PRM algorithm is that it can require a large number of points to construct the graph in complex environments. This can lead to high computational complexity and memory requirements. Additionally, PRM does not

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guarantee finding the optimal path because it operates on random samples and may miss better paths.

However, the PRM algorithm remains a popular choice for route planning in 3D space due to its efficiency and ability to work in a variety of environments. It can take into account complex obstacle shapes and dynamically changing conditions, making it applicable to a wide range of motion planning problems for mobile robots.

Let V be a set of graph vertices, where each vertex represents a point in space, E be a set of graph edges, where each edge connects two vertices, if these vertices can be connected without intersecting with obstacles, then:

$$G = (V, E) \quad (1)$$

G – routes graph;

V – graph vertices set;

E – graph edges set.

Let us denote by P_{start} and P_{end} – start and end points respectively.

Then the main steps of the PRM algorithm can be represented as follows:

– points generation:

$$V = \{P_{start}, P_{end}, P_1, P_2, ..., P_i, ..., P_n\} \quad (2)$$

P_{start} – start point;

P_{end} – end point;

P_i – randomly generated points;

– edge search:

$$E = \{(P_i, P_j) \mid C(P_i, P_j) = False\} \quad (3)$$

C – function for checking collisions between two points or their surroundings and obstacles;

P_i, P_j – randomly generated points and

– pathfinding (you can use standard pathfinding algorithms such as Dijkstra's algorithm or A* to find the optimal path between the starting and ending points).

This can be represented as follows: let P_{cur} be the current point on the path, be $N(P_{cur})$ the set of all neighbors of the poin P_{cur} t, $C(P_{cur}, P_{next})$ be a function that determines the cost of moving from point P_{cur} to point P_{next}, let $D(S_{start}, P_{end})$ be the

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length of the path from point P_{start} to point P_{end}. Then the path search can be described as follows:

– initialization:

$$P_{cur} = P_{start}, Path = \{P_{start}\}, Visited = \{P_{start}\} \quad (4)$$

Under the condition that while $P_{cur} \neq P_{end}$ then:

1. Selecting $P_{next} \in N(P_{cur})$, such that $P_{next} \notin Visited$ and $C(P_{cut}, P_{next}) \rightarrow \min$
2. Adding P_{next} to $Path$ and $Visited$
3. $P_{cur} = P_{next}$ and $Path$ is returned

Software implementation and experiments

To check the correctness of the reasoning, we will develop a program in Python in the development environment PyCharm 2022.2.3 (Professional Edition). Let us give an example of software implementation of the above described mathematical expressions.

```
# Generate PRM path
num_samples = 50
num_neighbors = 1
prm_path = generate_prm_path(start, end, obstacles, num_samples, num_neighbors, radius)
```

This code uses the previously defined start point, end point, obstacles list, and the num_samples, num_neighbors, and radius parameters to generate a path using the generate_prm_path function.

The num_samples parameter determines the number of random points that will be generated to construct the PRM graph, num_neighbors is the number of nearest neighbors taken into account when constructing the graph, and radius is the collision radius to check the intersection of points with obstacles.

After executing this code, the prm_path variable will contain the generated path from the start to the end point using the PRM algorithm.

```
# Rendering space with obstacles
for obstacle in obstacles:
    ax.plot([obstacle.x], [obstacle.y], [obstacle.z], color='black', marker='s')
```

This code is used to draw obstacles in 3D space on a graph. For each obstacle in the obstacles list, it calls the plot method of the ax object, indicating the obstacle's X,

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Y, and Z coordinates. The obstacles are displayed as black cubes (marker 's'). This code should be placed after the space is created and before the graph is displayed so that obstacles are added to the graph

```
# Draw start and end points
ax.scatter(start.x, start.y, start.z, color='g', marker='o')
ax.scatter(end.x, end.y, end.z, color='b', marker='o')
```

This code is used to draw the start and end points on the graph. It calls the scatter method of the ax object (coordinate axes) to display points with the coordinates of the starting point start and the end point end. The start point is shown with green color (color='g') and a circle marker (marker='o'), and the end point is shown with blue color (color='b') and a circle marker (marker='o'). This code should be placed after the obstacles are drawn and before the graph is displayed so that the points are added to the graph.

The following hardware was used for research: CPU Intel(R) Core(TM) i5-9300H CPU @ 2.40GHz, RAM 16 Gb, GPU NVideo GeForce GTX 1660Ti (Ram 8Gb), Web-camera HD WebCam, OS Windows 10 Pro (Version 22H2). A program for implementing route construction in 3-dimensional space based on the PRM algorithm was developed in the PyCharm 2022.2.3 (Professional Edition) environment in Python. The results of the program are presented in Figure 1.

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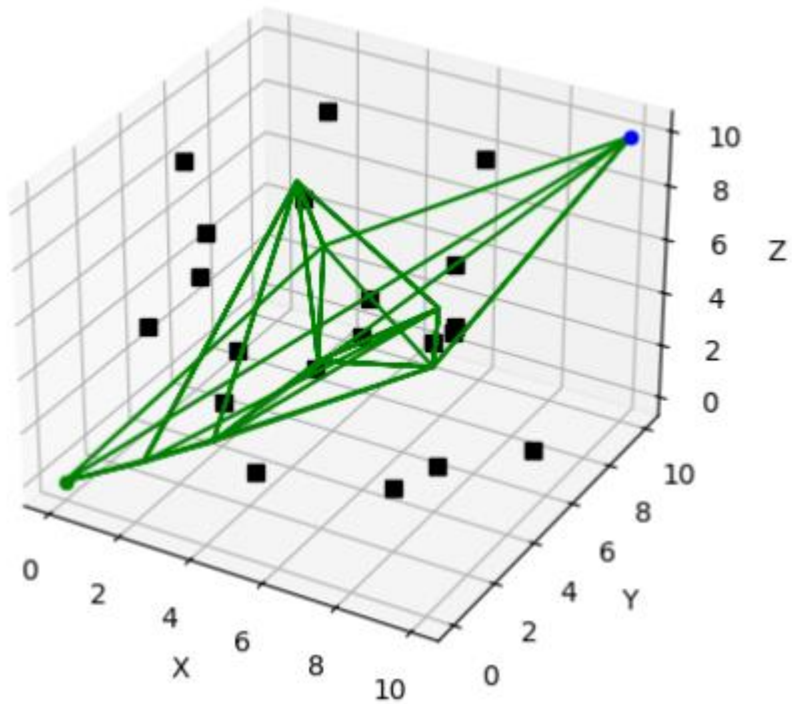
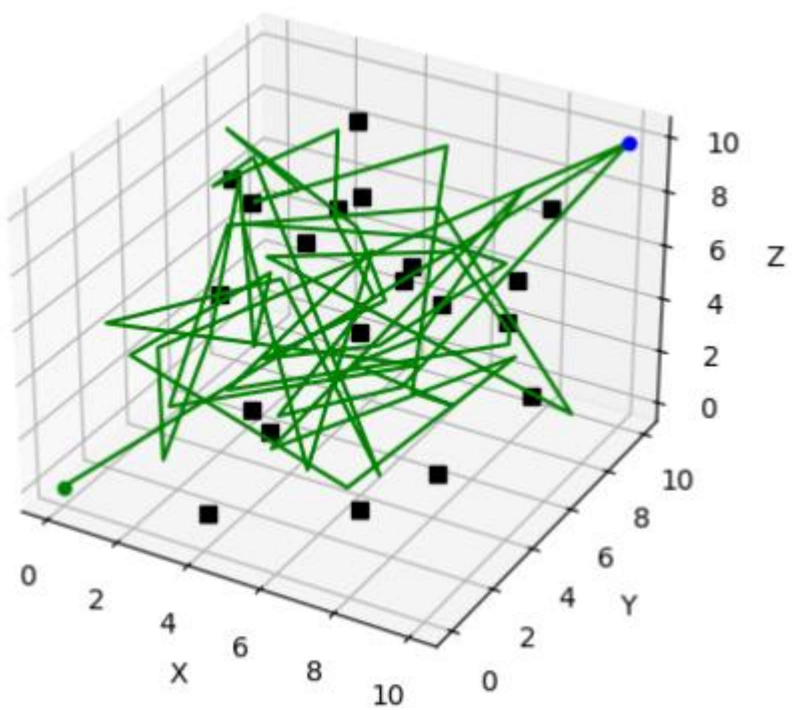


a) (num_samples = 10; num_neighbors=5)



b) (num_samples = 50; num_neighbors=1)

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Figure 1: Results of the program for constructing a route in 3D space based on the PRM algorithm

However, the PRM algorithm also has some disadvantages. It can require a lot of computational resources and time to build a route graph in complex environments. In addition, PRM does not guarantee that the optimal path will be found, since it is based on random samples of points and may miss more efficient routes.

To successfully implement the PRM algorithm, it is recommended to conduct a thorough analysis of the environment and its features to determine the optimal parameters for generating points and checking collisions. It is also important to take into account the limitations of the robot and the features of its movement when building a route.

CONCLUSION

The PRM (Probabilistic Roadmap) algorithm is an efficient approach to route planning for mobile robots in 3D space. It is widely used due to its ability to operate in complex environments with obstacles and dynamically changing conditions. The advantage of the algorithm is its probabilistic nature, which allows it to take into account random factors and uncertainty in the environment.

One of the key benefits of PRM is the ability to build a path that takes into account the shape of obstacles and optimal use of available space. This makes it suitable for tasks where it is necessary to avoid collisions with obstacles and find the optimal route given various constraints.

To successfully implement the PRM algorithm, it is recommended to conduct a thorough analysis of the environment and its features to determine the optimal parameters for generating points and checking collisions. It is also important to take into account the limitations of the robot and the features of its movement when building a route.

Overall, the PRM algorithm is a powerful tool for planning routes for mobile robots in 3D space, which can take into account complex environmental conditions and ensure safe and efficient robot movement.

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