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Study of global path planning for ground robots in complex 3D terrain

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1. Introduction

The role of robots in critical incidents, such as radiation leaks, has become increasingly important. The ability of robots to navigate autonomously is required when human access is not possible. Path planning is an important part of the autonomous mission. There is a lot of research on two-dimensional path generation. However, in the indoor area of a nuclear power plant, obstacles such as stairs and berms are present, so three-dimensional path generation is required in such terrain.

Wheeled and tracked ground robots have been widely used for missions such as rescue [1]. Tracked robots are well suited to missions with complex terrain, including ramps, steps, and stairs, due to their track and flipper characteristics. The autonomy of ground robots is important to perform missions without human assistance. Global path planning methods for 3D complex terrain have an important role to play in terms of autonomy. Path planning methods such as Dijkstra, A*, D* lite, RRT* have been successfully applied to various applications such as robots, cars, etc [2].

In this paper, we consider the 3D terrain of stairs in a nuclear power plant and perform global path planning for a ground robot using Dijkstra and A* algorithms.

2. Methods and Results

In power plants, there are many obstacles such as machinery and tubes, and the passageways such as stairs and corridors are narrow. In order to perform tasks in such environments, path planning plays a very important role. Path planning is divided into global path planning and local path planning, and this paper performs global path planning. Global path planning is a high-level planning method that calculates a path between a starting point and a goal point by receiving information of a map recognized by various methods (i.e. camera or lidar). The path calculated by this method is used as an input for local planning methods.

In this paper, global path planning for ground robots was performed for complex terrains with stairs and multiple floors. To simplify the problem, it was assumed that an occupied map like Figure 1 was known. Figure 1 includes two floors, two stairs, and several obstacles on each floor. The strategy for 3D terrain path planning is as follows: divide the terrain into regions according to each floor and stairs, and select multiple mid-waypoints to determine each starting and goal point. As a result, the entire problem is divided into sub-planning methods for each region. The overall path can be calculated by integrating the calculated sub-planning problems.

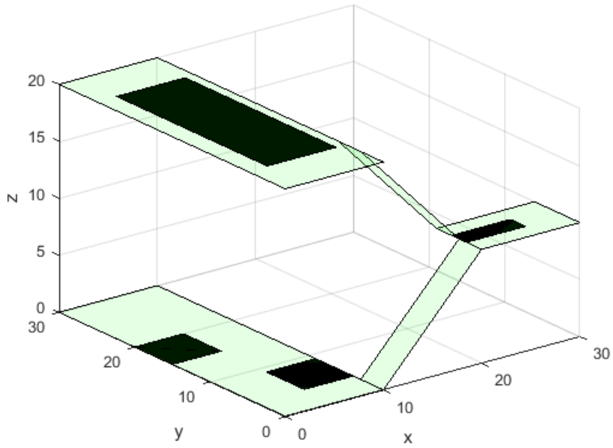

Fig. 1. A 3D occupied map that contains complex terrain features such as stairs and narrow passages (Black: obstacle, yellow: traversable).

For sub-planning problems, an arbitrary node was assigned to each region and the graph was connected. The graph is connected by straight lines between all nodes while avoiding areas with obstacles. If the number of nodes is small, it may not be possible to create a graph that can be traversed by obstacles to reach the goal. In contrast, if the number of nodes is large, the computation time will be very high because the graph is connected between each node. It is important to choose the right number of nodes by making trade-offs. Figure 2 shows the graph with connections between each node.

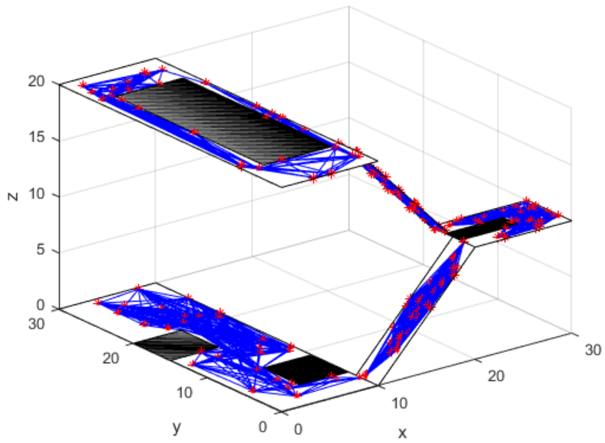

Fig. 2. Graph connectivity in 3D terrain for global path planning.

Then, Dijkstra and A* path planning algorithms were used to calculate the paths. The difference between the two algorithms is in the way of searching nodes or cells. A* method uses heuristics and has a smaller frontier.

The common point between the two algorithms is that they both minimize the cost of the path. Simulation results showed that the path cost calculated using Dijkstra's algorithm and A* algorithm was the same at 106.0389. The calculation time increases depending on the number of nodes. Figures 3 and 4 show the results of path generation using the Dijkstra and A* methods, respectively.

In this study, the path was calculated using 30 nodes per region. In this case, it took about 1.11 seconds to generate the nodes and graph for the given map. The resulting computation time for the Dijkstra and A* methods to find a path to minimize the graph length was 109ms and 99ms, respectively.

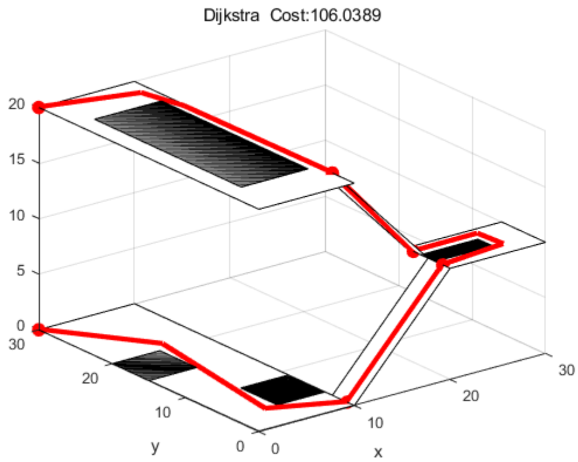

Fig. 3. The global path planning results using the Dijkstra algorithm.

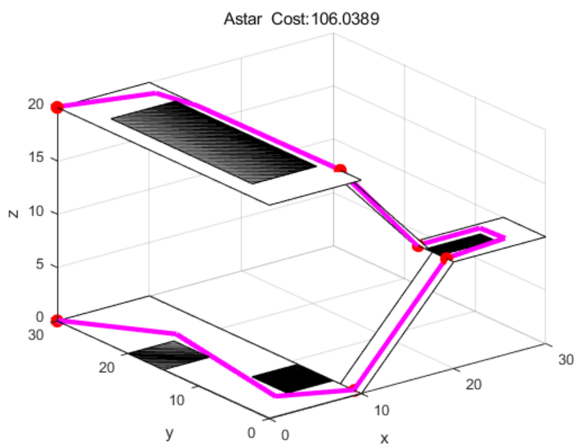

Fig. 4. The global path planning results using the A* algorithm.

Finally, since the ground robot maneuvers on a 2D surface, the generated 3D graph must be converted to 2D. In this paper, the normal vector of the terrain was calculated using the generated graph. Using this value, the tilt angle of the 3D terrain was calculated and applied to the coordinate transformation matrix (CTM). As a result, the 3D path is represented as a 2D path and provided to the ground robot. Figure 5 shows a schematic view for projecting a 3D path onto 2D plane.

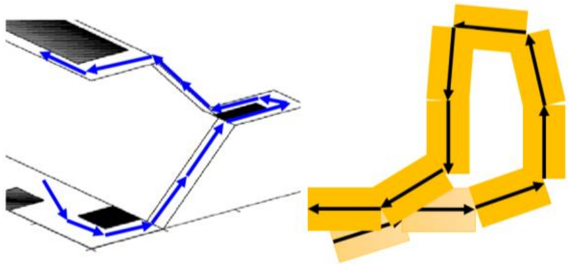

Fig. 5. Schematic view for projecting 3D paths onto 2D plane (Left: 3D path, right: 2D path).

To get the projected 2D path, follow the steps below. Calculate the normal vector using Equation (1) and substitute it into Equation (2) to get the tilt angle. Finally, use Equation (3) to get the projected 2D path using CTM [2].

$$\mathbf{n}_1 = \frac{(\mathbf{r}_0 - \mathbf{r}_1) \times (\mathbf{r}_1 - \mathbf{r}_2)}{\|\mathbf{r}_0 - \mathbf{r}_1\| \|\mathbf{r}_1 - \mathbf{r}_2\|} \quad (1)$$

$$\theta = \cos^{-1}\left(\frac{\mathbf{n}_1 \cdot \mathbf{n}_z}{\|\mathbf{n}_1\| \|\mathbf{n}_z\|} \right) \quad (2)$$

$$\mathbf{r}_{0,proj} = \mathbf{T}_{3\times 3}(\theta)(\mathbf{r}_0 - \mathbf{r}_1) + \mathbf{r}_1 \quad (3)$$

where $\mathbf{r}$ is the position vector of the node, $\mathbf{T}$ is the CTM, and $\mathbf{n}_z$ is the z-directional normal vector.

3. Conclusions

In this paper, we performed global path planning for a ground robot in a narrow and complex terrain, such as the interior of a power plant. Each floor contains various sizes of obstacles and narrow passages. To perform path planning in such terrain, we classified the terrain into regions and used waypoints to solve sub-planning problems in each region. Finally, the paths in each region were connected to calculate the overall path and projected onto a 2D plane. The research results of this paper are expected to be applied to autonomous driving of ground robots in complex 3D terrains such as the interior of a nuclear power plant.

REFERENCES

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