Route Planning Algorithm in FRA Based on Lazy Theta* Algorithm

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Abstract. Aiming at the problem of route planning in FRA, this paper proposes a route planning algorithm based on Theta * algorithm. After discretizing the free route airspace into unity cells, algorithm based on lazy Theta * algorithm is used to find the shortest path from the entry node to the exit node. Compared with the traditional A* algorithm, the algorithm proposed in this paper plans the route more smoothly.

Keywords: lazy Theta*, route planning, shortest path problem

1 INTRODUCTION

The problem of air routing is to find route between departure and destination airports. Many previous solutions relied on predefined topology of airways [1-2]. Here we focus on routing in Free route airspace (FRA) where there are no fixed air traffic service (ATS) routes. FRA is an important part of the single European sky ATM research (SESAR) project. It is an important measure to expand the airspace capacity and increase the air traffic efficiency. At present, 3/4 of the airspace in Europe is based on free route airspace. In FRA area, airlines can freely plan their routes between predefined entry points and exit points without referenced to fixed ATS routes, which helps airlines to reduce aircraft flight time, fuel consumption, flight cost and carbon emissions.

Given the starting point and the end point, the problem of finding the shortest path is called route planning. Route planning is a complex multi-constrained conditional optimization problem, which has a wide range of application scenarios in the fields of unmanned aerial vehicles [3-4], robots [5-7], game maps [8] and etc. Classic route planning algorithms include A* algorithm, Dijkstra algorithm, genetic algorithm, ant colony algorithm and etc.

2 PROBLEM DEFINITION

Since there are no predefined air routes in FRA, topology need to be generated artificially before routing planning algorithms can be applied. The free route airspace is discretized into unity cells as shown in Fig.1. Graph nodes are located at cell centers. Although there are no fixed air routes in FRA, there are some areas that are not allowed to enter due to military

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restrictions or adverse weather. The shapes of unavailable areas are irregular. To simplify the problem, rectangular envelope is used to represent the unavailable area. Although the unavailable areas will be expanded, the planning efficiency can be greatly improved. The grey cells in Fig. 1 represent unavailable areas while the white cells represent available areas. The problem is to find the shortest path from the entry node S and exit node T avoiding unavailable cells in graph G.

$G=(V,E)$

v : nodes in graph G

V : set of nodes in graph G, $V=\{v_1,v_2,\ldots,v_n\}$

e : edges in graph G

E : set of edges in graph G, $E=\{e_1,e_2,\ldots,e_n\}$

S, T : the entry node and exit node respectively

The optimization objective is to find a path with lowest fuel consumption from the entry node S to the exit node T. The cost of an edge is the fuel that an aircraft consumes to fly through it. Unlike many network optimization problems, the cost associated with each edge in aircraft route planning is not a simple value that can be pre-computed, since these costs depend on the state of the aircraft at the initial node of the edge and the meteorological conditions on this edge. For simplicity, we make the following assumptions:

1. Assume that the edges are short enough and the weight of the aircraft does not change when fly through an edge.

2. Suppose that the landing weight of the aircraft is 0. So the aircraft weight at the initial point of an edge can be estimated by the Euclidean distance between its initial node and the exit node T.

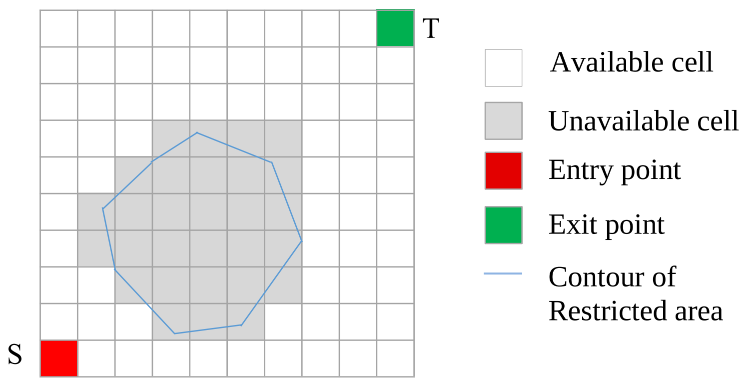

Fig.1 An example of FRA airspace

3 SOLUTION APPROACH

A* algorithm is a commonly used heuristic route planning algorithm, which seeks the optimal path by constantly evaluating the cost of search nodes in the search space. The estimation function of A* algorithm can be defined as:

$$f(n) = g(n) + h(n) \tag{1}$$

Where $g(n)$ represents the route cost from the entry node s to the current node n, and $h(n)$ represents the estimated route cost from the current node n to the exit node t. A* algorithm maintains two lists, the open list stores the node expansion priorities and the close list stores the updated points. A* algorithm can quickly find a path in the graph, but since it must search along the grid so the shortest path it finds is not smooth.

In order to solve the above mentioned problems of A* algorithm, researchers proposed some improved algorithm. Nash et al [9] proposed Theta* algorithm, which combines the advantages of traditional A* algorithm and visual graph based A* algorithm in the path search process, which reduces the number of path turns and makes the route smoother. In A* algorithm, the parent node of a node must be adjacent to that node, while in Theta* algorithm, there is no such limitation, thus it can find path with any-angle.

Steps of Theta* algorithm:

1) Initialize a open list and a close list, insert the starting node S into the open list;

2) If the open list is null, then the search process fails, exit the process;

3) Remove the node with the lowest path cost $f(n)$ from open list and insert it into the close list as the current node n.

4) If the current node n is the target node d, backtrack to the starting point through the parent node p (n) of node n, that is, find the path node set, and the algorithm search process ends. If node n is not the target node d, execute 5).

5) Perform the following operations on each node n' in the adjacent node set N (n) of node n: if node n' is in the close list, then ignore node n ', otherwise execute 6).

6) Calculate the cost of node n' and do the line of sight check for node p (n) and node n'.

7) Sort nodes in open list by path cost, go to 2).

Euclidean distance is used to evaluate the estimated cost, and the cost function of Theta* is equation (2):

$$d = \sqrt{(x_{\mathrm{n}} - x_{\mathrm{T}})^2 + (y_{\mathrm{n}} - y_{\mathrm{T}})^2} \tag{2}$$

Where (x_n, y_n) and (x_T, y_T) are the coordinates of the current node and the sink node T respectively.

Lazy Theta* algorithm [10] is an improvement to Theta* algorithm, which reduces the number of line of sight checks by optimistically believes that the current node n is visible to parent(n) and directly add it to the open list. When expanding with n' from open list, check its visibility with parent(n). If it is visible, find the next adjacent point, if not, find the adjacent parent node from the close list. Since line of sight checks only performed for nodes that been expanded, the amount of computation significantly reduced.

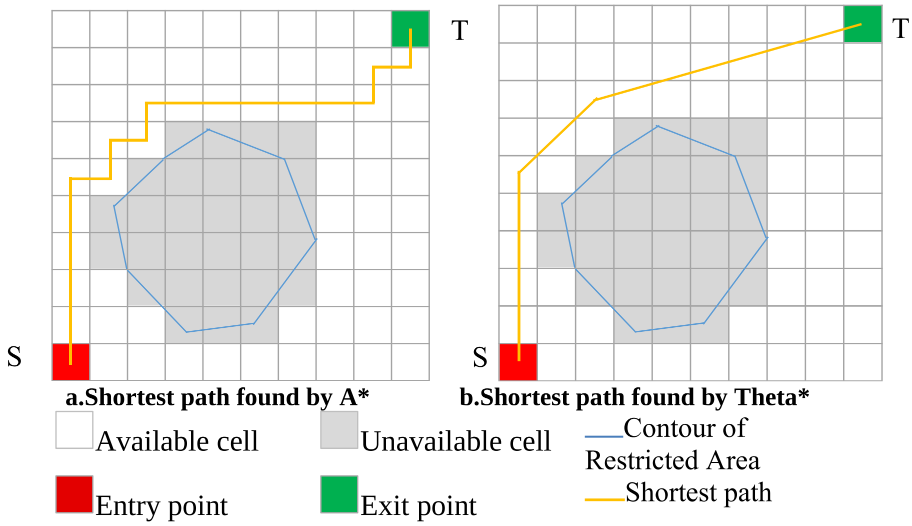

Fig.2 Shortest path find by A* and Theta* algorithm

Fig.2 gives the shortest path found by A* algorithm and shortest path found by Lazy Theta* algorithm for the example in Fig.1. The shortest path found by Lazy Theta* algorithm is smoother than that found by A* algorithm.

4 CONCLUSIONS

Here we proposed a lazy Theta * algorithm to solve the routing problem in FRA. Compared with the traditional A* algorithm, the algorithm proposed in this paper plans the route more smoothly.

Since the number of LOS checks is reduced in lazy Theta* algorithm, the search time of lazy Theta * algorithm is also improved compared with traditional Basic Theta * algorithm.

In this article, we've made an assumption that the aircraft weight is not changed along an edge, in future work, we may model the fuel consumption more precisely.

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