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The application of Voronoi algorithm in the planning of forest-fire

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Abstract. Voronoi graph method is used for forest-fire relief supplies' shortest way of planning. Global path planning model has been established initially based on Voronoi and Geography Information System (GIS) method. Ellipse model is used to express forest fire spread region. For simplified computation, the excircle of the ellipse instead is utilized to calculate threat degree, which also makes the planned route has bigger security. In order to enhance flight vehicle's feasibility, smooth processing carries on above path's elevation by grade limitation smooth algorithm and curvature limit smooth algorithm. The simulation result shows: this simple plan method might effectively solve the problem of vehicle's 3D global path planning, simultaneously also lay the foundation for the actual flight in dynamic flight path planning.

1. Introduction

Forest fires bring harm and loss to forests, forest ecosystems, and human beings. Forest fire is a kind of natural disaster which is sudden, destructive and difficult to deal. With the protection of forest resources and the emphasis on forest fire prevention and fighting in the world, how to fight forest fires faster and better has become an important research topic under the basic premise of adhering to the general principle of fire safety and ensuring the life safety of firefighters [1]. Therefore, how to quickly and accurately deploy and concentrate fire resources on the fire scene at the critical moment has an important impact on the success or failure of disaster relief work. In this way, on the one hand, rescuers can get real-time fire information to provide a basis for fire commanders to make fire extinguishing decisions, on the other hand, it can reduce the possibility of connecting fire sources, thereby reducing the losses caused by fire [2-6].

In forest fires, surface fires burn along the surface of trees faster, requiring more rescue forces and equipment. Portable backpacks and pumps (where water supply is available) and fire lines are preferred methods. These can be said to be very labor-intensive work, unless as there is machinery in flat areas that can be used to clear shrubs along fire lines, which is blocked by very complex terrain of forests.

2. Voronoi Path Planning Method

2.1. Voronoi graph method

Voronoi graph, also known as Tyson polygon or Dirichlet graph, consists of a group of adjacent polygons composed of vertical bisectors connecting two adjacent points. Given N different points on a plane, the plane will be divided according to the nearest neighbor principle; each point is associated with its neighbor region. From the characteristics of Voronoi graph: the edge of Voronoi graph is the farthest from the point it contains (i.e. dangerous point), we choose the edge of Voronoi graph as the route planning section.

Voronoi diagram has some features: 1. Each Tyson polygon contains only one discrete point data. 2. The distance between the points in the Tyson polygon and the corresponding discrete points is the closest.3. The distance from the point on the edge of the Tyson polygon to the discrete points on both sides is equal.

2.2. Main ideas of algorithms

Voronoi diagrams are constructed by using known fire source centers (represented by discrete points or nodes). Then, three points (plus two upper endpoints) are selected on each edge of Voronoi graph to calculate the weights at each point to replace the weights of the whole edge, and a threat weighted graph based on Voronoi graph is constructed in the study area. Then, the weighted Voronoi graph are obtained by superimposing various fire threat Voronoi graph and threat weighted graph. Then Dijkstra search algorithm is used to calculate the shortest flight path with the smallest total threat value, that is, the optimal path. On the basis of Voronoi graph, the elevation of the corresponding track points is calculated by using GIS method, and then the vertical track is planned by using gradient restriction algorithm and curvature restriction smoothing algorithm (because the path only meets the minimum threat and the short path does not necessarily satisfy the flyability of aircraft, so it is necessary to smooth it. Finally, actual topographic map is used to draw the three-dimensional track, and the cubic spline interpolation is used to optimize the processing.

2.3. Calculating track cost using weighted Voronoi graph

When the aircraft carries out the task of delivering rescue resources, the planned flight path is required to enable the aircraft to find the safest, shortest and farthest flight path from each fire source: avoid fire threat and terrain obstacles as far as possible, shorten the flight distance as possible, and meet the maneuverability constraints [7-8].

2.3.1. Terrain threat. Terrain threat is a complex terrain, such as mountains and hills, which may pose a threat to flight when an aircraft carries out the task of delivering rescue resources. In this paper, terrain threat is simulated by real terrain in a certain area.

2.3.2. Threat Cost Calculation of fire Source. The threat cost of fire source is related to the distance between fire source and aircraft, the size of fire source and the direction of fire source. Let d_{Mmax} be the maximum radius of fire source at present. In order to ensure the safety of track, a 2 km buffer band is chosen. The size of the threat in the buffer band is inversely proportional to the minimum distance (d) to the fire source threat zone. Then the size of the fire source threat to one side of Voronoi diagram is shown in formula (1):

$$P_M(d) = \begin{cases} 0 & d > d_{M\max} + 10 \\ 1/d & d_{M\max} + 10 >= d > d_{M\max} + 2 \\ 1 & d < d_{M\max} \end{cases} \tag{1}$$

Similarly, the cost of fire threat at the edge of Article I is:

$$J_{rt} = L_i \sum_{j=1}^{N} \left(\frac{1}{d_{\frac{1}{6}ij}^4} + \frac{1}{d_{\frac{1}{2}ij}^4} + \frac{1}{d_{\frac{5}{6}ij}^4} \right) \tag{2}$$

2.3.3. Threat cost calculation of fire source. After Voronoi graph is formed, the main problem of reference path generation is to calculate the cost of each side. The cost of each point on each side can be calculated discretely, that is, it is divided as three parts: terrain threat cost, fire threat cost and fuel cost. L_k represents the k Voronoi edge, and its threat cost J_{tk} is a function of the distance from M track points on each edge to N threats. Then the threat cost function formula is:

$$J_{tk} = L_k \sum_{j=1}^{N} \sum_{i=1}^{M} g(d_{i,j}) \tag{3}$$

$$g(d_{i,j}) = \begin{cases} k_T P_T(d_{i,j}) & (Terrain\ threat) \\ k_R P_R(d_{i,j}) & (Fire\ threat) \end{cases} \tag{4}$$

Assuming that the cruise speed of the flight is constant, fuel cost is proportional to the length of the path, which can be expressed as formula (5). The total cost of one side is shown in formula (6):

$$J_{fk} = k_f L_k \tag{5}$$

$$J_k = w J_{tk} + (1-w)\ Jfk \tag{6}$$

k_T, k_R, k_f and w are dynamic weighting factors, reflecting the weights of each threat source and fuel cost. The determination of weighting factor requires that the value of each weight should be selected according to the constraints of each threat source and specific aircraft type.

3. Threat model optimization and track smoothing

3.1. Threat cost calculation of fire source.

At present, most of the forest fire diffusion models are elliptical [7-11], but the calculation of threat size using elliptical model is complex, and the direction of ellipse is constantly changing with the change of wind direction, which is not conducive to the timely formulation of flight routes. In this paper, a large circle tangential to the ellipse is used. This method is not only simple in calculation, but also suitable for ellipses in different directions. At the same time, because the area of the tangential circle is larger than the ellipse, the planned track has greater security.

3.2. Track smoothing

In order to ensure the safety of penetration flight, track smoothing with real map is met through elevating whole terrain to airplane's safe height, while ensuring that it meets the requirements of aircraft manoeuvrability. Literature [12] proposes a method of smoothing the whole map before planning, obtaining a comprehensive equivalent terrain surface, and then trajectory planning on this surface. On the basis of reference [12], this paper adopts the optimization method: lifting the vertical plane topographic profile containing horizontal track upward 150 meters (minimum distance above ground), then smoothing the vertical track, which greatly reduces the amount of calculation and improves the calculation efficiency.

Track smoothing includes the limits of climb angle, normal overload. In smoothing process, the terrain slope and curvature are respectively confined into operable scope. If one track point failed to the requirements of slope or curvature detected, it will be lifted to a minimum value, as a result, the whole terrain elevation is adjusted by the integral iteration method accordingly.

4. Simulation analysis

In the space of 20 km x 20 km, starting point coordinates (22.40 km, 5.41 km, 0.404 km) and target point coordinates (22.46 km, 5.398 km, 0.484 km) are used to construct a two-dimensional Voronoi graph using the known location of the ignition source. The simulation results are shown in Figure 3. In this paper, the pitch angle of the aircraft is set between - 10 degree ~20 degree. The trajectory planning time is 0.359 seconds. Using the results of Figure 1, optimal methods of slope, curvature, and three-dimensional track (Figure 2) and its mapping are obtained in Figure 3.

It can be seen that the trajectory obtained by this method can basically follow the terrain contour, and avoid the large obstacles when the performance constraints of the aircraft are satisfied; and the

trajectory can be adjusted in real time when the wind direction changes, resulting in the change of the threat source by a quick response.
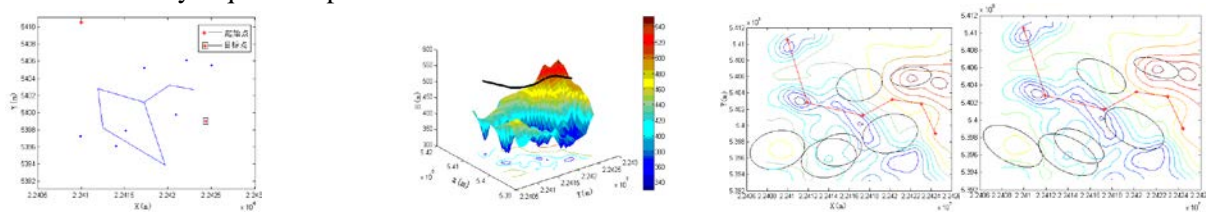

Figure 1. Fire Threat Voronoi Diagram. **Figure 2.** Three-dimensional track display. **Figure 3.** Track with contours.

5. Conclusion

Voronoi diagrams use graphics to express the path to be chosen intuitively and clearly. In this paper, we use Voronoi graph, slope restriction smoothing algorithm and terrain curvature restriction method to plan the three-dimensional trajectory of forest fire transportation resources. In order to ensure the effectiveness of trajectory planning, this paper uses actual terrain data to plan three-dimensional trajectory, so it has great practical value. At the same time, the tangential circle of ellipse is used instead of ellipse in calculation, which has the advantages of simple calculation and wide adaptability. the constraints of flyability and minimum cost of flight are additionally considered comprehensively, so that the planned trajectory takes into account both the requirements of optimality and practicability; and the geographic and topographic information is fully taken into account to make the trajectory avoid ground and fire threats possible.

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