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Research on UAV scheduling problem in fire

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Abstract: Drones have been very important in the Australian forest fire's rescue activity. As one of the most severely affected areas the fire, Victoria deservedly has more demands for drones with different functions. Considering the risk, terrain, observation and communication mission requirements and other factors, we first establish a cost model. Then, the minimum spanning tree algorithm is combined with the three-dimensional spatial data of longitude, latitude and altitude of all five points at a certain time in 2019 to get the shortest path. Finally, the optimal number of SSA UAVs and radio relay UAVs is determined.

1. Introduction

Every year, Australia goes through the test of bushfires. Starting in 2019, devastating wildfires have occurred in all states of Australia. In the fire rescue, drones played a vital role. There are two main types of drones: SSA drones and Radio Repeater drones. SSA drones carry high-definition and thermal imaging cameras and telemetry sensors to monitor and report data from wearable devices for frontline personnel. Radio Repeater drones are used to greatly expand the range of front-line low-power radios and play a role in signal transmission. Thus, it is crucial to assess the optimal number of these two drones and their combinations to help the Victorian government to put out fires at the lowest cost as quickly as possible.

2. Establishment of Cost Model

2.1 Generating undirected weighted graph

We selected August 2019 as the sample representative for the study of our paper. Then we determined the range of Victoria based on the latitude and longitude, and randomly selected data of all fire points in Victoria at a certain time on August 1, 2019 for visualization (5 fire points) in the state. The points can be seen in Figure1.After that, we calculated the horizontal distance between the fire points according to the latitude and longitude relationship between the fire points. Taking into account the influence of the terrain, the altitude of different fire points was obtained through the topographic map of Victoria, Australia combined with the latitude and longitude information, and the altitude between every two fire points Use the Pythagorean theorem to obtain the relative spatial distance between different ignition points at this moment, and combine the visualization results to obtain an undirected weighted graph between the ignition points. The graph is shown in Figure 2.

2.2 Calculating Shortest Path by Dijkstra Algorithm

Dijkstra algorithm is the shortest path algorithm from one vertex to the other vertices. It adopts the greedy algorithm strategy, each time it traverses to the adjacent node of the vertex that is closest to the starting point and has not been visited, until it expands to the end point [1]. The shortest path is shown in Figure 3.

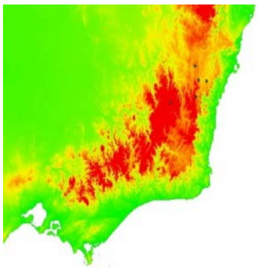

Figure 1: 5 fire points

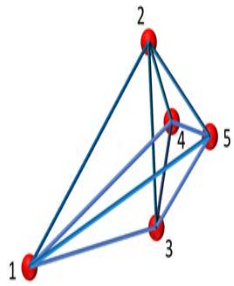

Figure 2: Undirected weighted graph

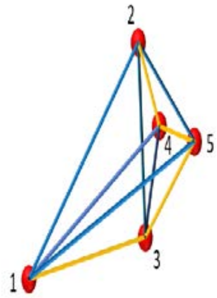

Figure 3: The shortest path

We use matlab to implement the Dijkstra algorithm and get the path from each starting point, the total length of the 5 paths are shown as follows. We can find that the length of 2→4→5→3→1 is the shortest, which means that the shortest length of path is169.416km and the path is shown in figure in orange.

Table 1

Path	Length (km)
1→3→4→2→5	187.968
2→4→5→3→1	169.416
3→4→5→1→2	274.954
4→5→2→3→1	207.284
5→4→3→2→1	236.954

2.3 Cost Model and Results

We take expenditure minimization as the overall goal which incorporates other four factors and build a cost model. We firstly made a total cost equation:

$$Z = x \cdot c + y \cdot b \tag{1}$$

Where Z is the total cost. x is optimal numbers of Radio Repeater drones, y is optimal numbers of SSA drones, b is 10000 Australian dollars, c is the total cost of per Radio Repeater drone.

In terms of the total cost of per Radio Repeater drone, we divide the total cost of a single Radio Repeater drone into three parts: purchase cost, path cost, and communication cost. The purchase cost is $10,000 per drone based on known information. The path cost per drone is calculated as follows:

$$c_p = \frac{dis_{sum}}{c_f} \tag{2}$$

Where c_p is path cost, dis_{sum} is the sum of the shortest path length modified by the fire risk factor, c_f stands for flight cost per km.

Our flight cost is directly replaced by the electricity cost required for charging the lithium battery. Therefore, it can be calculated that the flight cost of a UAV flying 1km is 0.18354 cents. That is to say, c_f is 0.18354 cents. dis_{sum} is expressed as follows:

$$dis_{sum} = \sum_{n=1}^{4} dis_n \cdot \alpha_n \tag{3}$$

$$dis'_n = dis_n \cdot \alpha_n \tag{4}$$

Where dis_n is the distance of each straight line in the shortest path we got above, n indicates the number of line segments, α_n is fire risk factor, dis'_n is the distance of each straight line in the shortest path modified by the fire risk factor. As for α_n, we only consider the influence of fire radiation power and fire frequency on it. Since the fire radiation power and the fire frequency are independent of each other, we try to use the linear weighting method to express as:

$$\alpha_n = w_1 u_n + w_2 f_n \tag{5}$$

Where u_n is fire radiation power of each path, f_n is frequency of fire in each path, w_1 is weights of u_n, w_2 is weights of f_n. As for w_1 and w_2, we use the entropy method to objectively determine the weight. The calculation steps of the entropy method are roughly divided into the following three steps:

Step1: Determine whether there are negative numbers in the input matrix, and if so, re-normalize to a non-negative interval.

Step2: Calculate the proportion of the i sample under the j index and regard it as the probability used in the calculation of relative entropy.

Step 3: Calculate the information entropy of each indicator, calculate the information utility value, and normalize to get the entropy weight of each indicator.

Through the above calculation, we can get the weight of available fire radiation power is 0.181, and the weight of fire frequency is 1. So we can obtain the expression of the fire risk coefficient as:

$$\alpha_n = 0.181 u_n + f_n \tag{6}$$

Substituting the average flame radiation power and total fire frequency of each path in the optimal path into equation (6), we can calculate that $\alpha_1 = 2.4887, \alpha_2 = 3.5656, \alpha_3 = 3.0679, \alpha_4 = 2.9231$ combined with the length of each line segment in the shortest path we obtained above, we can further get 501028.4 meters, $dis'_1 = 83289.32, dis'_2 = 76400.11, dis'_3 = 139405.4, dis'_4 = 201933.6$.

The communication cost is related to the distance of the target position (fire points). Combined with the communication signal attenuation formula in free space [2] below:

$$Lbf = 32.5 + 20\lg F + 20\lg D \tag{7}$$

The path cost can be expressed as follows:

$$c_{com} = 20 * \lg(\frac{dis_{sum}}{c_f}) \tag{8}$$

Therefore, we can get equation(9):

$$c = x \cdot \left(10000 + \frac{dis_{sum}}{c_f} + 20 \cdot \lg\left(\frac{dis_{sum}}{c_f} \right) \right) \tag{9}$$

Eventually, we can get the equation of total cost:

$$Z = 12799x^2 + 10000y \tag{10}$$

Since each ignition point is approximated as a circular point to measure, and the signal transmission range of the SSA drones is assumed to be infinite, the problem of the number of SSA drones is equivalent to the problem of the number of ignition points. At the moment, there are 5 ignition points, and the optimal number of solid SSA drones is 5.

$$x_n = \left(dis'_n - m\right)/t \tag{11}$$

Considering that the fire point is a forest area, it will have an impact on the ultra-high frequency (VHF)/very high frequency (UHF) signal, that is to say, m is 2000 meters, combined with the value of t ($t = 20000m$)from the formula (11) and we get the best amount of Radio Repeater drones is 26.

Considering that the fire point is a plain area, the terrain is flat, and there are no obstructions, that is to say, m is 5000meters. Then according to the above formula (11) and the optimal number of Radio Repeater drones is 25.

3. Model Evaluation

When establishing cost model, we consider the influence of different topography on the relative distance between fire points, when calculating the distance between different fire points, we calculated the distance in the three-dimensional space of longitude, latitude and terrain height, which improved the accuracy of the model and ensured that no one The optimal placement of the machine.

When calculating the shortest path, we selected different ignition points as the starting point, respectively calculated the shortest path obtained from different starting points, and then compared the shortest path at an optimal starting point, so that the mobile EOC can be deployed in the most economical UAV.

When calculating the optimal number of radio-relay drones, we split the path between every two adjacent fire points in the shortest path, and calculated the optimal number of radio-relay drones on each path.

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[2] Ma Chunchao, Yin Dong, Zhu Huayong. Multi-UAV scheduling problem in a networked battlefield environment [J]. Firepower and Command Control, 2015, 40(10): 31-36.