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Establishment of UAV Path Planning Model Based on Ant Colony and Simulated Annealing Algorithm

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Abstract: This paper is about the optimal allocation, optimal path planning and optmization of two kinds of UAV (SSA UAV and Radio Relay UAV). Describes the planning and allocation of unmanned aerial vehicles (UAVs) for wildfire rescue and reconnaissance operations in Australia. First of all, we build model using analytic hierarchy process (AHP) and simulated annealing algorithm to determine the constraint conditions, considering safety, capacity, economy, Victoria region of the terrain and the size of the fire, frequency and other factors, through the branch and bound method of integer to get optimal allocation of unmanned aerial vehicle (UAV) is out of the optimal route. Secondly, we use ant colony algorithm to optimize the three-dimensional path of the UAV and plan it. Finally, we use MATLAB to consistency check, to get a comparison matrix, and then the weights for each survey and plan the best path, so as to determine the optimal number of drones and combination, and analyzes the error of the model, to ensure the accuracy of the models.

1. Introduction

In today's era, everything we do needs to be reasonably planned and distributed. However, in our production and life, we also need to be reasonably planned and distributed so as to save costs. And in the background of this paper is to build a fire season in Australia in the eastern part of new south wales and Victoria wildfires. The Australian National Fire Agency (CFA) intends to deploy the Emergency Operations Centre (EOC) in the vicinity of the most severe wildfire areas as the command center and control point for emergency related actions and activities and requires SSA and Radio Relay UAVs as auxiliary tools to engage in fire-fighting, information transmission and rescue operations. In order to save and reduce costs, this paper will briefly introduce how to establish the best mathematical model to solve the problem of UAV allocation and planning in fire.

So we need to build a model that can plan the optimal number and combination of the two types of Drones, and this model needs to weigh the two types of Drones in terms of capability and safety versus economy, and also take the requirements of the mission and terrain, and the size and frequency of fire events as parameters.

2. Drone Planning and Allocation Model

Firstly, the southeast of Australia was modeled. Considering the geographical environment and fire characteristics in the southeast of Australia, 1 UAV was selected to build the basic model [1], the economic problem faced by UAV flight is related to flight path, that is, to solve the shortest total flight path. We used the simulated annealing algorithm to plan the shortest path and selected the wildfire hot spot in August 2019 as the reference data.

According to the known data, after analyzing the problem, we find that this kind of optimization problem has a lot of similarity with the steps of the simulated annealing algorithm, and the simulated annealing algorithm can solve the problem well.

2.1 Construction of This Model

The total sample is the wildfire hot spots in August 2019 in southeastern Australia [2]. To avoid the contingency caused by too few samples, we selected several major nodes in southeastern Australia as drone passing nodes [3]. We selected 300 from the total sample and numbered the wildfire hot spots in southeastern Australia successively as 1,2,3...300.

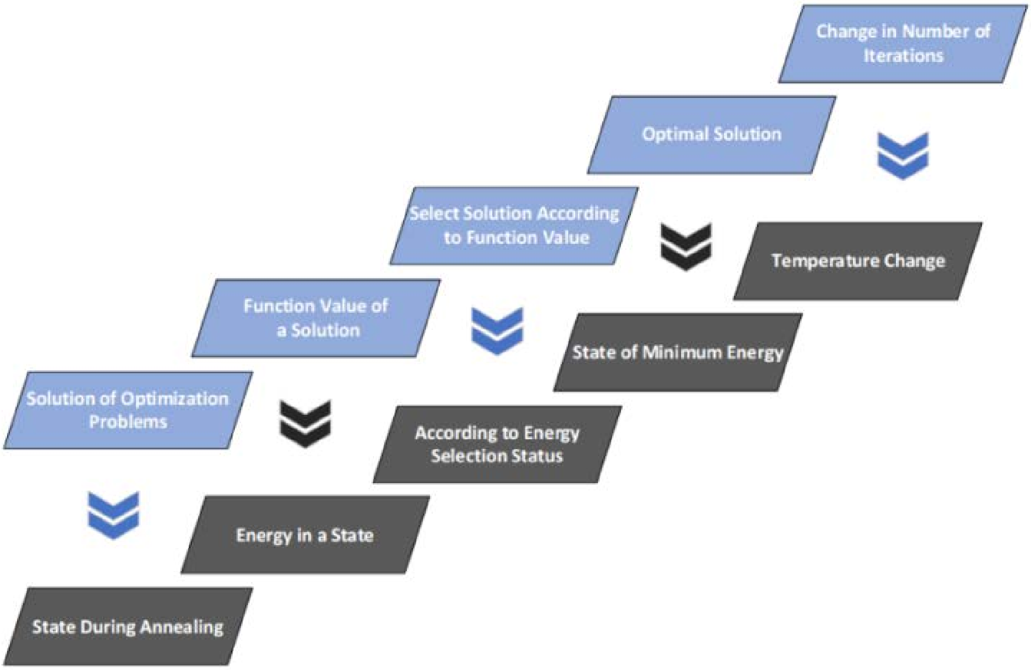


Figure 1: Similarity with the simulated annealing algorithm

Distance matrix $D = (d_{ij})$, where d_{ij} represents the distance between points i and j, i, j= 1,2..., 300, where D is the real symmetric matrix. The problem we want to solve is the shortest path from point 1, through all the intermediate points, to point 300.I and J determined that 300 Drones mainly passed through nodes, because the sample data were given longitude and latitude, rather than the exact distance. Astatizing and sorting out the data, extracting the longitude and latitude information of these nodes, establishing the coordinate system and carrying out the projection coordinate operation. Therefore, let the geographic coordinates of points A and B be respectively (,) and (,). The arc length of the great circle passing through points A and B is the actual distance between the two points (x_a, y_a) and (x_b, y_b).The three-dimensional Cartesian coordinate system is established by taking the geocentric plane as the origin, the equatorial plane as XOY plane, and the plane where the warp coil is located as XOZ plane [4]. 0° According to the rectangular coordinate system of the sphere, it can be concluded that the rectangular coordinates of A and B are:

$$A(R\cos x_a \cos y_a, R\sin x_a \cos y_a, R\sin y_a)$$

$$B(R\cos x_b \cos y_b, R\sin x_b \cos y_b, R\sin y_b)$$

List the actual distance between points A and B.

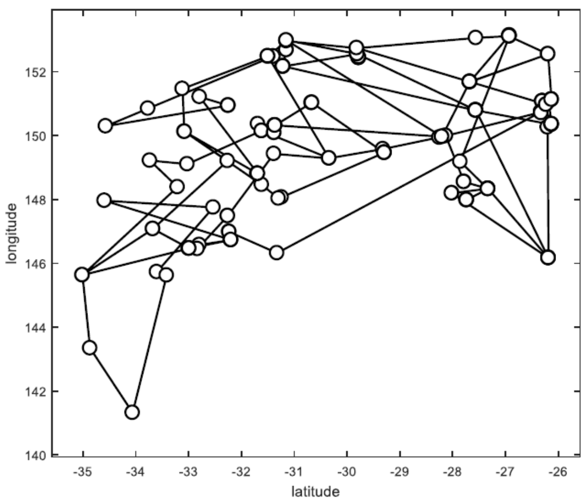
$$d = R\cos^{-1}\left(\frac{\overrightarrow{OA}\,\overrightarrow{OB}}{\left|\frac{\vec{O}}{OA}\right|\left|\overrightarrow{OB}\right|}\right)$$

Reduction to $d = R\cos^{-1}[\cos(x_1 - x_2)\cos y_1 \cos y_2 + \sin y_1 \sin y_2]$

$$d = R \cdot \cos^{-1}[\cos(x_a - x_b) \cdot \cos y_a \cdot \cos y_b + \sin y_a \cdot \sin y_b]$$

Our team searched for data online and processed and analyzed the data after several simulations, the following results were obtained (data from Australia wildfire data on August 1, 2019 - September 30, 2019)

We screened the national data of Australia, and finally obtained the location points of wildfires in southeastern Australia through drawing. Then, 300 location points were randomly selected from the data for simulation solution using the simulated annealing algorithm (data source [5]). The results are shown in Figure 2



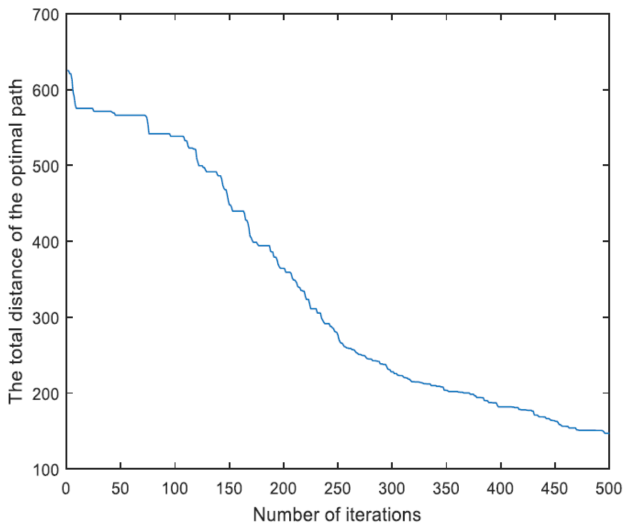


Figure 2: Longitude and latitude diagram of fire prone points and Distance between the number of iterations

We iterated 500 times and finally got the optimal total distance of about 146.8 dimensions. Therefore, the optimal total distance is 163183.68km.

According to the network data[6] : The price of SSA Inorganic and Radio Repeater is both $10,000, where X_1 is the number of SSA UAV and X_2 is the number of radio transponder UAV. Wherein, our model plans the optimal path for UAV detection, and the constraint condition is as follows:

$$30 \cdot X_1 \geq 146.88 \times 111$$

$$20 \cdot 20 \cdot \pi \cdot X_2 \geq 100000$$

$$X_i \geq 0 \quad , \quad (i = 1, 2), X_i \in N^+$$

Suppose the objective function is $f(X)_{\min}$.

$$f(X)_{min} = 10000 \cdot (X_1 + X_2)$$

The solution is. $X_1 = 543, X_2 = 80$

3. 3D path planning based on ant colony algorithm

In this section, the new model is established to optimize the position of the UAV as the research object, and the three-dimensional path planning of the UAV is carried out through the method. Basic ant colony algorithm. It not only has strong robustness, easy parallel implementation, but also has a strong global optimization ability. In this section we think of drones as ants.

Establish a three-dimensional environment space model[7] , O, the starting point of the path planning for unmanned aerial vehicle (UAV), A three-dimensional map of the lower left corner vertex as the origin of coordinates of the third dimension A, establish A three-dimensional coordinate system in the point A, one of the x axis is increasing along the longitude direction, the direction of the y axis is increasing along the latitude, the z axis as the altitude, 3 D cube space structure, three dimensional path planning space is shown in figure 9. ABCD − A′B′C′D′ The drone is placed inside the three-dimensional cube. Divide X, Y and Z axes into N, L and M equal parts, respectively. The plane division is shown in Figure 3.

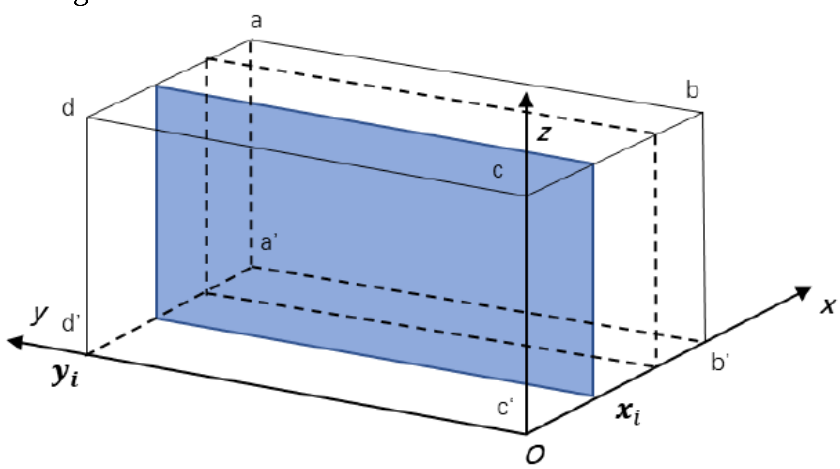


Figure 3: Schematic Diagram of Planning Space Division

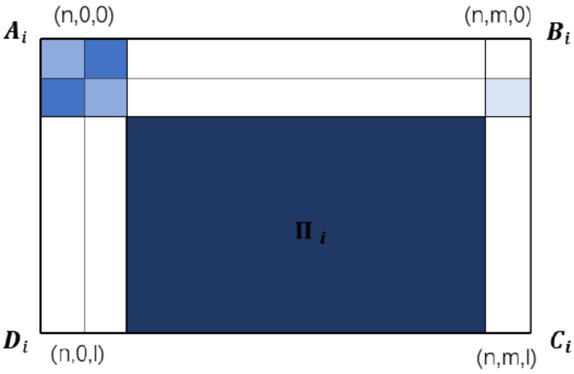


Figure 4: Distance between the number of iterations and the optimal path

Suppose there are m ant looking for food in the environment, the ants in selecting the next path under the influence of pheromone, the greater the value of the α, ants will rely more on pheromones to choose the path points, the greater the value of β, explain the ants tend to choose the closer of the node.

$$p_{ij}^k = \begin{cases} \dfrac{\tau_{ij}^{\alpha}(t)\sigma_{ij}^{\beta}(t)}{\sum_{s\in \text{allowed}} \left[\tau_{ij}^{\alpha}(t)\sigma_{ij}^{\beta}(t)\right]} & , \quad j \in \text{ allowed }_k \\ 0 & , \quad \text{other} \end{cases}$$

Adjust the pheromone update function.

$$\tau_{ij}(t+n) = (1-\rho)\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t)$$

According to the topographic data of East Victoria, knowing the fire-prone locations, we can draw the following optimal route for investigation.

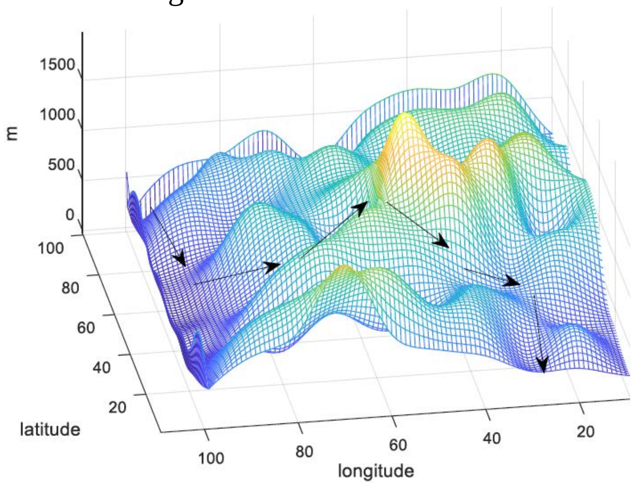


Figure 5: Optimal roadmap

4. Analysis on the Model's Sensitivity

We previously used the location of fires occurring every day from August 2019 to September 2019 for a specific analysis. And we have collected some latitude and longitude information about wildfire hotspots in southeastern Australia, the monthly data from October 2019 to January 2020 were used to test our model. (Data in table 1)

The total distance of the optimal total path is 146.968 dimensions, and the total distance of the previous optimal total path is 146.88 dimensions. (1 dimension equals 111km).

Although the optimal path is different, the total distance of the optimal path is the same. Therefore, it can be judged that the error generated by Model is reduced, and the model is suitable and accurate.

Table 1: Wildfires point data tables

Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
-41.62	147.94	-34.01	150.01	-31.10	150.37	-37.57	149.29
-41.67	148.00	-22.63	150.36	-33.05	150.42	-36.61	148.08
-35.70	148.07	-15.57	144.33	-42.16	147.06	-35.87	148.88
-35.82	150.05	-25.71	153.02	-10.90	142.45	-37.18	149.43
-36.08	149.97	-12.84	133.83	-15.95	145.28	-41.60	147.85
-30.77	123.35	-16.38	141.60	-30.37	150.20	-17.02	144.01
-34.28	150.00	-28.26	125.28	-28.65	126.58	-19.36	143.22
-29.27	152.10	-22.70	150.19	-31.27	152.55	-16.68	145.10
-31.83	152.62	-35.43	149.52	-28.64	127.05	-25.64	153.06
-32.82	150.63	-16.30	124.12	-21.15	118.44	-35.25	147.83
-33.02	150.01	-37.62	147.98	-28.39	134.44	-19.85	144.24
-18.20	144.09	-29.23	152.67	-15.89	135.83	-36.35	148.12
-26.29	150.43	-33.10	150.26	-31.81	152.67	-36.63	148.10
-14.73	143.57	-16.33	141.63	-23.60	131.79	-25.14	147.52
-32.68	150.16	-33.98	150.03	-27.24	129.83	-16.07	144.80

According to the above data, we can use MATLAB to plan the following optimal path (as shown in Figure 6).

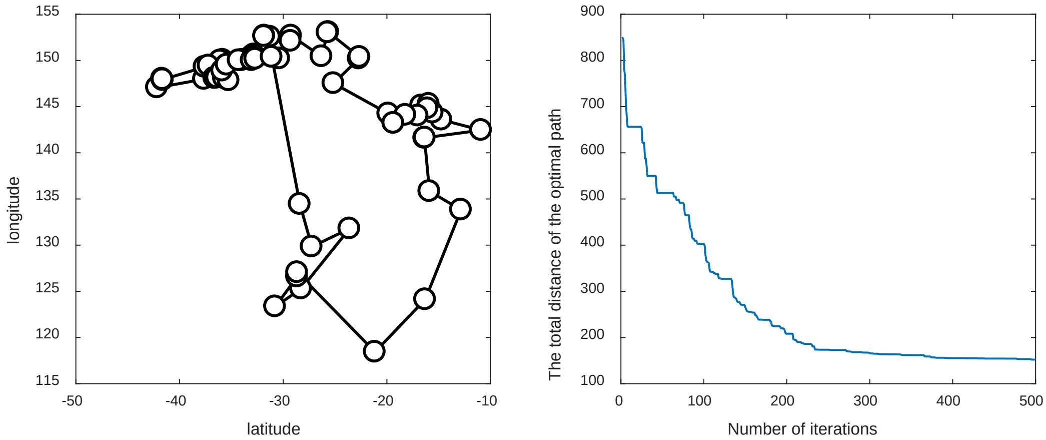


Figure 6: Optimal path detection

5. Model Evaluation and Further Discussion

5.1 Advantages

- The analytic hierarchy process (AHP) is adopted to fully consider the influence of various factors on the selection of UAV, such as capability, cost, safety, terrain, size of fire event, frequency of fire event and so on, so the result has a high reliability.

- The ant colony algorithm based on three-dimensional path planning, considering the size of the terrain and fire modeling factors, so the model is more complex terrain conditions.
- The branch-and-bound method is used to obtain the optimal solution of two kinds of UAV distribution quickly
- In the ant colony algorithm of three-dimensional space, the longitude and latitude are meshed, and the 3D view of the optimal path is obtained through simulation planning with MATLAB. Finally, our results are shown to be more convincing through the analysis of model errors.

5.2 Disadvantages

- In the use of AHP, the comparison matrices obtained are different according to the different scales of Santy, which has certain subjective factors and may cause some errors in the results.
- The lack of some key data may lead to certain deviations in some plans.

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