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Path planning of UAV in mountain area's forest rescuing

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Abstract. In forest rescuing，unmanned aerial vehicle(UAV) can not save all the areas at a time due to the influence of its physical properties and risk factor. So it is extremely important to bring the service efficiency of the UAV into full play. The optimal path planning problem of the UAV for forest rescuing is presented and a mathematic model of the problem is built up. On the basis of this, a fuzzy clustering - PSO - genetic algorithm is presented. The computational amount is decreased, a method combined of both the shortest distance and point clustering is adopted. The simulation test result indicates that when task number less than 30, particle swarm algorithm is superior to genetic algorithm, and vice versa. Both methods plan the same airline but time, and it can resolve the path planning problem of the UAV for water environmental monitoring effectively.

1. Introduction

Forest fires have a great destructive effect on forest resources, but also caused considerable direct economic losses, indirect economic losses less incalculable, such as soil erosion, environmental degradation [1-3]. Forest resources in China are very limited, but forest fires occur frequently, which cause serious damage to forest resources and ecological environment. Not only do they burn down forests, reduce stand density, but also destroy forest structure and reduce the use value of forests. As a result, the direct economic losses are 50-10 billion yuan. In recent years, forest fires have become more and more frequent in China. It is of great significance to prevent and extinguish forest fires for the protection of forest resources, ecological security and national security.

2. Route Planning Algorithm

There are many fire spots in the forest, how to choose the appropriate task for each aircraft to assign the highest efficiency is the focus of our research. Fuzzy clustering analysis is a method to classify the ignition point by using fuzzy mathematics method and establishing fuzzy similarity

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relation of the ignition point according to the close relation of the ignition point. Fuzzy clustering method is used to calculate the distance of each ignition point, and the nearer points are classified into a class and assigned to an aircraft.

The calculation process of fuzzy clustering method is as follows: Firstly, the data of fire point are normalized, and then the distance fuzzy similarity matrix is constructed. Finally, the distance of each fire point is classified into different categories by using the fuzzy similarity matrix, and the number of rescue aircraft is considered to assign corresponding tasks to each aircraft. The method is simple in calculation and small in computation, which can meet the requirement of real-time task assignment.

As the soul of aviation rescue, route planning algorithm is related to the efficiency or even the success or failure of aviation rescue. The traditional optimal control method transforms the complex integral equation solving problem into the differential equation solving problem through the Euler equation; He Ling et. al. [9] put forward a new deviation-differential synthesis control method to solve the violent oscillation problem of control variables; Genetic algorithm is a kind of searching the most by simulating the natural evolution process. The method of optimal solution can be used to express and solve complex problems by means of its propagation mechanism and simple coding technology [10,11]. Particle swarm optimization algorithm is used to simulate birds flying and foraging, and birds can obtain the optimal solution through group cooperation. The algorithm has the advantages of simple calculation, high precision and fast convergence, so it is selected to calculate the optimal flight path for each aircraft. Genetic algorithm is widely used at present, In this paper, which is compared with the specific performance of particle swarm optimization (PSO) to determine their adaptability in forest fire rescue route planning.

(1) Main idea of the algorithm

Fuzzy clustering method is used to calculate the distance fuzzy similarity matrix for the known location of the fire source center point, and then according to the minimum value of different columns in the fuzzy matrix, which kind of fire point belongs to is calculated. Then, the optimal flight route is selected in each aircraft's mission, and the flight path can ensure the safe and rapid completion of the assigned fire extinguishing task. Then, the terrain threat field is established by using the potential theory, and the three-dimensional flight routes of all the ignition points are searched by using the ion swarm algorithm. The elevation of the corresponding track points is calculated by GIS method, and then the vertical track is planned by slope restriction algorithm and curvature restriction smoothing algorithm. The trajectory is optimized by three spline interpolation.

(2) Terrain threat

Forest fires often occur in steep mountains, wind direction is changeable, wind greater mountain areas, aviation forest fire rescue personnel in complex terrain, hilly forest fires and fire demons difficult to "fight". There are many shrubs on the mountain, the fire is big, the temperature is very high, the smoke is diffuse, the visibility is very low, which seriously affect the flight safety. Terrain threat is a complex terrain, such as mountains and hills, which may pose a threat to flight during aircraft forest fire rescue mission. The terrain threat is simulated by simulated terrain.

(3) Route planning process

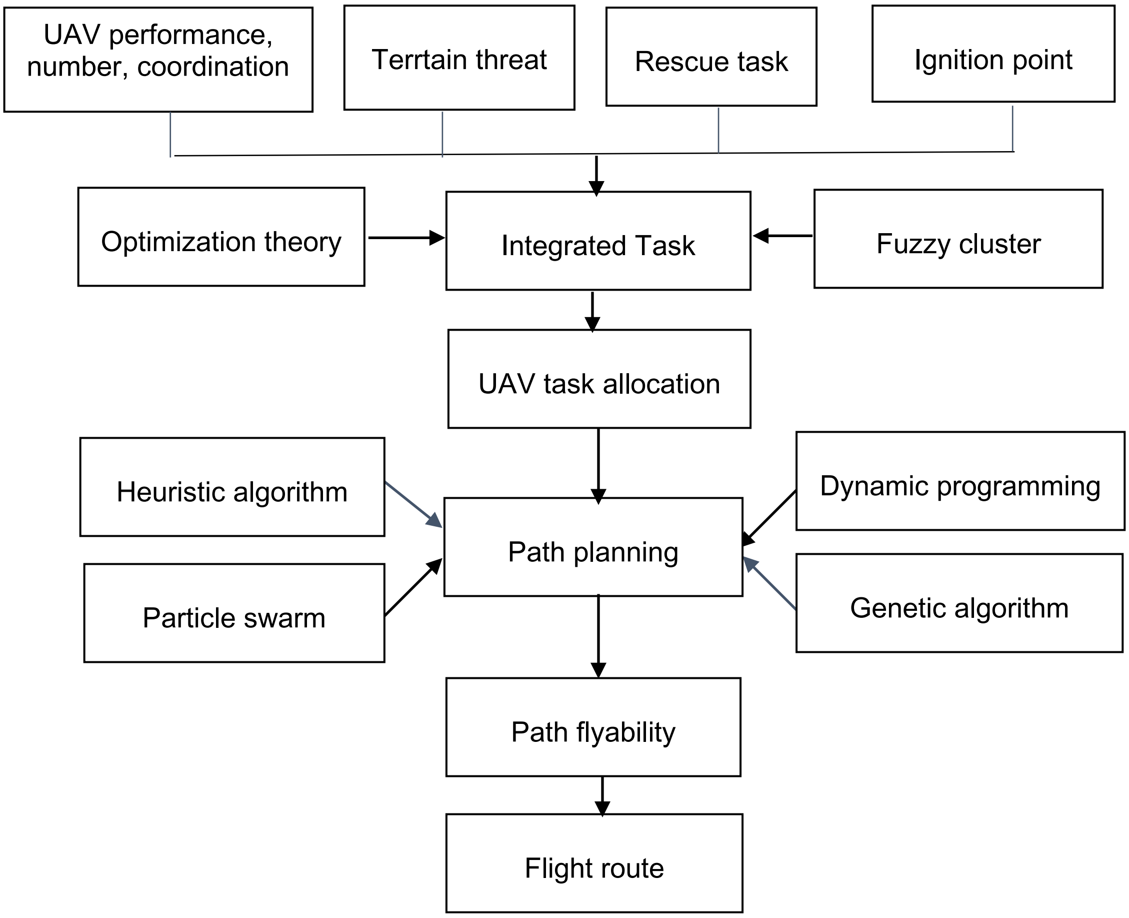

Fig. 1 flow chart of forest fire rescue planning

In order to find the safest, shortest flight path and the route of each ignition point, the flight path should be planned to satisfy the appropriate distance to the ignition point and avoid the terrain obstacles, and shorten the flight range as far as possible, and meet the maneuverability constraints [9-11].

3. Smooth Processing of Tracks

In order to ensure the safety of penetration flight, the terrain smoothing processing based on digital map needs to raise the whole terrain to the flying height of aircraft, and at the same time to ensure that it meets the requirements of aircraft maneuverability. Reference [12] proposes a method of smoothing the whole map before planning to obtain a comprehensive equivalent terrain surface, and then planning route on this surface.

Based on the method of reference [12], this paper adopts the optimization method: the vertical plane of the horizontal track is lifted up to a safe height of 150 meters (vertical minimum clearance), and then the vertical track is smoothed, which greatly reduces the amount of calculation and improves the calculation efficiency.

The smooth processing of track includes maximum track climb angle and maximum normal overload. The maximum track climbing angle corresponds to the slope of each point in the topographic elevation curve, i.e. the topographic slope; the maximum normal overload corresponds to the curvature of each point in the topographic elevation curve. In the smoothing process, terrain gradient and terrain curvature are limited respectively. When a point is detected which does not meet the requirements of slope or curvature, the point will be lifted to the minimum extent, and then the whole terrain elevation is adjusted by the whole iteration method.

4. Simulation Experiment

In an airspace of 100 km 100 km, 10 ignition points are calculated. The distribution of ignition points is shown in Table 1. It is assumed that the ignition points are randomly distributed in the airspace of 60 km 60 km. 2 extinguishing aircraft are used and fuzzy clustering matrix is constructed by using the location of known fire sources. This paper sets the aircraft pitch angle at -10 ~20 degrees. The parameters used in PSO are: pheromone importance 1; heuristic factor 5; pheromone evaporation coefficient 0.1; maximum number of iterations 200; pheromone increase intensity coefficient 100; initial selection iteration algebra of genetic algorithm is 500, and population number is 60.

Table 1 Ignition distribution

Ignition location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
X_coordinate（km）	29	1	45	36	41	15	4	15	47	33
y_coordinate （km）	21	20	2	56	42	3	9	16	25	45

The coordinates of Table 1 are normalized for fuzzy clustering analysis, and the classification centers are (0.2180, 0.1914), (0.6320, 0.6520) and the number of iterations is 8. Table 2 shows the fuzzy clustering classification matrix obtained by fuzzy clustering analysis. According to the distance from each ignition point to the classification center, the ignition point is classified into the nearest point to the classification center. The final classification result is shown in Table 3. The number of tasks assigned to the first category, the first extension, is 6, while the number of second aircraft is 4.

Table 2 Fuzzy clustering distance classification matrix

Ignition point number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Distances to class 1（10^{-4}）	5691	8858	5726	1005	69	9597	9524	9848	1773	347
Distances to class 2（10^{-4}）	4309	1142	4274	8995	9931	403	476	152	8227	9653

Table 3 Fuzzy clustering distance classification results

Ignition point number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
class 1	√	√	√			√	√	√		
class 2				√	√				√	√

Fig. 2 shows that there is no overlap between the flight path 1 and the flight path 2, which shows that the fuzzy clustering method can successfully classify the mission. According to the idea of traveling salesman algorithm, it can ensure that every city can traverse without repetition, and make every city do not go through two or two times to meet the requirements of forest fire extinguishing, that is, to operate each fire point to ensure the effect of fire extinguishing; therefore, traveling salesman algorithm based on particle swarm optimization and genetic algorithm is used to realize the road path planning respectively.

Figure 2 shows the results of path planning and planning costs using PSO-based traveling salesman algorithm. From the graph, we can see the path calculated by PSO, which ensures the shortest time to complete the assigned tasks. At the same time, we can get the order of path passing through the task points: aircraft 1 is 2 - > 6 - > 1 - > 3 - > 4 - > 5, where 1 - 6 is The assignment number is relative to the ignition point 1, 2, 3, 6, 7, 8; the flight passing point of aircraft 2 is 4 - > 1 - > 2 - > 3, of which 1 - 4 is the assignment number relative to the ignition point 4, 5, 9, 10. Since the path planning does not require the aircraft to fly back to the origin, the above assignment results show that the red line represents the path of the aircraft 1, the red star symbol represents the mission of the aircraft 1, the green dotted line represents the flight route of the aircraft 2, and the green star represents the mission location of the aircraft 2, as shown in Figure 3.

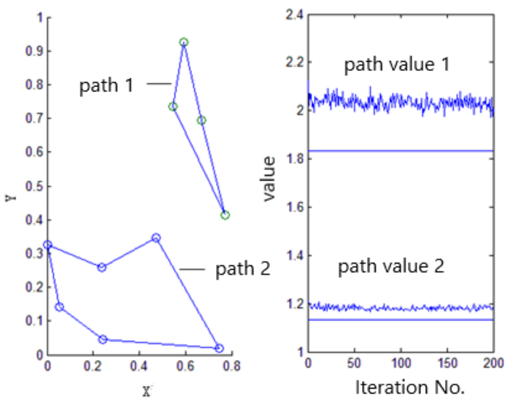

Fig. 2 classification results of PSO algorithm

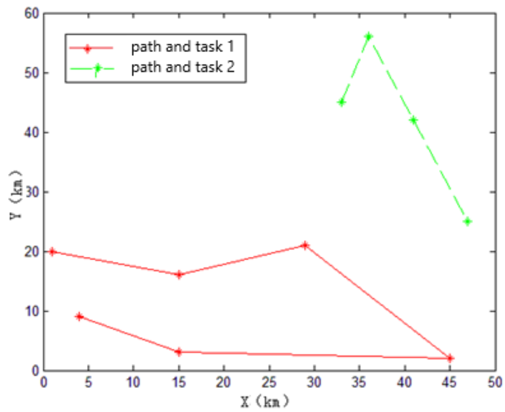

Fig. 3 Aircraft planning path and task allocation map

The result of searching path by genetic algorithm is the same as that by particle swarm optimization, but the planning time is 2-9 times as long as that by particle swarm optimization. However, with the increase of the number of tasks, the time required by genetic algorithm is not much longer, but the particle swarm optimization algorithm increases sharply (see Figure 4). It can be seen that particle swarm optimization has the advantage of faster planning speed than genetic algorithm when the number of tasks is small. This is because particle swarm optimization does not have the crossover and mutation of genetic algorithm, so it reduces the calculation time. However, as the number of tasks increases, the computational complexity increases, and the genetic algorithm can find feasible paths faster by its crossover and mutation operations, but there may be crossover phenomena, for example, when the number of tasks is 130, the iteration No. needs to be increased from 500 to 800 generations, and when the number of tasks is 150, without changing. In the case of variable iteration No., increasing the population from 60 to 100 can also find non-crossing paths, but these operations do not make the calculation time increase too much, for each aircraft to choose the optimal flight path, so that it can pass through all the fire points assigned by the task.

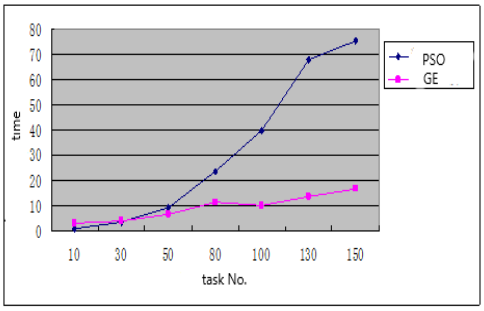

Fig. 4 Time comparison of particle swarm optimization and genetic algorithm for path planning

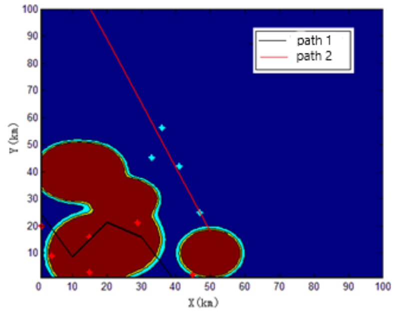

Fig. 5 Two-dimensional path optimization

The flight paths planned by these two algorithms are the same, that is, the order of the mission points is the same, and the difference is mainly reflected in the planning time shown in Fig. 4. Therefore, the optimization results of the flight paths planned by the two algorithms are the same. Because the trajectory planned by the above algorithm cannot satisfy the maneuverability and flyability constraints of aircraft, it is not practical yet, so it needs to be optimized.

Flyability constraints include maximum turning angle constraints, minimum track segments, coordination between two aircraft, gradient constrained smoothing algorithm, terrain curvature constraints and so on. The flight path is smoothed by cubic B-spline curve, and the flight path is effective (Fig. 5). From the planning results of Fig. 5, it can be seen that the two flight paths are intersected between the mission points to ensure that the mission can be accessed, and the path is the shortest, there is no overlap between the two tracks, so there is no threat of collision between the two aircraft.

5. Conclusion

Fuzzy clustering method is used to classify the ignition point. According to the distribution of the ignition point, the task quantity can be selected reasonably for each aircraft, and the number of aircraft needed can be determined. Then, the particle swarm optimization algorithm or genetic algorithm (GA) is used to select the optimal flight path for each aircraft according to the different choice of the number of ignition points. Finally, the slope restriction smoothing algorithm and the terrain curvature restriction method are used to plan the flight path of forest fire extinguishing. In order to select the route planning method reasonably, the time of particle swarm optimization (PSO) and genetic algorithm for route planning with different ignition points is studied. When the number of tasks is less than 30, the time of PSO is shorter, but with the increase of the number of tasks, the time of PSO is increased sharply, so it is more reasonable to adopt GA. In addition, the constraints of the flyability and the minimum cost of flight are considered comprehensively, so that the planned trajectory takes into account the requirements of optimality and practicability, and the geographic terrain information is fully considered, so that the trajectory can safely and automatically avoid terrain threat and fire source threat.

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