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UAV Path Planning Method Based on Improved Wolf Pack Algorithm

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Abstract: At present, there are more and more situations using drones to perform missions, and the working environment of drones is becoming more and more complex. Path planning has become the basic premise for the smooth completion of missions. Although the Wolf pack algorithm is fast and robust in trajectory planning, which has good results for solving problems with complex high dimensions and multiple peaks. In view of the premature convergence, the poor global optimization ability and the final result does not reach the optimal route of Wolf package algorithm (WPA), and the slow convergence of genetic algorithm, an improved trajectory planning method is proposed. First, the equivalent terrain simulation method is used to equivalent and analyze the terrain obstacles in the working environment with the mountains, and constructed the equivalent terrain map of the work of UAV. Planning known UAV orbit at the beginning and end positions, simulations in matlab found that the improved Wolf pack algorithm can find the shortest path with shorter time. Eventually, our simulation results are better than using the Wolf Pack Algorithm or the Genetic Algorithm.

1. Introduction

Due to the development of current technology, drones are becoming more and more used. Because of its low cost, simple take-off and landing is widely used in pesticide spraying, rescue and relief, cargo transportation. Scholars have done a lot of research on the track planning and put forward many algorithms that can improve the efficiency of path planning. At present, the commonly used methods include WPA, Particle Swarm Optimization (PSO), Bat Algorithm (BA),Artifical Potential Field(APF), Ant Colony Optimization(ACO), Atom Search Algorithm(ASO), Genetic Algorithm(GA) and so on. The WPA is fast and robust in trajectory planning, which has good results for solving problems with complex high dimensions and multiple peaks. However, its control over the overall situation is not high, and the communication between each wolf is very little, easy to disperse, leading to the local optima. The convergence is premature, the global optimization ability is poor, and the final result cannot reach the optimal route. In its three intelligent behaviors, the slow convergence speed and the low convergence accuracy of the algorithm result to the fixed step size and the number of walk direction. In view of the above shortcomings, many scholars have proposed the improvement methods.

Zhou Jianxin [1] combined with the search algorithm, added a pair of antennae to each wolf and increased the adaptive variable step length associated with the two whiskers of the bovine, and introduced into the wandering behavior of WPA. All the individual wolves have the ability of simple calculation and fast convergence, and optimize the convergence speed and accuracy of WPA, but the convergence rate is slow. Wang Liwen [2] proposed a search strategy based on the combination of Levy flight and adaptive walk for the wandering behavior, which improves the problem that the algorithm easily falls into local optimal, ensures the coverage of wolf search, and improves the convergence speed of the algorithm and the global optimization ability. Chen [3] improves the solution of the optimal trajectory of the UAV in a complex three-dimensional space, combined with the dynamic performance of the UAV, and smooth UAV trajectory to make it more in line with the track of the UAV. Chen [4] increases the search radius of the wolves by introducing the explosion rule of the pyrotechnic algorithm, improves the local optimization effect of the algorithm, and improves the global optimization ability of the algorithm by improving the way of the pack update rules. Although it improves the local power of the wolf pack algorithm, limitations remain.

This paper uses a combination of WPA and GA. Integrating the idea of GA into the WPA and change to improve the global search ability and convergence accuracy of the WPA. In the pack, two suitable wolves were selected for pairing and then selected according to factors such as the distance between wolves. Introreproductive behavior into the WPA greatly improves the global search ability and convergence accuracy. However, the implementation of reproductive behavior may get the algorithm into the local optimal solution or premature convergence. Therefore, we need to consider the crossover rate and variation rate[5].

2. Modeling of the path-planning problems

When operating in complex environments, drones can run into tall buildings, be entangled by electric wires, and hit big trees. We can reduce these obstacles to the threat area. The topographic obstacles encountered by a drone during a mission can also be considered as a threat area. Threat equivalent terrain simulation method, which is to process threats and obstacles in complex environment into mountain terrain, has been applied in multiple literature. By treating obstacles and threats into special terrain, the position and range of action are superimposed on a digital map, and the role of threat is equivalent to the terrain that raises the range of action. After this treatment, the known terrain obstacles and enemy threats in the UAV flight area are integrated into comprehensive terrain information, and various threat avoidance is equivalent to terrain avoidance, which makes the track planning problem greatly simplified. According to this equivalent method, this paper models the obstacle threat and terrain obstacle in the task environment, and the threat equivalent terrain mathematical model can be obtained:

$$z = \sum_{j=1}^{N} h_j \tag{1}$$

Where N indicates the number of peaks, which is the number of equivalent threats. z is the topographic height corresponding to the coordinate point of the water plane. Changing these parameters can simulate the threat-equivalent peak topography.As shown in the Figure 1:

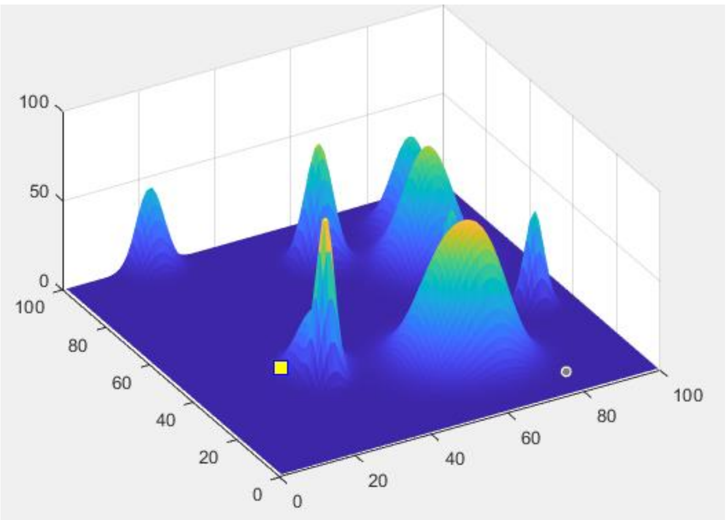

Figure 1: Topographic map of the equivalent peaks

2.1 Way cost

The path cost is used to measure the impact of the range on the mission execution of the UAV. The path cost refers to the relationship between the flight path and the flight time and energy consumption. With fixed speed and altitude, the longer the path, the longer the flight time, the more energy consumption. The path cost is directly proportional to the track length. Therefore, the voyage cost is calculated as follows:

$$Cost_{flight}(L) = k_{f,t} \cdot \sqrt{(x_{j+1} - x_j)^2 + (y_{j+1} - y_j)^2 + (z_{j+1} - z_j)^2} \qquad (2)$$

Among, $k_{f,t}$ is the proportional coefficient related to fuel oil and flight time, x_j, y_j and $z_j$indicating the horizontal, vertical and height coordinates of the NO. j track point in track L.

2.2 Hazard costs

The probability of the drone crash is related to the distance to the center of the obstacle; the closer the distance, the greater the probability of the drone crash, the more dangerous the flight path. Let (x, y) be the current position coordinate of the UAV, (x_d, y_d) is the coordinate of the center of the obstacle, r is the threat radius, t is the threat level, and d is the distance between the UAV and the center of the obstacle. When the drone is outside the obstacle range (i. e., the threat radius), it is almost not crash, so we assume that in this case, the probability of the crash is 0. The relationship between the probability of a collision and the distance from the center of the obstacle is expressed in the following formula:

$$P = t \cdot e^{-\frac{d^2}{r^2}} \qquad (3)$$

Therefore, the probability $P(d)$ of a drone crash during the flight can be expressed as:

$$P(d) = \begin{cases} 0 & (d > R) \\ t \cdot e^{-\frac{d^2}{r^2}} & (d < R) \end{cases} \qquad (4)$$

So the total hazard cost of the path is expressed as:$Cost_{threat}(L)$

$$Cost_{threat}(L) = \sum_{j=1}^{D+1} \int_{0}^{Lj} P(d)dl \tag{5}$$

$$\mathrm{L} = \sqrt{\left(x_{j+1} - x_j\right)^2 + (z_{j+1} - z_j)^2 + \left(y_{j+1} - y_j\right)^2} \ . \tag{6}$$

2.3 Comprehensive cost function

Combining the previous functions, we get the comprehensive cost cost function of the UAV path planning used in this paper:

$$C(L) = \omega Cost_{flight}(L) + (1 - \omega)Cost_{threat}(L) \tag{7}$$

ω is the weight of the path cost, ω is the variable between 0 and 1 that can be artificially changed. It represents a trade-off between energy consumption, flight time and exposed obstacles.ω Close to 1 means that the current mission time is limited or the aircraft's fuel is insufficient, requiring planning a short path and paying less attention to safety or forcing it to pay less attention to safety. On the contrary, ω close to zero means that the safety of the task is the most important, and we should avoid exposure as far as possible, and the track should try to avoid various threats.

Some parameters and variables involved in the experimental process are explained below, and the physical significance is explained in combination with the specific problem of UAV path planning.

3. Wolf Pack Algorithm

Wolf is a social animal, and the social division of labor is clear. By assuming their own responsibilities and united cooperation, they jointly promote the survival and development of the whole wolf pack. The Wolf Pack Algorithm (WPA) adopts a bottom-up design method based on the artificial wolf subject and a collaborative search path structure based on the division of responsibilities. WPA mainly consists of wandering, call, siege and updating mechanisms.

3.1 Walk behavior

The wolf senses the smell of the prey and approaches the prey along each direction. The fitness of each wolf is calculated separately. If the search is greater than the fitness of the wolf, the wolf becomes the head wolf and initiates the calling behavior again. This behavior can be seen as the global development capability of the WPA.

$$x_{id}^{p} = x_{id} + sin(2\pi \times \frac{p}{h}) \times step_{s}^{d} \tag{8}$$

x_{id}^{p} is the spatial position of the scout wolf; $step_{s}^{d}$ is the step length of the scout wolf; p is the number of selected exploration directions.

3.2 Call behavior

After the end of the wandering behavior, the resulting wolf calls the fierce wolf, the surrounding *n* wolves quickly called to its location, the fierce wolf with the running step fast to the head wolf and then conduct the prey search. In the process of the attack, if the fitness is higher, the fierce wolf to the head wolf. When the distance between the fierce wolf and the head wolf is less than the threshold, it transforms to siege behavior.

$$x_{id}^{k+1} = x_{id}^{k} + step_{b}^{d} \times \frac{g_{d}^{k} - x_{jd}^{k}}{\left|g_{d}^{k} - x_{jd}^{k}\right|} \tag{9}$$

x_{jd}^{k+1} is the spatial location of the fierce wolf; $step_b^d$ is the attack stride length; g_d^k is the spatial position of the wolf.

3.3 Siege behavior

The fierce wolf and the scout wolf jointly rounded up and captured it, which can be regarded as the local search ability of WPA.

$$x_{id}^{k+1} = x_{id}^k + \lambda \times step_w^d \times \left|G_d^k - x_{id}^k\right| \tag{10}$$

Where λ represents the random number between [-1,1];$step_w^d$ is the attack step; G_d^k is the spatial location of the prey.

Among them, $step_s^d, step_b^d$,$step_w^d$ the step length relationship of the three is:

$$step_s^d = \frac{step_b^d}{2} = 2 \times step_w^d = \frac{|M_d - m_d|}{C} \tag{11}$$

The C in the formula is the step size factor.

4. Improved WPA based on the genetic algorithm

4.1 Genetic Algorithm

GA originates from the law of "natural selection" and "survival of the fittest" in nature. It is a random search algorithm that simulates the evolutionary process of biological life in nature. GA mainly consists of three basic processes: selection, crossover, and variation.

The initial population was generated, setting the maximum evolutionary number of generations is T, population size is N, cross probability is P, variation probability is S, and N individuals were randomly generated as the initialized population A.

a. Select

More adapted individuals from the group. Use these selected individuals to reproduce the next generation. A fraction of individuals selected from the current population is used to generate the next generation of populations. The probability of being selected is determined by calculating the fitness of each individual.

b. Cross connection

In the next generation selected for reproduction, genes at the same location for two different individuals are exchange to generate new individuals.

c. Heteromorphosis

In selected individuals, execute changes to certain genes in individuals. Increase the diversity of the population and prevent falling into the local optima.Repeat the above three steps until the conditions are met, usually when the maximum number of iterations or the preset target value is reached.

4.2 Improve the binding mechanism of WPA

In this paper, the population will be endowed with genetic characteristics, search in the target space, and can update the location of wolves in an adaptive step way, the GA and WPA walking behavior, can better improve the speed of individual Wolf optimization and the ability of global optimization. According to the advantages of GA and WPA, in order to improve the global search ability and convergence speed of the algorithm, and better play the performance of WPA.

5. The algorithm operation and simulation

Simulation environment setting: The threat equivalent terrain is shown in Figure 1, and the UAV is minimized when flying with the equivalent peak terrain envelope. The search space of the UAV track is set to 10000 km^2, the coordinates of the starting point are (1,1,60), the end point are (100,100,60), and the mountain terrain is the equivalent of radar and terrain threat. There are ten equivalent peaks in total.

In this paper, WPA and GA are used to compare, and the maximum number of iterations of the two algorithms is 100.

The parameters of the WPA are set as: N=100, the scale factor of the artificial wolves a=0.5, the step length factor S=20, the number of walk directions T=20, and the distance determination factor D=10.

The parameters of the GA are set as: chromosome length Ch=2, selection probability Se=0.4, crossover probability Cr = 0.7, variation probability mu=0.3, and maximum number of iterations M=100.

In order to facilitate the comparison of these three algorithms, their planned track maps are presented, as shown in Figure 2, Figure 3 and Figure 4. The performance comparison of these three algorithms is shown in Table 1.

Table 1: Comparison performance of each algorithm

	Actual minimum distance	The optimal number of iterations is reached	Ideal minimum distance
WPA	149.4355	43	140.0071
GA	150.2711	50	140.0071
The improved WPA	140.3194	25	140.0071

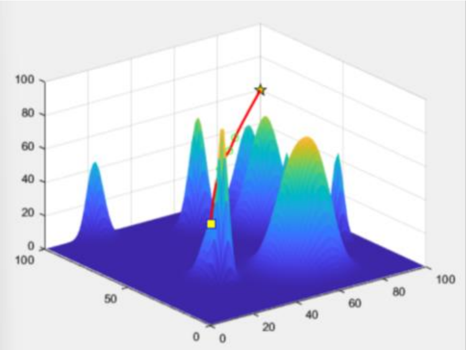

Figure 2: Optimal track of the Wolf Pack Algorithm planning

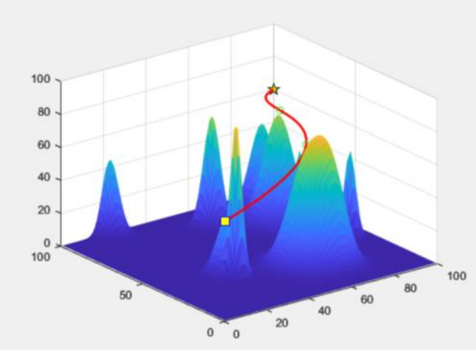

Figure 3: Optimal track of Genetic Algorithm planning

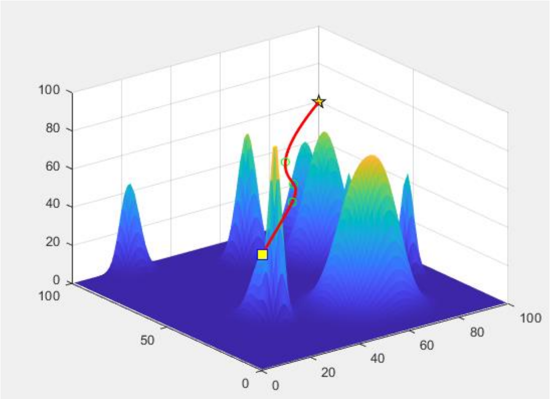

Figure 4: Optimal track for improving Wolf Pack Algorithm planning

It can be seen from Figures 2, 3 and 4, various complex situations are effectively transformed through the equivalent terrain simulation method to facilitate the track planning of the UAV. And, you can see from Figure 2, 3 and 4, using PSO and WPA planning the drone track although better to avoid the equivalent mountain terrain, but compare the three figure can draw, by using the improved WPA planning track than using the WPA planning track bending radian is obvious and the track is shorter. As can be seen from the data in Table 1, the track length planned by the improved Wolf algorithm is 140.3194 km, while the track length planned by the Wolf algorithm is 149.4355km, and the track length planned by the genetic algorithm is 150.2711km. Therefore, the search of the GA is trapped in the locally optimal track, while the track length of the improved WPA program is shorter. The simulation results show that the improved wolf pack algorithm can effectively solve the problem of UAV trajectory planning.

6. Conclusion

In this paper, the equivalent terrain simulation method is used to equivalent the terrain and obstacles within the working range to mountains, and the topographic map of UAV track planning is established. Furthermore, the start and end point. The simulation results show that compared with the WPA or the genetic algorithm, the UAV track planned by the improved WPA safely avoids the peaks, with a shorter length and fewer iterations. However, in the application of the improved WPA, many parameters are involved, and the small adjustment of each parameter will cause the change of the planning track. Our next task is to find the optimal parameter setting for the trajectory planning.

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