Research on Key Technologies of UAV Tracking Based on Adaptive Control

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ABSTRACT

Ecological environment monitoring is the basis of ecological environment protection. The application of UAV remote sensing technology in ecological environment monitoring has made breakthroughs in time and space. This can improve the scope, efficiency and capacity of monitoring. Based on adaptive control technology, this paper studies the application of UAV in ecological environment monitoring. This paper studies the online path planning of UAV in water environment monitoring and proposes an online path planning algorithm based on genetic algorithm. The simulation results show that this method can quickly generate feasible track or even sub optimal track.

Keywords: Ecological environment monitoring, environmental protection, UAV, online route planning algorithm.

AIMS AND BACKGROUND

Unmanned Aerial Vehicle (UAV) is a kind of Unmanned aircraft with power, control, ability to carry a variety of mission equipment, perform a variety of tasks, and can be reused. It has many advantages such as low cost, low loss, reusable and low risk[1]. The characteristics of UAV remote sensing, such as high timeliness, high resolution and flexibility, are incomparable to traditional satellite remote sensing. It is increasingly favored by researchers and producers, greatly expanding the application range and user group of remote sensing, and has broad application prospects[2-3]. In recent years, UAVs have been successfully used for water environment monitoring, including monitoring the water quality of rivers and lakes, monitoring the changes of water environment caused by natural disasters, and monitoring and evaluating the leakage of oil and harmful substances[4-6]. The research of UAV route planning in water environment monitoring plays an important role in water environment protection and emergency treatment of sudden water environment problems[7-9]. Therefore, it is of great significance to study the path planning of UAV in water environment monitoring, both in theory and in practical application.

HIERARCHICAL PLANNING IDEA OF FLIGHT PATH

In water environment monitoring, UAVs perform normal cruising tasks in most cases, with the purpose of monitoring the target points to be monitored. In normal cruise, considering that the maximum flight distance of UAV is limited, it is impossible to monitor the target point without limitation, how to plan the UAV track so that the total monitoring time of the target point to be monitored is the longest, which is the task of overall track planning. The overall path planning is the offline path planning before the UAV executes the flight mission. It determines the cost function for evaluating the quality of the UAV flight path according to the known information and considering the task requirements, constraints and risks of the UAV. According to this function, the optimal UAV flight path is obtained by using the path planning algorithm. UAV environment monitoring system is shown in Figure 1.

Fig. 1. UAV Environment Monitoring System

Real time path planning is the online path planning of UAV during flight. After obtaining the reference track, the UAV flies along the reference track. Once new water environment information is found (such as oil leakage, harmful substance emission, etc.) and the monitoring target points are temporarily changed, it is necessary to re plan the flight track in the current situation when monitoring other target points. It is required to complete the track planning in the shortest possible time. Because the real-time track planning is generally completed by the airborne computer, and the processing capacity of the airborne computer is limited, it is not required to obtain the optimal track, sub optimal track or even feasible track.

The purpose of real-time track planning includes: (1) reduce the calculation amount of airborne equipment. The UAV flies according to the reference track. Once the real-time track planning is found, it must carry out the re planning of the track. However, due to the limited computing capacity of the airborne computer, the real-time track planning algorithm used should reduce the calculation amount of airborne equipment and generate new tracks quickly. The new track generated can be a feasible track or a suboptimal track[10]. (2) To remedy the limitations of the airborne equipment area, the detection range of the UAV's airborne equipment is limited, and information beyond the detection range cannot be mastered. The UAV can be guided to monitor new target points that need to be monitored through online real-time track.

TRACK CONSTRAINTS

An important reason why UAV path planning is very difficult is that it is subject to many constraints, including environmental and its own factors. These constraints determine that UAVs can fly over some areas in the planning space, while some are not suitable or even cannot; Some UAV maneuvers can be completed while others cannot. The set of these constraints makes it extremely difficult to find the optimal and even feasible track. The constraints considered in the route planning in this paper mainly include the following aspects.

The minimum step length is the shortest distance that the UAV must maintain a direct flight before changing its attitude. Before turning or climbing dive maneuver, UAV must have a process of attitude adjustment, in which the UAV has the opportunity to adjust its attitude to a normal position conducive to maneuver. If the adjustment is not made or not enough, the UAV will not be in place or will be in an abnormal attitude after maneuver, leading to greater error, or even the UAV will lose control and crash. Generally speaking, in order to make the UAV fly more safely and accurately, before and after turning and other maneuvers, the UAV should maintain a direct flight distance, which is called the minimum step length, expressed in L, so that the length li of any track is not less than L:

$$l_i \geq L\left(i=1,2,\ldots,n\right) \qquad (1)$$

The maximum turning angle means that the UAV flight path can only turn within the predetermined maximum turning angle. This constraint is related to the maneuverability and mission of the specific UAV. If the maximum turning angle is θ, then when the track is at point P, it can only turn in the left and right e angles along the original direction.

Record that the coordinates of the ith track point are (xi, yi), let $\theta_i = (x_i - x_{i-1}, y_i - y_{i-1})^T$, and assume that θ is the maximum turning angle, then the constraint can be expressed by the formula:

$$\cos\theta \geq \frac{\theta_i^T \theta_{i+1}}{|\theta_i||\theta_{i+1}|} \quad (2)$$

The maximum flight distance refers to that because the UAV can carry fuel and has limited flight time, the track length must be less than a preset maximum distance. In route planning, the straight-line distance between the starting point and the end point is D, but because UAVs will not simply fly along a straight line according to mission needs, the feasible track must be longer than D. On the other hand, due to the range limitation or task execution time limitation of UAVs, the total length of the track must be limited. If the maximum flying distance is d_{max}, the constraint can be expressed as follows:

$$\sum_i l_i \leq d_{\max} \quad (3)$$

The monitoring range of UAV airborne equipment is limited, so the target points to be monitored during flight must be within the effective monitoring range. If the UAV flies along the planned track and does not detect one or several target points, the route planning task fails. Assuming that the distance between the ith segment li of the track and the kth target point to be monitored is d_{ik}, the constraint can be expressed by formula (4), and R is the effective monitoring range defined previously.

$$\exists i, i \in [1, n], d_{ik} \leq R \quad (4)$$

TRACK OBJECTIVE FUNCTION

Before determining the track objective function, let's review the tasks mentioned earlier in this paper. The tasks of UAV in water environment monitoring mainly include two aspects: one is the normal patrol of the target points to be monitored. At this time, the UAV is required to monitor these target points for as long as possible; Secondly, when the UAV detects sudden water environment problems, it is necessary to make track adjustment as soon as possible, that is, to re plan the track. At this time, it is required to obtain a suboptimal or feasible track in the shortest possible time, so that the UAV can fly along the new track to monitor the new target point. In addition, the risk factors of UAV in water environment monitoring should be considered. Therefore, the objective function used should include the above factors.

For any track, it is assumed that there are n+1 track points, 9_{1i} is the effective monitoring distance of segment i of the track, 9_{2i} is the track length value of segment i of the track, and the starting point is assumed to be the land location, while the flight area of the UAV is in the water environment. t_s is the total distance between each track point and the starting point in the track, and the objective function is as follows:

$$\min\ f = \sum_{i=q}^{n} (-w_1 q_{1i} + w_2 q_{2i}) + h + g(t_s) \quad (5)$$

Where h is the penalty function and g is the hazard function, the greater the value is for the track far from the land. W_1 and W_2 are weighting coefficients, $W_1+W_2=1$. In specific tasks, if the target point is required to be monitored for the longest time, $W_1=1$, $W_2=0$; If the UAV is required to monitor the target point quickly and fly to the destination, $W_1=0$, $W_2=1$. This paper calculates the minimum value of the target function f.

Now let's discuss the following function $g(t_s)$. When UAV is monitoring the water environment, it is different from executing tasks over land. Once a failure occurs, it cannot land immediately and must return to the land for maintenance. Therefore, this problem must be considered in route planning. Therefore, the purpose of this function is to punish the tracks far from land. For this function, we can know that the farther the drone is from the land, the greater the potential danger. Therefore, this function is an increasing function with the independent variable t_s. For simplicity, this paper assumes that $g(t_s)= t_s$, then Formula (5) becomes:

$$\min\ f=\sum_{i=1}^{n}(-w_1q_{1i}+w_2q_{2i})+h+t_s \tag{6}$$

GLOBAL ROUTE PLANNING BASED ON GENETIC ALGORITHM

Darwin's theory of natural selection includes heredity, variation, survival struggle and survival of the fittest. Heredity is the universal phenomenon of living things. As the saying goes, you can reap what you sow, and you can reap what you sow. The next generation will develop according to the biological information passed on by their parents. Therefore, the parents and the next generation have the same characteristics. The selection and accumulation of variation is the origin of biodiversity. The difference between parents and offspring, as well as the difference between offspring, is called variation, and variation has great randomness. Natural selection comes from survival struggle, individuals with adaptive variation are retained, and species variation accumulates in a direction conducive to survival. This process of natural selection is long and slow. Genetic algorithm is a bionic algorithm that simulates the natural evolution process. It generates a good structure by simulating Darwin's principle of "survival of the fittest".

The rudiment of genetic algorithm came into being in the 1950s and 1960s. Due to the lack of a universal coding system, the early algorithm did not work well. In the 1960s and 1970s, John Holtand made pioneering contributions to promote it. Especially in the past 30 years, genetic algorithms have achieved good results in various modeling and solving practical problems, which mainly depends on the maturity of genetic algorithms themselves and the mixed use of various algorithms.

Genetic algorithm starts from a population, which is composed of a certain number of individuals. In practical applications, the population represents a set of possible potential solutions. An individual is a possible solution after specific coding. After the initial population is generated, according to the biological evolution principle of survival of the fittest and survival of the fittest, better solutions are generated through genetic evolution generation by generation. In the process of artificial evolution, individuals are selected according to the fitness of each generation of individuals, and then genetic operators are used for crossover and mutation operations to generate new individuals, thus generating new populations. The offspring generated in this process will be closer to the optimal solution than the previous generation. This process is repeated until the termination conditions are met. The optimal individual in the last generation is decoded to obtain the optimal solution of the problem.

The genetic algorithm searches according to the fitness function. The selection of the fitness function directly affects the convergence speed of the genetic algorithm and even whether the optimal solution can be obtained successfully, so it is extremely important. For the single objective function, the fitness function can be converted from the objective function. Assume that the objective function is f (x), and the commonly used method of constructing fitness function (to minimize the objective function as an example) is as follows:

(1) Directly convert the objective function into the fitness function:

$$fit(f(x))=-f(x) \tag{7}$$

(2) Limit construction method:

$$fit(f(x))=\begin{cases}C_{\max}-f(x),\ f(x)<C_{\max}\\ 0,\ \ \text{other}\end{cases} \tag{8}$$

The first fitness function is simple and intuitive, but there are some problems: first, the objective function value may be negative, which is not conducive to genetic operation; Second, some functions with solutions differ greatly in function distribution, and the average fitness obtained may not be conducive to reflecting the performance of the population. The second method improves the first one, but the limit is not easy to estimate. Formula (9) can effectively solve the above problems.

$$fit(f(x))=\frac{1}{1+c+f(x)}\quad c\geq 0,c+f(x)\geq 0 \tag{9}$$

The parameters to be selected for genetic algorithm mainly include crossover probability Pc, mutation probability Pm, population size M, individual coding length 1, termination algebra G. The running parameters of genetic algorithm have great influence on its running performance. (1) Population size M. The population size M represents the number of individuals in the population. When M is large, the diversity of the population will be improved, but the calculation time of the genetic algorithm will be longer; When M is small, it can improve the operation efficiency but reduce the diversity of individuals, so it is easy to fall into the local optimum. Therefore, the value range is usually 20-100. (2) Encoding string length 1. Different encoding methods require different encoding string lengths, which are generally related to the number of decision variables, solution accuracy, etc. For example, when floating point coding is used, the length of coding string 1 is equal to the number of decision variables n. (3) The crossover probability Pc crossover operation is used to generate new individuals for the next generation population. Generally, it should take a larger value. However, if the value is too large, it will damage the goodness of the population. If the value is too small, it will slow down the generation of new individuals. Therefore, the general value range is 0.4-0.99. (4) Probability of variation pm. The selection of mutation probability directly affects the local search effect of genetic algorithm. If its value is small, it can not better inhibit the premature of the population, and is not conducive to the generation of new individuals; If the value is large, it may destroy many better individuals, and mechanical mutation will produce random search effect. Therefore, the general value range is 0.0001-0.1. (5) Termination algebra G. The termination algebra G means that the genetic algorithm runs until generation G, and the individual with the highest fitness in the current population is the optimal solution to the problem. The general value range of G is 100-1000. Image analysis of UAV environmental monitoring is shown in Figure 2.

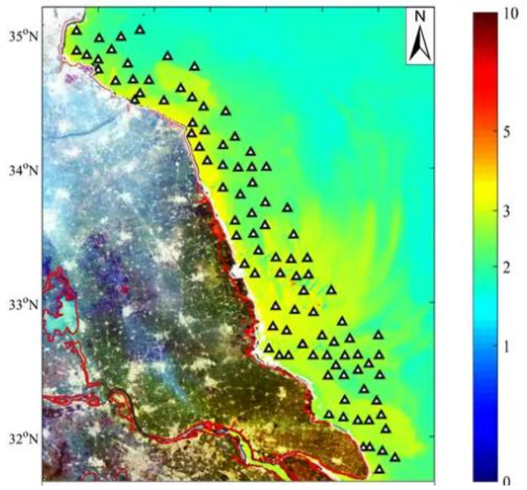

Fig. 2. Image Analysis of UAV Environmental Monitoring

ONLINE ROUTE PLANNING BASED ON GENETIC ALGORITHM

In online track planning, the minimum length track is calculated under various constraints that the track is required to meet. Therefore, its objective function uses the formula:

$$\min F' = \sum_{i=1}^{n} w_2 q_{2i} + h + t_s \tag{10}$$

For any track, suppose that it includes n+1 track points, let q2i be the track length value of the ith segment of the track, h be the penalty function, and ts be the sum of the distances between the few track points in the track and the starting point. Values a=50, b=100, c=300, d=500. The fitness function is expressed by Formula (9). If c=0, the following functions can be obtained:

$$fit(F') = \frac{1}{1+F'} \tag{11}$$

The steps of online real-time route planning algorithm using genetic algorithm are as follows:

1. The algorithm in Chapter 3 is used to generate a reference track for UAV;

2. If the UAV reaches the destination, the algorithm is terminated; Otherwise, go to step 3;

3. The UAV detects the water environment information while flying along the generated track;

4. If the UAV detects new water environment information, go to step (1); Otherwise, go to step 2;

(1) Update task data;(2) The node at a certain distance in front of the track is taken as the new initial point;(3) Genetic algorithm generates a new track for UAV;

5. Go to step 2.

Among them, updating task data includes updating the maximum flight distance, starting point coordinates, number of remaining track points and other data.

CONCLUSIONS

When UAV is used in water environment monitoring, route planning is extremely important. On the one hand, due to the influence of UAV flight performance, it is impossible to monitor all interested areas or target points at once, so UAV can spend more fuel consumption on key monitoring targets through route planning; On the other hand, when UAVs complete water environment monitoring tasks, different tasks will lead to different targets. For example, during normal patrols, UAVs are required to monitor the monitoring target points for as long as possible. In case of emergencies, UAVs are expected to monitor the target points quickly; In addition, UAV flying in the water environment is different from the land environment, and special risks should be considered. Aiming at the water environment monitoring of UAV, I established a mathematical model according to the flight mission, and studied the overall route planning and online route planning methods, and achieved good results.

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