Research on Obstacle Avoidance Control of Multiple UAV Formation based on Genetic Algorithm

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Abstract. The UAV (Unmanned Aerial Vehicle) group cooperative formation flight technology has the advantages of wide coverage, large activity radius, strong overall search ability and high efficiency of the aircraft group. Therefore, it is suitable for various complex tasks in the military field such as battlefield environment reconnaissance, tactical attack and cooperative search. This paper proposes a consistency control strategy based on GA (Genetic Algorithm) and applies it to multi-UAV formation obstacle avoidance, which can effectively solve the collision between UAVs and between UAV formation and obstacles. Demodulate the received ground desired control command, and introduce an additional auxiliary traction acceleration through GA to avoid the local optimal solution. The auxiliary traction acceleration is related to the speed and relative position of UAV and obstacles. It can be used as a disturbance to solve the local optimal solution, and also as an auxiliary acceleration to improve the speed of avoiding moving obstacles. Finally, the rapid formation and obstacle avoidance of UAV fleet during flight are realized, and the survivability of the fleet in the battlefield environment is improved.

Keywords: Genetic Algorithm; Multiple UAVs; Formation Obstacle Avoidance Control.

1. Introduction

UAV formation technology has become one of the hot topics in the field of intelligent control research, especially in the research of track planning, cooperative control of multi-UAV formation and obstacle avoidance, and some achievements have been made. The cooperative formation flying technology of UAV fleet has the advantages of wide coverage, large activity radius, strong overall search ability and high efficiency, so it is suitable for all kinds of complex tasks in military fields such as battlefield environment reconnaissance, tactical strike and cooperative search. Multi-aircraft autonomous formation capability is the premise for UAV cluster to perform diversified tasks, one is to realize cluster formation control, the other is to realize cluster perception and avoid cluster formation control, which mainly solves two problems: formation reconstruction and formation maintenance. Multi-UAV vision is the main source of information. Vision sensor can detect obstacles to assist track planning, and can also detect and track targets. High-performance processors are often accompanied by large volume and weight. Because of the small size and weak load capacity of UAV, it is difficult to equip computers with high processing capacity. Therefore, it is of great theoretical significance and application value to study the formation obstacle avoidance of UAV fleet in battlefield environment.

In this paper, a consistency control strategy based on GA is proposed and applied to multi-UAV formation obstacle avoidance, which can effectively solve the collision between UAVs and between UAV formations and obstacles. In this paper, the formation obstacle avoidance problem of multi-UAV fleet in battlefield environment is studied. In view of the situation that the fleet should deal with fast moving obstacles when performing tasks, the situation that the obstacles always move in the straight line between the UAV and the target point and the moving speed is greater than the maximum speed of UAV is considered. With the increasing diversity of UAV's application range and the increasing complexity of flight environment, only by constantly proposing new theories and methods can we meet the requirements of UAV's safe flight. Obstacle avoidance is a collision-free path planning problem, which is essentially an optimization problem with constraints. For path planning, there have been many algorithms that can be used. Among the existing algorithms, some have advantages in real-time, but their ability to find the global optimal solution is insufficient. In order to improve the response speed of multi-UAV formation process, this paper puts forward a method of

UAV formation obstacle avoidance based on GA, which realizes the rapid formation and obstacle avoidance of UAV fleet during flight and improves the survivability of UAV fleet in battlefield environment.

2. Research on Obstacle Avoidance Control

2.1 Obstacle Avoidance Control Method based on Genetic Algorithm

In the process of barrier-free flight, flight path planning is carried out with the goal of minimizing energy consumption; In the process of flying with obstacles, aiming at minimizing the length of flight path and reducing the number of turns during flight, a GA-based flight path planning algorithm for multiple UAVs is proposed. In this paper, the route distance between adjacent marker points is calculated by GA, and the number of turns and the change value of heading angle are obtained; Track fitness is calculated according to fitness function, and genetic operation of plant protection UAV flight path is carried out. Any UAV only interacts with a limited number of UAVs. The formation flight of multiple UAV clusters is the key research direction in UAV cooperative operations. It usually refers to multiple UAVs with independent and autonomous functions. The results of model predictive control are optimized using long-term trajectory planning results; At the same time, the polynomial trajectory parameters are used to interact with the neighboring machine's trajectory information, which effectively reduces the communication volume required for the trajectory interaction, and makes the control system more practical. Based on mission requirements, maintain flight in a certain formation and cooperate to complete the mission.

The virtual navigator and the follower are one-way communication, and the follower is two-way communication. Based on GA, the flight attitude angle is used as the outer loop of the control system, and the flight angular velocity is used as the inner loop of the control system. Therefore, calculate this problem trajectory three times, and so on, and finally get a trajectory to avoid all obstacles. The flow chart of automatically adding and calculating the middle point to avoid obstacles is shown in Figure 1.

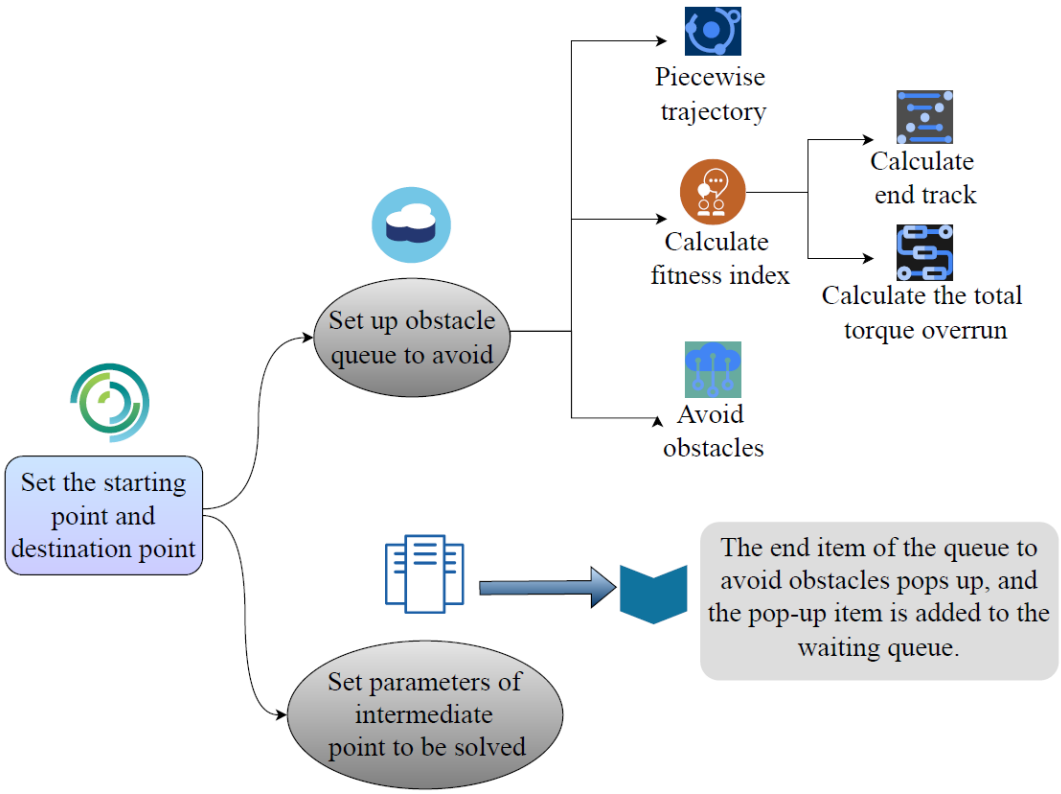


Figure 1. Automatic obstacle avoidance calculation process

In the flight control process, each degree of freedom forms an independent closed-loop control. In the process of multi-UAV flight control, closed-loop control based on angle and position is adopted, and its algorithm can be expressed as follows:

$$u(t) = Ke(t) + kd(e(t-1)) \tag{1}$$

Where $e(t)$ is the angle deviation value; $e(t-1)$ is the angle deviation value at the last moment; kd is the angle loop control integral coefficient; ke is the differential coefficient of angle control. The fitness function of trajectory planning is:

$$F_i = \frac{3}{L + M_i + N_i} \tag{2}$$

Where F_i is the fitness of individual trajectory; L is the normalized length of the i trajectory; M_i is the normalized data of the i turn times; N_i is the data after the i terrain width normalization.

During the flight of the fleet, there is no collision between UAVs and between UAVs and obstacles. Assuming that there is an ideal segmented trajectory, when each joint angle obtained by spline fitting in the joint space is mapped to Cartesian space, all obstacles are avoided, and the length of the terminal trajectory is short. Moreover, the trajectory will not exceed the maximum torque of the joint at every moment in the joint space, and the UAV fleet can quickly return to formation after avoiding obstacles. From the trajectory of multiple UAVs, it can be seen that the system initially encountered the local extreme solution, but escaped from the location of the local extreme solution through the action of random disturbing force, and at the same time, other UAVs adjusted their positions to achieve a new balance, and finally each UAV reached the desired position to form a standard formation configuration.

2.2 Design of Obstacle Avoidance Control Scheme

The obstacles encountered during formation flight are divided into two categories: static obstacles and moving obstacles. At present, the mainstream UAV formation control is to solve the problem of maintaining the distance between UAVs in the UAV formation. The pilot-following method selects the pilot aircraft, and controls the formation by setting the relative position with the random. UAV cooperative operations can improve the efficiency of UAV mission execution in complex environments and large-scale combat missions, and at the same time increase the reliability of the mission, expand the coverage of the mission area and expand the mission execution capability. In practical applications, it is usually hoped that a single control framework and as few control law designs can be used to meet all control objectives at the same time, so as to reduce the coupling between control algorithms and the complexity of the controller.

GA only needs the value of the objective function of the feasible solution, and does not need other information. It has no requirements for the continuity and differentiability of the target function. Therefore, it is convenient for the user to select and generate the solution in a probabilistic way, so it has strong adaptability and robustness. And the relative height difference between them is zero. The long plane and the wingman close to the inside of the obstacle are on one side of the triangle formation, which is parallel to the envelope, and is also the expected path of the long plane.

UAV mission execution is affected by some unknown or known but complex, dangerous and unreachable environments. The application of UAV route planning and UAV formation flight is limited by traditional GPS and navigation guidance technology, which makes it difficult to ensure UAV flight safety. The virtual structure method selects the virtual reference point and determines the geometric position of each UAV formation to maintain the UAV formation. Generally, the shape of the obstacle is not a regular geometric figure. In order to facilitate the study, the obstacle area is enveloped by the external surface of the cylinder and simplified into a cube model. Only when the expected flight path of the formation and the envelope of the obstacle maintain a dynamic parallel relationship can the UAV formation successfully avoid obstacles and complete the combat mission, as shown in Figure 2.

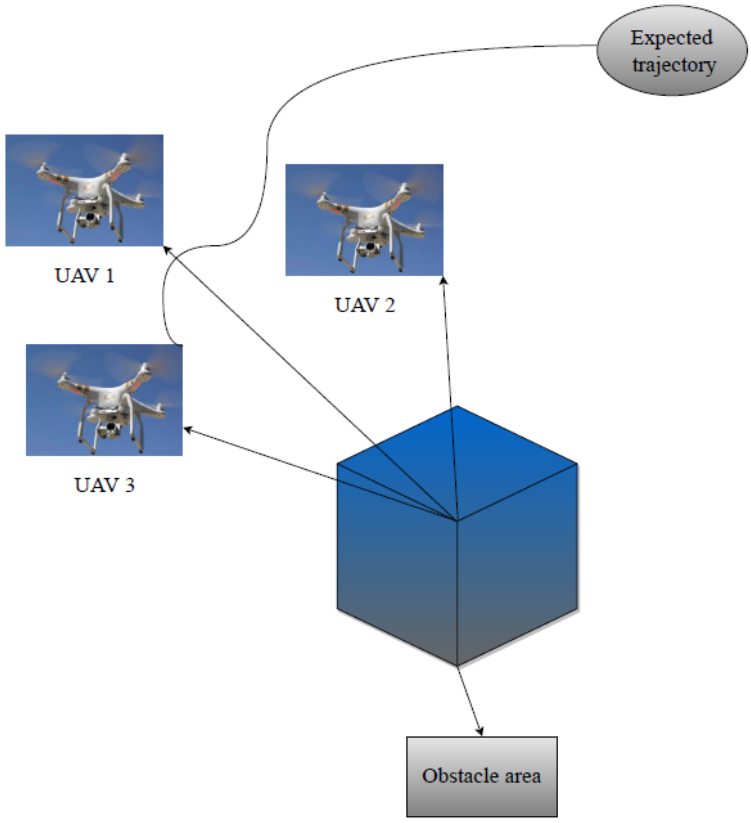


Figure 2. UAV avoids obstacles when obstacles move.

According to the information of roadside constraints and the moving speed and direction of obstacles obtained by machine vision and lidar, a safe and feasible shortest reference path is planned in real time within a certain preview range of machine vision, and the reference path must meet the path. In UAV formation, the control law of UAV is expressed as:

$$T_{total} = \sum_{j=1}^{N+1} a_{ij} \tag{3}$$

$$h_j = h_j^k - h_{hj}^k \tag{4}$$

Where, the symbol subscript $N+1$ represents the long machine, and a_{ij} is the positive real control gain; h_j indicates the status of UAV in vertical direction.

Demodulate the received ground desired control command, control the UAV to fly according to the desired flight attitude, ensure the self-balance stability of multiple UAVs, and enable them to fly according to the control command. This obstacle avoidance method is relatively simple. The control algorithm is embedded in the long aircraft controller. The long aircraft keeps a safe distance from the obstacle, and tracks the long aircraft to form an equilateral triangle formation flight according to the set formation command, which can effectively avoid collision.

3. Analysis and Discussion

Aiming at the problem of flight control and obstacle avoidance of multi-UAV formation, the communication topological relationship in graph theory is used as the communication model of UAV formation. Consistency protocol is introduced as the control algorithm of multi-UAV formation flight controller. It is proved that the consistency protocol of UAV formation is stable under certain communication delay. An additional auxiliary traction acceleration is introduced through GA to avoid local optimal solution, which is related to the speed and relative position of UAV and obstacles. It

can be used as a disturbance to break the local optimal solution, and also as an auxiliary acceleration to improve the speed of avoiding moving obstacles.

Therefore, in view of the formation process of large-scale UAV, it is necessary to propose a more effective local extreme solution from the definition of each virtual force in the mimicry physical method, which can eliminate the existence of local extreme solution while ensuring the stability of formation control law. In addition, this paper adjusts the weight of formation and obstacle avoidance algorithm according to the type and speed of obstacles, and improves the speed of obstacle avoidance by GA, which avoids the problem that the formation algorithm may influence the formation algorithm in the process of obstacle avoidance, resulting in poor obstacle avoidance effect. The specific information of the UAV closest to each obstacle is shown in Table 1.

Table 1. Specific information of UAV closest to each obstacle

Obstacle	Minimum range	Time	UAV
Fixed 1	6.12	101.2	Follower4
Fixed 2	9.45	91.23	Follower8
Move 1	3.182	112.4	Follower7
Move 2	4.541	88.6	Follower3

When avoiding moving obstacles, the minimum distance is 3.182m, and after adjusting various parameters according to the type and speed of obstacles, the speed of avoiding moving obstacles is improved. Based on the consistency protocol, the formation transformation algorithm of multi-UAV formation is designed. The algorithm in this paper can be extended to obstacle avoidance trajectory planning of robots with arbitrary degrees of freedom, but with the increase of degrees of freedom, the parameters to be solved of GA will increase and the calculation cost of interference inspection will increase, and the calculation time will increase exponentially.

In the process of flight trajectory optimization, firstly, the operation area is initialized, so that the operation area is divided into plan, and the edge of the operation area is found, and individuals with different heading angles are randomly generated. Through GA, the virtual leader in the multi-UAV fleet can track the target point in real time, and the flight state of each follower is consistent with that of the virtual leader in a limited time. The fleet can form a designated formation in a limited time and can maintain the formation for a long time. Therefore, all heading angles are required to cover the whole operation. The algorithm is prevented from falling into local optimal solution, which makes the UAV fleet more viable in the battlefield.

4. Conclusion

In this paper, under the same initial condition and initial setting, the trajectory planning based on GA can obtain the trajectory with similar performance but not identical in each calculation. The obstacle avoidance problem is solved by GA, and the idea and modeling process of the algorithm are discussed in detail. Inspired by the Human Genome Project, the method of constructing a "gene bank" is proposed for the design of genetic operators, so that the overall guidance is added to the adaptive evolution of GA. Multiple UAVs can effectively avoid different obstacles during flight, and achieve the purpose of avoiding obstacles during flight control; There is a slight deviation between the obstacle avoidance trajectory and the theoretical trajectory, but it will not affect the flight status of multiple UAVs. However, these trajectories are those that meet the performance requirements and can avoid obstacles. In order to eliminate the formation error faster, the hypothetical state trajectories of itself and its neighbors are introduced into the objective function, so that multiple UAVs can quickly form formation and maintain formation flight during the process of tracking their desired trajectories. Demodulate the received ground desired control command, and introduce an additional auxiliary traction acceleration through GA to avoid the local optimal solution. The auxiliary traction acceleration is related to the speed and relative position of UAV and obstacles. It can be used as a

disturbance to solve the local optimal solution, and also as an auxiliary acceleration to improve the speed of avoiding moving obstacles.

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