Research on Dynamic Path Exploration and Planning Method of Quadrotor Unmanned Aerial Vehicle in Complex Environment

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Abstract. As a research hotspot in the field of mobile robots in recent years, UAV(Unmanned Aerial Vehicle) has been improving its autonomous performance. Compared with traditional UAV, UAV has many advantages, such as vertical lifting, strong maneuverability and convenient operation. However, the dynamic path planning of quadrotor UAV, as a typical autonomous ability of mobile robot, has always been the research focus in the field of UAV. In this regard, this paper will try to study the dynamic path exploration planning method of quadrotor UAV in complex environment. In the complex environment model, the comparative simulation from the aspects of calculation time, calculation complexity and success rate shows that the selection of high-order polynomials can ensure high-order continuity, but it will also increase the calculation time and complexity. Compared with CF algorithm, the calculation time in this paper is 57% lower on average and the success rate is 17.6% higher on average, which shows that this algorithm is more suitable for online flight path planning of quadrotor. Comparatively speaking, the success rate of the other two methods decreases with the increase of environmental complexity, and the overall calculation time is longer.

Keywords: Complex environment, Four-rotor UAV, Dynamic path, Explore planning methods

1. Introduction

With the continuous enhancement of human's ability to explore the living environment, mobile robots with autonomous behavior will provide more abundant and comprehensive information for human beings. Compared with the traditional UAV, the four-rotor UAV has the advantages of vertical lifting, strong mobility and easy operation, which makes it play an important role in many fields such as aerospace launch and recovery, military reconnaissance, police search, fire rescue, agricultural monitoring, film and television shooting [1]. Path planning has been widely concerned by researchers in the field of artificial intelligence because of its strong autonomous behavior performance. Path planning is to search for the best path from the starting point to the destination on the basis of meeting the requirements of the planned object's motion trajectory. As a research hotspot in the field of mobile robots in recent years, the four-rotor UAV has continuously improved its autonomous performance. As a typical autonomous capability of mobile robots, path planning has always been the focus of research in the field of UAV [2-3]. The research of four-rotor UAV path planning is usually focused on the outdoor open environment. The indoor environment is more time-varying and unpredictable. It is of great significance to carry out UAV precise path planning in the indoor complex time-varying environment for UAV autonomous cooperation and precise operation [4].

In the complex environment, refer to the research findings of domestic and foreign scholars on local dynamic path planning in recent years. It is particularly important that how to maintain the original flight attitude and independently plan the flight route according to the original waypoint, safely and stably fly to the destination and land, so as to avoid sudden accidents of aircraft damage and personal injury when the four-wheel UAV is out of manual control or other emergencies [5]. The superiority of the search path depends on the accuracy of the environment model and the real-time and effectiveness of the algorithm. These search paths limit the form of flight motion. Therefore, we hope that from the perspective of motion learning, we can not only plan a desired path, but also integrate the motion characteristics by learning the existing motion forms. At present, the research of such problems is mainly aimed at the path planning of UAV in the outdoor environment, while the problems faced by UAV in the indoor environment are more complex. In the case of obstacles, it is also possible to plan a feasible obstacle avoidance path through dynamic motion primitives [6]. Such a motion learning mechanism improves the autonomous navigation capability of the micro four-rotor UAV. Obstacles and environment are more uncertain, so the local dynamic programming algorithm proposed for outdoor environment cannot be applied in indoor environment.

2. Indoor local dynamic path planning of quadrotor unmanned aerial vehicle

2.1 Memoryless A* algorithm

On the path planning problem, A* algorithm, as a heuristic algorithm, has high search efficiency and can meet the real-time performance of UAV path planning in complex indoor environment. At the same time, A* algorithm, as a greedy algorithm, can make up for the shortcomings of heuristic search algorithm and find the optimal path. Then, the nodes with the minimum cost are screened out from the open set and put into the closed set, and the nodes put into the closed set continue to carry out extended search for the current node, and the cost is updated in the process of each extended search [7]. The algorithm node expansion is shown in Figure 1.

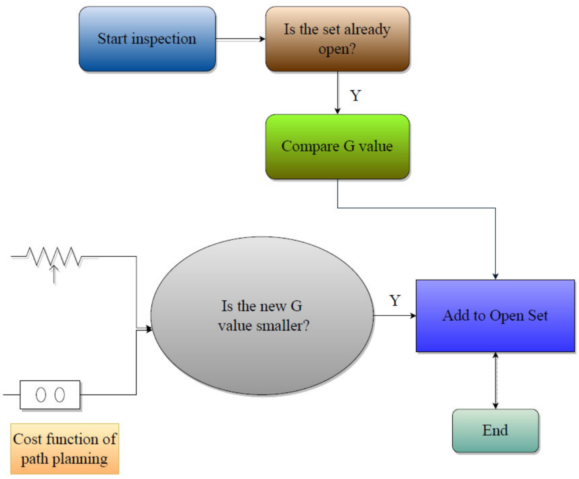

Figure 1 A * algorithm node expansion process diagram

Due to the dynamic obstacles in the environment, it is necessary to continuously rescan the environment information and repeat the environment modeling during the planning process. When the A * algorithm performs path search, its planning efficiency is seriously affected due to frequent environment modeling. The four-rotor UAV adopts a symmetrical "X" shaped rigid body structure, in which two pairs of positive propellers and two pairs of reverse propellers are installed on the same diagonal. The forward rotation of the positive rotor produces clockwise torque, while the reverse propeller produces reverse torque. After the offset between the torques, the UAV obtains vertical upward lift.

This kind of traversal search has great randomness and blindness, resulting in reduced real-time performance of the algorithm, and will generate too many redundant nodes, plan the route twists and turns, increase the four-rotor maneuver, and reduce the track tracking [8]. In a three degree of freedom motion system, a point to point motion model is established in three-dimensional Cartesian space. In formula (1), the coupling term C is added to build a dynamic system with obstacle avoidance function, namely:

$$\tau \upsilon = \alpha_{\upsilon} + C_{i,j} \quad (1)$$

The vector form of motion coupling term with three degrees of freedom is the key to avoid obstacles in $C_{i,j} = \lfloor C_{i,x} \quad C_{i,y} \rfloor$ planning.

A motion perpendicular to the current velocity direction is added to the coupling term, which is a function of distance vector and velocity vector, as shown in the following formula:

$$C_t = kRy\mu e^{-\beta} \quad (2)$$

$$\mu = \arccos \frac{o-y}{o-y(y)} \quad (3)$$

According to the above dynamic model of micro quadrotor UAV, it can be seen that the movement of UAV can be the movement of the center of mass and the rotation of the fuselage, and the movement of the center of mass depends on the lateral acceleration provided by the roll of the fuselage, so the key to control UAV is attitude control. Therefore, in the flight process, the central control unit provides control signals to adjust the motor speed after receiving the feedback information, so that a variety of flight state outputs can be obtained by adjusting the four motor speeds. Next, the stress analysis of the X-shaped quadrotor UAV in several flight states under normal operation will help to explain its flight principle more clearly.

2.2 Memoryless regression A * algorithm

In view of the above ideas about local dynamic path planning solutions, to realize this idea, we must first improve the global planning algorithm and local planning algorithm. Analyze the characteristics of global planning algorithm and local dynamic planning algorithm. Considering the complexity of the indoor environment, this paper takes A * algorithm as the global planning algorithm, and refers to the memoryless A * algorithm, improves and designs the memoryless regression A * algorithm as the local dynamic path planning algorithm [9]. According to the above micro four-rotor UAV dynamics model, it can be seen that the movement of the UAV can be the movement of the center of mass and the rotation of the body. The movement of the center of mass depends on the lateral acceleration provided by the body's roll. Therefore, the key to control the UAV is attitude control. The control structure diagram is established as shown in Figure 2.

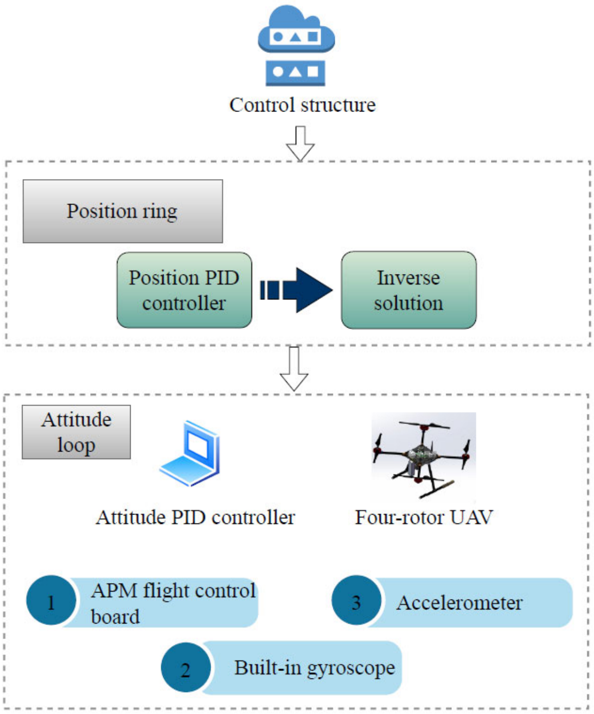

Figure 2 Schematic diagram of control structure

The planned track must meet the dynamic performance constraints of the four-rotor wing, otherwise the four-rotor wing cannot fly according to the planned track, and the planned track is not feasible. After dealing with sudden dynamic environment changes, in order to obtain the local coupling equation, a performance index function that depends on the local adjacency consistency error and coordinated control strategy is designed. The path should return to the originally planned path as soon as possible, so the local dynamic planning algorithm should have the ability to return to the global path.

The reduction of track points can cut most of the tortuous track points and only retain the track points necessary for the UAV to avoid obstacles. This optimization step can significantly reduce the number of UAV maneuvers, not only enhance the safety of UAV flight, but also save fuel and increase the flight distance [10]. The four-rotor UAV conducts global path planning in the indoor environment. Although the global environment information is fully known and can be fully utilized, considering the small indoor environment space, small obstacle avoidance margin, irregular and complex obstacles, and the three-dimensional planning space, a path planning algorithm is required to solve the problem, which can not only ensure the planning efficiency, but also meet the requirements of environmental accuracy.

3. Experiment and analysis

3.1 Experimental data transmission link

Set the IP address of the workstation server running Motive software, click the "Adjust IP" button corresponding to the IP of the client to automatically obtain the IP address of the ground station, and then click the "Enable" button below to realize the communication between the ground station system based on UDP communication protocol and the Motive software workstation, and receive the position, attitude and spatial state environment information of the multi-rotor UAV obtained by the indoor visual positioning system. When the quadrotor UAV passes through the area represented by the Euclidean distance field, the gradient of the Euclidean distance field will suddenly change near these obstacles, making it impossible for the flight path to smoothly bypass these obstacles. Then the data transmission and recovery system can ensure the accurate transmission of remote control instructions, ensure that UAV can feedback flight data in real time, and can fly at a safe altitude and speed according to the instructions.

Under normal circumstances, a complete quadrotor UAV will be loaded with global positioning system, ranging sensor, gas sensor, gyroscope, photoelectric pod and other equipment. By setting the serial number, baud rate and transmission frequency of the wireless data transmission module, click the "Enable" button below to establish the communication interactive link between the ground station system and the multi-rotor UAV. In order to further solve this problem, additional parameter information is introduced, and the penalty terms of distance cost, collision cost, speed and acceleration are added, and the on-line trajectory avoidance optimization model of four-rotor UAV is constructed. Tick the "path planning" option under the position expectation, and the ground station system will carry out environmental modeling and dynamic path planning according to the current space state information and the position and attitude data of the multi-rotor UAV. After the modeling and planning are completed, the planned route trajectory points will be sent to the four-rotor UAV one by one according to the set transmission frequency.

3.2 Dynamic path planning simulation in complex environment

When the four-rotor UAV is flying in an unknown environment, due to the limited range of perception, it is necessary to re-plan the flight path frequently, that is, when the scheduled flight path will collide with the new obstacles, it is necessary to re-plan the flight path online to ensure that once any collision is detected, a new safe flight path will be available. Use the same reference track to initialize all methods, and limit the optimization time to within 18ms. This paper compares CF (Collaborative Filtering) with the algorithm in this paper, and the relevant data statistics are shown in Table 1. The comparison results show that the method in this paper can always maintain a high success rate and obtain a feasible escape route in the unknown environment. In comparison, the success rate of the other two methods decreases with the increase of the complexity of the environment, and the overall calculation time is longer.

Table 1 Comparison of simulation data of two algorithms in different complex environments

Obstacle environment	Algorithm	Time consuming	Success rate
Low density	CF	12.4	86.5
	This text	4.2	100
Medium density	CF	15.3	88.7
	This text	7.3	100
High density	CF	15	90.3
	This text	6.24	100

This chapter combines the actual flight environment of the four-rotor UAV, based on the traditional dynamic window algorithm, adds the improvement of obstacle circle and gives collision detection conditions, further speeds up the trajectory simulation speed, improves the feasibility of the safe flight of the UAV, ensures the stability of the closed-loop system, and ensures the good control performance of the multi-UAV formation system in the case of switching communication topology.

4. Conclusions

In this paper, the memoryless regression A* algorithm is designed and combined with the traditional A* algorithm for dynamic planning, which overcomes the limitations and blindness of the algorithm in the process of local dynamic path planning. Four-rotor UAV carries out global path planning in indoor environment. Although the global environmental information is completely known and can be fully utilized, considering the small indoor environment space, small obstacle avoidance margin, irregular and complex obstacles, and the planning space is three-dimensional, a path planning algorithm is needed to solve this problem, which can not only ensure the planning efficiency, but also meet the requirements of environmental accuracy. In the complex environment model, the comparative simulation from the aspects of calculation time, calculation complexity and success rate shows that the selection of high-order polynomials can ensure high-order continuity, but it will also increase the calculation time and complexity. Compared with CF algorithm, the calculation time in this paper is 57% lower on average and the success rate is 17.6% higher on average, which shows that this algorithm is more suitable for online flight path planning of quadrotor. The comparison results show that the method in this paper can always maintain a high success rate and obtain feasible evasive paths in unknown environments. Comparatively speaking, the success rate of the other two methods decreases with the increase of environmental complexity, and the overall calculation time is longer.

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