Multi-constraint UAV Fast Path Planning Based on Improved A* Algorithm

Xiaodi Kong¹, Bin Pan¹*, Evgeny Cherkashin³, Xiaoyang Zhang¹, Linke Liu¹ and Jian Hou¹

¹ School of Computer and Communication Engineering, Liaoning ShiHua University, Fushun, China
² School of Science, Liaoning ShiHua University, Fushun, China
³ Matrosov Institute for System Dynamics and Control Theoiry of SB RAS, Novosibirsk, Russia

*Corresponding author email: panbin@lnpu.edu.cn

Abstract. Path planning is an important part of UAV intelligent control technology. For the current UAV path planning, the A* algorithm has a large memory overhead during the planning process, and the search speed is slow. It cannot meet the path planning in a complex three-dimensional environment. The immediacy requirement and considering the constraints are less, this paper made the following improvements to the A* algorithm. The first, combining an anytime repair search framework with a weighted A* algorithm, it is possible to quickly find a feasible path during the search process. The second, aiming at the defect of relying on low heuristic function weights in the algorithm, a double ranking criterion is proposed to improve the efficiency of the algorithm approaching the optimal path in the iterative process. And third, to reduce the number of node expansions in the planning process, increase list storage constraints have been improved. Finally, the results of simulation experiments show that the improved algorithm proposed in this paper can quickly generate feasible paths, and can continuously optimize the approach to the optimal path within a specified time, which is far superior to the traditional A* algorithm in terms of planning efficiency and immediacy.

1. Introduction

With the continuous development of technology, unmanned aerial vehicles have been widely used in many fields such as street photography, agriculture, rescue, surveying, and electric power inspection. In the process of performing tasks, planning an appropriate and effective path is the key to the success and high efficiency of UAV task execution. At present, research on autonomous flight of drones has achieved relevant research results, but it still faces problems such as slow path search speed and inability to meet real-time search in complex environments. Therefore, how to efficiently plan a path that satisfies the constraints in a three-dimensional complex environment has become a serious challenge for UAV flight.

In the solution of artificial intelligence path planning problems, for large and complex problems, finding the optimal solution path may take a long time, and finding suboptimal solutions quickly can better meet the real-time planning requirements in practical applications[1]. Heuristic search algorithms are now widely used because of their faster convergence speed. A * algorithm [2] is a widely used heuristic algorithm, but due to the algorithm itself storing data structure and the requirements on constraints, the traditional A * path planning algorithm will lead to slow search and high cost [3], so it can’t meet the real-time planning requirements. In response to the above problems, this paper proposes
an improved A* algorithm, which combines an instant repair search framework and a weighted A* algorithm, which can quickly generate an initial suboptimal feasible solution, and then continuously optimize the path quality through loop planning. To the optimal path, and improved the calculation of the cost function, the update method of the node expansion list, and the storage constraints in the algorithm, to achieve a reasonable trade-off between planning timeliness and optimal results, and finally through the traditional. The planning results of the A* algorithm are compared to verify the efficiency of the algorithm.

2. Basic Principles of the Algorithm

2.1. Weighted A* Algorithm

The weighted A* algorithm changes the cost function in the A* algorithm by further strengthening the role of the heuristic evaluation function $h(n)$, making its effect higher than the actual cost $g(n)$ of reaching the target node, and can be more inclined to choose the look during the search process The node closer to the goal [5], so that the A* algorithm can find the bounded optimal solution with less calculation. The cost function is:

$$f_w(n) = g(n) + \omega h(n)$$

(1)

Among them, $\omega$ is the weight coefficient of the heuristic $h(n)$.

2.2. Anytime Search Framework

The anytime search algorithm can quickly generate an initial sub-optimal feasible solution. It can output the current optimal search results at any time after the start of planning, and the path quality is continuously improved through circular planning as the calculation time increases. The anytime search architecture mainly has three types: heavyweight, windowed and repaired [6, 7, 8]. According to the research results in [7], the instantaneous repair architecture has the highest overall performance and the highest efficiency compared to the other two, it can converge to the optimal solution faster, and the framework is more robust. Therefore, this paper introduces the instant repair framework into the A* algorithm path planning.

2.3. Environmental Modeling

Path planning must first establish an environment model for drone movement. The establishment of a good and appropriate environment model can improve the efficiency of path planning and also have good visibility. The three-dimensional space of the UAV is marked as $(x, y, z)$, where the planned path is represented by a set of sequences $\{V_s, V_1, ..., V_n, V_g\}$, $V_s$ representing the starting node, $V_g$ as the target node, and $V_1...V_n$ represents the node to be planned in the path. In the actual three-dimensional space, the flight path of the UAV must meet the constraints of turning constraints, minimum track length, maximum climb/dive angle requirements, etc [9]. The constraints are considered as follows: suppose the maximum turning angle of the UAV is $\theta_{\text{max}}$, the minimum track length is $L_{\text{min}}$, and the maximum yaw angle is $\theta_{\text{max}}$.

3. Instant Repair Weighted A* Path Planning Algorithm

This paper proposes that this algorithm combines the instantaneous repair search framework and the weighted A* algorithm, which can output the optimal planning results of the current search plan at any time after the planning starts for the complex dynamic environment [10], and as the planning time increases, successively reduce the weight of heuristic items and execute the weighted A* algorithm in multiple iterations, and can use each extended information to improve the quality of subsequent path searches and obtain better planning results.
3.1. Algorithm Related Introduction

In the process of iteratively searching for a feasible path, a list of three storage nodes is set, namely an OPEN table, a CLOSED table, and a TEMP table. The TEMP table is used to save nodes with inconsistencies, and will be merged with the OPEN table in the next iteration search process, and reordered for expansion. After the single path planning is completed, if the planning time has not exceeded the limit, heuristic item weights and list updates are performed, and the next planning operation is performed accordingly. The weights of heuristics in the algorithm are updated in a linear decreasing manner, the formula is as follows:

$$\omega = \omega - \Delta \omega$$  \hspace{1cm} (2)

Set storage limits on the list to reduce the expansion of unnecessary nodes. Set the upper limit of the number of nodes stored in the OPEN table, if the number of nodes stored in the OPEN table exceeds the storage limit, sort the nodes according to the size of the value, delete the nodes with larger generation value in the list to meet the constraints of the storage space, and improve the entire efficiency of the path search process.

3.2. Algorithm Cost Function Improvements

After the weighting algorithm completes a search, it moves the nodes in the TEMP table into the OPEN table and updates the node information in the table according to the new heuristic weights. However, due to the influence of the heuristic weight in the cost function, the nodes near the starting point have a greater chance of being expanded only when the heuristic weight is small. Therefore, to find the optimal path, the heuristic weight must be reduced to a smaller value \cite{11}. This shortcoming reduces the speed of searching the optimal path by the instantaneous repair weighted A* algorithm. To solve this problem, it is proposed to set different heuristic weights at different stages of the search path. That is, according to the distance between the current node and the target point, different cost functions are used for calculation, that is $f_1(v)$ and $f_2(v)$:

$$\begin{align*}
    f_1(v) &= g(v) + \omega_1 \ast h(v) \\
    f_2(v) &= g(v) + \omega_2 \ast h(v)
\end{align*}$$  \hspace{1cm} (3)

Among them, $\omega_1$ and $\omega_2$ are weight coefficients of heuristics, and satisfy $\omega_1 < \omega_2$.

In the first half of the path search, if the actual distance between the current node and the starting point is less than the intermediate node, that is $g(v) < mid(v, v_{g})$, $mid(v, v_{g})$ is the actual intermediate distance between the starting point and the target point, then use the cost function $f_1(v)$ to sort the nodes in OPEN table. In the latter part, it is used $f_2(v)$ as a cost function for sorting, which speeds up the algorithm to search for the optimal path.

3.3. Algorithm Flow

In the traditional standard A* algorithm, the target is successful when the target node is expanded, so the path search process is performed only once. In the algorithm of this paper, the path can be continuously and iteratively optimized based on the instant repair search architecture. The detailed steps are as follows:

- 1: Initialize the node linked list, and initially set the true cost of the node to infinity;
- 2: Determine whether the plan exceeds the required time limit or whether the heuristic weight coefficient is less than 1, if so, the algorithm exits and outputs the current optimal track, otherwise step 3 is performed;
- 3: According to the input starting point and target point, use the current heuristic weight coefficient to execute the weighted A* algorithm to perform a single feasible path search;
- 4: After the execution of the single path planning algorithm is completed, according to the nodes stored in the CLOSED table, the current planned path information is obtained and saved;
• 5: Update the weights, according to the iterative decreasing rule in the instant search framework;
• 6: Add the nodes stored in the inconsistent TEMP to the OPEN table, update the generation value of the nodes according to the weight of the heuristic items updated in the new round, and return to step 2.

The steps of the single path planning algorithm in the search process are as follows:
• 1: Determine whether the minimum value of the cost \( f_2(v) \) of all nodes in the OPEN list is less than the cost of the current optimal path. If it matches, proceed to the second step, otherwise exit the plan;
• 2: Determine whether the currently expanded node satisfies \( g(v) < mid(v_i, v_g) \), if it is, remove the smallest \( f_1(v) \) node from the OPEN table, put it in the CLOSED table, and expand the node; otherwise, do the same operation to \( f_2(v) \);
• 3: During the expansion process, it is stored in the corresponding node list according to the information of each extended child node;
• 4: Determine whether the storage quantity of the OPEN list exceeds the limit value during the search process, and if so, delete the node with a larger \( f_2(v) \) generation value to satisfy the storage constraint condition, and return to step 1.

4. Simulation

In the simulation part, establish a flight environment. In the three-dimensional environment, set the mission planning area as a three-dimensional area of 10km*10km*100m, and set up multiple obstacle models in the area. Within the planning range, the starting point and target point of the path You can choose settings, set 10 sets of path starting points and target points, and use the standard A* algorithm and the improved instant repair weighted A* algorithm for simulation experiments. In order to compare the two algorithms, the feasible path, the optimal path planning time and the path cost of the algorithm are used as evaluation criteria. The path cost takes into account the different choices of the starting point and the target point. The ratio of the total length of the path to the Euclidean distance between the starting point and the target point is used as a relative cost to verify the planning ability of the algorithm.

In the algorithm parameter setting part, set the weighting coefficient of the heuristic term in the cost function \( \omega_1 = 1.2 \), \( \omega_2 = 3 \), the decrement value during the iterative execution of the algorithm is set \( \Delta \omega = 0.1 \), and the minimum track segment extension length is set to \( L_{min} = 500m \), the radius of the threat range of the obstacle The storage limit of the to-be-expanded node list OPEN table is set to 300, and the path planning time requirement is 15s. The planning result is shown in the following figure.

![Figure 1. Simulation results of path for improved A* algorithm.](image)
As shown by the results in the figure and table, the standard A* algorithm obtains a feasible and optimal path through one-time planning, but it takes a long time, and the instantaneous repair weighted A* algorithm can plan a feasible path in a short time. In the process of feasible path planning, the number of expansions of each list node is less than the number of nodes stored in the standard A* algorithm list, and iterative and continuous optimization can be performed, and at the prescribed time, the optimality of the algorithm is close to the standard A* algorithm. The path greatly shortens the time to solve the feasible path, and meets the requirements of rapid planning of feasible path and immediacy in complex environment.

5. Conclusion
Aiming at the problem of fast path search in the complex three-dimensional environment of unmanned aerial vehicles, the A* algorithm is deeply researched. Considering the anytime requirements of path planning, an anytime repair architecture and weighted A* are proposed. The combination of algorithms can achieve fast and feasible path planning goals according to environmental conditions, and iteratively optimizes to the optimal path as time increases. In view of the shortcomings of relying on low heuristic function weights in the algorithm, two different sorting rules for nodes and the corresponding constraints on the storage space limits of the list are used to reduce storage costs and improve planning efficiency. The final simulation experiment results show that the anytime repair weighted A* algorithm can meet the immediacy requirements of the UAV path planning problem in complex environments, and greatly reduce the planning time of feasible paths. The algorithm can meet the needs of optimal route planning and has certain practicality.

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