

Path Planning Approaches for Unmanned Aerial Vehicle

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Abstract. The difficulty of finding the ideal path from the starting point to the destination site for a UAV is one of the most essential challenges related with the deployment of unmanned aerial vehicle (UAV). Path planning algorithms are classified into traditional and intelligent algorithms in this article based on the order of discovery of the path planning methods. Intelligent algorithms are algorithms that are inspired by nature and can efficiently tackle the complex path planning problem. In this article, by introducing the different advantages of traditional algorithms and intelligent algorithms, it proposes employing intelligent algorithms to address the inefficiencies of traditional algorithms in uncertain conditions. The essay also outlines three classical intelligent algorithms and proposes optimization algorithms for their respective deficiencies. The article also discusses the objectives and constraints of UAV path planning. This analysis will help define the outcomes of UAV path planning and suggest the future research directions.

Keywords: Path planning, Intelligent algorithms, traditional algorithms.

1. Introduction

With the rapid growth of electronic science and technology, artificial intelligence, automatic control, and other technologies during the twentieth century, the future will be a highly automated, information-based era. Drone is the product of the new era of science and technology, referred to as UAV. It is the unmanned aerial vehicle through remote operation to carry out the task [1]. Because of flexibility, operability and low-cost, UAVs are widely used in the military and people's livelihoods and other fields, especially in the disaster rescue applications [2]. France Parrot released the world's first quadcopter drone in 2010, which has become one of the most common drones in life through virtue of its small size, easily to maneuver and other advantages. Path planning is a critical issue for UAVs in order to discover the optimal path from the beginning point to the target point. It needs to satisfy the shortest range with maintaining the highest performance of the UAV with the least possibility of being destroyed [3]. Path planning is a difficult problem, and in the past few years lots of studies have outlined some methods, Jiang Wei [1] classified path planning into global planning and local planning based on different degrees of mastery of the surrounding environment. Pengfei Wu [4] improved particle swarm optimization and genetic particle fusion algorithms based on path planning in UAV 3D environment. From the traditional algorithm to the later combination of bionics and biology developed algorithms, intelligent algorithms have made great progress. This article will review the research on UAV path planning, classify the path planning algorithms into traditional algorithms and intelligent algorithms, analyze their different application scenarios, and then solve the problems of long time consuming and high computational complexity that occur in traditional algorithms. The analysis helps to identify the advantages and disadvantages of different UAV path planning methods and suggests a feasible direction for future research.

2. Path Planning: Goals and Constraints

2.1. Path Planning Goals

2.1.1 Path optimization

The path found by the matching algorithm is not always a viable path for the UAV to follow, it must be further processed and refined in order to become a viable path.

2.1.2 Collision avoidance

It needs to satisfy the shortest range with maintaining the highest performance of the UAV with the least possibility of being destroyed.

2.1.3 Completeness

Ability to find the solution to UAV path planning in finite time when it exists.

2.2. Path Planning Constraints

2.2.1 Maximum range

The maximum range distance determines the mission execution capability of the UAV, and when all other external conditions are equal, the maximum range depends on the UAV on-board fuel.

2.2.2 Minimum turning radius

Drones will have a minimum turning radius constraint when turning due to their own maneuverability constraints and inertia.

2.2.3 Altitude

When the UAV is flying in the air, the lower it is from the ground, the greater the risks of collision with ground obstacles, so it is necessary to set a minimum flight altitude H_{min} , because of the performance of the UAV, there exists a maximum flight altitude H_{max} .

3. Path planning methods in UAV

There are many methods for path planning, and their scopes of application varies according to their own advantages and disadvantages. Path planning approaches for UAVs are classified into two types in this paper: traditional algorithms and intelligent algorithms.

3.1. Traditional Algorithms

Traditional optimization techniques are classified as graph algorithms for searching, geographical sampling algorithms, and artificial potential field methods.

3.1.1 Graph search algorithms

1) A* algorithm: P.Hart, N.Nilsson, B.Raphael of Stanford University proposed A* algorithm in 1968. The evaluation function is $f(n) = g(n) + h(n)$, where n is the current node, $g(n)$ is the current node-to-start generation value, $h(n)$ is the present node-to-terminal estimate, and $f(n)$ is the least estimated generation value by using node n to connect the start and finish points. The theory of A* algorithm was shown in the Figure 1.

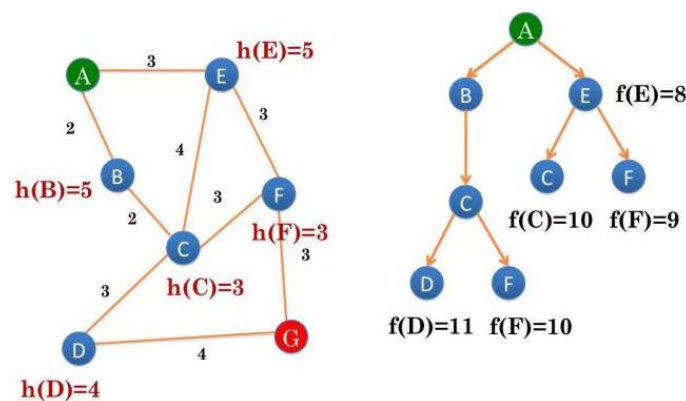


Figure 1. The theory of A* algorithm

The A* algorithm is a famous heuristic algorithm used as a graph search tool. It computes pathways based on the cost of getting from the present node to the start and end points. Because the

A* algorithm is responsive to the environment and direct in searching for paths, it is commonly employed in path planning problems. The algorithm search efficiency diminishes as the number of nodes rises. Chen et al [5] analyzed the method's benefits and drawbacks and compared it to the genetic algorithm. and reduced the fuel consumption of UAVs by path planning model. To reduce the computation time of the A* method, Guruji et al. [6] suggested a time-saving A* method for mobile robot path planning in 2016. This technique, which estimates the value of the heuristic function in the A* algorithm prior to the collision phase, has a fast-processing time.

Dijkstra algorithm: Dijkstra's algorithm is an example of a shortest path algorithm, using the idea of breadth-first search defined by the priority it is the starting point as the center of the outward expansion until the expansion of the end point. Because it traverses all the nodes to get the shortest path, this algorithm will get the information of the whole graph. However, searching through a large number of nodes takes time. Qi et al [7] wanted to solve the Dijkstra algorithm computationally large and inefficient problems, proposed the use of A star algorithm to extend the generation value of the path point, then the value of each generation and the path point of the search procedure time and the distance cost of the comparison.

3.1.2 Spatial sampling algorithms

1) PRM algorithm: The PRM (Probabilistic Roadmap) algorithm was proposed by Kavraki et al. in 1996, To form a connected graph, the algorithm finds path points and collision-free paths in a free bitmap space by random sampling and collision detection. It is made up of random nodes and straight edges, and the connecting line is discarded if it interacts with an obstruction. PRM simplifies the computation of parsing the environment, which can quickly obtain a travelling map with probabilistic completeness, it is suitable for various dynamic models. However, its completeness depends on the number of samples, and the result of each planning may be different. Xue Yang [8] et al. improved the speed of constructing the undirected graph and reduced the algorithm's execution time by using a locally sensitive hash algorithm instead of the nearest neighbor search algorithm in PRM. The theory of PRM algorithm was shown in the Figure 2.

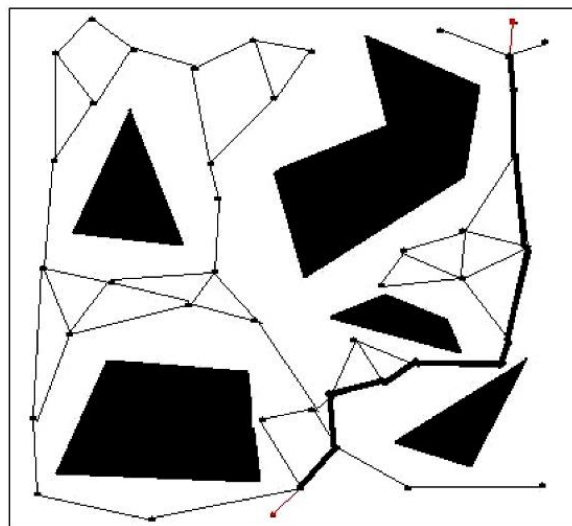


Figure 2. The theory of PRM algorithm [14]

2) RRT algorithm: The RRT algorithm is a sampling-based search method. The connectivity graph of this method is in the form of a tree, the starting location of the path planning is set as the root node of the searching tree, and then the node is expanded to form a brand-new node, which is placed in the search tree, based on the restrictions of the path planning. The preceding process is repeated until the final point is located. The advantages of this method are that it has strong search capability and does not require preprocessing of the map, but the disadvantages are that it is time-consuming and has the problem of local minimum. The theory of RRT algorithm content was shown in the Figure 3.

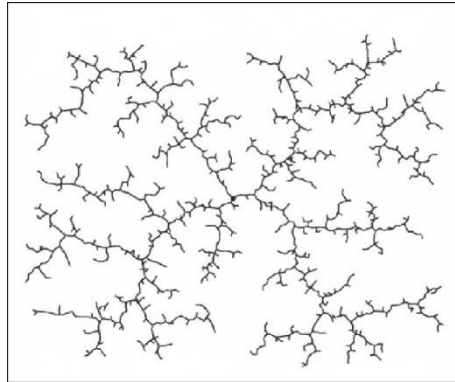


Figure 3. The theory of RRT algorithm [14]

3.1.3 Artificial potential field algorithm

Khatib proposed the Artificial Potential Field (APF) technology of virtual force fields in 1986, The APF method simulates the UAV's working environment as a place with the force, which can be separated into gravitational and repulsive forces. The force generated at the target location is the force of gravitation used to the robot, increasing with decreasing distance between the target point and the robot. The repulsive field, on the other hand, is formed by the obstruction, and the closer it is to the impediment, the stronger the repulsive force, and finally, under the impact of gravitational and repulsive forces, the UAV travels in the direction of the combined force.

Repulsive force field equation is

$$U_{rep} = \begin{cases} \frac{1}{2}k\left(\frac{1}{q} - \frac{1}{\lambda}\right)^2, & q \leq \lambda \\ 0, & q > \lambda \end{cases} \quad (1)$$

k is the repulsive field constant; q is the distance between the UAV and the obstacle., and λ is the distance of the obstacle to the UAV.

The total force equation is

$$\begin{aligned} F(x) &= -\nabla U(x) \\ &= -\nabla U_{att}(x) - \nabla U_{rep}(x) \\ &= F_{att}(x) + F_{rep}(x) \end{aligned} \quad (2)$$

It has the ability to plan fast and save a lot of computational work in time. However, if there are impediments at the goal point, the target location cannot be achieved. The theory of Artificial potential field algorithm content was shown in the Figure 4.

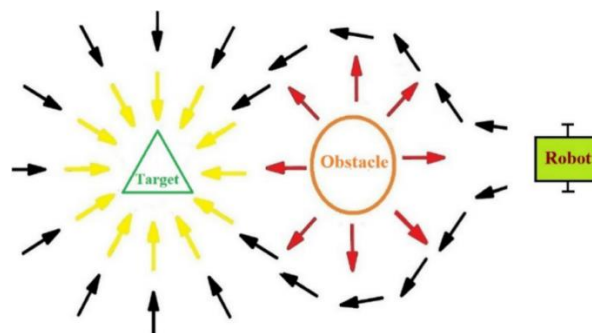


Figure 4. The theory of Artificial potential field algorithm [15]

3.2. Intelligent Algorithms

Traditional optimization algorithms are difficult to solve complex problems efficiently, although they have strong exploratory capabilities and can have better path planning results in simple environments. Compared with traditional algorithms, intelligent algorithms are more real-time and

have a higher success rate. Intelligent algorithms can be divided into particle swarm algorithms, ant colony algorithms and genetic algorithms.

3.2.1 PSO algorithm

The particle swarm algorithm is an iterative algorithm developed by Eberhart and Kennedy in 1995 that depends on bird foraging behavior. It starts from a random solution and searches for the optimal solution by iteration. Its algorithmic method is approximately as follows: first, initial particles are produced and assigned initial velocities. Then, for every particle placement, the objective function is assessed, and the ideal function values and the ideal position are determined. Finally, iteratively update the particle positions and velocities until the algorithm reaches the stopping criterion. Better global search capability and faster computational speed compared to traditional algorithms, but the optimization cannot be continued when converging to a certain accuracy. The introduction of Logistic chaotic sequences by Wu improved the accuracy of the algorithm, diversified the particle population and avoided falling into local optimal solutions [4]. Wu et al [9] effectively improved the quality of routes and reduce the planning time by introducing an adaptive Cauchy variation operator in the update rule. Li Guangseng and Chou Wusheng [10] proposed an adaptive learning particle swarm algorithm, which selects the updating strategy from four kinds of particle updating strategies in the optimization phase to improve the quality of the route effectively.

The PSO algorithm does not perform selection, crossover and mutation processes like GA, it has a memory function and shares collective best information for optimal spatial search.

3.2.2 ACO algorithm

ACO Algorithm is a probabilistic path-seeking algorithm generated by the Italian scholar Dorigo from the idea of ants searching for food. The ACO algorithm mimics ant activity while seeking for food and returning to the nest, and searches for the optimal path through the positive feedback and hair search of pheromone. Each ant releases pheromone in the path it passes through, and later ants select the path based on the concentration of the pheromone as the pheromone concentration is used as a criterion for choosing the path. The path taken by one ant indicates a plausible solution, and the entire ant colony's paths are used as the solution space to be optimized. In UAV formation control, ACO algorithm has good global optimization ability, it can be used for path planning and task allocation to make UAVs act together, but ACO algorithm suffers from high computational volume and easy to fall into local optimum. Liu Shuangshuang et al [11] considered the node-to-start line distance and node-to-terminal distance, the secondary elite ant technique was utilized to update the pheromone on the trail, guided the ants on a better route, and improved the ants' global search capabilities, avoided the generation of local optimums, and obtained the optimal path with fewer iterations. When studying the 3D obstacle avoidance path planning issue for robots, Wang Gang et al [12] proposed an improved ACO algorithm based on the artificial potential field method, modifying the heuristic value parameter of the ACO algorithm and changing the algorithm's updating rule, so that the improved ACO algorithm will converge faster and find the optimal solution. The theory of ACO algorithm was shown in the Figure 5.

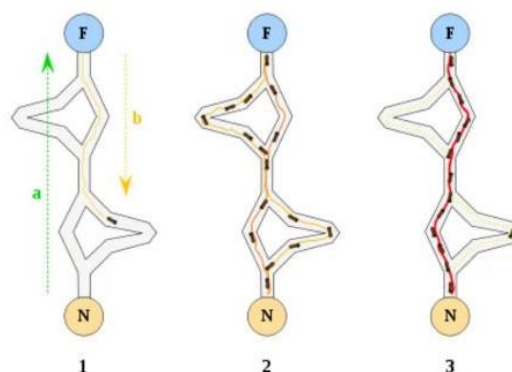


Figure 5. The theory of ACO algorithm

3.2.3 Genetic algorithm

The Genetic Algorithm, proposed by Professor Holland, is a global optimization algorithm that incorporates the natural law of survival of the fittest and serves as a form of Darwin's theory of evolution. The algorithm is an abstraction of Darwin's theory of evolution, incorporating the laws of nature of life of the fittest, which results in candidate solutions for each generation from which an ideal solution is produced. The three basic operations of the algorithm are selection, crossover and mutation. The algorithm is an iterative search technique based on genetic engineering ideas. The key advantage is that it is simple to integrate with other algorithms and fully use its own iterative advantages; nevertheless, the disadvantage is that its computing efficiency is low, and finding the global best solution is frequently challenging. While the procedure is operating, certain undesired populations will make subsequent calculations more complex, thus making the operation inefficient, slow convergence there is a premature phenomenon, and is not suitable for online path planning. Wei Tong et al [13] improved roulette selection operator and introduced insertion operator and deletion operator to ensure the path is continuous and shortest, which significantly improved the efficiency and smoothness of the mobile robot travelling. Wu [4] designed adaptive dynamic crossover probability and fixed variability, which reduces the difficulty of the algorithm's operation, improves the algorithm's speed of solution and the accuracy of the solution, and prevents the use of the local best solution.

4. Discussion

One of the most difficult difficulties in UAV navigation is path planning. Although classical methods have a strong search capability, due to the increased complexity of the function, they can substantially limit the efficiency of path search or even fail to search. If there are excessive target points or 3D path planning is performed. In these settings, intelligent algorithms reply faster than normal methods and can better deal with UAV planning issues in dynamic environments; yet, when faced with multi-copter coordination, they may fall back on local optimal solutions. To deal with the path planning problem, it is vital to blend methods and take advantage of the benefits offered by various algorithms. For example, it is possible to combine ACO and neural network algorithms to avoid the local minimum problem of using neural network algorithms alone.

Table 1. Summary of typical intelligence algorithms

Algorithms	Environment type	Drawbacks	Improvement
PSO	2D/3D	Easy to fall into local optimum	Logistic chaotic sequence [4]
			Update Strategy [9, 10]
ACO	2D/3D	Easy to fall into local optimum	Pheromone Initialization [11]
			Combined with artificial potential fields [12]
GA	2D/3D	Easily precocious astringency	Genetic operator [13]
			Adaptive crossover probability [4]

5. Conclusion

This paper reviews some classical UAV path planning algorithms, classifies them into two categories of traditional and intelligent algorithms by the discovery order of the algorithms, compares and discusses the application scope and characteristics of the different algorithms and highlights the goals and constraints of UAV path planning. Meanwhile, intelligent algorithms are adopted as a solution to the problems of path failure and low planning efficiency caused by using only traditional algorithms. The amount of processing required for the application of intelligent route planning methods will fall into the optimal local solution and other problems. This paper for intelligent algorithms introduced some hybrid algorithms, which are more conducive to the advantages of different algorithms. By utilizing the advantages and correcting for the defects, this sort of complimentary hybrid algorithm enables the integration of multiple algorithms and the development

of some more exceptional algorithms. By studying and summarizing the issues existing in current UAV mission planning, it has some significance as a reference for choosing the future research direction and advancement for UAV route planning. As technological and scientific developments improve, UAVs will be utilized in a wider range of industries, and planning of paths technologies will make UAVs more convenient and intelligent.

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