Research on UAV Path Planning Algorithms

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Abstract. UAVs have received extensive attention and research due to their superior mobility and flexibility, and they replace manned aircraft to perform tasks in some specific complex environments. In order to deal with the complex and changeable environment and various obstacles, it is necessary to use appropriate algorithms to plan the UAV path. This paper divides the existing UAV path planning algorithm research into three categories: traditional algorithm, intelligent algorithm and fusion algorithm. The basic principles, advantages and disadvantages of various algorithms are analyzed, and the future research and development are prospected based on the actual operation of UAV.

1. Introduction
In recent years, UAVs have received extensive attention and research due to their superior maneuverability and flexibility. At the same time, with the improvement of manufacturing technology and the development of related algorithms, UAVs have been widely used in wireless communications, search and rescue, agriculture, military and other fields. During the actual flight of the UAV, it is necessary to analyze its own position, environment, obstacles and other information to calculate the safe path. Due to the complex and changeable scenarios and environments in which UAVs perform tasks, it is necessary to select appropriate algorithms for UAV path planning. This paper studies the existing UAV path planning algorithms, analyzes the advantages and existing problems of various commonly used algorithms, and finds future research directions.

2. Classification of Path Planning Algorithms
The algorithms proposed by different researchers for UAV path planning research can be roughly divided into three categories, one is traditional algorithms, intelligent algorithms, and fusion algorithms that combine traditional algorithms with intelligent algorithms. Traditional path planning algorithms based on divided maps mainly include Dijkstra algorithm, A* algorithm, RRT algorithm, artificial potential field algorithm, and so on. Intelligent algorithms that combine environmental element information and their own location to plan real-time paths mainly include ant colony algorithm, genetic algorithm (GA), particle swarm optimization algorithm (PSO) and other algorithms. The third category is to combine the advantages of different algorithms to obtain a better path planning fusion algorithm (as shown in Figure 1).
3. Traditional Algorithm for Path Planning

3.1. Dijkstra Algorithm
Dijkstra algorithm is a classic breadth first state space search algorithm [1], which was first proposed by the Dutch computer scientist Edsger Wybe Dijkstra [2]. It searches the shortest distance of any point in the whole free space layer by layer through the initial point until it reaches the target point, which is widely used to solve the shortest path problem.

Due to the use of free search, the amount of data of Dijkstra algorithm is greatly increased, which affects the speed of solution. Different researchers have improved and optimized Dijkstra algorithm and gradually replaced it. In reference [3], Dijkstra algorithm is optimized by node constraints, which reduces the time complexity and improves the solution efficiency.

3.2. A* Algorithm
In order to solve the problem of large amount of calculation and low efficiency of Dijkstra algorithm, A* algorithm is proposed as a heuristic algorithm [4], because of its simple algorithm and fast calculation speed, it is rapidly applied in various fields. The A* algorithm evaluates the cost value of the scalable path points in the path area through the heuristic function, compares the value of each generation and the search operation time and distance cost of the path point, and finds the optimal path.

The advantage of the A* algorithm is that it has fast calculation speed and can efficiently obtain UAV path information. However, when there are many target points or three-dimensional path planning is performed, the A* algorithm will greatly reduce the path search efficiency due to repeated calculations, increase in grid nodes and increase in the complexity of the evaluation function, and even search failures. In view of its shortcomings, the researchers also made different improvements and optimizations to the A* algorithm. Literature [5] reduces the node calculation amount of the A* algorithm by removing some network nodes, and restricts the flight trajectory with the fourth derivative, which greatly improves the search efficiency and enables the UAV to fly continuously and smoothly with a small position error. Literature [6] adds a multi-layer step search strategy and UAV attitude angle information to the A* algorithm, which improves the algorithm's solution efficiency; Literature [7] addresses the inefficiency or even search failure of the A* algorithm under complex paths. The problem is that by optimizing the evaluation function, the undirected search is converted to the directed search, and local evaluation is performed, which improves the efficiency of the algorithm.
3.3. RRT Algorithm

The Rapid Search Random Tree (RRT) algorithm was first proposed by SM LaValle in 1998 [8]. As an incremental sampling search method, it does not require any parameter tuning in applications and has good performance. Taking the initial point as the root node, a search tree is generated by randomly extracting leaf nodes, and the search tree can be expanded to the entire space to find the target path.

RRT algorithm uses an incremental method to build a search tree. Since the dynamic constraints of the robot are considered during the search process, the generated path is very feasible, but at the same time, the path is connected by straight lines, the path is not smooth. The randomness of the algorithm also requires a long time to converge and a large amount of data to search for the optimal path. In response to the above problems, in reference to the problem of too strong randomness in the RRT algorithm, literature [9] added UAV kinematics constraints to the node expansion, improved the random sampling strategy, added heuristic information to overcome the randomness of the search, and planned close to the optimal. Literature [10] uses the B-spline function to generate a smooth path with continuous curvature while avoiding collisions with obstacles.

3.4. Artificial Potential Field Method

The artificial potential field method is a simulation force field method for motion path planning proposed by Khatib [11]. Transform the impact of targets and obstacles on the movement of the drone into an artificial potential field. The target point has low potential energy, and the obstacle point has high potential energy. This potential difference is that the target and the obstacle generate gravitational and repulsive forces respectively, and the combined force controls the UAV to move to the target point along the negative gradient direction of the potential field.

The artificial potential field method is simple to calculate and can obtain a safe and smooth flight path. However, in a complex potential field environment, a local minimum point may be generated outside the target point and the target point cannot be reached [12]. In [13], in order to make up for the defect that the artificial potential field method is easy to fall into the local minimum and cannot be solved, the global information of the pre-planned threat distribution is used, and the gravity function is improved to obtain an improved algorithm with better optimization and adaptability. Literature [14] integrates the position dynamic information into the force field function improved by adjusting the scale factor, so that the improved algorithm meets the safety and real-time performance of path planning under dynamic conditions.

Table 1. Summary of traditional algorithms

| Algorithm                  | Principle                                      | Advantage                              | Disadvantage                                                   |
|----------------------------|-----------------------------------------------|----------------------------------------|----------------------------------------------------------------|
| Dijkstra Algorithm         | Breadth first State space search              | Strong search ability                  | Large amount of data; low computational efficiency             |
| A* Algorithm               | Heuristic function guide Introduce cost function | Simple algorithm; easy to implement; fast calculation speed | Inefficient when dealing with multi-target points and 3D path planning |
| RRT Algorithm              | Random sampling search; Random tree expansion | Strong searchability; Good path         | The randomness of the algorithm leads to only probabilistic completeness |
| Artificial Potential Field Method | Virtual force field                          | Safe and smooth solution path          | It may not be possible to get results under complex potential fields |

4. Intelligent Algorithm

Intelligent response algorithms mainly include ant colony algorithm, genetic algorithm, particle swarm optimization algorithm, etc., as shown in Table 2. Compared with traditional algorithms, they can deal with the uncertainty in path planning more effectively [15].
4.1. Ant Colony Algorithm
The ant colony algorithm was first proposed by Italian scholars Dorigo, Maniezzo and others in the 1990s [16]. It uses pheromone as the basis for ants to choose the follow-up behavior of the path, so that the ants are concentrated on the best path.

As an intelligent optimization algorithm, the ant colony algorithm can achieve global optimization through a parallel random search algorithm and has a strong positive feedback effect [17]. At the same time, the ants are independent in the search process, relying on pheromone for information interaction, constantly updating the solution set, and parallel distributed search, which can improve efficiency and search for optimal solutions. Because of the existence of pheromone, all ants will tend to the optimal solution will also fall into a local optimum due to randomness. The effect of positive feedback makes the false optimal path gradually accumulate pheromone on the path as the number of iterations increases, falling into a local optimal path. Literature [18] uses rasterization to number the grids and introduces a two-way search mechanism. The improved information is an update rule, so that the improved algorithm can avoid premature entry into the local optimal solution and speed up the convergence compared with the traditional ant colony algorithm. Speed to obtain the optimal path; literature [19] implements safety constraints for obstacles, reduces the solution area, accelerates the convergence speed, and obtains a shorter path; literature [20] introduces a cross-tabu search strategy to solve the problem of traditional ant colony algorithm convergence. It is easy to fall into the problem of local optimal solution later.

4.2. Genetic Algorithm
The genetic algorithm uses simple coding techniques and reproduction mechanisms to represent complex phenomena, thereby solving very difficult problems [21]. Because the algorithm itself is not constrained by the restrictive assumptions of the search space, does not require assumptions such as continuous, derivable and unimodal, and the inherent parallelism of the algorithm itself, it has advantages that traditional optimization methods cannot match. Literature [22] speeds up the search speed and improves the efficiency of path planning through selection strategies and improved coding schemes.

As a global optimization algorithm, generally it can quickly converge to the vicinity of the optimal solution, but when it is close to the optimal solution, the convergence speed may become very slow. You can consider adopting other search techniques after converging to the near optimal solution.

4.3. Particle Swarm Algorithm
The particle swarm algorithm originated from the study of group activities such as flocks of birds and fish groups. It is a swarm intelligence algorithm that simulates the behavior of biological populations in nature and is applied to solve optimization problems.

The particle swarm algorithm is widely used in the UAV path planning problem. Literature [23] introduces the chemotaxis and migration strategies in the bacterial foraging algorithm into the particle swarm algorithm to improve the algorithm's optimization ability; Literature [24] adopts the adaptive particle swarm algorithm and adaptively adjusting the inertia weight of the particle swarm to better avoid the UAV search path from falling into the local optimal solution.

| Algorithm               | Principle                                           | Advantage                                      | Disadvantage                                      |
|-------------------------|-----------------------------------------------------|-----------------------------------------------|--------------------------------------------------|
| Ant Colony Algorithm    | Random distributed search; Global algorithm         | Strong positive feedback; High search efficiency; Parallel solving, high efficiency | Pheromone accumulation is easy to fall into local optimal solutions |
| Genetic Algorithm       | Coding technology and reproduction mechanism        | Easy to implement; fast convergence            | Convergence is slow when approaching the optimal solution |
| Particle Swarm Algorithm| Overall search Iterative solution                   |                                               | It is easy to enter the local optimal for high-dimensional complex problems |

Table 2. Summary of intelligent algorithms
5. Fusion Algorithm

At present, scholars at home and abroad have conducted a lot of research on the UAV path planning problem. Although there are many types of UAV path planning algorithms, the path planning during the actual flight of UAVs still faces many problems.

Traditional algorithms have strong search capabilities, but in the face of unknown environments, the path planning success rate is low, and it is difficult to adjust the path in real time; smart algorithms respond faster than traditional algorithms and can better handle drones in dynamic environments. Path planning problems, but when dealing with multi-machine coordination problems, the amount of calculation is likely to increase sharply due to excessive exchange of information and fall into local optimal solutions.

In view of the above problems, the method of combining different algorithms can be used to combine the advantages of different algorithms. Literature [25] uses Dijkstra algorithm to find the rough shortest path. On this basis, adaptive particle swarm algorithm is used to solve the optimal path, which enhances the convergence and effectiveness of the algorithm; Literature [26] combines particle swarm optimization and ant colony algorithm. With fuzzy logic, pheromone is introduced into the particles to speed up the convergence speed, and the path planning input is fuzzy processed to avoid falling into the local optimum.

The fusion algorithm that combines different algorithms is more advantageous in dealing with UAV path planning problems in unknown and dynamic environments; at the same time, for multi-aircraft cooperative path planning problems, traditional algorithms are used to reduce the amount of UAV information calculations during normal flight. The use of intelligent algorithms to avoid obstacles in emergencies can improve the feasibility and robustness of the operation of the multi-machine cooperative system.

6. Conclusion

In summary, the existing UAV path planning algorithms have a lot of research on static global path planning and path planning problems with known environmental element information, and different algorithms have their own advantages for path planning. However, there are few researches on path planning under unknown environment, many uncertain factors, and multi-machine coordination. Therefore, research on UAV path planning in dynamic, complex and changeable environments through the fusion of multiple algorithms will become the mainstream direction of UAV algorithms in the future.

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8. References

[1] Jiang Chenkai, Li Zhi, Pan Shubao, Wang Yongjun. Collision-free path planning for AGVs based on improved Dijkstra algorithm[J]. Computer Science, 2020, 47(08): 272-277.
[2] Zhang Zhaoning, Wang Tong. Airport taxi path optimization based on Dijkstra algorithm[J]. Aeronautical Computing Technology, 2018, 048(006): 1-5, 10.
[3] Wu Hongbo, Wang Yingjie, Yang Xiaoxiao. Urban traffic path analysis based on Dijkstra algorithm optimization[J]. Journal of Beijing Jiaotong University, 2019, 43(04).
[4] Qi Xiaogang, Li Bo, Fan Yingsheng, et al. Research review of multi-UAV mission planning under multiple constraints[J]. Journal of Intelligent Systems, 2020(2): 204-217.
[5] Liu Yongqi, Xu Dan, Cheng Gui, et al. UAV rapid trajectory planning method based on improved A* algorithm[J]. Flight Mechanics, 2020(2).
[6] Wang Hongbin, Yin Pengheng, Zheng Wei, et al. Mobile robot path planning based on improved A-* algorithm and dynamic window method[J]. Robot, 2020, v.42(03): 92-99.
[7] Zhang Zhe, Wu Jian, Dai Jiyang, et al. Fast penetration route planning for stealth drones based on improved A-Star algorithm[J]. Acta Aeronautica Sinica, 2020.
[8] Lavalle S M. Rapidly-exploring random trees: A new tool for path planning[J]. Computer science Dept. Oct, 1998, 98.

[9] Yin Gaoyang, Zhou Shaolei, Wu Qingpo. UAV trajectory planning based on improved RRT algorithm[J]. Chinese Journal of Electronics, 2017, 45(007): 1764-1769.

[10] Li Chenglei, He Jilin, Deng Yu, et al. Quadrotor UAV obstacle avoidance trajectory planning algorithm based on improved RRT-connect [J]. Sensors and Microsystems, 2019, 038(005):136-139.

[11] Ding Xuzhao, Hu Jinwen, Ma Yunhong, Wang Man, Zhao Chunhui. Research on UAV Collision Avoidance Path Planning Algorithm[J]. Journal of Northwestern Polytechnical University, 2019, 37(01): 100-106.

[12] Tian Yazhuo, Zhang Yongjun. UAV path planning in dynamic environment based on improved artificial potential field method[J]. Journal of Wuhan University of Science and Technology, 2017(06): 54-59.

[13] Ding Jiaru, Du Changping, Zhao Yao, Yin Dengyu. UAV path planning algorithm based on improved artificial potential field method [J]. Computer Applications, 2016, 36(01): 287-290.

[14] Wang Qiang, Zhang An, Wu Zhongjie. UAV route planning based on improved artificial potential field method and simulated annealing algorithm[J]. Firepower and Command Control, 2014, 000(008): 70-73.

[15] Chen Qijie, Jin Yuqiang, Han Lu. Overview of UAV Path Planning Algorithm Research [J]. Flying Missile, 2020(05): 54-58.

[16] Pan Han, Chen Mou, Chen Shaodong, et al. UAV trajectory planning based on improved ant colony algorithm[J]. Journal of Jilin University (Information Science Edition), 2013(01): 66-72.

[17] Xu Zhao, Hu Jinwen, Ma Yunhong, et al. Research on UAV Collision Avoidance Path Planning Algorithm[J]. Journal of Northwestern Polytechnical University, 2019, 037(001): 100-106.

[18] Li Xigang, Cai Yuanli. UAV path planning based on improved ant colony algorithm[J]. Flight Mechanics, 2017, 35(001): 52-56.

[19] Tang Li, Hao Peng, Zhang Xuejun. Mountain UAV path planning method based on improved ant colony algorithm[J]. Transportation System Engineering and Information, 2019, 19(01): 158-164.

[20] Han Pan, Chen Mou, Chen Shaodong, et al. UAV trajectory planning based on improved ant colony algorithm[J]. Journal of Jilin University (Information Science Edition), 2013(01): 66-72.

[21] Wang Jing, Li Jinghua, Ni Ning, et al. Hierarchical genetic algorithm for UAV path planning with limited search area[J]. Journal of Detection and Control, 2011, 33(004): 39-43.

[22] Luo Cheng, Cui Sheng. UAV trajectory planning based on genetic algorithm[J]. Journal of Fudan University (Natural Science Edition), 2011, 050(006):792-796.

[23] Ma Huawei, Zhu Yimin, Hu Xiaoxuan. UAV-ship-aircraft cooperative mission planning based on particle swarm optimization[J]. Systems Engineering and Electronic Technology, 2016, 38(07): 1583-1588.

[24] Wang Yihu, Wang Siming. UAV path planning based on improved particle swarm algorithm[J]. Computer Engineering and Science, 2020, 42(09): 1690-1696.

[25] Liu Ke, Zhou Jiqiang, Guo Xiaohui. Research on UAV path planning based on improved particle swarm algorithm[J]. Journal of North University of China (Natural Science Edition), 2013, 34(04): 441-447.

[26] Chen Tianpei, Wang Yuhui, Wu Qingxian, Zhou Zeyu. Three-dimensional path planning based on fuzzy logic particle swarm algorithm[J]. Electro-Optics and Control, 2020, 27(06): 1-5.