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Review on the research status of Unmanned Aerial Vehicle mission planning technology

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Abstract

Unmanned aerial vehicle (UAV) have been widely used in civil and military fields. UAV mission planning technology is an important research direction of UAV control, and the research on UAV mission planning technology is of great significance. Aiming at the technical problems of UAV mission planning, the key issues of UAV mission planning are analyzed, the research status of centralized decision control system architecture and distributed decision control system architecture is systematically reviewed, the advantages and disadvantages of various methods are compared, and the current situation is summarized. The problems existing in the UAV mission planning technology, the exhibition is expected to provide reference for theoretical research and engineering practice in this field.

Keywords

Mission planning, Centralized, Distributed, UAV.

1. Introduction

In the future, information warfare will have the characteristics of multi-dimensional battlefield space, scattered element configuration, overlapping operational levels, and complex electromagnetic environment. Realime and accurate intelligence acquisition is a necessary prerequisite for various military activities, and efficient inspection of specific targets is the key to intelligence acquisition. . As an outstanding representative of emerging inspection methods, UAVs have the advantages of strong risk tolerance, long battery life, low manufacturing costs, and good maneuverability. They often replace manned aircraft to perform "bad, boring, deep, and dangerous" tasks, such as intelligence Acquisition, tracking and monitoring, etc., have been highly valued and vigorously developed by today's military powers. In the early days of multi-UAV cooperative operations, due to the small amount of information processing and the low task difficulty, human decision-making played an absolutely dominant role. However, with the continuous improvement of the autonomous performance of UAVs, the sharp increase in the difficulty of tasks, and the rapid improvement in the performance of airborne sensors, the amount of information that needs to be processed when multiple UAVs perform tasks collaboratively increases, and it is difficult to rely on manual operations alone. meet real-time requirements. By studying the multi-UAV collaborative task planning technology, the task allocation during the inspection process can be realized, which is conducive to shortening the prewar preparation time, reducing the burden of ground operators, and improving joint combat effectiveness.

At present, many UAVs at home and abroad focus on the problem of multi-UAV cooperative reconnaissance, but very few studies on the problem of cooperative patrol mission planning. The difference between the two is that the task of cooperative reconnaissance is usually a point target with known coordinates. Under the condition of no nofly zone, the UAV can fly from any point target to another point target without flying along a specific path. , the sign of task completion is to achieve the traversal of all point targets; the task of collaborative inspection is usually a line target, and which point has special circumstances is unknown before planning. The UAV must patrol along the known road network, the track is restricted, and the sign of mission completion is to achieve the coverage of all line targets. Since real-time intelligence acquisition and accurate battlefield perception are the necessary basis for carrying out various military combat activities and determine the initiative of war, multiple UAVs cooperate to complete tasks through intermachine communication to achieve singlemachine capability expansion and overall efficiency improvement. It has become an important trend of multi-UAV operations in the future. However, if there is a lack of scientific and reasonable planning, the overall efficiency of the multi-machine system will be greatly reduced, not only will the advantages of the formation be lost, the patrol resources will be wasted, and there may even be a situation where the drones collide with each other and crash. Under the condition of limited inspection resources, it is of great significance to study the problem of multi-UAV cooperative inspection mission planning to achieve the largest intelligence gain and the least resource consumption.

Because UAVs have played a huge role in recent high-tech wars, a large number of researches on the coordinated control of multiple UAVs have been carried out rapidly, such as the UAV Formation Hybrid Autonomous Control Project (MICA, Mixed Initiative Control of Automata-teams)[1], this project is dedicated to exploring new means of control and surveillance, to achieve the control of largescale UAV formations with as few operators as possible, and to enable commanders to better participate in battlefield management. The U.S. Army Aviation-led Multi-UAV Autonomous Collaborative Operation (UACO, Unmanned Au-tonomous Collaborative Operation)[2] project aims to achieve multi-machine fully autonomous tasks without manual intervention, so that it has the adaptability of communication network, Collaborative reconnaissance and swarm system fault tolerance and other performance[3]. The Real-time Coordination and Control of Multiple Heterogeneous UAVs project (RTCCMHU, Real-time Coordination and Control of Multiple Heterogeneous UAVs) initiated by Europe researches the cooperative detection and surveillance system composed of heterogeneous UAVs[4,5], and conducts research in forests. Validation of system capabilities in fire surveillance missions.

2. Key Issues in UAV Mission Planning

To study the multi-UAV cooperative task planning technology, the key point is to solve the modeling and solution of the cooperative task assignment problem. Multi-UAV task assignment refers to the definition of the overall objective function of patrol revenue according to the type, quantity and task characteristics of UAV resources, under certain constraints, such as voyage time constraints, sensor performance constraints, task time window constraints, etc. Assign the task sequence to each UAV to maximize the objective function benefit. This problem is a NP problem with complex constraints, due to the need to comprehensively consider cooperative constraints, task execution costs and algorithm rationality. The models for solving such problems mainly include the Multiple Traveling Salesman Problem (MTSP, Multiple Travelling Salesman Problem) model[6], the Vehicle Routing Problem (VRP, Vehicle Routing Problem) model[7], and Mixed Integer Linear Programming (MILP, Mixed Integer Linear Programming). Programming) problem model[8] and Multiple Processors Resource Allocation (MPRA, Multiple Processors Resource Allocation) problem model[9] and so on. However, in order to standardize the modeling, the above models generally ignore some real problem elements and cannot reflect the actual inspection situation. Reference[10] considers the reconnaissance resolution constraints of the target, and takes into account different bases, the number of heterogeneous UAVs and the reconnaissance performance, and establishes a multi-base and multi-UAV cooperative reconnaissance problem model (MUCRMPM, Multi-UAV Cooperative

Reconnaissance). Mission Planning Model), the modeling of multi-UAV cooperative execution of patrol tasks can refer to the above models. Combined with the complex launch vehicle maneuvering path inspection requirements, the nodes of the mission environment in the traditional model are divided into the central library, the path intersection, the nodes that must be inspected and the launch pad; comprehensively consider the hard time window of the launch pad, all necessary The inspection of inspection nodes, UAV endurance time, UAV connectivity constraints, as well as the optimization objectives of the shortest task completion time, the largest inspection revenue, and the smallest inspection cost, establish a multi-machine cooperative inspection task planning problem model, which can reflect more realistically inspection process.

3. Centralized Decision Control System Architecture

In order to improve the overall efficiency of the multi-machine system, the mission planning decision control system must have high fault tolerance, strong robustness, rapid response and dynamic reconfiguration capabilities. The architecture of decision control system can be mainly divided into two types: centralized and distributed. At present, centralized architecture is commonly used. At this stage, scholars at home and abroad have carried out a lot of research on centralized control architecture. Reference [11] proposes a real-time mission planning strategy based on a global mission planner, which shows good robustness and real-time allocation in simulation and indoor flight. Reference [12] proposed a more general multi-UAV cooperative task assignment model under the consideration of task execution priority, time, range and other constraints. Reference [13] proposes a redundant centralized solution strategy, which is based on discrete particle swarm optimization, and has the advantage of being able to compute in parallel with different initial solutions. By running the same task assignment algorithm on multiple UAVs, it can fully Utilize communication and computing resources to obtain globally optimized solutions within acceptable time and computational cost. Reference [14] studied the centralized multi-type UAV formation task assignment method, and analyzed the advantages and disadvantages of the method, and carried out simulation experiments in static and dynamic environments respectively. Reference [15] proposed a centralized cooperative control method for UAV formation. Through the multi-layer centralized cooperative control strategy, the cooperative positioning and track tracking task assignment of multiple UAVs are realized, which effectively reduces the task planning problem. Control complexity.

The characteristic of the centralized structure is that there is only one central processing node to control the whole system, each UAV can only accept the instructions from the ground station, and it only has the underlying control function. The centralized control structure can solve and optimize the problem from a global perspective, and realize the unified decisionmaking and control of the system. Due to the relatively sufficient preparation time before the war, there is a high requirement for the solution quality of the task assignment results. The centralized structure is easy to obtain the global optimal solution of the problem, and is often used for task preassignment before the war. Various emergencies may occur during wartime, requiring UAVs to quickly adjust to achieve replanning. At this time, the centralized structure cannot meet the real-time requirements. Centralized methods commonly used at this stage mainly include optimization meth-ods and heuristic methods, see Figure 1.

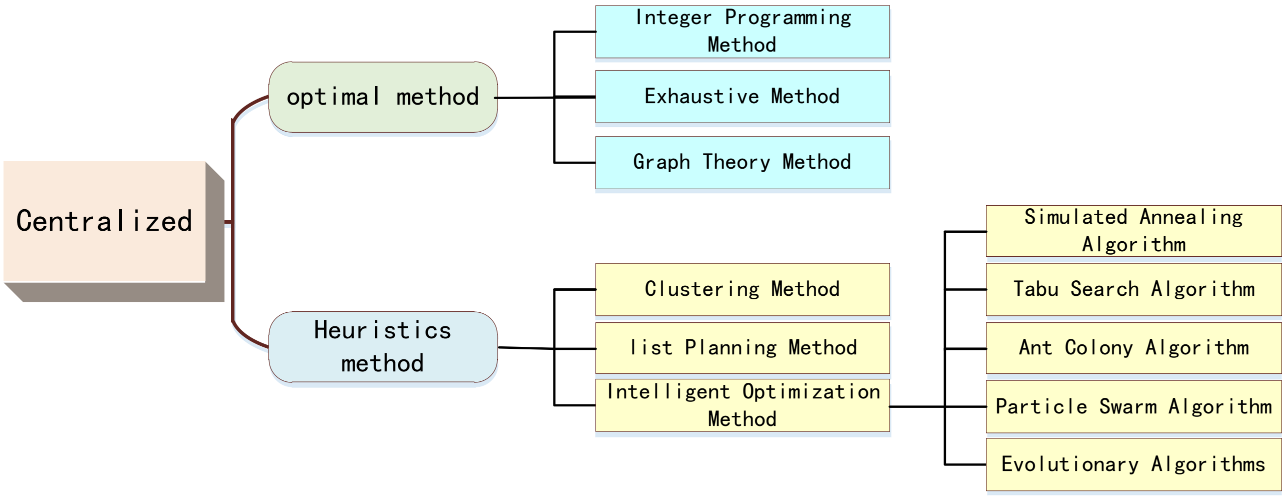

Figure 1: Centralized methods taxonomy

3.1. Optimal method

Optimization methods study how to solve the optimal value of some indicators under given constraints. The commonly used optimization methods mainly include integer programming method, exhaustive method, graph theory method and so on. If the problem has a solution based on certain assumptions, the optimization method is guaranteed to give the optimal solution to the problem. The integer programming method constructs the objective function and finds its extreme value according to the task constraints. The method is flexible and simple, and the solution speed is fast. Reference [16] adopts the mixed integer linear programming method to realize the rapid solution of the cooperative task assignment problem, but the modeling of this method is too simple for complex problems and cannot represent the complex patrol environment. Machine multi-objective assignment problem is not very effective. The exhaustive method is a mathematical calculation method to find the optimal solution. It studies how to determine the approximate range of the optimal solution according to the constraints, and then verifies all feasible solutions within the range one by one until all feasible solutions are verified. The exhaustive method is simple and easy to implement. However, when the search space is too large, the method is time-consuming and inefficient. It is suitable for the case where feasible solutions are discrete and the range is small. Reference [17] proposed a satisfactory decision-based UAV task assignment method, which eliminated infeasible solutions to reduce the search space, and achieved good results when the UAV task assignment scale was small. A graph in the graph theory method is a graph composed of a number of given vertices and an edge connecting two vertices. The vertices represent things, and the edges connecting two vertices represent a certain relationship between two things, and are often used to describe certain things. a specific relationship between them. Reference [18] applied the evengraph matching model to the mapping of organizational members and task networks, illustrating that the advantage of mapping is the least time-consuming. The graph theory method can clearly represent the relationship between the task and the UAV, but the effect is poor when the task scale is large. To sum up, when the task scale is small, the optimization method can quickly give the optimal solution of task assignment. However, the multi-UAV cooperative task planning problem is a NP problem with complex constraints. With the continuous expansion of the UAV task allocation scale, the difficulty of solving the problem increases greatly, and the time consumed by the algorithm increases sharply, which cannot meet the requirements of the dynamic environment. real-time requirements. Therefore, this method is suitable for preallocation of tasks with low time requirements and small scale.

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3.2. Heuristics method

Heuristic methods are mainly based on limited knowledge and experience to find solutions to problems in a short time. Different from the optimization method, the heuristic method does not pursue the optimal solution of the problem, but seeks a balance between the time consumption and the algorithm result, that is, to find a satisfactory solution or a local optimal solution in a limited time. Commonly used heuristic methods mainly include clustering method, list planning method and various intelligent optimization algorithms. The clustering method clusters similar tasks near the nodes of the critical path by multiple UAVs, until the formed task clusters are consistent with the number of UAVs performing the tasks. Reference [19] established a multi-UAV cooperative task planning model, then proposed the task clustering index, and finally used an improved Kmeans clustering algorithm to achieve multi-UAV task assignment. The clustering algorithm has a fast convergence speed, but it is only suitable for scenarios with similar tasks and cannot be generalized to the general situation. The list planning method defines the order of task execution by constructing the priority function of each task, and then assigns the generated task sequence to the UAV members in the formation. Commonly used list planning methods include dynamic list planning methods, multi-priority dynamic list planning methods, and the like. Reference [20] uses the dynamic list programming method to solve the problem of computing resource allocation, which is suitable for situations where task priorities are clearly distinguished. The intelligent optimization algorithm uses modern intelligent algorithms to solve the multi-UAV mission planning problem, which has the advantages of easy implementation, strong adaptability, and low algorithm complexity. Commonly used intelligent optimization algorithms mainly include ant colony algorithm and particle swarm algorithm, evolutionary algorithm, tabu search algorithm, simulated annealing algorithm, etc. Ant colony algorithm simulates the process of ant colony capturing food in reality. Reference [21] introduces ant colony algorithm and its improvement method in detail. References [22] and [23] use ant colony algorithm to solve multi-UAVs The problem of collaborative task assignment has achieved good results. The inspiration of particle swarm optimization comes from flocks of birds foraging. In the process of evolution, particles are not only influenced by social elites, but also closely related to the status of their neighbors[24]. Reference [25] realizes multi-UAV multi-target task assignment, which reflects the simplicity and efficiency of particle swarm optimization. However, when the scale of task assignment is large, it is very easy to fall into local extreme points when using swarm intelligence algorithm to solve.

4. Distributed Decision Control System Architecture

Compared with the centralized control system structure, the biggest feature of the distributed structure is to solve the global decision-making control problem through information sharing, conflict mediation and task coordination, decompose the complex global problem into a series of subproblems and assign them to the noncontrolling problems in the system. The human-machine members, and finally the drones get a satisfactory solution to the problem through negotiation. Commonly used distributed methods include distributed model predictive control method, multi-machine cooperative task planning algorithm based on particle swarm intelligence algorithm, etc. Reference [26] proposed a distributed multi-machine cooperative reconnaissance mission planning model (MPCU, Mission Planning for Cooperative UAVs), which was optimized by genetic algorithm, and finally verified the correctness of the proposed model. Reference [27] proposes an Intelligent Selforganized Algorithm (ISOA) for the problem of multi-machine collaborative search task assignment. This algorithm adopts a distributed control architecture and divides the global optimization problem into several local optimization problems. , each UAV can solve its own local optimization problem, and then make optimal decisions for the multi-machine system through the exchange of information between the UAVs. Reference [28] uses the discrete cuckoo search (DCS, Discrete Cuckoo Search) algorithm to solve the multi-task area track planning problem. This strategy is aimed at the standard MTSP problem, considers multiple constraints, and adopts the improved DCS algorithm to realize multi-UAV. Tracks are quickly planned. Reference [29] studies the collaborative task assignment problem of heterogeneous UAVs performing reconnaissance, strike and evaluation tasks on different types of targets, and uses the change of entropy in information theory to measure the amount of information obtained in the reconnaissance and evaluation tasks. The ability of manmachine to attack different types of targets is abstracted into the probability of damage to the target, and the interrelationship between each task is considered, and the optimal solution of the problem of multi-UAV cooperative task assignment is realized. Reference [30] proposed a multi-UAV cooperative target search method with a pheromone return visit mechanism. The performance index of collaborative search decisionmaking based on the environment-aware map is designed. Under the distributed rolling time domain optimization framework, a multi-UAV collaborative search decision-making method is established, so that the UAV can search for more targets as soon as possible, and reduce the overall cost as soon as possible. Uncertainty of the search area.

The distributed structure has the characteristics of less communication dependence, high autonomy, and strong robustness, and can adapt to the dynamic and uncertain battlefield environment . With the substantial improvement of the autonomous performance of the UAV platform, the distributed control structure has a broader application prospect, and has become an important research direction of multi-UAV cooperative control. It is often used to solve the task replanning problem in a dynamic environment. Humans and machines were shot down, patrol missions were added, and damaged nodes were detected. However, when solving the task allocation problem between largescale UAVs , combined with the complex multi-launch vehicle maneuvering path inspection requirements, the current distributed method has the problems that the convergence cannot be guaranteed, the convergence speed is slow, and the solution is easy to fall into local extreme values. point and so on. Table 1 gives a comparison of the advantages and disadvantages of typical task planning algorithms. In various emergencies during wartime, such as the discovery of special harassment by a small group of enemies, the discovery of road damage and the inability to continue to pass, etc. it is difficult for the UAV formation to adjust quickly and generate an effective response plan. Therefore, there is an urgent need for a fully distributed multi-machine collaborative task assignment algorithm to realize task replanning in dynamic environments, and the quality of the generated solutions is significantly improved compared with general task assignment algorithms, which can meet the inspection requirements and various constraints..

Table 1: Comparison of advantages and disadvantages of typical task planning methods

Numble	advantage	shortcoming
Integer Programming Methods	Flexible and simple, fast solution speed	Modeling is too simple and has poor fault tolerance
Exhaustive method	Simple and easy to implement	When the search space is too large, time-consuming and inefficient
Graph Theory Methods	Ease of expressing the relationship between tasks and drones	When the scale of the task is large, the effect is poor
clustering method	The algorithm converges faster	cannot be generalized

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List planning method	Algorithms solve fast	Algorithms solve fast Limited scope of application
Intelligent optimization algorithm	Easy to implement, strong adaptability, low algorithm complexity	Easy to fall into local extreme points
Model Predictive Control Methods	Less communication dependence and strong robustness	Algorithm convergence is not guaranteed

To sum up, a lot of research has been done on the multi-UAV collaborative task planning problem at home and abroad, but there are still some problems to be solved:

(1) The modeling of the problem is ideal and not accurate enough. In the current research on the problem of multi-UAV cooperative task assignment, most researchers abstract the multi-UAV cooperative task assignment problem based on some existing models, such as TSP model, VRP model, MILP model, etc. one of the above models. There is a serious problem with this modeling approach: some elements of the launch vehicle 's crossarea operations are ignored for the sake of modeling standardization. Only by closely combining practical problems, establishing models and then abstracting solutions can research results be applied to practical problems. If the established problem model is quite different from the actual problem, the practicality of the research results will be greatly reduced. Therefore, in the next step, it is necessary to closely combine multiple launch vehicles to perform the unsupported launch mission process, carefully consider the characteristics of the patrol mission, and then establish an appropriate problem model.

(2) The autonomy of task assignment is insufficient in an uncertain environment. At present, the research on multi-UAV cooperative mission planning problem mainly focuses on a certain environment, that is, to realize multi-UAV cooperative inspection under the condition of known targets and threats. However, due to the high dynamics, uncertainty and complexity of the battlefield environment, such as the unobservable part of the environment, the harassment of small enemy stocks, and the wrong intelligence information in the early stage, it has caused severe problems in the assignment of multi-UAV autonomous inspection tasks. challenge. In view of the limited preallocation capability of multi-UAV systems at this stage, when performing tasks in a realistic flight environment with high dynamics, uncertainty and complexity, onthespot decision-making and real-time control problems have become the main technical challenges faced by multi-aircraft systems. Therefore, it is necessary to comprehensively consider the above factors, and use methods such as probability and statistics to enhance the fault tolerance and adaptability of the multi-machine system.

(3) The convergence speed of the algorithm cannot meet the requirements. In the pre-assignment stage, the completeness and optimization of the task assignment results are required to be high, while the fast convergence requirements of the algorithm are low; when the battlefield environment changes dynamically, such as mission changes, sudden threats, UAV failures, etc. need to quickly achieve efficient reallocation based on the preallocation scheme. In the redistribution stage, the real-time requirements of the algorithm are relatively high. At this time, the multi-machine system expects to obtain a " relatively satisfactory " new task assignment scheme, which is not necessarily optimal, but needs to quickly generate feasible solutions so that the drone can quickly adapt to the new task environment. However, the current algorithm has the problems that the convergence cannot be guaranteed, the convergence speed is not fast enough, and the reallocation in the dynamic environment cannot be quickly realized

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5. Conclusion

At present, extensive research work has been carried out on UAV mission planning technology at home and abroad, and corresponding academic achievements have been obtained. This paper investigates and summarizes the related issues of UAV mission planning technology, analyzes the key issues of UAV mission planning, and summarizes UAV missions from two aspects: centralized decision control system architecture and distributed decision control system architecture. Planning techniques and methods. The problems existing in UAV mission planning technology are analyzed and summarized, in order to provide reference for the research in related fields.

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