Discussion on multiple UAVs cooperative mission planning in precision agriculture

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Abstract. In this paper, the cooperative task planning of agricultural plant protection multi-UAVs is studied. The related concepts of cooperative task allocation are discussed. Firstly, the content of cooperative task is summarized; secondly, many kinds of constraints, including individual constraints and cooperative constraints, are discussed and studied, the connotation of the problem is analyzed from different levels, different aircraft trajectory planning methods are studied, the mathematical model of practical engineering is established, and the results are analyzed. This research has certain guidance and practical reference significance for solving the application of UAV cooperative task allocation in the agricultural field.

1. Introduction
Agriculture is important for expanding domestic demand and making structural adjustment, and it is a sector vital for ensuring China's stability. The total grain output of China reached 66385 million tons in 2019. However, compared with the developed countries, there is still a significant gap in China's agricultural development level, such as low utilization rate of mechanization, high production cost, low production efficiency and low level of intelligence. Unmanned aerial vehicle (UAV) is creating a new agricultural revolution. When UAV is equipped with cameras and other data acquisition equipment, UAV becomes the "eye of the sky". UAV can intelligently carry out various types of operations in agriculture, such as using UAV to spray pesticides, evaluate products, prevent diseases and insect pests, diagnose crop nutrition. so as to liberate labor force and reduce production costs. Therefore, improving production efficiency has also changed the traditional agricultural mode. At present, the outbreak of COVID-19 in the world, the epidemic situation prompted people to reduce contact indirectly promoted the application of plant protection UAV. In the long run, China will also face the population aging and the decrease of rural labor force, which will also promote the development of agricultural modernization. Therefore, UAV will have irreplaceable application prospects and advantages in the future agricultural development.

At present, agricultural UAVs in the market mainly have obvious functional characteristics, such as plant protection UAV, aerial UAV (natural light, multispectral). with the integration and cost reduction and other factors, it will be able to realize multi-functional UAV that can achieve multiple purposes. In the initial stage, the modular cutting and assembly of UAV load can achieve the required function switching, and finally it will be realized Now the multi-functional integration development. Because the future agricultural application needs a variety of tasks, such as crop nutrition diagnosis, pest monitoring, pesticide spraying and so on, one UAV has been difficult to meet the needs of tasks, it has become an inevitable choice for multi-UAVs to cooperate to complete the task, which is an urgent focus for future research and practical application.
Multi-UAVs cooperative work planning is a very complex decision-making and optimization problem. There are many factors and constraints involved, such as the flight performance and load performance of UAV, the cooperation between multi-UAVs, the natural climate and environmental conditions in the mission area[1]. At present, researchers all over the world are still working on the multi-UAVs cooperative mission planning technology, and some problems have been solved effectively. For example, traditional mathematical programming method, market mechanism based method, graph theory based method, modern intelligent optimization algorithm such as ant colony algorithm, genetic algorithm, tabu search algorithm[2]. However, at present, most of the algorithms have not achieved satisfactory results in terms of time, global optimization and large-scale and complex optimization and combination problems[3,4]. It is still of great practical significance to study the different task types and application environment complexity of multi-UAVs in specific industries such as agriculture, forestry, animal husbandry and other applications. With the development and use of new technologies, new challenges have emerged for multi task collaboration of multi-UAVs, such as environmental awareness and recognition, multi-UAVs collaborative task planning, information interaction and autonomous control, human-computer intelligent fusion and adaptive learning technology[5-7].

2. Overview of cooperative mission planning for multi-UAVs

2.1. Conception
Multi-UAVs cooperative task planning is to plan tasks for each UAV according to specific tasks on the premise of meeting multiple kinds of constraints, and achieve the best or better under the specified performance indicators. The research of multi-UAVs cooperative task planning is based on the development of single UAV, so it still has the planning characteristics of single UAV task, but multi-UAVs are different from single UAV in essence because it has the ability of coordination and coordination, so the "coordination" in time and space should be considered in planning "Coordination" establishes a "mutual help" relationship for the UAV team, so the planning complexity and calculation amount are greatly increased[8].

2.2 Cooperative mission planning
Taking three UAVs spraying pesticide in one area as an example, according to the idea of hierarchical task, the problem of collaborative task is how to effectively allocate and control three UAVs to complete the task in a large area at the lowest cost. This problem is also called area coverage search problem, that is, multi-UAVs task area allocation and complete Coverage path planning[9]. Collaborative task planning is shown in Figure 1.

![Initial state](a)
2.2.1 Task area assignment
The task area assignment is to evaluate the performance of UAVs according to their respective endurance time, operation spray amplitude, flight speed, initialization position and other relevant parameters, so as to obtain the maximum workload of a single mission under the above conditions[10,11]. Then, according to the maximum workload, task area and initial position, the UAV is assigned area, that is, each UAV is assigned corresponding task area which does not overlap each other and can cover the whole area.

2.2.2 Full path planning
The path planning of all area needs to design the optimal path which can cover the task area, and the path of optimal area should be the most efficient in task execution. When the UAV is carrying out regional tasks, it should try to fly in a straight line rather than in a turn[12]. Given more UAVs, the initial position of the aircraft is on the edge of the polygon to take off. A task allocation area and control mode are designed. The UAV carries out the operation of complete area in the assigned task area[13]. At last, the overall performance of the task is the greatest, and it should be completed as soon as possible.

3. Constraint analysis of collaborative tasks
UAV collaborative task allocation needs to meet the comprehensive ability of each UAV to perform tasks and the constraints of daily environmental conditions such as wind, so that each UAV can play its best efficiency, and then maximize the overall task completion efficiency. Therefore, after the mathematical model of the task is established, it is equivalent to solving the problem of the minimum working time of the task. We are still the case of pesticide spraying, and analyze the constraints involved in the task of UAV. Constraints involve a single constraint collaborative constraint[14]. The individual constraints involved in a single UAV mainly include the maximum endurance time of a single operation, the flight speed, the time of pesticide loading, the concentration and range of...
operation spray amplitude, the factors affecting the climate and environment, and the flight path planning of the UAV. Cooperative constraints mainly include simultaneous arrival constraints and task timing constraints.

3.1 Maximum endurance time of single operation
The maximum operating range of the UAV under the condition of its own fuel load is equivalent to the maximum operating time, which reflects the UAV's endurance, that is, after the UAV performs its mission, there is enough fuel to support its return to the base. The mission planning scheme should not exceed the maximum endurance capacity constraint of UAV, usually with margin, and it is the first constraint to be considered[15].

3.2 Flight speed
According to the flight speed set by different tasks such as spraying potatoes, rice, corn and other crops, the speed affects the operation area and the maximum endurance time of the operation, which should be set according to the operation task. Generally, the speed of the UAV can be freely adjustable within 3-10m/s.

3.3 Pesticide loading time
Due to the limited capacity of the tank, it is necessary to return to the initial point for pesticide filling after the completion of the operation, which will increase the completion time of the operation.

3.4 Concentration and range of spraying
According to different crops and different types of dispensing, the spray amplitude concentration needs to be set, or the flight speed can be set to adjust the concentration. The operation spray amplitude range is a fixed attribute of the UAV spray system, usually the operation width, which is also related to the flight height of the UAV.

3.5 Climate and other external factors
The operation of UAV will be limited by natural climate such as wind, temperature and humidity, which will mainly affect the operation.

3.6 Flight path planning of UAV
The traditional method of UAV flight path planning is to generate a series of track points in the operation area, and then generate the track of coverage area by zigzag connection. However, the trajectory generated by Z-shaped trajectory planning method is not consistent with the dynamic performance of UAV, resulting in the flight attitude is not smooth. Some domestic scholars plan the speed of each straight line to ensure the attitude of UAV in acceleration and deceleration process is smooth. This method requires UAV to accelerate and decelerate frequently at the inflection point, which is inefficient. Frequent acceleration and deceleration increase the energy consumption of UAV and shorten the endurance time of UAV. According to the application requirements of UAV in regional operation, domestic scholars put forward a spiral spline regional trajectory generation method. Linear programming method is used to solve the planning problem with the shortest flight time as the goal, and the second-order Taylor expansion method is used to generate the trajectory sequence for control[16]. Through the track tracking experiment, it can be seen that compared with the traditional broken line area track planning method, under the same dynamic constraints and operation requirements, this method effectively shortens the operation time and improves the operation efficiency. The two flight paths are shown in Figure 2, Figure 2 (a) is showed Z-shaped trajectory planning; Figure 2 (b) is showed Region trajectory of spiral spline.
Due to the diversity of tasks, constraints include but are not limited to the above types of constraints. Multiple constraints reflect that task allocation is a typical multi-objective nonlinear optimization problem. At present, the main method to solve this kind of problem is heuristic optimization algorithm. For example, genetic algorithm, ant colony algorithm, particle swarm algorithm, evolutionary algorithm. The advantage of this method is that it does not require the objective function to be differentiable, but to search the solution space through a large number of samples. The search process itself does not have the purpose and direction, but through the comprehensive fitness function to screen samples, so that the whole search process converges to the optimal solution. Therefore, the design of the comprehensive fitness function plays a key role in the optimization effect and convergence speed of the scheme. In the process of task allocation, multiple constraints form a comprehensive fitness function by constructing the corresponding reward and punishment mechanism, which is used as the basis for the evaluation of the post selection allocation scheme, so as to select the individuals with lower comprehensive cost and eliminate the individuals with higher comprehensive cost, so that the whole post selection allocation scheme population gradually evolves towards the direction of cost reduction.

4. Simulation result
Let's take a 100m*100m rectangular area as an example, under the same dynamic constraints, the spiral trajectory generation algorithm and the polyline trajectory planning algorithm are used to generate and plan the trajectory respectively. In the actual operation process, according to the actual situation of the UAV's power and operation demand, the maximum speed, the maximum flight attitude angle and the maximum attitude angular speed of the UAV will be limited. Corresponding to the UAV's speed, acceleration and jump, this paper sets the UAV's operation duration as 30 minutes, the speed constraint as 5m/s, and the acceleration constraint as 5m/s². The spray width is 5m. If we start from the ideal starting point, The mathematical model is established and calculated. It takes 420s to complete this operation by using the broken line trajectory planning algorithm and 401s by using the spiral trajectory algorithm. The time of the latter is 4.5% shorter than the former, and the flight efficiency of the spiral trajectory algorithm is obviously higher.

5. Conclusion
The Paper discusses the problem of multi-UAVs cooperative task allocation in agricultural plant protection, this paper focuses on the integration of the theory of allocation optimization and the actual task requirements. The basic concept of multi-UAVs cooperative task assignment is described, and the constraints of cooperative task are analyzed in detail. In multi-UAVs cooperative task planning, not only the safety index of UAV cluster should be maximized, but also the task should be completed in the shortest time. A reasonable and efficient cooperative task planning scheme can greatly improve the success rate and efficiency of task execution, reduce the risk and cost. At present, for the application of multiple UAVs in the field of agriculture, how to optimize the task allocation has certain theoretical guidance and practical reference significance for the future application.
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