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UAV forest fire early warning and inspection plan based on multiple nests

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Abstract:

Forest fires are sudden and destructive, and it is difficult to deal with and extinguish them after they occur. Therefore, effective forest fire prevention measures are very important to protect forests. The development of drone technology in recent years, especially the emergence of drone nests(airports), has given a new idea of forest fire early warning. This article proposes a UAV forest fire early warning inspection plan based on a multi-UAV automatic nest. Three sets of UAV nest equipment are used to cover a specific range and inspect. The main purpose is to ensure that the target area is inspected. While covering inspections, it also improves the efficiency of drone inspections and the utilization rate of the nest, for reference.

Keywords: UAV airport, UAV nest, UAV depot, forest fire warning monitoring, automatic inspection

1 Introduction

Forest fire refers to the behavior of a fire that loses human control, spreads and expands freely in forest land, and brings certain harm and losses to forests, forest ecosystems, and humans. It is a sudden, destructive natural disaster that is difficult to deal with and rescue. Once such a disaster occurs, it will not only consume a lot of manpower and material resources to fight it, but also cause extremely serious damage and irreparable losses to the ecological environment in the region. In severe cases, it may even endanger the lives, health, and property safety of the surrounding people. In recent years, the application of a variety of new technologies in forest fire early warning monitoring has significantly reduced the number and scale of forest fires. Drones and drone nests have also entered the market and been put into use. As a mobile technology platform, UAVs (Unmanned Aerial Vehicles) are small in size, highly maneuverable, low in cost, safe, and controllable, allowing them to be used in urban, rural, water, forestry, and other scenarios (such as environmental monitoring, disaster warning, and data collection). Especially in the field of forest fire monitoring and early warning, drones can carry a variety of multispectral and hyperspectral equipment to dynamically monitor forest vegetation and forest fire danger levels from the air [1], enabling timely fire detection, elimination of hidden dangers, and achieving early detection, early warning, early preparation, and early response. This can nip fires in the bud and avoid or reduce losses caused by forest fires. Drone nests are smaller in size, have lower installation site requirements, and can work in different weather and climate environments. Multi-rotor drones are used as the supporting drone nests because they are small in size and can take off and land vertically. Since its inception, drone nests have been used in various fields such as data collection, environmental monitoring, power, pipeline inspection, etc. [2-7], which has greatly saved labor costs and improved operating efficiency.

Many scholars have conducted extensive and in-depth research on the deployment of UAV nests, which are mainly divided into two directions: regional inspection scheme based on a single UAV nest (one aircraft and one supporting operation, that is, the UAV operates from Takeoff and landing at the same nest) [8] and an inspection scheme based on multi-drone nests [9]. In the forest fire prevention and control monitoring scenario, inspection and monitoring of large-scale forest areas requires the use of multiple drone nests to cover the inspection area. Although the regional inspection solution based on a single drone nest can automatically inspect and cover the set area, if multiple drone nests are used to form an operating system in a certain area, continue to use "one drone, one drone" "The UAV take-off and landing operation mode will cause unnecessary waste of energy generated by the UAV returning to the departure nest.

The Inspection route based on multi-UAV nests generally inspects the target along a fixed line. The UAV takes off from the starting nest and patrols along the fixed inspection route to the terminal nest for landing and recharging. For example, Liu Maofeng [10] proposed the "frog" method. "Jump" inspection plan and vehicle-mounted movable drone nest power inspection plan [11]. To improve the inspection efficiency of drones in forest fire early warning scenarios, drones need to patrol along relatively fixed routes and cover the areas to be monitored. At the same time, some emergencies that cause drones to be inspected must also be considered. Flight path changes cause landing nests to be reassigned. Therefore, it is necessary to combine the above two solutions to design a unique inspection method. This project plans to use a system composed of multiple drone nests to allocate inspection paths and charging solutions to the drones in the system in a forest fire inspection and early warning scenario to improve energy utilization and operational efficiency.

2 Design of automatic drone inspection plan

As shown in Figure 1, in order to reduce the energy consumption of UAVs during the return process and improve the overall efficiency of UAV inspection work, it is necessary to arrange multiple UAV nests in the covered inspection area to form a A collaborative inspection system. In this system, drones need to follow preset fixed inspection routes to ensure full coverage and inspection of the entire area. However, in actual operations, when the inspection route needs to be temporarily adjusted (for example, due to human intervention, one or more drones in the system need to immediately go to a specific point in the area for detection), the original inspection route Patterns will be disrupted. In this case, in order to ensure that the drone can efficiently complete the mission and return smoothly, the nearest landing nest should be assigned to the drone performing the mission.

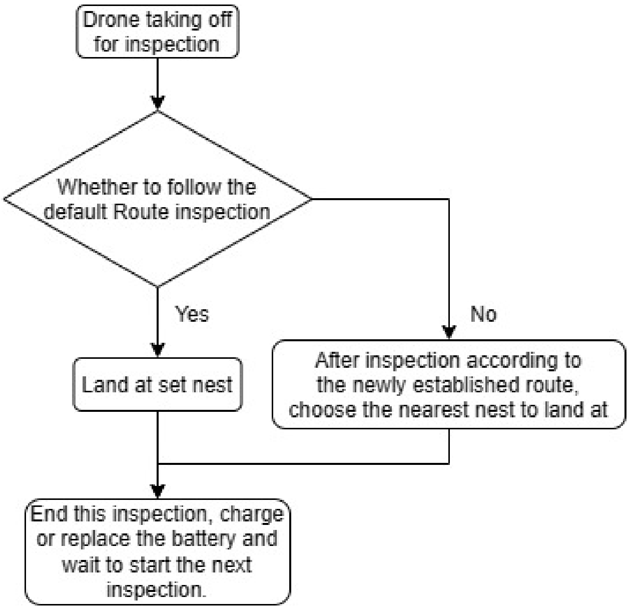

Figure 1 UAV automatic inspection flow chart

2.1 Design of drone inspection scope and drone nest deployment

In scenarios where comprehensive monitoring of a specific area is required, it is crucial to properly set up the number and location of drone nests. This not only ensures full coverage of the monitoring area, but also effectively prevents waste of resources due to excessive drone density (such as repeated monitoring of the same area). It also reduces the risk of drone collisions in the air, thereby significantly Improve the efficiency of inspection work. In addition, this strategy helps optimize budget expenditures while maintaining efficient inspections. This article proposes an optimal deployment and route planning scheme for the drone inspection system in a flat rectangular forest area. Specifically, three drone nest equipment are deployed in the area and distributed at the vertices of the triangle to form a collaborative inspection unit. (as shown in picture 2). In order to distinguish the inspection area where the drone is located, the entire covered rectangular area is subdivided into three sub-areas with as equal an area as possible, and a drone nest is deployed in each sub-area (as shown in Figure 3). Show). This layout ensures that each drone can efficiently and orderly conduct inspections in the area it is responsible for. The size of the rectangular area is set to 3.2*3.2km. Through the implementation of this strategy, while ensuring comprehensive coverage of inspection work, the optimal allocation of resources and reasonable budget control can be achieved. Among them, the area of sub-region 2 and sub-region 3 is equal, 3.2 square kilometers, and the area of sub-region 1 is slightly larger than that of sub-region 2 and 3, which is 3.84 square kilometers.

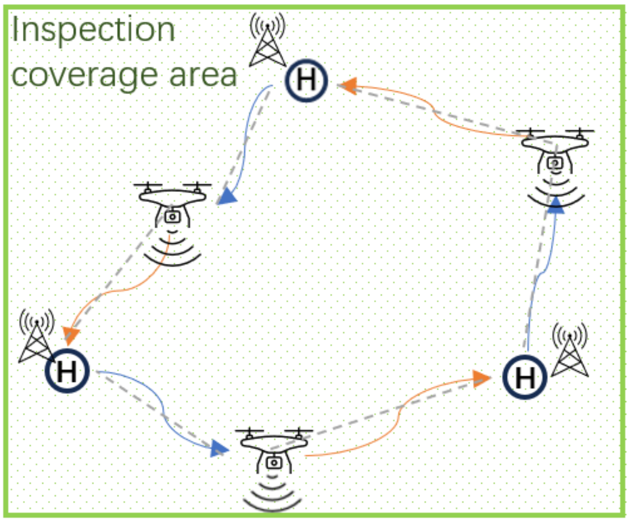

Figure 2 Schematic diagram of drone coverage inspection

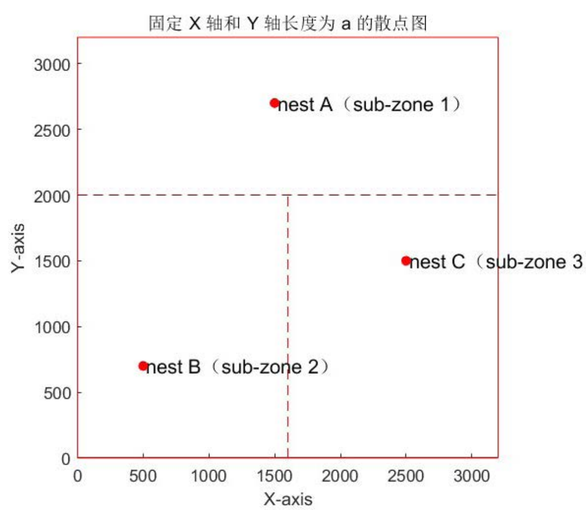

Figure 3 Inspection sub-area division and drone nest deployment

2.2 Design of regular drone inspection routes

The drone has a specific detection field of view during the inspection process, and its detection range is mainly concentrated within a certain distance on both sides of the inspection route. As shown in Figure 4, by adopting a reentrant inspection route design, the drone can effectively cover and inspect the entire designated area. Set the effective detection range of the drone to the area 100 meters directly in front and on both sides. For the forest area of 3.2km*3.2km, designing the drone inspection route as shown in Figure 5 can be efficient. Achieve coverage and inspection of the entire forest area. Taking the left half of Figure 5 (x-axis 0-1600, y-axis 0-3200) as an example, this area adopts a reentrant inspection route. The drone starts from the starting point (1600,100), first flies in the -x direction to (100,100), then reaches (100,300) in the y direction, then flies in the x direction to (1500,300), and continues on a similar path We turned back for inspection and finally arrived at the end point (1600, 3100), thus completing the comprehensive coverage and inspection of the area.

When deploying drones at nests, it is necessary to ensure that the drones take off from any nest and fly as close as possible to the next nest along the established inspection route. This layout strategy aims to ensure the balance of energy consumption of UAVs during the inspection process and avoid the decrease in inspection efficiency caused by uneven energy consumption. The total length of the inspection route in Figure 5 is 51.2km, so ideally the drone inspection distance between nests should be close to 17km. If the drone nests are deployed at three locations: A (1500, 2700), B (500,700) and C (2500, 1500), it is known through calculation that the distances along the inspection route between AB, BC and CA are respectively are 17km, 17.2km and 17km. Although the distance between BCs slightly exceeds the set value of 17km, it still meets the overall inspection distance balance requirements.

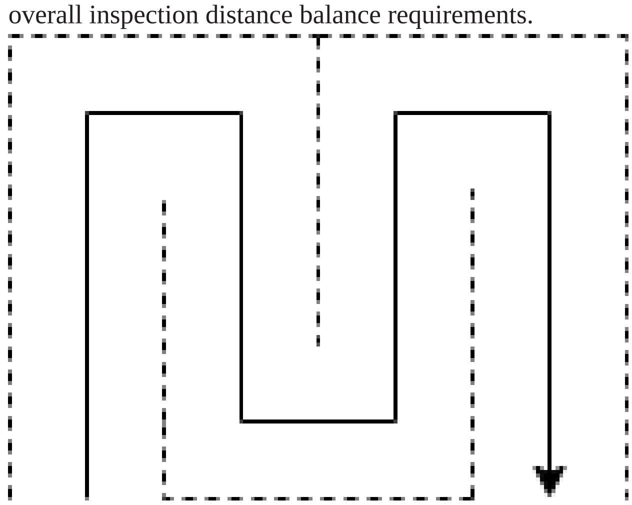

Figure 4 Turnaround UAV inspection route

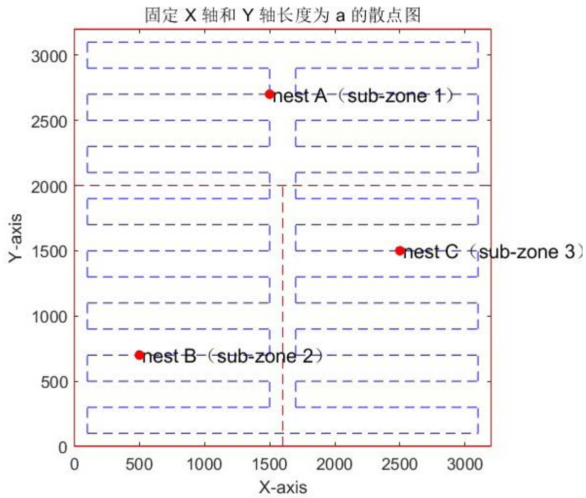

Figure 5 Schematic diagram of routine UAV inspection route

2.3 Plan to allocate the nearest landing nest for drones under unconventional inspection conditions

When the drone does not inspect according to the set route (such as temporarily going to a certain point in the area to detect whether there is a fire), the drone needs to efficiently complete the new inspection task and the drone needs to find the nest. Landed safely. Assigning the UAV to a nearby nest for landing and charging can not only avoid the decrease in energy utilization efficiency caused by returning home, but also ensure that the UAV has enough energy to return to the nest for landing and recharge.

In the design scheme described in Section 1.2 of this article, three UAV nests are deployed in three sub-areas, and their point coordinates in the x-y coordinate system are A (1500, 2700), B (500, 700), and C respectively. (2500,1500). When performing unconventional inspection tasks, three drones at the nest took off at the same time and went to the target area to conduct inspection operations. After completing the monitoring task, they returned to the nearest nest. The position coordinates of the target point of the drone in the x-y coordinate system are obtained through positioning. Assume that the target points of the drone are a, b, and c respectively. Then the target points of the three drones are located in the entire inspection area. Then there will be three cases in the distribution of the target points where the three drones are located in the entire inspection area, namely:

Case (1) three points a, b, and c are each distributed in three sub-areas.

Case (2) a, b, c Two points are distributed in the same sub-area, and the remaining point is distributed in the other two sub-areas.

Case (3) a, b, c are distributed in the same sub-area.

For case (1), it is only necessary to guide the drone to land at the nest within the sub-region after completing the mission. For cases (2) and (3), it is necessary to introduce the calculation of the distance from the target point of the drone to the nest. In case (2), if there is only one drone in the sub-area, it will be guided to land at the nest in the area. If there are two drones within one of the remaining two sub-areas, calculate the straight-line distance between the target point of the drone and the remaining two drone nest s:

$$d_{dtn} = \sqrt{(x_d - x_n)^2 - (y_d - y_n)^2} \tag{1}$$

(1) In the formula (1), the coordinates of the target point where the UAV is located are (x_d, y_d), and the coordinates of the UAV nest are (x_n, y_n).

x_d, x_n and y_d, y_n are the horizontal and vertical coordinates of the target point where the man and machine are located and the UAV nest respectively.

d_{dtn} is the straight-line distance between the target point of the drone and the remaining two drone nest s.

The landing nest of the UAV is determined by calculating the distance between the UAV and the nest in each sub-region and comparing it.

The following are specific examples:

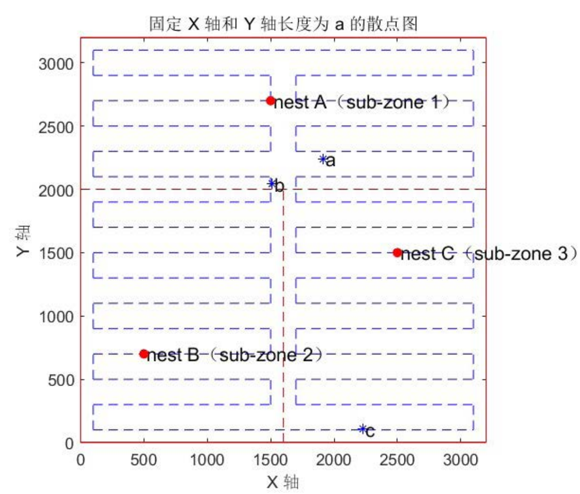

Figure 6 The case that two drones are in the same sub-zone and one drone is in the other sub-zone

As shown in Figure 6, if UAV c is within the range of sub-area 3, it is guided to land at nest C. UAVs a and b are located in sub-area 1, which requires guiding them to land at nest B and nest A. Calculate the distances $d_{aA}, d_{aB}, d_{bA}, d_{bB}$ between a and A, a and B, b and A, and b and B respectively, and compare them as follows:

$$d_{aA} \leqslant d_{bA}, d_{aB} \leqslant d_{bB} \quad (2)$$

$$d_{aA} > d_{bA}, d_{aB} > d_{bB} \quad (3)$$

$$d_{aA} > d_{bA}, d_{aB} \leqslant d_{bB} \quad (4)$$

$$d_{aA} \leqslant d_{bA}, d_{aB} > d_{bB} \quad (5)$$

Formula (2) means that the distance from the drone at a to nest A is less than or equal to the distance from the drone at b to nest A, and the distance from the drone at a to nest B is less than or equal to the distance from the drone at b to nest B. At this time, the drones at a and b are randomly assigned to land at nest A or B.

Equation (3) means that the distance from the drone at a to nest A is greater than the distance from the drone at b to nest A and the distance from the drone at a to nest B is greater than the distance from the drone at b to nest B. Here At this time, the drones at locations a and b are randomly assigned to land at nest A or B.

Equation (4) indicates that the distance from the drone at a to nest A is greater than the distance from the drone at b to nest A and the distance from the drone at a to nest B is less than or equal to the distance from the drone at b to nest B. At this time, the UAV at A is assigned to land at nest B, and the UAV at B is assigned to land at nest A.

Equation (5) indicates that the distance from the drone at a to nest A is less than or equal to the distance from the drone at b to nest A and the distance from the drone at a to nest B is greater than the distance from the drone at b to nest B. At this time, the drone at location a is assigned to land at nest A, and the drone at location b is assigned to land at nest B.

In case (3), the target points of the three UAVs are located in the same sub-area, and the target points of the UAVs are a (x_a, y_a), b(x_b, y_b), c(x_c, y_c). First, compare the ordinate values of a, b, and c, determine the point with the largest ordinate value, assign the UAV at this point to land at nest A, and then use the solution in case (2) to allocate the remaining two UAVs Land at nest B and nest C. The following are specific examples:

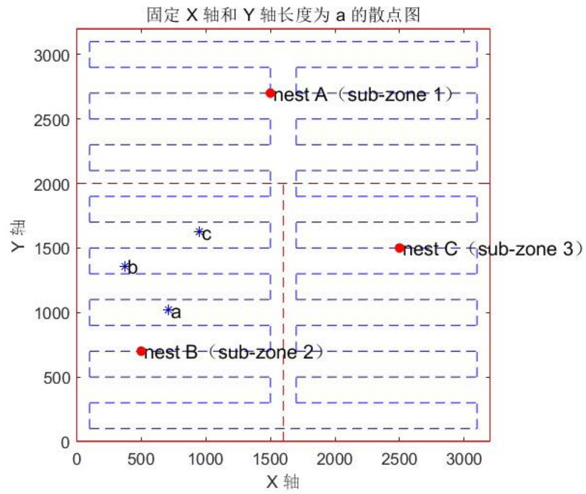

Figure 7 The case that three drones are in the same sub-zone

As shown in Figure 7, the target points a, b, and c where the drone is located are all located in sub-area 2. The ordinate y_c of point c has the largest value ($y_c > y_b > y_a$), so the drone at c should be assigned to land at nest A. For the two drones at b and c, calculate the distances $d_{bB}, d_{cB}, d_{bC}, d_{cC}$ between b and B, c and B, b and C, c and C, and use the scheme in case (2) based on this. Assigned to landing at nest B and nest C.

3 Simulation experiment

For the design of UAV inspection range, UAV nest deployment and conventional UAV inspection routes in Sections 1.1 and 1.2 of this article, MATLAB is used for image drawing; for the unconventional inspection in Section 1.3 In this case, the solution is to allocate the nearest landing nest for the UAV. This article uses MATLAB to build the relevant simulation model. The whole process is shown in Figure 8.

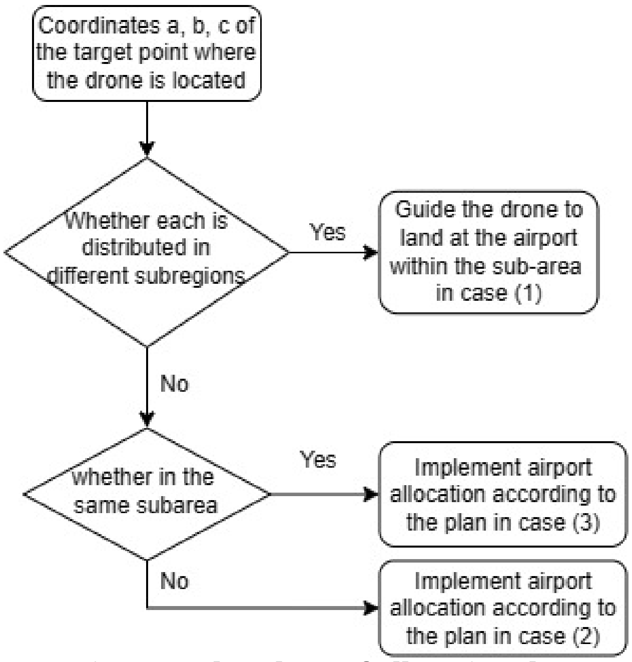

Figure 8 Flowchart of allocating the nearest landing nest for UAVs in the case of unconventional inspections

3.1 Experimental design

In the case of unconventional inspections, the drones in the inspection area operate from three drone nest s to the determined target point. At this time, the target point where the drone is located can be regarded as patrolling at 3.2*3.2km. Three randomly distributed points within the detection range. The designed algorithm program assigns the nearest landing nest to the UAV based on the cases (1), (2), and (3) in Section 1.3.

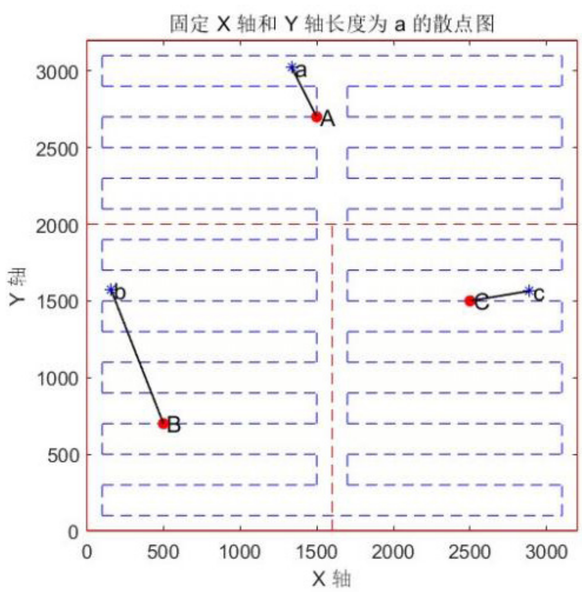

Figure 9 Assigning landing nest for UAV in case (1)

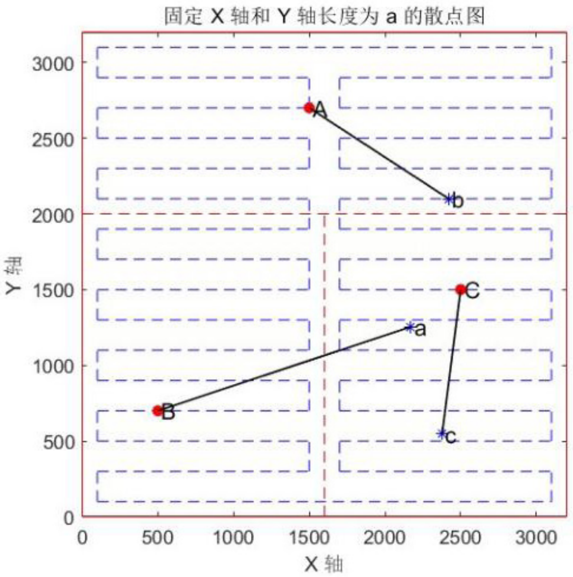

Figure 10 Assigning landing nest for UAV in case (2)

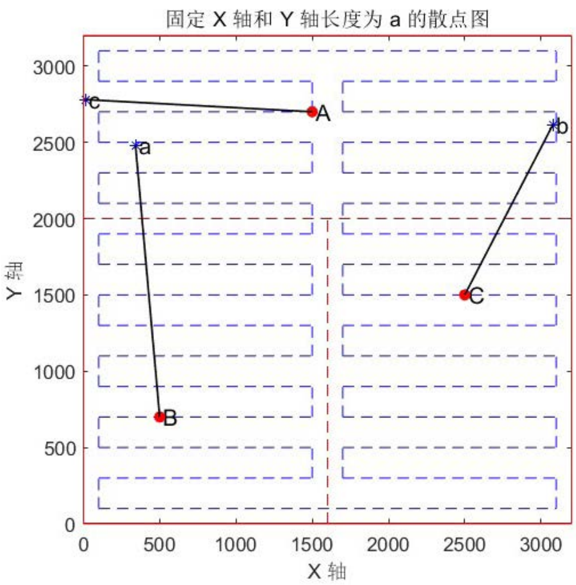

Figure 11 Assigning landing nest for UAV in case (3)

3.2 Results and discussion

Since there are infinite simulation results, here we select one simulation result for each case (1), (2), and (3), as shown in Figure 9, Figure 10, and Figure 11. The simulation results show that in three different cases, namely cases (1), (2), and (3), the experiment successfully met the requirements of allocating the nearest landing nest for UAVs in the inspection area, effectively improving the efficiency of UAVs in the inspection area. The efficiency of human-machine inspection.

However, although the UAV inspection plan proposed in this article designs the UAV inspection route and the allocation of landing nest s, it has not fully considered the impact of UAV energy consumption, forest terrain and other external factors. In future research, these factors should be considered more comprehensively to further optimize the scheme and improve its practical feasibility. At the same time, the new ideas for the application and networking of this solution in forest fire early warning inspection scenarios still need to be verified in actual applications, and improved and optimized based on field data and feedback. But overall, this solution provides a new idea for the application and networking of drone nest s in forest fire early warning and inspection scenarios.

4 Conclusion

This study proposes a multi- nest -based UAV forest fire early warning inspection scheme, aiming to effectively respond to the challenges posed by forest fires, protect forest resources and reduce losses caused by fires. By arranging multiple UAV nest s, designing reasonable inspection routes and nest allocation plans, this solution can achieve comprehensive coverage of inspections in the target area, and allocate the nearest landing nest for UAVs in unconventional inspection situations. Improved the efficiency of drone inspections and nest usage. However, this scheme still has some shortcomings, such as not fully considering the influence of external factors such as UAV energy consumption and forest terrain, and lack of support from field verification data. Therefore, in future research, it is necessary to further improve the scheme, consider more actual situations, and combine it with field data for verification and improvement.

Overall, this study provides new ideas and methods for the application of UAVs in forest fire early warning inspections, and has certain reference value for the protection of forest resources and fire prevention and control. It is hoped that this study can provide some reference and inspiration for academic research and practical applications in related fields.

References

[1] Wang Yimin. Analysis on the application of small drones in forest fire early warning monitoring and investigation and evaluation [J]. Hubei Emergency Management, 2023, (12): 64-66.

[2] WU Tian-yu, LI Bin. Application of UAV in terrain surveying of hydrological station [J]. Guangxi Water Resources & Hydropower,2024,(02):19-23.DOI:10.16014/j.cnki.1003-1510.2024.02.001.

[3] KONG Hui . Application and innovation of drones in environmental monitoring [J]. Shanghai Light Industry,2024,(02):138-140.

[4]LI Erfei. Research on the application of drones in fire rescue [J]. China Plant Engineering,2024,(07):40-43.

[5] HU Dazhi, CHANG Yufeng. Application of UAV remote sensing technology in forestry resources survey and monitoring[J]. Contemporary Horticulture ,2024,47(02):136-138.DOI:10.14051/j.cnki.xdyy.2024.02.038.

[6] YANG Zhi, LI Linjian, SHEN Junhao. Prospects for research and application of drone airport automatic patrol technology for oil and gas field gathering and transportation pipelines [C]// The 33rd National Natural Gas Academic Annual Conference (2023) Proceedings (06 Comprehensive). China Petroleum Southwest Oil & Gas Field Company's Communication and Information Technology Center;,2023:10.DOI:10.26914/c.cnkihy.2023.069977.

[7] WANG Ming. Reach on Control Technology of Automatic Inspection of Transmission Line Based on Fixed Nest of Multi Rotor UAV[J]. Electric Engineering,2022,(11):67-69. DOI:10.19768/j.cnki.dgjs.2022.11.019.

[8] WANG Wei, WANG Yinsheng, WANG Yulong. Design and research of automatic monitoring system for waterway regulation buildings based on UAV hangar technology [J]. China Water Transport,2023,(S1):157-160.DOI:10.13646/j.cnki.42-1395/u.2023.s1.028.

[9]LIU Maofeng. Intelligent nest design for inspection drones [D]. Nanjing University of Information Science and Technology,2021.DOI:10.27248/d.cnki.gnjqc.2021.000645.

[10] GUAN Jiahua, SUN Guanghui, LU Kaiye, et al. Technology and System of UAV Autonomous Line Patrol Based on Leapfrog Charging(I): Autonomous Positioning of UAV Based on GPS/RTK [J]. Journal of Electric Power Science and Technology,2021,36(05):195-200.DOI:10.19781/j.issn.1673-9140.2021.05.024.

[11] LU Qiaofeng, CHEN Changling, XU Zhou, et al. Design of a multi-UAV cooperative intelligent inspection nest for power transmission and transformation [J]. Lamps & Lighting,2022,(11):182-184.