Research on Path Planning of Plant Protection UAV Based on Grid Method and Improved Ant Colony Algorithm

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Abstract. Recently, unmanned aerial vehicles (UAVs) have rapidly emerged as a new technology in the fields of plant protection and pest controlling. The flight path planning is a key point of plant protection UAV, which directly affects the efficiency of spraying process. In this work, a novel method of planning spraying path for multiple irregular discontinuous working areas is proposed. Based on traditional grid method, the improved grid method is applied to reduce transitional working path for irregular working areas. Using the improved ant colony algorithm, a shortest total flight path between multiple discontinuous regions is designed. The results show that the optimized flight path based on this method is shortened about 4.46\% and has broad prospects for application.

1. Introduction

As a new application in the field of plant protection, the unmanned aerial vehicles (UAVs) has been widely researched and applied due to its high efficiency, safety, resource saving and environmental friendliness. Flight path planning is an important research direction in the field of plant protection UAV. A reasonable flight path will make the spraying process efficient and high-quality. Hence, several flight path planning methods have been studied. Boccalatte Marco et al. [1] proposed the task planning and design of multi-UAV collaborative management monitoring. Valente, João et al. [2] developed a useful tool for acquiring aerial images using low-cost unmanned aerial vehicles (UAVs). Verbeeck et al. [3] came up with an effective solution method for ant colony systems based on finite-time directional motion.

Some domestic researchers have been also studied diverse flight path planning methods. Liu Yunling et al. [4] aimed at a path planning algorithm for the multiple obstacle areas in the plant protection process. Xu Bo et al. [5] optimized the route planning of plant protection drones for the first time and proposed a full coverage route planning method. Wang Yu et al. [6] put forward a two-dimensional and three-dimensional path planning method for plant protection drones based on gravity search algorithm. In general, the flight path planning technology of plant protection UAV is not mature enough in China, and it is urgent to develop spraying process in an autonomous and energy-efficient manner.

In this work, the irregular grid areas were built by the improved grid method firstly. Then, the improved ant colony algorithm was used to plan the spraying of multi-block area. Lastly, a path planning method for plant protection drone based on improved grid method and ant colony algorithm was obtained.
2. Model Building for Working Areas

For the ground operation in the regular area, the cattle reciprocating method is often used. For irregular work area plots, the grid method is usually applied. At present, there are relatively few track plans for irregular areas. This paper mainly analyzes the path planning of many irregular fields. Through the field (sampling location is the field of Wexian in Henan Province), and the actual farmland irregular area D, is shown in Fig. 1. It is transformed into a mathematical model as shown in Fig. 2:

3. Grid Method

3.1. Common Grid Method

The grid method decomposes the entire area into a number of unit grids, which is concise and effective. When the working area of the plant protection drone is relatively regular, the grid method should be used, and the spray paths of the plant protection operation are straight lines. In this study, the M615 model six-rotor electric plant protection drone is taken as an example. The spray width of the plant protection drone is equal to the grid side length of 5m so that to improve the accuracy of the route planning.

The D4 area is meshed separately below. We draw a grid for the D4 work area with the black border which represents the actual parcel boundary. The length of each side of D4 is 116m, 44m, 42m, 15m, 20m, 11m, 54m respectively, covering an area of 8.0 acres. As Fig. 3 is shown: The location of the aircraft is the starting point of the plant protection drone, and the flight path according to the grid method is 1377.38m.
3.2. Improved Grid Method

The grid method is a track formed by covering all the grids, which causes unnecessary coverage within a certain range. Because of this, we adjust the job boundary based on the fact that there are some spraying areas in the grid. It is shown in Fig. 4 below. Firstly, in the case of ensuring coverage of the entire field, the boundary is retracted by using two rows of grids as the basic unit as indicated by the red boundary. By improving the grid method, excess coverage can be reduced. In addition, work time can be shortened and pesticides application can be reduced. The total route of the ordinary grid method is $S_1$, and the improved total route is $S_2$, and the reduction rate is $\varepsilon$.

![Figure 4. Path of the improved grid method](image)

Based on this, we analyze and verify the $D_6$ and $D_9$ regions by using the improved grid method. The results are shown in the table 1.

| Field $D_i$ | $S_1$ of Grid method | $S_2$ of after improvement | Reduction rate $\varepsilon$ |
|------------|-----------------------|----------------------------|-----------------------------|
| $D_4$      | 1377.38m              | 1316.78m                   | 4.40%                       |
| $D_6$      | 1015.00m              | 965.18m                    | 4.91%                       |
| $D_9$      | 186.00m               | 178.40m                    | 4.08%                       |

4. Improved Ant Colony Algorithm (ACO)

4.1. Introduction of Basic Ant Colony Algorithm

Firstly, the ant colony algorithm is basically explained, and the ant colony algorithm is improved by combining the model to find the best track. The principle of the ACO algorithm is as follows: $\tau_{ij}(t)$ is the amount of information on the time path. The ant calculates the state transition probability based on the amount of residual information. $\rho_{ij}^k(t)$ indicates the state transition probability that ant $k$ is transferred from field $i$ to $j$.

$$
\rho_{ij}^k(t) = \begin{cases} 
\frac{[\tau_{ij}(t)]^\alpha \cdot [\eta_{ij}(t)]^\beta}{\sum_{j \in \text{allowed}_k} [\tau_{ik}(t)]^\alpha \cdot [\eta_{ik}(t)]^\beta}, & \text{if } j \in \text{allowed}_k \\
0, & \text{otherwise} 
\end{cases}
$$

(1)

Where $\text{allowed}_k$ represents the plot that the ant $k$ next allows to select. $\alpha$ is the information heuristic factor, and it reflects the role of the information accumulated by the ant during the movement of the ant; $\beta$ is the desired heuristic factor and it reflects the degree of importance of the heuristic...
information in the ant selection path. \( \eta_{ij}(t) \) is the heuristic function. The expression is as follows: \( d_{ij} \) is the distance between two adjacent parcels. Obviously, the heuristic function represents the desired degree of ant transfer from parcel \( i \) to \( j \).

4.2. Improved Ant Colony Algorithm

4.2.1. Introduction of Regional Plot Shape Factor. We introduce the ant colony algorithm and make a brief description of each impact factor. We also consider various topographical factors, especially the degree of influence of the grid method. The regional block shape factor is introduced, so the improved heuristic function is as followed:

\[
\eta_{ij}(t) = \eta_d(t) \cdot \eta_s(t)
\]

In the above formula, \( \eta_d(t) = \frac{1}{d_{ij}} \), \( \eta_s(t) = \frac{1}{x_{ij}} \)

4.2.2. Setting Flight Safety Factors. Considering the irregular shape of each plot and the threat of the surrounding environment, we introduce flight safety factors. We order \( \gamma \in (0, 1] \) and set five levels respectively. The greater the safety factor it is, the greater the probability of it will select.

\[
\gamma_1 \subset (0, 0.2], \gamma_2 \subset (0.2, 0.4], \gamma_3 \subset (0.4, 0.6], \gamma_4 \subset (0.6, 0.8], \gamma_5 \subset (0.8, 1.0]
\]

4.2.3. Improved state transition probability formula. We suppose an ant is in the (i, j) grid. \( \tau_{ij}(t) \) is the amount of information on the grid. \( \eta_s(t) \) is the parcel shape factor. The state transition probability formula is improved. Thereby it can increase the probability of preferentially selecting the rule graph to promote global optimality. So the probability of selecting a parcel is defined as:

\[
\rho_{ij}^{x_k}(t) = \begin{cases} 
\frac{[\tau_{ij}(t)]^\alpha \cdot [\eta_d(t)]^\beta \cdot [\eta_s(t)]^\gamma}{\sum_{j \in \text{allowed}_k} [\tau_{ij}(t)]^\alpha \cdot [\eta_d(t)]^\beta \cdot [\eta_s(t)]^\gamma}, & \text{if } j \subset \text{allowed}_k \\
0, & \text{otherwise}
\end{cases}
\]

5. Simulation and Analysis

We use MATLAB simulation analysis to verify the improved ant colony algorithm, and the procedures are listed as follows:

Step 1: Taking each plot as a particle \( D_1 (80, 380), D_2 (250, 670), D_3 (330, 400), D_4 (370, 50), D_5 (450, 950), D_6 (570, 350), D_7 (620, 600), D_8 (750, 370), D_9 (850, 500) \). We establish the positional relationship in the same coordinate system, as shown in Fig. 5.
Step 2: We perform simulation analysis by using the improved ant colony algorithm. The information of each plot is imported into Matlab, and the operation route of the plant protection drone obtained is shown in Fig. 6. The shortest flight distance is shown in Fig. 7. The shortest route of the flight path of the parcel in the full coverage area is D$_3$$\rightarrow$D$_1$$\rightarrow$D$_2$$\rightarrow$D$_7$$\rightarrow$D$_9$$\rightarrow$D$_8$$\rightarrow$D$_6$$\rightarrow$D$_4$$\rightarrow$D$_3$.

Step 3: Establish nine plot areas, and the shortest total distance of flight is optimal at the 7th iteration, and the total shortest flight distance is 2628.9m.

6. Conclusion

A novel method of path planning for multiple irregular discontinuous working areas was proposed. The actual irregular regions were modeled and meshed by the common grid method and the improved grid method respectively. The improved ant colony algorithm was applied to find the shortest flight path linking multiple discontinuous regions. The results of simulation analysis showed the improved flight
path is shortened about 4.46% and the overall flight path was shortened from 2898m to 2628.9m after 7 iterations. This method makes spraying path planning efficient, time-saving and has a promising application future.

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