Agricultural UAV Path Planning Based on Improved A* and Gravity Search Mixed Algorithm

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Abstract. In order to ensure the accuracy, efficiency and energy saving of Unmanned Aerial Vehicles (UAVs) in irregular working areas, this paper has carried out research on its path planning methods. Taking the heading angle and return point of agricultural UAVs as the optimization objectives, the plan was made by improving the A* and gravitational search algorithm to plan the optimal path. First, the execution process of the algorithm is analysed, the application model is solved, and then the simulation experiment is performed through MATLAB. The path calculated by the proposed method was also compared with the unplanned and gravitational search algorithm planned path respectively, which showed the non-spraying distance of the proposed method was reduced by 23.18% and 5.83%, while the excess coverage of pesticide spraying was reduced by 64.47% and 64.47%. The study indicated that the proposed method which could produce paths with less working time was a reasonable, feasible and useful solution for the path planning problem of the plant protection UAV.

Keywords. Agricultural UAV; path planning; grid method; A* algorithm; gravity search algorithm.

1. Introduction

As a new type of agricultural machinery and equipment, UAV is attracting more and more attention due to its small size, easy operation, good mobility and low environmental pollution [1-3]. At present, most agricultural UAVs are based on manual remote control, which will cause the artificial immediate path to deviate from the theoretical planned path. The deviation of the running path will make the pesticide spraying repetition rate and omission rate very high, resulting in unsatisfactory work efficiency [4-5]. Therefore, solving the work efficiency and accuracy of agricultural UAVs and making reasonable path planning based on actual terrain are urgent problems that need to be solved.

In recent years, many experts and scholars have conducted in-depth research on the path planning of UAVs. Xu et al. [6-7] proposed a trajectory plan that takes the minimum total energy consumption of UAVs as the target, and reduces energy consumption by planning UAVs to return to the destination in regular work areas; Wang et al. [8-9] proposed a path planning method based on gravity search algorithm to plan a reasonable return point for irregular working areas, which improved the working efficiency of agricultural UAVs to a certain extent. Although path planning based on the gravity search algorithm can obtain the best solution for the number and location of return points in irregular work areas, grid method modelling will affect the improvement of some problems, such as the guaranteed operating distance, non-plant protection operating time, and the excess coverage of drugs.
This paper proposes a method based on the combination of improved A* algorithm and gravity search algorithm to plan the path of agricultural UAVs: First, aiming at the minimum turning distance of agricultural UAVs and the lowest coverage rate of pesticide spraying, the optimal full-cover reciprocating rotary path planning is carried out by improving the A* Algorithm. Then, on the basis of the planned full coverage path, with the minimum non-guaranteed operation time as the goal, the gravitational search algorithm is used to plan the home point, and the optimal solution of its number and position is obtained. The algorithm in this paper greatly improves work efficiency.

2. Path Planning Optimization Method

2.1. Establishment of Environmental Model
Before operating autonomously, agricultural UAVs should first determine the shape, size and boundary coordinates of the work area, and then generate the corresponding operation route based on the drug spray, and finally plan the location and number of return points based on the total length of the operation route. Because pesticide spraying of agricultural UAV is a full-coverage operation mode, the drug spraying routes are parallel to each other, and the drug spraying width is the distance between adjacent parallel lines. Therefore, dividing the work area by the grid method is simple, effective and widely used for quickly obtaining the operation route of the UAV.

As shown in figure 1, the length and width of the rectangular work area are $hd$ and $nd$. The grid method divides the working environment into a series of grids of the same size, the size of $d$, which is half the width of the UAV’s pesticide spraying. $O$ is the support point for UAV operations, A is the starting point for UAV operations, and B is the home point for UAV operations. The direction of the arrow indicates the operation direction of the agricultural UAV, and the line segment where the arrow is indicates the operation path of the agricultural UAV. If the UAV reaches the corner of the working area, it stops spraying medicine, reaches a new working path and adjusts the position to start spraying.

![Figure 1. Schematic diagram of the work area grid.](image)

2.2. Planning of Return Point of Gravity Search Algorithm
During the operation of agricultural UAVs, as the medicine or energy is exhausted, it is necessary to return to the operation support point to supplement the medicine or energy. Due to the influence of environmental factors such as the size and shape of the work area, the location and number of return points greatly affect the work efficiency. Ref. [9] adopts the gravity search algorithm for path planning for these problems, sets the working distance of each UAV as a variable, and sets the shortest distance between the return point and the support point as the optimal target. Gravity search algorithm is a kind of heuristic algorithm, adopting the iteration rules of speed and position:

$$
\begin{align*}
    v_i^n(t+1) &= r_i v_i^n(t) + a_i^n(t) \\
    x_i^n(t+1) &= x_i^n(t) + v_i^n(t+1) \\
    (i &= 1, 2, ..., I; n = 1, 2, ..., N)
\end{align*}
$$

(1)
where, $v_i(t)$ is the velocity of particle $i$ at time $t$ in the $n$th dimension, $r_i$ is a random number in the interval $[0,1]$, $a_i(t)$ is the acceleration of particle $i$ at time $t$ in the $n$th dimension, and $x_i(t)$ is the value of particle $i$ at time $t$ in the $n$th dimension.

During the working process of the UAV, since the working area is determined, the UAV support operation time is determined. In order to improve the work efficiency, it is necessary to improve the total non-spraying time, which includes the UAV round-trip flight time, battery replacement time and agent filling time, etc.

1) The distance of each UAV flight in the algorithm optimization variable:

$$X = [X_1, X_2, ..., X_m]$$

(2) Flight time of UAV return flight:

$$F = \frac{2 \| P_m - P_0 \|}{v_{\text{max}}} + t_m$$

$$= \frac{2 \| P_m - P_0 \|}{v_{\text{max}}} + t_m \quad (m = 1, 2, ..., M)$$

Among them, $F$ is the $m$-th supply return time of the UAV, $P_m$ is the coordinate position of the $m$-th home return point of the UAV, $P_0$ is the coordinate position of the UAV supply point, $v_{\text{max}}$ is the speed when the drone returns, and $t_m$ is the extra time consumed during the initial and end stages of the UAV's return flight.

3) During the replenishment process, the filling time of the medicament and the replacement of the battery can be performed at the same time. The longest consumption time is taken as the operation support time at that time. The expression is expressed as:

$$E = \sum_{n=1}^{M-1} \max(T_{m}, T_{mn})$$

(4) The total time for the agricultural UAV to reach the turn of the ground, the expression is:

$$G = D_n / v_n$$

Among them, $G$ is the total turning time, $D_n$ is the total distance of head rotation, and $v_n$ is the speed of the ground turning.

Based on the above ideas, the total non-spraying time of agricultural UAVs in the working process is

$$T_{\text{z}} = F + E + G$$

Due to the limitation of the working area environment, the problems of the agricultural UAVs’ guaranteed working distance, unsupported working time and excess coverage of medicines have not been obtained the optimal solution. Therefore, before using the gravity search algorithm, this paper refers to the improved A* algorithm for the optimization of the full coverage operation route, so as to improve many of the above deficiencies and improve work efficiency.

2.3. Optimization of The Full Coverage Operation Route with Improved A* Algorithm

The traditional A* algorithm is an 8-neighborhood search algorithm, which limits the direction of movement of agricultural UAVs to an integral multiple of, so that the turning distance of the ground and the excess coverage of pesticide spraying cannot be optimally optimized. Because the traditional A* algorithm [10-12] has too many search nodes during the search process, the storage space and search time are too large, which affects the optimization effect. Aiming at the above problems, this paper
improves the traditional A* algorithm. Firstly, the searchable neighborhood of A* algorithm is improved to make its search direction unrestricted. Then introduce line-of-sight algorithm [13-14] and jump point search method [15-16] to remove the redundant nodes in the path search process and improve the operation speed.

2.3.1. Improvement of Searchable Neighborhood. In this paper, the improved A* algorithm is used to optimize the route of the full coverage operation. The operating node is not the centre of the grid, but instead defines any edge of the grid as an accessible node. After the improvement, there are countless accessible nodes around each node. At this time, there is no limit to the direction of the UAV.

The nodes on the grid line are divided into two types: edge intersection and non-edge intersection. As shown in figure 2b, c and e are grid edge intersections, and d and f are non-edge intersections.

If the current node X is the intersection of the edges, as shown in figure 3a, the cost of any node Y between node X and AB on the edge can be expressed as:

\[ f(y) = g(y) + (1 - d) \cdot h(A) + d \cdot h(B) \quad y \neq A \]  \hspace{1cm} (7)  
\[ f(y) = g(y) + h(A) \quad y = A \]  \hspace{1cm} (8)  

where

\[ g(y) = g(X) + a\sqrt{1 + d^2} \quad y \neq A \]  
\[ g(y) = g(X) + \min\{a, b\} \quad y = A \]

Figure 2. Schematic diagram of node accessibility before and after improvement.

Figure 3. The position of the current node in the grid.
The cost on the edge XA is $\min\{a, b\}$, $d$ is the distance from point Y to point A.

If the current node X is not the intersection of the edges, according to figure 3b, it is divided into two cases, the first is the edge perpendicular to the edge of the segment (see AB in figure 3b), the second is the edge parallel to the edge of the segment (see BC in figure 3b).

For the first case, the current node is the cost expression of the intersection of the edges:

$$f(y) = g(y) + (1 - d) \cdot h(A) + d \cdot h(B) \quad y \neq A$$

$$f(y) = g(y) + h(A) \quad y = A \quad (9)$$

where

$$g(y) = g(X) + a \sqrt{t^2 + d^2} \quad y \neq A$$

$$g(y) = g(X) + \min\{a, b\} \cdot t \quad y = A \quad (10)$$

For the second case, the current node is the intersection of the edges, as shown in figure 3b, the cost expression of node X to any point Z on the edge parallel to this segment:

$$f(z) = g(z) + m \cdot h(C) + (1 - m) \cdot h(B) \quad (11)$$

$$g(z) = g(X) + a \sqrt{1 + (t - m)^2} \quad (12)$$

$$m \in [0, 1]$$

2.3.2. Deletion of Redundant Nodes. In the process of searching the path, there are many redundant nodes, which results in a large amount of calculation and calculation space. Therefore, this article introduces the line-of-sight algorithm and the hop search method to further optimize the improved A* algorithm. In the end, only the starting point, ending point and turning point in the protection path of agricultural drones are left. This optimization operation reduces the running space, improves the calculation speed, and greatly improves the work efficiency.

As shown in figure 4, the path is composed of countless nodes, including collinear nodes and polyline connection points. This paper first divides the planned path with a relatively large step size, and then uses the line-of-sight algorithm to sequentially detect all nodes on this path. If there are no obstacles or turning points between the two nodes, then all nodes between these two nodes are directly crossed by using the hop search method. If an obstacle or turning point is found between the two points, the current key node is retained and the search for the next node continues. By analogy, the final full coverage path search leaves only the key nodes C, B, A, and D.

Figure 4. Schematic diagram of key node selection.

2.4. Implementation Process of the Improved A* and Gravity Search Mixed Algorithm

All in all, based on the above working principle, the overall flow chart of the path planning method combining the improved A* and gravity search algorithm adopted in this paper is shown in figure 5.
3. Results and Analysis

In order to verify the effectiveness of the algorithm in this paper, the gravitational search algorithm in the unplanned and Ref. [9] and the method combining the improved A* and gravitational search algorithm in this paper were simulated and compared respectively. The empty flight time of the agricultural drone is 33min, the longest spray time is 15min, the operating speed is 3m/s, the return speed is 8m/s, the ground rotation speed is 2m/s, and the operating width is 5m. The time $T_b$ for battery replacement and the time $T_p$ for maximum medicament replenishment are both 1 min.

The farmland area is abstracted into a two-dimensional plane, and the coordinates of each vertex of the farmland are found through image processing and other operations. The GPS longitude and latitude of the farmland are transformed into the coordinates of each vertex in the rectangular coordinate system through coordinates. The vertex coordinates are (2.5, 0), (2.5, 405), (130, 660), (210, 0). Set (0,0) as the guarantee point and (2.5,0) as the starting point. Through MATLAB simulation, it can be concluded that the unplanned working path in the irregular working area, Ref. [9] and the algorithm planned work path in this paper are shown in figures 6-8. The total unmanned operation time of agricultural drones is 1513.30m, 1234.5m and 1162.49m respectively, the turning distances are 288m, 288m and 230.47m respectively, and the excess coverage rate of pesticide spraying is 6.53%, 6.53% and 2.32% respectively.
Figure 7. Ref. [9] algorithm path planning output.

Figure 8. The output of the algorithm path planning in this paper.

In the same environment, compared with the unplanned and the algorithmic planning situation in Ref. [9], the simulation comparison results of the proposed algorithm are shown in table 1. The total time of non-guaranteed operations of agricultural drones decreased by 23.18% and 5.83%; the turning distance decreased by 19.96% and 19.96%; and the excess coverage rate of pesticide spraying decreased by 64.47% and 64.47%, respectively.

Table 1. Data comparison of path planning results.

| Parameter                  | Unplanned | Algorithm planning | Ref. [9] |
|----------------------------|-----------|--------------------|----------|
| Number of return flights   | 7         | 8                  | 8        |
| Safe working distance/m    | 17862.53  | 17788.49           | 17862.41 |
| Round trip distance/m      | 3850.36   | 2090              | 2160     |
| Turning distance/m         | 288       | 230.47             | 288      |
| Guarantee operation time/s | 6002.18   | 5967.91            | 6002.86  |
| Round-trip flight time/s   | 481.30    | 261.25             | 262.5    |
| Total non-spraying time/s  | 1513.3    | 1162.49            | 1234.5   |
| Initial route search time/s| 25.78     | 5.32               | 25.78    |
| Excess coverage/%          | 6.53      | 2.32               | 6.53     |

4. Conclusion
This paper proposes a planning method based on the combination of improved A* and gravity search algorithm for the plant protection process of agricultural drones. By inputting the inherent attributes of
agricultural UAVs and the relevant parameters of the operating environment into the algorithm, the optimal operating path can be obtained immediately. The optimization of the parameters such as the operation path and the position of the home point to achieve autonomous operation, and specific improvement measures were proposed for irregular work areas. The path calculated by the proposed method was also compared with the unplanned and gravitational search algorithm planned path respectively, which showed the non-spraying distance of the proposed method was reduced by 23.18% and 5.83%, while the excess coverage of pesticide spraying was reduced by 64.47% and 64.47%, and other indicators have improved to varying degrees. Simulation shows that compared with other path planning algorithms, the algorithm used in this paper is more efficient, stable, reasonable and feasible.

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