Multi-target oriented UAV reconnaissance path planning algorithm

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Abstract. Aiming at the problem of path planning when unmanned aerial vehicle (UAV) reconnoitre multiple targets, a UAV path planning algorithm for multi-target reconnaissance is proposed. Firstly, the optimal k-means clustering algorithm is used to cluster a plurality of closely related targets into one target, which reduces the scale of the problem. Then, in order to reduce the path cost of the algorithm, the coding method and crossover operation of the genetic algorithm (GA) are optimized to solve the reconnaissance sequence under the minimum path cost. Finally, the reconnaissance path is generated based on the reconnaissance sequence. The simulation results show that the algorithm can effectively reduce the path cost by 17.5%.

1. Introduction

UAV is a kind of aircraft that is operated autonomously or controlled by wireless remote control relying on programs. Compared with manned vehicle, UAV has been repeatedly applied to perform various military missions in modern wars, such as reconnaissance, attack and patrol, etc, due to its advantages such as low casualty rate, high cost performance and strong environmental adaptability [1]. When UAV performs the mission of reconnoitre over a large number of targets, how to quickly and effectively plan the reconnaissance path is a difficult problem [2].

Many scholars at home and abroad have conducted extensive research on this problem. [3] transformed the problem into a traveling salesman problem (TSP), and then the optimal path can be rapidly planned by improving the intelligent single particle optimization algorithm. [4] adopted the fast non-dominant ranking algorithm, and took the path length, concealment and safety as specific evaluation indexes, which could plan the track to maximize the combat effectiveness. However, this algorithm has some disadvantages, such as strong subjectivity and large amount of calculation. [5] proposed a recursive bayesian estimation algorithm to detect multiple ground moving targets, but it is only applicable to the case that the scale of target is small, and the stability of the algorithm is poor. [6] used clustering algorithm to solve the problem by treating the path that traverse targets within target group is considered as a TSP, and the path that fly between different targets groups is regarded as a Vehicle Routing Problem (VRP). Finally, a feasible UAV path for multi-target reconnaissance can be planned. However, this method is complex, computationally intensive and inefficient.

To some extent, the above methods can solve the problem of path planning for UAV in multi-target reconnaissance. But there is a common shortcoming, that is, they ignore the detection range of the payload carried by UAV, and it is considered that the reconnaissance mission is completed only when the UAV passes over the target. In practice, the payload carried by UAV has a certain detection range, and the target can be reconnoitred without flying over the target. Therefore, the current reconnaissance method will cause the target to be repeatedly reconnoitred, resulting in low reconnaissance efficiency.
Based on the above disadvantages, a UAV path planning algorithm for multi-target reconnaissance is proposed. Firstly, the reconnaissance radius of UAV is solved. Combining with the optimized k-means clustering algorithm, multiple targets smaller than the reconnaissance radius are clustered into one target, thus simplifying the scale of the problem. Secondly, the coding method and crossover operation of the standard GA algorithm are optimized, the integer coding is adopted to encode the gene, and the best operator is designed to solve the reconnaissance path of the UAV with the goal of minimizing the path cost. Finally, the effectiveness of the algorithm is verified by simulation.

2. Mission model
Suppose there are \( n \) targets to be reconnoitred, the set of target is \( T=\{T_1, T_2, \ldots, T_n\} \), \( c_{ij} \) represents the path cost of the UAV from the target \( i \) to the target \( j \), and \( u_{ij} \) represents whether the target \( j \) is reconnoitred after the drone reconnoitred target \( i \), and 1 indicates being reconnoitred, 0 means no being reconnoitred. The model of the path planning for UAV reconnoitre multi-target can be expressed as:

\[
\begin{align*}
\min & \quad \sum_{i=1}^{n} \sum_{j=1}^{n} u_{ij} c_{ij} \\
\text{subject to} & \quad \sum_{j=1}^{n} u_{ij} = n.
\end{align*}
\]

The model is a TSP model, where equation (1) represents the objective function that seeking the minimum path cost, and equation (2) is the constraint, ensuring that all targets are reconnoitred by the UAV.

3. Improved K-means clustering algorithm
K-means clustering algorithm is a commonly used clustering algorithm with simple operation, fast operation speed and easy to understand. However, since the algorithm needs to set the number \( K \) of clustering and select the initial clustering target, the final clustering result is highly random, so the universality of the algorithm is poor [7].

Therefore, in order to obtain stable clustering results, the clustering criteria of k-means clustering algorithm is optimized, that is, the error between the distance between the targets and the detection radius of the payload is used as the basis for targets clustering, which is multiple targets smaller than the detection range of payload are clustered into one target. The final clustering result is not only stable, but also can reduce the scale of the problem, and also reduce the probability that the target will be repeated reconnoitred.

The specific steps are as follows:

3.1 Calculate the distance between the targets.
Supposed \((T_i(x), T_i(y))\) and \((T_j(x), T_j(y))\) represent the position coordinates of the targets \( T_i \) and \( T_j \), then the distance from the \( i \)-th target to the \( j \)-th target is

\[
d_{ij} = \sqrt{(T_i(x) - T_j(x))^2 + (T_i(y) - T_j(y))^2}
\]

3.2 Count the number of times targets are spied on each other
Assuming that the reconnaissance radius of the payload is \( R \), when the UAV is located at target \( T_n \), its distance from other targets satisfies

\[
D_{ij} = \begin{cases} 
1, & d_{ij} < R \\
0, & \text{else} 
\end{cases}
\quad (j = 1, 2, \ldots, n)
\]

1 indicates being reconnoitred, 0 means no being reconnoitred. Then, when the UAV is located at target \( T_n \), the total number of targets has detected is
\[ D = \sum_{j=1}^{n} D_j, (i = 1, 2, \ldots, n) \]  

Expressed by the set as:

\[ T_i = \{ D_i \mid (T_i, \ldots) \in T_i \}, (i = 1, 2, \ldots, n) \]  

It means that when the UAV is located at target \( T_i \), a total of \( D_i \) targets are detected. The target in the reconnaissance range is \( (T_i, \ldots) \), and the final clustering result is \( T_i \).

When \( T_i = \{0\} \) represents that the UAV is located at the target \( T_i \), the number of detected target is 0, which can be clustered into a single class.

### 3.3 Clustering

Find the collection with the largest number of reconnaissance targets. Then, the target that have been clustered are deleted in the set with them.

Repeat steps 3.2 and 3.3 until all targets are clustered and the clustering results are organized.

### 4. Improved Genetic Algorithm (IGA)

The GA is a heuristic random search algorithm that imitates the natural law proposed by Charles Darwin. By simulating selection, crossover, mutation and other operations, the purpose of global search is achieved, and then the optimal solution of the problem is obtained. It has the advantages of fast convergence, high calculation accuracy and strong robustness. But it can't solve large-scale problems, and it is easy to fall into local optimum, easy to premature [8].

In order to ensure that the path planning of UAV reconnaissance multi-target develops toward the direction of path cost minimization, the standard GA is optimized, which makes it difficult to fall into local optimum and enhance its search ability.

#### 4.1 Gene encoding

The gene of GA is encoded by integer, that is, a full permutation is generated randomly, and each gene is a reconnaissance sequence.

Example: The number of target is 5, and the resulting fully-arranged gene is coded as \([4-1-5-3-2]\), indicating that the sequence of the targets within the target group is detected by the UAV, which takeoff from the initial, first scouting target 4, then reconnoitre in turn, and finally return to the initial.

#### 4.2 Fitness function

From the previous mission model, it can be seen that the fitness function is the path cost, which is

\[ \text{fitness}(m) = \sum_{i=1}^{n} \sum_{j=1}^{n} u_{ij} c_{ij} \]  

indicates the fitness of the \( m \)-th gene.

#### 4.3 Crossover operation

The crossover operation of GA is improved, and the best operator is designed, including the best crossover operator and the best reversal operator.

For the best crossover operator, the best intersection is randomly selected, and the code of the left and right positions of the best intersection is exchanged. If the fitness value is reduced, it is retained and the sequence of the UAV access target is updated. If the best intersection is in the first or last position, it is only exchanged with the adjacent location.

For the best reversal operator, two best reversal positions are randomly selected, and invert the sequence between the two reversal positions. If the fitness value is reduced, it is retained and the sequence of the UAV access target is updated.

As shown in figure 1, the best crossover positions are 2 and 5. After using two crossover operations, the best feasible solutions are \([3 2 1 5 4]\) and \([1 5 4 3 2]\) respectively.
5. Simulation

The experimental platform is Dell laptop of Inter(R) Core(TM) i5-5200u CPU, 4GB memory and 64-bit Win7 operating system. The programming tool is Matlab R2016a (64-bit).

5.1 Parameter settings

Assuming that there are 40 targets need to be reconnoitred, and the target coordinates are as shown in table 1. The UAV coordinates are (0, 0), and the payload detection radius carried by the UAV is \( R = 12 \). The target position and UAV position are shown in figure 2.

![Figure 2. Schematic diagram of target position and UAV position](image1)

![Figure 3. Schematic diagram of targets clustering results](image2)

| \( T_i \) (x,y) | \( T_i \) (x,y) | \( T_i \) (x,y) | \( T_i \) (x,y) | \( T_i \) (x,y) | \( T_i \) (x,y) |
|----------------|----------------|----------------|----------------|----------------|----------------|
| (64,96) | (72,42) | (48,67) | (58,43) | (81,34) | (79,17) |
| (29,51) | (78,92) | (57,91) | (40,35) | (68,40) | (76,73) |
| (93,54) | (30,9) | (77,13) | (82,88) | (73,28) | (30,23) |
| (27,43) | (95,86) | (48,83) | (54,38) | (63,36) | (44,33) |
| (16,74) | (17,22) | (5,45) | (79,70) | (9,100) | (98,7) |

5.2 Simulation results and analysis

Simulation 1: Verification of the effectiveness of the target clustering algorithm based on IGA.

First, clustering all targets can be simplified to 20 targets. The clustering results are shown in table 2 and figure 3.

Then, the IGA is used to track the results before and after clustering of the targets. The path cost and reconnaissance sequence are shown in table 3. The tracks are shown in figure 4 and figure 5.
The simulation results show that the improved K-means algorithm has stable clustering results, and the initial 40 targets are clustered into 20 targets with known detection radius, which greatly reduces the complexity of the problem, reducing the probability of repeated reconnoitred of the target, reducing the path cost from 58258.55m to 48071.80m, and improving the reconnaissance efficiency by 17.5%.

Simulation 2: Verifying the convergence of IGA

In order to compare the improved genetic algorithm with the standard genetic algorithm, under the same conditions, the two algorithms are used to iterate 5000 times of the clustered targets, and the comparison diagram of algorithm convergence is shown in figure 6.

As shown in figure 6, the final path cost of both the improved genetic algorithm and the standard genetic algorithm converges to 48071.80m, but the IGA converges to the optimal solution in the 120th generation, while the standard genetic algorithm converges to the optimal solution in the 3485
generation, and its convergence speed is nearly 30 times faster. Therefore, the optimization speed of the IGA is fast.

6. Conclusion
When the UAV reconnoitred multiple targets, there is a problem of low reconnaissance efficiency. A UAV path planning algorithm for multi-target reconnaissance is proposed. The problem of the multi-target oriented UAV reconnaissance path planning is regarded as the traveling salesman problem. Firstly, all the targets are clustered by improving the k-means clustering algorithm to reduce the repetitive reconnaissance rate. Then the IGA is used to solve the TSP. Finally, the simulation results show that the proposed method can effectively solve the problem of UAV reconnoitre multi-target, and the convergence speed is fast and the solution precision is high.

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