Research on Multi-UAV Loading Multi-type Sensors Cooperative Reconnaissance Task Planning Based on Genetic Algorithm

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Abstract. Unmanned Aerial Vehicle (UAV) has been playing an increasingly important role in modern military fields recently. The multi-UAV cooperative reconnaissance mission planning is one of the task allocation and resource scheduling problems in the field of multi-UAV co-operative control, which is full of challenges. In this paper, a multi-base, multi-target, multi-load and multi-UAV cooperative task model is established. Taking the actual battlefield situation into account, this paper built a confrontation scenario between the UAVs and radars. The objective function of the established model is the shortest route length of UAVs staying in the detection range of radars. This paper presented an improved genetic algorithm to address the problem scenario. The solving procedure consists of two steps. First of all, the route of UAVs that traverse targets within target group is considered as a Traveling Salesman Problem (TSP). Second, the route of UAVs that fly between different target groups is regarded as a Multiple Depot Vehicle Routing Problem (MDVRP). In addition, the working patterns of different sensors carried by UAVs are concerned. As a consequence, a more optimized route of UAVs is acquired. Finally, A simulated case is designed to verify the feasibility of our proposed algorithm.

Keywords: Multi-UAV · Mission planning · Genetic algorithm · TSP · MDVRP

1 Introduction

Unmanned Aerial Vehicle (UAV) is a new combat platform with autonomous capability and independent execution capability. It can not only perform non-offensive tasks such as military reconnaissance, surveillance, search and target orientation, but also can perform combat missions such as attack and target bombing and so on. With the rapid development of UAV technology, more and more UAVs will be used in the future battlefield. In a variety of applications of UAVs, arranging UAVs with different loads when they performing reconnaissance mission is an important application.

The implementation of reconnaissance missions by multi-UAV has been a research topic of concern to scholars all over the world. In the early days, Air Force Institute of

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Technology (AFIT) conducted a number of studies on multi-UAV collaborative reconnaissance mission planning with the background of ‘Global Hawk’ and ‘Predator’ unmanned reconnaissance aircraft. Ryan et al. [1] chose the ‘Global Hawk’ and ‘Predator’ of the US military as the objects of study, and transforms the task assignment problem of UAV into the Vehicle Routing Problem (VRP) model. The model regards the UAV as a vehicle, and reconnaissance target as a customer. Finally this paper used tabu search algorithm to solve the model. Vincent et al. [2] abstracted the multi-UAV collaborative reconnaissance problem into a multi-traveling salesman problem (MTSP), and used evolutionary algorithms to solve it. The paper [3] also modeled the same problem as a traveling salesman problem, and focused on the application of particle swarm optimization in solving TSP problems. Yang et al. [4] built a more practical model, namely the multi-base, multi-target, multi-UAV cooperative reconnaissance (M-M-MUCRM) model and designed a heuristic genetic algorithm to solve it.

While some studies have taken the situation in which multi-UAV carry different loads into account. Tian et al. [5] considered the type of sensor, indicating how to choose the sensor in different environments. Park et al. [6] mainly concerned about the function of sensors, and used them to build a multi-UAV information sharing structure. However, these papers remain to own the following deficiencies: (1) the previous literature rarely considered the working condition of the sensors for the UAV path planning. Most of them roughly dealt with the use of sensors, didn’t consider the constraints related to sensors. So the path planning is not good enough. (2) And in the battlefield, the enemy’s radar usually can detect and combat UAVs. How to make the UAVs effectively avoid them also need attention.

In this paper, we focus on the influence of multi-type load on the route planning of multi-UAV co-operation, and find a more optimized route. At the same time, this paper also considers the situation of radar defense in the real battlefield, and carries on the simulation solution of UAV reconnaissance task planning in this scene. In Sect. 2, the problem scenario we studied is introduced and the related mathematical model is established. After that in Sect. 3, a solving process based on genetic algorithm is put forward. Then in Sect. 4, simulation experiments are developed to validate the performance of our designed algorithms. Finally Sect. 5 displays our conclusion.

2 Scenario Description and Problem Modeling

2.1 Problem Scenario Description

A UAV combat troops are now equipped with a number of UAV bases and each base is equipped with a certain number of reconnaissance UAVs. The main function of reconnaissance UAV is to scout targets. Two kinds of sensors can be loaded on UAV. One is the imaging sensor, using the wide-area search mode to take images of targets, that is, once the targets fall within the sensor imaging bandwidth, can these targets be imaged. The imaging bandwidth of the sensor is generally 2 km, and the working principle of this kind of sensor is shown in Fig. 1.

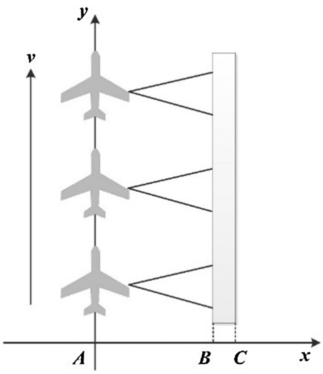

Fig. 1. The working pattern of imaging sensor

In Fig. 1, the length of BC is 2 km. The imaging sensor can only image on one side of UAV and is no longer adjusted during flight. In general, the target reconnaissance process needs some time to collect the required information. So the lateral distance AB must greater than a certain threshold AB_{min}, and there is also a maximum range limit AC_{max} of AC too. When the imaging sensor uses the wide area search mode to image the target, in order to ensure the imaging quality, the UAVs is required to make uniform linear motion.

Another kind of load is optical sensor, in order to achieve the required target recognition accuracy, the distance between optical sensor and target is under a required distance. And this kind of sensor can take photo instantly. Each UAV can only load one kind of sensor each time and in order to ensure the reconnaissance effect, two kinds of sensors are required to scout each target for at least once. Two different sensors have no more than 4 h of reconnaissance intervals for the same target. While the task is performed at the same time, multi-UAV can fly in formation, but a safe distance needed to maintain. After the completion of the task, the UAV will return to its original base.

According to the needs of combat missions, UAVs need to scout all targets in several target groups and each target group is equipped with a radar station. In the actual combat environment, once the reconnaissance UAVs fly into the radar detection range, the radar will turn on the air alert and search targets, then take appropriate measures, such as launch the missiles to destroy the UAV. So the longer the UAVs stay in the detection range of radar, the greater the possibility of its destruction. And the length of the UAV path directly determines the time it stays in radar detection range. Aiming at this complex confrontational task scene, it is necessary to develop a proper route and cooperative dispatching strategy for multi-UAV carrying multi-loads from multi-bases.

2.2 Mathematical Model

Notations

Base set: A total number of N_B bases are equipped with reconnaissance UAVs, and the base set is denoted as $B = \{B_1, B_2, \ldots, B_{N_B}\}$. The coordinate of one certain base is $(xb_i, yb_i), i = 1, 2, 3, \ldots N_B$.

Target set: Atotal number of N_T targets need to be detected, and the target set is denoted as $T = \{t_1, t_2, \ldots, t_{N_T}\}$. The coordinate of one target is $(xt_i, yt_i), i = 1, 2, 3, \ldots, N_T$. And all the targets are grouped into N_{TG} target groups, which is denoted as $TG = \{tg_1, tg_2, \ldots, tg_{N_T}\}$.

Radar set: Each target group is equipped with one radar station, so the total number N_R is equal to N_{TG}. The set of radar is $R = \{R_1, R_2, \ldots, R_{N_R}\}$, and the coordinate of one certain radar is $(xr_i, yr_i), i = 1, 2, 3, \ldots, N_R$. R_a is the detection radius of each radar.

UAV set: UAVs with Nv kinds of loads are located at N_B bases. The UAV set of loading k-type sensor equipped with base b is denoted as $V^{bk} = \left\{v_1^{bk}, \ldots, v_{N_b^k}^{bk}\right\}$. N_b^k is the maximum number of UAVs of this type. And V^{bk} can be null, which indicates that this base is not equipped with UAV carrying k-type load. In the problem discussed in this paper, $k \in \{1,2\}$, and 1-type load is imaging sensor while 2-type load is optical sensor. $NV = \Sigma_{b=1}^{N_B} \Sigma_{k=1}^{N_V} N_b^k$ is the number of all UAVs can be used.

The speed of UAV is υf. The takeoff time of one certain UAV is $T_0^{(b,k,i)}$ and the maximum flight time of UAV is T_{max}. The flying height of UAV is h. When a certain UAV from base b, carrying the k-type load is flying, the coordinates of it at the moment t is denoted as $\left(xv_{(t)}^{(b,k,i)}, yv_{(t)}^{(b,k,i)}\right), i = 1, 2, \ldots, N_b^k, T_0^{(b,k,i)} \leq t \leq T_{max}$.

rs_2 indicates the farthest distance from the target when optical sensor takes a picture. $TG_{(b,i)}^k$ indicates the target group set scouted by the i-th UAV from base b, carrying the k-type sensor.

$distance^k(t)$ denotes the sum of the distances of the UAVs loading the k-type sensor and scouting all targets in each target group.

$L_{(b,i)}^k$ denotes the edge set of the i-th UAV carrying the k-type sensor flying between the target groups.

$length(l)$ represents the length of each edge in the L set. To be more specific, the sketch map of the edge set $L_{(b,i)}^k$ is shown in Fig. 2.

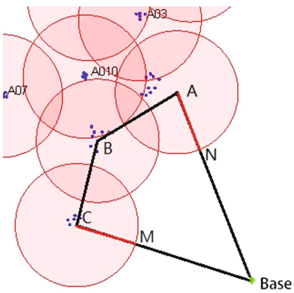

Fig. 2. The sketch map of the edge set $L_{(b,i)}^k$

As shown in Fig. 2, one certain UAV v_1^{bk} flies into target group C from M point, after scout all targets in group C, it flies to target group B and then flies to target group

A and returns to base. So $length(l) = L_{BC} + L_{BA}$ and the sum distance of UAV in the detection range of radar is $length(l) + 2r_a$.

Objective function

$$min\ Z = \sum_b \sum_i \sum_k \left(\sum_{l \in L(b,i)} length(l) + \sum_{t \in T(b,i)} distance^k(t) + 2r_a \right) \tag{1}$$

$$s.t.\ TG^k_{(b,i)} \subseteq \{1,2,3,\ldots,N_{TG}\}, k = 1,2 \tag{2}$$

$$\bigcup_{b,i} TG^k_{(b,i)} = \{1,2,3,\ldots,N_{TG}\}, k = 1,2 \tag{3}$$

Constraint conditions

$$\forall t, \forall v_i^{bk}, \forall v_j^{bk} \in V^{bk}, \left(\sqrt{(xv_{(t)}^{(b,k,i)} - xv_{(t)}^{(b,k,j)})^2 + (yv_{(t)}^{(b,k,i)} - yv_{(t)}^{(b,k,j)})^2} \le 200\right) \tag{4}$$

$$\forall v_i^{bk} \in V^{bk}, \frac{\sum_{l \in L(p,q)} length(l) + \sum_{v \in V(p,q)} distance^k(v) + 2r_a}{vf} \le T_{max} \tag{5}$$

$$\forall v_i^{\mathrm{bk}}, v_j^{\mathrm{bk}} \in V^{bk}, \left| T_0^{(b,k,i)} - T_0^{(b,k,j)} \ge T_{interval} \right| \tag{6}$$

Inequality (4) indicates that the flying distance between every two UAVs should bigger than 200 km. And since the average speed of the UAV is vf km/h, the maximum life time of T_{max} must meet inequality (5). Due to the limitation of the technical support of the base, the time interval between two UAVs' takeoffs from the same base must meet inequality (6).

2.3 Model Analyze

In order to solve the objective function, it is necessary to make further analyze whether the problem is applicable to some classical problem models. The objective function can be divided into two parts. When calculate

$$min \sum_b \sum_i \sum_k \left(\sum_{t \in T(b,i)} distance^k(t) \right) \tag{7}$$

the sub-problem can be modeled as a Traveling Salesman Problem (TSP). It can be described as finding a shortest path to traverse all targets in one certain target group.

And when calculate

$$min \sum_{b} \sum_{i} \left(\sum_{l \in L(b,i)} length(l) \right) \tag{8}$$

the sub-problem can be modeled as a Multiple Depot Vehicle Routing Problem (MDVRP). Mapped to this problem, the bases are regarded as depots, the targets are regarded as customers, and the UAVs are regarded as vehicles.

3 Algorithm Design

Based on the model analyze, a proper algorithm need to be designed to solve the problem scenario. As one of the classical evolutionary algorithms, genetic algorithm has a strong search ability and is widely used in solving TSP problems and performs well [7–9]. When solve the MDVRP problem, genetic algorithm also shows good performance [10–12]. So genetic algorithm was chosen to solve the problem proposed in this paper. And the overall pseudo-code of genetic algorithms designed in this paper is shown as follows.

```
1.FindOptimalSolution(B, TG, R,V^bk):
2.Initialize the optimal value to 0or infinity
3.solution = 0
4.Calulate the distance of UAV traversing targets in target group
5.For tg in TG:
6.  For v_i^bk in V^bk:
7.    tspRoute = CalculateTSPbyGA(B,TG, V^bk )
8.    tspRoute = tspRoute  - L(CuttingEdge) –L(SensorWorkingPattern)
9.  solution += tspRoute
10.Calculate the distance of UAVs flying between target groups
11.For  v_i^bk in V^bk:
12.  solution += CalculateVRPbyGA(F,n,TG)
13.Return solution
```

3.1 Genetic Algorithm for UAV Traversing Targets in a Target Group

This paper takes the working pattern of sensor into account, and the solving process of function (7) is shown as follows.

Genetic algorithm for solving TSP problem. This paper uses genetic algorithm to solve TSP problem, the brief solving process is shown in Fig. 3.

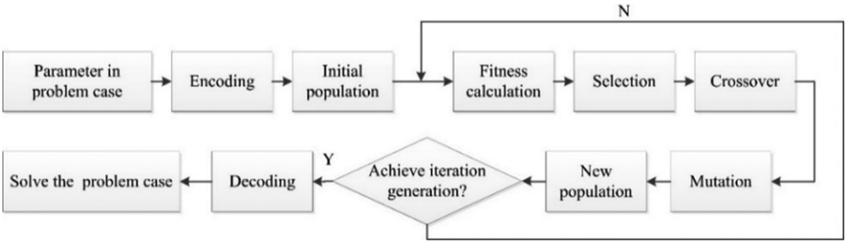

Fig. 3. The process of genetic algorithm

Encoding. Using integer encoding method, there are n targets in a target group, so the chromosome can be divided into n parts, and the order of genes indicate the order of targets under reconnaissance. For example, there are 10 targets in a target group, then 6|8|7|2|4|5|9|3|1|10 is a legal chromosome.

Population initialization. After completing the chromosome coding, an initial population must be generated as a starting solution. In this problem, the number of initialized populations depends on the number of targets.

Fitness function. Suppose that $|t_1|t_2|\cdots|t_i|\cdots|t_n|$ is a legal chromosome, and $D_{t_it_j}$ is the distance between target t_i and t_j, the fitness of the individual is:

$$fitness = \frac{1}{\sum_{i=1}^{n-1} D_{t_it_{i+1}} + D_{t_nt_1}} \tag{9}$$

Selection. Using roulette method to choose, the greater the individual fitness, the greater the probability of being selected.

Crossover. Suppose that the number of targets is 10, and the crossover method used in this paper is shown in Fig. 4.

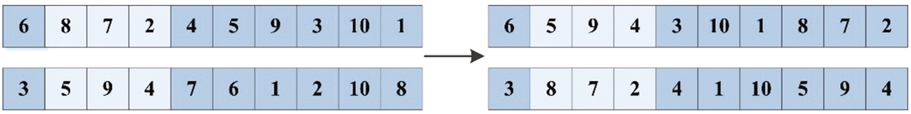

Fig. 4. The crossover operation in genetic algorithm

As it is shown in Fig. 4, two parent chromosome is a group, each of which repeats the following procedure: (1) Generates two random integers r_1 and r_2 in the [1, 10] interval, determining the two positions, crossing the intermediate data of these positions. (2) After crossing, there are duplicate target numbers in the same chromosome, non-repetitive numbers are retained. By using partial mapping, the conflicted numbers are eliminated, that is, mapping with the corresponding relationship of the middle segment.

Mutation. Generates two random integers r_1 and r_2 in the interval of [1, 10], determines two positions and swaps them.

Considering the working pattern of the imaging sensor. The 1-type sensor mages the target in a wide-area search mode, so the UAV does not need to reach the target point for reconnaissance. As it is shown in Fig. 5, if the reconnaissance of UAV must reach the target point, the path is indicated by the black line. But according to the performance of the imaging sensor, the target can be scouted only fall in the imaging bandwidth, which is colored in red.

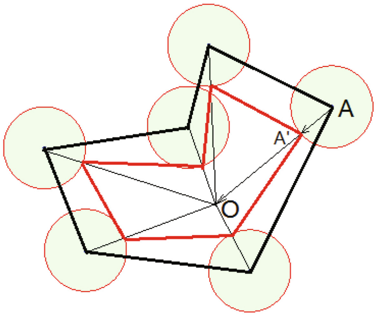

Fig. 5. The sketch map of UAV flight route when traversing targets in a target group (Color figure online)

As it is shown in Fig. 5, taking the target point as the center and inward extension of the distance α as the radius. Distance α is a certain value between the limits of AB and AC in Fig. 1. After that, we establish the center of gravity of the polygon, denoted as O in the figure, connect the point O and one certain target A, then the point A' is the new reconnaissance point and $\left|\overrightarrow{AA'}\right| = \alpha$. Set $\left|\overrightarrow{AA'}\right| = \lambda\left|\overrightarrow{A'O}\right|$ and the coordinates of A, A', O are $(x_1, y_1), (x, y), (x_0, y_0)$. The coordinates of A' are calculated as follows, then a shorter UAV route can be calculated.

$$x = \frac{x_1 + \lambda x_0}{\lambda + 1} \tag{10}$$

$$y = \frac{y_1 + \lambda y_0}{\lambda + 1} \tag{11}$$

$$\lambda = \frac{\left|\overrightarrow{AA'}\right|}{\left|\overrightarrow{A'O}\right|} = \frac{\alpha}{\left|\overrightarrow{AO}\right| - \alpha} \tag{12}$$

Cutting the edges. When a UAV traversing a target group, it usually chooses an entry point and an exit point, which are not coincide. Therefore, it is necessary to cut the edge of the UAV route in one target group. According to the law of military detection, when the UAV flies into a target group, it will detect the radar first, because only the first to understand the deployment of enemy's 'eyes', can you have a better grasp of the battlefield environment. Based on the working pattern of sensors introduced above, UAV can only detect the targets in one direction. Therefore, in each target group, when taking the radar as the entry point, it is necessary to calculate the total distance of UAV traversing all targets in clockwise direction and counterclockwise direction respectively. Then we can select the correct edge need to be cut.

Considering the working pattern of the optical sensor. The working pattern of the optical sensor is different from the imaging sensor. Optical sensor can take pictures of targets when the distance between UAV and targets does not exceed rs_2 km. While the UAV cruise flight height is h, so this paper will take the projection distance k as the effective range of optical sensor shooting range, as shown in Fig. 6.

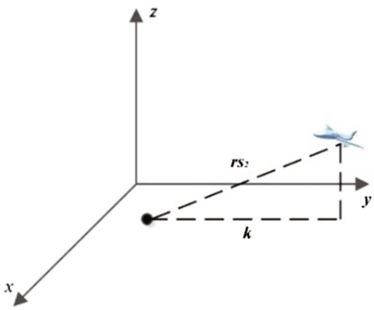

Fig. 6. The working pattern of optical sensor

Thus, when the target in the target group falls in the circle, of which center is the UAV and radius is k, the UAV can take photos of them all at once.

3.2 Genetic Algorithm for Calculating the UAV Flight Distance Between Target Groups

Encoding. According to the characteristics of this problem, this paper designed a two-part chromosome, that is, divided an individual chromosome into two parts. The length of the first part is n, which represents the feasible sequence of a group of UAV scouting target groups. The length of the rear part is m, which indicates the number of target groups should be scouted by each UAV base. The rear part and the front sequence corresponds in the same order from left to right. Thus, the length of the chromosome is $n + m$. To be more specific, an example of chromosome is shown in Fig. 7.

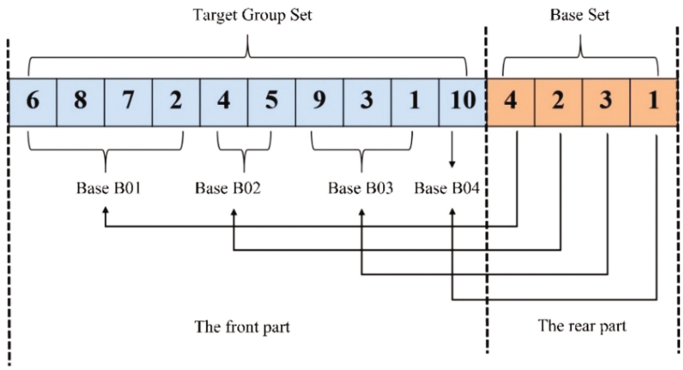

Fig. 7. The structure of two-part chromosome

In Fig. 7, the UAVs from base 1 scout four target groups, which are numbered 6, 8, 7, 2. And the UAVs from base 2 scout two target groups, which are numbered 4 and 5, while base 3 scout three target groups, which are numbered 9, 3 and 1. The remaining target groups numbered 10 is scouted by the UAVs from base 4. In particular, when the value of a position at the rear is 0, it indicates that the base does not dispatch the UAV.

Fitness function. In the fitness function, q_1, q_2, q_3, q_4 represent the value of the rear part coding. And $D_{t_i t_{i+1}}$ represents the distance between target t_i and t_{i+1}. So the fitness function of the individual is:

$$fitness = \frac{1}{\sum_{0}^{q_1-1} D_{t_i t_{i+1}} \sum_{q_1}^{q_1+q_2-1} D_{t_i t_{i+1}} + \sum_{q_1+q_2}^{q_1+q_2+q_3-1} D_{t_i t_{i+1}} + \sum_{q_1+q_2+q_3}^{n-1} D_{t_i t_{i+1}} + \sum_{i \in B} 2r_a} \quad (13)$$

And it is worth mentioning that fitness function (9) and (13) is used to evaluate the performance of individuals in population of genetic algorithm. These two fitness functions are all parts of the objective function and are essential to it.

Crossover. The crossover operations of the front part and rear part are carried out separately. The method is as same as described in Sect. 3.1.

Mutation. The mutation operation of the front part is as same as the previous one. As shown in Fig. 8, in order to ensure the diversity of offspring chromosomes, the rear part of the chromosome carried out two kinds of mutation operations, which may occur in the same possibilities.

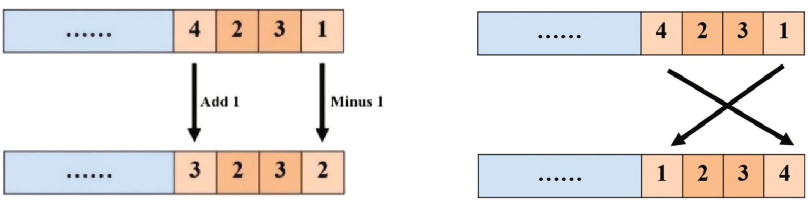

Fig. 8. The mutation operation in genetic algorithm based on two-part chromosome

4 Case Study

The case we studied in this paper is based on the problem description in Sect. 2. A simulated battlefield scenario is designed. The UAVs of attack side perform renaissance mission on the targets of defensive side, at the same time, in order to combat UAV, the defender also set the radar to detect the UAVs of attack side.

4.1 Case Generation

The coordinates of the bases and the number of UAVs equipped with each base is shown in Table 1.

Table 1. The situation of each UAV base

Name of base	Coordinates(Km)	The number of UAVs
Base B01	(368,319)	2
Base B02	(392,220)	2
Base B03	(392,275)	2
Base B04	(256,121)	2

Ten target groups of defensive side are generated and contain 68 targets. Each target group equipped with one radar station, and the detection radius of radar r_a = 70 km. The distribution of bases, targets and radars is shown in Fig. 9. The red circle is the detection range of radar station

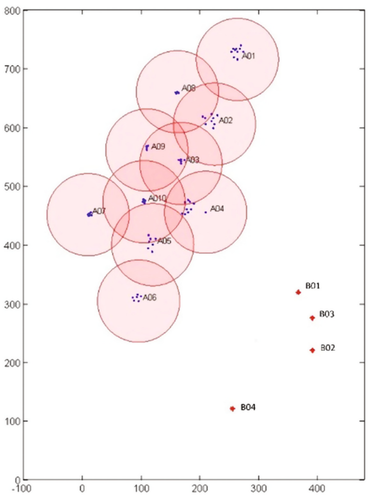

Fig. 9. The distribution of bases, targets and radars. The red circle is the detection range of radar station (Color figure online)

The flight parameters of UAV is shown in Table 2. And the parameter of genetic algorithm used in this paper is shown in Table 3. N_{pop} is the number of individuals in each generation, N_{gen} is the generation of both two genetic algorithms designed in this paper, p_c is the crossover probability, and p_m is the mutation probability

Table 2. The parameters of UAV

Parameter	Value (unit)	Parameter	Value (unit)
vf	200 km/h	AB_{min}	2 km
T_{max}	10 h	AC_{max}	8 km
h	1.5 km	rs_2	7.5 km

Table 3. The parameters of genetic algorithm

Parameter	N_{pop}	N_{gen}	p_c	p_m
Value	100	300	0.9	0.1

4.2 Results and Analyze

The proposed solving method is verified by using PYTHON code running on a PC with an Intel Core i7 processor operating at 3.30 GHZ. We repeated the experiment 5 times, and one of the results is shown as follows.

When performing cutting edge, the total distance of UAV traversing targets in each target group in clockwise direction and counterclockwise direction is shown in Table 4. $L_{end}^{clockwise}$ is the end edge of UAV flight routine when it traversing targets in a target group in clockwise direction, and $D_{clockwise}$ is the total distance after cutting edge under this situation. While $L_{end}^{counter}$ is the end edge of UAV flight routine when it traversing targets in a target group in counterclockwise direction, and $D_{counter}$ is the total distance after cutting edge under this situation.

Table 4. Table of the discussion on cutting edges

Name of target group	Number of targets	$L_{end}^{clockwise}$	$D_{clockwise}$	$L_{end}^{counter}$	$D_{counter}$
A01	10	16.4	59.14	7.21	68.33
A02	7	7.07	77.25	7.28	77.04
A03	5	8.49	18.67	4	23.16
A04	10	25	84.76	25.5	84.26
A05	7	11.18	57.95	12.04	57.09
A06	6	8.94	31.35	8.06	32.23
A07	6	2.24	16.77	2.83	16.18
A08	5	1.41	11.19	2.83	9.77
A09	5	7.28	9.40	2	14.68
A10	5	2.24	13.85	2	14.09

From Table 4, we can get the total length of route for UAV in clockwise direction is 380.33 km, while the total length of route for UAV in counterclockwise direction is 396.83 km. So UAV should fly in clockwise direction in each target group, and the imaging sensor should load on the left side of UAV. The final optimized distance of UAV traversing targets in each target group is shown in Table 5.

Table 5. Final optimized distance of UAV traversing targets in each target group

Name of target group	Final optimized distance (Km)	Name of target group	Final optimized distance (Km)
A01	47.40	A06	19.43
A02	56.65	A07	8.02
A03	10.21	A08	5.54
A04	70.06	A09	5.56
A05	43.63	A10	5.04

And Fig. 10. is the line chart compares the total distance of ignoring the working principle of imaging sensor and considering the working pattern of imaging sensor.

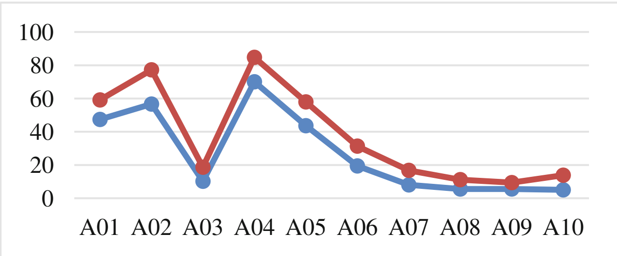

Fig. 10. The line chart compares the total distance of ignoring the working principle of imaging sensor and considering the working pattern of imaging sensor. The black line is the distance ignoring the working principle of imaging sensor, and the red line is the distance considering the working pattern of imaging sensor (Color figure online).

It is clearly that the length of route is shorter when taking the working pattern of imaging sensor into account. Considering the working pattern of optical sensor, the targets in target group A03,A07,A08,A09,A10 can be imaged once by optical sensor. And the optimized length of route for UAV carrying optical sensor traversing targets in each target group is shown in Table 6.

Table 6. The optimized length of route for UAV carrying optical sensor traversing targets in each target group

Name of target group	Final optimized distance (Km)	Name of target group	Final optimized distance (Km)
A01	47.40	A06	19.43
A02	56.65	A07	0
A03	0	A08	0
A04	70.06	A09	0
A05	43.63	A10	0

Then, the schedule table of UAVs is shown in Table 7.

Table 7. The schedule table of UAVs

UAV	Base	Flight route
v_1^{11}	B01	B01->A04->A03->A09->A08->A02->A01->B01
v_2^{12}	B01	B01->A04->A03->A09->A08->A02->A01->B01
v_1^{41}	B04	B04->A06->A05->A10->A07->B04
v_2^{42}	B04	B04->A06->A05->A10->A07->B04

As shown in Table 7, four UAVs needed to finish the simulated case. And two UAVs from the same base fly in formation, loading imaging sensors and optical sensors respectively. The takeoff time interval $T_{interval}$ between two UAVs from one base is 3 min. The UAVs flight routine and the length of UAV flying between different target groups is shown in Fig. 11.

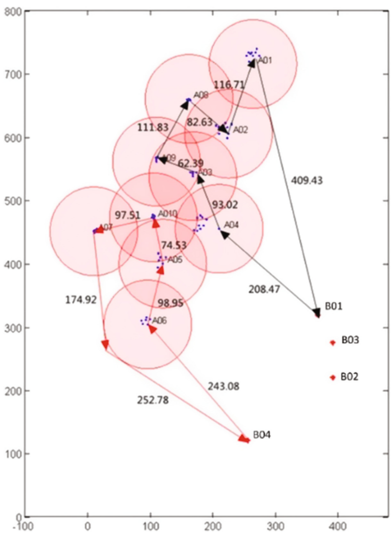

Fig. 11. The map of UAVs flight routine

And the minimum total distance of four UAVs staying in the detection range of radar is 2545.03 km. The schedule plan of UAVs of five experiments are same, and the total distances of five times experiments is shown in Table 8, and it verifies that the algorithms designed in this paper is relative stable.

Table 8. The results of five times experiments

Experiment	1	2	3	4	5
Total distance (km)	2545.03	2540.71	2545.03	2545.03	2540.71

5 Conclusion

Nowadays, multi-UAV cooperative control is one of the hot issues studied in the area of multi-robots system, which has great practical and academic influence in both military and civil aspect [13]. And this paper built a multi-base, multi-target, multi-load, multi-UAV cooperative task model and used genetic algorithm to solve the problem scenario. A simulated case is built and used the solving method proposed in this paper, we can get that the imaging sensor should be loaded on the left side of UAV, and when traversing targets in a target group, UAV should fly in clockwise direction. There are four UAVs needed to complete the simulated case and the average minimum total distances when UAVs stay in the detection range of radars is 2543.3 km. It is proved that the solving method proposed in this paper is feasible and stable.

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