Unmanned Aerial Vehicle (UAV) Cooperative Mission Planning

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To cite this article:
Le Yu, Qian Liu. Unmanned Aerial Vehicle (UAV) Cooperative Mission Planning. American Journal of Engineering and Technology Management. Vol. 2, No. 4, 2017, pp. 36-44. doi: 10.11648/j.ajetm.20170204.11

Received: March 27, 2017; Accepted: April 12, 2017; Published: October 24, 2017

Abstract: Unmanned Aerial Vehicle (UAV) is a kind of new operational platform possessing ability to flight autonomously and perform independently a task, which can not only carry out non-attack tasks, such as military reconnaissance, surveillance and search, but also to carry out tasks to air-to-ground attacking, target bombing and so on. With the rapid development of UAV technology, more and more UAV will be applied in the future battlefield. An UAV combat troops have seven UAV bases, which are from P01 to P07. Every base has some FY-1 type UAVs. At the same time, FY-1 UAV can be loaded by two kinds of load, which are S-1 and S-2. Now we need to achieve the aim to detect 10 target groups from A01 to A10, which are total 68 goals. And each target group has radar station. Under the above condition, this paper makes the best plan for the UAV combat troops, and uses FY-1 UAV to find best route and scheduling strategy of UAV, which including each UAV drone off base, loading, departure time, track and target reconnaissance. The goal is to ensure minimum time summation in an effective probe range to stay defense radar for UAV. First of all, this paper considers only four UAV bases with FY-1 UAV, so the 68 targets are divided into four regions by K-means algorithm; Then the global shortest path model is established, when the local route is the shortest. The route is drawn according to the route. According to the former route, the general shortest path model is established. It is composed of shortest route distance and the distance from UAV to the corresponding area. And then this paper determine which base the UAV will go to. Finally, the minimum time is calculated as 17.52h. The eight UAVs are arranged in this process, which are composed of four UAVs with S-1 and four UAVs with S-2. The UAVs are offered by P01, P03, P05 and P07.

Keywords: Multi UAV Cooperative, Task Planning, K-Means Algorithm, Dynamic Time Window

1. Introduction

Unmanned Aerial Vehicle (UAV), is a unmanned plane to use wireless remote control equipment and own program control device to control oneself, which installment Autopilot, program control device, etc. Ground control station personnel use transmitting station device to tracking, positioning, remote control, telemetry and digital transmission for UAV [1]. UAV can take off like ordinary plane under the wireless remote control or be used launching cradle to blast off in the military, the UAVs not only are widely used and low cost, but also has the advantages of no casualties risk and great viability [2]. UAV plays a very important role in the modern war, and has broad prospects in the civil field.

Unmanned Aerial Vehicles have great significance to the future air combat. Therefore the world's major military countries are stepping up the development of UAV. However, the route and operational strategy of UAV are the key factors that affect the operation of UAV directly. The key factor to the successful completion of the combat mission are a reasonable running route and detection of a target. Therefore, this paper used a specific example to build model and design reasonable flight path and strategy, which provided a new operation scheme for UAV application in military. This is the significance of the paper.

2. Restatement of the Problem

UAV combat troops have P01–P07 7 UAV bases. Each base have some FY-1 UAV (The specific coordinates and number of each base can be seen in Table 1. The location diagram can be seen in Figure 1). The main purpose of the FY-1 UAV is the target reconnaissance and target indication. Its cruising speed is 200km/h, the longest cruise time is 10h,
the cruising altitude is 1500m; Due to the lack of fuels, UAVs try to reduce the turning, climbing, diving and other maneuvers during the flight. In general, Fuel consumption of maneuvering are 2 ~ 4 times bigger than cruise. The minimum turning radius is 70 m.

FY-1 UAV can load S-1 and S-2. The load S-1 imaging sensor uses the wide area search mode to image the target, and the imaging bandwidth of the sensor is 2km; Load S-2 is optical sensor, in order to achieve a certain target recognition accuracy, when the ground target requires no more than 7.5km distance from the camera, the camera can be completed immediately. Due to the limitations of various technical conditions, FY-1 UAV can be loaded one of S-1 and S-2. To ensure the effectiveness of the reconnaissance, S-1 and S-2 should be arranged to detect at least once for every target. Investigation interval time of two different loads on the same target is not more than 4 hours. When the two FY-1 UAVs fly in the air, the distance are more than 200m. Due to the limitations of the base logistics technical support, the two UAVs time interval of take-off and descent on same bases are more than 3 minutes. UAV needs to return to the original base after the completion of the mission.

FY-1 UAV is now required to complete the reconnaissance targets such as A01~A10 10 target groups. Each group contains the number of ground targets, a radar station for each target group are assigned (The location of the targets and the radar of each target group is shown in Figure 1. The specific coordinates are shown in Table 2). The effective detection range of the radar target group on FY-1 are 70km. But once the reconnaissance UAV enter into radar detection range of defending a target group. The radar of ten targets works for alert and search targets and take the corresponding measures, including missiles launched to destroy UAV etc. Therefore, the longer the reconnaissance UAV detained the defense radar detection range, the greater the likelihood of its destruction. To complete the reconnaissance mission of FY-1 UAV to 10 target groups (a total of 68 targets). This paper needs to find best route and scheduling strategy of UAV (including each UAV drone off base, loading, departure time, track and target reconnaissance). The goal is to ensure minimum time summation in an effective probe range to stay defense radar for UAV.

![Figure 1. Schematic diagram of target groups and UAV bases.](image)

**Figure 1. Schematic diagram of target groups and UAV bases.**

| Base name | P01   | P02   | P03   | P04   | P05   | P06   | P07   |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| (X, Y)(unit: km) | (368, 319) | (264, 44) | (392, 220) | (360, 110) | (392, 275) | (296, 242) | (256, 121) |
| The quantity of FY-1 | 2 | 0 | 2 | 0 | 2 | 0 | 2 |

**Table 1. Coordinate and FY-1 attachment quantity of UAV bases.**

| Pointname | (X, Y) (unit: km) | Remarks | Point name | (X, Y) (unit: km) | Remarks |
|-----------|------------------|---------|------------|------------------|---------|
| Target group A01 | Target group A05 | Radar station | A0101 | (264, 715) | A0501 | (120, 400) | Radar station |
| A0102 | (258, 719) | A0502 | (119, 388) |
| A0103 | (274, 728) | A0503 | (112, 394) |
| A0104 | (264, 728) | A0504 | (125, 410) |
| A0105 | (254, 728) | A0505 | (114, 405) |
| A0106 | (257, 733) | A0506 | (116, 410) |
| A0107 | (260, 731) | A0507 | (113, 416) |
| A0108 | (262, 733) | | | | | |
| A0109 | (268, 733) | Target group A06 | | | | |
| A0110 | (270, 739) | | A0601 | (96, 304) | | Radar station |
| A0111 | | A0602 | (88, 305) |
| Target group A02 | | A0603 | (100, 312) |
| A0201 | (225, 605) | Radar station | A0604 | (93, 311) | | |
| A0202 | (223, 598) | | A0605 | (86, 310) | | |

**Table 2. Target and radar station location.**
### 3. Problem Analysis

Under the requirements of the problem, this paper solves that FY-1 completes ten target groups task of investigation. Radar of 10 target groups in the range of detection rangesearch and destroy the UA V. Therefore, the goal is to ensure that the UA V stayed in the radar detection range for a little time to arrange UA V of the seven bases to complete the task of investigation. In this process, this paper first divides the 10 target groups into the following four areas by using the K-means algorithm in this paper. Then FY-1 UA V on four bases are assigned to each region to perform tasks. At the same time, by understanding the imaging range and bandwidth requirements of the imaging sensor S-1 and the camera range of the optical sensor S-2, the optimal position of the UA V is determined. Next, the shortest path is used to determine the best path in each region [3]. Finally, time limit, detection time interval on the same goal and combat radius of the two UA Vs in a same base are considered, which concluded the scheduling strategy and the best way to solve the above problems.

### 4. Basic Assumptions

1. Assuming that the UAV does not take into account the maneuver, such as turning, climbing and diving;
2. Assuming that the FY-1 UAV payload can be completed immediately to take the photo reconnaissance mission;
3. Assuming that the FY-1 UAV is not destroyed in the radar detection range.

### 5. Model Development

#### 5.1. Building a Model

Before establishing the model, the necessary symbols are defined as follows:
- \(i\)-The ith base \((i=1,\ldots,7)\)
- \(j\)-The jth target \((j=1,\ldots,68)\)
- \(N\)-Number of UAV
- \(M\)-Number of tasks to be performed
- \((X_i,Y_i)\)-Location coordinates of base i
- \((x_j,y_j)\)-Location coordinates of target j

| Point name | (X, Y) (unit: km) | Remarks | Point name | (X, Y) (unit: km) | Remarks |
|------------|--------------------|---------|------------|--------------------|---------|
| A0203      | (210, 605)         |         | A0606      | (94, 315)          |         |
| A0204      | (220, 610)         |         |            |                    |         |
| A0205      | (223, 615)         |         |            |                    |         |
| A0206      | (209, 615)         |         | Target group A07 | (X, Y) (unit: km) | Remarks |
| A0267      | (230, 620)         |         | A0701      | (10, 451)          | Radar station |
| A0208      | (220, 622)         |         | A0702      | (11, 449)          |         |
| A0209      | (205, 618)         |         | A0703      | (13, 450)          |         |
| A0207      | (210, 655)         |         | A0704      | (16, 450)          |         |
| A0203      | (168, 538)         | Radar station | A0705      | (12, 453)          |         |
| A0202      | (168, 542)         |         | A0706      | (15, 455)          |         |
| A0203      | (164, 544)         | Target group A08 | A0701      | (162, 660)         | Radar station |
| A0204      | (168, 545)         |         | A0801      | (161, 659)         |         |
| A0205      | (174, 544)         |         | A0802      | (159, 659)         |         |
| A0206      | (168, 554)         |         | A0803      | (160, 657)         |         |
| Target group A04 |         |         | A0804      | (164, 658)         |         |
| A0401      | (210, 455)         | Radar station | A0805      | (164, 658)         |         |
| A0402      | (180, 455)         |         | A0901      | (110, 561)         | Radar station |
| A0403      | (175, 452)         |         | A0902      | (110, 563)         |         |
| A0404      | (170, 453)         | Target group A09 | A0903      | (110, 565)         |         |
| A0405      | (185, 460)         |         | A0904      | (109, 567)         |         |
| A0406      | (178, 460)         |         | A0905      | (112, 568)         |         |
| A0407      | (190, 470)         |         | A0906      | (112, 568)         |         |
| A0408      | (183, 473)         |         | A0907      | (112, 568)         |         |
| A0409      | (175, 472)         |         | A0908      | (112, 568)         |         |
| A0410      | (180, 476)         |         | A0909      | (112, 568)         |         |
| A0411      | (185, 478)         |         | A1001      | (105, 473)         | Radar station |
| A0412      | (190, 476)         |         | A1002      | (106, 471)         |         |
| A0413      | (195, 478)         |         | A1003      | (103, 473)         |         |
| A0414      | (200, 478)         |         | A1004      | (107, 475)         |         |
| A0415      | (205, 478)         |         | A1005      | (112, 477)         |         |
dij - The distance between the base i and the target j.

$t_i^r$ - The takeoff time of the base FY-1 UAV

$t_i^f$ - The landing time of the base FY-1 UAV

Other models involved in the many parameters and symbols are not listed, but in each calculation of the specific explanation below.

In this paper, the target of multi UAV cooperative task allocation is to make the time of multi UAVs within the effective detection range in defense radar are as short as possible. That is, UAVs were assigned the task, stayed in the range for a little time. So the objective function is as follows:

$$\text{Min } T = \sum_{i} \sum_{j} T_{ij}$$

### Inequality Constraints

- The number of the UAVs should not exceed the number of targets: 
  $$\sum x_i \leq N$$

- The distance between two targets:
  
  $$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

- The two UAVs take-off time interval and the time interval in the same base are not more than 3 minutes: 
  $$t_{i}^{r} - t_{i}^{f} > \frac{3}{60}$$
  $$t_{i}^{f} - t_{i}^{r} > \frac{3}{60}$$

- The time interval between two different loads for the same target are not more than 4 hours: 
  $$t_{i}^{r} - t_{i}^{r} < 4$$

### Cluster Algorithm

By the principle of K-means algorithm [6], we used the C language to divided the 68 targets into four regions. Each region contains the number of targets were 14, 24, 10, 20 respectively. The results as shown in the following figure:

- The longest cruising time of FY-1 UAV is 10h, 
  $$t_{f}^{u} - t_{f}^{u} \leq 10$$

5.2. Resolve the Model

By the principle of K-means algorithm [6], we used the C language to divided the 68 targets into four regions. Each region contains the number of targets were 14, 24, 10, 20 respectively. The results as shown in the following figure:
Now there are four FY-I UAV bases with one by one correspondence regions. The shortest distance between them can be assigned as follows: arranging P01 UAV to the blue area of the above, P03 UAV to the red area, P05 UAV to light blue area, P07 UAV to the green area.

By the imaging range of the load S-1 and the camera scope of the S-2, the most appropriate location away from the target is R2=42-1.52. Thus UAV tracks are determined. According to the above analysis and data, using MATLAB programming, the circle is painted [7-9]. Coordinate is the center of the circle. UAV reach once the point of circle to finish successfully the task on a point of circle.

In each area, the shortest path is the path of the UAV when it flights according to the tangent of circle of each target detection range and the intersection location of the two targets [10]. Thus, the track and the shortest path in the four regions are obtained:
For the base P01, arranging for the investigation of the specific area of FY-1 UAV reconnaissance blue area as shown below:

The UAV from the base (368,319) - (224,601.6) - (213,611.5) - (227,618) - (216,5,622) - (208,619) - (210,608) - (161,657) to search something, and return base after the task. This is the shortest path. And the shortest distance is 846km.

For the base P03, arranging FY-1 UAV to detect the red area. The specific track as shown below:

Figure 4. Regional internal track.

Figure 5. Blue area track.

Figure 6. Red area track.
The UAV from the base (392,220) - (208,458) - (192,467) - (179,473) - (178,473) - (183,458) - (177,56) - (176,455) - (172,450) - (103,476) - (113,562) - (113,564) - (112,568) - (110,571) - (114,571), (165,543), (171,544), (171,540) to search something, and return base after the task. This is the shortest path. And the shortest distance is 997.2km.

For the base P05, arranging FY-1 UAV to detect the blue area. The specific track as shown below:

![Light blue area track.](image)

The UAV from the base (392,275) - (261,717) - (257,730) - (265,731) - (270.5,735.6) - (271,730) to search something, and return base after the task. This is the shortest path. And the shortest distance is 967.8km.

For the base P07, arranging FY-1 UAV to detect the green area. The specific track as shown below:

![Green area track.](image)

The UAV from the base (256,121) - (98,301) - (89,308) - (97,314) - (116,386) - (110,397) - (122,403) - (117,407) - (122,411) - (114,419) - (103,449) - (14,453) - (10.5,452.5) to search something, and return base after the task. This is the shortest path. And the shortest distance is 924km.

Because there are 10 radar detectors in 68 goals. The detection distance is 70km. Detection scope can be detected by the radar. The scope can be seen by the following figure. (Yellow part of the map is the base position):
It can be concluded that the distance from the base to each region and the UAV’s distance from the radar detection range are as follows [11]:

Because the longest cruise time of type FY-1 is 10h. The flight speed is 200km/h, so the maximum flight distance of the FY-1 UAV is 2000km. At the same time, from the above data and analysis, the distance traveled by the base to each area is less than the maximum flight distance. That is, each region only sent a S-1 carrying UAVs and a carrier carrying S-2 UAV complete only the task from the base.

The chart can be calculated. The total distance of radar detection range in each region were 402.73km, 539.62km, 235.48km, 574.2km. So the minimum time summation in the range of detection is 17.52h.

6. Results and Analysis

To sum up, to successfully complete the task of investigation and time summation UAV stayed in the range of detection are little [12]. This problem needs 8 FY-1 UAVs, which are provided 2 respectively by the base P01, P03, P05, P07.

The first FY-1 carries S-1, the second FY-1 carries S-2. For the same base, after the first UAV took off for 3min,

The second UAV carrying S-2 took off. This ensures that each UAV can meet all the time constraints. The two UAVs detection target of base P01 are A0201, A0202, A0203, A0205, A0206, A0207, A0208, A0204, A0209, A0801,
A0802, A0803, A0804, A0805; The two UAVs detection goals of base P03 are A0301, A0302, A0303, A0304, A0305, A0401, A0402, A0403, A0404, A0901, A0405, A0902, A0406, A0903, A0407, A0904, A0408, A0905, A0409, A1001, A1003, A1004, A1005; The two UAVs detection goals of base P05 are A0501, A0502, A0503, A0504, A0505, A0506, A0602, A0603, A0604, A0605, A0606, A0701, A0702, A0703, A0704, A0705, A0706, A1002, A0601. At present, the minimum time is 17.52h.

7. Evaluation and Improvement of the Model

7.1. Strengths of the Model

(1) In the model design, this paper considers the shortest time of flight of UAV, UAV total flight time, multi UAV best route and investigation target coverage degree. This paper considers the number of the UAV, UAV combat radius, the number of combat tasks, task load, high degree of base location, the position of the target audience to build model. It has the feasibility and applicability of the high.

(2) Planning missions in some typical conditions, combining with actual situation, the factors considered comprehensively. The model is reasonable, the algorithm is complete. And the algorithm result can reflect the specific impact of distance, task time, target value for task allocation.

7.2. Weaknesses of the Model

Because the variables involved in this paper are too many, the situation is more complex, the main problem is to extract the main analysis of the thinking, weakening the impact of certain variables, so the accuracy of the results are decline. At the same time, the algorithm optimization is simple, the details of the modification is not perfect, which did not achieve the desired results.

7.3. Improvement of the Model

(1) Multi UAV cooperative operation requires that each UAV’s flight route is the best. In this paper, this paper can not obtain the optimal multi route for the cooperative reconnaissance mission, and also need to modify the model and the algorithm to meet the requirements of multi UAV cooperative mission;

(2) In the scenario assumptions and model assumptions, the assumptions and indicators are still too simple to implement some complex scenarios. So we need more complex conditions and tasks to improve.

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