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The Air Combat Task Allocation of Cooperative Attack for Multiple Unmanned Aerial Vehicles

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Abstract

The problem of Multi-UAV cooperative air combat task assignment is a hot research issue in the field of UAV at present. This paper presents a new method of multi-UAV cooperative air combat task allocation. Firstly, the capability function and Jacobian matrix of UAV are established, and then the calculation method of multi-UAVs cooperative combat position is presented. After that, through analyzing the air combat situation of the UAV and the combat earnings of the combat position, the model of multi-UAV cooperative air combat task allocation is established, and a new method for multi-UAV cooperative air combat task allocation is presented. Finally, the simulation experiment is conducted, the result of simulation shows that the method that considering multi-UAVs cooperative task allocation capabilities gets more profit and damage efficiency of the targets, and improves the capability of multi-UAVs cooperative combat, which compared with the collaborative capability is not considered.

***Keywords**:* Multiple unmanned aerial vehicles; capability function; the collaborative task allocation; Jacobian Matrix

1. Introduction

With the increasing complexity of the combat environment, the combat missions of UAVs are also have increasingly diversified. The multi-UAV work together can attack more than one target, and improve the probability of destruction. So it will become the main trend of the air combat in the future. The cooperative engagement of multiple unmanned aerial vehicles refers to the mutual cooperation of two or more fighters in a task [1]. The most significant difference between multi-UAV and one by one combat is to assign targets and firepower according to our resources when faced with multiple tasks. However, one of the key issues is the problem of proper coordination between the multi-UAV in a task [2]. So it's a hot topic that how to make a reasonable decision which UAVs could accomplish complex coordination task in the field of UAV research [3]. At present, the research that the air combat task allocation of multiple unmanned aerial vehicle cooperative attack has made some valuable research results [4-7]. In [4], an air combat decision making model for single UAV against single UAV in uncertain condition was built up based on multistage influence diagram, and the maneuver decisions of the cooperative air combat for UAVs were effectively solved. In [5], a new algorithm is put forward according to the questions of multiple unmanned aerial vehicles cooperative attacking beyond over-the-horizon condition, through the data chain information sharing of multiple unmanned aerial. In [6], an analytical method for multi-UAV cooperatively attacking multiple targets in an uncertain environment was presented, the air combat situation under uncertain environment was analyzed, and the task allocation model was established. Then the ACBAA (asynchronous consensus-based auction algorithm)

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algorithm was proposed. In [7], a new analytical method for multiple UAV cooperatively attacking multiple targets was given, and then a method for multi-UAV cooperatively air combat decision making based on DIAA was proposed. However, in the prior literature, two factors that cooperative combat ability of multi-UAV and the value of the ability that the target was required are not in the model. So the model is not perfect.

Currently, the research of considering the capability function of robot in the task allocation of multi-robot has attracted the attention of scholars [8-9]. In [8], a task allocation of multi-robot system based on the utility function was proposed, the mathematical model of the utility function was established based on the vector of the robot's capability and the vector of capability that the subtasks required, then make the task assignment according to the size of the utility function. In [9], a new method of the task allocation of multi-robot system based on the utility function of robot was proposed. But so far, the papers about the task assignment related to the capability function of the multi-UAV cooperative combat task haven't been reported in the literature. This paper proposes the method of calculating the positions of multi-UAV cooperative combat and the method of multiple unmanned aerial vehicle cooperative air combat task allocation.

2. The Establish of Capability Function of the UAV

The capability function reflects the capability of UAV attack to the target, and it's based on the requirements and form of the task. The capability function is related to the factors such as the distance and azimuth between UAVs and targets. The capability function of multi-UAV is the sum of the capability function of the single UAV. In order to simplify the analysis, we assume that the capability function is only related to the distance between UAV and the target, when the distance between the UAV and the target meet the requirements, the maximum capability value of the UAV will be achieved. The information of the position of UAV is stored in the $n \times 3$ matrix, n indicates the number of UAV. The information of the position of targets is stored in the $n \times 3$ matrix, m indicates the number of targets. The initial position matrix of the UAV and target is described as

$$P_{\mathrm{UAV}} = \begin{bmatrix} X_{U1} & Y_{U1} & Z_{U1} \\ X_{U2} & Y_{U2} & Z_{U2} \\ \vdots & \vdots & \vdots \\ X_{UN} & Y_{UN} & Z_{UN} \end{bmatrix} \qquad P_{\mathrm{target}} = \begin{bmatrix} X_{T1} & Y_{T1} & Z_{T1} \\ X_{T2} & Y_{T2} & Z_{T2} \\ \vdots & \vdots & \vdots \\ X_{TN} & Y_{TN} & Z_{TN} \end{bmatrix} \tag{1.1}$$

The distance d_{ij} between UAV i and target j is described as

$$d_{ij} = \sqrt{\left(X_{Ui} - X_{Tj}\right)^2 + \left(Y_{Ui} - Y_{Tj}\right)^2 + \left(Z_{Ui} - Z_{Tj}\right)^2} \tag{1.2}$$

Assume that the combat radius of UAV is D_i, the maximum capacity of the function is 1, the capacity function of the i-th target is described as C_i,

$$C_i = \begin{cases} D_i / d_{ij}, \forall d_{ij} \geq D_i \\ d_{ij} / D_i, \forall d_{ij} < D_i \end{cases} \tag{1.3}$$

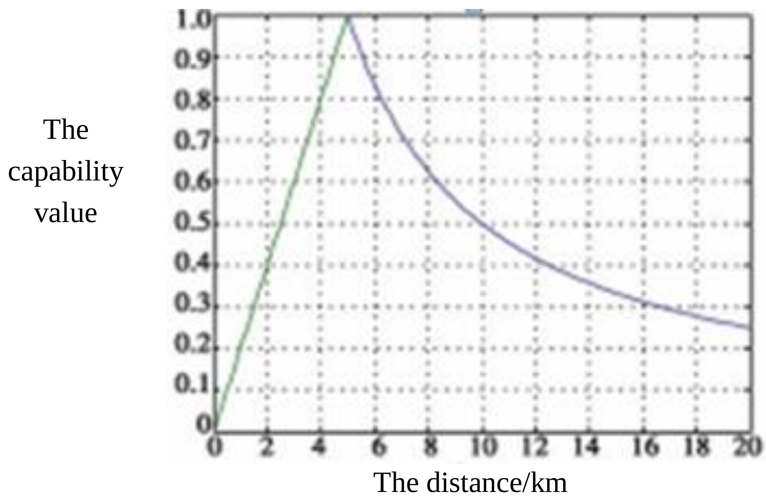

Figure 1. The curve of the Capability Function of UAV

Assume that the radius of tactical reconnaissance of UAV is 4.5km, in Figure 1, the capability decreases with the increasing of the distance, when the distance between the UAV and the target is more than 4.5km, and the capability increases with the decreasing of the distance, when the distance between the UAV and the target is less than 4.5km.Only when the distance between the UAV and the target is more than 4.5km, the maximum capacity value of the UAV will be achieved.

2 The Calculation of the Distance between the Combat Position of Multi-UAV Cooperative and the Position of the Target

2.1. The Jacobian Matrix

For the UAV, in order to complete the task more effectively, we need to analyze that the relationship between the changes of the UAV's position and the ability that the target is required.

So the Jacobian matrix of the capability function is established as follow.

$$J_{Jacobi}=\begin{bmatrix} \frac{\partial C_1}{\partial X_{U1}} & \frac{\partial C_1}{\partial Y_{U1}} & \frac{\partial C_1}{\partial Z_{U1}} \cdots & \frac{\partial C_1}{\partial X_{Un}} & \frac{\partial C_1}{\partial Y_{Un}} & \frac{\partial C_1}{\partial Z_{Un}} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial C_m}{\partial X_{U1}} & \frac{\partial C_m}{\partial Y_{U1}} & \frac{\partial C_m}{\partial Z_{U1}} \cdots & \frac{\partial C_m}{\partial X_{Un}} & \frac{\partial C_m}{\partial Y_{Un}} & \frac{\partial C_m}{\partial Z_{Un}} \end{bmatrix} \tag{2.1}$$

Besides,

$$\frac{\partial C_j}{\partial X_{Ui}}=\begin{cases} \dfrac{-D_i * X_{Ui}}{\left[\left(X_{Ui}-X_{Tj}\right)^2+\left(Y_{Ui}-Y_{Tj}\right)^2+\left(Z_{Ui}-Z_{Tj}\right)^2\right]^{3/2}}, d_{ij}>D_i \\ \dfrac{X_{Ri} * \left[\left(X_{Ui}-X_{Tj}\right)^2+\left(Y_{Ui}-Y_{Tj}\right)^2+\left(Z_{Ui}-Z_{Tj}\right)^2\right]^{-1/2}}{D_i}, d_{ij}<D_i \end{cases} \qquad ((2.2)$$

$$\frac{\partial C_j}{\partial Y_{Ui}}=\begin{cases} \dfrac{-D_i * Y_{Ui}}{\left[\left(X_{Ui}-X_{Tj}\right)^2+\left(Y_{Ui}-Y_{Tj}\right)^2+\left(Z_{Ui}-Z_{Tj}\right)^2\right]^{3/2}}, d_{ij}>D_i \\ \dfrac{Y_{Ri} * \left[\left(X_{Ui}-X_{Tj}\right)^2+\left(Y_{Ui}-Y_{Tj}\right)^2+\left(Z_{Ui}-Z_{Tj}\right)^2\right]^{-1/2}}{D_i}, d_{ij}<D_i \end{cases} \tag{2.3}$$

$$\frac{\partial C_j}{\partial Z_{Ui}}=\begin{cases}\dfrac{-D_i * Z_{Ui}}{\left[\left(X_{Ui}-X_{Tj}\right)^2+\left(Y_{Ui}-Y_{Tj}\right)^2+\left(Z_{Ui}-Z_{Tj}\right)^2\right]^{3/2}}, d_{ij}>D_i \\ \dfrac{Z_{Ri} * \left[\left(X_{Ui}-X_{Tj}\right)^2+\left(Y_{Ui}-Y_{Tj}\right)^2+\left(Z_{Ui}-Z_{Tj}\right)^2\right]^{-1/2}}{D_i}, d_{ij}<D_i\end{cases} \tag{2.4}$$

2.2. The Calculation of the Combat Position of Multi-UAV Cooperative

The capability function is determined by the position of the UAV, and the relationship between the position and the change of the capability function as follow.

$$\left[\dot{C}_1 \cdots \dot{C}_m\right]^{T}=J_{Jacobi} * \left[\dot{X}_{U1} \quad \dot{Y}_{U1} \quad \dot{Z}_{U1} \quad \cdots \quad \dot{X}_{Un} \quad \dot{Y}_{Un} \quad \dot{Z}_{Un}\right]^{T} \tag{2.5}$$

Assume that the ideal capability that the target j needed is C_j^d, and the ideal change of the capability function is equal to the difference between the current capability value C_j and the ideal capability value C_j^d. If the number of UAVs is n and the number of targets is m, the ideal capability value that every target got is n/m. To pre-allocate the UAV according to the strategies of UAVs to get the corresponding $C_k^1, C_k^2, \ldots C_k^m$ (C_k^m is the capability value of the *m*-th target in the *k*- th allocation scheme) as shown in (2.6)

$$\left[\dot{X}_{U1} \quad \dot{Y}_{U1} \quad \dot{Z}_{U1} \quad \cdots \quad \dot{X}_{Un} \quad \dot{Y}_{Un} \quad \dot{Z}_{Un}\right]^{T}=J_{Jacobi}^{+} * \left(\begin{bmatrix}C_1^d \\ \vdots \\ C_m^d\end{bmatrix}-\begin{bmatrix}C_k^1 \\ \vdots \\ C_k^m\end{bmatrix}\right) \tag{2.6}$$

J_{Jacobi}^{+} is the pseudo inverse of the Jacobian matrix J_{Jacobi} in (2.6).

$$J^{+}=J^{T}\left(JJ^{T}\right)^{-1} \tag{2.7}$$

J^{+} represents the pseudo inverse and J^{T} represents the transposition of Jacobian matrix.

The positions of UAV need to be updated if the cooperative combat of multi-UAV can't reach the ideal capability. To get the ideal changes $\dot{X}_{Ui}$, $\dot{Y}_{Ui}$ and $\dot{Z}_{Ui}$ of the positions of UAV, according to (2.6), and the time step is Δt, that we can get the new positions of UAV, and the equation that the UAV update their positions is shown as (2.8).

$$\begin{bmatrix}X_{Ui}[k+1] \\ Y_{Ui}[k+1] \\ Z_{Ui}[k+1]\end{bmatrix}=\begin{bmatrix}X_{Ui}[k] \\ Y_{Ui}[k] \\ Z_{Ui}[k]\end{bmatrix}+\begin{bmatrix}\dot{X}_{Ui} \\ \dot{Y}_{Ui} \\ \dot{Z}_{Ui}\end{bmatrix} * \Delta t \tag{2.8}$$

2.3. The Calculation of the Distance between the Combat Position of Multi-UAV Cooperative and the Position of the Target

We can get the new value of the capability of UAV by putting the updated position coordinates into（1.2）and（1.3）, and update the position of UAV according to a series of formulae that from the formulae（1.1）to (1.3）and from the formulae (2.1) to (2.8)， the UCV walks *l* steps to reach the ideal value of the capability C_j^d.

Then we get the information of positions $\left(x_k^i, y_k^i, z_k^i\right)$ that the UAVs carry out attacks, and gets the distance between the combat position of multi-UAV cooperative and the position of the target is shown as (2.9). The distance between the combat position of multi-UAV cooperative and the position of the target is shown as (2.9).

$$r_k^i = \sqrt{\left(x_k^i - (x_{Tj} + v_{jx} * l * \Delta t\right)^2 + \left(y_k^i - (y_{Tj} + v_{jy} * l * \Delta t)\right)^2 + \left(z_k^i - (z_{Tj} + v_{jz} * l * \Delta t)\right)^2} \quad (2.9)$$

$\left(X_k^i, Y_k^i, Z_k^i\right)$ is the coordinate of the attack position of the *i*-th UAV in the *k*-th allocation scheme, and $\left(X_{Ui}, Y_{Ui}, Z_{Ui}\right)$ is the coordinate of the initial position of the *i*-th UAV.

3. The Task Allocation Model of multi-UAV Cooperative Air Combat

Two factors are considered in the multi- UAV cooperative air combat task allocation in this paper. Firstly, the situational advantages of our UAVs at the home positions. Secondly, the attack earnings of our UAVs located at the attack positions. Assume that the quantity of our UAVs is *n*, and the quantity of the enemy's UAVs is *m*.

3.1. The Air Situational Analysis of the Initial Position

In the multi-UAV air combat, the main factors which can affect the damage probability of the UAVs destroy the targets are the angles between our UAVs and the enemy's UAVs, which affect kill probability of the UAVs destroy the targets include the angles between our UAVs and the enemy's UAVs, the relative speed between our UAVs and the enemy's UAVs and the distance between our UAVs and the enemy's UAVs, that is the air combat superiority of our UAVs are the angle advantage, the speed advantage and the distance advantage.

3.1.1. The Angle Advantage

When the enemy's targets are located directly in front of our UAVs, our UAVs are in the best detective position and aggressive position, the enemy is not easy to get rid of the track and the attack locking of our UAVS. At this time, our UAV can achieve the best tracking performance and aggressive effect. When the enemy's targets are behind our UAV, it's hard for us to lock the enemy.

Assume that the angle between the UAV of us and the UAV of enemy is φ, and $0 \le \varphi \le 180$, the angle advantage function can be configured as (3.1).

$$T_{ka}^{ij} = 1/(1 + e^{0.033|\varphi| - 3}) \quad (3.1)$$

T_{ka}^{ij} is the angle advantage between the i-th UAV of us and the j-th UAV of the enemy in the *k*-th allocation scheme. The angle advantage T_{ka}^{ij} achieves the maximum when $\varphi = 0^\circ$, and the angle advantage T_{ka}^{ij} achieves the minimum when $\varphi = 180^\circ$.

3.1.2. The Distance Advantage

On the one hand, the distance advantage is related to the distance which between the enemy and us, and on the other hand, the distance advantage is related to the attack range of the weapon that carried by the UAV. Especially, the attack range of the weapon is the most important factor. Assume that the biggest launch distance of air-to-air missile is $D_{\max}$ and the smallest distance of air-to-air missile is $D_{\min}$, and the distance between the UAV of us and the UAV of the enemy is R. When $R = (D_{\max} + D_{\min})/2$, the distance advantage achieves the maximum, and the bigger the R the smaller the distance advantage when $R > (D_{\max} + D_{\min}) / 2$, and the smaller the R the bigger the distance advantage when $R < (D_{\max} + D_{\min}) / 2$,so the distance advantage function can be configured as (3.2).

$$T_{kd}^{ij} = e^{-(\frac{R-R_0}{o})^2} \tag{3.2}$$

T_{kd}^{ij} is the distance advantage between the *i*-th UAV of us and the *j*-th UAV of the enemy in the *k*-th allocation scheme.

3.1.3. The Speed Advantage

Assume that the speed of the enemy's UAV is V_R, and the speed of our UAV is V_B. It's generally believed that the speed advantage of our UAV achieves the minimum when the speed of our UAV is 0.5 times less than the speed of the enemy's UAV, and the speed advantage of our UAV achieves the maximum when the speed of our UAV is 1.4 times more than the speed of the enemy's UAV, so the distance advantage function can be configured as (3.3).

$$T_{kv}^{ij} = 1 / (1 + e^{-6V_{rat}+6}) \tag{3.3}$$

T_{kv}^{ij} is the speed advantage between the *i*-th UAV of us and the *j*-th UAV of the enemy in the *k*-th allocation scheme, and $V_{rat} = V_R / V_B$.

3.1.4. The Index of the Air Combat Situation

The index of the air combat situation is mainly for the angle advantage, the speed advantage and the distance advantage. These factors needed to be considered comprehensively. Therefore, we can get the air combat situation with the weighted sum, which can be described as (3.4).

$$T_{ks}^{ij} = w_1 T_{ka}^{ij} + w_2 T_{kv}^{ij} + w_3 T_{kd}^{ij} \tag{3.4}$$

T_{ks}^{ij} is the index of the air combat situation between the *i*-th UAV of us and the *j*-th UAV of the enemy in the *k*-th allocation scheme, the weighted sum of the angle advantage, the speed advantage and the distance advantage are w_1, w_2 and w_3, $0 \le w_1, w_2, w_3 \le 1$,and $w_1 + w_2 + w_3 = 1$.

3.2. The Index of the Air Combat Attack Earnings

The air combat attack earnings are mainly related to the probability that our UAVs destroy the enemy's UAVs, and the value of the enemy's UAVs. The probability that our UAVs destroy the enemy's UAVs is mainly related to the angle advantage, the distance advantage and the air combat effectiveness and so on, and the decrease of any one of the angle advantage and the distance advantage will reduce the probability that our UAVs destroy the enemy's UAVs. To consider conveniently, the distance advantage is only be considered in this paper, so the ability to destroy the enemy's UAV can be expressed as (3.5).

$$T_{kc}^{i} = T_{kd}^{i}{}' * C \tag{3.5}$$

$$T_{kd}^{i}{}' = e^{-(\frac{r_k^i - R_0}{o})^2} \tag{3.6}$$

$T_{kd}^{i}{}'$ is the distance advantage of the *i*-th UAV of us at the attack position, C is the air combat effectiveness of our UAVs, r_k^i is the distance between the attack position of the *i*-th

UAV of us and the enemy's UAV in the *k*-th allocation scheme.

The combat attack earning of our UAVs is the multiply of the probability that our UAVs destroy the enemy's UAV and the value of the enemy's UAV, assume that there are *g* UAVs of us to attack the *m*-th UAV of the enemy, that the attack earnings can be expressed as (3.7).

$$T_{km}^{j} = [1 - \prod_{i=1}^{g}(1 - T_{kc}^{i})] * v_j \tag{3.7}$$

T_{km}^{j} is the attack earning that the *j*-th UAV of the enemy obtained, and v_j is the value of the *j*-th UAV of the enemy.

3.3. The Overall Earning Model of the Multi-UAV Cooperative Combat Task

Because of the large differences between the index of the air combat situation and the index of the air combat attack earning, some information may be lose if to weight sum directly, the index of the air combat attack earning needed to be standardized which can be expressed as (3.8) and (3.9).

$$v_j' = v_j / v_{j\max},\ j = 1, 2, ..., m \tag{3.8}$$

$$T_{km}^{j}{}' = [1 - \prod_{i=1}^{g}(1 - T_{kc}^{i})] * v_j' \tag{3.9}$$

$v_{j\max}$ is the maximum of the enemy's UAVs, and the model of multi-UAV cooperative air combat task assignment can be expressed as (3.10) to (3.12).

$$\max J = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}(n_1 * T_{ks}^{i} + n_2 * T_{km}^{j}{}') \qquad n_1 + n_2 = 1 \tag{3.10}$$

s.t.

$$\sum_{i=1}^{n} x_{ij} = n / m \tag{3.11}$$

$$\sum_{j=1}^{m} x_{ij} = 1 \tag{3.12}$$

x_{ij} is the decision variable, $x_{ij} = 1$ when the *i*-th UAV of us attack the *j*-th UAV of the enemy, otherwise, $x_{ij} = 0$ .The index of the air combat situation and the index of the air combat attack earning are w_1 and w_2, and $w_1 + w_2 = 1$ .We can see from (3.11) that every UAV of the enemy is attacked by *n/m* UAVs of us, and we can see from (3.12) that every UAV of us can attack a UAV of the enemy at most.

4. The Flow Chart of the Multi-UAV Cooperative Air Combat Task Allocation

The flow chart of the multi-UAV cooperative air combat task allocation is expressed as Figure 2

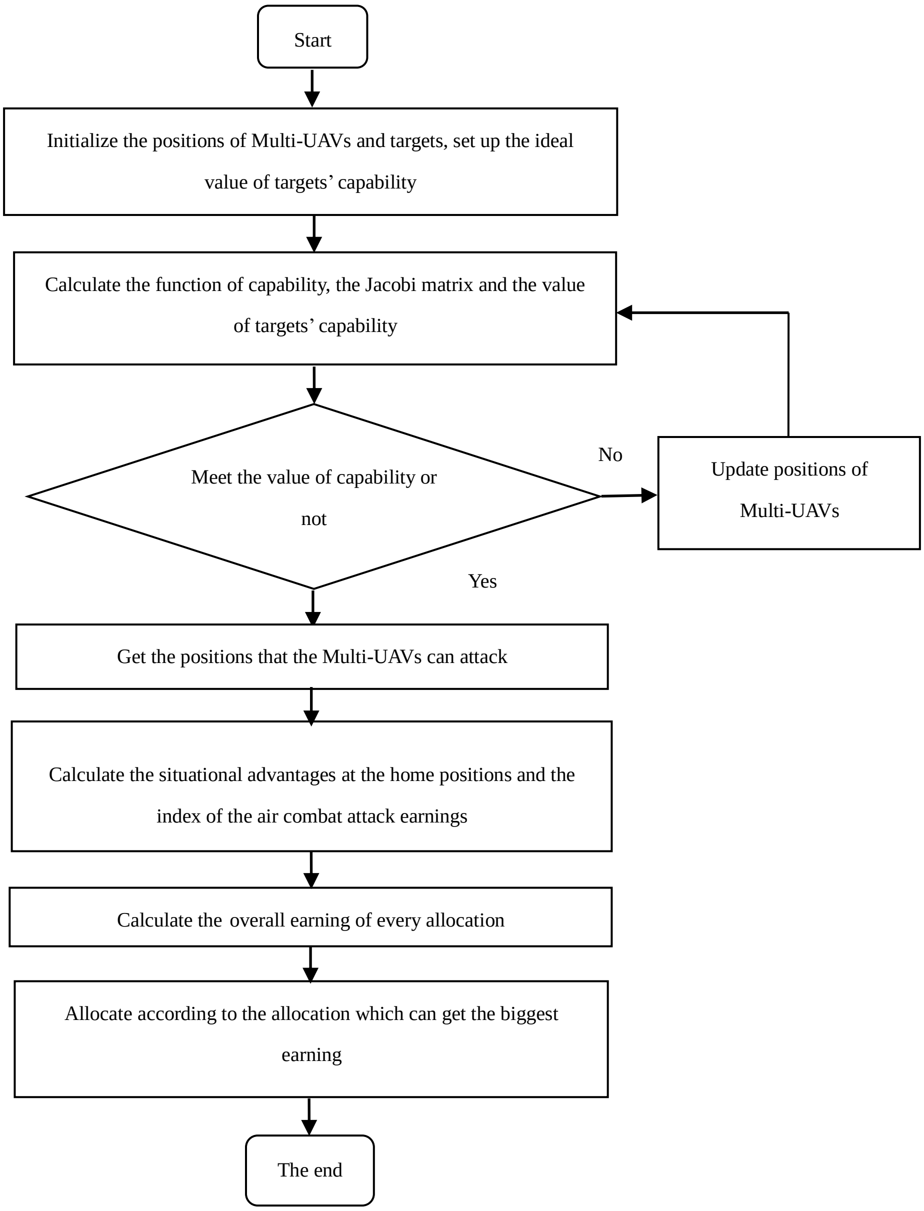

Figure 2. The Flow Chart of the Task Allocation

5. Simulation Results and Analysis

Suppose that the number of our UAV is four and the number of missile carried by every UAV is one, the number of targets is two, and the number of missiles belonged to every target is two. The targets are the enemy's UAVs. Besides,

$$P_{\text{UAV}} = \begin{bmatrix} 23.5 & 24.2 & 22.4 \\ 23.4 & 24.1 & 22.3 \\ 23.6 & 24.1 & 22.4 \\ 23.7 & 24.2 & 22.5 \end{bmatrix} km, \quad P_{\text{target}} = \begin{bmatrix} 18.6 & 17.2 & 19.3 \\ 18.2 & 18.8 & 20 \end{bmatrix} km, \quad \begin{bmatrix} C_1^d \\ C_2^d \end{bmatrix} = \begin{bmatrix} 1.5 \\ 1.5 \end{bmatrix}$$

The speed of the enemy's UAVs is 80*km/h*, and the flight direction of the enemy's UAV 1 is along the positive direction of *y*-axis, the flight direction of the enemy's UAV 2 is along the positive direction of *x*-axis. The information of the UAVs' orientation angles is shown as Table 5.1, and the information of the speed of our UAVs and the enemy's UAVs is shown as Table 5.2.

Table 5.1. The information of the UAVs' Orientation Angles

	Target 1	Target 2
UAV 1	45	45
UAV 2	60	30
UAV 3	60	30
UAV 4	45	45

Table 5.2. The Information of the UAVs' Speed

	Target 1	Target 2
UAV 1	80/100	80/100
UAV 2	80/120	80/120
UAV 3	80/150	80/150
UAV 4	80/100	80/100

The air combat effectiveness of our UAVs is $C = [0.67 \quad 0.63 \quad 0.56 \quad 0.6]$, the value of the enemy's UAVs is $v = [76 \quad 85]$, and there are six allocation schemes for four UAVs to attack two targets. The allocation plans are shown as the Table 5.3.

Table 5.3. The Allocation Plans

The plans	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6
Allocation matrix	[1 2 3 4]	[1 3 2 4]	[1 4 2 3]	[2 3 1 4]	[2 4 1 3]	[3 4 1 2]

The allocation matrix of plan 1 is [1 2 3 4]. The matrix [1 2 3 4] means that the target 1 is attacked by the UAV 1 and UAV 2,and the target 2 is attacked by UAV 3 and UAV 4.The other plans are similar to the plan 1.

Now, we allocate the UAVs by two methods as follow.

The method 1:To get the capability function of our UAVs, the Jacobian matrix, and the distance between the combat position of multi-UAV cooperative and the position of the target according to (1.3)、(2.1) and (2.9),and calculate the situational advantages and the attack earnings according to (3.4) and (3.5) to (3.7),and then we can get the earning value of every plan which is shown as Table 5.4.

Table 5.4. The Earning Values of the Allocation Plans of the Method 1

The plan	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6
The earning value	1.7209	1.7234	1.7309	1.7157	1.7290	1.7210

We can see from the Table 5.4 that the biggest earning value belongs to the plan 3, that the allocation is [1 4 2 3] means that the target 1 is attacked by the UAV 1 and UAV 4, and the target 2 is attacked by UAV 2 and UAV 3, and the earning value is 1.7309.The capability that got by target 1 in scheme 3 is showed in Figure 3 and the capability that got by target 2 in scheme 3 is showed in Figure 1.

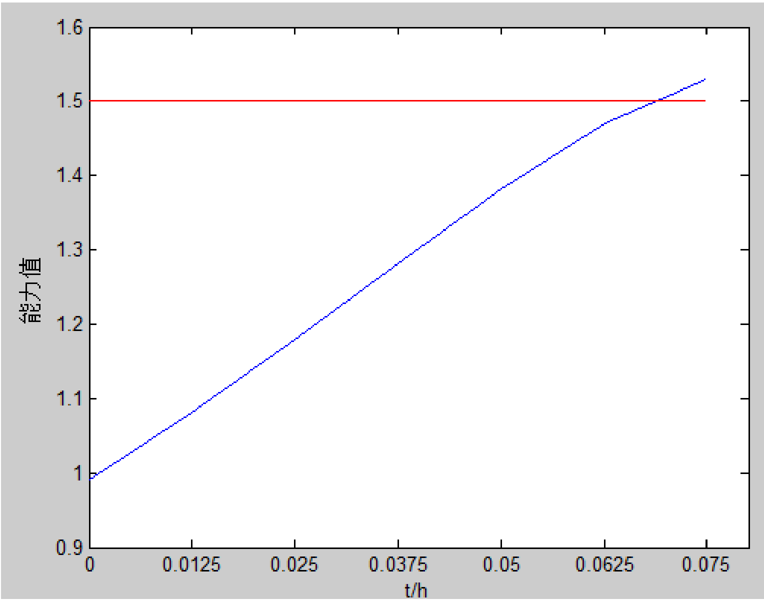

Figure 3. The Capability That Got By Target 1

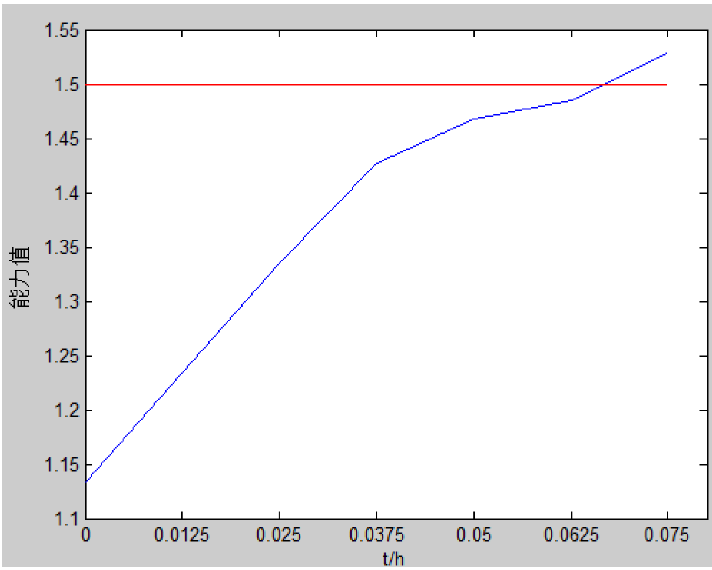

Figure 4. The Capability That Got By Target 2

We can see from Figure 3 that the capability value is calculated once every 0.00125 hour, and the capability of target 1 and target 2 can reach 1.5 after six times, that 0.075 hour. So the target 1 can be attacked by the second UAV and the fourth UAV and the target 2 can be attacked by the first UAV and the third UAV after 0.075 hours.

The method 2: According to the previous method of multi-UAV task allocation, the capability function of multi-UAV cooperative attack and the capability that the targets needed are not considered. In the model (3.10), d_i is the distance between the *i*-th UAV and the *j*-th target. Finally, we can get the earning value of every plan by simulation and the earning value of every plan is shown as Table 5.5.

Table 5.5. The Earning Values of the Allocation Plans of the Method 2

The plan	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6
The earning value	1.4693	1.4736	1.4781	1.4702	1.4782	1.4748

We can see from the Table 5.5 that the biggest earning value belongs to the plan 5, that the allocation is [2 4 1 3] means that the target 1 is attacked by the UAV 2 and UAV 4,and the target 2 is attacked by UAV 1 and UAV 3,and the earning value is 1.4782.

As can be seen from the results of the two methods, the difference between the two methods mainly includes two aspects. Firstly, the capability of multi-UAV cooperative attack and the capability that the targets needed are not considered in the method 2. Secondly, the results of the two methods are different completely, that the earning value of method 1 is bigger than the other, the allocation plan of the method 1 is plan 3 and the allocation plan of the method 2 is plan 5. Therefore, we can draw the following conclusions that the task allocation which the cooperative combat capability of multi-UAV is considered can get more profit and damage efficiency of the targets, and improve the capability of multi-UAV cooperative attack.

6. Conclusion

This paper presents a new method for multi-UAV cooperative air combat task allocation through the establishment of the capability function and Jacobian matrix. The result of simulation shows that the method that considering multi-UAVs cooperative task allocation capabilities can get more profit and damage efficiency of the targets, and improves the capability of multi-UAVs cooperative combat, which compared with the collaborative capability is not considered，and it’s a new method for multi-UAVs task allocation.

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