Study on the Task Assignment for Multi-UCAV in Air-Combat

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***Abstract*—Considering the decision-making problem for UCAV cooperative attack on multiple aerial targets, this paper analyzed the air combat situation superiority, established the UCAV angel superiority model and speed superiority model. Taking into account the target value and the ability of our UCAV attacks on targets, we established the attacks income model. Considering air superiority and attack income we established the UCAV combat task assignment model. Simulation results show that the UCAV combat task assignment model is effective, and can meet the needs of different tactics.**

Keywords-UCAV; cooperative air-combat; air combat situation; task assignment

I. INTRODUCTION

The UCAV is playing a more and more important role in modern war, and it will also be a key to fight for the air supremacy, there are a lot of combat between the multi-UCAV formation contemporary, the trend of air combat will also the multi-UCAV formation in the future. In air combat, taking the case of multi-UCAV search range overlap and unnecessary attack into account, so it is very important for multi-UCAV to effectively allocate tasks and it also can greatly reduce the waste of searching resources and weapons. There a lot of research results on multi-UCAV combat decision-making [1]-[5], literature [1] considered a Beyond Visual Range (BVR) air combat scenario with a group of UCAVS versus multiple hostile airborne targets, the decision-making problem for Cooperative Attack on Multiple Targets (CAMT) was investigated. The air combat threat situation was analyzed; the decision-making for CAMT was converted into a Missile-Target Assignment (MTA) optimization problem with the establishment of the attack effectiveness evaluation model. Then, a Simulated Annealing Genetic Algorithm (SAGA) was proposed to find out the optimal solution to the MTA problem. In [2], the models of superiority and degree of threat during the process of attacking were built up, based on which the superiority and degree of threat were analyzed and weighed, and according to the superiority and degree of threat to make decision in multi-target attacking. In [3], the model of multi-objective optimization problem for air combat decision-making was established, an improved particle swarm algorithm was put forward to solve air combat decision-making, and the basic particle swarm algorithm is an effective method to solve the continuous optimization problem in the air combat. In [4], the detection task allocation model was first built by the battlefield situation and the detection capability of radar, then, the attack task allocation was built by the battlefield situation and the engagement capability of weapon. Finally, the multi objective decision problem was translated into single objective optimization and Particle swarm optimization algorithm was designed to solve the problem. In these studies, our UCAV generally only take the current situation into consider, and the goal of our task allocation in air combat is increasing the advance of ours and reducing the threat of the enemy. The air combat situation includes the superiority of attack and the degree of threat. Therefore, the superiority of attack can only reflect our ability of damaging the enemy, the degree of threat can only reflect the enemy ability of damaging the UCAV. Both of them have not considered the value of the UCAV and the fighter of enemy. In this paper, on the attacking superiority model of our UCAV considering the value of the two sides to build a revenue model of the UCAV, and establishing the model of UCAV combat task allocation.

II. THE ANALYSIS OF AIR COMBAT SITUATION

In Multi-UCAV air combat, the main factors of which can affect the damage probability of our UCAV attacking on the enemy targets is that the orientation of the UCAV, the relative speed between the UCAV and the targets, the distance between the UCAV and the targets, which means that the air combat situation of our UCAV mainly include the angle superiority, the speed superiority, the distance superiority. We assume that there is no threat from the targets.

A. The angle superiority

When the target is front of the UCAV, we can achieve the best tracking performance of the target and combat effects, when the target is behind of the UCAV, the UCAV has the worst target tracking and attacking effect, so constructing angle superiority functions are as follows:

$$T_a = 1/(1+e^{0.033|\varphi|-3}) \tag{1}$$

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φ is the angle between the Velocity vector and two planes connection line $0 \le \varphi \le 180$, when $\varphi = 0^\circ$, T_a is the maximum, when $\varphi = 180^\circ$, T_a is minimum.

B. The distance superiority [2]

The distance superiority is not only related to the distance between the UCAV and the target, but also related to the attack range of the weapons which are carried by the two sides. Especially the range of air-to-air missile attack range, suppose the maximum transmitting distance of air-to-air missile is $D_{\max}$, the minimum transmitting distance of air-to-air missile is $D_{\max}$, the distance between the two sides is R, when $R = (D_{\max} + D_{\min})/2$, the target is in the best of our UCAV attacking range ,the distance superiority is maximum, when $R > (D_{\max} + D_{\min})/2$, if R is getting greater on the contrary the distance superiority is getting smaller, when $R < (D_{\max} + D_{\min})/2$, if R is getting smaller and the distance superiority is getting smaller, so constructing distance superiority functions are as follows:

$$T_d = e^{-(\frac{R-R_0}{o})^2} \tag{2}$$

Here, $R = (D_{\max} + D_{\min})/2$, $\sigma = 2*(D_{\max} - D_{\min})$.

C. The speed superiority

Suppose the speed of target is V_R, the speed of our UCAV is V_B, while the speed is getting faster, the ability of UCAV attacking is getting stronger, so it has bigger combat superiority. Generally we suppose speed of our UCAV is less than 0.5 times the enemy speed, our UCAV has the least superiority. When the speed of our UCAV is faster than 1.4 times the enemy speed, our UCAV has the best superiority, so constructing speed superiority functions are as follows:

$$T_v = 1/(1+e^{-6V_{rat}+6}) \tag{3}$$

Here, $V_{rat} = V_R / V_B$.

III. AIR COMBAT ASSIGNMENT MODEL

Suppose there are m UCAV and n aerial targets in the battlefield, and our UCAV set is $U = \{U_1, U_2, \cdots, U_m\}$, the aerial target set is $T = \{T_1, T_2, \cdots, T_m\}$. Each of our UCAV in a time only attack one air target, and enemy on our no missile threat. Multiple UCAV task allocation in air combat can be described as: Within the shortest possible time, all tasks should be assigned to UCAV, Achieve the overall combat effectiveness of unmanned aerial vehicle formation best. In multi-UCAV air combat, the considered indicators are: the superiority of our UCAV formation, the threat of enemy targets. In air combat the enemy target value and our UCAV capability to destroy the target also influence our UCAV overall combat effectives, in this paper we consider a UCAV formation maximum superiority index and UCAV formation maximum profit index.

A. UCAV formation maximum superiority index

The superiority of our UCAV formation are the sum of superiority what is all of our UCAV in the formation related to its corresponding to the target, so we can take a different task allocation scheme, the superiority of our UCAV formation are different, the UCAV obtains the largest index of the UCAV formation superiority though maximizing the superiority of our UCAV formation to make the task allocation of the UCAV achieve the best of our air combat situation.

The superiority of our UCAV mainly reflected in the superiority of angle, the superiority of distance ,the superiority of speed, so we can get the air combat situation by weighed sum, suppose $T_a = [T_a^{ij}]_{m\times n}$, $T_v = [T_v^{ij}]_{m\times n}$, $T_d = [T_d^{ij}]_{m\times n}$ are the superiority matrix of angle, the superiority matrix of distance, the superiority matrix of speed, T_a^{ij}, T_v^{ij}, T_d^{ij} are the angle superiority of the UCAV i relative to the target j, the distance superiority of the UCAV i relative to the enemy target j, the speed superiority of the UCAV i relative to the enemy target j, suppose the superiority matrix of our UCAV is $T_s = [T_s^{ij}]_{m\times n}$, then:

$$T_s^{ij} = k_1 T_a^{ij} + k_2 T_v^{ij} + k_3 T_d^{ij} \tag{4}$$

Here, k_1, k_2, k_3 are weighting coefficients, $0 \le k_1, k_2, k_3 \le 1$ and $k_1 + k_2 + k_3 = 1$.

The superiority of our UCAV formation is:

$$T_s^v = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} * T_s^{ij} \tag{5}$$

And x_{ij} is that whether the UCAV i take the mission j or not, if the UCAV take the mission the $x_{ij} = 1$ other $x_{ij} = 0$.

B. UCAV formation maximum proceeds index

In current situation, the proceeds of the UCAV formation is the total value which the UCAV gained by attacking the targets. It can make our UCAV realize maximize operational effectiveness by maximize the index of the task allocation of our UCAV formation. The UCAV attacking gains is mainly related to the hit probability of the UCAV, the kill probability and the value of the enemy targets. The hit probability of the UCAV is mainly in matter of the superiority of the angle, the superiority of the distance and other factors. However if any one factor is too small, it will lead the hitting ability of the UCAV too small, suppose $T_m = [T_m^{ij}]_{m\times n}$ is our proceeds matrix, then:

$$T_m^{ij} = T_a^{ij} * T_v^{ij} * P_{ij} * V_j \tag{6}$$

Here, V_j is the Value information of the target j. P_{ij} is the kill probability of our weapons systems on target UCAV formation proceeds is as follows:

$$T_m^v = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} T_m^{ij} \tag{7}$$

Comprehensive consideration of UCAV formation maximum superiority index and UCAV formation maximum profit index, and the air combat assignment model could be established. On T_s^v and T_m^v normalization:

$$\begin{aligned} T_s^v{}' &= [\frac{T_s^{ij}}{\max(T_s)}]_{m\times n} \\ T_m^v{}' &= [\frac{T_m^{ij}}{\max(T_m)}]_{m\times n} \end{aligned} \tag{8}$$

Using equation (8) we can get T_s', T_m', Multiple UCAV task allocation models in air combat can be expressed as:

$$\begin{aligned} &\max J = w_1 * T_s' + w_2 * T_m' \\ &s.t. \quad w_1 + w_2 = 1 \\ &\qquad 0 \le w_1 \le 1 \\ &\qquad 0 \le w_2 \le 1 \end{aligned} \tag{9}$$

Here, w_1 and w_2 is the weighting factors $w_1, w_2 \in [0,1]$, represent the preferences of decision makers on the operational effectiveness. w_1 representative of policy makers tend to attack high hit probability targets, w_2 representative of policy makers tend to attack high value targets. By changing the size of w_1 and w_2, Decision-makers can get the results of the decision-making to meet the different needs of the battlefield.

IV. MULTIPLE UCAV TASK ALLOCATION IN AIR COMBAT EXAMPLES

Suppose there are 3 UCAV and 3 aerial targets in the battlefield. Both sides of the battlefield environment and situation are operational information as shown in the table 1; and the battlefield situation schematic as shown in the figure 1. The value of the targets is [95 80 85]. The UCAV weapon attack range is [(0.5, 20), (0.5, 20), (0.5, 20)].

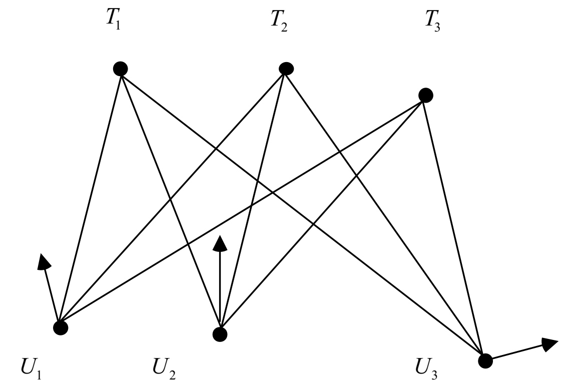

Figure 1 The battlefield situation schematic

TABLE I. THE AIR COMBAT SITUATION PARAMETER VALUE

		T1	T2	T3
Angle	U1	30	50	80
	U2	25	30	45
	U3	150	120	90
Distance	U1	16	20	21
	U2	22	20	22
	U3	23	22	17
Speed	U1	1.1	0.9	1
	U2	1.32	1.08	1.2
	U3	1.045	0.855	0.95
Kill probability	U1	0.81	0.94	0.91
	U2	0.95	0.80	0.92
	U3	0.96	0.85	0.94

Using the data in table 1 and the model established in the paper we can get the air combat superiority value as shown in table 2.

TABLE II. THE AIR COMBAT SUPERIORITY VALUE

		T1	T2	T3
Angle Superiority	U1	0.8818	0.7941	0.5890
	U2	0.8980	0.8818	0.8198
	U3	0.1246	0.2769	0.5075
Distance Superiority	U1	0.9785	0.9394	0.9268
	U2	0.9132	0.9394	0.9132
	U3	0.8986	0.9132	0.9705
Speed Superiority	U1	0.6457	0.3543	0.5
	U2	0.8721	0.6178	0.7685
	U3	0.5671	0.2953	0.4256
Superiority	U1	0.8353	0.6960	0.6720
	U2	0.8945	0.8130	0.8339
	U3	0.5301	0.4951	0.6345

TABLE III. THE ATTACK INCOME OF UCAV

	T1	T2	T3
U1	66.399	56.1	42.229
U2	74.011	53.019	58.546
U3	10.208	17.194	39.353

Let $k_1 = k_2 = k_3 = \frac{1}{3}$, simulate the situation of $w_1 = 1, w_2 = 0$ and $w_1 = 0.4, w_2 = 0.6$ respectively. And we can get the synthetic utility matrix as shown in table 3 and table 4.

TABLE IV. THE SITUATION OF $w_1 = 1$

	T1	T2	T3
U1	0.9339	0.7781	0.7513
U2	1	0.9089	0.9323
U3	0.5926	0.5536	0.7094

TABLE V. THE SITUATION OF $w_1 = 0.4$

	T1	T2	T3
U1	0.9119	0.7660	0.6429
U2	1	0.7934	0.8475
U3	0.3198	0.3608	0.6028

Using the Hungarian algorithm to solve the two questions, when $w_1 = 1, w_2 = 0$, Constructing decision matrix：

$$[J_1^{ij}] = \begin{bmatrix} 0.9339 & 0.7781 & 0.7513 \\ 1 & 0.9089 & 0.9322 \\ 0.5926 & 0.5536 & 0.7094 \end{bmatrix}$$

Let $K_1 = \max(J_1^{ij}) = 1$， and we can get the matrix:

$$R_1 = K_1 - [J_1^{ij}] = \begin{bmatrix} 0.0661 & 0.2219 & 0.2487 \\ 0 & 0.0911 & 0.0678 \\ 0.4074 & 0.4464 & 0.2906 \end{bmatrix}$$

For the matrix R_1 using Hungary algorithm we can get the decision matrix:

$$[x_{ij}^1] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

UCAV 1 performs the task 1, UCAV 2 performs the task 2, and UCAV 3 performs the task 3. In this case, policymakers fully prefer the superiority, through qualitative analysis on the current situation, UCAV 1 to perform task 1 have the biggest superiority, UCAV 2 to perform task 2 have the biggest superiority, and UCAV 3 to perform task 3 have the biggest superiority. The decision results consistent with the qualitative analysis result.

When $w_1 = 0.4, w_2 = 0.6$, Constructing decision matrix：

$$[J_2^{ij}] = \begin{bmatrix} 0.9119 & 0.7660 & 0.6429 \\ 1 & 0.7934 & 0.8475 \\ 0.3198 & 0.3608 & 0.6028 \end{bmatrix}$$

Let $K_2 = \max(J_2^{ij}) = 1$， and we can get the matrix:

$$R_2 = K_2 - [J_2^{ij}] = \begin{bmatrix} 0.0881 & 0.2340 & 0.3571 \\ 0 & 0.2066 & 0.1525 \\ 0.6802 & 0.6392 & 0.3972 \end{bmatrix}$$

For the matrix R_2 using Hungary algorithm we can get the decision matrix:

$$[x_{ij}^2] = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

UCAV 1 performs the task 2, UCAV 2 performs the task 1, and UCAV 3 performs the task 3. In this case, policy makers prefer to attack income, because the target 1 is the greatest value target, and the kill probability of UCAV 2 attack on target 1 is the largest, so the UCAV 2 performs the task 1.

CONCLUSION

For multiple UCAV mission assignment problem under air combat, we analyzed the air combat situation superiority, established the UCAV air superiority model. Taking into account the target value and the ability of our UCAV attacks on targets, we established the attacks income model. Considering air superiority and attack income we established the UCAV combat task assignment model. Simulation results show that the UCAV combat task assignment model is effective, and can meet the needs of different tactics It should be noted that, the research on task assignment of Multi-UCAV for air combat, and we believe that there will be more other analysis methods to appear.

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