Research on the WTA problem in UAV formation air-to-ground attack

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Abstract. In view of the process of UAV formation air-to-ground attack, the characteristics a nd new requirements of UAV combat were deeply studied and analyzed. A dynamic fire assi gnment model was established, which mainly included the target assignment, the state transf er of target and fire channel in the dynamic fire assignment model, and the suitability test method was deeply analyzed. Considering the constraints of attack, resource and destruction probability, an optimization algorithm for solving fire allocation was proposed. Finally, the im proved particle swarm optimization algorithm is used to solve the target assignment model a nd the feasibility of the model and algorithm is verified by an actual case.

Keywords: UAV formation; particle swarm optimization; hybrid algorithm; dynamic target assignment model WTA problem.

1. Introduction

In the current surrounding situation and the possible form of air combat, the establishment of a reliable combat system has become very critical. The problem of weapon target allocation has become one of the core problems of modern combat system and joint combat mission planning. This problem studies the allocation of our weapon resources to attack targets and protection planning, and finally obtains the highest efficiency of mobile decision-making[1]. Whether the operational plan is efficient directly affects the trend of the war. The essence of WTA problem is a combinatorial optimization problem. At present, the WTA problem can be divided into two types of analysis, one is the static fire allocation research, the other is the dynamic fire allocation research. The method to solve WTA problem is to establish a model of WTA problem and solve the best operational plan through algorithm. Due to the need for super polynomial time to solve the problem, the traditional algorithms such as linear and nonlinear programming, dynamic programming, multi-objective programming, integer programming, queuing theory, inventory theory, game theory, decision theory and so on can not meet the requirements of efficiency and accuracy. At present, Heuristic algorithms such as Tabu Search (TS), Simulated annealing algorithm (SA), Genetic Algorithm (GA), etc[2]. GA, ant colony optimization (AO) and other methods have been applied in this field to solve WTA problems. However, the logic of these methods has its own shortcomings. For example, TS algorithm is strongly dependent on the initial solution, and a bad initial solution often makes the search difficult or impossible to reach the optimal solution. The optimal solution in TAA algorithm is often affected by the number of iterations. The search speed of GA algorithm is slow and so on.

The idea of simulated annealing is introduced to supplement the optimization and search of the local optimal solution, in order to obtain more local optimal solutions that meet the conditions and have higher fitness[4], so as to obtain the global optimal solution. In addition, in order to avoid the loss of control caused by the large difference between the new solution and the benchmark solution in the simulated annealing process, the exchange mechanism is used to generate new solutions.

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2. Overview of UAV formation air-to-ground attack maneuvering problem

In recent years, through its efficient, agile and stable self-organization, UCAV (Unmanned Aerial Vehicle) has gained a great deal of attention and application in transportation support, fire rescue, and public security maintenance[5]. With the advancement of frontier technologies such as big data and artificial intelligence, Uavs have a broad development prospect in the military field. Especially in complex battlefield environments, how to efficiently and orderly arrange the formation of Uavs for firepower allocation has attracted wide attention[6].

Aiming at the above analysis, this paper combines the extended and improved intuitionistic fuzzy sets with the particle swarm optimization (PSO) [3] algorithm in the classical swarm intelligence algorithm, and proposes a hybrid PSO algorithm based on intuitionistic fuzzy sets by establishing the WTA problem model of fire target assignment. At the same time, due to the iteration of the hybrid particle swarm optimization algorithm, the local optimal solution can not fully meet the constraints in the WTA problem model.

3. Research on dynamic fire distribution in weapon target assignment problem

(1) Target allocation model. The ground attack of UAV formation is an attack problem, so the objective function should be the minimum survival probability of anti-aircraft fire unit. It is assumed that our UAV formation pairs, the number of ground attack fire channels is m, the number of UAV is the variable in the dynamic weapon target allocation decision[7], the number of UAV in a certain stage is N, the threat degree of the i the UAV $(i=1,2,\dots,N)$ to the enemy is U_i , the ^{*j*} air defense fire unit $j = (1, 2, \dots, m)$ The probability of destroying the ^{*i*} the UAV is p_{ij} .

The $N \times m$. Matrix composed of x_{ij} is the decision matrix denoting P. The meaning of the P matrix is the anti-aircraft fire unit attack scheme. Therefore, the survival probability of anti-aircraft fire unit in the ground attack of UAV formation is the lowest[8], and the optimal decision matrix P^* should meet:

$$\min f = \prod_{i=1}^{N} (1 - \bigcup_{i} \prod_{j=1}^{m} (1 - p_{ij})^{x_{ij}})$$

$$\min g = \sum_{i=1}^{N} \sum_{j=1}^{m} x_{ij}$$
(1)

N(t) represents the number of UAVs in the t stage, and N(t)dimension vector u(t)represents UAVs in the t stage. The value of u(t) is as follows: $u(t)_{i} = \begin{cases} 1, t \ Phase \ start \ UAV \ i \ undamaged \\ 0, t Phase \ start \ UAV \ i \ Be \ damaged \end{cases}$

At the same time, $p_{ij}(t)$ is used to express the destruction probability of UAV by air defense weapon t in stage j. According to the state transition of the decision matrix[9], the target vector can be expressed as follows.

$$\Pr\left(u(t)_{i}=k\right) = k \cdot \prod_{j=1}^{M} (1-p_{ij}(t))^{x_{ij}(0)} \cdot \prod_{l=1}^{t} \prod_{j=1}^{M} (1-p_{ij}(t))^{x_{ij}^{(l)}} + (1-k) \left(1-\prod_{j=1}^{M} (1-p_{ij}(t))^{x_{ij}^{(0)}}\right)$$

$$\cdot \left(1-\prod_{l=1}^{t} \prod_{j=1}^{M} (1-p_{ij}(t))^{x_{ij}^{(l)}}\right)$$
(2)

4. Simulation analysis

4.1 Simulation example and parameter setting of dynamic fire assignment model are solved

In order to test the performance of the proposed IFE-C-PSO-SA algorithm in solving the static firepower allocation model, the WTA problem instance [10] is tested. In the case, there are 10 batches of UAV formation n=10 and 7 weapon platforms m=7 of anti-aircraft fire unit. The maximum number of ammunition available for each weapon platform is W = (4, 5, 4, 5, 4, 5, 4), and the hit probability of the *i* weapon platform W_i attacking the *j* batch of UAV formation is P_{ij} . According to the attack effect and experience analysis, the hit rate and the threat coefficient of UAV are shown in Table 1.

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Weapon platform	Uav formation									
	1	2	3	4	5	6	7	8	9	10
1	0.82	0.85	0.78	0.75	0.52	0.88	0.44	0.39	0.82	0.56
2	0.56	0.72	0.88	0.46	0.72	0.56	0.68	0.45	0.48	0.75
3	0.45	0.61	0.54	0.73	0.84	0.84	0.78	0.42	0.53	0.65
4	0.56	0.42	0.76	0.84	0.73	0.83	0.86	0.62	0.78	0.82
5	0.45	0.58	0.38	0.44	0.36	0.59	0.78	0.77	0.65	0.81
6	0.46	0.61	0.55	0.68	0.75	0.83	0.73	0.66	0.82	0.48
7	0.66	0.71	0.65	0.44	0.86	0.79	0.44	0.85	0.53	0.39
	0.00	0 12	014	0.06	0.05	0.10	0.00	0.00	0.15	0.12

Table 1. Hit rate p_{ij} and threat coefficient of Uavs u_{ij}

4.2 Simulation results and analysis of basic static firepower model

The running environment of the algorithm is: Matlab 2014 test software, Inter(R) Core(TM) i7-4790 CPU processor, 8Gb memory and Windows 7 system. The operation status and operational effectiveness of the proposed algorithm, simulated annealing hybrid particle swarm algorithm (SA), intuitionistic fuzzy set hybrid particle swarm algorithm and particle swarm algorithm were obtained by running 30 times each, and the solution results are listed in Table 2.

In the scale of Size / MaxIt = 100/200, the optimal WTA allocation scheme obtained by the IFECPSO-SA algorithm simulation calculation is shown in Table 2.

Scheme	Uav formation										
Anti-aircraft weapon units	3	1	0	0	0	0	0	0	0	0	
	0	1	4	0	0	0	0	0	0	0	
	0	0	0	0	2	1	1	0	0	0	
	0	0	0	3	0	0	2	0	0	0	
	0	0	0	0	0	0	0	1	0	3	
	0	0	0	0	0	2	0	0	3	0	
	0	1	0	0	1	0	2	0	0	0	

Table 2. Optimal WTA allocation scheme

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Table 2 shows that for the fire unit of No. 1 air defense weapon, 3 weapons are assigned to the first batch of UAV formation, and 1 weapon is assigned to the second batch of UAV formation. For the No. 2 anti-aircraft weapon fire unit, one weapon is assigned to the second batch of UAV formation, and two weapons are assigned to the third batch of UAV formation. Analogously, for anti-aircraft fire unit 7, one weapon is assigned to the second batch UAV formation, one weapon is assigned to the fifth batch UAV formation, and two weapons are assigned to the second batch UAV formation. It can be seen from Table 2 that the best combat effectiveness of the anti-aircraft weapon fire unit in this mode is 0.9949. After the UAV formation prediction obtains the optimal system combat effectiveness strike allocation scheme of the air defense fire unit, the strategy should be actively adjusted to avoid risks and effectively perform reconnaissance and strike tasks.

5. Conclusions

In the process of modern UAV formation air-to-ground attack, the characteristics of multi-batch, multi-angle, long-range attack on anti-aircraft fire units and enemy assets appear, which puts forward higher requirements for the firepower allocation in UAV formation air-to-ground attack. In this paper, the dynamic target assignment of UAV formation to ground attack is analyzed in detail, and the basic verification model and the target assignment, target and fire channel status in the dynamic fire assignment model and the test method of interception suitability are constructed. An improved particle swarm optimization algorithm is proposed, and the solution process of the model is given. Combined with the relevant examples in the moving target assignment model, the feasibility of the instance model is verified by solving.

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