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(Research Article)

# Optimization of attack coordination decisions for UAVs based on genetic algorithms

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## Abstract

Unmanned Aerial Vehicles (UAVs) are increasingly demonstrating their superiority in air raids. Making accurate and effective coordinated attack decisions is one of the most important factors in ensuring victory in aerial combat involving drones. Therefore, optimizing joint attack decisions for UAVs is also garnering increasing attention. This article introduces a method of using genetic algorithms to determine the threat index and optimize target distribution and firepower.

**Keywords:** Unmanned Aerial Vehicles; Genetic algorithms; Attacks; Air raids; Threat index; Target; Firepower.

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## 1. Introduction

In an increasingly complex international context, possessing drone technology represents an undeniable strategic advantage [2, 4]. The AD-AF Military Technical Institute, with its relentless efforts, has made significant strides in researching and manufacturing domestic UAVs, not only demonstrating technological self-sufficiency but also strengthening national defense capabilities. These UAVs are designed to meet the most stringent requirements of military missions, ranging from reconnaissance and surveillance to precise strikes, while ensuring flexibility and effectiveness in all combat situations [3, 5]. Faced with the challenges of modern warfare, the ability to make quick and accurate decisions becomes extremely important. This is especially true in aerial confrontations, where every second can determine the outcome of the battle [6-10]. The paper conducts an extensive analysis of UAV attack options, proposing an optimized approach based on threat analysis, target allocation, and firepower adjustment to ensure the most effective use of resources.

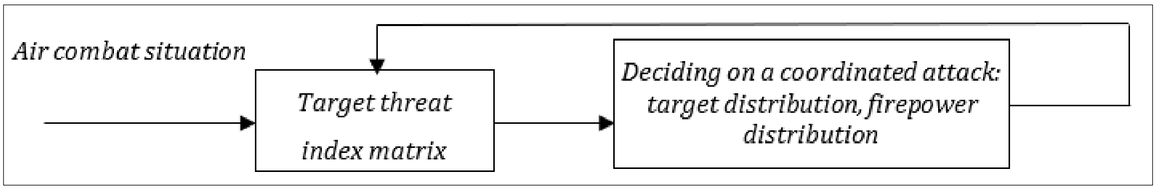

**Figure 1** Attack coordination decision diagram

At present, the AD-AF Military Technical Institute has achieved success in researching and manufacturing Vietnamese-branded drones, fulfilling mission requirements, and contributing to the development of the Vietnamese army in new circumstances. The aerial confrontation between our squadron and the enemy's requires making the correct attack decision in the shortest possible time to secure victory [11-14]. This paper has researched and synthesized UAV attack strategies for aerial combat. Figure 1 is a diagram for optimizing UAV attack decisions.

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The target threat index matrix is calculated on the following theoretical basis:

### 1.1. Air combat effectiveness index

UAV combat capabilities are often evaluated through seven main factors [2–4]: maneuverability, firepower, target detection ability, control efficiency, survivability, flight path, and electronic warfare capabilities. The air combat effectiveness index is calculated according to the following formula:

$$C = \left[ \ln B + \ln\left(A_1 + 1\right) + \ln A_2 \right] \varepsilon_1 \varepsilon_2 \varepsilon_3 \varepsilon_4$$

where B is the mobility parameter, $A_1$ is the firepower parameter, $A_2$ is the detectability parameter, $\varepsilon_1$ is the control efficiency coefficient, $\varepsilon_2$ is the survivability coefficient, $\varepsilon_3$ is the travel coefficient, and $\varepsilon_4$ is the electronic warfare capability coefficient.

### 1.2. Target Threat Index

Enemy and friendly squadrons participating in air combat can be considered objects moving in space [15, 16]. Threat indicators include:

- Distance threat index: $T_{\mathrm{Dij}}$
- Angular Threat Index: $T_{\varphi_{\mathrm{ij}}}$
- Speed Threat Index: $T_{\mathrm{Vij}}$
- Altitude threat index: $T_{\mathrm{Hij}}$

Air combat effectiveness threat index of the jth enemy aircraft against the ith friendly aircraft:

$$T_{C_{\mathrm{ij}}} = \begin{cases} 0.5 + 0.5 * \sin((C_j / C_i - 1) * 90^0) & C_j / C_i \le 2 \\ 1 & C_j / C_i > 2 \end{cases}$$

### 1.3. Target threat index matrix

Formula to calculate the general threat index [17, 18]:

$$q_{\mathrm{ij}} = \lambda_1 T_{\mathrm{Cij}} + \lambda_2 T_{\varphi\mathrm{ij}} + \lambda_3 T_{\mathrm{Dij}} + \lambda_4 T_{\mathrm{Vij}} + \lambda_5 T_{\mathrm{Hij}}$$

In which $q_{ij}$ is the threat index of the ith aircraft on our side to the jth aircraft on the enemy side, $\lambda_i$ is the corresponding weight value.

Assuming there are m friendly aircraft and n enemy aircraft, the threat index matrix is:

$$Q_{mn} = \begin{bmatrix} q_{11} & \cdots & q_{1n} \\ \cdot & & \cdot \\ \cdot & q_{\mathrm{ij}} & \cdot \\ \cdot & & \cdot \\ q_{m1} & \cdots & q_{mn} \end{bmatrix}$$

## 2. Simulate, calculate, and discuss

### 2.1. Model of attack decision optimization problem

*2.1.1. General problem model*

The enemy squadron has N aircraft: $R = \{R_j,\ j = 1, 2, \ldots, N\}$

Our squadron has M UAV aircraft: $B = \{B_i,\ i = 1, 2, \ldots, M\}$

each UAV carries L long-range air-to-air missiles. Therefore, we have Z=M.L missile. To attack T=N targets, the following conditions must be met: $Z \geq T$.

When the threat index is greater than the limit value, $q_{ij} \geq q_{gh}$, it is necessary to increase the number of $T_b$ missiles to attack. So the total number of missiles used to attack the target is $W=T+T_b$, and $T \leq W \leq Z$.

Let's optimize the decision to attack multiple targets.

*2.1.2. Specific Problem Model*

We detected four enemy aircraft (MBD) flying into protected airspace. They were arranged in a flight formation with a front-rear, right-left distance of 10 km.

Our aircraft (MBT) has three UAVs capable of attacking multiple targets, each with four long-range air-to-air missiles (TL). Our flight formation has a front-rear distance of 10 km and a right-left distance of 15 km.

The enemy and our aircraft were at the same altitude, and the enemy aircraft were all within the attack range of our aircraft. Flight numbers and formation are as shown in Figure 2.

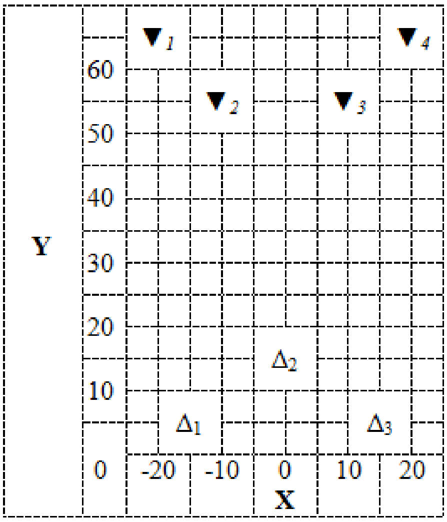

**Figure 2** Flight numbers and formations. Our aircraft Δ, enemy aircraft ▼

Our plane's speed is: $V_R$ = 300 m/s. The enemy's aircraft speed is: $V_B$ = 350 m/s. Our maximum detection distance is $D_R$ = 120 km. The enemy's maximum detection distance is $D_B$ = 70 km.

Let's optimize the decision to attack multiple targets.

### 2.2. Solve problems using genetic algorithms

The decision to attack includes the issue of distributing firepower and distributing tasks in order before and after attacking the enemy. Deciding on the order of attacks first and last is determined by the large or small value of the threat index. The decision to distribute firepower must cause the enemy aircraft to lose the ability to continue fighting. Using genetic algorithms for these two problems is the optimal search solution, making the threat index of the enemy squadron to our squadron the smallest.

The genetic algorithm [1] for the problem of optimizing multi-target attack decisions can be divided into the following steps:

#### *2.2.1. **Step 1.** Chromosomal coding*

Each individual is a missile-target attack pairing: $\pi = (w_1, w_2,..., w_k,..., w_W)$. The chromosome chain length is the number of missiles in the squadrons ($W=T+T_b$).

$$\mathrm{w_k} \in \{1, 2, ..., m_{i\tau}, ...Z\}, k \in [1,\mathrm{W}],$$

with $m_{i\tau} = (i-l).L + \tau, \qquad \tau \leq L$

**Table 1** Chromosomal Coding Table

| π = | $w_1$ | $w_2$ | ... | $w_k$ | ... | $w_T$ | $w_{T+1}$ | ... | $w_W$ |
|---|---|---|---|---|---|---|---|---|---|
| T = | 1 | 2 | ... | j | ... | T | T+1 | ... | $T+T_b$ |

#### *2.2.2. **Step 2.** Initialization*

Mainly set by the size of the POPsize population, the maximum number of MAXgen iterations, the crossover probability Pc, and the mutation probability Pm,.

#### *2.2.3. **Step 3.** Adaptation function*

After initializing the population, or at the time new generations are formed, we must use the fitness function to evaluate the fitness level of each chromosome in order to have a basis for selecting parents for calculations of hybridization and mutation.

The function to evaluate the danger of all enemy squadrons to our unmanned squadron is:

$$E(\pi) = \sum_{j=1}^{N} \sum_{i=1}^{M} \left[ q_{ji} \left( \prod_{r=1}^{Z} (1-q_{rj})^{X_{rj}} \right) \right]$$

In there:

$q_{rj}$ is the threat index of the jth enemy aircraft to the rth friendly aircraft.

If attacked by a missile, $X_{rj} = 1$. If do not attack with a missile, $X_{rj} = 0$. The fitness function is:

$$f = \frac{0.1}{0.001 + E(\pi)}$$

#### *2.2.4. **Step 4.** Select and filter*

In each generation, based on the value of the fitness function, selection is made to form a new generation population and prepare for performing hybridization and mutation operations later. The larger the fitness value, the greater the competitive advantage this chromosome chain has in the population, the greater the ability to survive, and the greater the probability of hybridization into the next generation. Through the process of mutation and hybridization, better generations can be born.

### *2.2.5.* ***Step 5.*** *Hybridization*

In genetic algorithms, the number of individuals in the population in each generation is constant. Selection selected some individuals with high fitness and eliminated some individuals with low fitness. The shortage in the number of individuals in the new population will be compensated for by taking highly adapted individuals as the parent generation, creating offspring by cross-breeding.

For example: M=2, L=4, T=6. So the number of missiles is Z=M.L=8. Need to use W=6 missiles to attack 6 targets. Suppose there are 2 types of chromosomes in the attack plan: A, B, and then the daughter chromosomes A' , B' can be crossed .

| | | |
|---|---|---|
| A: 2 4 1 6 8 3 | → | A': 2 4 1 3 5 7 |
| B: 5 7 6 3 2 1 | | B': 5 7 6 8 3 2 |

The hybridization point position is c = 3. Gene sequence 1-3 of A' is gene sequence 1-3 of A; gene sequence 4-6 of A' Determined by exchanging the 2 front and back parts of the hybrid point position of B to get "3 2 1 5 7 6", removing the duplicate gene 2 4 1 to "3 5 7 6", and taking the first 3 genes, we have:

A ' : 2 4 3 5 7
1

Similarly, the gene sequence 1-3 of B' is the gene sequence 1-3 of B, and the gene sequence 4-6 of B' is determined by exchanging the two parts before and after the position of the hybridization point of A. "6 8 3 2 4 1", remove the gene that coincides with 5 7 6, and leave "8 3 2 4 1", taking the first 3 numbers we have:

B ' : 5 7 8 3 2
6

### *2.2.6.* ***Step 6.*** *Mutation*

Mutation is a random change in the chromosome sequence to create diversity. Mutation is controlled by the mutation probability Pm. If there is no mutation, the algorithm will only search for solutions in the initial space. However, if Pm is too large, the search process becomes a random search.

Continuing the above example, a mutated individual A' will produce a new individual A''; if the mutation site is gene number 4, the set of genes not yet in A' includes (6, 8); choosing arbitrarily, we have A'' (4) = 8.

| | | |
|---|---|---|
| A ' : 2 4 **3** 5 7 | → | A '' : 2 4 **8** 5 7 |
| 1 | | 1 |

### *2.2.7.* ***Step 7.*** *Generate a new population generation*

After the processes of selection, hybridization, and mutation in the parent generation, the next generation will be created.

### *2.2.8.* ***Step 8.*** *Assess the quality of the new generation of populations*

In step 3, calculate the fitness function values of each chromosome in the new population. If the fitness function values of the individuals in the new population are higher, then they are selected; otherwise, the individual in the new population is not selected. previous generation populations. Check the termination condition; if satisfied, terminate the algorithm; otherwise, repeat steps 4–8 until a termination condition is met.

### 2.3. Simulation calculation results

Use a genetic algorithm written on Matlab software to model a specific problem with: population size POPsize = 80, maximum number of iterations MAXgen = 100, probability of hybridization Pc = 0.72, probability of mutation Pm =0.08. Carry out calculations; after each inheritance, the optimal adaptive value is shown in Figure 3.

We see that when genetics is carried out to the 70th generation, a stable adaptive value has been achieved, and the calculation shows that the optimal attack decision has been reached. The threat index of enemy aircraft to our aircraft is calculated in Table 2.

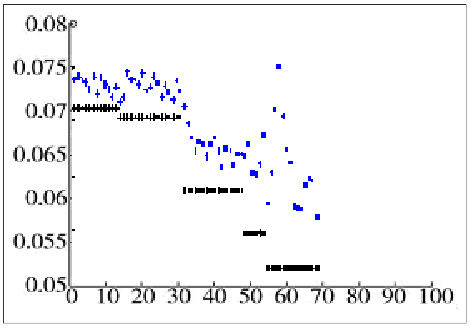

**Figure 3** Optimal fitness value of the gene after each inheritance

**Table 2** Threat index of enemy aircraft to our aircraft

| | **MBT1** | **MBT2** | **MBT3** | **The index threatens the entire squadron** |
|---|---|---|---|---|
| MBD1 | *0.6975* | *0.214 7* | *0.3575* | *1.2697* |
| MBD2 | *0.6324* | *0.9058* | *0.6649* | *2.2031* |
| MBD3 | *0.5469* | *0.9134* | *0.7576* | *2.2179* |
| MBD4 | *0.2785* | *0.1270* | *0.6706* | *1.0761* |

**Table 3** Fire distribution board

| **MBD** | ***first*** | ***2*** | ***2*** | ***3*** | ***3*** | ***4*** |
|---|---|---|---|---|---|---|
| TL($\pi_g$) | *first* | *2* | *3* | *4* | *5* | *6* |
| MBT | *first* | | *2* | | *3* | |

The decision to coordinate the attack can be calculated as follows:

Our aircraft, UAV1, uses two missiles to attack targets 1 and 2.

Our UAV2 aircraft uses 2 missiles to attack targets 2 and 3.

Our UAV3 aircraft used 2 missiles to attack targets 3 and 4.

## 3. Conclusion

The advent of UAVs has revolutionized the landscape of aerial warfare. The precision and efficacy of UAVs in coordinated attack missions are paramount in drone-involved aerial combat. The optimization of joint attack decisions for UAVs, therefore, has drawn significant scholarly and practical interest. This paper has presented a novel approach that leverages the computational power of genetic algorithms to enhance the decision-making process in UAV operations.

Through simulation research, this study has demonstrated the utility of genetic algorithms in calculating a precise threat index and in refining attack decisions—two interlinked aspects that are vital in the context of air combat. The application of genetic algorithms facilitates the rapid and accurate determination of the threat index and fitness function, which are essential for the strategic deployment of UAVs. Moreover, the genetic algorithm serves as a surrogate for the human commander, adeptly managing the distribution of firepower among UAVs. This innovative method stands to significantly improve the operational efficiency and combat effectiveness of UAVs, ultimately playing a pivotal role in achieving victory.

The implications of this research are far-reaching, suggesting that the integration of genetic algorithms into UAV command systems could mark a paradigm shift in aerial warfare tactics. By automating critical decision-making processes and optimizing resource allocation, UAVs equipped with genetic algorithm-based systems could deliver superior performance, ensuring swift and decisive outcomes in future aerial engagements. The findings of this paper underscore the transformative potential of genetic algorithms in military technology, heralding a new era of automated warfare where speed, accuracy, and adaptability are the keys to triumph.

## Compliance with ethical standards

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### *Disclosure of Conflict of interest*

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential sources of interest.

### *Author Contributions*

The authors have made a substantial direct and intellectual contribution to the work and approved it for publication. Each author contributed equally to all sections of the paper.

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## Author’s short biography

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