Evaluation of attack capability of UAV intelligent swarm based on AHP Fuzzy Evaluation

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Abstract: In order to evaluate the attack ability of UAV intelligent swarm, the evaluation index system of UAV intelligent swarm attack capability is established, the factors influencing the attack capability of UAV intelligent swarm are analyzed, the capability evaluation model is established, and the weight of each factor is determined by AHP, and finally the effectiveness index is evaluated by fuzzy evaluation matrix [1]. The results show that the evaluation results are objective and reasonable, which can provide theoretical reference for the optimal design and use of UAV intelligent swarm system.

1. Introduction
As a new type of attack force, UAV intelligent swarm has obvious advantages. It has many capabilities, such as distributed perception, target recognition, autonomous decision-making, collaborative planning and attack, which is expected to bring a new strike style. At present, the research on UAV path planning, task allocation, network communication and so on is mostly focused on single function, while there are few theoretical methods to study its strike capability from the perspective of completing the strike task. In the complex battlefield environment of the future, it is of great significance to improve the ability of maneuver, reconnaissance, control, protection and strike among UAV swarms to achieve the optimal overall strike capability. Therefore, the evaluation method based on AHP and fuzzy comprehensive evaluation is proposed to carry out the evaluation of UAV intelligent swarm attack capability.

2. Evaluation index system of UAV intelligent swarm attack capability

2.1. integrated mobility
The integrated mobility capability reflects the ability of UAV intelligent swarm system to overcome all kinds of natural and man-made obstacles, quickly transfer positions, fast March and March battle conversion in order to complete tasks quickly and accurately. The corresponding secondary indexes include maximum flight range, maximum flight speed, acceleration, maneuvering positioning accuracy, steering ability and emergency capability.

2.2. reconnaissance and surveillance capability
The reconnaissance and surveillance capability reflects the ability of UAV intelligent swarm system to detect the battlefield situation within the enemy's control range, which can be considered from the aspects of intelligence reconnaissance and battlefield link monitoring. The corresponding secondary
indicators include cruise time, target detection probability, tracking and positioning error, reconnaissance altitude and reconnaissance distance.

2.3. command and control capability
Command and control capability reflects the information level of UAV intelligent swarm system, and reflects the ability to plan and control UAV according to the battlefield situation. It can be considered from the aspects of network communication, task planning and collaborative control. The corresponding secondary indicators include the maximum communication distance, packet loss rate, transmission delay, response planning time, unit control accuracy and swarm control accuracy.

2.4. overall protection capability
The overall protection capability refers to the ability to resist the enemy's attack and destruction by taking various protective means and measures, which can be considered from the aspects of anti-reconnaissance and surveillance, anti-precision strike, interference and anti-jamming. The corresponding secondary indexes include stealth efficiency, jamming efficiency, protection disposal time, anti-jamming efficiency and anti damage efficiency.

2.5. fire strike capability
Firepower attack capability refers to the ability to carry out accurate strike amount against enemy targets, which can be considered from the aspects of target coverage and comprehensive damage. The corresponding secondary indicators include maximum projection distance, penetration probability, strike accuracy, kill radius and cooperative strike time.

3. Analytic hierarchy process [2]

3.1. determining index weight

3.1.1. establish judgment matrix
Experts judge the importance of each element in the index system and express it by numerical value. Here, the 1-9 scaling method [3] is used to form the judgment matrix Q: for n index elements

\[ Q = \begin{pmatrix} q_{11} & \cdots & q_{1n} \\ \vdots & \ddots & \vdots \\ q_{n1} & \cdots & q_{nn} \end{pmatrix} \]

(1)

3.1.2. hierarchical single sort
Hierarchical single ranking is to calculate the eigenvalue and eigenvector of judgment matrix, and the components of eigenvector M corresponding to the largest eigenvalue \( \lambda_{\text{max}} \) can be used as the weight of each element. In this paper, the square root method is used to solve \( \lambda_{\text{max}} \) and M, and the final normalization treatment can obtain the following formula:

\[ QM = \begin{pmatrix} q_{11} & \cdots & q_{1n} \\ \vdots & \ddots & \vdots \\ q_{n1} & \cdots & q_{nn} \end{pmatrix} \begin{pmatrix} m_1 \\ m_2 \\ \vdots \\ m_n \end{pmatrix} = \lambda \begin{pmatrix} m_1 \\ m_2 \\ \vdots \\ m_n \end{pmatrix} \]

\[ \overline{m_i} = \sqrt[n]{\prod_{j=1}^{n} q_{ij}}, \quad m_i = \frac{m_i}{\sum_{i=1}^{n} m_i} \]

(2)

3.1.3. consistency test [4]
The random consistency index CR was defined

\[ CR = CI / RI \]

Define consistency index CI:

\[ CI = \lambda_{\text{max}} - n / n - 1, \quad \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} m_j / m_i \]

(3)
RI is defined as the average random consistency index, and the values are shown in Table 1 [5].

| Order (n) | RI  |
|-----------|-----|
| 1         | 0   |
| 2         | 0   |
| 3         | 0.52|
| 4         | 0.89|
| 5         | 1.12|
| 6         | 1.26|
| 7         | 1.36|
| 8         | 1.41|
| 9         | 1.46|
| 10        | 1.49|
| 11        | 1.52|
| 12        | 1.54|

Only when CR < 0.1, it means that the consistency of the comparison matrix passes the test, otherwise, the relationship between the elements of the judgment matrix needs to be adjusted until the consistency requirements are met.

4. **Fuzzy comprehensive evaluation method [6-9]**

Fuzzy comprehensive evaluation is an evaluation method based on fuzzy mathematics to make an overall evaluation of things or objects restricted by many factors. Its basic idea is to use membership to replace belonging or not. Fuzzy comprehensive evaluation needs to complete the following general steps.

4.1. **determine the evaluation factors and levels**

Suppose \( U = \{u_1, u_2, \ldots, u_n\} \) is n evaluation indexes of the evaluated object, and n is the number of evaluation indexes. According to the attribute of the evaluation index, it can be divided into the first level evaluation index, the second level, and the third level evaluation index, and so on.

Suppose \( V = \{v_1, v_2, \ldots, v_m\} \) is the set of evaluation grades and m is the number of grades. The purpose of evaluation set is to find out the effectiveness of rating objectives in the minds of users and experts. Therefore, the following evaluation sets can be established:

\[ V = \{excellent, good, qualified, poor\} \]

4.2. **building single factor fuzzy evaluation matrix**

Based on the single factor evaluation, the membership degree of the evaluated object is determined, and then the single factor fuzzy evaluation matrix is obtained:

\[
K = \begin{bmatrix}
    k_{11} & k_{12} & \cdots & k_{1n} \\
    k_{21} & k_{22} & \cdots & k_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    k_{n1} & k_{n2} & \cdots & k_{nn}
\end{bmatrix}
\] (5)

4.3. **comprehensive evaluation of multi factor indexes**

The fuzzy comprehensive evaluation model can be obtained as follows:

\[
A = \eta \ast K = (\eta_1, \eta_2, \ldots, \eta_n) \ast \begin{bmatrix}
    k_{11} & k_{12} & \cdots & k_{1n} \\
    k_{21} & k_{22} & \cdots & k_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    k_{n1} & k_{n2} & \cdots & k_{nn}
\end{bmatrix} = (a_1, a_2, \ldots, a_n)
\] (6)

Where \( \eta \) is the weight vector.

4.4. **analyze the results of fuzzy comprehensive evaluation**

(1) The principle of maximum membership degree can be used to compare the size of \( (a_1, a_2, \ldots, a_n) \), the largest one is the quantitative evaluation results of attack capability of UAV intelligent swarm system, and the corresponding evaluation concentration position is the qualitative evaluation result.

(2) The weighted average principle is adopted:

\[ a_j = \sum_{i=1}^{n} b_ik_{ij} \] (7)
Where \( b_i(i = 1, 2, \ldots, n) \) is the weight of each factor.

5. **UAV intelligent swarm attack capability evaluation system**
The comprehensive way of AHP and fuzzy theory is adopted to evaluate the attack ability. The qualitative and quantitative methods are combined. The weight coefficient is given by AHP, and the final evaluation is made by fuzzy theory.

5.1. **determination of weight coefficient**
Employ more than 10 experts to engage in equipment demonstration, test appraisal, scientific research and teaching, command and training and other professional work, and evaluate and score the five first level indicators and corresponding secondary indicators of overall mobility, overall protection, fire strike, command and control, and reconnaissance and surveillance capability according to the importance comparison method of analytic hierarchy process (AHP). See the final scoring results, so as to determine the weight of all levels of indicators.

5.1.1. **first level index weight**
The relationship between the elements filled in by experts is abstracted into a judgment matrix, and the judgment matrix for a certain index is as follows:

\[
P = \begin{pmatrix}
1 & 1/3 & 1/3 & 1 & 1/5 \\
3 & 1 & 1 & 3 & 1/3 \\
3 & 1 & 1 & 3 & 1/3 \\
1 & 1/3 & 1/3 & 1 & 1/5 \\
5 & 3 & 3 & 5 & 1
\end{pmatrix}
\]

(8)

The square root method is used to calculate the eigenvector \( \mathbf{M}_i \) of the largest eigenvalue of the decision matrix:

\[
M_1 = \sqrt[5]{1 \times 1/3 \times 1/3 \times 1 \times 1/5} = 0.467
\]

\[
M_2 = \sqrt[5]{3 \times 1 \times 1 \times 3 \times 1/3} = 1.246
\]

\[
M_3 = \sqrt[5]{1 \times 1/3 \times 1/3 \times 1} = 1.246
\]

\[
M_4 = \sqrt[5]{1 \times 1/3 \times 1 \times 1/5} = 0.467
\]

\[
M_5 = \sqrt[5]{5 \times 3 \times 3 \times 5 \times 1} = 2.954
\]

(9)

Normalization was performed:

\[
\sum_{i=1}^{5} M_i = 0.467 + 1.246 + 1.246 + 0.467 + 2.954 = 6.38
\]

(10)

The weight of each of these five indicators is calculated

\[
M_i = \frac{M_i}{\sum_{i=1}^{5} M_i} = \begin{cases} 
0.073 & \text{for } M_1 \\
0.195 & \text{for } M_2 \\
0.195 & \text{for } M_3 \\
0.073 & \text{for } M_4 \\
0.464 & \text{for } M_5
\end{cases}
\]

(11)

Therefore, the eigenvector: \( \mathbf{M}_o = [0.073, 0.195, 0.195, 0.073, 0.464] \), the corresponding maximum eigenvalue \( \lambda_{\text{max}} = 5.055 \). The consistency index of judgment matrix \( CI = 0.014 \), the relative consistency index \( CR = CI / RI = 0.012 < 0.10 \), meeting the requirements of consistency.

5.1.2. **secondary index weight**
The relationship of index elements filled in by experts is abstracted into judgment matrix, and the judgment matrix corresponding to a certain index is as follows:
According to the calculation method of the weight eigenvector and the maximum eigenvalue of the secondary index, it can be concluded that:

The maximum eigenvalue $\lambda_{\text{Max}}$ corresponding to eigenvector $\mathbf{P}_1$ is $6.188$. The index $C_I = 0.038$, the relative consistency index $C_R = C_I / R_I = 0.03 < 0.10$, which meet the requirements of consistency.

The maximum eigenvalue $\lambda_{\text{Max}}$ corresponding to eigenvector $\mathbf{P}_2$ is $5.055$. $C_I = 0.014$ and $C_R = C_I / R_I = 0.012 < 0.10$, which meet the requirements of consistency.

The maximum eigenvalue $\lambda_{\text{Max}}$ corresponding to eigenvector $\mathbf{P}_3$ is $6.143$. The index $C_I = 0.028$, relative consistency index $C_R = C_I / R_I = 0.023 < 0.10$, which meet the requirements of consistency.

The maximum eigenvalue $\lambda_{\text{Max}}$ corresponding to the eigenvector $\mathbf{P}_4$ is $5.055$. $C_I = 0.014$ and $C_R = C_I / R_I = 0.012 < 0.10$.

The maximum eigenvalue $\lambda_{\text{Max}}$ corresponding to eigenvector $\mathbf{P}_5$ is $5.088$. $C_I = 0.002$, relative consistency index $C_R = C_I / R_I = 0.002 < 0.10$.

5.2. adaptability evaluation based on Fuzzy Theory

5.2.1. determine the evaluation factor set and evaluation set

To use the fuzzy theory to evaluate, we must first determine the evaluation factor set and the evaluation set. As can be seen from Figure 1, the factor set can be divided into two levels.

5.2.2. construct judgment matrix and calculate evaluation results

The fuzzy evaluation of each evaluation index can be obtained by the above method, as shown in Table 2:

| Criteria domain | weight $M_i^\xi$ | Criteria domainPi | weight $W_P^\xi_i$ | On the hierarchy of comments |
|-----------------|-----------------|-------------------|-------------------|----------------------------|
| Integrated mobility | 0.073 | | | |
| Maximum flight range | 0.069 | 0.4 | 0.3 | 0.2 | 0.1 |
| Maximum flight speed | 0.186 | 0.3 | 0.3 | 0.2 | 0.2 |
| Capability                                      | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 |
|------------------------------------------------|---------|---------|---------|---------|---------|
| Acceleration                                   | 0.186   | 0.3     | 0.3     | 0.3     | 0.1     |
| Mobile positioning accuracy                    | 0.416   | 0.4     | 0.4     | 0.1     | 0.1     |
| Steering ability                               | 0.069   | 0.5     | 0.3     | 0.1     | 0.1     |
| Emergency capability                           | 0.074   | 0.3     | 0.2     | 0.3     | 0.2     |
| Cruise time                                    | 0.195   | 0.5     | 0.4     | 0.1     | 0        |
| Target detection probability                   | 0.195   | 0.4     | 0.1     | 0.4     | 0.1     |
| Tracking and positioning error                 | 0.464   | 0.3     | 0.3     | 0.2     | 0.2     |
| Reconnaissance altitude                        | 0.073   | 0.4     | 0.3     | 0.2     | 0.1     |
| Reconnaissance distance                        | 0.073   | 0.4     | 0.4     | 0.1     | 0.1     |
| Maximum communication distance                 | 0.420   | 0.5     | 0.3     | 0.1     | 0.1     |
| Packet loss rate                               | 0.078   | 0.4     | 0.3     | 0.2     | 0.1     |
| Transmission delay                             | 0.078   | 0.3     | 0.3     | 0.2     | 0.2     |
| Response planning time                         | 0.036   | 0.4     | 0.3     | 0.1     | 0.2     |
| Unit control accuracy                          | 0.194   | 0.4     | 0.4     | 0.1     | 0.1     |
| Swarm control accuracy                         | 0.194   | 0.4     | 0.4     | 0.1     | 0.1     |
| Stealth efficiency                             | 0.064   | 0.4     | 0.3     | 0.2     | 0.1     |
| Jamming efficiency                             | 0.064   | 0.4     | 0.3     | 0.2     | 0.1     |
| Protection disposal time                       | 0.152   | 0.3     | 0.3     | 0.3     | 0.1     |
| Anti jamming efficiency                        | 0.360   | 0.3     | 0.3     | 0.2     | 0.2     |
| Anti damage efficiency                         | 0.360   | 0.3     | 0.3     | 0.2     | 0.2     |
| Maximum projection distance                    | 0.057   | 0.3     | 0.4     | 0.2     | 0.1     |
| Penetration probability                        | 0.161   | 0.5     | 0.3     | 0.1     | 0.1     |
| Strike accuracy                                | 0.460   | 0.4     | 0.4     | 0.1     | 0.1     |
| Kill radius                                    | 0.161   | 0.4     | 0.3     | 0.1     | 0.2     |
| Coordinated strike time                        | 0.161   | 0.3     | 0.3     | 0.3     | 0.1     |
According to the values in Table 2, the following fuzzy transformations can be made:

\[ A_i = W_i \cdot K_i, \quad i = 1, 2, \ldots, n \]  

The fuzzy evaluation \( A_i \) \((i = 1, 2, \ldots, n)\) of each evaluation index \( p \) in the first level is as follows:

\[
A_1 = M_1 \cdot K_1 = (0.069\ 0.186\ 0.186\ 0.416\ 0.069\ 0.074) \cdot \\
\begin{bmatrix}
0.4 & 0.3 & 0.2 & 0.1 \\
0.3 & 0.3 & 0.2 & 0.2 \\
0.3 & 0.3 & 0.3 & 0.1 \\
0.4 & 0.4 & 0.1 & 0.1 \\
0.5 & 0.3 & 0.1 & 0.1 \\
0.3 & 0.2 & 0.3 & 0.2
\end{bmatrix}
\]

\[
= (0.3623\ 0.3342\ 0.1775\ 0.1260)
\]  

Similarly, the value of \( A_2, A_3, A_4, A_5 \) can be obtained:

\[
A_2 = (0.3731\ 0.2878\ 0.2122\ 0.1269) \\
A_3 = (0.4342\ 0.3388\ 0.1156\ 0.1114) \\
A_4 = (0.3128\ 0.3000\ 0.2152\ 0.1720) \\
A_5 = (0.3943\ 0.3517\ 0.1379\ 0.1161)
\]  

If \( A_i \) is combined into the first level evaluation matrix \( A = [A_1, A_2, A_3, A_4, A_5] \), the second level evaluation matrix is (using weighted algorithm) \([10]\):

\[
B = M^\frac{1}{2} A = (0.3897\ 0.3317\ 0.1566\ 0.1221)
\]  

As can be seen from the above results, 39% of the people think it is excellent, 33% of the people think it is good, 16% of the people think it is qualified, and 12% of the people think it is poor. The corresponding situation of the evaluation set score is shown in table 3 \([10-11]\).

| Evaluation set | excellent | good | qualified | bad |
|----------------|-----------|------|-----------|-----|
| assignment     | 100       | 80   | 60        | 40  |

Finally, the score of the UAV intelligent swarm cooperative attack system is as follows:

\[
\omega = (0.3897\ 0.3317\ 0.1566\ 0.1221) \cdot \\
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
= 79.786
\]  

6. Conclusion

In this paper, through the analysis of several factors that affect the attack capability of UAV intelligent swarm system, a comprehensive capability evaluation system model is established. At the same time, combining AHP and fuzzy comprehensive evaluation method, it provides ideas and methods for UAV intelligent swarm system strike capability evaluation. The evaluation results have certain objectivity, which can be used for the next optimization and development of UAV intelligent swarm, the system provides a certain basis.

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