Efficiency evaluation of intelligent swarm based on AHP entropy weight method

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Abstract: With the rapid development of high-tech, UAV intelligent swarm is expected to become an important means to deal with the complex situation environment in the future due to its intelligent and high cost-effective characteristics. UAV intelligent swarm is a nonlinear complex system, and the traditional single effectiveness evaluation method can not effectively reflect the system capability. Therefore, this paper proposes an evaluation method based on AHP entropy weight method for UAV intelligent swarm system effectiveness evaluation. The final weight is obtained by combining the two weights, which can reduce the impact of subjective factors. Finally, the feasibility of the proposed method is verified by simulation experiments.

Mathematics Subject Classification 2010: 62P applications

1. INTRODUCTION

At present, due to the lack of evaluation index system of UAV intelligent swarm, and the lack of quantification and refinement of technical indicators, this paper will carry out the research on the index system of UAV intelligent swarm from the perspective of completing the task of intelligent swarm, select effective effectiveness evaluation method, optimize the evaluation index system, and use the effectiveness evaluation results of UAV intelligent swarm to guide the large-scale intelligent swarm. The system architecture, intelligent perception, mission planning and other key technologies are optimized to achieve the optimal comprehensive efficiency of the swarm system, which provides the basis for the development and validation of UAV intelligent swarm system, and supports the UAV swarm system to perform tasks intelligently.

The confidence degree of system effectiveness evaluation results is largely affected by many factors, such as whether the evaluation index system is perfect, whether the evaluation method is feasible, and whether the evaluation set is reasonable. The evaluation results are greatly affected by individual subjectivity when AHP is used to evaluate the system effectiveness. The combination of entropy weight method and AHP method can effectively improve the objectivity of evaluation results. Therefore, this paper considers the combination optimization weighting method based on AHP and entropy weight and considering the decision-maker preference and the consistency of weighting method to evaluate the effectiveness of UAV intelligent swarm. Finally, the simulation results show that the method is feasible.

2. SYSTEM EVALUATION INDEX SYSTEM

The UAV intelligent swarm is designed as an intelligent system integrating reconnaissance, attack, jamming and evaluation, which can realize the functions of rapid swarm launching, complex situation awareness, whole network communication transmission, intelligent online decision-making, and
independent cooperative attack. To carry out the effectiveness evaluation of UAV intelligent swarm, it is necessary to establish a scientific and comprehensive evaluation index system. In the process of constructing the index system, the principles of systematicness, hierarchy, independence and testability should be fully considered. Through continuous modification and improvement, the index system including index set and evaluation set should be established finally.

2.1. INDEX SET
The evaluation index set of UAV intelligent swarm system is established, which is divided into three layers: the whole system effectiveness index layer, the single system index layer and the detailed index layer, as shown in Figure 1.

![Fig.1 Effectiveness Index Structure Chart of UAV intelligent swarm system](image)

2.1.1 COMMAND AND CONTROL SUBSYSTEM
Command and control subsystem reflects the information level of UAV intelligent swarm system, and reflects the ability to plan and control UAV intelligent swarm cooperation according to complex situation. It can be considered from networking communication, task planning, collaborative control, etc. It includes transmission delay, bit error rate, data transmission rate, maximum communication distance, packet loss rate, node density, task response time, task adjustment time, individual control accuracy, swarm control accuracy, formation response time, etc.

2.1.2 STRIKE COVERAGE SUBSYSTEM
The attack coverage subsystem reflects the ability to carry out accurate attack on the target, which can be considered from the aspects of fire coverage and damage, including flight range, maximum projection distance, target search time, target vulnerability, strike accuracy, kill radius, cooperative strike efficiency, fire response time, etc.

2.1.3 INTEGRATED DEFENSE SUBSYSTEM
The integrated defense subsystem refers to the ability to resist attack and damage by taking various protective means and measures, which can be considered from the aspects of anti reconnaissance jamming and anti strike damage. It includes anti-jamming efficiency, radar reflection cross section, signal adjustment error, overload, damage evaluation efficiency, etc.

2.2. ASSESSMENT SET
Evaluation set is a set of elements that evaluate the evaluation results. The number and size of the elements can be set according to the evaluation object and the complexity of the evaluation results.
Here, five elements can be set as I, II, III, IV and V, respectively representing extremely strong, strong, general, insufficient and low efficiency of UAV intelligent swarm system.

2.3. EVALUATION INDEX
The evaluation index system of the system includes rigid index and flexible index. The rigid index is an objective evaluation of the characteristics of the system itself, which can be scored according to the standard. Flexibility index is a subjective evaluation index related to the system, so whether the assessors are familiar with the system, understand the index system, whether the standards before and after the evaluation are consistent, whether the evaluation is independent and undisturbed, etc., especially have a great impact on the flexibility index. Therefore, the appraisers should be based on the principles of comprehensiveness, independence and impartiality, and make objective and reasonable judgments as far as possible.

3. COMBINATION WEIGHTING QUANTITATIVE EVALUATION ALGORITHM
Based on the idea of combination weighting, entropy weight evaluation method and AHP method are combined to evaluate the effectiveness of UAV intelligent swarm system.

3.1. ENTROPY WEIGHT EVALUATION METHOD
The entropy weight method mainly determines the weight coefficient by using the information content of a single index, and the specific steps are as follows:

(1) Establish judgment matrix
Suppose that the number of evaluation samples and corresponding evaluation indexes are m and n, the index value \( P_j \) \((i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n)\) \( P = (P_{jm})_{mn} \) represents the evaluation value of the jth expert for the ith index \(^{[1,2]}\).

\[
P = \begin{pmatrix}
P_{11} & \cdots & P_{1n} \\
\vdots & \ddots & \vdots \\
P_{m1} & \cdots & P_{mn}
\end{pmatrix}
\]  

(2) Normalized index matrix
Through normalization, the dimensionless index matrix is obtained:

\[
Q = (q_{jm})_{mn}
\]

\[
q_{ij} = \frac{P_{ij}}{\sum_{i=1}^{m} P_{ij}}
\]  

(3) Determine objective index weight
The entropy of the j-th index of the sample \( W_j \) is as follows:

\[
W_j = \frac{1}{\ln m} \sum_{i=1}^{m} S_{ij} \ln S_{ij}
\]  

\( i = 1, 2, 3, \ldots m; j = 1, 2, 3, \ldots n \)

In the above formula, \( S_{ij} \) represents the proportion of the i-th sample under the j-th index, and \( S_{ij} \) is:
\[ s_{ij} = \frac{q_{ij}}{\sum_{j=1}^{n} q_{ij}} \quad (4) \]

Then the entropy weight \( h_j \) of the \( j \) index is as follows:

\[ h_j = \frac{1 - w_j^\beta}{n - \sum_{j=1}^{n} w_j^\beta} \quad \text{if } i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \quad (5) \]

Finally, the objective weight vector of the index is as follows:

\[ H = (h_1, h_2, \ldots, h_n)^T \quad (6) \]

When the entropy value \( h_j \) is close to 1, the index weight is easy to lead to error when the entropy weight method is used, and the evaluation result is lack of rationality \[^3\]. At this time, the traditional entropy weight method can be modified by using formula (7), and the influence of entropy weight can be controlled in a certain reasonable range. The entropy weight corresponding to \( j \) index is as follows (8):

\[ h_j = \frac{1}{10} \sum_{j=1}^{n} (1 - w_j^\beta) \quad (7) \]

\[ h_j = \frac{1 - w_j^\beta + \frac{1}{10} \sum_{j=1}^{n} (1 - w_j^\beta)}{n - \sum_{j=1}^{n} \left\{ w_j^\beta + \frac{1}{10} \sum_{j=1}^{n} (1 - w_j^\beta) \right\}} \quad (8) \]

3.2. AHP EVALUATION METHOD \[^{14-5}\]

(1) Building structural model

It is divided into three levels: the first is the target level, that is, the predetermined target or ideal state of the analysis problem; the second is the criteria layer, which is the criteria for evaluating the ranking of schemes; the third is the scheme layer, which is the optional decision-making scheme \[^6\].

(2) Establish judgment matrix

By comparing the indexes by two and assigning their importance, the \( n \times n \) judgment matrix \( A \) is obtained. The element \( a_{ij} \) in the matrix \( A \) represents the relative importance of the \( i \)th index and the \( j \)th index.

Through the expert scoring method, the judgment matrix is obtained by comparing \( n \) elements in each layer \( A = (a_{ij})_{n \times n} \). For the above elements, \( a_{ij} \) shall meet the following conditions:

\[ a_{ij} > 0; \]

\[ a_{ij} = \frac{1}{a_{ji}} \text{ if } i \neq j; \quad (9) \]

\[ a_{ii} = 1(i, j = 1, 2, 3, \ldots, n) \]

(3) Calculate weight vector

The method to solve the approximate value of \( \lambda_{\text{max}} \) is as follows:
1) Calculate the product of the elements in each row of the judgment matrix to the n-th power:

\[ w^*_j = \sqrt[n]{ \prod_{i=1}^{n} a_{ij} } \]

\[ i = 1, 2, \ldots, n \]

2) Weight calculation

\[ w'_j = \frac{w^*_j}{\sum_{j=1}^{n} w^*_j} \]

\[ j = 1, 2, \ldots, n \]

The eigenvector \( w = (w_1, w_2, w_3, \ldots, w_n)^T \) is the weight vector of \( B \) relative to \( A \).

3) Sum the elements of each column of the judgment matrix

\[ s_j = \sum_{i=1}^{n} a_{ij}, j = 1, 2, \ldots, n \]

4) Solving the maximum eigenvalue \( \lambda_{\text{max}} \) of judgment matrix

\[ \lambda_{\text{max}} = \sum_{j=1}^{n} w^*_j s_j, j = 1, 2, \ldots, n \]

(4) Calculate the combination weight and conduct consistency test\(^{[6-7]}\)

If the consistency index is CI, then there are:

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \]

The average random consistency index was RI, and the consistency ratio CR was calculated

\[ CR = \frac{CI}{RI} \]

According to the average random consistency index \(^{[8]}\), when the consistency ratio CR < 0.10, the judgment matrix is considered to pass the consistency test, and the solution is effective weight, otherwise, the judgment matrix should be re estimated \(^{[6-7]}\).

3.3. COMBINATION WEIGHTING

The index weight obtained by AHP focuses on the decision-maker's subjective preference \(^{[9]}\). In order to eliminate the influence of subjective factors, the combination weight \( w_j \) of evaluation index can be obtained by combining AHP with entropy weight method.

\[ w_j = \delta w^*_{ij} + (1-\delta)w^j \]

Where \( \delta \) represents the weight ratio, and \( \delta \in [0,1] \).

4. EFFECTIVENESS EVALUATION EXAMPLE AND RESULT ANALYSIS

4.1 EXAMPLES OF EFFECTIVENESS EVALUATION

The effectiveness of UAV intelligent swarm system is evaluated

\[ G = [G_1, G_2, G_3] \]
In formula (18), \( G_1 \) is the index matrix of command and control subsystem; \( G_2 \) is the index matrix of strike coverage subsystem; \( G_3 \) is the index moment of integrated defense subsystem, which can be known from the index system: \( g_i \) represents the lower level index vector of each subsystem, \( g \) represents the lowest index in the index system.

Because different indicators have different dimensions, it is necessary to standardize the indicators here, and define the conversion rule [10] as

\[
g^{*}_{ij} = \begin{cases} 
\frac{(g_{ij} - g_{ij}^\text{min})}{(g_{ij}^\text{max} - g_{ij}^\text{min})} & \text{if } g_{ij} \leq g_{ij}^\text{max} \\
1 - \frac{(g_{ij} - g_{ij}^\text{min})}{(g_{ij}^\text{max} - g_{ij}^\text{min})} & \text{if } g_{ij} > g_{ij}^\text{max}
\end{cases}
\] (18)

In formula (21), where "ij" corresponds to the j-th index of the i-th evaluation subsystem in the index set.

After pretreatment, different evaluation indexes no longer have dimensions, which lays the foundation for the next step of weight calculation.

The specific evaluation index values are shown in Table 1.

| Serial number | \( g_1 \) | \( g_2 \) | \( g_3 \) | \( g_4 \) | \( g_5 \) | \( g_6 \) | \( g_7 \) | \( g_8 \) | \( g_9 \) | \( g_{10} \) |
|---------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 1             | 0.9402  | 0.8930  | 0.6702  | 0.9897  | 0.6011  | 0.6243  | 0.8248  | 0.9621  | 0.9235  | 0.9512  |
| 2             | 0.9006  | 0.6582  | 0.9604  | 0.5123  | 0.3021  | 0.2215  | 0.6815  | 0.4523  | 0.2341  | 0.1256  |
| 3             | 0.7102  | 0.7806  | 0.7641  | 0.9322  | 0.3021  | 0.7915  | 0.6815  | 0.4523  | 0.2341  | 0.9046  |

| Serial number | \( g_{11} \) | \( g_{12} \) | \( g_{13} \) | \( g_{14} \) | \( g_{15} \) | \( g_{16} \) | \( g_{17} \) | \( g_{18} \) | \( g_{19} \) | \( g_{20} \) |
|---------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 1             | 0.7821   | 0.9402   | 0.6702   | 0.3897   | 0.2011   | 0.6243   | 0.8248   | 0.1621   | 0.9235   | 0.6502   |
| 2             | 0.7033   | 0.9301   | 0.3545   | 0.8569   | 0.4562   | 0.7821   | 0.5634   | 0.9711   | 0.9254   | 0.3545   |
| 3             | 0.2543   | 0.2216   | 0.2236   | 0.5867   | 0.8541   | 0.4258   | 0.9531   | 0.9765   | 0.1242   | 0.2236   |

| Serial number | \( g_{21} \) | \( g_{22} \) | \( g_{23} \) | \( g_{24} \) |
|---------------|----------|----------|----------|----------|
| 1             | 0.3654   | 0.8897   | 0.9011   | 0.6243   |
| 2             | 0.7569   | 0.4562   | 0.5621   | 0.5634   |
| 3             | 0.6867   | 0.1541   | 0.4258   | 0.9531   |

### 4.1.1 SOLVING WEIGHT VALUE BY ENTROPY WEIGHT METHOD

Firstly, the original data matrix \( X_1 \) of command and control subsystem is normalized, and the matrix \( Y_1 \) is obtained as follows

\[
Y_1 = \begin{bmatrix} 0.3606 & 0.3090 & 0.2759 & 0.4066 & 0.4087 & 0.3813 & 0.3770 & 0.5154 & 0.6636 & 0.4801 & 0.4496 \\
0.2530 & 0.2823 & 0.4011 & 0.2105 & 0.2966 & 0.1353 & 0.3113 & 0.2423 & 0.1682 & 0.6634 & 0.4043 \\
0.2764 & 0.3318 & 0.3080 & 0.2596 & 0.4034 & 0.3113 & 0.2423 & 0.1682 & 0.4565 & 0.1462 \\
\end{bmatrix}
\] (19)

The information entropy vector is calculated by equation (3)

\[
S = \begin{bmatrix} 0.3240 & 0.3335 & 0.3318 & 0.3346 & 0.3157 & 0.3198 & 0.3307 & 0.3136 & 0.2729 & 0.3258 & 0.2559 \\
\end{bmatrix}
\] (20)

According to formula (5), the weight is calculated
Similarly, according to the entropy weight method, the weights of each index of the strike coverage subsystem and the comprehensive defense subsystem are calculated as follows:

\[ w^1 = \{0.1362, 0.1251, 0.1161, 0.1228, 0.1202, 0.1159, 0.1174, 0.1463\} \]

\[ w^2 = \{0.2029, 0.1881, 0.2226, 0.1963, 0.1900\} \]

In the above formula, \( w^1 \) is the weight of each index of the strike coverage subsystem, and \( w^2 \) is the weight of each index of the integrated defense subsystem.

### 4.1.2 Analytic Hierarchy Process for Weight Calculation

Firstly, the consistency of judgment matrix \( A_1, A_2, A_3 \) was tested, and the results showed that CR was 0.0549, 0.0233, and 0.0982, respectively, which passed the test. Then, the eigenvectors corresponding to the maximum eigenvalues of the three matrices are solved:

\[ V^1 = \{0.0552, 0.0297, 0.0993, 0.0290, 0.0639, 0.0182, 0.2123, 0.0294, 0.0294, 0.0936, 0.1368\} \]

\[ V^2 = \{0.0418, 0.0301, 0.1510, 0.1132, 0.3058, 0.0542, 0.2166, 0.0873\} \]

\[ V^3 = \{0.0800, 0.3766, 0.1736, 0.1213, 0.2484\} \]

### 4.1.3 Combination Weighting to Solve the Final Weight

In order to eliminate the adverse effects of subjective and objective factors on the effectiveness evaluation of UAV intelligent swarm system, the index weights obtained by the above two methods are weighted and superimposed. When \( \delta = 0.65 \), the weight after the combination of weights is the best.

\[ w_j = 0.65 \cdot [w^1 \cdot w^2 \cdot w^3] + 0.35 \cdot [w^1 \cdot w^2 \cdot w^3] \]

After combination weighting, the final weights of each index in the effectiveness index system of UAV intelligent swarm system are obtained, as shown in Table 2.

| Index | \( g_1 \) | \( g_2 \) | \( g_3 \) | \( g_4 \) | \( g_5 \) | \( g_6 \) | \( g_7 \) | \( g_8 \) | \( g_9 \) | \( g_{10} \) |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| \( W_j \) | 0.0848 | 0.1604 | 0.0702 | 0.0680 | 0.0783 | 0.0655 | 0.1306 | 0.0681 | 0.0714 | 0.0956 |

| Index | \( g_{11} \) | \( g_{12} \) | \( g_{13} \) | \( g_{14} \) | \( g_{15} \) | \( g_{16} \) | \( g_{17} \) | \( g_{18} \) | \( g_{19} \) | \( g_{20} \) |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| \( W_j \) | 0.1071 | 0.1032 | 0.0919 | 0.1283 | 0.1194 | 0.1852 | 0.0943 | 0.1521 | 0.1257 | 0.1599 |

| Index | \( g_{21} \) | \( g_{22} \) | \( g_{23} \) | \( g_{24} \) |
|-------|-------|-------|-------|-------|
| \( W_j \) | 0.2541 | 0.2055 | 0.1701 | 0.2104 |

### 4.1.4 Effectiveness Evaluation Results

The result set function is defined as follows:
The effectiveness of the subsystem is evaluated by gray swarming, and the swarming function is \[ f_j^k(x_j) \quad (28) \]
\[ k \in \{1, 2, 3, 4, 5\} \]

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\[ k \in \{1, 2, 3, 4, 5\} \]

The quantitative results are shown in Table 3.

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| System to be evaluated | I     | II    | III   | IV    | V     | Qualitative results |
|------------------------|-------|-------|-------|-------|-------|--------------------|
| Command and control    | 0.2892| 0.4332| 0.1238| 0.1751| 0.0918| II                 |
| Strike coverage        | 0.4523| 0.2154| 0.1352| 0.0872| 0.0438| I                  |
| Integrated defense     | 0.6121| 0.1546| 0.3753| 0.0876| 0.0911| I                  |

The overall effectiveness of UAV intelligent swarm system is quantitatively evaluated by using the index weight after combination weighting, and the overall effectiveness of UAV intelligent swarm system is evaluated by using weighted average fuzzy operator \[ f_j^k(x_j) \quad (28) \]. The qualitative result is II.

4.2 RESULT ANALYSIS

The above results show that command and control, strike coverage and integrated defense are level II, I and I respectively. The result of effectiveness evaluation of the UAV intelligent swarm system is level II, which is objective.

5. CONCLUDING REMARKS

This paper proposes to solve the problem of UAV intelligent swarm system effectiveness evaluation based on AHP entropy weight method. The feasibility of the method is verified by an example. This method can solve the problem of human subjective uncertainty caused by relying on expert scoring strategy to determine the weight, and improve the accuracy and objectivity of the effectiveness evaluation results. It has a certain reference value for the next optimization of intelligent system performance design.

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