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Evaluation of Unmanned Aerial Vehicles Cooperative Combat Effectiveness Based on Conditional Entropy Combination Weight Method

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ABSTRACT

For evaluating the cooperative combat effectiveness of unmanned aerial vehicles (UAVs), traditional entropy methods have an undue weight coefficient of the index due to its high degree of dispersion, and the interrelationship between the indices are not considered. To deal with this problem, this paper proposes a conditional entropy combination weighting method for evaluating the cooperative combat effectiveness of UAVs. Firstly, with the aim of establishing the UAV cooperative combat index system, the modified Delphi method has been combined with analytic hierarchy process (AHP) and interval estimation. This method has been used for estimating the degree of contribution of each index and to remove the indices that have a low contribution. Secondly, the principle of conditional entropy has been introduced for modifying the entropy method with the consideration of the interrelation between the indices. Finally, the modified entropy and AHP have been combined to assign the final weight in the UAV cooperative combat system. Testing results demonstrate that the index system established by this method is more comprehensive and reasonable as compared to that established by the traditional Delphi method. Compared with the single weighted method, this method is more suitable for the evaluation system of UAVs cooperative combat effectiveness.

Keywords: Cooperative Combat Capability; Interval Estimation; Analytic Hierarchy Process.

INTRODUCTION

In recent years, unmanned combat aircrafts are being increasingly used in modern battlefields (Dai and Long 2013). From earliest target drone training, reconnaissance, intelligence gathering, tracking, communication, and other auxiliary means of warfare to the current direct participation in combat. During the Vietnam war in the 1950s and 1970s, the Gulf war, and the NATO airstrikes over Yugoslavia, drones have been frequently used for military missions. The brilliant achievements of unmanned aerial vehicles (UAVs) in modern warfare have demonstrated that they can play a vital role in future information-based high-tech wars. The use of UAVs solves the problem of casualties and high costs. They can also adapt to different kinds of extreme environments and have other advantages that manned aircraft do not have. A UAV cooperative combat system involves a combination of UAVs with manned aircraft or other combat

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forces, thus forming an organic combat unit, and combines their advantages to avoid the limitation of a single combat platform (Zhu and Zhou 2005). Therefore, having a scientific evaluation method for the effectiveness of the UAV collaborative combat system is crucial.

The first step for evaluating the effectiveness of a UAV cooperative combat system is to establish a cooperative combat index system. In the traditional Delphi method, an indicator system is established by sending consultation tables to the experts in the relevant areas (Zhang and Jiang 2020). However, this is prone to problems such as the experts unwilling to modify their original incomplete opinions out of self-esteem. The traditional Delphi method is too subjective and uncertain, and this leads to incomplete or redundant selected indicators and an unreasonable indicator system. Although many modified methods have improved the defects of the traditional methods to some extent, they still have not been able to overcome the problem of uncertainty.

The determination of the weight of an index is the most crucial part of evaluating the effectiveness of a UAV cooperative combat system. The method of assigning weights to indices include the subjective analysis method, the objective analysis method, and the compound analysis method. The subjective analysis method includes the analytic hierarchy process (AHP) (Dong *et al.* 2006), the expert evaluation method (Li *et al.* 2020), and the least-squares method. Analytic hierarchy process is a method in which experts provide preference information of indicators by relying on their accumulated experience and knowledge, construct a judgment matrix, and calculate the weight by a reasonable calculation (Yao *et al.* 2019). During the application of AHP, each index in the ladder hierarchy is required to be independent of each other, and the possible interrelationship between each index in the hierarchy is ignored. Qin *et al.* (2020) added a network layer based on AHP and, by employing the analytic network process (ANP), described the interaction between different indicators. Although this method considers the relationship between indicators at different levels comprehensively, it still relies on the subjective experience of experts and lacks objectivity. In contrast, the objective analysis methods include the entropy method, the rough set method, the weighted analysis method, and the regression analysis method (Zhou *et al.* 2004), among which the entropy method is commonly used. This method relies on the instance data, and the weight obtained is definite and objective. However, during its application, the difference coefficient that is caused by the degree of dispersion of a certain index is too large, and this results in a single index influencing the final weight (Tian *et al.* 2020). In work by Huang *et al.* (2012), a modified entropy method, which uses AHP, is proposed, in which the difference coefficient of the index in pairs is compared to establish a judgment matrix, and the weight is estimated. This overcomes the situation where the weight of a single index is too large due to its large degree of dispersion. However, the method still does not take the interrelationship between the indices into account. The evaluation of the effectiveness of a UAV cooperative combat system studied in this work has a complex background and many influencing factors. The evaluation angle of the general weighting method is one-sided, and the result of the efficiency evaluation is inaccurate and thus cannot meet the requirements of the evaluation.

In order to address the abovementioned problems, in this work, the Delphi method has been modified, and the index system of cooperative combat has been preliminarily established. By combining AHP with interval estimation (Yan *et al.* 2019), the degree of contribution of each index has been obtained, and the low contribution index has been eliminated to establish the UAV cooperative combat index system. Considering the influence of the subjective and objective factors in the complex background of UAV cooperative combat comprehensively (Shi *et al.* 2019), the principle of conditional entropy has been introduced into the entropy method, and the index has been weighted by combining the modified entropy method with AHP. The effectiveness evaluation results thus obtained are quite reasonable (Yang *et al.* 2019). The rationality of the method has been verified by taking an example, and the results obtained from it indicate that the modified entropy method combined with AHP exhibits good adaptability of UAV cooperative combat system to complex situations and the weighted results are fairly objective.

ESTABLISHMENT OF THE EVALUATION INDEX SYSTEM

The selection of the capability index of a UAV cooperative combat system is affected by many factors and has a large uncertainty. When the evaluation object is relatively complex, the evaluation results of decision-making experts are often difficult to reach a consensus, and multiple rounds of evaluation are needed, which increases the decision-making time and cost. The specific selected indices should not only depict the UAV cooperative operation system comprehensively and concretely but also avoid the redundancy phenomenon caused by repeated indices. The traditional Delphi method issues a consultation table to experts and relies on the subjective will of the experts to determine the index system (Guo *et al.* 2014). However, this method has strong subjectivity and a large uncertainty, and the constructed index system is incomplete. Further, it is difficult for nonexperts in this field to accurately grasp the important indicators. Thus, to solve the abovementioned problems, a new technique based on the Delphi method has been proposed in this work. Here, the AHP and interval estimation have been combined to estimate the weight of the index. Subsequently, the weak weight index has been eliminated in order to construct the index system of cooperative combat capability.

Construction of the capability index

The evaluation of the effectiveness of a UAV cooperative combat system can be comprehensively described by its cooperative combat capability, cooperative perception capability, and cooperative communication capability. In this work, the Delphi method was modified by combining the modified AHP method and interval estimation to construct the index system of cooperative combat capability. In the traditional AHP method, the 9-point scale method is usually used to construct the judgment matrix, which is difficult for experts to grade, and the constructed judgment matrix is not easy to meet the requirements of consistency and compatibility. In this paper, the 5-point scale is adopted. It not only solves the problem of difficult marking by experts, but also avoids the loss of information. By sending consultation tables to experts in the field of UAV cooperative combat, this method makes full use of their experience and knowledge and initially constructs a relatively objective and scientific index system of cooperative engagement capability. The degree of contribution of each index is calculated by the AHP and interval estimation, and the indices that have a very small degree of contribution are removed. Finally, the index system of the UAV cooperative engagement capability is constructed. The full construction process is shown in Fig. 1.

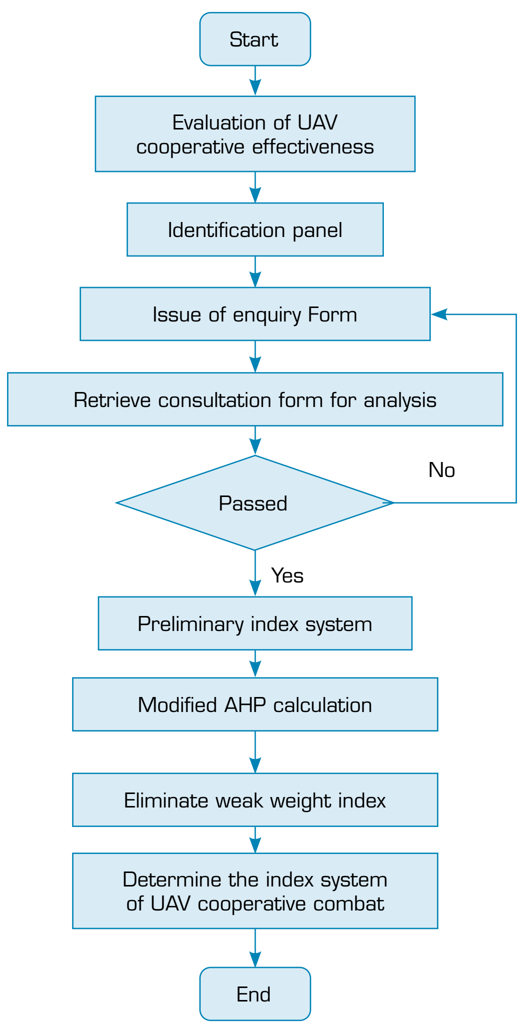

Figure 1. Flowchart showing the construction process of the index system of the UAV cooperative engagement capability.

The specific steps in the construction process are as follows:

1. Determination of the evaluation object and preparation of the survey outline. The evaluation object is the UAV cooperative combat system. Information such as the purpose of the survey, the consultation form, and the filling method will be prepared to be sent to the experts.
2. Determination panel. Depending on the scope of knowledge required for cooperative combat of the UAV, experts from the relevant specialties are sought to form expert groups.
3. Issuance of the consultation form. The consulting form and the filling method are sent to the experts, and the experts put forward their own opinions on the index system of cooperative engagement capability according to the received information.
4. Retrieval of the consultation form for analysis. The consultation forms of the experts are collected and analyzed. Following this, the initial index set of cooperative combat is drawn. The set of indices is sent to the experts to collect their feedback. The process is repeated several times until the experts do not change their opinion.
5. Preliminary determination of the index system of cooperative combat. After several rounds of feedback from the panel, a final consensus is reached, and the index system of the UAV cooperative combat is determined preliminarily.
6. Comparison of the relative importance of each index in the UAV cooperative combat system is made, and a judgment matrix, A_n, is established according to the 5-point scale method.

$$A_n = \left[a_{ij} \right]_{n\times n} \tag{1}$$

where a_{ij} represents the comparison result of index i relative to index j. $a_{ij} > 0$, $a_{ij} = \frac{1}{a_{ji}}$, and $a_{ij} = 1$.

7. The maximum eigenvalue, λ_{max}, of A_n is calculated. The matrix representation of the weights is as follows:

$$W = \left[w_1, w_2, \cdots, w_n \right]^T \tag{2}$$

where $w_1 + w_2 + \ldots , w_n$ and Eq. 1 and 2 satisfy:

$$[a_{i1}, a_{i2}, \cdots a_{in}]W \leq \lambda_{\max} W \tag{3}$$

i.e., $A_n W \leq \lambda_{\max} W$

8. The upper and lower limit problem of interval estimation of the index weight is transformed into the optimization problem of linear programming.

$$\bar{A}_n = A_n - \lambda_{\max} I \tag{4}$$

According to Eq. 4, it is possible to construct a polyhedral closed convex cone as follows.

$$\bar{A}_n W \leq 0 (W \geq 0) \tag{5}$$

where $W = \left[w_1, w_2, \cdots, w_n \right]^T \geq 0$.

Therefore, the upper and lower limit problem of interval estimation of the index weight is transformed into the minimum/maximum optimization problem of linear programming, as Eq. 6. The maximum, w_i^U, and the minimum, w_i^L, values obtained by the minimum/maximum optimization are used as the upper and lower limits of the interval, respectively.

$$Q = w_i^U \; (or \; w_i^L)$$
$$s.t. \begin{cases} \bar{A} W \leq 0 \\ W = \left[w_1, w_2, \cdots, w_n \right]^T \geq 0 \\ w_1 + w_2 + \cdots + w_n = 1 \end{cases} \tag{6}$$

9. Elimination of the low contribution index. The system deviation is reflected by the upper and lower limits of the interval estimation, and thus the maximum deviation value is used for measuring the index.

$$\Delta_{\max} = \max_{1 \le i \le n}(w_i^U - w_i^L) \tag{7}$$

For an index A_{ij} , if $w_i^U \le \Delta_{\max}$, it is considered that the index contribution is too low and the index should be eliminated.

10. Finally, the index system of the cooperative engagement capability is determined.

Index system

According to expert opinions, the UAV collaborative combat effectiveness index system consists of three layers: the overall target object layer, the subsystem index layer, and the specific index layer. A UAV cooperative combat system is divided into a cooperative combat system, a cooperative perception system, and a cooperative communication system. After the indices having low weights are eliminated by the modified AHP, the final index system obtained, which reflects the effectiveness of the UAV cooperative combat system, is as shown in Fig. 2.

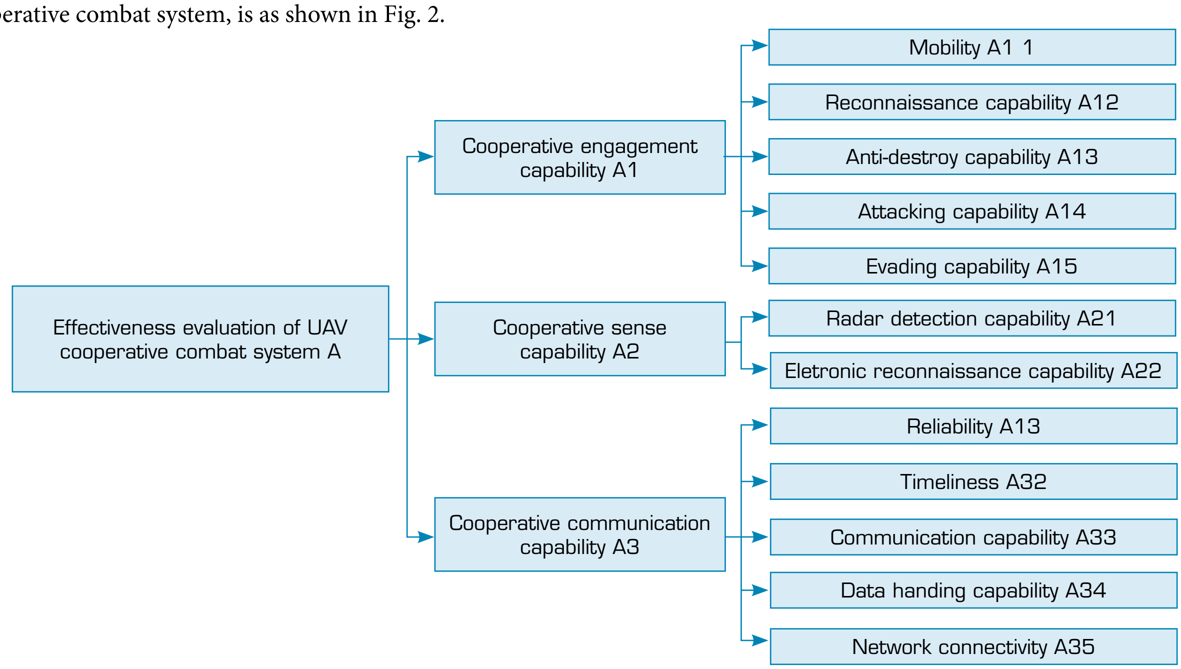

Figure 2. Unmanned aerial vehicles (UAV) cooperative combat capability index system.

CONDITIONAL ENTROPY COMBINATION METHOD

The entropy method is an objective weighting method. It relies on the instance data, the calculation is clear, and the weight obtained by this method is definite and objective. However, during its application, the difference coefficient, caused by the degree of dispersion of a certain index, becomes too large. This leads to a single index to influence the final weight. Therefore, the principle of conditional entropy has been introduced in this work to modify the entropy method.

Principle of conditional entropy

The amount of information is the parameter that is used for measuring the quantity of information that is generated by a specific event, and entropy is the expectation value of the amount of information that may be generated before the event ends. Information entropy is defined by Eq. 8.

$$H(X) = -\sum_{i=1}^{n} p(x_i)\log p(x_i) \tag{8}$$

where $p(x_i)$ represents the probability of a random event x_i.

Conditional entropy is defined as the mathematical expectation of the entropy of the conditional probability distribution, Y, for X, given a condition of X. Conditional entropy $H(Y|X)$ is the uncertainty of the random variable Y given the random variable X. On the contrary, $H(X|Y)$ is the uncertainty of the random variable X given the random variable Y. The larger the uncertainty, the larger the information and the higher the entropy. Conditional entropy is defined by Eq. 9.

$$H(Y \mid X) = -\sum_{x\in X} p(x)\sum_{y\in Y} p(y \mid x)\log p(y \mid x) \tag{9}$$

The combined entropy represents the uncertainty of the system when the event X is associated with event Y. It is defined by Eq. 10.

$$H(X,Y) = -\sum_{y\in Y}\sum_{x\in X} p(x,y)\log p(x,y) \tag{10}$$

The entropy $H(X|Y)$ of an event Y under the circumstance of an event X is equal to the entropy of event Y minus the mutual information entropy of events Y and X and can be expressed as Eq. 11.

$$H(Y \mid X) = H(Y) - I(X,Y) \tag{11}$$

where $I(X,Y)$ represents the degree to which event X is related to event Y.

This relationship can be represented as shown in Fig. 3.

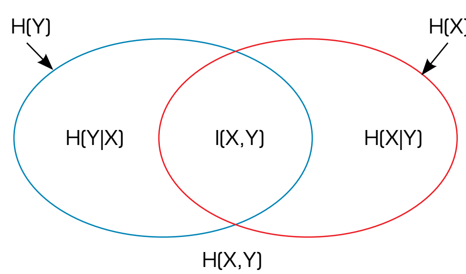

Figure 3. Schematic showing the conditional entropy relation.

Introduction of conditional entropy

The principle of conditional entropy has been introduced in this work to comprehensively consider the interrelation between the indices. In other words, the conditional entropy of an index, s, based on another index, j, is equal to the entropy of the s minus the mutual information entropy of s and j. The entropy of mutual information is equal to the entropy of the index j multiplied by the relevancy a, where the range of a is 0 to 1. Suppose that the initial data matrix of n evaluation indices of m samples is $X = \{x_{ij}\}$ $m\times n$, where x_{ij} represents the j-th index value of the i-th evaluative object. The specific calculation steps are as follows:

1. Calculate the proportion, p_{ij}, of the index value of the i-th evaluative object under the j-th index:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{12}$$

2. Calculate the entropy, e_j, of the j-th index:

$$e_j = \frac{1}{\ln m}\sum_{i=1}^{m} p_{ij} \ln \frac{1}{p_{ij}} \tag{13}$$

Calculate the conditional entropy, $e_{(s|j)}$, of the s index based on the j-th index.

$$e_{(s|j)} = \frac{1}{\ln m} p_{is} \ln \frac{1}{p_{is}} - \alpha e_j \tag{14}$$

where a is the degree of correlation between the indices given by the experts.

Calculate the conditional entropy vector based on the index j: $[e_1, e_2, \ldots, e_j, \ldots, e_n]^T$. Similarly, the conditional entropy vector based on each index is obtained as follows: j: $[e_1', e_2', \ldots, e_j', \ldots, e_n']^T$, j: $[e_1'', e_2'', \ldots, e_j'', \ldots, e_n'']^T$, j: $[e_1''', e_2''', \ldots, e_j''', \ldots, e_n''']^T$, … $[e_1^m, e_2^m, \ldots, e_j^m, \ldots, e_n^m]^T$. The conditional entropy vectors of each column are averaged to obtain a synthetic conditional entropy vector,$[e_1^m, e_2^m, \ldots, e_n^m]$.

3. Calculate the weight of the conditional entropy of each index:

$$W_t = \frac{1-e_t}{\sum_{t=1}^{n}(1-e_t)} \tag{15}$$

Combination weighting method

When using AHP or the entropy method alone for evaluating the performance of the index system, the allocation of the index weight could be inconsistent with the actual objective situation. In addition, the effectiveness evaluation results for a UAV cooperative combat system with a complex background are extremely uncertain (Huang and Su 2015). Therefore, the combination weighting method has been adopted in this work for evaluating the effectiveness of the UAV cooperative combat system.

The specific calculation steps are as follows:

1. Using the modified AHP, the weight $\gamma=[\gamma_1, \gamma_2, \cdots, \gamma_m]$ of m upper indices, the weight $\eta=[\eta_1, \eta_2, \cdots, \eta_n]$ of n specific indices, and the subjective weight, $W_j^S = [\tau_1, \tau_2, \cdots, \tau_n]$, are obtained.
2. Using the conditional entropy method, the objective weight, $W_j^O = [\mu_1, \mu_2, \cdots, \mu_n]$, of n indices is obtained.
3. Finally, the combined weight is calculated according to Eq. 16.

$$W_j = \alpha W_j^O + (1-\alpha) W_j^S \tag{16}$$

The background of a UAV cooperative combat system is complex, including many subjective as well as objective factors. Therefore, the combination weighting method has been used for evaluating its effectiveness and the evaluation result thus obtained is objective.

INSTANCE VERIFICATION

The modified AHP and the conditional entropy method were used for calculating the subjective and objective weights, respectively. Furthermore, the traditional entropy method and the conditional entropy method were also compared. Finally, the combined weight was calculated using Eq. 16.

Calculation of the subjective weight

By issuing the consultation table to the experts and using their experience and knowledge, a judgment matrix was constructed, and the consistency test was performed on it. Finally, the weight of each index was calculated. As shown on Table 1, the judgment matrix constructed by the index layer of the subsystem comprises the collaborative combat capability, collaborative perception capability, and collaborative communication capability of a UAV under the collaborative combat effectiveness evaluation. Table 2 shows the judgment matrix constructed by the specific index layer, including the mobility, reconnaissance, anti-destruction, attack, and avoidance capabilities under the cooperative combat capability.

Table 1. Judgment matrix for the subsystem index.

A	A1	A2	A3	W_i^U	W_i^L	Weight	λ_{max}	*CI*	*RI*	*CR*
A1	1	5	4	0.6744	0.6738	0.6741	3.0857	0.0428	0.58	0.0738
A2	1/5	1	1/3	0.1008	0.1007	0.1008				
A3	1/4	3	1	0.2256	0.2255	0.2256				

Table 2. Judgment matrix for the specific index layer.

A1	A11	A12	A13	A14	A15	W_i^U	W_i^L	Weight	λ_{max}	*CI*	*RI*	*CR*
A11	1	3	3	1/4	2	0.2146	0.2141	0.2143	5.2897	0.0724	1.12	0.0646
A12	1/3	1	1/2	1/4	1/3	0.0676	0.0675	0.0676				
A13	1/3	2	1	1/3	1/2	0.1019	0.1018	0.1019				
A14	4	4	3	1	4	0.4707	0.4704	0.4705				
A15	1/2	3	2	1/4	1	0.1471	0.1469	0.1470				

A consistency test was carried out for the judgment matrix, and the weight of each index in the index layer was calculated. The flow of consistency test is as follows.

1. Calculate consistency indicator (*CI*).

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{17}$$

2. According to Table 3, look-up random consistency index (*RI*).
3. Calculate consistency ratio (*CR*).

$$CR = \frac{CI}{RI} \tag{18}$$

where $CR < 0.1$ represents the judgment matrix meet the consistency requirement.

Table 3. Numerical table for *RI*.

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

On the basis of the calculation procedure of the modified AHP method, the index weight of the judgment matrix corresponding to each index layer was calculated. According to the calculation method for *CI, RI, CR*, the consistency test was carried out. The conformance rate (CR) of each index layer was less than 0.1 and met the consistency requirement. Finally, the weights of each index were obtained as W^s = [0.1441, 0.0453, 0.0685, 0.3168, 0.0989, 0.0672, 0.0336, 0.0658, 0.0148, 0.0181, 0.0906, 0.0362].

Calculation of the objective weight

While conducting the performance evaluation, it is required to normalize the initial data of the indices due to the differences in their dimensions and the scope of transformation among them. Table 4 shows the three existing cooperative combat schemes of UAVs, in which all the indices are the results of standardized processing.

Table 4. Index data corresponding to the UAV collaborative combat schemes.

Parameter	Targets		
	Scheme 1	Scheme 2	Scheme 3
A11	0.5793	0.7621	0.6325
A12	0.7891	0.8092	0.9629
A13	0.6953	0.6425	0.6734
A14	0.8731	0.5439	0.3951
A15	0.2115	0.3113	0.2405
A21	0.7267	1.3238	0.9425
A22	1.2115	1.0267	0.8726
A31	0.9635	0.8372	0.7343
A32	0.4000	0.3000	0.3000
A33	0.7825	0.8767	0.9131
A34	0.9980	0.7357	0.9389
A35	0.7096	0.9846	0.8938

Based on the calculation procedure of the conditional entropy method described in the UAV cooperative combat effectiveness index system, the weight of each index based on the conditional entropy was calculated to be W_o = [0.0228, 0.0745, 0.0923, 0.1494, 0.1331, 0.0739, 0.0543, 0.0975, 0.0716, 0.0645, 0.0786, 0.0875].

Based on the traditional entropy method, the weight of each index was calculated to be W_c = [0.0440, 0.0266, 0.0034, 0.3510, 0.0873, 0.1985, 0.0586, 0.0403, 0.0637, 0.0136, 0.0537, 0.0590].

As it is possible to see from Fig. 4, when the traditional entropy method is applied to the example, the degree of dispersion of an index causes the difference coefficient of one of the indices to be very large, which results in this index influencing the final weight. The principle of conditional entropy was introduced in this work to consider the interrelation between the indices comprehensively in weight assignment in order to avoid this situation. Therefore, the weight obtained by the modified entropy method is objective and reasonable.

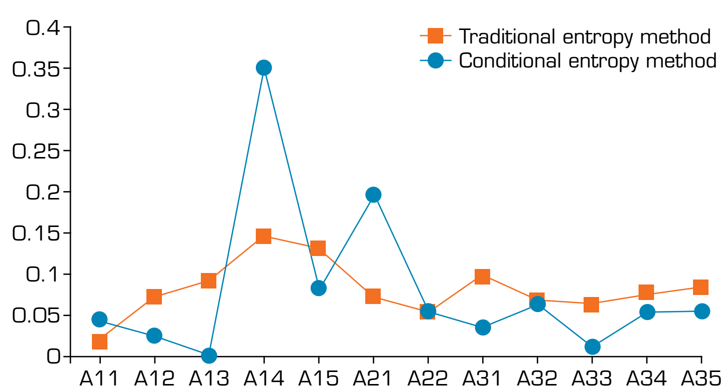

Figure 4. Comparison of the weights obtained from the traditional and the conditional entropy methods.

Calculation of the combined weight

In this work, the value of *a* was 0.5 (Yang *et al.* 2019). Based on the calculation procedure of the combination weight method, the comprehensive weight of each index of the UAV cooperative combat system was calculated to be W = [0.0835, 0.0599, 0.0803, 0.2331, 0.1159, 0.0706, 0.0440, 0.0817, 0.0432, 0.0413, 0.0847, 0.0619].

The weights of the subjective, objective, and combined weights have been compared in Table 5, and Fig. 5 shows a comparison of the weights of each index obtained by the abovementioned three weighting methods.

Table 5. Comparison of the subjective, objective, and combined weights.

Parameter	Weights		
	Subjective	Objective	Combination
A11	0.1441	0.0228	0.0835
A12	0.0453	0.0745	0.0599
A13	0.0685	0.0923	0.0803
A14	0.3168	0.1494	0.2331
A15	0.0989	0.1331	0.1159
A21	0.0672	0.0739	0.0706
A22	0.0336	0.0543	0.0440
A31	0.0658	0.0975	0.0817
A32	0.0148	0.0716	0.0432
A33	0.0181	0.0645	0.0413
A34	0.0906	0.0786	0.0847
A35	0.0362	0.0875	0.0619

The synthetic efficiencies, C_{ce}, C_{AHP}, and C_{cw}, of the three schemes obtained using the conditional entropy method, the modified AHP and the combination weighting method, respectively, are C_{ce} = [0.7278, 0.7169, 0.6604], C_{AHP} = [0.7535, 0.6947, 0.6092], and C_{cw} = [0.7409, 0.7060, 0.6349]. Based on their advantages and disadvantages, the three schemes can be sorted as scheme 1 > scheme 2 > scheme 3 for all the three weighting methods.

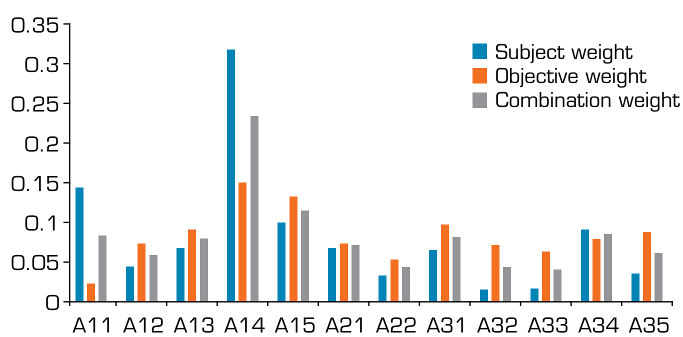

Figure 5. Comparison of the subjective, objective, and combined weights.

RESULTS

The effectiveness of the three UAV cooperative combat schemes was comprehensively compared by using the improved conditional entropy method, AHP, and the combination weighting method. The comparison of the combat capabilities of the three schemes is shown in Fig. 6. The ordinate in the figure represents the value of comprehensive efficiency. On the whole, the results of the above three weighting methods are consistent and based on their performance, scheme 1 > scheme 2 > scheme 3.

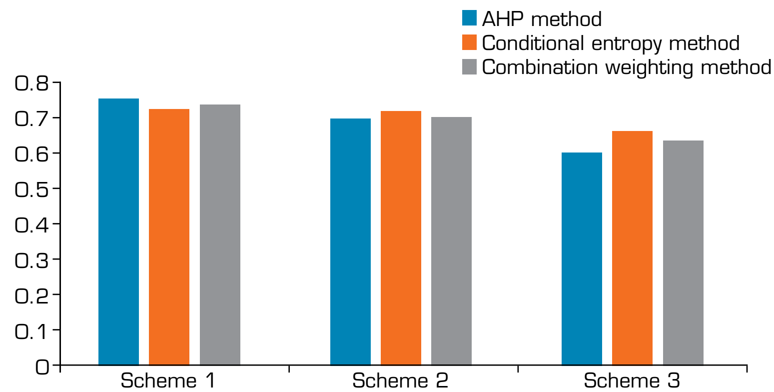

Figure 6. Comparison of the effectiveness of the three combat schemes.

It can be seen from the example verification analysis that the introduction of the modified entropy method, based on the conditional entropy principle and taking into account the mutual relationship among the indices, helps to avoid the situation where a single index affects the final weight due to its large degree of dispersion.

The combination weighting method, which combines the AHP and the modified entropy method by taking the subjective and objective factors into account to reduce the risk of using a single weighting method, can also allocate enough weight to the key indices in the cooperative combat index system. This can be seen from the comparison of the subjective, objective, and combined weights, as shown in Fig. 5. The weighting method of AHP relies on the subjective experience judgment of experts, which is generally manifested as an uneven distribution of index weights and a large degree of dispersion. The modified entropy method relies on objective data and is greatly influenced by the combat scheme. Therefore, the combination weighting method takes the subjective and objective factors into consideration, which is suitable for the complex situation of a UAV cooperative combat system and provides objective assessment results.

CONCLUSION

With the aim of establishing an efficiency evaluation index system of a UAV cooperative combat system, the modified Delphi method combined with AHP and interval estimation was adopted to establish a complete and effective index system for evaluating the effectiveness of a UAV cooperative combat system. Evaluation of the efficiency of the system has been done by applying the modified AHP, the conditional entropy method, and the combination weighting method. The results of the example verify that the combined weight method developed in this work can effectively evaluate the UAV cooperative combat system.

AUTHORS' CONTRIBUTION

Conceptualization: Lifan Sun and Jiashun Chang; **Data Curation:** Jie Zou; **Conceptualization:** Lifan S, Jiashun C; **Methodology:** Lifan S, Jiashun C; **Investigation:** Jinjin Z; **Data Curation:** Jie Z; **Funding Acquisition:** Zhumu F; **Resources:** Jie Z; **Supervision:** Jie Z; **Writing – Original Draft:** Lifan S; **Writing – Review & Editing:** Jiashun C.

DATA AVAILABILITY STATEMENT

All the datasets were generated during the current study.

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