A target threat assessment method for low-altitude aircraft

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Abstract. In recent years, with the gradual opening up of Chinese low-altitude airspace, and the government active support for the development of the general aviation and drone industries, the traditional physical protection is mainly aimed at ground threats, resulting in the threat and harassment from air targets has become increasingly prominent. In order to effectively and effectively deal with low-altitude small aircraft in a timely and effective manner, the target threat assessment has become an important part of the command and control process. The target threat degree is the threat degree of the aircraft to the air defense early warning and surveillance system, and is an important basis for handling the detection targets in the safety prevention and control work. The purpose of the threat assessment is to conduct a comprehensive evaluation based on the qualitative and quantitative analysis of the target on the basis of the target identification, and rank the threat levels for all the targets to prepare for the next step.

1. Introduction
The term threat assessment comes from the air defense combat system. The air defense information center further analyzes the situation of the target to make a threat level assessment and further complete the command deployment. The earliest literature on air defense threat assessment at the tactical level appeared in the late 1980s. Subsequently, with the participation of relevant institutions and scholars in the United States, Britain and China, after nearly 30 years of development, threat assessment technology has received extensive attention and achieved fruitful research results. Threat assessment is usually divided into three steps: threat factor extraction, threat calculation, and threat assessment. At present, the commonly used threat degree model evaluation methods at home and abroad include: fuzzy set method, rough set method, Vague set method, information entropy method, TOPSIS method and so on [1].

2. research methods

2.1. Fuzzy set method
The fuzzy theory method quantifies the threat factor by setting the membership function, and sorts the pair by using the average weighting method. The fuzzy set method calculates the membership degree of each threat factor by membership function and performs weighted summation. Finally, the threat degree is assessed [2].
2.2. Rough set method
Rough set theory is a mathematical method to solve the problem of uncertainty and incompleteness. In rough set theory, knowledge is regarded as the division of regions, and all classification sets constitute a basic knowledge base. Threat estimation factors can be reduced using rough set theory [3].

2.3. Vague set method
The Vague set is an improvement on the fuzzy set. It is defined as assuming that x is an object space, then the Vague set in space can use two functions, a membership function \( t_\delta(x) \) and a non-membership function \( f_\delta(x) \). Description, for \( \forall x \in X \), \( t_\delta(x) \) is the lower bound of the membership derived from the argument supporting \( x \in A \). \( f_\delta(x) \) is exactly the opposite, and \( t_\delta(x) + f_\delta(x) \leq 1 \). The membership degree interval of element \( x \) in \( A \) is \( v(x) = [t_\delta(x),1 - f_\delta(x)] \), and \( v(x) \) is called the Vague number of \( A \). \( \pi_\delta(x) = 1 - t_\delta(x) - f_\delta(x) \) is the degree of hesitation of \( x \) for Vague set \( A \), which is an uncertainty measure of \( x[4] \).

2.4. Information entropy method
The information entropy theory has great advantages in solving the incomplete problem, and the threat assessment system is introduced. If an object may have \( n \) and states, and the probability of each state is \( (p_1, p_2, \ldots, p_n) \), then the information entropy of the object is defined as

\[
H(x) = -\sum_{i=1}^{n} p_i \times \log p_i
\]

The more uniform the probability distribution is, the larger the entropy value is, and the discriminability is reduced. According to this, each evaluation index is defined according to the threat degree of the multi-objective relative to each threat factor, so the information entropy expression is:

\[
H_j = -\sum_{i=1}^{n} e_{ij} \times \log e_{ij}
\]  

The multi-objective threat assessment model is calculated by the above formula. There is a formula for calculating the threat:

\[
E_i = \sum_{j=1}^{m} \frac{e_{ij} \times \log(1+e_{ij})}{H_{ij}}
\]

Where: \( E_i \) represents the threat degree of the i-th target, and the larger \( E_i \) indicates that the threat degree of the i-th target is larger [5].

2.5. TOPSIS method
The multi-attribute decision-making theory comprehensively considers multiple factors in the target threat and can comprehensively reflect the influence of multi-factors on the assessment. TOPSIS is a relatively mature multi-attribute decision-making method. The TOPSIS theory normalizes the original data matrix, calculates the weighted normalization matrix, compares the decision schemes, and finds the optimal solution (positive ideal solution) and the worst solution (negative ideal solution) in the alternative. Then, calculate the distance between a certain scheme and the optimal scheme and the worst scheme, and then obtain the closeness of the scheme and the optimal scheme, and use this as the basis for evaluating the advantages and disadvantages of each scheme [6].

3. A target threat assessment method for low-altitude aircraft
The low-altitude small aircraft, which is different from the attacking target in general air defense operations, is characterized by low-altitude flight, slow speed, difficulty in being discovered, and strong handling for its disposal device. The assessment of threats should be intuitive, simple, easy to implement, and fast to calculate. Considering a variety of factors affecting the threat degree of low-altitude small aircraft, combined with the actual situation of nuclear power plant, the system uses fuzzy set information
entropy combined with Topsis to establish a threat assessment model suitable for low-altitude small aircraft.

The TOPSIS method is a very effective method for solving multi-objective decision analysis. TOPSIS sorts the closeness of a limited number of evaluation objects with idealized targets, and evaluates the relative merits of existing objects.

When solving the multi-objective decision problem through the TOPSIS method, the weight of each attribute indicator should be analyzed. The rationality of the attribute index weight directly determines the accuracy of the target threat assessment. There are subjective methods (expert method, AHP method, binomial coefficient method) and objective method (principal component analysis method, entropy weight method) for determining the weight of attribute index. Subjective law reflects the subjective preferences and experience of decision makers, but lacks accuracy and consistency; objective methods can make full use of objective information, but lack subjectivity. The system comprehensively considers the subjective and objective factors, and uses the combination of expert scoring and information entropy to determine the index weight.

The threat assessment model selects a fuzzy set based method to assign values to the attributes and assigns weight coefficients using an evaluation method combined with information entropy and Topsis. The fuzzy theory method quantifies the threat factor by setting the membership function, and sorts the pair by using the average weighting method. The information entropy theory has great advantages in solving the incomplete problem, and the threat assessment system is introduced. The basic idea of the TOPSIS algorithm is to first calculate the maximum and minimum ideal solutions of the threat degree, and then calculate the closeness of the threat attribute of each target to the ideal solution, and obtain the threat ranking of the target according to the degree of closeness.

Specific steps are as follows:

3.1. Entropy-based target weight
The selection of weights is important for the threat assessment factor and is also important for the results of the ranking. The entropy method is used to measure the threat degree more objectively. The calculation steps are as follows:

The first step is to assume that there are n targets and m threat factors. First, construct the target attribute matrix \( A = [a_{ij}]_{n \times m} \), and \( a_{ij} \) represents the value of the jth threat factor of the i and the target.

In the second step, the interval number matrix is normalized; if the interval number matrix is \( A = [a_{ij}]_{n \times m} \), the decision matrix after normalization is \( R = [r_{ij}]_{n \times m} \), \( r_{ij} = [r_{ij}^L, r_{ij}^U] \) and \( r_{ij}^L, r_{ij}^U \in [0,1] \).

The third step is to find the entropy, which is the weight. According to the information theory calculation formula, the entropy value of the j-th attribute is

\[
E_j = \lambda \left( - \frac{1}{\ln m} \sum_{i=1}^{m} r_{ij}^L \ln r_{ij}^L \right) + (1 - \lambda) \left( - \frac{1}{\ln m} \sum_{i=1}^{m} r_{ij}^U \ln r_{ij}^U \right) .
\]

where \( 0 < \lambda < 1 \), is the balance coefficient and generally takes a value of 0.8. The difference degree of the threat degree is solved \( G_j = 1 - E_j \), and finally the weight of the jth threat factor is \( w_j = G_j / \sum_i G_i \).

3.2. TOPSIS threat ranking
TOPSIS is a common method for multi-attribute decision making. It can achieve better results by sorting the positive and negative ideal solutions of multi-attribute problems.

The algorithm process is as follows:

Determination of subjective weight: According to the expert's analysis of threat assessment and its experience and preference, comprehensively consider the target and the actual application environment, and assign weights to the threat factor \( w_s = [w_{s1}, w_{s2}, w_{s3}, w_{s4}, w_{s5}, ..., w_{si}] \).

The objective factor based on information entropy gives objective weight. According to the first step, the objective weight of the target attribute based on information entropy is \( w_o = [w_{o1}, w_{o2}, w_{o3}, w_{o4}, w_{o5}, ..., w_{oj}] \).
The combination of two factors determines the weight of the combined index \( w = \alpha w_s + (1 - \alpha)w_o \), where \( \alpha \) is the weighted combination factor of the objective weight, which ranges from 0 to 1.

Construct the target decision matrix, in the process of solving the information entropy in the previous step, obtain the target decision matrix \( R \); normalize the decision matrix \( \tilde{R} = (\tilde{r}_{ij})_{m \times n} \), where \( \tilde{r}_{ij} = r_{ij} / \sum^m r_{ij} \); The weighted decision matrix \( \bar{R} = (\bar{r}_{ij})_{m \times n} \) is determined according to the combined index weights, where \( \bar{r}_{ij} = \tilde{r}_{ij}w_j \).

Determine the ideal solution and the negative ideal solution, and calculate the distance from each target to the positive and negative ideal solutions. The positive ideal solution is the most threatening solution of the target, and the negative ideal solution is the solution with the least threat to the target;

\[
\begin{align*}
\tilde{t}_j^+ &= \max_{1 \leq i \leq n} (\tilde{r}_{ij}) \\
\tilde{t}_j^- &= \min_{1 \leq i \leq n} (\tilde{r}_{ij})
\end{align*}
\]

(4)

Calculate whether each target and the ideal solution are close, and calculate the target threat degree according to the progress of the posting. The greater the threat of the progress progress.

\[
\begin{align*}
\bar{d}_i^+ &= \sum_{j=1}^m (\tilde{r}_{ij} - \tilde{t}_j^+) \\
\bar{d}_i^- &= \sum_{j=1}^m (\tilde{t}_j^- - \tilde{t}_{ij})
\end{align*}
\]

(5)

In the formula, \( \bar{d}_i^+ \) and \( \bar{d}_i^- \) are the distances from the target to the positive and negative ideal solutions. The following formula is used to calculate the progress of the stickers, and the progress of each target is calculated.

\[
\bar{c}_i = \frac{\bar{d}_i^-}{\bar{d}_i^+ + \bar{d}_i^-}
\]

(6)

The target threat rankings are calculated by posting progress, as shown in Table 1.

| Threat factor range | Threat level         |
|--------------------|----------------------|
| (0.75~1.0]         | Heavy threat         |
| (0.51~0.75]        | Threatening          |
| (0.25~0.5]         | Mild threat          |
| [0.0~0.25]         | Does not pose a threat |

4. Conclusion
When multiple targets are invaded, they are sorted according to the threat degree, and the decision is made quickly, and the target with high threat is preferentially disposed.

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References
[1] Li F, Feihu C, Jin X, et al. Research of Air Combat Situation Assessment Method[C]// Digital Manufacturing and Automation (ICDMA), 2012 Third International Conference on. IEEE
[2] Guan X, Liu W, Papalexopoulos A. APPLICATION OF A FUZZY SET METHOD IN AN OPTIMAL POWER-FLOW[J]. ELECTRIC POWER SYSTEMS RESEARCH, 1995, 34(1):11-18.

[3] Wang L, Song Y. Rough Set-based Medical Image Enhancement Method Research[C]// International Conference on E-business & E-government. IEEE Computer Society, 2012.

[4] Cui C, Wu Q. Research on Electric Commerce Recommender Systems Based on Vague Set[C]// First IEEE International Conference on Information Science & Engineering. IEEE Computer Society, 2009.

[5] Rubinstein R Y, Kroese D P. The Cross-Entropy Method[M]. Springer New York, 2004.

[6] M. Socorro García-Cascales, Lamata M T. On rank reversal and TOPSIS method[J]. Mathematical and Computer Modelling, 2012, 56(5-6):9-0.