

Target situation assessment based on twice variable weight strategy

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Abstract. How to reasonably calculate index weight is an important topic in target situation assessment and other information processing studies. The traditional method is to obtain the subjective weight and the objective weight respectively, and then calculate the summation by multiplying the given coefficients. However, the traditional method is constant weight summation, which could not adjust under different situation and easily lead to unreasonable result, and the coefficients are difficult to determine. This letter presents a twice variable weight strategy. The strategy could provide a better consideration of subjectivity and objectivity without additional coefficients, and adaptively adjust index weight as the situation changes. Experimental results demonstrate that the target situation assessment based on the proposed strategy is more reasonable than that under constant weight.

1. Introduction

The target situation assessment is a fundamental problem in information fusion and has important practical applications in many fields, especially in military field [1,2]. Four basic problems in target situation assessment are the selection of indexes, the determination of index weight, the expression of index value and the integration of index information. How to reasonably calculate index weight attracts many scholars to study.

The weights calculating methods are generally divided into three categories, subjective weights method, objective weights method and the combination of subjective and objective weights. The third one is proved to be more reasonable, which obtains the subjective weight and the objective weight respectively and calculates the summation by multiplying the given coefficients. But it is constant weight summation, which could not adjust under different situations and easily lead to unreasonable result, and the coefficients are difficult to determine.

This letter proposes a twice variable weight strategy for index weight. The strategy carries out twice variable weight based on normalized decision matrix and initial weights which are obtained by group analytic hierarchy process (GAHP). The first variable weight operation is to highlight the high discrimination index by analyzing the data distribution of normalized decision matrix weighted by initial weights. And the second variable weight operation is to adjust the index weight to conform the actual situation. The strategy could provide a better consideration of subjectivity and objectivity without additional coefficients, and adaptively adjust as the situation changes.

2. The proposed strategy

2.1. Data pre-processing



Assume that there are M enemy air targets and N indexes detected by our sensing network system at a moment, recorded as $T=\{T_1, T_2, \dots, T_M\}$ and $I=\{I_1, I_2, \dots, I_N\}$ respectively. And the index values are transformed into benefit type via index membership function, denoted as $X=(x_{ij}), x_{ij} \in [0,1], i \in [1,M], j \in [1,N]$.

2.2. Initial weight

We obtain the initial weights based on GAHP [3].

(a) Assume that there are P experts, the judgement matrix of expert k is $Q^k=(q_{ij}^k)_{N \times N}, k \in [1, P]$, whose authority degree is ε_k . All judged matrix meet the consistency demand, i.e. the rate of error is less than 0.1.

(b) The subjective weight equation for initial weight is

$$\min f(W^{(0)}) = \sum_{i=1}^N \sum_{j=1}^N \sum_{k=1}^P \varepsilon_k \left[\ln(q_{ij}^k w_j^{(0)}) - \ln(w_i^{(0)}) \right]^2 \quad (1)$$

with $w_i^{(0)} \in (0,1), i \in [1, N]$ and $\sum_{i=1}^N w_i^{(0)} = 1$. Then we can easily solve (1) by the method of Lagrange multipliers. The initial weight is

$$w_i^{(0)} = \left[\prod_{j=1}^N \prod_{k=1}^P q_{ij}^{\varepsilon_k} \right]^{1/N} \left(\sum_{i=1}^N \left[\prod_{j=1}^N \prod_{k=1}^P q_{ij}^{\varepsilon_k} \right]^{1/N} \right)^{-1} \quad (2)$$

2.3. The first variable weight

We obtain the first variable weight by maximizing the distinction among targets via the normalized decision matrix weighted by initial weights, i.e. increasing the index weight of high discrimination and decreasing the weight of low discrimination [4].

(a) Modify the normalized decision matrix, as follows:

$$\hat{X} = (\hat{x}_{ij})_{M \times N}, \hat{x}_{ij} = w_j^{(0)} x_{ij} \quad (3)$$

(b) The weight equations for the first variable weight are

$$\begin{cases} \max (W^{(1)})^T H W^{(1)} \\ (W^{(1)})^T W^{(1)} = 1 \\ H = (Z^T Z) / M \\ Z = (z_{ij})_{M \times N} \end{cases} \quad (4)$$

with $z_{ij} = \hat{x}_{ij} - \hat{x}_j$, $\hat{x}_j = \left(\sum_{i=1}^M \hat{x}_{ij} \right) M^{-1}$ and $w_i^{(1)} \in (0,1), i \in [1, N]$.

(c) Through the theory of matrix decomposition, we can know that the first variable weight $W^{(1)}$ is the eigenvector which corresponds to the maximum eigenvalue of H . Usually the summation of indexes weights is 1, so we also make the eigenvector normalized to meet the rule.

2.4. The second variable weight

Firstly, in the process of air attack, when an index value of a target is very small, the threat of the target is low though the index weight is very large. Otherwise an index value of a target is very large,

the threat of the target is high though the index weight is very small. Secondly, for one air target, when a specific index is analysed, the threat of target will not significantly improve as the index value is higher, even highest. And the threat of target will significantly reduce as the index value is lower. Thirdly, the constant weights represent the relative importance of indexes, so the change ranges of index weight should meet the importance of index.

(a) In order to fulfil these requirements, based on variable weight theory proposed by Professor Wang [5], we construct the state variable weight vector as follows:

$$S_{ij}(x_{ij}) = \begin{cases} \exp\left\{-\mu N w_j^{(1)} (x_{ij} - k\bar{x}_i)^2\right\}, & x_{ij} \in [0, k\bar{x}_i] \\ 1, & x_{ij} \in [k\bar{x}_i, \bar{x}_i/k] \\ \exp\left\{N w_j^{(1)} (x_{ij} - \bar{x}_i/k)^2\right\}, & x_{ij} \in (\bar{x}_i/k, 1] \end{cases} \quad (5)$$

Where $\mu \in [1, +\infty)$ is the amplitude ratio of punishment and reward. N is the number of index. $k \in [0, 1]$ denotes the punishment threshold coefficient and $\bar{x}_i = \frac{1}{N} \sum_{j=1}^N x_{ij}$ is the mean index value of target. In this letter, $\mu = 2.8$, $k = 0.95$ (concluded from experimental data).

(b) According to the state variable weight vector, we can obtain the second variable weight via Hadamard Product, as follows

$$w_{ij}^{(2)} = w_j^{(1)} S_{ij}(x_{ij}) \left(\sum_{i=1}^N w_i^{(1)} S_{ii}(x_{ii}) \right)^{-1} \quad (6)$$

(c) Aggregate the second variable weight and normalized decision matrix to get the situation threat assessment ranking of air targets. The situation threat assessment of target i is given by

$$R_i = \sum_{j=1}^N w_{ij}^{(2)} x_{ij}, i \in [1, M] \quad (7)$$

3. Experimental results

To evaluate the reasonability and validity of the proposed strategy, we exemplify the procedures on five targets with five indexes, as shown in Table 1. Due to limited space, this letter focuses on twice variable weight strategy, so other parts are simply explained, such as the normalized index information, as shown in Table 2. We invited three experts, whose authority degree $\varepsilon_k = [0.3 \ 0.4 \ 0.3]$, gave their judgement among these indexes, and then we get the initial weight

$W^{(0)} = (0.2064 \ 0.3890 \ 0.1403 \ 0.0554 \ 0.2090)^T$.

Table 1. Air targets situation information

Target	Type	Arrival time (s)	Course short (m)	Jamming ability	Height (m)
T ₁	Anti-radiation missile	60	200	Strong	1000
T ₂	General aircraft	80	3000	Strong	3000
T ₃	Jamming aircraft	100	1000	Very strong	6000
T ₄	Slow target	120	1500	General	1500
T ₅	Cruise missile	90	500	Strong	150

Table 2. The normalized index data representing the threat degree

Target	Type	Arrival time	Course short	Jamming ability	Height
T_1	0.9	0.8353	0.9993	0.7	0.9980
T_2	0.7	0.7261	0.9575	0.7	0.9512
T_3	0.2	0.6065	0.9920	0.9	0.7851
T_4	0.5	0.4868	0.9822	0.5	0.9920
T_5	0.6	0.6670	0.9980	0.7	1.0000

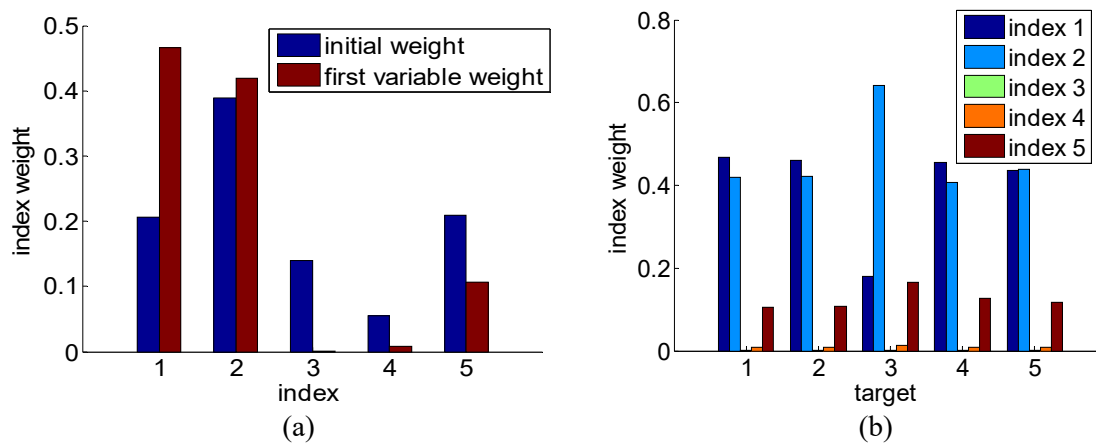


Figure 1. Target, index and index weight

(a) Initial weight and first variable weight for five indexes

(b) The second variable weight of five indexes for five targets

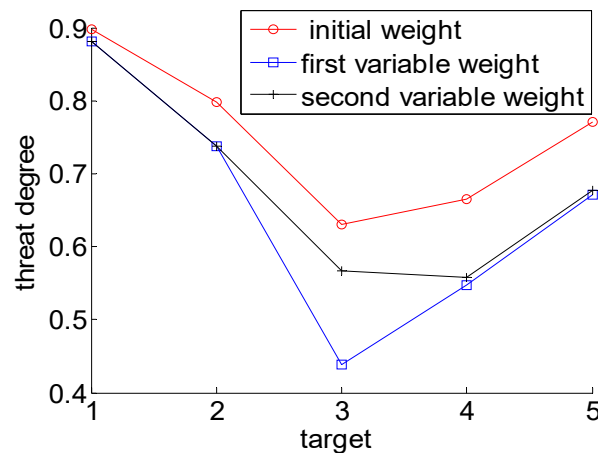


Figure 2. Target situation threat assessment under different weights

The different weights and the air targets situation threat assessment results under different weights are shown in Figure 1 and Figure 2. Firstly, both subjective experience and objective data are taken into account in the first variable weight and the second variable weight without additional coefficients. Secondly, the threat assessment under the first variable weight and the second variable weight improve the distinction among targets by increasing the index weight of high discrimination and decreasing index weight of low discrimination. Thirdly, the second variable weight can adjust as situation changes, avoiding unreasonable result. We can see from the Figure 2, the threat degree

ranking of target 3 and target 4 is different between the second variable weight and the others. The height of target 4 is lower, but the jamming ability, course short and arrival time of target 3 are lower. So the jamming aircraft with strong jamming ability will approach us more quickly and the threat will be higher. So the result under the second variable weight is more reasonable and is in line with the reality. Although the procedures are elaborated by static air targets situation assessment, the proposed strategy is also appropriate for dynamic target situation assessment and other problems.

4. Conclusion

This letter proposes a twice variable weight strategy for calculating index weight in target situation assessment. And the experimental results show that the proposed strategy could provide a better consideration of subjectivity and objectivity without additional coefficients, and adaptively adjust as the situation changes.

References

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