Ballistic Missile Detection Performance Evaluation for the Skywave OTHR based on the Modified AHP and the Cloud Gravity Center Theory

LIU Shihua[1,a] SHENG Wen[1,a] BI Zengjun[1,a]

[1]Dept.2, AFEWA, Wuhan 430019, China

[a]kyoliu2010@sina.com

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Abstract. A ballistic missile detection performance index system is constructed of the skywave OTHR based on the ballistic missile detection characteristics of the skywave OTHR system. Combined the AHP method to the GRG method, the index weights of the index system are computed. With the theory of cloud gravity center, the cloud model of the ballistic missile detection performance evaluation of the skywave OTHR is built. The ballistic missile detection performance on the typital detection condition of the skywave OTHR is evaluated using the cloud model. The feasibility of this method is verified through the calculation of example.

Introduction

The skywave radar is a complicate and huge system, its detection performance, which includes many factors and uncertainty, is an integrated index. It is also a complicate task but benefit for the national defense decision and scientific study to evaluate the detection performance of the skywave radar[1]. On the one hand, the current application ability of the skywave radar may estimated objectively according to the evaluation; on the other hand, based on the evaluation, the development of the skywave radar may promoted[2].

The appropriate detection performance evaluation model is the basis to evaluate the equipment[3]. At present, the phased array radar combat effectiveness evaluation models[1, 2, 4-6] and the radar netting combat effectiveness evaluation models[7-9] are widely studied, but the skywave radar ballistic missile detection performance evaluation model is rarely reported. The ballistic missile is a special kind of object, it has the characteristics of long flight distance, high flight speed, low RCS and echo coherence. In this paper, using the evaluation models of the phased array radars and the other equipments, the skywave radar ballistic missile detection performance evaluation indexes are analyzed and quantized, the skywave radar ballistic missile detection performance evaluation model is constructed.

In this paper, the skywave radar ballistic missile detection performance evaluation model is constructed based on the detection characteristics of the ballistic missile. The modified AHP method, which combined by the AHP method[10-12] and the GRG method[13], is used to compute the colony index weight in the index system. According to the cloud gravity center theory, the skywave radar ballistic missile detection performance is evaluated.

Construction of the Ballistic Missile Detection Performance Index System

The construction of the index system is the prerequisite of the ballistic missile detection performance evaluation[6]. The skywave radar ballistic missile detection performance is influenced by many indexes. In this paper, the indexes, which influenced the skywave radar ballistic missile detection performance significantly, are considered. A ballistic missile detection performance index system is constructed by a first grade index, three second grade indexes and twelve third grade indexes. The index system is shown as Table 1.

Table 1 Ballistic missile detection performance index system based on the weighted index

First grade index	Second grade index	Third grade index
Ballistic missile detection performance of the skywave radar	Detection ability	Detection coverage
		Data rate
		Measurement Precision
		Resolution
	Confrontation ability	Anti-jamming ability
		Counter-reconnaissance
		Anti-destruction ability
		Support ability
	Environment property	Missile burnout point altitude
		Channel usability
		Propagation loss
		Environment noise

Weights Computation of the Index System based on GRG

After constructed the detection performance index system, the weights of the indexes is need to confirmed to compute the skywave radar ballistic missile detection performance. At present, the AHP method is widely used in the weight computation of the index system. But, the computation result of the AHP method is subjective. Therefore, the GRG method is introduced in the AHP method to make the computation result of the weight computation more objective. The steps of the modified AHP are shown as bellows[13].

(1) The individual index weight of n experts for constructed index system are computed by AHP.

(2) Considering that the individual expert weight is unknown, so let the expert weight is equal to $1/n$. The individual index weight of each expert $\mathbf{W}^k (k=1,2,\cdots,n)$ is aggregated to the group index weight through weighted method, that is

$$\mathbf{W}=(w_1,w_2,\cdots,w_m)^{\mathrm{T}}=\frac{1}{n}\sum_{k=1}^{n}\mathbf{W}^k \tag{1}$$

(3) Because the judgement matrixs of all experts are different, thus, the credibility of individual index weight and group index weight of all experts are disparate. In this paper, the similarity between individual index weight of the k-th expert and group index weight is scaled using grey relational grade r^k, consequently, the expert weight is determined.

The relational coefficient of the i-th index between individual index weight obtained by jungement matrix of the k-th expert and group index weight is

$$\xi_i^k=\frac{\Delta\min+\rho\Delta\max}{|w_i^k-w_i|+\rho\Delta\max} \tag{2}$$

Where $\Delta\min=\min_i\min_k|w_i^k-w_i|$, $\Delta\max=\max_i\max_k|w_i^k-w_i|$, ρ is the resolution coefficient and $\rho\in(0,1]$. In order to enhance the resolution, let $\rho=0.1$.

The grey relational grade between individual index weight of the k-th expert $\mathbf{W}^k$ and group index weight $\mathbf{W}$ is

$$r^k=\frac{1}{m}\sum_{i=1}^{m}\xi_i^k \tag{3}$$

Where $r^k\le 1$. The above grey relational grade is normalized and the expert weight vector $(\varphi^1,\varphi^2,\cdots,\varphi^n)$ is determined. The k-th expert weight is

$$\varphi^k = \frac{r^k}{\sum_{k=1}^{n} r^k} \tag{4}$$

(4) The individual index weight is aggregated based on expert weight of each expert, the new group index weight $\mathbf{W}'$ is

$$\mathbf{W}' = \begin{bmatrix} w_1' \\ w_2' \\ \vdots \\ w_m' \end{bmatrix} = \varphi^1 \begin{bmatrix} w_1^1 \\ w_2^1 \\ \vdots \\ w_m^1 \end{bmatrix} + \varphi^2 \begin{bmatrix} w_1^2 \\ w_2^2 \\ \vdots \\ w_m^2 \end{bmatrix} + \cdots + \varphi^n \begin{bmatrix} w_1^n \\ w_2^n \\ \vdots \\ w_m^n \end{bmatrix} \tag{5}$$

The difference between $\mathbf{W}'$ and $\mathbf{W}$ is computed through a range quantization index d, that is

$$d = \sqrt{\sum_{i=1}^{m} (w_i - w_i')^2} \tag{6}$$

The threshold d_0 is set according to the precision requirement of evaluation. When $d \le d_0$, it means the difference between $\mathbf{W}'$ and $\mathbf{W}$ is very small and tend to stability, this new group index weight $\mathbf{W}'$ is index weight of the layer of concern. Otherwise, the $\mathbf{W}$ is replaced by new group index weight $\mathbf{W}'$, the grey relational grade between each index weight and new group index weight is computed by "Eq.(2)" and "Eq.(3)", and the expert weight vector $(\varphi^1, \varphi^2, \cdots, \varphi^n)$ is obtained. The group index weight $\mathbf{W}'$ is renewed by substituting expert weight vector into "Eq.(5)". Then, compute the difference d between $\mathbf{W}'$ and $\mathbf{W}$. Repeat the above steps until $d \le d_0$.

Determination of the Detection Performance based on the Cloud Gravity Center Theory

The cloud is a transform model that represent the uncertainty between the qualitative concept and its quantitative expression by linguistic label. The digital characteristics of the cloud include the expectation, the entropy and the excess entropy, it integrated ambiguity and random to form a mapping between qualitative and quantitative expression[6].

(1) The system statue expression of the performance index

The N indexes can be abstracted by N cloud models, therefore, the system statue, which expressed by N performance indexes, can be expressed by a N-dimension synthetic cloud. When the system statue is changed, the shape of the N-dimension synthetic cloud is simultaneously change. The gravity center T of the N-dimension synthetic cloud can be expressed by a N-dimension vector, that is,

$$T = (T_1, T_2, \cdots, T_N) \tag{7}$$

Where $T_1, T_2, \cdots, T_N$ are the attribute values of the N performance indexes. When the system statue is changed, its gravity center is change to

$$T' = (T_1', T_2', \cdots, T_N') \tag{8}$$

(2) Measurement of the cloud gravity center deviation

The cloud gravity center vector of the system under the ideal statue is

$$T^0 = (T_1^0, T_2^0, \cdots, T_N^0) \tag{9}$$

Then, the difference of the synthetic cloud gravity center between the ideal statue and the given statue can be scaled by the weighted deviation θ. Firstly, the synthetic cloud gravity center vector under the given statue is normalized to obtain a vector $T^G = (T_1^G, T_2^G, \cdots, T_N^G)$. Where

$$T_i^G = \begin{cases} (T_i - T_i^0)/T_i^0, & T_i < T_i^0 \\ (T_i - T_i^0)/T_i, & T_i \ge T_i^0 \end{cases} \quad i = 1, 2, \cdots, N \tag{10}$$

Secondly, after the normalization, the synthetic cloud gravity center vector, which repress the system statue, is a dimensionless value. The weighted deviation is

$$\theta = \sum_{i=1}^{N} w_i T_i^G \tag{11}$$

Where w_i is the weight value of the i-th index.

(3) Computation of the system performance

Based on the cloud gravity center deviation, the performance quantization value of the whole system is

$$E_S = 1 - \theta \tag{12}$$

(4) Definition of the cloud remark assembly

The cloud remark assembly, which defined by the cloud generator, is composed of eleven remarks. The cloud remark assembly is shown as Table 2[6].

Table 2 Cloud remark assembly

Grade	None	Extreme bad	Very bad	Bad	Comparably bad	Normal	Comparably good	Good	Very good	Extreme good	Perfect
Attribute value	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

Example and Analysis

(1) Confirmation of the Index Weight

Considering the scorings of three experts, The index weight is computed by AHP method. The index weights of these three experts are w_1=(0.1671 0.0355 0.0355 0.0355 0.0626 0.0355 0.0626 0.1057 0.1671 0.1671 0.0626 0.0632)、w_2=(0.1994 0.0509 0.0300 0.0300 0.0863 0.0509 0.0300 0.0863 0.1344 0.1994 0.0509 0.0515)、w_3=(0.1523 0.0591 0.0337 0.0337 0.0591 0.0337 0.0990 0.1523 0.2245 0.0591 0.0598)。

Based on the modified AHP method, the colony index weight is w=(0.1760 0.0521 0.0322 0.0322 0.0721 0.0418 0.0358 0.0940 0.1460 0.2052 0.0557 0.0569)。

(2) Confirmation of the Weighted Index Attribute Value

The weighted index attribute value is obtained by the expert scoring and the mathematic model. The ballistic missile detection weighted index attribute value of the skywave radar in typical condition is shown as Table 3 (the value is 1 in ideal condition).

Table 3 Ballistic missile detection weighted index attribute value of the skywave radar in typical condition

Index	**Attribute value**	**Index**	**Attribute value**
Detection coverage	0.85	Anti-destruction ability	0.80
Data rate	0.50	Support ability	0.80
Measurement Precision	0.50	Missile burnout point altitude	0.75
Resolution	0.50	Channel usability	0.75
Anti-jamming ability	0.80	Propagation loss	0.70
Counter-reconnaissance	0.60	Environment noise	0.70

(3) Detection Performance Evaluation based on the Cloud Gravity Center Theory

The normalized cloud gravity center vector is computed by the weighted index attribute value and the Eq.10, the computation result is T^G=(0.15 0.50 0.50 0.50 0.20 0.40 0.20 0.20 0.25 0.25 0.30 0.30). Based on the cloud gravity center vector T^G and the expert weight w, the weighted deviation is computed and the result is θ=0.2633. Hence, the ballistic missile detection performance value based on the weighted index in a typical condition is E_S=0.7367. Then compared the whole performance value to the cloud remark assembly (Table 2), the performance value belong to good, which corresponded to the actual situation.

Conclusion

In order to evaluate the ballistic missile detection performance of the skywave radar, for the ballistic missile detection characteristic and the complicate electromagnetic environment, the skywave radar ballistic missile detection performance evaluation model is constructed. In the computation of the index weight, the GRG method is introduced in the AHP method due to the AHP method is subjective and the modified AHP method is achieved. Based on the cloud gravity center theory, the skywave radar ballistic missile detection performance is evaluated. Finally, the ballistic missile detection performance of the skywave radar in the typical condition is calculated. The feasibility of this method is verified through the calculation result.

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