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## Anti-jamming Effectiveness Evaluation of Radio Fuze based on the grey analytic hierarchy process

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# Anti-jamming Effectiveness Evaluation of Radio Fuze based on the grey analytic hierarchy process

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**Abstract.** Considering the working environment and characteristics of the radio fuze, the seven indicators that respectively reflect the radio fuze's anti-repression and anti-deception interference ability are selected to construct an anti-jamming performance evaluation index system. Based on this system, an evaluation model based on Grey Hierarchy Analysis (GAHP) was constructed, and the judgment matrix, weight vector, evaluation set, evaluation sample matrix, whitening weight function, and evaluation weight matrix and other key factors of the model were analyzed and determined. The scientific and feasibility of this method is verified by an example, which provides a more accurate and effective method for quantitatively studying the anti-interference performance of radio fuze.

## 1. Introduction

Radio fuze is a proximity fuze which determines the time of detonation of ammunition by transmitting and receiving radio waves to obtain target information [1]. It is widely used in all types of missiles.

With the continuous development of the interference technology and the rapid change of the environment, the effectiveness of the radio fuze is increasing rapidly in today's battlefield. Therefore, how to evaluate the anti-jamming effectiveness of the radio fuze objectively and practically has become an urgent problem that needs to be overcome, but the radio fuze is different from that of the general. Many characteristics of radar [2] make the researchers have great variability and fuzziness in evaluating the anti-jamming effectiveness of the researchers. The methods for measuring and evaluating the anti-jamming effectiveness of radio fuze are [3], the fuzzy function cutting method [4] based on information criterion, the processing of the gain square method [5] and the probability criterion based fuze starting probability [6] And so on. These methods can measure and quantify the anti-jamming effectiveness of Radio Fuze under different interference conditions, but in engineering practice, these indexes are low measurability, it needs a lot of calculation and deduction, and it is inappropriate to use it as an evaluation index. Literature [7] puts forward the factors based on power, time, interference and efficiency. Evaluation index system, but its index independence, completeness is not strong, in addition, its interference mode set index is too subjective.

Therefore, this paper comprehensively analyzes the interference environment and anti-interference measures facing the radio fuze, selects the index system which can reflect the effect of the corresponding interference effect, and constructs an anti-jamming effectiveness evaluation model of radio fuze based on the grey analytic hierarchy process (GAHP), and combines the anti-jamming effectiveness test data of a certain type of radio fuze. The feasibility of the method is verified by an example evaluation.



## 2. Determination of Evaluation Index system

### 2.1. Analysis of working Environment and characteristics of Radio Fuze.

As the key component of missile weapon damage, radio fuze has many different characteristics from general radar because of its special working environment and function [8].

*2.1.1. Action distance:* To change the default, adjust the template as follows. Detection capacity is much weaker than radar, the lowest less than one meter. This is due to the low transmitter power and receiver sensitivity, compared with the general radar, often several orders of magnitude difference. Some fuzes have good range cutoff characteristics. Therefore, the jammers need more input power.

*2.1.2. The number of confrontations is high:* Under real combat conditions, cruise missiles and artillery and other weapons are often multiple firing. When attacking the target area, the jammers are often faced with several fuzes working in different frequency bands. That is, the jammer must have the ability to fight a fuze at the same time.

*2.1.3. High speed relative motion between the target and the target:* When the radio fuze has a certain distance from the target, it often does not start work, so the enemy can not carry out the necessary interference. When the fuze is turned on, it is usually in the area close to the target. Therefore, it is more difficult to implement effective jamming to high speed radio fuze.

*2.1.4. Strong confidentiality and difficult reconnaissance:* Because of the special military significance, it is very difficult for countries to keep the information about radio fuze strictly confidential. It is very difficult to understand the effectiveness of the fuze through the open channel, but the information of the fuze is restricted by the particularity of its work to detect the information of the enemy fuze by the relevant technical means.

*2.1.5. Electromagnetic signal environment is dense and complex:* Many missile radio fuzes work in the vhf or uhf band, and many civil signals also work in this frequency band. The interleaving of radio signals and the variability of modulation forms form a complex and changeable electromagnetic environment.

Because of the characteristics of the above radio fuze, the commonly used anti-jamming performance evaluation index of general radar is often not suitable for radar fuze. Therefore, we should closely combine the working environment and characteristics of radio fuze, select the indexes that can reflect the effect of different interference on radio fuze from different angles, and consider comprehensively the scientific nature, independence, completeness and testability to construct index system.

### 2.2. Selection of evaluation index

#### 2.2.1. Evaluation indicators corresponding to suppressive interference

##### a) Interference power factor:

Under the condition that the input power of the radio fuze is invariable, the jamming power factor means that when the enemy jamming equipment carries on the suppressive interference to our radio fuze at a given distance, The successful jamming makes it impossible for our fuze to output elevation information or the ratio of the minimum power required  $P_{j\min}$  compare to its maximum power  $P_0$  when the accuracy does not meet the requirements. Which is:

$$K_P = P_{i\min} / P_0 \quad (1)$$

Where:  $P_{i\min}$  is the minimum power used to achieve the effect of the set spacing;  $P_o$  is the reference power.

b) Sensitivity degradation factor:

Sensitivity degradation factor Indicates the minimum input power required to find the target. At a certain distance, under ideal conditions, the minimum power needed to find the attacking object is  $S_{\min}$ . When the interference signal is detected, the lowest power used by the attacking object is  $S_{j\min}$ , and the ratio between the two is defined as the sensitivity degradation factor, that is:

$$K_{SD} = S_{\min} / S_{j\min} \quad (2)$$

c) Target intercept distance factor: The target intercept distance is defined as the maximum distance from which the target echo signal is intercepted and the elevation information is given by the radio fuze under a certain power suppression jamming, expressed by  $R$ . The furthest detection range of the fuze in the absence of interference is expressed by  $R_o$ , and the target intercept distance factor is defined as the ratio of the two. Which is:

$$K_R = R / R_o \quad (3)$$

d) Target discovery probability factor: Generally speaking, the better the anti-jamming efficiency of fuze is, the less the negative effect of detecting target is [9]. Therefore, the anti-jamming effect can be characterized by comparing the change of target detection probability under different conditions [10]. When there is no intentional interference and other conditions are fixed, the target detection probability of the fuze is  $P_f$ , reduced to that of the target detection probability after the intentional interference is applied, expressed by  $P_{jf}$ . then the target discovery probability factor of the radio fuze can be recorded as:

$$K_f = P_{jf} / P_f \quad (4)$$

2.2.2. *Evaluation indicators for fraudulent interference.* a) Elevation precision degradation factor: Elevation accuracy is the elevation error caused by radio fuze in operation. When other conditions are fixed, the fuze elevation error before and after the deception jamming of certain intensity is defined as the  $E_o$  and  $E_r$ . The elevation precision degradation factor is defined as:

$$K_\theta = (E_r - E_o) / E_o \quad (5)$$

b) Forward gain factor: The forward gain is mainly aimed at the forward deception jamming, the latter receives the radiation energy of the fuze through the jammer, analyzes and judges, modulates the signal similar to the target, then amplifies and forwards the signal to the fuze. The conditions required for the successful jamming of the repeater are independent of the absolute power of the jammer, and only depend on the forward gain [4]. Therefore, the forward gain factor is defined as when the fuze input power and distance are certain, The successful jamming of the enemy jammer makes our fuze unable to output elevation information or the ratio of the minimum forwarding gain required  $K_{j\min}$  compare to its maximum forwarding gain  $K_o$  when the accuracy does not meet the requirements. Which is:

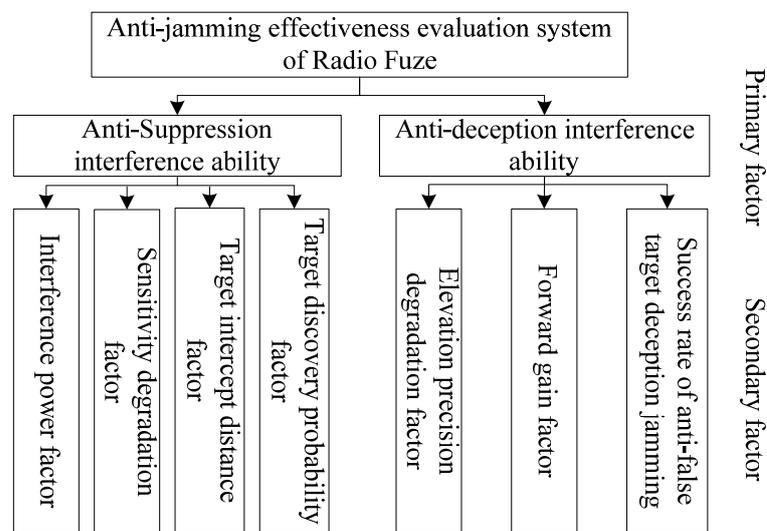
$$K_G = K_{jG\min} / K_{jG} \tag{6}$$

c) Success rate of anti-false target deception jamming: The range false target deceptive interference forms a deceptive signal by modulating or forwarding the radio fuze signal. After the radio fuze is set and detected, a number of deceptive decoys are produced, forcing the radio fuze to select the target. In order to reduce the damage probability of radio fuze to actual target [11], therefore, under the condition of certain number of decoys, the success rate of anti-false target deception jamming is defined as  $P_{anti-f}$ . Which is:

$$P_{anti-f} = \frac{n_e}{n} \times 100\% \tag{7}$$

Where:  $n$  for the total number of interference;  $n_e$  for the effective number of anti-interference.

2.2.3. *Evaluation indicators for fraudulent interference.* Based on the above indexes, according to the construction principle of the index system and from the point of view of radio fuze countermeasure technology, the anti-suppression jamming ability and the anti-deceptive jamming ability are regarded as the first grade factors of the radio fuze anti-jamming effectiveness evaluation system. The corresponding index is secondary factor. In order to build the radio fuze anti-jamming effectiveness evaluation index system, as shown in figure 1.



**Figure 1.** Structure map of anti-jamming performance evaluation index system

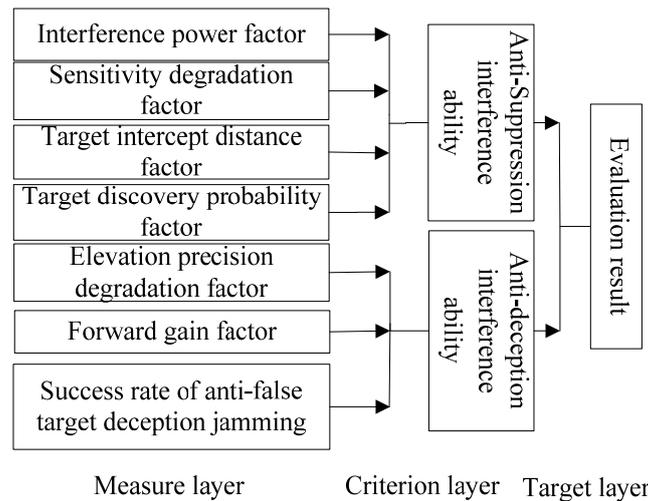
### 3. Model of Radio Fuze Anti-jamming efficiency based on Grey Analytic hierarchy process

#### 3.1. Establishment of GAHP Model

The grey analytic hierarchy process [12] combines the grey system theory with the analytic hierarchy process (AHP), and can also be evaluated synthetically under the condition that the system information is not perfect. The main steps are as follows: the weight of each single index at different levels is obtained by analytic hierarchy process (AHP), and the data obtained from the experiment are processed by using the grey system theory, and the evaluation sample matrix describing the degree of grey class is obtained. The distribution of grey classes of each index data is analyzed and the grey comprehensive evaluation weight matrix is constructed. Finally, combined with the grey

comprehensive evaluation weight matrix and index weight vector, the comprehensive evaluation results of fuze anti-jamming effectiveness are obtained.

Firstly, the evaluation model is established, including target layer, criterion layer and measure layer. According to the index system constructed in the previous section, the target level of the evaluation model is determined to be  $U$ , the criterion layer is  $U_1, U_2$ . the measure level is  $U_{11}, U_{12}, U_{13}, U_{14}$  and  $U_{21}, U_{22}, U_{23}$ , as shown in figure 2.



**Figure 2.** Grey analytic hierarchy process evaluation model structure chart

3.2. Establishment of judgment matrix and determination of weights of evaluation indicators

After determining the subordinate relation of the upper and lower layer elements, the influence weight of each index on the upper layer can be obtained by constructing the judgment matrix [13]. In this paper, we use the 1-9 scale method to quantify and construct the judgment matrix:  $A = (a_{ij})_{n \times n}$ , the elements  $a_{ij}$  in the matrix represent the measure of the importance of the  $i$  index relative to the  $j$  index. After consistency test, the maximum eigenvector of the judgment matrix is the weight of the index relative to the upper layer [14-15].

Considering each index of anti-jamming effectiveness evaluation of radio fuze, combined with expert opinion, the judgement matrix corresponding to each index of measure layer is set up, and the consistency ratio is calculated as follows:

$$A_1 = \begin{bmatrix} 1 & 3 & 1/2 & 2 \\ 1/3 & 1 & 1/4 & 1/2 \\ 2 & 4 & 1 & 3 \\ 1/2 & 2 & 1/3 & 1 \end{bmatrix}, \quad CR_1 = 0.01 < 0.1 \tag{8}$$

$$A_2 = \begin{bmatrix} 1 & 1/5 & 1/4 \\ 5 & 1 & 2 \\ 4 & 1/2 & 1 \end{bmatrix}, \quad CR_2 = 0.022 < 0.1 \tag{9}$$

All matrices meet the requirements of consistency. The judgment matrix corresponding to the criterion layer is:

$$A = \begin{bmatrix} 1 & 1/2 \\ 2 & 1 \end{bmatrix} \tag{10}$$

The maximum eigenvector of each judgment matrix is the weight vector, and the weight vector of each index at the measure level is:

$$W_1 = (0.278, 0.095, 0.467, 0.160)$$

$$W_2 = (0.097, 0.570, 0.333)$$

The weight vectors of each index at the criterion level are:

$$W = (0.333, 0.667)$$

**3.3. Determination of evaluation set and evaluation sample matrix [16]**

When analyzing the test data, the evaluation set is defined as excellent, good, medium, qualified and unqualified. Respectively to build the evaluation set as  $C = (9, 7, 5, 3, 1)$ .

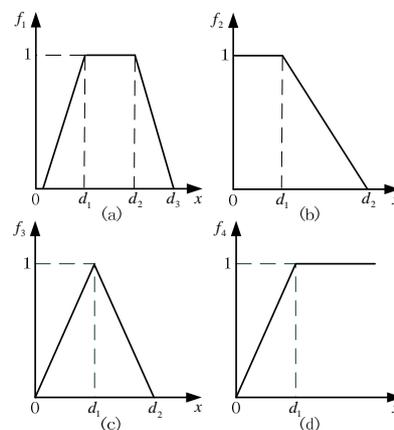
Let the radio fuze anti-jamming performance index set be  $I$  set, the set of experts participating in the evaluation is  $J$ , The rating given by the  $j$  reviewer for indicators  $i$  in the layer is  $d_{ij}^{(A)}$ . Then the evaluation sample matrix can be written as:

$$D_{ij}^{(A)} = \begin{bmatrix} d_{11}^{(A)} & d_{12}^{(A)} & \cdots & d_{1j}^{(A)} \\ d_{21}^{(A)} & d_{22}^{(A)} & \cdots & d_{2j}^{(A)} \\ \vdots & \vdots & \ddots & \vdots \\ d_{i1}^{(A)} & d_{i2}^{(A)} & \cdots & d_{ij}^{(A)} \end{bmatrix} \tag{11}$$

**3.4. Determination of evaluation set and evaluation sample matrix [17]**

The main contents of determining and evaluating grey class are: determining the number of grades, grey number and whitening weight function of grey class.

The five grades of the evaluation set correspond to the five grades of the grey class respectively. There are four basic forms of grey number and whitening weight function, respectively, corresponding to the white weight function in fig. 3.



**Figure 3.** Four basic forms of whitening weight function

The turning point of whitening weight function is the threshold of grey number. Combining with the tactical index of radio fuze and literature data, the grey number and whitening weight function corresponding to different grey class grades are obtained by consulting experts.

The first type of evaluation grey class is "excellent" and the corresponding grey number is set to  $\otimes_1 \in [0, 8, 9, \infty)$ . The whitening weight function is:

$$f_1 = \begin{cases} x-8 & 8 < x \leq 9 \\ 1 & x > 9 \\ 0 & 0 < x \leq 8 \end{cases} \quad (12)$$

The second type of evaluation grey class is "good" and the corresponding grey number is set to  $\otimes_2 \in [0, 7, 8, 9, 10, \infty)$ . The whitening weight function is:

$$f_2 = \begin{cases} x-7 & 7 < x \leq 8 \\ 1 & 8 < x \leq 9 \\ 10-x & 9 < x \leq 10 \\ 0 & 0 < x \leq 7 \text{ \& } x > 10 \end{cases} \quad (13)$$

The third type of evaluation grey class is "medium" and the corresponding grey number is set to  $\otimes_3 \in [0, 6, 7, 8, 9, \infty)$ . The whitening weight function is:

$$f_3 = \begin{cases} x-6 & 6 < x \leq 7 \\ 1 & 7 < x \leq 8 \\ 9-x & 8 < x \leq 9 \\ 0 & 0 < x \leq 6 \text{ \& } x > 9 \end{cases} \quad (14)$$

The fourth type of evaluation ash class is "qualified" and the corresponding grey number is set to  $\otimes_4 \in [0, 6, 7, 8, \infty)$ . The whitening weight function is:

$$f_4 = \begin{cases} x/6 & 0 < x \leq 6 \\ 1 & 6 < x \leq 7 \\ 8-x & 7 < x \leq 8 \\ 0 & x > 8 \end{cases} \quad (15)$$

The fifth type of evaluation grey class is "unqualified" and the corresponding grey number is set to  $\otimes_5 \in [0, 6, 7, \infty)$ . The whitening weight function is:

$$f_5 = \begin{cases} 1 & 0 < x \leq 6 \\ 7-x & 6 < x \leq 7 \\ 0 & x > 7 \end{cases} \quad (16)$$

### 3.5. Calculation of grey evaluation weight vector and matrix

For the index  $i$ , the evaluation coefficient of the first type of evaluation grey class is  $x_{i,e}$ . The total evaluation coefficient of the five types of evaluation ash class is  $r_{i,e}$ , and the evaluation power of the evaluation grey class is recorded as, there are:

$$x_{ie} = \sum_{k=1}^n f_e(d_i^k) \quad (17)$$

$$x_i = \sum_{e=1}^5 x_{i,e} \quad (18)$$

$$r_{i,e} = \frac{x_{i,e}}{x_i} \quad (19)$$

Thus, the normalized grey evaluation weight vector is obtained as follows:

$$r_i = (r_{i,1}, r_{i,2}, \dots, r_{i,5}) \quad (20)$$

The evaluation weight matrix can be obtained by combining the evaluation weight vectors of each index as:

$$R = \begin{bmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,5} \\ r_{2,1} & r_{2,2} & \cdots & r_{2,5} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m,1} & r_{m,2} & \cdots & r_{m,5} \end{bmatrix} \quad (21)$$

### 3.6. Grey comprehensive evaluation results

According to the weight of index and the matrix of evaluation weight, the grey comprehensive evaluation results of index  $U_1$  and  $U_2$  of criterion layer can be obtained as follows:

$$B_1 = W_1 R_1 = (b_{11}, b_{12}, b_{13}, b_{14}, b_{15}) \quad (22)$$

$$B_2 = W_2 R_2 = (b_{21}, b_{22}, b_{23}, b_{24}, b_{25}) \quad (23)$$

Using the evaluation results, the evaluation weight matrix of the index can be formed directly as

$$R = \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \end{bmatrix} \quad (24)$$

The result of grey comprehensive evaluation of target layer is as follows:

$$B = WR = (b_1, b_2, b_3, b_4, b_5) \quad (25)$$

If the evaluation results are converted to a tenth system, the final evaluation results are obtained as follows:

$$E = BC^T \tag{26}$$

**4. Illustrations**

In order to ensure the objective rationality of the index data, a set of index data is obtained through the anti-jamming effectiveness evaluation test of a certain type of fuze outside the field, which is shown in Table 1 after densification.

**Table 1.** Single index data

Criterion layer	Measure layer	Indicator data
<i>Anti-suppressive interference ability</i>	Interference power factor	0.79
	Sensitivity degradation factor	0.76
	Target intercept distance factor	0.73
	target discovery probability factor /%	47.86
<i>Anti-deception interference ability</i>	Elevation precision degradation factor /%	25
	Forward gain factor	0.65
	Success rate of false target deception jamming /%	42.46

Among them, the relative indexes are measured under the set distance, the power of the jammer and the number of false targets.

Five experts in the field were invited to rate the ability of radio fuze to resist suppression jamming and deceptive jamming respectively. The evaluation sample matrix was obtained as follows:

$$D_{ij}^{(A_1)} = \begin{bmatrix} 8.5 & 9 & 8.5 & 9 & 7.5 \\ 8 & 8.5 & 7.5 & 8.5 & 9 \\ 6.5 & 8.5 & 8 & 8.5 & 8 \\ 6 & 6.5 & 8.5 & 9 & 7.5 \end{bmatrix} \tag{27}$$

$$D_{ij}^{(A_2)} = \begin{bmatrix} 7.5 & 9 & 8.5 & 7.5 & 9 \\ 7 & 7.5 & 8 & 9 & 8.5 \\ 6 & 7.5 & 7 & 8.5 & 7.5 \end{bmatrix} \tag{28}$$

Then the weight vector and matrix of grey evaluation are calculated by formula (17)~(18). As for 1st evaluation ash class for indicator  $U_{11}$ , Then there is  $e = 1, i = 1$ . So:

$$x_{1,1} = \sum_{k=1}^5 f_1(d_1^k) = 3$$

At the same time  $x_{1,2} = 4.5, x_{1,3} = 2, x_{1,4} = 0.5, x_{1,5} = 0$ . So:

$$x_1 = \sum_{e=1}^5 x_{1,e} = 10$$

It can be obtained by (17) that:

$$r_1 = (0.3, 0.45, 0.2, 0.05, 0)$$

Combined grey evaluation weight vectors:  $U_{12}, U_{13}, U_{14}$ . The grey evaluation weight matrix of  $U_1$  is:

$$R_1 = \begin{bmatrix} 0.300 & 0.450 & 0.200 & 0.050 & 0 \\ 0.200 & 0.450 & 0.300 & 0.050 & 0 \\ 0.100 & 0.400 & 0.350 & 0.100 & 0.050 \\ 0.150 & 0.250 & 0.200 & 0.250 & 0.150 \end{bmatrix} \quad (29)$$

The grey evaluation weight matrix of  $U_2$  obtained by the same principle is

$$R_2 = \begin{bmatrix} 0.250 & 0.400 & 0.250 & 0.100 & 0 \\ 0.150 & 0.350 & 0.350 & 0.150 & 0 \\ 0.050 & 0.200 & 0.350 & 0.300 & 0.100 \end{bmatrix} \quad (30)$$

The results of the calculation are as follows

$$B_1 = W_1 R_1 = (0.173, 0.395, 0.280, 0.105, 0.047)$$

$$B_2 = W_2 R_2 = (0.127, 0.305, 0.340, 0.195, 0.033)$$

Using this result, the evaluation weight matrix of the index at the criterion level can be directly constituted as follows:

$$R = \begin{bmatrix} 0.173 & 0.395 & 0.280 & 0.105 & 0.047 \\ 0.127 & 0.305 & 0.340 & 0.195 & 0.033 \end{bmatrix} \quad (31)$$

The result of grey comprehensive evaluation of target layer is as follows:

$$B = WR = (0.142, 0.335, 0.320, 0.165, 0.038)$$

The result of the final evaluation is

$$E = BC^T = 5.755$$

Referring to the evaluation set matrix, we can see that the evaluation level of the radio fuze is "medium", which is consistent with the actual working condition of the radio fuze.

It can be seen that the grey analytic hierarchy process can synthesize many factors which are closely related to the anti-jamming effectiveness of radio fuze, and transform the qualitative analysis

into quantitative comprehensive evaluation results, and the evaluation results are in agreement with the actual situation, so this method is feasible.

## 5. Conclusion

This paper mainly discusses the index system, evaluation model and evaluation method of radio fuze anti-jamming effectiveness. First of all, from the point of view of fuze countermeasure technology, the jamming power factor, sensitivity degradation factor, target intercept distance factor and target discovery probability factor are proposed based on anti-suppression jamming ability and anti-deceptive jamming ability, respectively. The evaluation index system is constructed based on seven indexes, such as the degradation factor of high precision, the gain factor of forwarding, and the success rate of resisting deception jamming of false target. Based on this system, an evaluation model based on grey analytic hierarchy process (GAHP) is constructed, and the factors such as judgment matrix, weight vector, evaluation set, evaluation sample matrix, whitening weight matrix and evaluation weight matrix are studied. Finally, the scientific feasibility of the method is verified by the experimental data. This paper provides a more accurate and effective method for quantitative study of radio fuze anti-jamming performance.

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