Evaluation of ELINT system effectiveness based on Grey Relational Optimization Algorithm

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Abstract. Aiming at the problems and shortcomings of the current electronic intelligence reconnaissance system effectiveness evaluation methods, an ELINT system effectiveness evaluation algorithm based on grey correlation optimization algorithm is proposed. The algorithm firstly combines the principle of ELINT system to build its evaluation index system. Then, based on the subjective and objective attributes of the index, the algorithm combines the G1 sequence subjective weighting method with the CRITIC objective weighting method to obtain the combined weight of each index. Finally, the improved gray correlation optimization algorithm model is used to analyze the correlation of the index value of the system under test, and the system performance is determined by comparing each distance with the optimal system. Theoretical analysis and simulation results show that the method effectively combines qualitative and quantitative analysis and is feasible in the performance evaluation of ELINT system.

1. Introduction
The ELINT system mainly intercepts and analyzes radar signals in space, obtains radar signal parameters, and provides intelligence support for electronic countermeasures. A reasonable assessment of the effectiveness of the ELINT system will help the commander make correct decisions and operational deployments[1]. For the current common efficiency evaluation methods, the determination of the index weight is a very critical link. In this paper, the subjective weighting method of G1 sequence and the objective weighting method of CRITIC are used to obtain the combined weight of the indicators, and then the system performance is quantitatively evaluated based on the optimized gray correlation algorithm.

2. Basic algorithm principle
Currently, there are three main categories of system effectiveness evaluation methods based on the characteristics of weight: subjective weighting method, objective weighting method and combination weighting method. This article mainly integrates the characteristics of three types of weighting methods, and selects a weighting method based on the combination of G1 sequence method and CRITIC weighting method. Finally, the gray correlation optimization algorithm based on combination weight is used to evaluate the system performance.

2.1. Principle of Grey Association Algorithm
Grey relational analysis is a common system analysis method[2]. Mainly based on gray correlation between the factors measured by quantitative analysis method of the relationship between factors in this algorithm, the reference sequence generally consists of the best value of each index of the tested
object, which is recorded as: \( X_0 = \{ X_0(j) | j = 1, 2, \ldots, N \} \). Where \( j \) is the target index and \( N \) is the total number of targets. The comparison series is generally composed of the values of the indicators of the tested objects, and is recorded as: \( X_i = \{ X_i(j) | i = 1, 2, \ldots, M \} \). Where \( i \) is the object to be tested and \( M \) is the total number of objects to be tested. Then the difference between the index \( i \) of the object to be measured \( j \) is recorded as: 
\[
\Delta(j) = x_i(j) - x_0(j). 
\]

The number of gray relations between \( X_0 \) and \( X_i \) is:
\[
\min \min (\Delta(j)) + \rho \max \max (\Delta(j)). 
\]

d. The value range of \( \rho \) is \([0,1]\), usually \( \rho = 0.5 \). When calculating the grey correlation degree of indicators, due to the different importance of each indicator in the system, the weight of each indicator also varies. If the weight of indicator \( j \) is \( \omega_j \) \( (\sum_{j=1}^{N} \omega_j = 1, \omega_j > 0) \). Then its gray correlation is: 
\[
\gamma_i = \sum_{j=1}^{N} \xi(j) \omega_j. 
\]

When using the gray correlation algorithm to evaluate the system, for determining the weight of the overall evaluation of the effectiveness of the system is critical, this paper uses the weight indicators based on objective data and subjective nature indicators combinations of features heavy weighting method, so that the evaluation result is more reasonable and comprehensive, and the gray correlation algorithm is optimized to a certain extent.

### 2.2. Combined weighting

(1) G1 sequence method

The G1 sequence method is an improved subjective weighting method[3]. The judgment matrix is constructed by the scale expansion method without a consistency test. Sort \( N \) evaluation indicators \( \{x_1, x_2, \ldots, x_n\} \), in descending order based on expert experience. Assuming \( x_1 > x_2 > \cdots > x_n \), then compare the importance of \( x_j \) and \( x_{j+1} \) to get the scale value \( t_j \). The scale is shown in Tab. 1.

| Scale value | meaning       |
|-------------|---------------|
| 1           | Equally important |
| 1.2         | slightly important |
| 1.4         | Strongly important |
| 1.6         | Obviously important |
| 1.8         | Absolutely important |
| 1.1, 1.3, 1.5, 1.7 | Between each level |

(2) CRITIC weighting method

The CRITIC method is an objective weighting method based on indicator data, which is mainly based on the contrast strength and conflicting nature of the data[4]. The contrast intensity is expressed in the form of standard deviation. The conflict of evaluation indicators is reflected by the correlation coefficient. If there is a strong positive correlation, the less information, the smaller the weight. For an
evaluation system, it is assumed that there are \( n \) indicators and \( m \) tested objects, It is possible to construct an indicator information volume based on two characteristics, let \( C_j \) denote the information content contained in the indicator. \( C_j = \sigma_j \cdot \sum_{i=1}^{n} (1-r_{ij}), j=1,2,\cdots,n \). Standard deviation is \( \sigma_j \).

Correlation coefficient is \( r_{ij} \).

The larger \( C_j \) is, the greater the information amount of the indicator and its greater importance, so the objective weight of the indicator is:

\[
\beta_j = C_j / \sum_{j=1}^{n} C_j, \quad j = 1,2,\cdots,n.
\]

3) Least squares method for combining weights

It can be seen from the above that the subjective weighting method reflects the value of the indicator, and the objective weighting method reflects the amount of information of the indicator. Using the least square method can achieve the unity of subjective and objective weights[5], the unity of information and value. The optimal combination weight is \( \omega \), \( \omega = [\omega_1, \omega_2, \cdots, \omega_n]^T \).

Establish the least squares optimization combination evaluation model as:

\[
\begin{align*}
\min F(\omega) &= \sum_{i=1}^{m} \sum_{j=1}^{n} \left[ \left( \alpha_j - \omega_j \right) x_{ij} \right]^2 + \left[ \left( \beta_j - \omega_j \right) x_{ij} \right]^2 \\
&= \left[ \sum_{i=1}^{m} \sum_{j=1}^{n} \left( \alpha_j - \omega_j \right) x_{ij} \right]^2 + \left[ \sum_{i=1}^{m} \sum_{j=1}^{n} \left( \beta_j - \omega_j \right) x_{ij} \right]^2 \\
&= B \omega^2 + C \omega + e
\end{align*}
\]

The optimal solution to the least squares model can be obtained:

\[
\omega = B^{-1} \left( C + \frac{1}{e^T B^{-1} e} e \right)
\]

\[
e = [1, 1, \cdots, 1]^T
\]

\[
\omega = [\omega_1, \omega_2, \cdots, \omega_n]^T
\]

\[
B = \text{diag} \left[ \sum_{i=1}^{n} x_{i1}^2, \sum_{i=1}^{n} x_{i2}^2, \cdots, \sum_{i=1}^{n} x_{in}^2 \right]
\]

\[
C = \left[ \sum_{i=1}^{m} x_{ij} \right]^2, \sum_{i=1}^{m} \left( \alpha_j + \beta_j \right) x_{ij}^2, \cdots, \sum_{i=1}^{m} \left( \alpha_j + \beta_j \right) x_{ij}^2 \right]^T
\]

(4) Normalization

Quantification of qualitative indicators: Some indicators that are difficult to describe quantitatively are quantified using the quantitative ruler method[6]. The commonly used quantitative rulers are shown in Tab. 2.

|   | Very Good | Good | Better | General | Worse | Bad | Very Bad | Worst |
|---|-----------|------|--------|---------|-------|-----|----------|-------|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |

Normalization of quantitative indicators: The calculation of quantitative indicators of different dimensions will affect the analysis and interpretation of the physical meaning of the results. This article mainly uses the linear scale transformation method to normalize the index value. The efficiency index conversion function is \( r_{ij} = x_{ij} \max_{i} x_{ij} \). The cost index conversion function is \( r_{ij} = \min_{i} x_{ij} \min_{i} x_{ij} \).

3. ELINT System Effectiveness Evaluation Model

This article builds on the ELINT system effectiveness evaluation model based on the grey correlation optimization algorithm. The evaluation process is shown in Fig. 1.

3.1. ELINT system evaluation index system

This article characterizes the efficiency of the ELINT system as signal interception efficiency, parameter measurement efficiency and signal processing efficiency[7]. The system is shown in Fig. 2.

3.2. Index data preprocessing
For the ELINT system, its performance value is determined by multiple indicators. When evaluating the effectiveness of the system, it is necessary to normalize the data of different dimensions for calculation. This paper uses linear scaling method to preprocess the data. The index reference set of the index extreme value of each system under test is 

\[ X = \begin{bmatrix} x_1 & x_2 & \cdots & x_{12} \end{bmatrix} \]

The sample set of the index of the system under test is 

\[ X_i = \begin{bmatrix} x_{i1} & x_{i2} & \cdots & x_{i12} \end{bmatrix} \]

and sample measurement values of each system under test is 

\[ \hat{X}_i = \begin{bmatrix} \hat{x}_{i1} & \hat{x}_{i2} & \cdots & \hat{x}_{i12} \end{bmatrix} \].

3.3. Effectiveness evaluation based on grey correlation optimization algorithm

After processing the index values, the combined weight of each index is obtained by using the G1 sequence method and the CRITIC objective weighting method, and then the system is analyzed for correlation based on the gray correlation optimization algorithm. The gray correlation degree can be used to indicate the gap between the series to be tested and the reference series. The correlation distance can be used to express, \( Q_i = 1 - \gamma_i \). When evaluating system performance, a system with balanced capabilities in all aspects is better than a system with stronger unilateral aspects. Therefore, this article refers to the general method of obtaining the stability of the series\[8\], introduces the standard deviation to measure the stability of the system indicators, and uses the stability distance to characterize the stability of the system, \( S = \frac{1}{N} \sum_{j=1}^{N} (\hat{x}_{ij} - \hat{x}_{ij})^2 \). The system can be comprehensively evaluated using the evaluation distance \( P_i = \mu Q_i + (1 - \mu) S_i \), in general, \( \mu = 0.5 \).

4. Example simulation and Discussions

The five-tested ELINT system is: A0、A1、A2、A3、A4, and the sample values of its indicators are shown in Tab. 3. The effectiveness evaluation of these five ELINT systems is now under way.

4.1. Algorithm implementation

Calculate the three distances between the tested system and the optimal system under different weights. Weight of index shows in Tab. 4. Tab. 5 and Fig. 3 show comparison under subjective weight; Tab. 6 and Fig. 4 show it under objective weights; Tab. 7 and Fig. 5 show it under combined weights.
4.2. Results and Discussions

Tab. 3 Sample index value

| Sample value | A1 | A2 | A3 | A4 |
|--------------|----|----|----|----|
| X1 sensitivity | 67 | 56 | 70 | 100 |
| X2 azimuth coverage | 360 | 360 | 360 | 360 |
| X3 frequency search range | 18 | 8 | 12 | 10 |
| X4 instantaneous bandwidth | 0.60 | 0.50 | 0.40 | 0.70 |
| X5 intercept probability | 0.40 | 0.20 | 0.30 | 0.60 |
| X6 Pulse parameter measurement | 0.70 | 0.60 | 0.50 | 0.40 |
| X7 polarization analysis | 0.60 | 0.60 | 0.80 | 0.60 |
| X8 intrapulse analysis | 0.40 | 0.50 | 0.60 | 0.30 |
| X9 fingerprint analysis | 0.70 | 0.50 | 0.20 | 0.10 |
| X10 signal density | 2 | 3 | 4.50 | 1 |
| X11 sorting ability | 0.85 | 0.65 | 0.70 | 0.72 |
| X12 recognition ability | 0.93 | 0.90 | 0.85 | 0.88 |

Tab. 4 Index weight table

| Objective weight | Subjective weight | Combination weight |
|------------------|-------------------|--------------------|
| X1 | 0.16 | 0.09 | 0.12 |
| X2 | 0.1 | 0.00 | 0.05 |
| X3 | 0.07 | 0.09 | 0.08 |
| X4 | 0.04 | 0.09 | 0.07 |
| X5 | 0.03 | 0.16 | 0.10 |
| X6 | 0.13 | 0.07 | 0.10 |
| X7 | 0.09 | 0.06 | 0.07 |
| X8 | 0.08 | 0.11 | 0.09 |
| X9 | 0.05 | 0.15 | 0.10 |
| X10 | 0.11 | 0.15 | 0.13 |
| X11 | 0.08 | 0.03 | 0.06 |
| X12 | 0.05 | 0.01 | 0.03 |

Tab. 5 Performance comparison table (subjective weight)

| Relevance distance | Stable distance | Evaluation distance |
|--------------------|-----------------|--------------------|
| A0 | 0.26 | 0.22 | 0.24 |
| A1 | 0.37 | 0.18 | 0.28 |
| A2 | 0.28 | 0.22 | 0.25 |
| A3 | 0.33 | 0.24 | 0.29 |
| A4 | 0.15 | 0.19 | 0.17 |

Tab. 6 Performance comparison table (objective weight)

| Relevance distance | Stable distance | Evaluation distance |
|--------------------|-----------------|--------------------|
| A0 | 0.32 | 0.23 | 0.27 |
| A1 | 0.46 | 0.20 | 0.33 |
| A2 | 0.38 | 0.23 | 0.30 |
| A3 | 0.39 | 0.25 | 0.32 |
| A4 | 0.23 | 0.20 | 0.22 |

Tab. 7 Performance comparison table (Combination weight)

| Relevance distance | Stable distance | Evaluation distance |
|--------------------|-----------------|--------------------|
| A0 | 0.29 | 0.22 | 0.26 |
| A1 | 0.41 | 0.18 | 0.30 |
| A2 | 0.33 | 0.22 | 0.28 |
| A3 | 0.36 | 0.25 | 0.30 |
| A4 | 0.19 | 0.20 | 0.19 |

Fig. 3 Performance change trend chart (subjective weight)

Fig. 4 Performance change trend chart (objective weight)

Fig. 5 Performance change trend chart (Combination weight)
For the system index weights, combined with Tab. 4, it can be seen that the weights obtained by the purely subjective and objective weighting methods can’t match the actual conditions.

In the system performance analysis, when the gray correlation distance is used to measure the system performance, as can be seen from Fig. 3, Fig. 4 and Fig. 5, its performance is greatly affected by the weight. Therefore, when measuring the performance of the system, the combination weighting method mentioned can improve the accuracy of the evaluation; When the stability distance is used to measure the system performance, it can also be seen that its stability performance is not affected by the weight, indicating that the stability is related to the characteristics of indicator data. In summary, the following evaluations can be made for the five tested systems: by comparing the correlation distance, we can know the performance of each system: \( A_4 > A_5 > A_6 > A_7 > A_8 \). In terms of system performance, \( A_4 \) system has the best performance, and system \( A_8 \) has the worst; by comparing the stable distance, we can know the stability of each system: \( A_7 > A_6 > A_5 = A_4 > A_4 \). System \( A_8 \) is the most stable, it’s capabilities in all aspects are more balanced. System \( A_8 \) has the worst stability. System \( A_7 \) and system \( A_4 \) have the same stability; Finally, comprehensive consideration of the performance value and stability of the system under test shows: \( A_8 > A_6 > A_5 = A_7 > A_4 \). \( A_8 \) system has the best performance, \( A_4 \) system has the worst performance, \( A_5 \) system and \( A_7 \) system have the same performance. If the decision maker prefers the performance, the \( A_4 \) system can be selected according to the correlation distance, if the overall function of the system is stable, then it can Choose the \( A_8 \) system.

5. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

(1) The gray correlation analysis method can be used to evaluate the effectiveness of the ELINT system. Through comparative analysis, quantitative scoring and excellent ranking of the efficiency of the ELINT system can be achieved.

(2) The combined weighting method based on the combination of the subjective weighting method of G1 sequence and the objective weighting method of CRITIC can combine the subjective characteristics of the indicator and the characteristics of the objective data, thereby obtaining more scientific and reasonable indicator weight.

(3) The combination weighting method is used to optimize the gray correlation algorithm, and the system is evaluated in many aspects by introducing the correlation distance, stable distance and evaluation distance, and a more scientific and reasonable evaluation result is obtained.

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