Research on Evaluation Method of Radar Health Management System Based on Variable Weights

Zhijian Sun(✉), Taiyong Fei, Zhiguo Qu, Chaohua Liang, and Feng Xu

Early Warning Academy, 430019 Wuhan, China
sunnetqq@sina.com

Abstract. The evaluation index system of radar equipment PHM system is the foundation of the construction of radar equipment health management system. Building a scientific and reasonable index system helps to improve the quality of the construction of health management system. This article takes radar equipment as the research object, combines the characteristics of radar equipment systems, uses tree analysis technology to analyze key issues, constructs an initial indicator system for system evaluation, and studies the standardization and optimization of evaluation indicators. A variable weight based evaluation method for Rada Health Management System is proposed.

Keywords: variable weight · Health management · assessment

1 Introduction

At present, research in the field of fault diagnosis mainly focuses on the evaluation of system state and fault diagnosis, with a focus on the "current" operating state of the system, namely whether a fault has occurred, the location of the fault, etc. There is less research on system fault prediction and health management. However, in the actual production process, many production operating conditions require strict requirements, and the consequences of faults are relatively serious. It is not enough to only know whether the current operating conditions are normal, because the operating conditions may already be in a dangerous operating area when the fault is discovered. At this time, it is difficult for the operator to restore the system operating conditions to the normal area, or although the operating conditions can be restored to the normal area, but it has seriously affected the economic benefits of production [1, 2]. Monitor the state of the electronic system and estimate its health status, realize the prediction of its state, predict the probability of complete failure of the electronic system according to its health status, and make early prediction of the propagation and development of the failure, so that the loss caused by catastrophic failure can be prevented and greatly reduced. The fault diagnosis expert system in the communication system of the Voyager spacecraft in the United States is equipped with a prediction module, which is used to predict and analyze the performance of the aircraft in real-time [3, 4].

Prognostic and health management (PHM) is a new type of health management technology developed based on Condition based Maintenance (CBM). PHM includes

D. Kumar et al. (Eds.): IEIT 2023, AHSSEH 10, pp. 607–614, 2023.
https://doi.org/10.2991/978-94-6463-230-9_73

two aspects, namely fault prediction and health management [5]. Fault prediction is to use the current health status of the system/equipment as the starting point, predict the completion status of the system/equipment's functions, and predict potential faults that may occur in the future; Health management is based on the obtained fault prediction information, combined with usage requirements and available maintenance resources for diagnosis, in order to make appropriate decisions on equipment fault maintenance.

With the rapid development of advanced sensing technology and artificial intelligence technology, complex system health management technology has gradually become the focus of attention for researchers in domestic and foreign research institutes and military departments. After the design of the health management system is completed, whether its performance meets the specified requirements needs to be confirmed through verification and evaluation. In addition, the feedback information obtained through verification and evaluation can also improve and improve the design of the health management system [6–8]. Verification and evaluation are key links in the design and application of health management systems.

2 Evaluation Index System

2.1 Basic Requirements

The radar health management system should have capabilities such as status monitoring, fault diagnosis, health assessment, status prediction, and maintenance support decision-making. It should be able to monitor equipment status in real-time, detect and isolate faults in a timely manner, reasonably predict equipment status trends, effectively evaluate equipment health status, and scientifically support equipment maintenance support decision-making.

(1) Status monitoring.

State monitoring covers the entire radar system, covering key parts related to the performance and safety of radar equipment. State monitoring should fully reflect the technical status of radar equipment work.

(2) Fault diagnosis.

Equipped with fault detection and isolation function, it can achieve intelligent fault diagnosis support.

(3) Health assessment.

Able to evaluate the health status of radar equipment systems, subsystems, and key components.

(4) State prediction.

Capable of predicting the state of product life or performance parameters with gradual changes. The accuracy of state prediction meets the needs of maintenance support.

(5) Maintenance Support Assistance Decision.

It has the function of auxiliary generation of maintenance support plans. The maintenance support plan includes maintenance content, task level, maintenance method, maintenance timing, operation method, maintenance personnel, equipment, equipment, and related technical information.

2.2 Evaluation Index System

According to the analysis, the evaluation index system of the health management system can be divided into five categories based on the functions of the health management system: status monitoring, fault diagnosis, health assessment, status prediction, and maintenance support auxiliary decision-making, as shown in Fig. 1:

3 Optimization of Initial Indicator System Based on Grey Correlation Analysis

The initially established indicator system has a wide variety of categories, but there are some indicators that have poor correlation with the evaluation objectives, the importance of certain indicators cannot be distinguished, and some indicators are not suitable for in-service assessment issues. Therefore, optimization is needed.

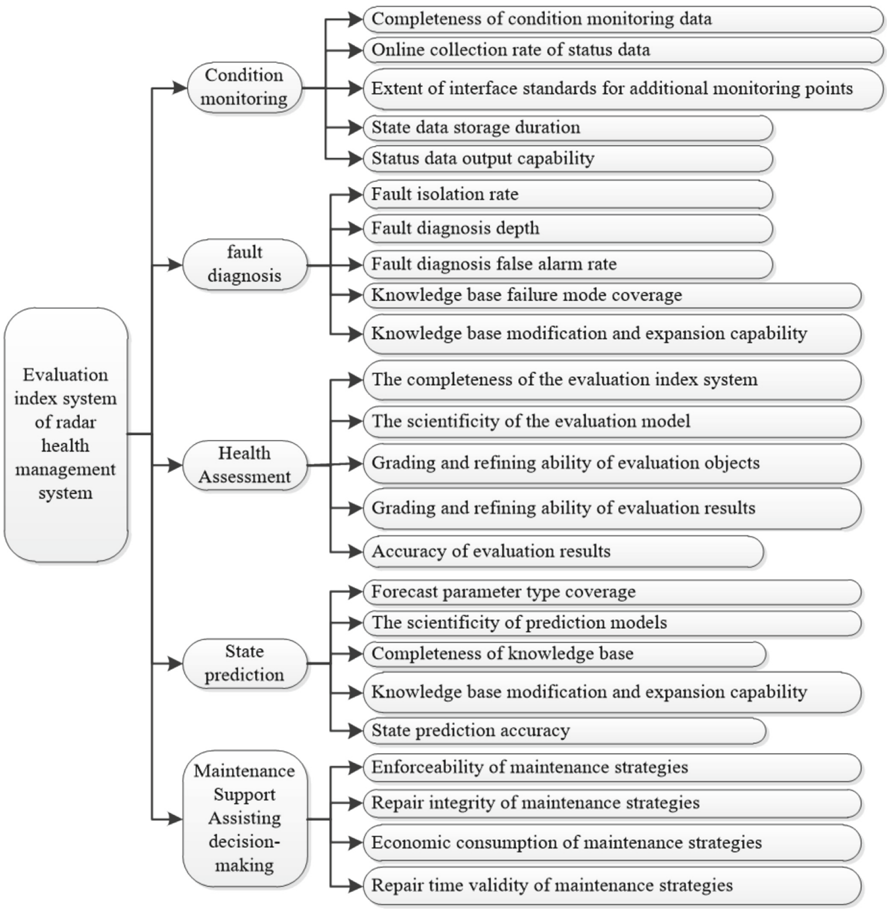

Fig. 1. Evaluation Indicator System for Radar Health Management System

3.1 Acquisition and Standardization of Initial Indicator Values

Due to the different evaluation scales, dimensions, and variation ranges of each indicator, it is difficult to compare different indicators together. Therefore, it is necessary to standardize the indicators in the indicator system. The threshold method compares the original value of an indicator with its maximum (minimum) or theoretical value, converting the indicator into a standard value. The standardized formula is:

$$b_{nk} = x_{nk}/\max_{n}(x_{nk}) \tag{1}$$

$$b_{nk} = \min_{n}(x_{nk})/x_{nk} \tag{2}$$

where x_{nk} is the actual collected value of the k-th indicator of n appraisal objects; The $\max_{n}(x_{nk})$ and $\min_{n}(x_{nk})$ are the relatively optimal or theoretical values among the collection numbers of the evaluation object, respectively.

Equation (1) is mainly used to calculate benefit indicators. The larger the result, the better the "benefit"; Eq. (2) is mainly used to calculate cost based indicators. The more accurate the results, the better the "cost" control.

3.2 Establishment of Grey Correlation Degree Model

Based on grey correlation analysis, the requirement for data volume is relatively low, and both large and small amounts of data can be analyzed; In view of its characteristics of only analyzing data and not considering the actual situation, the improved grey correlation degree model based on Delphi method method and correlation analysis method is adopted to further obtain a screening and perfect evaluation index system.

3.2.1 Establishment of Grey Correlation Degree Model.

The grey system is a system with incomplete and insufficient information, which is different from the white system (complete and clear information) and the black system (lack of information).

Grey correlation analysis takes the degree of correlation between indicators as the starting point, uses data processing methods to find the relationship between various factors in the system, uses grey correlation analysis methods to determine whether the relationship between factors is close, and then selects and rejects indicators. The general steps are as follows:

(1) Determine the set of evaluation target indicators. Namely.

$Y_0 = \{ x_0(1), x_0(2), \ldots, x_0(m)\}$.
$Y_n = \{ x_n(1), x_n(2), \ldots, x_n(m)\}$.

Among them, $x_0(k)$ is the theoretical or standard value of the k-th indicator, and x_{nk} is the actual data collected for the k-th indicator of the n-th assessment object.

(2) Calculate the grey correlation coefficient. After eliminating various indicator dimensions and standardizing the data, $Y_0(k)$ is the standard sequence, $Y_i(k)$ is the comparison sequence, and then $U = u_i(k)_{m*n}$, $u_i(k) = |Y_i(k)\text{-}Y_0(k)$, there are:

$$\varepsilon_i(k) = \frac{\min_i \min_k R + s^* \max_i \max_k R}{u_i(k) + u^* \max_i \max_k R} \quad (3)$$

Among them, s is the resolution coefficient, generally s should be greater than 0.4, usually between 0.5 and 1, and usually s = 0.5.

(3) Calculate the degree of correlation. The degree of correlation represents the degree of correlation between indicators, i.e. the degree of close correlation:

$$r_m = \frac{1}{n} \sum_{i=1}^{n} \varepsilon_m(i) \quad (4)$$

Sort r_m to determine the importance of the indicators and analyze their strengths and weaknesses.

3.2.2 Delphi Method Method to Adjust Index Ranking.

The basic principle of the Delphi method method is to consult the selected experts in terms of indicator selection and ranking in a confidential manner, summarize and sort out the answers after receiving them, and complete a communication and statistical process called a round. Anonymous feedback will be provided on the consistent and different results obtained from the consultation, and opinions will be solicited again. Communicate - count - communicate again - count again, repeat multiple times (usually 3–4 rounds) until the requirements are met. The consensus opinions are combined into the collective opinions of the expert group [9, 10].

Delphi method method is used to verify and simplify the results of correlation analysis, and finally determine the indicator system set to make the indicator system more perfect.

4 System Evaluation Method Based on Variable Weights

The evaluation of the radar health management system adopts a hierarchical and integrated evaluation system, so it is necessary to determine the weights between different index levels after calculating the index levels of each evaluation index, and integrate them into the level index of the previous system level.

The weight reflects the degree to which different indicators have an impact on the overall system evaluation performance. Different evaluation indicators should be given appropriate weights in order to accurately and reasonably evaluate the level of the radar health management system.

The traditional methods for determining weights are often divided into subjective and objective categories:

(1) The subjective weighting method is a method of directly or indirectly determining weights based on expert experience, represented by the Analytic Hierarchy Process. The evaluation results of this type of method are in line with common sense and can reflect the professionalism of experts, but the accuracy of the results is greatly influenced by the personal experience of experts.

(2) The objective weighting method is a method of directly calculating weights based on a certain model or rule, represented by the entropy weighting method. This type of method makes judgments based on the characteristics of the data itself, and the evaluation results are relatively objective, but it ignores the professional knowledge of experts, and sometimes the weight does not conform to common sense.

Due to the fact that the weight coefficients calculated by traditional weight determination methods are usually static and invariant, and the work of the radar health management system in the system is a dynamic process, it is not possible to consider the impact of different indicators changing over time during the evaluation process. More and more scholars have proposed a weighted integration method that uses variable weights to replace constant weights.

The variable weight synthesis method is a variable weight integration method that introduces equilibrium functions to construct variable weights on the basis of the constant weight synthesis method. While retaining the original importance of indicators in the system, it can also fully reflect the impact of changes in level indices between indicators on the overall evaluation system. Therefore, this article uses the variable weight synthesis method to study the evaluation of newly developed radar health management systems.

The traditional constant weight comprehensive method calculation method is:

$$\mathrm{V_c} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{w_i^c x_i} \tag{5}$$

In the formula, n is the number of evaluation indicators, w_i^c is the constant weight of the i-th indicator, $\mathrm{x_i}$ is the evaluation value of the i-th indicator, $\mathrm{V_c}$ is the rating index for constant weight evaluation.

When the value of a certain characteristic indicator parameter greatly exceeds the allowable range, if only relying on constant weight to evaluate the radar health management system, the final evaluation result of the indicator may still be at a normal level due to the low weight value of the characteristic indicator parameter. This is also the deficiency of the constant weight model, which cannot fully accurately and timely reflect the system evaluation level. Therefore, it is necessary to propose a variable weight comprehensive method to solve this problem, The model is:

$$\mathrm{V} = \sum_{i=1}^{n} w_i\left(x_1, \ldots, x_n, w_1^c, \ldots, w_n^c\right) x_i \tag{6}$$

In the equation, $\mathrm{w_i}$ is the variable weight.

The variable weight synthesis method introduces the equilibrium function as follows:

$$\sum(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} x_i^a \tag{7}$$

Among them, a is the equilibrium coefficient, $(0 < a \leq 1)$.

The formula for obtaining variable weight is:

$$w_i\left(x_1, \ldots, x_n, w_1^c, \ldots, w_n^c\right) = w_i^c x_i^{a-1} / \sum\nolimits_{k=1}^{n} w_k^c x_k^{a-1} \tag{8}$$

The corresponding variable weight comprehensive model can ultimately be represented as:

$$V = \sum_{i=1}^{n} w_i x_i = \sum_{i=1}^{n} w_i^c x_i^a / \sum_{k=1}^{n} w_k^c x_k^{a-1} \tag{9}$$

When considering the balance of various parameter indicators or components and equipment within the equipment system, the balance coefficient $a<0.5$ is taken; When it is more tolerant of defects in certain parameter indicators or components or equipment, take $0.5 \le a<1$; When $= a$ 1, it is the constant weight model.

5 Conclusion

The validation and evaluation of health management systems is an immature research field with great research potential and extensive research space. The research status at home and abroad shows that there are many problems to be solved in the verification and evaluation technology of the health management system [11, 12]. First, it is difficult to obtain the data of the object system and guarantee the data quality; Secondly, there is a lack of a universal health management testing environment; The third issue is that the verification and evaluation indicator system is not yet perfect. This article takes radar equipment as the research object, combines the characteristics of radar equipment systems, uses tree analysis technology to analyze key issues, proposes the overall requirements for validation evaluation, constructs the initial index system for system evaluation, and studies the standardization of evaluation indicators and the classification of system evaluation levels [13, 14]. This can provide a method reference for the construction of PHM system evaluation index system for radar equipment.

References

1. Wu Dong, Huang Yonghua, Wang Kaiwei. Analysis of Testability Verification Work in the New Situation of Equipment Test and Appraisal [J]. Electronic Product Reliability and Environmental Testing, 2019,37 (1); 30-34.
2. Zuo Qinwen, Zhang Jiemin, Liu Xiaohong, et al. Intelligent Combat Evaluation Method Based on Big Data and Machine Learning [J]. Journal of Weapon Equipment Engineering, 2020,41 (2); 107-110.
3. Chen Snow, Zhang An, Gao Fei. Evaluation Method of Equipment System Contribution Based on Deep Confidence Networks [J]. Command, Control and Simulation, 2021,43 (4); 26-31.
4. Luo Xiaoqiang, Wang Yigang, You Xiudong. Data collection and management methods for in-service assessment of mine weapons [J]. Digital Ocean and Underwater Attack and Defense, 2019,2 (4): 70-75
5. Li Ni, Li Yuhong, Gong Guanghong. Intelligent evaluation and optimization of system combat effectiveness based on deep learning [J]. Journal of System Simulation, 2020,32 (8): 1425-1435
6. Qi Zongfeng, Wang Huabing, Li Jianxun. Evaluation of Radar Reconnaissance System Operational Capability Based on Deep Learning [J]. Command, Control and Simulation, 2020,42 (2): 59-64

7. Duan Zunlei, Ren Guang, Li Ye. An Intelligent Evaluation Method for Marine Engineering Operations Based on Deep Belief Networks [J]. Journal of Dalian Maritime University, 2017,43 (3): 89-94
8. Chi Mingwei, Hou Xingming, Chen Xiaowei. Prediction of Strike Effectiveness of a Certain Anti Armor Weapon System Based on BP Neural Network [J]. Journal of Weapon Equipment Engineering, 2020,41 (8): 52-57
9. Tang Wenquan, Xu Wu, Wen Cong, et al. Transient Stability Assessment Based on Kernel Principal Component Analysis and Deep Confidence Networks [J]. Motor and Control Applications, 2021,48 (1); 46-52.
10. Zhang Binchao, Kou Yanan, Lin Meng, et al. Short range air combat situation assessment based on deep confidence networks [J]. Journal of Beijing University of Aeronautics and Astronautics, 2017, 43 (7); 1450-1459.
11. Huang Desuo, Yang Shanchao. Research on the Fusion Model of Qualitative Evaluation Indicators for Maintainability Requirements [J]. Journal of Ordnance Equipment Engineering, 2017.38 (4): 87,9
12. Zhang Ming. Research on an Evaluation Method for Engineering Series Equipment Allocation Scheme [J]. Journal of Equipment Command and Technology College, 2010.21 (1): 104-106
13. Peng Geng. Construction of a Task Oriented Remote Sensing Satellite Information Support Capability Evaluation Index System [J]. Command, Control and Simulation, 2019,40 (2): 15-19
14. Sun Peng, Zhu Haoyang, Zhao Yong, et al. Research on the Construction of Equipment Operational Test Evaluation Index System [J]. Modern Defense Technology, 2020,48 (6): 108–113+120