Research on the health management of an automatic magazine control system to the naval gun

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Abstract. According to the problems of low maintenance efficiency and high cost for traditional regular maintenance and after-the-fact maintenance methods, PHM technology is introduced to improve the success rate of the system operation, extend the service life, and reduce maintenance difficulty and cost. Aiming at the overall situation of the automatic magazine control system of a large-caliber gun weapon, a new health management system based on a data-driven method is proposed. Establishing a PHM model applied to automatic magazine control system by using the structure of open system architecture for condition-based Maintenance (OSA-CBM); the prediction and evaluation function of PHM system is studied with an example of transfer servo drive system; the prediction model based on BP neural network is established to predict the health parameters of the automatic magazine control system. Then the health state of system is evaluated according to the prediction result and the function is verified by simulation. The simulation results show this BP neural network model is applicable for the parameter prediction of the prediction and evaluation module of the automatic magazine PHM system. The prediction accuracy is over 90%, and the model has a good applicability.

1. Introduction

Automatic magazine is an important part of the naval gun weapon system, and its reliability is crucial for the normal operation of a naval gun. Once there is a problem with the automatic magazine, it will seriously affect the operational effectiveness of the gun. The automatic magazine control system of a large-caliber gun with complicated structure, many electronic components, high degree of automation, and inconvenient maintenance brings greater difficulties to the system maintenance. Traditional manual-based methods of periodic maintenance and after-the-fact maintenance cannot guarantee the safety and reliability of system. Therefore, using new technology and means to realize the maintenance and technical management of the automatic magazine control system is becoming an important way to save maintenance costs and ensure the safety of system.

Prognostics and health management (PHM) is a comprehensive health management technology, which includes fault monitoring, isolation and prediction technology. It uses the integration of advanced sensors, various algorithms and intelligent models to monitor and manage the state of the system to really achieve condition-based Maintenance [1] [2]. The application of PHM technology in system maintenance is transforming from traditional sensor-based diagnosis to intelligent system-based prediction, which greatly improved the efficiency of system maintenance. Using PHM
technology to achieve condition-based maintenance of system has the following advantages: 1) Provide failure warning of system in time. 2) Obtain equipment failure information and failure cause analysis. 3) Reduce repair time, extend maintenance intervals. 4) Reduce costs of maintenance and life cycle of equipment. 5) Information management: Inform accurate information to accurate personnel at accurate time.

In summary, the PHM technology has showed a strong vitality, improved the economic endurance, reliability and safety in applications of complex system. Therefore, in this paper, PHM technology is applied to the automatic magazine control system to establish its health management system according to the characteristics of the automatic magazine control system. This system can monitor the health status of the automatic magazine control system, make timely assessments and forecasts, and propose maintenance decisions to ensure the normal operation of the system.

2. The structure of the automatic magazine control system

The automatic magazine control system studied in this paper adopts all-digital electrical drive mode, which is composed of storage servo drive system, transfer servo drive system, lift missile servo drive system, health management system, distribution system and communication system. The controller receives the control command from the upper computer, calculates and processes correspondingly according to the input command and information, then issues a control command to the servo drive system such as the storage servo drive system to drive each module to act. It can also collect information of the servo drive system such as working state, fault signal and remaining ammunition.

The health management system proposed in this paper is a subsystem of the automatic magazine control system of the naval gun, it can communicate with the controller of the automatic magazine system. The premise of the health management system is to determine the status monitoring points and collect the system characteristic data by analyzing the function and fault mode of the automatic magazine system. When the controller receives the instructions from the upper computer of the naval gun, it will provide the collected relevant data to the health management system for processing. With the help of scientific intelligent algorithm model, health management system realizes the status monitoring, health prediction and fault diagnosis of the magazine and finally provides decision support for the establishment of maintenance schemes. After decision, the health management system will return the relevant results to the upper computer and displays it to guide the staff to maintenance system.

3. PHM model of automatic magazine control system

3.1. The structure of PHM model

The model structure of the PHM system is a description of its constituent elements and interrelationships, it not only affects the complexity of the PHM system itself, but also determines
function and behavior characteristics [3]. In general, the model structure of a PHM system depends on the composition and function relationships of the system. Therefore, different systems often have different structures. The Open System Architecture for Condition-based Maintenance (OSA-CBM) [4], [5], [6] applied to the US Navy is the most classic one of those. It divides the PHM system into seven function modules: data acquisition layer, data processing layer, condition monitoring layer, health assessment layer, fault prognostic layer, decision support layer and human interface layer, which comprehensively reflects the design ideas and methods of PHM system.

3.2. Establishment of PHM model for automatic magazine control system

The automatic magazine control system is different from the real-time equipment system, it is characterized by long-term storage, used in exercise or actual combat. Therefore, PHM system of Automatic magazine Control System mainly relies on historical data, state monitoring data and intelligent algorithm model established based on these data. PHM model of automatic magazine control system is shown in figure 2.

![Figure 2. Structure diagram of PHM system for automatic magazine system](image)

The PHM model of the automatic magazine control system was designed based on structure of the CBM model and in combination with the automatic magazine system. It can monitor the state of the automatic magazine control system in real time, the data acquisition module collects the state information of the relevant subsystems and then preprocesses the data; The signal processing module implements data fusion, denoising, feature extraction, and data conversion on the collected physical quantities; The processed feature data is used to predict the health performance parameter of the system through the intelligent algorithm model and evaluate the health status of the system in the prediction and evaluation module; Based on the evaluation results, the fault diagnosis module extracts the characteristic data of the fault state for fault diagnosis; Finally, The decision module makes decisions on prediction and diagnosis, and puts forward the decision report. Besides, dynamic database stores data and knowledge in each module in real time. Each module can transmit the processing...
information to the upper computer through the communication interface to realize the interaction and sharing of human-machine information.

This paper focuses on the study of the prediction and evaluation module, which is the key function module of the automatic magazine PHM system, it can be divided into two parts: parameter prediction and state evaluation. After the collected data is processed, the prediction and valuation module extracts relevant knowledge from the database, establishes a BP neural network model to predict the system health parameters, and then evaluates the health status of the system according to the predicted results.

4. The construction of the BP neural network model

From the structure of the automatic magazine control system shown in figure 1, it can be seen that the health state of the system is closely related to the health state of its subsystems. Therefore, in the prediction design, this paper firstly predicts the faults of the five subsystems separately, and then infers the health status of the whole system through that of the subsystems. Taking the transfer servo drive system as an example, the BP neural network prediction model is established to realize the prediction and evaluation of system.

4.1. Research on prediction and evaluation of system based on BP neural network

The basic model of BP neural network is a 3-layer structure, which includes input layer, hidden layer and output layer [7]. Due to many fault nodes in the transfer servo drive system, it is difficult to take all the fault states as the input of the network. In order to reduce the coupling of the system, here, the fault nodes which can well represent the system state are selected to design. Because the transfer servo drive system is mainly controlled by four kinds of servo motors, and through the historical data recorded by the testers, it can be seen that the common faults of the system come from the anomalies and even faults of each motor in the system. To sum up, the input layer of the neural network is considered as 8 neurons in this paper, namely, grasping motor voltage (X1), grasping motor current (X2), telescopic motor voltage (X3), telescopic motor current (X4), rotation motor voltage (X5), rotation motor current (X6), transfer motor voltage (X7), transfer motor current (X8). And the output layer is the health performance parameter of the system—health factor H. H is a performance parameter to characterize the health status of the automatic magazine control system, it is provided by experts through the research and testing of the system and in combination with the automatic magazine system. The table of health factors and system status is shown in table 1.

| H         | (0,0.4) | (0.4,0.7) | [0.7,1) |
|-----------|---------|-----------|---------|
| system state | health | sub-health | fault   |

It can be seen from table 1 that the system state is described as health state, sub-health state and fault state according to the value range of the health factor of the system. Therefore, the output layer of the model is defined as a neuron. As the design of the hidden layer, in general, the number of hidden layer nodes is related to the input/output nodes of the problem. Too many hidden layer nodes make the learning time too long and inefficient; The hidden layer nodes are too few that the ability to identify new samples is low, and the fault tolerance is not strong [8]. Based on repeated verification and comparison, this paper selects four hidden layer neurons. The BP neural network model structure of the system is shown in figure 3.
Figure 3. The BP neural network model structure of transfer servo drive system

Selecting different samples to train until the network error is small enough to meet the system requirements. The network weight and threshold are adjusted as follows:

a) Weight ($W_{in}$) and threshold ($b_n$) adjustment of the Hidden layer

$$W_{in}(k + 1) = W_{in}(k) + \eta \delta_n y_n$$  \hspace{1cm} (1) \\
$$b_n(k + 1) = b_n(k) + \eta \delta_n$$  \hspace{1cm} (2)

b) Weight ($W_{nj}$) and threshold ($b_j$) adjustment of the Output layer

$$W_{nj}(k + 1) = W_{nj}(k) + \eta \delta_j y_j$$  \hspace{1cm} (3) \\
$$b_j(k + 1) = b_j(k) + \eta \delta_j$$  \hspace{1cm} (4)

Where $\eta$ is the learning rate, $\delta$ is the error, $k$ is the iteration.

4.2. Simulation

Based on the above, this paper established a 3-layer BP neural network prediction model for the transfer servo drive system, collected feature data stored in the database was used as the training set and test set of the network model to achieve the prediction of health factor. Finally, the system health status could be determined by the prediction result. A few training samples obtained from tests and expert analysis are shown in Table 3

Table 2. Table of training sample

|   | X1  | X2  | X3  | X4  | X5  | X6  | X7  | X8  | H   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|   | 380 | 2.85| 380 | 14.6| 380 | 4.6 | 380 | 14.5| 0.1 |
|   | 390 | 2.84| 388 | 14.98| 390 | 4.97| 390 | 15.8| 0.4 |
|   | 400 | 6.3 | 410 | 18.7 | 410 | 6.2 | 399 | 18.5| 0.8 |
|   | 397 | 4   | 401 | 15.3 | 397 | 5.6 | 397 | 16.6| 0.5 |
|   | 390 | 2.9 | 390 | 15  | 389 | 5   | 390 | 15.5| 0.2 |
|   | 399 | 5   | 403 | 15.7 | 398 | 5.7 | 401 | 16.8| 0.6 |
|   | 413 | 6.5 | 411 | 18.3 | 411 | 6.3 | 399 | 18.8| 0.9 |
|   | 380 | 2.85| 398 | 16   | 402 | 5.5 | 358 | 14.6| 0.7 |
|   | 409 | 6.8 | 413 | 19   | 411 | 6.1 | 399 | 21.6| 1   |
|   | 379 | 2.85| 385 | 14.8 | 384 | 4.86| 380 | 15.1| 0.3 |

The input data of the model is normalized by [-1,1], the output data is not normalized because it is within the range of [0,1]. After training with a large number of samples, the connection weights of each layer are continuously adjusted until the accuracy requirements of the system is met, then the
A trained neural network can be used for parameter prediction. The prediction examples are shown in Table 3.

Table 3. Table of prediction example

| X1    | X2    | X3    | X4    | X5    | X6    | X7    | X8    | H(prediction) |
|-------|-------|-------|-------|-------|-------|-------|-------|---------------|
| (353,405) | (2.8,7) | (14,17) | (4.5,6) | (14,20) |       |       |       |               |
| 382   | 2.84  | 378   | 14.5  | 385   | 4.9   | 377   | 14.9  | 0.1385        |
| 380   | 2.95  | 381   | 16    | 385   | 5.7   | 400   | 16.5  | 0.5637        |
| 0     | 6.5   | 0     | 16.5  | 0     | 5.9   | 0     | 19.85 | 0.9946        |

The normal range of each characteristic parameter is shown in the first line of Table 3, which was from expert analysis and field test. The range of X3, X5 and X7 is the same as X1. At this point, combining the correspondence between the health factor and the system state shown in Table 1 with the prediction results shown in Table 3, the health status of the system could be judged.

According to the results of the table 1 and table 3, when the characteristic parameters are at the edge of the normal range, the system is in the sub-health state; when some characteristic parameters are out of the normal range, the system is in the fault state.

Then the prediction accuracy is verified by the 30 sets of characteristic parameters of the system. The Result of test is shown in Figure 4.

![Figure 4. Result of test](image)

It can be seen from Figure 4 that the actual health factor of the system is basically consistent with the predictive health factor, and the prediction accuracy is over 90%. The simulation shows that this BP neural network model is applied for the parameter prediction of the prediction and evaluation module of the automatic magazine PHM system. The prediction effect is good, and the health status of the system can be better evaluated.

5. Conclusion

According to the fault characteristics of the automatic magazine control system of a naval gun, the PHM technology was introduced to design and establish the automatic magazine PHM system; Based on the OSA-CBM of US Navy, the PHM model of the automatic magazine control system was established; Taking the transfer servo drive system as an example, a system prediction model based on BP neural network was established to predict the health performance parameters of the system, and the health status of the system was determined according to the prediction result. The functions described in this paper were verified by simulation, and this model has a good applicability. Health management of the automatic magazine control system can improve the quality of maintenance and ensure the safety and efficiency of naval gun weapons.
References
[1] Nian F Sh 2018  *Chinese Journal of Scientific Instrument*. 39 1-14.
[2] Wang H F 2018 *Electrical Automation*. 40 109-110.
[3] Lu Y Ch, Jiang L and Zhao H L  2014  *Acta Armamentarii*. 35 68-73.
[4] Pei D M, Wang J F, Zhou P T and Luo Q H  2016  *Journal of Electronic Measurement and Instrumentation*. 30 1289-97.
[5] Jing B, Xu G Y, Huang Y F, Jiao X X and Liang W  2017  *Journal of Electronic Measurement and Instrumentation*. 31 161-169.
[6] Li X W, Wang H Y, Shen Y and He Y F  2015  *Computer Measurement & Control*. 23 1069-79.
[7] Sun J G, Zhang Y and Zhang J N  2016  *Control Engineering of China*. 23 1519-22.
[8] Guo J J, Liu W and Zhai W H  2017  *Journal of Drainage and Irrigation Machinery Engineering*. 53 195-202.