Application of Fault Prediction and Health Management in Vehicle Control System

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Abstract. Vehicle control system is a large and complex system with high degree of integration and informationization, which makes fault diagnosis and support more difficult. It puts forward new requirements for fault prediction and maintenance in terms of improving the reliability and efficiency of vehicle control system and reducing the cost of use and maintenance. In order to ensure the stable operation of vehicle control system and give full play to its combat capability, it is necessary to strengthen the monitoring and health assessment of the operation state of vehicle control system, and make appropriate maintenance decisions according to the health state of the system, so as to improve the security level and effectiveness of the vehicle control system.

Keywords: Fault Diagnosis, Fault Prediction, Health Management, Vehicle Control System

1. Overview of Fault Prediction and Health Management (PHM)
PHM technology is a new solution for health management based on the latest research results of modern information technology and artificial intelligence technology. It mainly includes fault prediction and health management. Fault prediction is the technology and means to provide early detection and isolation capability, and to manage and forecast the failure state of components or accessory components. Health management is making appropriate decisions about maintenance activities based on diagnostic or predictive information, available resources, and usage requirements. This technology further makes selective reporting, decision-making assistance and information management of the information of the potentially faulty parts that have been timely located, so as to improve the automation degree of maintenance support, reduce various expenses caused by failures, reduce risks and improve the capability of vehicle control system. PHM represents a shift in approach from traditional opportunity sensor diagnostics to intelligent system-based forecasting, reactive communications to pilot operations to take accurate maintenance activities at the exact location at the exact time [1].
PHM system can timely and accurately determine its current state and the possibility of failure in a period of time in the future, and to use, maintenance activities to make assistant decision recommendations; PHM using advanced sensor integration, and with the help of various algorithms and intelligent model to predict, diagnosis, monitoring and management state of equipment, complete fault detection, fault isolation, fault prediction and residual service life estimation, component life tracking, performance degradation trends, warranty tracking, fault selective reporting, auxiliary decision-making and resource management, fault tolerance, information fusion and reasoning mechanism, and information management [2]. Therefore, the emergence of PHM technology is the integration of engineering, reliability, communication and other multidisciplinary technologies.

2. The Research Status
The IDEA of PHM appears with the development of fault diagnosis and prediction technology. In 1995, Professor Lennox used neural network to study the fault prediction of complex electronic system [3], and used the variance between the predicted value and the actual value to predict the fault. However, the fault prediction of neural network is difficult to determine its hidden layer function and requires complete data samples and other disadvantages. In 1998, Prieto applied the knowledge of probability theory to the real-time fault prediction of analog circuit, and Prof. Henderson et al. studied the problem of engine fault prediction of small hydropower station. In 2002, Kalandros studied the variance control of multi-sensor system and provided a more appropriate method for the determination of control threshold. In 2003, by combining wavelet transform and self-organizing neural network, Qiu realized the early fault monitoring of rotating bearings and evaluated their performance, so as to give an alarm before their complete failure.

Since the end of 1990s, THE US military has introduced CBM in the civilian field as a strategic equipment support strategy into the military equipment field. CBM can carry out real-time monitoring of equipment status, determine the best time for maintenance according to the actual condition of equipment, reduce maintenance cost and improve maintenance efficiency, and improve equipment availability and mission reliability. The PHM system of the US F-35 represents the highest level of CBM application available.

PHM technology has attracted the most attention in the field of aviation and aerospace. For example, Boeing's "Aircraft Status Management (AHM) system" has been successfully applied in a variety of passenger or cargo passenger planes, and spacecraft Integrated Health Management (IVHM) system has also been successfully applied in NASA's second-generation reusable launch vehicle [4].

3. The Research Background
The integration and information characteristics of modern vehicle control system determine the complexity of its structure and fault diagnosis. In general, the fault form of modern vehicle control system presents new characteristics such as hierarchy, propagation, correlation and uncertainty [5]. In recent years, the development of intelligent fault diagnosis technology has pointed out a new development direction for the fault diagnosis of vehicle control system. The application of intelligent fault diagnosis technology to modern vehicle control system has become a hot and difficult issue in the research of vehicle control system support. The maintenance support of modern vehicle control system not only needs the post-fault diagnosis, but also needs the pre-prediction and real-time monitoring of the status, and also has the urgent demand for the maintenance efficiency and the control of the support cost. Therefore, fault prediction and health management system is the inevitable trend of modern vehicle control system maintenance support. The successful application of PHM can not only make fault prediction, fault diagnosis, fault isolation, fault decision processing and component performance tracking for the vehicle control system, but also make reasonable maintenance, repair and update plan for the vehicle control system with the support of the condition maintenance system. It can not only guarantee the working performance of the vehicle control system, reduce the pressure of the operation and maintenance personnel, but also save a lot of time and cost. It can also provide rapid and accurate fault diagnosis and effectively improve effectiveness.
4. The Key Technology
PHM consists of four parts: data acquisition system, status monitor-fault prediction system, maintenance management and interface [6].

4.1. Data Acquisition System
The data acquisition system includes data acquisition and transmission module and data processing module.

The data acquisition and transmission module uses the component detection port to collect the data information of the vehicle control system, carry out A/D conversion of the data and transmit the data.

The data processing module classifies, processes and transfers the collected data to the state monitoring - fault prediction system.

4.2. Status Monitoring - Fault Prediction System
Based on the data processed by the data acquisition module, the status monitoring, health assessment and failure prediction of the vehicle control system and its key parts are carried out.

Status monitoring module. This module realizes the state detection by comparing the real-time data with the failure data. If the difference between the two data exceeds the set threshold value, the fault alarm will be conducted. According to the evaluation criteria, the status of the vehicle control system is evaluated online.

Health assessment module. This module evaluates the health status of the system by comparing the data of the system health status with the historical data of maintenance.

Fault prediction module. This module can comprehensively utilize the data information of the above-mentioned parts, and evaluate and predict the future health status of the vehicle control system with the help of various reasoning technologies such as mathematical physical model and artificial intelligence.

PHM widely uses artificial intelligence technology, including expert system, neural network and genetic algorithm, etc. Intelligent reasoning to obtain accurate monitoring and fault diagnosis of system state.

4.3. Maintenance Management Module
This section receives data from the status monitoring, health assessment, and failure prediction sections, realizing PHM system management capabilities. Develop a maintenance management plan for the vehicle control system that can be implemented at any appropriate time prior to the failure of the vehicle control system.

4.4. Interface Module
Man-machine interface mainly displays the information, such as the system information of the status-fault prediction module and maintenance management module, as well as the warning information of the status-monitoring module. Machine-component interface can realize information transfer and exchange between data acquisition module, state monitoring and fault prediction module, maintenance module and interface module, as well as the whole PHM system and other systems [7].

5. Performance Evaluation
Due to the system internal characteristics, external use environment, fault law, data and other uncertainties, resulting in the uncertainty of fault diagnosis and prediction, PHM technology performance evaluation and verification problems.

PHM performance evaluation includes fault detection capability evaluation, fault diagnosis capability evaluation and fault prediction capability evaluation. The evaluation parameters of detection ability include fault detection rate, detection coverage rate, detection time, detection threshold, stability, load sensitivity, etc. In GJB 3385-1998, The fault detection rate is defined as "the ratio of the
number of faults correctly detected by a specified method to the total number of faults, expressed as a percentage. The evaluation parameters of diagnostic ability include false positive and false negative rate, fault isolation rate, etc. The evaluation parameters of prediction ability include prediction accuracy, accuracy, prediction level, etc. Accuracy and accuracy are described as the early failure prediction capability of PHM system with certain prediction accuracy and confidence level. The prediction module of PHM should predict the finite life components so that the predicted components can be replaced in time when there is still a certain residual life. The prediction level is a description of the timing, confidence, and distance of the prediction. The gap between the predicted time and the actual failure time is called the prediction distance, which is another key parameter to describe the level of failure prediction and reflects whether the failure prediction is timely enough to reserve sufficient preparation time for maintenance support.

At present, detection threshold, total accuracy, stability and load sensitivity are used to describe the fault detection level, while prediction timing, confidence level and prediction distance are used to describe the fault prediction level. The detection threshold is used to represent the normalized residual strength when the specific detection confidence is reached. The total accuracy represents the average detection confidence level at the damage scale. The stability is used to reflect the fluctuation of confidence in the same damage scale. Load sensitivity is used to describe the variation of the detection confidence level under different working stress levels.

PHM needs to provide useful information to different users, so its design needs to meet multiple goals. Specifically, PHM helps the maintainer choose the best time to perform maintenance on the system. For operators and field commanders, provide them with information about production plans or mission requirements; For designers, it can help them improve the performance of existing systems and guide them to design new systems with better fault tolerance, more stable and more reliable.

Performance assessment is the assessment of the technical and economic feasibility of different fault diagnosis and prediction systems. The technical index is the algorithm used by PHM system to detect and extract symptoms when diagnosing and predicting faults. Economic feasibility can be estimated from the comparison of shutdown maintenance, preventive maintenance and on-condition maintenance, with intangible benefits (such as reduction of failures, improvement of equipment performance, time saving, etc.).

For deployed PHM systems, performance metrics are the key to diagnostic and predictive performance evaluation. The actual fault data and simulation results reveal the actual performance of the system. For example, the basic performance indexes can be obtained by monitoring and statistics of mechanical sound signals.

The performance indexes of fault prediction include the residual life and development trend of components, the time when components may fail, the risk of delayed maintenance, and the expected changes of operating environment. Therefore, the prediction of fault changes with time, which is characterized by statistics and fuzziness, and can be described by probability distribution function.

6. Validation and Validation

Verification and confirmation is an important part of PHM system design process and a necessary means to improve the credibility of the system. It runs through the whole PHM system development process, including feasibility study, clear system requirements, general design and detailed design, software and hardware development, implementation and installation and other steps.

At present, the main method for the quantitative evaluation and verification of the uncertainty of PHM technology is to verify and evaluate various fault diagnosis and prediction methods in the corresponding field by collecting historical data and data generated by fault injection and establishing a test platform in the corresponding field.

The research on PHM verification and validation methods mainly includes the following three key supporting technologies: PHM verification method and performance evaluation, PHM prototype verification system and PHM uncertainty management [8]. The prediction verification method needs to solve the following problems: to understand the fault mechanism from the actual system; Establish
a fault database from a large number of instances to find the corresponding relationship; From the sensor, algorithm and trend of the target system prediction analysis.

The PHM system is coordinated by hardware, software and model algorithm, which is used to analyze sensor data, identify and isolate potential faults, predict the residual life of components, etc., and verify the system through actual collected data or simulation data to confirm whether it has reached the set performance index. The core of verification is whether PHM has fully considered various implicit conditions and constraints, and whether it has carried out appropriate processing in the diagnosis and prediction algorithm, that is, whether the PHM system has carried out reasonable description for each state. Model validation is a formal method to check whether the model design of PHM is correct. Besides model validation, corresponding tools can also be used for validation and validation.

7. The Example Analysis
Through the acquisition, spectrum analysis, fault diagnosis and state evaluation of the component signals, the fault and state of the component are obtained, so as to carry out the health management of the vehicle control system. The following part of the DC signal analysis as an example for the ACTUAL PHM workflow.

The 26V power signal is selected as the analysis object, and data acquisition is carried out through the device connection detection interface. Spectrum analysis and state assessment of 26V power signal are carried out through the software.

Under normal working condition, the waveform of 26V power supply signal acquisition is shown in Figure 1.

![Figure 1. Normal waveform of DC signal](image1)

It can be seen from the waveform that the DC signal should be a constant straight line without fluctuation apart from the acquisition error in the time domain. The waveform display shows that the surface of the power supply has good performance and is in normal state. The spectrum diagram obtained through spectrum analysis of the collected signals is shown in Figure 2.

![Figure 2. Normal spectrum of DC signal](image2)

It can be seen that under normal working conditions, there is no harmonic component in the spectrum domain of the DC signal, and the characteristic points are all at the position of frequency 0 with the amplitude of 26V.

Through analysis, it can be concluded that "the 26V power supply of this component is in normal state".

With the increase of the running time of vehicle control system, the operation of components will degrade the internal components and some modules to a certain extent, and there will also be some influence among the systems. By examining the signal and analyzing the spectrum, we can have a more specific and direct observation of its change and performance. Figure 3 shows the waveform of 26V power supply after running for a period of time.
Figure 3. General fault waveform of DC signal

It can be seen from the waveform figure that the waveform of 26V power supply at this time presents a small amplitude fluctuation, and the voltage value changes between 26.4 and 26.6V, showing an upward trend compared with the normal operation. Through spectrum analysis, the signal spectrum diagram at this moment is shown in Figure 4.

Figure 4. General fault spectrum diagram of DC signal

After analysis, in the spectrum at this time, in addition to the characteristic point of 26.5V at 0Hz, the harmonic component of 0.5V appears at 400Hz, which affects the performance of the DC power supply.

Therefore, it can be concluded that the 26V power supply has some degradation, and there is ac interference in the system superimposed on the power supply, but it has little influence on it, and it can still be used normally.

As the components continue to be used, continue to monitor the 26V power supply, and the signal waveform is collected at a certain time, as shown in Figure 5.

Figure 5. Waveform of severe dc signal failure

As can be seen from the waveform figure, the amplitude of the 26V power at this time fluctuates greatly, which has a great impact on the power supply performance, and the power supply stability performance significantly decreases. The spectrum diagram obtained by spectrum analysis is shown in Figure 6.

Figure 6. Spectrum diagram of severe dc signal failure

It can be clearly analyzed from the spectrum diagram that there are three obvious components in the signal at this time: the DC component with an amplitude of about 27.8V reflected by 0Hz characteristic points, the AC component with an amplitude of about 1V reflected by 400Hz characteristic points, and the AC component with an amplitude of about 0.3V reflected by 650Hz characteristic points. Through spectrum analysis, the components in the signal can be distinguished,
and it can be seen that there is a serious deterioration of the power supply signal at this time and the anti-interference ability is obviously reduced. Therefore, the component's health state can be judged as a fault. The fault is located in the 26V power module. It is suggested to replace the power board or replace the components for maintenance.

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