The Enlightenment on Prediction and Health Management Technology of Elevator System

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Abstract. In China, the research on detection technology of elevator fault is relatively late, and most of the technologies are only in the research of theoretical stage and have not yet been tested by practical applications. Organize and summarize the relevant literature and personal research. The research status of fault diagnosis, Prediction and Health Management technology at home and abroad is summarized. And the latest research of elevator fault prediction and health management technology is analysed. Finally, the challenges and the development trend of elevator fault health management are expounded.

1. Introduction
By the end of 2020, the number of elevators will reach 7.8655 million, and the maintenance form will be quite severe [1]. Early failure depends on experience, through the establishment of the dynamic model of the elevator door system, the performance diagnosis of the elevator door system [2]. The intelligent maintenance scheme based on state signal extraction and door system analysis opens up a new situation for elevator fault analysis and life prediction. For the vertical vibration of the elevator, the dynamic differential equations are constructed, such as 1:1 and 2:1, and the influence of key structural parameters on the operation of the elevator is obtained [3]. However, the effect of horizontal vibration is ignored. Bayesian model is established to analyze elevator environment, hardware status and electrical parameters qualitatively and quantitatively. The ratio of electromagnetic interference, mechanical wear and other indicators to elevator risk coefficient provides a basis for improving elevator maintenance efficiency [4].

In this paper, based on the existing literature and research work, the author makes a detailed analysis of the development and application of PHM technology, especially for the elevator fault prediction technology, and puts forward reasonable suggestions for the development of elevator PHM technology.

2. The PHM technology of elevator
In Figure 1, the information of the elevator to be measured is collected. Data processing, such as data cleaning, data integration, data transformation, data reduction, normalization, etc. The eigenvalues are extracted and combined with the early experimental data and historical data to establish a fault model for fault diagnosis and prediction. Finally, the elevator maintenance decision is made, the maintenance
plan is updated, and the condition based on maintenance is realized.

![Elevator PHM system](image)

Figure 1. Elevator PHM system

3. Research on Elevator PHM Technology

Elevator fault prediction research technology can be classified from the mechanism aspect, including methods based on physical model, empirical model, system model and big data model [5].

3.1. Fault prediction method based on physical model

The physical model is the general term of a kind of methods that solve the actual situation. Such as, FEMA method, T-S method, Mathematical model etc. The Physical model method uses the method of "particle" to transform the actual problem into a physical model. The problem is solved by dynamic analysis, but the internal friction and external environment are ignored, so it is difficult to be applied to large-scale fault prediction process.

FMEA is one of the important methods for the safety analysis of the system. In the elevator equipment failure have human factors, equipment factors, environmental factors and management factors. The FMEA of elevator table is established to estimate the respective RPN values. The experimental can reduce the elevator trapped, sliding, abnormal vibration and other failure rates [6], but the proportion of human factors can’t be ignored. Through the establishment of risk rating table and comprehensive risk model of elevator system, the influence of human factors in traditional elevator safety assessment can be reduced, and the elevator risk classification and quantitative index can be improved [7]. Although FEMA method can reduce the occurrence of failure to a certain extent, it is too dependent on failure model. In order to simplify the nonlinear characteristics of elevator single maglev guidance system, T-S model is used to approximate. The experimental results show that the stability performance of the guidance system can be improved [8].

3.2. Fault prediction method based on empirical model

The fault prediction method based on empirical model usually uses long-term test or historical data to form a logical fault prediction method, including expert system and Fault-Tree model. Elevator door system mechanical, electrical fault, build the elevator door system Fault Tree diagram, can quickly analyze the fault type, improve the maintenance efficiency [9]. Fault diagnosis system is built, through the construction of fault tree model based expert system to solve the problem of knowledge update of expert system, to achieve efficient and accurate diagnosis of elevator fault [10].

The experience model uses long-term maintenance experience and test data to solve the faults. But it has high requirements for experience and data accumulation, and is not suitable for short-term and emergency fault prediction process.

3.3. Fault prediction method based on system model

The fault prediction method based on system model is mainly applied to each system model and algorithm to process the elevator fault sample data to get the expected results, improve the ability of
elevator fault prediction. Such as, Neural Network, Support Vector Machine and System Coupling etc., but these methods depend on the amount of data, and the selection of model and processing function is strict, the instability of data quality has a great impact, so the reliability of the model is low.

The fault prediction method of elevator door system based on neural network is proposed. By selecting the sample variables such as door motor drive slip and ash deposition in sill chute, the opening and closing state of elevator door is predicted [11]. However, this method selects few parameters and the sample data processing method is single. Constrained linear time invariant optimal control is proposed, and the research results show that the explicit model predictive control is better [12]. The coupling model of elevator mechanical and electrical system is established, and the lifting situation of elevator under no-load and full load is analyzed. The consistency between the coupling model and the working characteristics of the motor is verified, which provides a new idea for the comprehensive evaluation of the elevator [13].

The fault prediction method based on system model has the ability of reproducing and accurate prediction results, but it has high requirements for data processing and parameter selection, and depends on model processing. At present, most researchers use a single optimization method to optimize the optimization algorithm or optimization model.

3.4. Fault prediction method based on big data
With the development of artificial intelligence algorithm, the detection method of mechanical and electrical equipment has entered the era of big data. This method uses a large number of elevator fault data, through data processing, data mining, get a scientific maintenance plan.

Regression and clustering methods are used to analyze a large number of car vibration data. The results show that big data analysis and processing can quickly diagnose and predict elevator faults [14], but it requires a large amount of data and processing methods. Data fusion technology includes the fusion of data layer, feature layer and decision layer [15]. At the decision level, a neural network information fusion method for elevator fault diagnosis is proposed by using data fusion technology. Different neural network algorithms are used for different subsystems, and then D-S evidence theory is used for decision fusion. Experimental simulation shows that the accuracy of elevator fault diagnosis can be improved [16], but the fusion of data layer and feature layer is ignored.

The fault prediction method based on big data can improve the accuracy and reliability, but it requires a high amount of data. The existing data fusion methods are relatively single, multi information fusion and multi-level fusion should be the development direction.

4. The latest research on Elevator PHM Technology
The characteristic parameters such as brake clearance, voltage and current are selected, and the fault prediction method of LSTM-ED failure algorithm based on time series data reconstruction is adopted. In the experiment, 20% data is used for reconstruction learning, and 80% data is used to calculate the reconstruction error and adjust the correction coefficient to 0.78. Compared with MSE, MAE, AR model and LSTM-ED reconstruction, the result shows that LSTM-ED reconstruction method can predict the brake RUL more accurately. Based on the voltage current information of positive and negative double super sphere elevator fault diagnosis model, the elevator operation data is divided into health, fault and unknown drift three types of sample data. Firstly, the test data is processed by convex set interval to obtain positive and negative super sphere model, and then the distance from the outlier to the positive and negative ball center is compared and combined with B-SVDD. The model iterates the data and finds that the abnormal data almost disappears after 5 iterations, and the average recognition rate of limit switch, frequency converter, motor and contactor is as high as 98.3% [18]. A PHM-ML hybrid method is proposed, and the proportional hazard model is used to obtain the covariate relationship between elevator life and elevator service age, load and running speed, and the elevator risk function is obtained. Finally, the machine learning is used to estimate the remaining life of the elevator. The test data show that the hybrid method has high accuracy in predicting the remaining life of the elevator [19], but the prediction accuracy of this method has not reached the ideal level, so...
the deep learning model can be used to improve the prediction accuracy.

5. Challenges and development trend of Elevator PHM Technology

5.1. challenges and solutions of elevator PHM Technology
As the elevator control system continues to be intelligent and complex, the requirements for elevator maintenance and repair continue to improve. Elevator fault diagnosis and remaining life prediction technology are facing the following challenges.

1) The scope of technology is narrow. The final stage of elevator maintenance is the overall fault prediction, which needs the update iteration of prediction technology to meet.

2) The accuracy of data acquisition is insufficient. We should vigorously develop high-precision and intelligent sensor technology, especially for the data acquisition of horizontal and vertical vibration, wire rope torque, rail friction and other data in elevator operation state.

3) PHM technology verification is insufficient. At present, most of the domestic elevator fault prediction methods are in the theoretical stage. The verification of the theoretical model is the premise and guarantee of the development of prediction technology.

5.2. development trend of elevator PHM Technology
With the continuous research of PHM technology and the intelligent and complex elevator, the demand for maintenance is constantly improved, the development of elevator PHM technology is in the following trends:

1) The whole prediction technology. At present, most of the fault prediction methods only predict the subsystem or single component, and the integrated prediction of elevator fault is the final direction of development.

2) The development of model mixing technology. At present, the fault prediction method adopts single prediction model or single algorithm, which has certain limitations for prediction accuracy. The research method of multi model, multi algorithm mixing or selecting suitable model combination is the key point of PHM technology development.

3) Online. At present, the PHM technology of elevator adopts offline data acquisition and fault prediction, which can’t reflect the elevator health status in real time. The actual health data acquisition and fault prediction need to diagnose the elevator fault and life prediction online.

6. Conclusion
In this paper, starting from the development and difficulties of the elevator maintenance industry, the elevator fault prediction, in order to achieve Condition Based Maintenance. This paper studies PHM technology, and analyzes the overall framework of PHM technology, fault prediction model and life estimation method. This paper summarizes the current challenges of elevator PHM technology development, and gives the future development trend.

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