Research on equipment health diagnosis system of railway passenger station based on cloud-edge collaboration

Xiaoling He¹, Chunjie Xu¹*, Ruifeng Chen¹, Jing Wang¹ and Jun Li²

¹ Institute of Computing Technologies, China Academy of Railway Sciences Corporation Limited, Beijing, 100081, China
² Depart of Electromechanical Equipment and System, Beijing Jingwei Information Technology Co., Ltd Beijing 100081, China

*Corresponding author’s e-mail: xuchunjie@rails.cn

Abstract. In view of the current operation and maintenance mode for railway station equipment, the method of traditional manual and post-diagnosis for the equipment faults is still used, which cannot meet the reliability requirements of equipment operation and maintenance management. A health diagnosis system based on cloud-edge collaboration for railway station equipment is proposed. Firstly, it collects online operation information of multi-source perception equipment, which realized through edge intelligent gateway by componentized micro-service and Docker technology. Moreover, it realizes data storage and publishing, edge detection, monitoring online and early warning through the intellectual server models. Secondly, a life prediction model is established based on HSMM to calculate the health status and service life of the equipment. Finally, the cloud-edge collaboration model is designed based on KubeEdge to realize the cloud-edge communication and collaborative service of resources. It effectively solves the problems of remote condition monitoring, health diagnosis and predictive maintenance for railway station equipment, and it provides technical support for the safe operation of railway station.

1. Introduction

With the development of new technologies such as 5G communication technology, Internet of Things technology, fault diagnosis expert system theory and big data technology, Real-time collection of operation data of many types of equipment in railway passenger stations has been achieved. Distributed monitoring, sharing of diagnostic resources, collaborative work and centralized management of all kinds of connected equipment through the safety production network, an equipment health diagnosis system which based on a cloud-edge collaboration are built. It can realize the condition monitoring and fault diagnosis of the railway passenger station equipment in a wide area, can effectively reduce the operation and maintenance cost, ensure the safe operation of the railway passenger transportation organization.

At present, the intelligent operation and maintenance of railway passenger station equipment is mostly in the research of platform architecture and function, the operation and maintenance of passenger transportation equipment is still in the traditional manual stage [1]. Literature [2] proposes the overall architecture and functional structure of a new generation of intelligent operation and maintenance integrated management platform that combines new technologies such as big data, cloud computing, and artificial intelligence. Literature [1] proposes an intelligent operation and maintenance platform with technical characteristics of Cyber-Physical Systems (CPS), which realizes the unified certification management of equipment, intelligent perception of equipment status, allocation and sharing of spare
resources, and big data support for maintenance decisions. The fault diagnosis methods include traditional mathematical processing methods and intelligent diagnosis methods [3-6]. Traditional data processing methods mainly include analytical methods and statistical methods, while intelligent methods are mainly intelligent diagnosis techniques represented by neural networks. The existing equipment fault diagnosis is a post-diagnosis method, which can no longer meet the requirements of equipment operation and maintenance management reliability. How to prevent the probability of post-repair and maintenance cost of railway station equipment and formulate a scientific and reasonable maintenance strategy has become an urgent problem to be solved. Predictive maintenance has become a research hot topic for the maintenance industry [7]. In this paper, aiming at the problems in the equipment operation and maintenance of railway stations and developing of the new technology applications such as 5G in the integrated application, key technologies are explored. To achieve the target of remote condition monitoring, health diagnosis and predictive maintenance in equipment operation and maintenance business of railway station, a health diagnosis system based on cloud-edge collaboration is researched. And it provides the support for railway transport organization safely.

2. Architecture design of railway station equipment health diagnosis system based on cloud-edge collaboration

There are many types of railway transportation equipment, classified from the perspective of the use of each system, mainly including equipment of ticket system and passenger service and production control platform for railway station. Passenger ticket equipment mainly includes real-name gates, automatic ticket vending machines, automatic ticket checking machines and automatic ticket collection machines. Intelligent station passenger service and production control platform equipment mainly includes travel service system equipment and mechanical and electrical equipment. Passenger service and production control platform equipment includes broadcasting equipment, guidance equipment and video monitoring equipment. The electromechanical system equipment includes straight ladders, escalators, dual-cooling direct expansion units, air blowers and water pumps. The excellent features of railway station equipment health diagnosis system based on cloud-edge collaboration are optimizing the system architecture, make full use of the respective advantages of cloud and edge. It not only meets the low latency requirements of some passenger transportation equipment such as real-name gates, broadcasts, and guidance, but also reduces cloud computing pressure and network bandwidth costs. In the meantime, it realizes comprehensive online fault diagnosis, fault diagnosis and prediction, status warning, and networked maintenance and other applications objectives. Moreover, it improves the efficiency of operation and maintenance, reduces the risk of equipment failures, and meets the needs of remote operation and maintenance management of railway station equipment.

2.1. Functional design

From the functional point of view, it can be divided into comprehensive online fault diagnosis, fault hidden danger and remaining life and display warning, and networked maintenance functions.

2.1.1. Comprehensive online fault diagnosis. It mainly monitors the running status of various systems and equipment in railway stations, realizes data collection, identification analysis and feature extraction, and performs corresponding fault diagnosis. The diagnosis results, control instructions and auxiliary decision-making schemes are sent to the corresponding edge control equipment and users.

2.1.2. Hidden failures and remaining life and display warning. It is composed of functional modules such as data statistics and analysis, hidden failures and predictions, result expression and interpretation, hidden failures warnings, result presentations, emergency communications and other functional modules. Data mining and analysis algorithms such as association analysis, cluster analysis, classification analysis and deep learning (CNN, LSTM) are utilized in the architecture. They realize statistics and prediction of failure rate of each key system, equipment and key components of equipment, statistics and prediction of equipment and device reliability, estimation and prediction of remaining life, life cycle aging warning,
key characteristic critical value statistics, key characteristic critical value warning and other functions.

2.1.3. Network maintenance. Network maintenance is composed by function modules, including the maintenance process managements of the railway station critical systems, equipment and key components, the managements of maintenance experience database, the managements of equipment and key components resumes, spare parts, the managements of maintenance plans, fault repair and maintenance resource status, assistant decision-making of online fault diagnosis, and so on.

2.2 Architecture of the railway station equipment health diagnosis system based on cloud-edge collaboration

The railway station equipment health diagnosis system architecture based on cloud-edge collaboration is logically divided into three parts: “cloud-edge-end”. The railway station system and equipment operating status data collected at the end are processed by the edge server and sent to the cloud system. Cloud computing technology is used to realize applications such as the health evaluation and fault diagnosis of railway station system and equipment. The system architecture is shown in Figure 1.

2.2.1. Terminal data collection. The terminal data collection is the data source of the system, including the internal parameters of the key equipment and components of the railway station system, such as the number of times and opening speed of the gates every day, operating parameters such as software and server in railway station systems, maintenance records and fault records of equipment in each system.

2.2.2. Edge services. The edge services include edge processing and control, edge business applications and edge PaaS (service as platform). The edge processing and control part preprocesses the collected data, due to various types of system data acquisition equipment, and to facilitate identification and associated information. In this paper, the identification analysis technology based on the industrial Internet is used to uniformly identify and standardize the data structure of the related information of the same object. Methods such as data de-noising and completion are used for data preprocessing. According to the data type and the corresponding feature extraction algorithm, the corresponding feature set is extracted for unified identification and management, and the terminal equipment control is realized through the business of the intelligent station system and the cloud analysis command. Edge business applications include video based broadcast and guided display verification technology, data release with business release plan, feedback monitoring results and equipment control. Edge PaaS can realize edge-side operation collaboration, including edge communication services, edge container management services, and edge operation and maintenance services. It can also implement functions such as edge application security authentication, edge resource management and control, and edge application capability invocation.
2.2.3. Cloud platforms. The cloud platforms include AI services and storage, cloud edge collaboration services, and cloud business applications. The layer of AI service and storage includes diagnosis and prediction algorithms, feature parameter databases, historical fault databases, equipment maintenance databases, system and equipment rated parameter databases, and expert knowledge databases. The diagnosis and prediction algorithms include mainstream high-precision algorithms, such as clustering, classification, association rules, deep learning, prediction algorithms, deep learning and neural networks. Cloud edge collaboration realizes cloud edge collaborative management interaction, which mainly includes edge operation management, edge operation management, and edge resource management, and realizes centralized cloud management and control of different edges.

2.2.4. Business application. The business application realizes display functions such as comprehensive online fault diagnosis, fault hidden danger and remaining life and early warning, and networked maintenance.

3. Research on key technology of the system

3.1. Edge intelligent gateway design

The Internet of Things gate realizes protocol conversion and data forwarding between a variety of perceptual networks and the basic network. Edge computing performs computation at the edge of the
network, and its core concept is to compute close to the source of data \[9, 10\]. The edge intelligent gateway realizes the upstream interconnection of everything and downstream cloud services, and its value is mainly manifested in the massive heterogeneous connections, real-time business, data optimization, application intelligence, security and privacy protection \[9\]. End data perception collection is the source of system data. Due to the wide variety of railway station equipment, a variety of perception devices are built in accordance with the agreed protocol for information exchange and sharing of the Internet of Things network. The edge intelligent gateway that includes edge-side data processing services and upstream and downstream collaborative services, and which can carry edge computing at the same time is the key to system implementation.

The edge computing gateway designed in this paper adopts the componentized micro service architecture design based on container technology, as shown in Figure 2, which includes gateway management services, protocol adaptation services, and data processing services. The gateway management service manages parameters such as network parameters, sensing layer device table parameters, and protocol conversion parameters, it realizes dynamic management and task coordination of protocol adaptation services and data services. The protocol adaptation service has the functions of protocol conversion and data packet encapsulation and analysis. It can integrate the communication protocols such as Modbus and SNMP of the equipment in the computer room, and complete the format conversion of the perception data. Through the gateway management service, the data processing service is called, the processed data is encapsulated, and the data packet is pushed to the cloud through MQTT and other protocols; when the data is sent, the data packet analysis is completed, and the device control is completed according to the instruction. Data processing services mainly implement data preprocessing such as noise reduction and completion of different types of perception data.

![Figure 2. Edge intelligent gateway architecture.](image-url)

3.2 Equipment life prediction model based on hidden semi-Markov model

In this system, hidden semi-Markov model (HSMM) is used to predict the remaining service life of equipment. The HSMM model can be described as a four-tuple: \( \lambda = (\pi, A, B, D) \). \( \pi \) is the initial probability of state, \( A \) is the probability of state transition, \( B \) is the probability of observed value, and \( D \) is the residence time of state.

The hidden semi-Markov model (HSMM) adopts the improved forward and backward algorithm, Viterbi algorithm and Baum-Welch algorithm to effectively reduce the computational complexity of the model \[11,12\]. Based on Erlang distribution \[11\], the probability distribution of the residence time of the health state of the equipment is reassessed, and the prediction model of the remaining life of the equipment is established by using the failure rate theory.

The algorithm steps are as follows:

1. Use the historical collection information of the equipment for identification analysis and classification, and use the feature extraction algorithm. This paper use PCA features extraction to obtain feature data sets, and the HSMM algorithm model is used to iterate to obtain the best model parameters, including the initial state transition probability of the equipment health state and the residence time of
each health state;

(2) Carry out identification analysis and feature extraction based on the currently collected parameters of key systems or equipment and components of the railway station. Based on the improved forward-backward algorithm \cite{11-12}, using the Elon distribution density function \cite{11}, calculate the current state and failure rate of the equipment;

(3) On the basis of (2), the expected effective life residency of the device is calculated in the current state of health \cite{11};

(4) Calculate the effective remaining life of the equipment \cite{11}.

Figure 3. Equipment life prediction process.

3.3. Cloud-edge coordination service based on Kubernetes and Dockers

A cloud-edge collaborative environment is built based on Kubernetes and Dockers cloud-edge collaborative services. Through the cloud Kubernetes master and edge nodes to achieve edge collaborative services and edge PaaS to achieve system cloud edge collaboration. Cloud edge operation management realizes edge application monitoring, logging, communication detection and security strategy, edge application management realizes the active reporting of business data, business scheduling and priority management, and cloud edge resource management realizes the collaboration of network resources, computing resources, and storage resources. Edge communication services realize cloud-edge collaborative communication services, edge-side business applications and MQTT communication interaction that handles control.

The edge Dockers management service mainly completes the cloud application management module
to use the Docker to realize the gateway management update policy, redundant configuration and other services on the cloud, and edge operation and maintenance service realizes the function of monitoring the operating status of edge devices.

4. Conclusion
In this paper, aiming at the current management status and requirements of railway station equipment operation and maintenance, a equipment health diagnosis system based on cloud-edge collaboration is constructed. Which realize the remote status monitoring, health diagnosis and predictive maintenance for railway station equipment.

In this system, an intelligent gateway based on edge computing is designed to realize data collection and intelligent processing. Moreover, the remaining life of the equipment is predicted based on the HSMM model to realize the pre-maintenance of the station equipment. And then, the system resource collaboration is realized through the cloud-edge collaborative service model based on the KubeEdge. The focus of the next research is to make more accurate for residual life prediction of the equipment.

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