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Research on Intelligent Perception Architecture of Rail Transit Equipment Based on Modularization

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Abstract

This paper focuses on the contradiction between the rapid evolution of intelligent technology and the diverse intelligence requirements of industrial sites. Due to the rapid evolution of intelligent technology, which is challenging to develop, it will take a considerable amount of time to implement in the industrial setting. Meanwhile, there are various types of fault prediction and health management (PHM) systems for rail transit equipment to meet different requirements. These systems have complex interfaces within independent functional systems, which can result in the Islanding phenomenon. The cost of developing the PHM system is high, and it is difficult to modify or reuse it from one scenario to another. In the field of intelligent perception in rail transit, there is an urgent need for a unified architecture of condition monitoring technology. This architecture should be able to create a platform with standardized structure and open interfaces. In order to address these existing issues, an Intelligent Perception Architecture for Rail Transit Equipment based on modularization is proposed. Within this framework, the Device Intelligent Sensing Process Arrangement and Testing System has been implemented. The system can be used for pre-processing in PHM systems to efficiently establish the fault sensing process and conduct online testing. This helps address the challenge of integrating fault diagnosis technology into data processing management and scene-specific root causes.

Keywords

PHM, Modularization, Intelligent Perception

1. Backgrounds

With the development of China's rail transit, the internal structure of the train is becoming more and more complicated, meanwhile its operation safety, fault diagnosis, efficient and rapid maintenance, and safe operation of station infrastructure are becoming more and more important.

The application of artificial intelligence, the Internet of Things, 5G, and other technologies have increased the amount of passenger flow, equipment, and environmental data collection, facilitated data mining, analysis, and prediction, improved the efficiency of real-time data transmission and monitoring, and industry service capabilities, so as to discover security risks in a timely manner. During the operation of the rail transit system, data needs to be collected continuously for the analysis of vehicle status. Through intelligent perception technology [1], we can efficiently collect data resources and improve the efficiency of network resource scheduling. Intelligent transportation system is the key to improving transportation system efficiency, service quality, safety level, environmental protection, and energy conservation. However, because of the rapid iteration of intelligent technology, which is difficult to develop, it will take a long time to implement in the industrial scenario. The contradiction between the rapid iteration of intelligent technology and the diversified intelligent demand of industrial sites is constantly prominent, which retards the intelligent process of rail transit.

1.1 Research Status

In recent years, research on the technical architecture of Prognostics and Health Management (PHM) [2, 3] has been carried out both at home and abroad, which is to develop a system used to extract characteristic fault signals from the output signals of complex mechanical systems, analyze the fault characteristics of the parts, and diagnose the operating status of the mechanical system based on this characteristic, and finally predict the development trend of future faults. PHM has become an indispensable part of the field of aircraft, ships and warships, or vehicle systems.

The application of PHM technology in the rail transit industry can realize the identification and classification of rail transit equipment and the whole system status, and integrate the obtained forecast information, operation requirements, and available maintenance resources, so as to provide decision support for equipment operation and maintenance. So as to realize the optimization of equipment's maintenance cost and supply or human resource management system. However, most of the existing fault diagnosis systems are scenario-based customized systems, which lack reconfiguration and universality [4] with a high coupling degree between system architecture and scenarios. As a result, enterprises need to invest a lot of resources in learning and training for different software in the construction of intelligent systems, which hinders the integrated application of intelligent products.

In order to meet the needs of functional modularization [5] and technology integration, the ways in which intelligent perception big data analysis and other technologies are integrated with the field of rail transit are becoming more and more comprehensive, and the scope of coverage is becoming more and more extensive. It is committed to realizing comprehensive, real-time, accurate, and efficient operation control and management, effectively promoting the development of integrated transportation systems to the direction of network connectivity, coordination, and intelligence, and leading the scientific and technological progress of rail transit. In order to improve the scalability and maintainability of PHM systems in the application of projects, various hierarchical architectures [6-8] and distributed architectures [9, 10] have emerged in various fields. However, due to the complexity and diversity of the actual language environment and the complexity and redundancy of the system architecture, the system of research is scattered and lacks a unified and efficient coordination mechanism [11]. It is difficult for the rail transit detection system to be flexible and changeable, and the repeated construction of the system for different scenarios causes excessive cost consumption.

Reference [12] introduces software in the field of aerospace equipment named Design and Analysis System for Testability Engineering. The system enables visual device model building and testability analysis to assist PHM system developers in improving system design, which is intended to address the rapidly evolving technology and structural complexity of aerospace systems, as well as the increasing cost of component testing that aerospace systems face. In recent years, Shanghai [13], Beijing [14], and other cities have begun to study the overall architecture of urban smart rail transit, explore the top-level architecture design of rail transit informatization, and carry out comprehensive design from the core business, IT strategy, network security, and other aspects to achieve flexible, fast and efficient business deployment of PHM technology. However, even though the above research relies on a scalable architecture to achieve high coverage of the functional scope, it fails to solve the root cause of its closed data processing process management and scenarios-specific problems.

1.2 Problem to be Solved

In the field of intelligent perception of rail transit, a unified condition monitoring technology framework and system is urgently needed to standardize the development of intelligent detection technology. It is necessary to form a set of collaborative design tools and an integrated verification platform with standardized architecture and open interfaces as the input of the PHM system to provide engineers with a visual system that can quickly build a fault-sensing process. Thus, the construction of the PHM system is more convenient and faster, and the construction of an artificial intelligence service ecosystem in the field of rail transit is further promoted.

2. Architecture

Based on the idea of modularization, this paper is based on the modular packaging of four process steps of intelligent perception of rail transit equipment: data access, data processing, intelligent diagnosis, and application interaction, docking the unified hardware interface of data acquisition and the module interface of perception algorithm, designing and implementing the visual arrangement of equipment intelligent perception process and providing online deployment and testing. The overall architecture design is shown in Figure 1.

The overall architecture is divided into three layers: the input layer, the service layer (which is the Device's Intelligent Sensing Process Arrangement and Testing System), and output layer.

The input layer interconnects with hardware devices (such as data acquisition devices compute servers, etc.), common API (such as MQTT, HTTP, etc.), and model shop (provides mature data processing methods as well as intelligent algorithm models) to provide data sources, processing methods and computing environments on which data awareness processes rely.

The service layer conducts modular conversion of resources accessed by the input layer, and then realizes the construction and operation of intelligent perception process through interaction and cooperation between the computation center and process center, and also provides a platform for the development and management of algorithm modules for developers.

When the process is running in the service layer, the output algorithm model and data processing results can be output through the standardized interface for the PHM system of the output layer to carry out equipment fault diagnosis and data visualization, and other applications, so as to complete the whole process from data acquisition, visual intelligent analysis process construction to analysis result application and decision support.

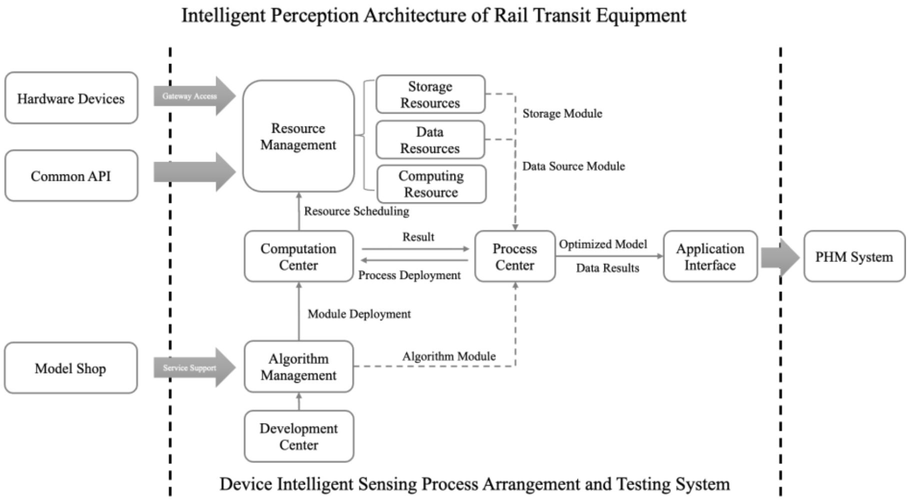

Figure 1. The Intelligent Perception Architecture of Rail Transit Equipment.

The overall architecture takes artificial intelligence technology as the core, deeply explores the application focus and advantages of intelligent perception algorithms in various scenarios in the field of rail transit, and then carries out modular classification and regularization of the system, interface, and algorithm. The architecture can realize the modular encapsulation of various intelligent detection algorithms through standardized interfaces, and then realize the Device Intelligent Sensing Process Arrangement and Testing System, so as to meet the application requirements of different application scenarios and different data analysis methods.

The application of this architecture will form an intelligent detection platform of rail transit with visualization, flexible components, and low coding. The system provided by the service layer is intended to simplify the creation of device state intelligence awareness processes applied to PHM systems. Through a visual interface and drag-and-drop mode of operation, the system provides a platform for engineers to quickly build intelligent data processing flow and provides a pre-input for the construction of the PHM system to edit flow in a visual way. It will increase the deployment and operation flexibility of intelligent detection products, effectively reduce user operation and maintenance costs, and improve the efficiency of rail transit equipment condition monitoring.

3. Functions

Based on B/S architecture, the Device Intelligent Sensing Process Arrangement and Testing System adopts the development mode of separating the front and back ends, and realizes six functional modules: data access, module configuration, process management, process deployment, model management, and data management. The users of this system are mainly engineers of industrial equipment development, operation, and maintenance. The transparent editing of the equipment perception process can be achieved by applying the system. The system supports the modularization of sensing methods, and users can connect modules to form data processing streams through the system operating interface to realize the training of intelligent algorithms and the testing of output models. Data sources can support offline upload of data packets and real-time data input of data acquisition devices. After the process is established, users can directly run it to view the data processing results. The overall functional architecture is shown in Figure 2.

The user interaction layer provides functional operations related to process management, module configuration, model management, and data management, establishes data interaction with the logical processing layer, and carries out real-time visual display of process running status and module operation results. The logical processing layer deals with data access, module configuration, model management, data management, process management, process deployment, and other related logic. In addition to handling the data transmission of the front-end interface, it also provides the module conversion logic related to real-time device access in the intelligent perception process. The logical processing layer calls the data collection interface of the data center, establishes a message channel with the algorithm server, realizes the transmission and data of the algorithm module, and connects to the database for data storage.

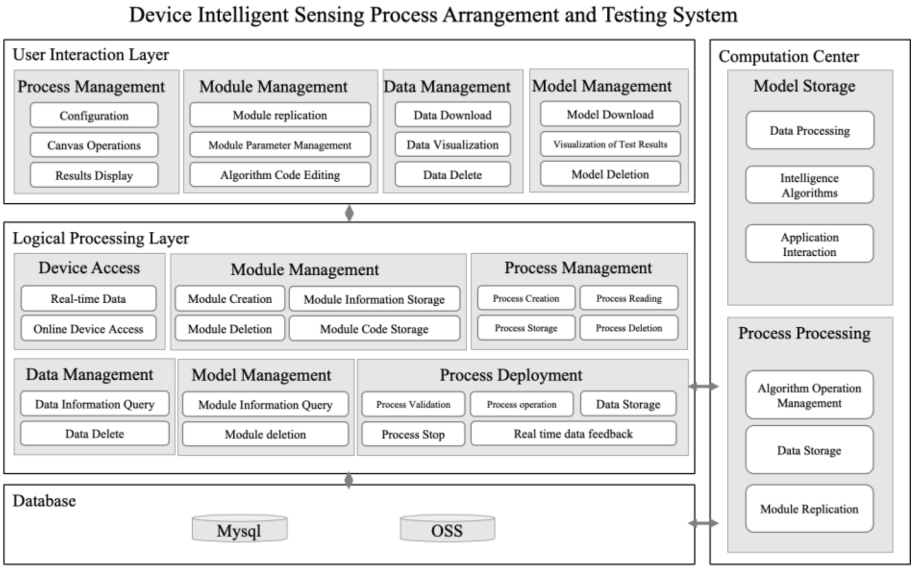

Figure 2. The functional architecture of the Device Intelligent Sensing Process Arrangement and Testing System.

The system decouples the front and back ends, so that the front-end system only needs to complete business logic and improve user experience, while the back-end server only needs to focus on service provision and data management. Such a layered architecture makes the overall structure of the system clearer and then combines modular technology to achieve modular management of algorithms, which is more conducive to later function expansion and system maintenance.

4. Conclusion

This paper introduces the equipment intelligent perception process arrangement and testing system based on the modular intelligent perception architecture of rail transit equipment. The system builds a low code algorithm application system, eliminates the gap between system users and algorithm developers, and breaks the closure of the existing traditional industrial system on the premise of ensuring security. By providing a flexible mode of independent combination development, the system gives users the right to decide on the degree of openness to the greatest extent and reduces the total cost of ownership of artificial intelligence with zero code, drag and drop, and building block structure.

Based on this research, a cloud-edge-end collaborative equipment fault prediction and health management system can be further developed by establishing a modular edge computing system. This will enhance the adaptive, self-learning, and self-optimizing capabilities, as well as the information interaction, data analysis, and decision-making processes throughout the equipment's operation and maintenance. Consequently, this will enhance the safety and efficiency of the system. Gradually develop an artificial intelligence technology platform customized for industrial applications. The system is well-suited to the requirements of field environments and user habits. Through the seamless integration of artificial intelligence and the Internet of Things, it can comprehensively monitor the status of applications in the field, lower the barrier for traditional enterprises to adopt high-tech solutions, offer a complete ecosystem, and provide end-to-end solutions from research and development to service delivery to expedite the intelligent transformation of traditional industries.

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