Research and Application of Industrial Equipment Management Service System Based on Cloud-Edge Collaboration

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***Abstract*— With the integration development of Internet of Things, edge computing, cloud computing and artificial intelligence, the computing paradigm centered on traditional cloud computing has begun to integrate the edge computing paradigm, forming an industrial Internet of Things revolution based on Cloud-Edge collaboration. It not only can improve the response speed of industrial field system and reduce the load pressure of network bandwidth caused by data transmission, but also can realize the refined management of industrial devices and the deep mining of industrial data by on the cloud platform. In short, the cloud platform and the edge platform can play their respective advantages and continue to promote the industrial Internet of Things to the intellectualized development. In this paper, it started from the system architecture, and an industrial equipment management service system based on Cloud-Edge collaboration was discussed, including the design of equipment management service cloud platform and edge intelligent gateway in detail. The central air-conditioning energy consumption monitoring and optimization application based on INDICS platform and SMART IOT edge intelligent gateway were introduced, to verify system availability.**

***Keywords*— Industrial Internet of Things (IIOT), Cloud-Edge Collaboration, Equipment Management, Edge Intelligent Gateway**

I. INTRODUCTION

With the rapid development of industrial Internet of Things (IIOT), the amount of industrial data has grown exponentially. The traditional cloud computing mode can no longer meet the requirements of time delay in industrial application scenarios. At the same time, massive data transmission will also exert great load pressure on network bandwidth. Therefore, edge computing, which aims to solve data transmission delay, reduce network bandwidth and improve data security, is rapidly emerging. Of course, the development of edge computing is not to replace cloud computing, and they are complementary relationship. Edge computing and cloud computing have their respective advantages. Cloud computing, which is more inclined to process the data in global, non-real-time, long-cycle analysis, can play its advantages in such fields as long-cycle maintenance and business decision support. While edge computing is suitable for locality, real-time and short-period data processing and analysis which can better support the real-time intelligent decision-making and execution of local business. In this way, the Cloud-Edge collaboration based on edge computing and cloud computing can better meet the requirements of various demand scenarios in the industrial field. Industrial equipment is a basic component of IIOT systems, a source of industrial data, and a target for system control. Therefore, the industrial equipment management service system is the basis for the development of IIOT to intelligent, and is also the key to determine other service systems such as IIOT resource management, operation and maintenance services.

Device management based on cloud platform has always been an academic research hotspot in the field of IOT, and edge computing has greatly promoted the research and application of the IOT in the industrial field. WANG Yan [1] studied the service aggregation and modelling methods of device resource, based on the research of Web-based IOT business architecture and integration of heterogeneous IOT devices. Literature [2,3] verified the usability of common IOT device management platforms designed respectively. Literature [4] studied the device management model based on cloud platform, which supports plug-and-play of heterogeneous devices. The above researches mainly cover general equipment. While the heterogeneous type and complexity of equipment resources in the manufacturing industry are more prominent. Literature [5,6] analyzed the architecture and characteristics of manufacturing interconnection. Literature [7] studied the remote control and data analysis system of industrial equipment based on cloud

978-1-7281-4094-0/19/$31.00 ©2019 IEEE

platform. Most of the researches provide services for a small number of equipment resources in local areas, but when the service is oriented to the massive equipment resources across regions and industries, network bandwidth, data delay and data security will have to be considered. The above researches focused on the cloud-centric equipment management services, while the industrial equipment management services based on Cloud-Edge collaboration are still in the initial stage, and there are still many problems to be studied.

Of course, in the field of industry, equipment management services have become the main service content of major cloud platform vendors, such as Huawei Cloud, Baidu Cloud, Ali Cloud, and AWS [8,9]. And these platforms have also launched their own Edge Computing product which extends the calculations to the edge side of the device (data source), and formed the service mode initially based on the cloud-edge collaboration. Huawei cloud equipment management service can realize product model definition and visual management of equipment of life cycle, and at the same time provide powerful open capabilities for industry application, so as to solve the problems faced by enterprises in the transformation process of the Internet of things, such as fragmented access, complex equipment management, difficult security assurance and small platform capacity [10]. Baidu cloud provides cloud services such as access to things, analysis of things, and visualization of things, helping enterprises establish safe and reliable two-way connection between devices and the cloud and device management, and supporting various Internet of things scenarios such as massive equipment data collection, control, fault prediction, etc. [11]. Ali cloud provides one-stop device management service through the IOT platform, establishes safe and reliable device connection and communication ability to help users collect massive device data on the cloud, and provides rich API and rule engine to help users quickly integrate applications [12]. AWS IOT Device Management service provided by AWS can support registration, organization, monitoring and remote Management of hundreds of thousands to millions of IOT devices. Firmware updates can be sent wirelessly, and users can use the same service to manage different types of devices [13]. These products are positioned in the extensive Internet of things field and are in the process of rapid promotion and application. If they play a greater role in the industrial field, they still need to optimize and verify the system according to the actual requirements of the industrial scene.

Focused on the intelligent management of industrial equipment, this paper firstly studies the industrial equipment management service system based on Cloud-Edge collaboration from the perspective of system architecture, and discusses the design of equipment management cloud platform and edge intelligent gateway in detail. Secondly, the application of energy consumption monitoring and optimization system of central air conditioning based on INDICS platform and SMART IOT edge intelligent gateway is introduced to verify the availability of system functions. Finally, the industrial equipment management service system based on Cloud-Edge collaboration is summarized and its future development is prospected.

II. Design and Implementation of Industrial Equipment Management Service System Based on Cloud-Edge Collaboration

Industrial equipment management service system is the basic and most important management system in the industrial Internet of things （IIoT）. It can provide data and equipment model for big data modeling and analysis, as well as a series of information such as equipment status, location and configuration for system operation and maintenance, supply chain optimization, energy consumption analysis, etc[14-19]. This paper is guided by the practical design idea of Cloud-Edge collaboration. Combined with IIoT platform and edge device management, this paper studies an industrial device management service system based on Cloud-Edge collaboration.

A. System Architecture

The industrial equipment management service system based on Cloud-Edge collaboration includes the equipment management of PaaS layer under cloud platform and the equipment management under edge layer, which is shown in the red box in fig.1.

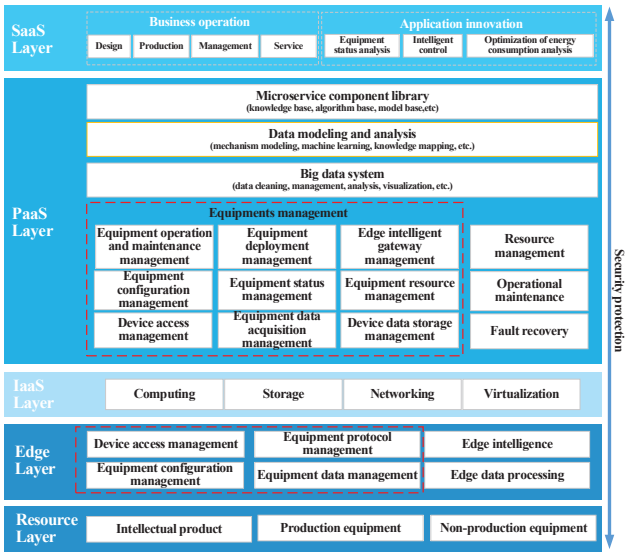

Fig. 1. Industrial equipment management service system architecture based on Cloud-Edge collaboration

a) Cloud layer

Cloud platform layer includes IaaS layer, PaaS layer and SaaS layer. The IaaS platform layer provides infrastructure such as computing, storage, networking, and virtualization. The PaaS layer provides equipment management, resource management, big data processing, data modeling and analysis, service components, algorithm library, knowledge base and other functions. SaaS layer provides online testing, operation optimization and intelligent services for industry users and specific scenarios. Among them, equipment management is an important part of PaaS layer, which consists of equipment access management, equipment configuration management, equipment data acquisition management, equipment data storage management, equipment state management, equipment deployment management, equipment resource management and edge intelligent gateway management. These sub-modules of equipment management provide basic data sources for big data processing in PaaS layer, and provide basic equipment models for data modeling and analysis. Meanwhile, the equipment management module provides open API to the outside world, including the downstream API for identification, which is for the device data transmission and event processing. And using the API based open environment, users can quickly realize the development of

different industrial applications and deploy them on the platform.

b) Edge layer

Edge layer is the specific technology implementation layer of edge computing in Cloud-Edge collaboration, including edge real-time operating system (ERTOS), virtualization (Docker, unikernel, etc.), timing data storage, edge device management, edge data processing, cluster collaboration, etc. Among them, edge equipment management includes equipment access management, equipment data management, equipment configuration management, equipment protocol management and so on. Edge layer builds edge capability through protocol transformation, data service and edge application as well as security protection, so as to realize equipment data acquisition, data preprocessing and real-time analysis response, which can establish safe and reliable connection between cloud platform and industrial equipment.

c) The relationship between them

The equipment management of Cloud platform layer and edge layer are complementary relationships, which are the basis of data collaboration, intelligent collaboration, application management collaboration, business management collaboration and service collaboration between cloud edges. Edge layer device management services have local device management capabilities. It can accept and execute cloud resource scheduling management policies. The cloud platform carries out overall management of the edge side equipment and senses the overall situation of the system, so as to generate reasonable equipment management strategies.

B. The Equipment Management of Cloud Platform

The equipment management system of cloud platform is equipped with device access, data collection, storage and device configuration services. Users can build applications based on their own business requirements in the basic platform environment. The platform architecture is shown in fig.2. The user-oriented device management service system adopts MVC framework design, including device access management, device data acquisition management, device data storage management, device resource management, device state management, device operation and maintenance management, device deployment management, edge intelligent gateway management and other functional modules.

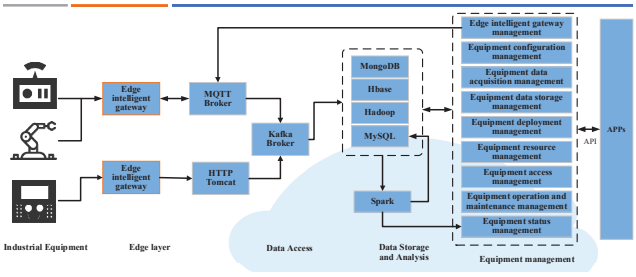

Fig. 2. Equipment Management Service Architecture of Cloud Platform

a) Equipment Access Management

The main functions of the equipment access management module include creating equipment, creating gateways and registering equipment models. It defines equipment information models by creating equipment groups and equipment models, accesses specific equipment through model instantiation and records equipment-related attributes and static information. By creating a gateway, it can record the basic information of the gateway and establish a relationship between the equipment and the edge intelligent gateway to determine the type of access protocol. Equipment model registration allows you to customize the equipment information model and add information items as needed.

b) Equipment Configuration Management

The equipment configuration management mainly implements equipment attribute management such as the equipment role, switch state, equipment operating environment and other basic information, forming a basic digital model of the equipment.

c) Equipment data collection management

The main function of the equipment data collection management module is the equipment data collection point configuration. It manages the equipment data collection frequency, the data protocol type, the register read/write type, the data type, the data range, the measurement unit.

d) Equipment data storage management

The equipment data storage management module is mainly responsible for selecting data storage methods according to data types and sources, and configuring the resources, capacity, status, etc. of the data storage. It regularly monitors data storage and supports the selection of stored data types to view browsing data.

e) Equipment resource management

The main function of the equipment resource management is the unified management of equipment resources, including equipment lists and specific equipment information. It can directly manage all access equipment and their types.

f) Equipment operation and maintenance management

The main functions of the equipment operation and maintenance management module include equipment alarm management, equipment maintenance activity management and equipment firmware upgrade management. It can store equipment alarm types, processing conditions, maintenance activity time, tasks, etc. It has the comprehensive analysis ability of failure rate, maintenance cost and so on.

g) Equipment deployment management

The equipment deployment management module has the functions of equipment group management, equipment distribution map and so on. It can quickly analyze equipment deployment location and online situation.

h) Equipment status management

The main functions of the equipment status management module include operation status monitoring, key parameter monitoring, energy efficiency analysis and capacity analysis. It can establish an evaluation model of the equipment by analyzing the operating parameters of the equipment, and evaluate the operating status of the equipment and its trend analysis and prediction. It can combine the equipment production planning and equipment operation status to analyze the comprehensive efficiency of the equipment. It sends the equipment data real-time monitoring task to the edge intelligent gateway to grasp the equipment status in real time and feed back to the cloud platform.

i) Edge intelligent gateway management

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The edge intelligent gateway management module mainly implements the configuration and management functions of the edge layer gateway. It provides tools such as gateway management list, gateway configuration, calculation formula editing, event management and gateway management. The functions of data acquisition protocol configuration, edge data processing rule configuration, edge application management, configuration download and edge intelligent gateway monitoring are realized in cloud through gateway configuration. After the configuration file is delivered to the gateway, the equipment performs equipment data collection, edge data processing and the edge application in the gateway. And it periodically feeds back the equipment data and the edge application running status to the cloud platform to implement cloud edge collaboration.

C. Edge Intelligent Gateway

As the communication hub of cloud platform layer and edge layer device management service, edge intelligent gateway plays a role of implementing edge computing and related functions of edge layer. It is unified configuration and management by cloud platform, but at the same time, edge intelligent gateway is independent to achieve normal operation of edge side system supported by cloud. The hardware of edge intelligent gateway is determined according to storage, computing requirements and hardware interface requirements. It is equipped with Linux operating system and supports Docker operating environment at the same time. Develop device interaction modules which support various industrial communication protocols, data pool modules which support data storage and distribution services, and network connection modules which support HTTPS, MQTT and other communication protocols. Data interaction and sharing between modules are conducted through API interfaces. Some API interfaces are open to the outside world to provide basic services for edge application development.

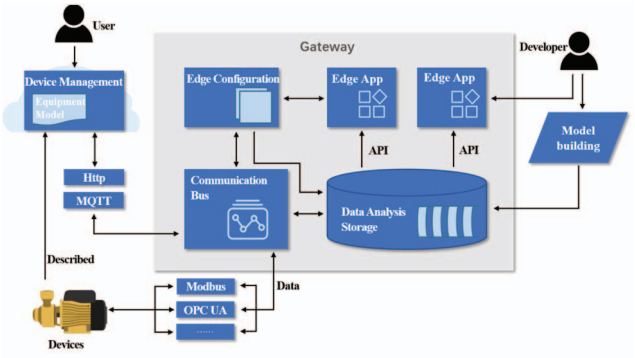

Fig. 3. Edge Intelligent Gateway.

As shown in figure 3, according to the configuration information issued by the cloud platform, the communication protocol of the device is adapted to synchronize the static information of the device, and real-time dynamic data is collected. The data is stored and analyzed and then provided to the edge application, or transferred to the cloud platform through protocol conversion for further analysis and processing. Developers can deploy the data processing model or APP in the gateway through the cloud platform, conducting time-delay and security-sensitive edge data analysis, reducing the pressure on transmitting date to cloud, and improve the flexibility of services for different devices.

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At the edge layer, equipment management mainly includes equipment access management, equipment status monitoring, equipment protocol management, equipment data management and other functions. The edge side management is coordinated with the cloud platform management to synchronize data at time intervals and maintain normal operation of the edge side when the cloud side connection fails.

a) Equipment access management

The device access management at the edge could analyzes different protocols (Modbus, OPC, CAN, Profibus, etc.), so as to unify the format of data. In addition, it offers device access management functions which are like cloud's, such as device creation, gateway creation, device model registration and other functions.

b) Equipment status management

Setting the equipment according to the cloud platform equipment management configuration information. Meanwhile, edge device configuration management has local configuration and management functions.

c) Equipment protocol management

Deploying various industrial communication protocols supported by the gateway, according to the access configuration information scheduling of cloud platform devices to establish channels for data interaction between gateway and devices through protocol analysis.

d) Equipment data management

The collected equipment data will be stored locally according to the configuration, and the corresponding data will be uploaded to the cloud platform through the communication module according to the configuration requirements of cloud platform data collection points. Meanwhile, edge device data management equips with local configuration and management functions.

III. Application Case Study

There are a lot of industrial equipment with high energy consumption, high safety risk and low utilization efficiency in the industrial field, which is an important application object of equipment management system, such as large and medium-sized air compressor, CNC machine tool, wind turbine, smelting boiler, etc. Equipment operation monitoring, energy efficiency optimization, predictive maintenance and other services provided by the equipment management system can reduce the average energy consumption of equipment, improve the utilization rate of equipment, reduce losses, and generate direct economic value. At the same time, these complex equipment have a large amount of data acquisition, high frequency, large volume, high concurrency, long cycle characteristics, the traditional IT architecture of data storage, processing and analysis ability is difficult to meet the application requirements.

This paper combines the energy consumption monitoring and optimization application of central air conditioning based on INDICS platform and SMART IOT gateway to carry out case analysis. Typical water-cooled central air conditioning is mainly composed of multiple cooling pumps, cooling towers, condensing pumps and cooling devices, which are all energy-consuming devices [20-22].Through edge intelligent gateway collection central air conditioning system equipment in and out of the water pressure, circulating water temperature,

differential pressure, flow, such as data, comprehensive test system running parameters and monitor equipment running status, control of water pump, cooling tower fan operation frequency and number of equipment start-stop, track air conditioning host conditions change, ensure system under various load conditions in the best working state, to improve the air conditioning system running stability and reduce energy consumption.

A. Edge Intelligent Gateway

The edge intelligent gateway in the application case was connected to 3 water chillers, 2 cold pumps and 1 cooling tower in the central air conditioning system of a building. Gateway configuration is carried out in the device management cloud platform, and key data such as pressure, temperature and flow rate are collected through Modbus protocol and uploaded to the platform. Using SMART IOT 6100 as the edge intelligent gateway, with IMX 6UL CPU and DDR512MB, supporting storage expansion, 2*100M\s Ethernet interfaces, 4*COM interfaces, WIFI/4G/3G/ NB-IOT, and supporting concurrent access of 10 devices, as shown in figure 4.

Fig. 4. Smart IOT 6100.

Cloud platform is in charge of a full-life cycle management for gateway applications, which includes configuration, unloading, update, monitor and log collection, acquiring Modbus communication protocol TCP transport model, and the parameters such as IP address and port number through the gateway to establish equipment connection. At the same time, cloud platform will issue the data processing strategy to the edge node. Edge node will send the real-time logs and monitoring information during processing as feedback.

B. Equipment Management based on INDICS Platform

Energy consumption monitoring and optimization application of central air conditioning includes operation monitoring, data analysis, historical data, equipment management, user management and system log function module. The system block diagram is shown in figure 5.

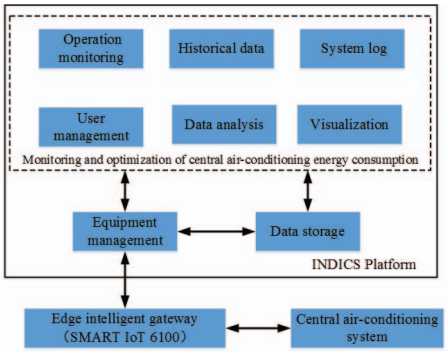

Fig. 5. Central air-conditioning energy consumption monitoring and optimization application system.

Setting up and configure chiller, cold water pump and cooling tower equipment in the Internet of things access tool of cloud platform, collect data such as inlet and outlet water pressure, circulating water temperature, pressure difference and flow, and conduct the above gateway configuration. Connect the acquisition system equipment to provide data for application analysis. The equipment management user interface of INDICS platform is shown in figure 6.

Fig. 6. The Equipment Management User Interface of INDICS Platform.

The key information is displayed by energy consumption monitoring and optimizing application and analyzed by EER system. Through continuous monitoring of accumulated data to further analyze the energy consumption optimization scheme, then determine the optimal operating condition parameters of low energy consumption. The parameter is sent to the edge of the intelligent gateway. System control algorithm (intelligent edge node) based on real-time monitoring data and the optimization of parameters optimization control passes the output parameter to the air conditioning control system for precise control of temperature and pressure difference, realizes the cloud side coordination of energy consumption monitoring and optimization.

Fig. 7. The central air conditioning energy consumption monitoring and optimization application.

As shown in figure 7, the application can comprehensive test system running parameters, monitor equipment operation state, start-stop frequency, track air conditioning host condition changes, realize real-time online monitoring equipment information and parameters, which guarantees system is in the best working state under various load conditions. Besides it realizes the air-conditioning systems, intelligent management, real-time adjustment equipment operation condition, ensure the safe operation of the system.

IV. Conclusion And Future Work

This paper introduces the equipment management service system based on Cloud-Edge collaboration from three aspects: system architecture, design and function implementation of equipment management cloud platform and edge intelligent gateway. Combined with the central air conditioning energy consumption monitoring and optimization application case, the system application program and system verification were analyzed.

The Cloud-Edge collaborative service model will be an important trend for the future development of Internet of Things applications. The equipment management service system based on Cloud-Edge collaborative that designed and developed in this paper was currently only verified in several equipment, and there is still lack of verification in a large number of devices service scenario, which requires more industrial applications to improve the system capabilities. At the same time, in-depth research on data collaborative analysis is needed.

Acknowledgment

The acknowledge and project are supported by the National Key R&D Program of China, (No.2018YFB1702700), National Natural Science Foundation of China under Grants 61773381, (61773382 & 61872365), Beijing Natural Science Foundation (No.182065); 2017 Special Cooperative Project of Hubei Province and Chinese Academy of Sciences. The development team and application case partners had put a lot of effort into the implementation of the project, and the authors would like to thank them.

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