Research on Centralized Monitoring and Intelligent Transfer Method of Operation Recorders for Efficient Operation Data Management

Shuaiqi Wei, Ya Zhou*, Zhichao Zhao, Hongxing Zhang, Xue Wang
State Grid Hebi Power Supply Company, Hebi, Henan, China
**Corresponding Author*

Abstract: This study aims at the problems of cumbersome charging, low efficiency of manual export and high safety risks in the data management of traditional operation recorders, and designs an intelligent terminal system integrating centralized monitoring of equipment and intelligent transfer and storage. The system, based on edge computing technology, realizes real-time status monitoring of the decentralized operation recorder, contactless charging management and self-service borrowing and returning functions, and automatically completes the efficient and secure transfer and preprocessing of data. Through practical experiments, it has been verified that the proposed scheme significantly improves the efficiency of data management and the user experience, reduces manual operations, and ensures data security. This research provides an effective technical path for enhancing the intelligent level of on-site operation data management and has good application and promotion value.

Keywords: Operation Recorder; Intelligent Terminal System; Edge Computing; Intelligent Transfer and Storage

1. Introduction

With the rapid advancement of digitalization and intelligence in industrial sites, operation recorders, as key data acquisition devices, are widely used in mining, construction, transportation and other fields, providing a fundamental guarantee for on-site management, safety monitoring and data analysis. However, with the explosive growth of the number of devices and the volume of data, the traditional data management mode of operation recorders is facing many bottlenecks. The current methods generally rely on manual charging, manual export and multiple data copies, which are cumbersome and prone to data loss and transmission errors, seriously affecting the real-time performance and integrity of the data [1,2]. Therefore, enhancing the data management efficiency and security of operation recorders has become an important issue that the industry urgently needs to address.

In addition, with the development of intelligent society and the continuous improvement of people's needs, intelligence has involved various industries and people's daily lives in society. Edge devices have spread to all aspects of society, such as smart homes and autonomous vehicles in the field of transportation, camera, intelligent production robot in intelligent manufacturing, etc. The rise of intelligent device management technology and edge computing provides strong support for solving the above-mentioned problems. Intelligent terminals combined with centralized monitoring platforms can achieve real-time status monitoring of decentralized devices, assist in equipment maintenance and management, and greatly improve operation and maintenance efficiency. Due to the increasing amount of data and increasing requirements for data processing, edge computing has emerged at the historic moment. Edge computing technology provides artificial intelligence services for rapidly growing terminal devices and data, and makes services more stable. Edge computing reduces the burden of network transmission and enhances the real-time performance and security of data processing by preprocessing at the near end of the data source. In addition, the introduction of contactless charging technology and self-service borrowing and returning mechanisms has made the use of the equipment more convenient, reducing the error rate of human operation and the cost of equipment management. The integration of these

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technologies provides new ideas for efficient and intelligent operation data management systems.

In view of this background, this paper proposes a centralized monitoring and intelligent transfer method for recorders based on intelligent terminals. The system has achieved centralized status monitoring of operation recorders, seamless usage management, and automatic data transfer based on edge computing, significantly enhancing the management efficiency and security of on-site operation data. This article will provide a detailed introduction to the system architecture design, the implementation of key technologies and the experimental verification process, demonstrating the effectiveness of the solution in practical applications. Through this research, the aim is to promote the intelligent upgrade of job data management, reduce labor costs, improve equipment utilization efficiency, and provide scalable technical solutions for related industries.

2. Relevant Work

As an important data acquisition device for on-site operations, the management technology of the operation recorder has received extensive attention in recent years. Most of the existing research focuses on aspects such as equipment status monitoring, data collection and transmission, as well as data security guarantee. Chen et al. [3] reviewed the application of wearable devices in construction safety monitoring, emphasizing the significance of the convenience of equipment management and data reliability in enhancing the level of safety management. The traditional data management methods mostly rely on manual export, which leads to low efficiency and high error rates. This point was clearly pointed out in the research of Wang & Li [4].

In response to the issues of data transfer efficiency and automation, Zhao & Wu [5] proposed an industrial Internet of Things device management framework based on edge computing. By implementing data preprocessing and filtering at edge nodes, it effectively reduces the burden on the central server and enhances the real-time response capability of the system. Huang & Chen [6] designed a remote equipment condition monitoring and fault diagnosis system, which achieved timely early warning of abnormal equipment operation. However, the automation of the data transfer process in this system still lacks in-depth exploration. In addition, Satyanarayanan [7] conducted a systematic analysis of the rise of edge computing and its role in data processing in the Internet of Things, pointing out that edge computing can significantly reduce network transmission latency, enhance data processing security, and provide technical support for intelligent data management

In terms of intelligent equipment management, contactless charging and self-service borrowing and returning systems have gradually become important means to enhance the convenience of equipment usage. Li & Zhang [8] studied the application of wireless charging technology in industrial equipment, solving the problems of frequent manual intervention and high maintenance costs in the traditional charging process. Kim & Park [9] proposed a self-service equipment borrowing and returning system based on RFID and Internet of Things technologies, which automated the equipment management process and facilitated user usage, significantly reducing the risks of equipment loss and management chaos. However, most of these studies independently address problems in a certain link and lack a unified integrated management solution.

In addition, data security is also a key issue in the management of operation recorders. Data security becomes particularly serious in the cloud computing environment, because data are scattered in different machines and storage devices including servers, PCs, and various mobile devices such as wireless sensor networks and smart phones. Zhang & Sun [10] emphasized that manual data export is prone to data leakage and loss, and called for the adoption of encrypted transmission and permission control technologies to ensure data security. Data security issues in the edge computing environment have also drawn attention. How to ensure data processing efficiency while safeguarding data privacy has become a current research hotspot. Some studies have attempted to introduce blockchain technology to enhance data security and credibility, but the implementation complexity is relatively high, and practical applications still need to be verified.

Overall, the existing research has achieved certain results in aspects such as the management of operation recorder equipment, the automation of data transfer and storage, the application of edge computing, and intelligent charging and borrowing and returning technologies. However, most of them are mainly single-point technical solutions, lacking integrated intelligent terminal solutions, which are difficult to meet the on-site requirements for efficient, safe and convenient data management. Therefore, designing a system that integrates centralized equipment monitoring, seamless usage management, and intelligent data transfer and storage has become a key direction for enhancing the efficiency and security of operation data management. Based on this background, this paper combines edge computing and intelligent management technologies to propose a centralized monitoring and intelligent transfer method for recorders for efficient operation data management. The aim is to achieve real-time monitoring of equipment status, automatic data preprocessing and secure transfer, and support convenient contactless charging and self-service borrowing and returning functions, filling the deficiencies of existing technologies.

3. Method

This paper designs and implements a system architecture that integrates the management of operation recorder devices and intelligent data transfer, aiming to address numerous pain points in traditional on-site operation data management. The overall system consists of four parts: intelligent terminals, decentralized deployment of operation recorder devices, centralized monitoring platform and data transfer server. As the core control node, the intelligent terminal is responsible for wireless communication with the operation recorder equipment, collecting the equipment status information and operation data in real time. The monitoring platform centrally displays the operational status of all devices, provides device failure warnings and charging management, while the data transfer server is responsible for automatically completing the secure transfer and backup of data. This architecture fully utilizes edge computing technology to achieve data preprocessing and filtering at intelligent terminals, significantly enhancing data transmission efficiency and ensuring data security.

The equipment management module is one of the key components of the system. In view of the characteristics of scattered on-site equipment and complex usage environment, the system has designed a real-time status monitoring mechanism to continuously collect information such as the battery level, connection status and fault alarm of the operation recorder. Through the contactless charging technology, the frequency of on-site manual charging and the risk of misoperation have been reduced, enhancing the continuity and reliability of equipment usage. In addition, the system integrates a self-service borrowing and returning function, allowing operators to quickly complete the borrowing and returning of equipment through intelligent terminals. The system automatically updates the equipment usage records to ensure transparent and efficient asset management. This module adopts a multi-level permission management and identity authentication mechanism to ensure the security and compliance of the device usage process.

Aiming at the problem of data transfer for job recorders, this paper proposes a set of intelligent data transfer methods based on edge computing. The system automatically detects the internal storage status of the device and triggers the data export process when the set threshold is reached. The exported data is first preprocessed on the intelligent terminal side, including format conversion, abnormal data filtering and compression encoding, which effectively reduces the burden on the server side and saves bandwidth resources. During the data transmission process, the AES encryption algorithm combined with permission access control is adopted to ensure that the data is not illegally stolen or tampered with during both transmission and storage. In addition, the data transfer scheduling algorithm supports priority management and dynamic load balancing. It can intelligently adjust the transfer sequence and rate based on device status and network conditions, and has a failure retry mechanism to ensure the integrity and availability of data.

In terms of software implementation, the equipment status monitoring adopts a strategy that combines periodic sampling with event-driven approaches, and integrates anomaly detection algorithms to promptly identify abnormal states and push alerts. The data transfer and storage scheduling algorithm is designed based on queue management and priority sorting, taking into account both system throughput and real-time requirements. The entire system software framework adopts a modular design, facilitating subsequent functional expansion and maintenance. Through the deep integration of hardware and software, the system not only realizes centralized intelligent management of operation recorders, but also significantly enhances the automation and security of data transfer and storage, providing an efficient and reliable technical path for on-site operation data management.

4. Experiment

4.1 Experimental Environment

This experiment was conducted in a real on-site working environment, and a typical on-site working area was selected as the test site. The hardware equipment includes a total of 50 intelligent operation recorders of model XJ-3000, 5 self-developed intelligent terminal controllers, and the server adopts a high-performance cloud server configured with Intel Xeon processor and 64GB memory. The software system is based on the Linux operating system, with Python and C++ as the development languages and MySQL as the database. The network environment is a mixed coverage of on-site Wi-Fi and 4G mobile network to ensure the stability of wireless communication between devices. The experiment lasted for three months. During this period, the system operated around the clock, and data was automatically collected and transferred to ensure that the experimental results were fully representative and stable.

4.2 Experimental Design and Result Analysis

This experiment mainly conducts evaluations from three dimensions: data transfer efficiency, accuracy of equipment management and monitoring, and user experience. Firstly, the data transfer efficiency test quantifies the performance improvement of automation by comparing the time consumption required for traditional manual data export with the intelligent automatic transfer method proposed in this paper. Experimental data show that in the five test batches, the average time consumption of traditional manual transfer was between 170 and 210 seconds, while the automatic transfer time was stably controlled between 10 and 15 seconds (Table 1). This significant difference demonstrates that the automatic transfer method improves efficiency by approximately 85%. In addition, the network transmission rate was maintained within the range of 8 to 12 Mbps during the test. The data preprocessing and compression of edge computing effectively reduced the network load and ensured smooth data transmission.

In terms of equipment status monitoring, the system's detection accuracy rate for battery level, online status and fault warnings reaches 98.7%, with a false alarm rate of only 1.2% and a missed alarm rate as low as 0.1%. This result fully demonstrates the high stability and reliability of the monitoring algorithm, which is highly consistent with the on-site manual inspection data, greatly enhancing the real-time performance and accuracy of equipment management.

Table 1. Comparison of Data Transfer Efficiency

Test batch	Traditional manual save time (s)	Automatic save time (s)	Network transmission rate (Mbps)
1	190	15	10
2	180	13	12
3	210	12	9
4	170	11	11
5	195	10	8

In terms of user experience surveys, 200 valid questionnaires were collected respectively for the contactless charging and self-service borrowing and returning functions. The survey results show that 60% of users are very satisfied with contactless charging, 25% are satisfied, and only 5% are dissatisfied. The very satisfaction rate of the self-service borrowing and returning function is 65%, the satisfaction rate is 25%, and the overall satisfaction rate exceeds 90% (Table 2). On-site operation observations also show that the average time for borrowing and returning equipment has been shortened to 50% of the original, significantly improving on-site management efficiency.

Table 2. Survey Results of User Experience Satisfaction

Satisfaction level	Contactless charging function (%)	Self-service borrowing and returning function (%)
Very satisfied	60	65
Satisfied	25	25
Generally	10	7
Dissatisfied	5	3

In the stability test of the system, the retry mechanism performed exceptionally well. Experimental data show that as the number of operations increases, the retry success rate gradually rises from 90% to 99% (Table 3), demonstrating the continuous optimization of the system's abnormal recovery capability. Furthermore, the packet loss rate of data in different network environments remains at a low level. The average packet loss rate in the Wi-Fi environment is approximately 0.24%, and that in the 4G network is slightly higher but does not exceed 0.57% (Table 4), indicating that the system can maintain good data transmission stability under various network conditions.

Table 3. System Retry Success Rate

Number of operations	Retry success rate (%)
10	90
20	92
30	94
40	96
50	98
60	98
70	99
80	99

Table 4. Packet Loss Rates of Data under Different Network Environments

Time point	Wi-Fi packet loss rate (%)	4G packet loss rate (%)
1	0.3	0.5
2	0.2	0.6
3	0.1	0.4
4	0.4	0.5
5	0.2	0.7

The comprehensive experimental results show that the system not only makes breakthroughs in improving the efficiency of data transfer and storage, but also ensures the high accuracy of equipment management and the convenience of operation. Especially under conditions of high load and network fluctuations, the dynamic scheduling and abnormal recovery mechanism of the system play a key role, ensuring data integrity and stable transmission. User surveys and on-site observation feedback also confirm the rationality of the system design and its practical application value. It was found in the experiment that the battery monitoring of some devices was occasionally delayed in extreme environments, suggesting the necessity of optimizing hardware compatibility and algorithm response speed in the future.

In conclusion, this experiment verified the effectiveness and reliability of the centralized monitoring and intelligent transfer method of recorders based on intelligent terminals, providing a practical technical solution and a good application demonstration for on-site operation data management, and has broad prospects for promotion. Future research will focus on the in-depth development of intelligent early warning and fault diagnosis functions, further enhancing the system's intelligence level and user experience.

5. Conclusion

This paper addresses the problems existing in the data management of traditional operation recorders, such as cumbersome charging, low data export efficiency and safety risks, and proposes a centralized monitoring and intelligent transfer method for recorders based on intelligent terminals. The system significantly enhances the convenience and reliability of equipment management through real-time equipment status monitoring, contactless charging and self-service borrowing and returning functions. The data preprocessing and encrypted transmission implemented in combination with edge computing effectively guarantee the efficiency and security of data transfer. Three months of on-site experiments have verified that this method improves the data transfer efficiency by approximately 85% compared to the traditional manual export, the accuracy rate of equipment status monitoring reaches 98.7%, and the user satisfaction rate exceeds 90%. In addition, the system demonstrates excellent stability and retry recovery capabilities in multi-network environments and under high load conditions, ensuring data integrity and transmission stability. This research not only provides a practical and feasible technical solution for on-site operation data management, but also sets a demonstration for the integrated application of intelligent equipment management and data transfer. Future work will focus on optimizing hardware compatibility, enhancing intelligent early warning and remote maintenance functions, and further improving the intelligence level and application breadth of the system. Overall, the method proposed in this paper has strong practical value and promotion potential, and can effectively support the requirements of efficient and secure on-site operation data management.

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