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Research Article

Remote Data Acquisition and Management Technology of Power Equipment Based on Internet of Things

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This paper proposes an architecture scheme for realizing the power equipment data acquisition IoT monitoring network using the latest Internet of Things technology. At the same time, a power equipment data acquisition and monitoring system based on Narrowband Internet of Things (NB-IoT) and exclusive-OR (XOR) encryption algorithms is designed. The system is mainly researched and designed from the aspects of monitoring terminal software and hardware design, data encryption processing, and remote data management cloud platform. This paper installs a big data analysis processor and a network routing processor based on the Internet of Things technology and modifies the system memory, display, and connection circuit to optimize the system hardware equipment. Finally, the system conducts experimental tests to monitor the state of power equipment, such as transmission and distribution towers, power manhole covers, cable tunnels, and distribution line knife gate temperature. The experimental results show that the system can realize low power consumption, comprehensive coverage, low-cost unified access, and centralized management of power equipment status information in different power scenarios. The application of this system dramatically improves the reliability and efficiency of the operation and maintenance of terminal equipment of the power system. The promotion of this system has a great application value.

1. Introduction

The Internet of Things has been widely used in industrial production optimization, management improvement, service improvement, energy conservation, and emission reduction in recent years. The application prospect of the industrial Internet of Things is comprehensive. State grid also plans to build a hub-type, platform-type, and shared-type energy Internet data management platform to promote the integrated development of smart grid and ubiquitous power Internet of Things [1]. In the Internet of Things information technology, traditional wireless access technologies represented by short-range wireless access and mobile cellular networks are limited in power consumption and cost, especially coverage width and depth. They cannot provide instrument data collection or real-time transmission. It provides an ideal communication solution for power grid in-depth application scenarios, such as sensor monitoring and other terminal nodes, with a large number, wide distribution, and small data transmission. As an emerging technology in the Internet of Things information technology, NB-IoT has the technical characteristics of comprehensive coverage, massive connections, low cost, and low power consumption. It just makes up for the shortcomings of traditional wireless access technology in some applications. However, in the power terminal monitoring system, NB-IoT devices are mostly energy-constrained systems, and their processing power, storage space, and communication bandwidth cannot support complex encryption algorithms and key distribution protocols [2]. Based on the above analysis, to realize the rapid acquisition of "small data" in the power system and the encrypted data transmission, this system selects NB-IoT with comprehensive coverage, massive connections, low cost, and low power consumption as

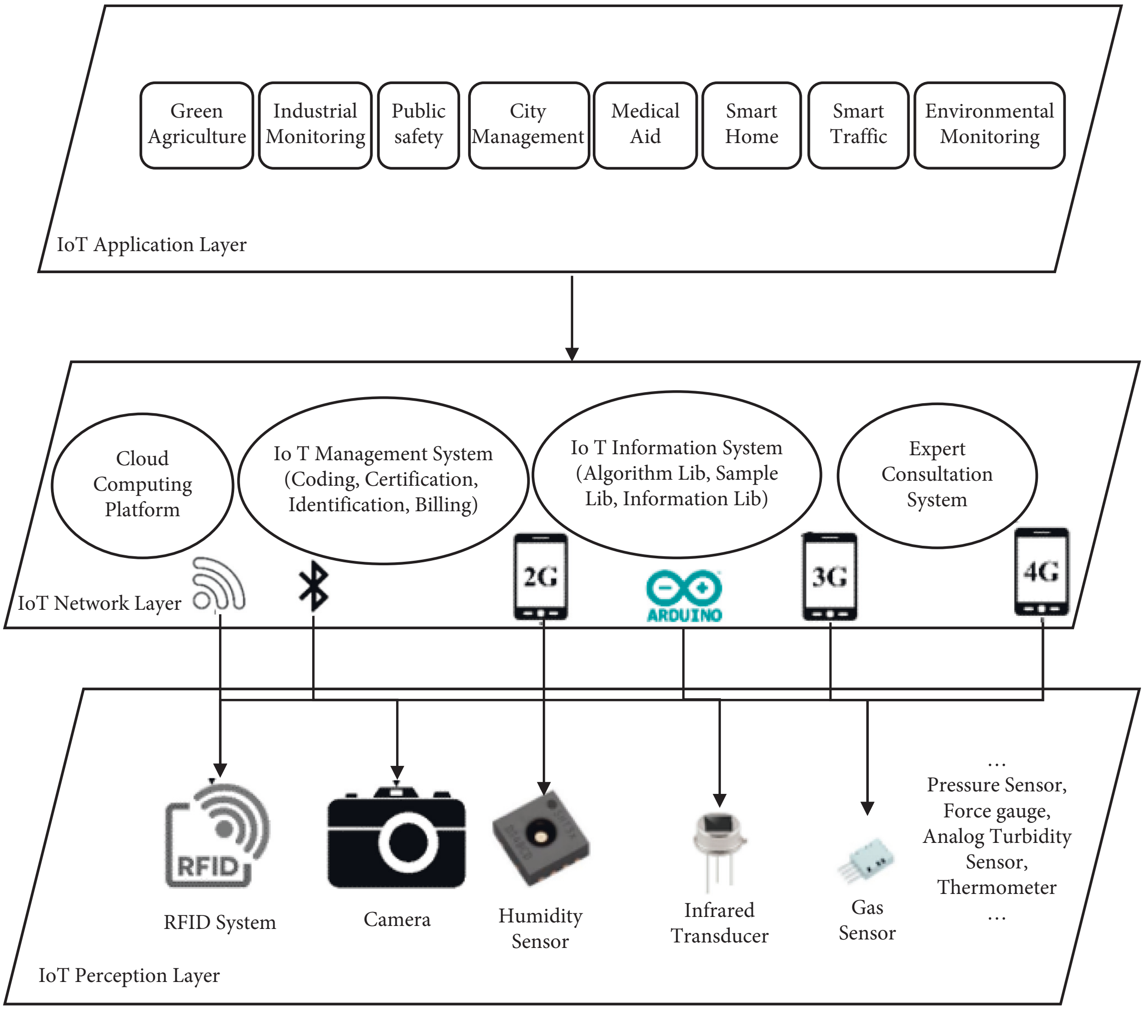

Figure 1: Functional composition diagram of the power equipment IoT monitoring system.

the communication network. STM32L151 is used as the terminal master controller, combined with the XOR encryption algorithm, to achieve real-time monitoring of multiple equipment and scenarios in the power system, including transmission and distribution towers, power manhole covers, power pipe galleries, and distribution line knife gates. The system has the function of an abnormal data alarm.

2. Overall System Design

2.1. System Function Design. As shown in Figure 1, the power equipment IoT monitoring network is mainly divided into monitoring platform, IoT network, and sensor identification (the picture is quoted from the Development of IoT Technologies for Air Pollution Prevention and Improvement). In addition to the traditional network environment, the Internet of Things network mainly adds a wireless access network built on LPWAN technology. Sensing identification can cover substations and distribution lines along the line. The data acquisition terminal covers the original environmental sensing devices and focuses on the introduction of data measurement and identification devices, such as pole position tilt data detection on the line, equipment operation data measurement, and other safety measuring devices [3]. The monitoring platform collects the data of the whole network. The monitoring center and the monitoring station of the work area can display the environmental status and equipment operation data information of the substation and distribution lines in real-time. When an abnormality occurs (monitoring or operation data exceeding the alarm threshold, environmental alarms generated by emergencies, etc.), it can quickly alarm and carry out emergency power repairs in time.

2.2. System Structure Design. The network of the power equipment IoT monitoring system adopts flat secondary management as a whole, including the control network and the access terminal. It can be deployed in combination with the actual production management link. Figure 2 shows a basic schematic diagram of a city-level IoT monitoring network (the picture is quoted from Low-Power Wearable ECG Monitoring System for Multiple-Patient Remote Monitoring). The LPWAN wireless gateway is deployed according to the management area and can be adjusted

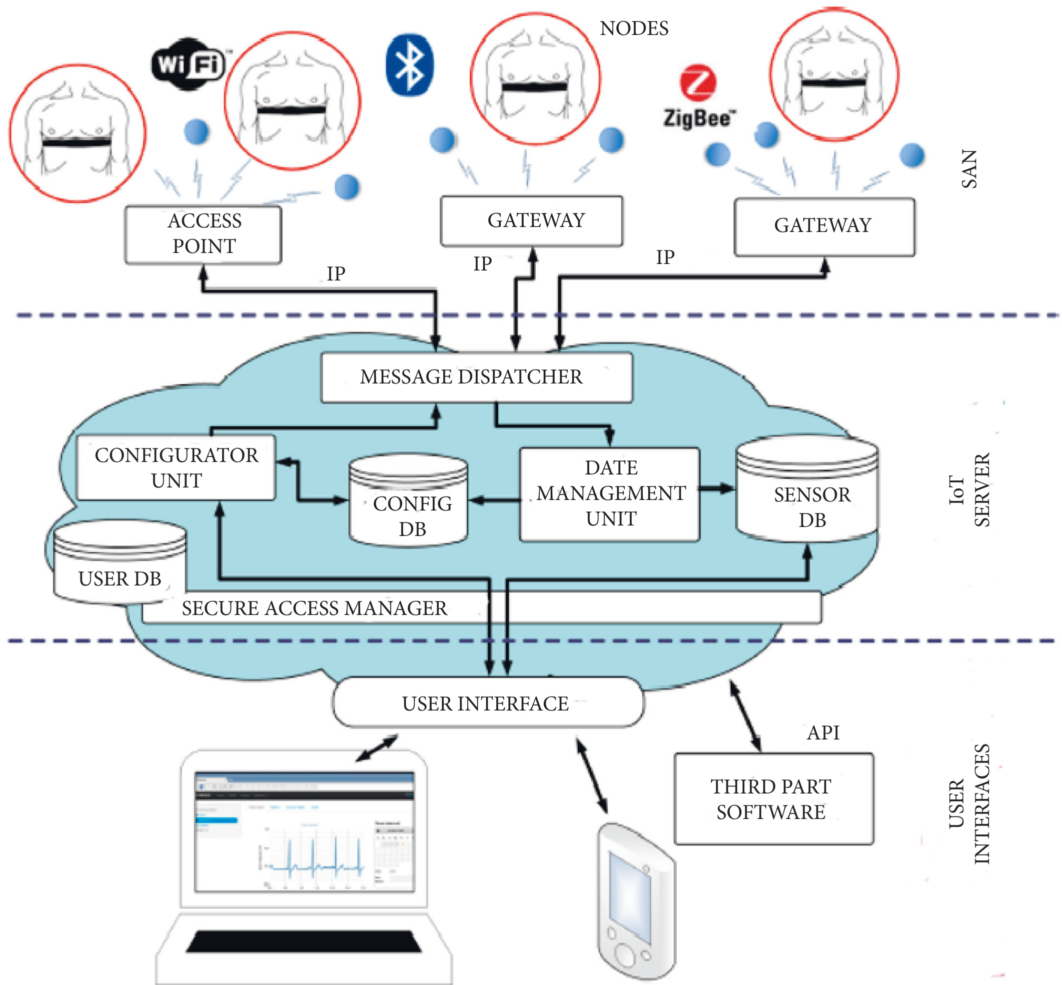

FIGURE 2: Basic schematic diagram of the IoT monitoring network.

according to the actual coverage of the management area. Usually, a LPWAN wireless gateway can cover a radius of about 10 km. The IoT monitoring server manages the data collected by IoT, and the server manages all IoT elements (equipment, personnel, etc.) to ensure the information security of the monitoring network [4]. The monitoring center and the monitoring station in the work area are connected to the control network through the internal network to obtain equipment status information and environmental status information concerned in real time.

2.3. Terminal Hardware Design of Power Terminal Monitoring System. Controller selection: STMicroelectronics STM32 series chips are designed for embedded applications with high performance, low cost, and low power consumption and are very suitable for monitoring of power equipment with a large number of applications and wide distribution. Therefore, the ultra-low-power STM32L151 microcontroller is selected for the system. STM32L151 is based on the Cortex-M3 core, equipped with high-speed embedded memory and a large number of enhanced I/Os, and peripherals connected to two APB buses [5]. At the same time, it pays more attention to the better choice for energy-saving applications. It has built-in 128 k of FLASH, 16 k of RAM, and is equipped with a memory protection unit (MPU), a real-time clock, and a set of backup registers that remain powered in standby mode to prevent data loss. The terminal hardware of this system is composed of sensors, NB communication module, power supply module, and main control module. It completes a series of processes from sensor data acquisition to data information processing to ciphertext transmission. Terminal hardware architecture is shown in Figure 3 (the picture is quoted in Design and development of an IoT-based web application for an intelligent remote SCADA system).

2.4. Software Design of Power Terminal Monitoring System. The software design part of the monitoring terminal is designed with layered architecture, which are the underlying driver layer, the operating system layer, and the user task layer. The software architecture diagram of the monitoring terminal is shown in Figure 4 (the picture is quoted from Improved Resource Directory Based on DNS Name; Self-Registration for Device Transparent Access in Heterogeneous IoT Networks). The program design mainly includes four tasks: watchdog and

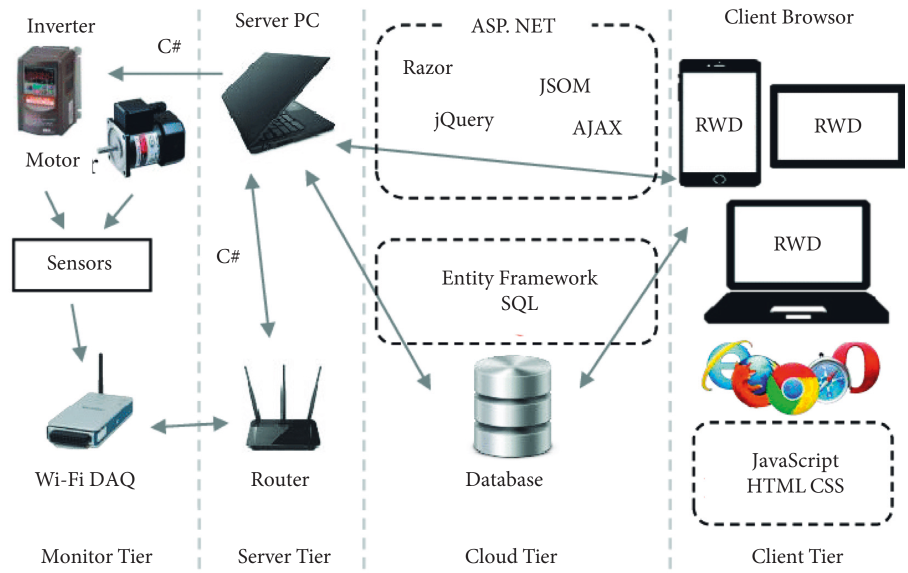

Figure 3: Terminal hardware architecture diagram.

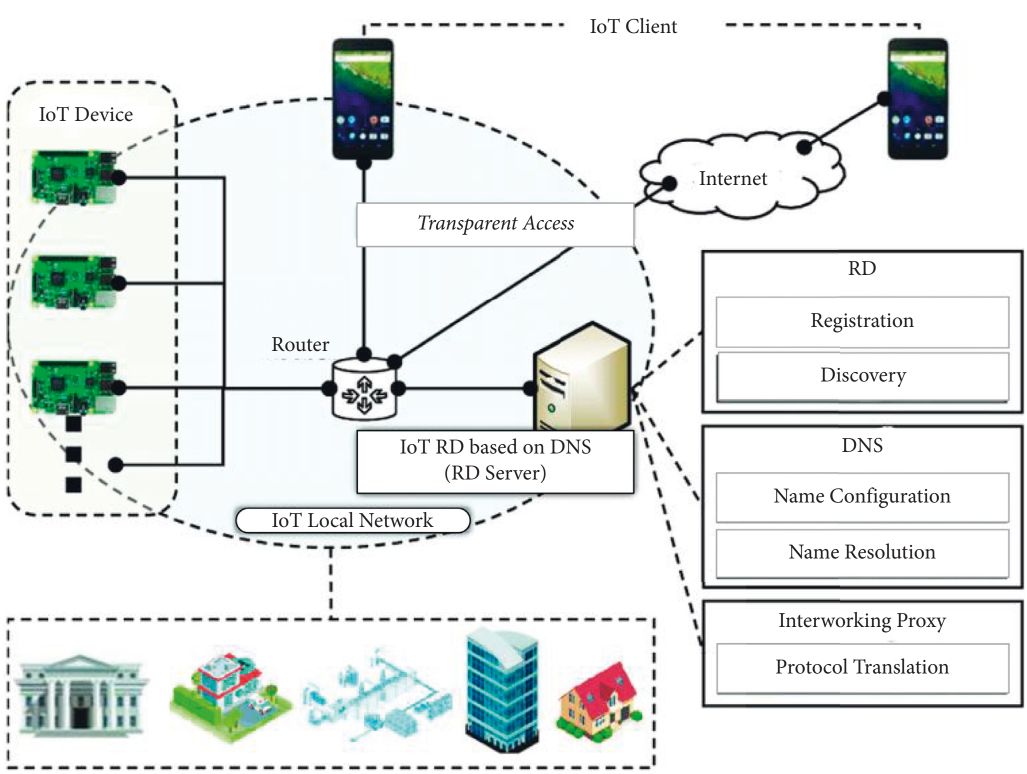

Figure 4: Monitoring terminal software architecture.

flag bit detection, system status lights, debugging sensors, data acquisition, processing, and communication [6]. The specific functions use the FreeRTOS embedded real-time operating system for task scheduling. Among them, the data acquisition and communication tasks have the highest priority as the core tasks of the monitoring terminal. Data acquisition and communication tasks periodically collect sensor data when flag bits are normal, and they make simple judgments on the data. If the data is abnormal, package the data packets according to protocol requirements and upload them to the remote data management platform. Otherwise, monitor the terminal uploads sensor data to the remote data management cloud platform in a fixed period.

2.4.1. Data Communication. Taking the automatic verification device of sulfur hexafluoride density relay as an example, the automatic device includes automatic

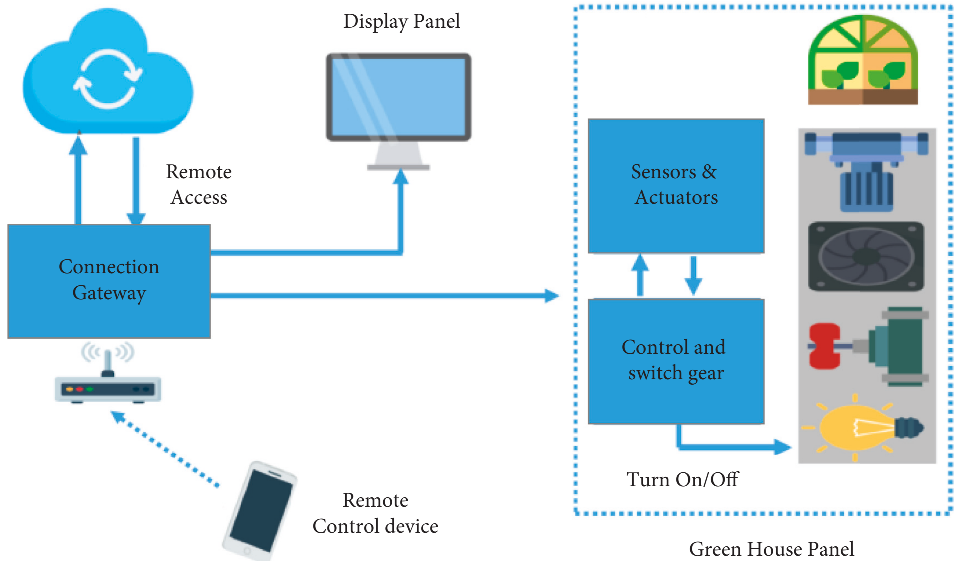

Figure 5: System communication principle.

verification hardware equipment, safety communication control module, and corresponding serial port. Through the information interaction between the module and the window of the hardware device and the custom interface protocol, the module's positioning module, encryption module, communication module, battery module, touch screen module, and other information are transmitted [7]. Through the information communication with the background service manager through the positioning data, the test data are transmitted to the cloud platform server through the mobile network and the corresponding data channel. As shown in Figure 5 (the picture is quoted from Internet of Things is a revolutionary approach for future technology enhancement: a review), the cloud platform server and the background service manager are parallel servers, which are used for background data monitoring storage and online real-time data, respectively. the data obtained by the two are communicated with the handheld terminal and the intelligent terminal, and the data can be displayed on the terminal. At this point, the uplink communication is completed. The handheld terminal and the corresponding smart device can also send query information, function requirement information, etc., to the corresponding background service manager, cloud platform server, etc., for a query. During the query process, the corresponding positioning data and test data need to be called, and then the background server and the cloud platform server send the query data downlink to the automatic verification device again, and the data is retrieved through the communication module inside the device, and finally the data is sent downlink.

2.4.2. System Topology. As shown in Figure 6, the system topology relationship is mainly divided into server room, cloud platform, warehouse, operation office, and corresponding network peripherals, etc., (the picture is quoted in Topology and broken Hermiticity). The data is extracted through testing equipment designed for different power equipment in the warehouse and uploaded to the local area network. The office can view the corresponding data through the display terminal; the data from the local area network is uploaded to the server room, and the cloud computing and big data technology in the server room are used for integration [8]. It can realize analysis and processing of the cloud platform; after the data is stored, it is uploaded to the Internet and sent to the big data cloud platform, and finally the data of the cloud platform is displayed through different network transmission forms. The safety communication control module is connected to test equipment through the serial port, and has modules, such as encryption, communication, positioning, battery, and touch screen.

2.4.3. Data Processing Flow. Data collector equipment in the hardware system is installed on each node position of the power monitoring system network, and the collection of real-time system network data is realized by setting the collection duration and collection interval. On the basis of the initial network data, big data technology is used for processing and analysis, and the specific processing steps include data cleaning, data conversion, data clustering, etc., to facilitate the extraction and analysis of network data features. The process of data cleaning is also the process of filtering noise/redundant data and supplementing missing data [9]. The threshold compensation method is used. First, the distance between missing data and other data is calculated. The calculation formula is

$$D = \sqrt{\sum_{i=1} \left| x_i - y_i \right|^2}. \quad (1)$$

In the formula, x_i and y_i are the attribute values of the system network data x and y, respectively. Set the distance threshold as η, and judge the size relationship between the calculation result of formula (1) and η. If the calculation

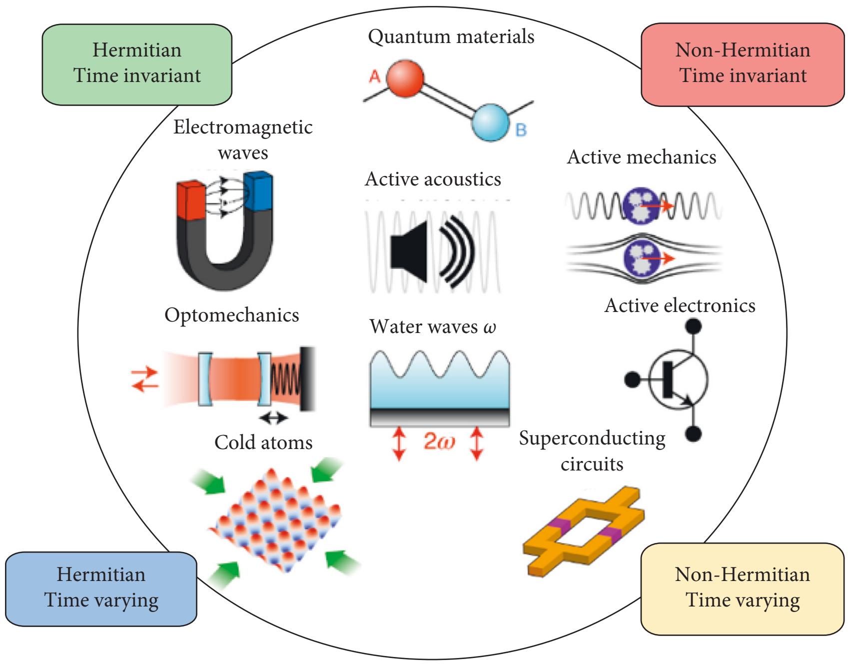

FIGURE 6: System topology.

result is less than the distance threshold, use the attribute value smaller than the threshold data to replace the null value, otherwise, assign the missing null value to be greater than the threshold value. Data conversion includes three steps: unit conversion, data generalization, and normalization [10]. Data normalization can be divided into normalization processing and normalization processing. The corresponding processing process can be expressed as

$$x' = \frac{x}{x_{\max}}, \quad \overline{x} = \frac{x-\mu}{\sigma}. \tag{2}$$

In the formula, x' and x are the results obtained by the two processing methods; x is the initial system network data; $x_{\max}$ is the maximum value of the data attribute. μ and σ are the mean and standard deviation of the network data x, respectively [11]. On this basis, define θ_j to represent the j clustering data of the network, and the processing result obtained by fuzzy clustering is

$$J(\theta_j) = \sum_{i=1}^{n}\sum_{j=1}^{m} \mu_{ij}^{q} d(x_i, \theta_j). \tag{3}$$

In the formula, μ_{ij}^{q} is the (i, j) element in the system network matrix. $d(x_i, \theta_j)$ is the similarity between x_i and θ_j.

2.5. Database Design. MySQL is selected as the operating environment of the network security monitoring system database. Through the collection and storage of the location and operation data of each node in the power monitoring system network, the design of the database is realized to provide storage space for the system data [12]. The database tables included in the optimized network security monitoring system include monitoring system network node basic information table, network security level data table, network real-time operation data table, historical monitoring data storage table, network security log data table, etc. The design structure of the system network security log data table is shown in Table 1.

The construction results of other database tables in the system network security monitoring system can be obtained using the same method. According to the logical relationship between different types of data, the connection between the database tables is formed. Since the power monitoring system is running in real time, the corresponding network environment is also running in a dynamic form, and the generated network data gradually increases with time [13]. Therefore, the updated time of the data in the database is set to 0.5 s, and all data in the database is backed up.

3. Detailed Analysis of Functional Modules

3.1. Data Preprocessing

3.1.1. Data Cleaning. In the current operation of the power grid system, as the data of power equipment used is getting larger and larger, there is always incomplete, complex and changeable, and redundant data analysis in the process of collating the massive data. At the same time, it will lead to a direct impact on the efficiency of data analysis. Therefore, it is necessary to perform preprocessing analysis on its system data, so as to screen out some useless information in advance, so that in the process of processing, various types of data information. At present, the operational data of power equipment presents various characteristics, such as power

Table 1: System network security log data.

Data name	The data shows	Storage type	Primary key
Journal_id	System network node id	int (8)	Yes
Journal_time received	Security log reception time	datetime (16)	No
Journal_time sended	Security log sending time	datetime (16)	No
Journal_message	Log content	Varchar (1000)	No
Journal_district server id	Repeater id	FK, bigint	No
Journal_is parsered	Analysis situation	smallint	No
Journal_dest IP	Target IP	nvarchar (40)	No
Journal_attack IP	Attack IP	nvarchar (40)	No
Journal_log type	Security log type	nvarchar (40)	No
Journal_Syslog parser id	Parser id	FK, bigint	No

equipment detection data, current data, voltage data, and temperature data [14]. Therefore, in order to be able to process various types of data and information, it is necessary to ensure the processing of the design of targeted data cleaning.

3.1.2. Substation Equipment Detection Function. In the current smart grid detection process of smart substations, its important foundations and smart nodes always need targeted processing of numerous status information in the substation equipment status analysis module. Secondly, it is necessary to make full use of big data analysis and mining theory to clarify the state of power equipment and the mechanism of fault evolution, so as to provide a good foundation for subsequent operation and maintenance work. With the construction of the Internet of Things in Chinese new generation of substation equipment, the Internet of Things technology has been widely used, so the detection ability in its operation has also been comprehensively improved.

3.2. Data Acquisition Module. In the operation of this module, the main purpose is to provide a good data collection work to the upper-layer application, and correspondingly in the process of the module, to help the design of data collection, and to provide a multithreaded collection mode. For the remote control function, it is a non-real-time functional operation, which can form a good processing effect in the subsequent operation process. In the design of this module, it is essentially an operation mode that does not operate independently, but is integrated into the main thread module. In the use of data acquisition tools, the structural design basically includes active design patterns, such as physical layer, access layer, and data acquisition layer. The physical layer is the data collection in the black box. In the access layer, the serial port protocol is used to connect the host computer with the black box accordingly, so as to ensure the corresponding processing of the address resources of the power site. In general, the black box is represented in the address processing of dynamic division, so as to ensure that the data can be analyzed and processed correspondingly in the actual processing process.

3.3. Data Analysis Module. Among such analysis modules, it is a function to realize dynamic detection of power system. However, with the progress of detection, a large amount of data information is gradually formed. Therefore, it is necessary to carry out targeted status assessment in the process of analyzing historical data, so as to ensure targeted analysis in a limited time and processing, and within a reasonable time period, complete the corresponding data processing.

4. System Application Example

4.1. Application Background. A substation is configured with 220 MVA and 220 kV transformers, and its model is SFMZ1-220000/220. A part of information about the online monitoring of equipment according to the system is shown in Table 2.

During the routine inspection and inspection of workers, it was found that there was oil leakage in the appearance of the transformer. The gas content in the oil and gas is shown in Table 3. After inspection, transformer accessories have the following problems: the winding is hot, the oil temperature is too high, the tap changer has noise and vibration, and the oil level of the exhaler does not match the actual.

4.2. Troubleshooting

4.2.1. Determination of Fault Sets. According to the returned data, the system determines the power equipment fault set F as partial short circuit (F1), insulation aging (F2), lead fault (F3), shell discharge, and inter-turn short circuit (F4).

4.2.2. Local Fusion of Online Monitoring Information Based on Fuzzy Theory. The system preprocesses the monitoring data to obtain the input value $\underline{X}_1$ of local fusion: the partial discharge amount is 0.83, the micro-water amount in the oil is 0.1, and the discharge fault is 0.86, that is, $X_1 = (0.83, 0.1, 0.86)$. Then, the system obtains the result of local fusion of information through the fuzzy transformation matrix method: $Y_1 = (0.41, 0.54, 0.69,$ and $1.21)$, and the fault sequence is {F4, F2, F3, and F1}.

4.2.3. Information Local Fusion Based on Fuzzy Theory. The inspection information is calculated according to the bipolar proportional method, the input value $X_2 = (5, 5, 4)$ of the local fusion can be obtained, and the result of

Table 2: Monitoring information.

Online monitoring information	Winding DC resistance unbalance factor (%)	Partial discharge (pC)	Winding dielectric loss (%)	Core ground current (mA)	Micro water content in oil (mg/L)
Numerical value	0.55	800	0.59	37.4	21

Table 3: Dissolved gas content in oil.

Dissolved gas in oil	Content μL/L
CO	197
CO_2	711
H_2	92.1
CH_4	28
C_2H_2	5.71
C_2H_4	48
C_2H_6	9.1

normalization is (0.4, 0.4, 0.3). Then, through the operation, the result is $Y_2 = (0.22, 0.29, 0.76)$. Finally, according to the information fusion results, the possible faults of the power equipment are obtained as {F4, F2, F3, and F1}.

4.2.4. Decision Fusion Diagnosis Based on Evidence Theory. The system first establishes an identification framework and analyzes the most likely diagnosis results as F4 and F2 through the subnetwork. According to the results of system analysis, the identification framework F based on evidence theory is set as {insulation aging F2, inter-turn short circuit F8}. Then, the reliability coefficients of system online diagnosis and manual inspection were manually set to 0.8 and 0.7, respectively. Finally, the system obtains the final reliability values of the four preset faults through local fusion of diagnostic information and evidence theory. The final result shows that the fault (F4) has the largest assigned value, and the assigned value of this fault is greater than the set threshold of 0.5. According to system analysis, the diagnostic result of the transformer is: inter-turn short circuit (F4), which is consistent with the system analysis result after manual on-site inspection. This test shows that the power equipment fault information collection system based on the Internet of Things designed in this paper is reliable, and its analysis results are real; applying this system to the actual production process can maximize work efficiency and reduce economic loss.

5. Conclusion

This paper designs the remote data acquisition and control of power equipment in the Internet of Things. Firstly, the current status of power equipment testing is analyzed, and the data types, monitoring purposes, monitoring forms, and operating requirements of the power equipment status monitoring data for the system are described. Then, the application of cloud technology in power equipment testing is analyzed, and the principles of data processing technology, distributed storage, and other technologies in power equipment testing are explained. Aiming at the design of the remote management and the control system for power equipment testing, system architecture is given, the system topology relationship is explained, the data communication principle is proposed, and the parallel data storage and other functions are realized. Finally, the function of the system based on cloud platform is briefly analyzed. The system design of this paper can provide corresponding guidance for the remote management and control of power equipment status data.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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