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A Hybrid Deep Learning Framework for Real-Time Fault Diagnosis and Prediction of Elevator Systems

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Abstract: With the rapid rise of the number of elevators in China, the connection between elevators and daily production and life is more and more close. How to ensure the normal operation of elevators and timely diagnosis and early warning of faults has become the focus of the government and relevant scholars. In this context, this paper monitors and warns the corresponding faults in the main components of traction elevator (control system, mechanical system), and visually displays the monitoring and early warning results. The main research contents are as follows: analyzes the typical faults of the elevator, mainly analyzes the main characteristics of broken wire defects based on the basic type of wire rope defects; expounds the basic principle of magnetic leakage detection and the basic design idea of the excitation device; designs an elevator fault detection and early warning system. The system collects the vibration acceleration signal of the elevator car through the sensor and uses Ethernet to transmit the data flow processing engine using Fume, Kafka and Flink, aggregate and distribute the data to MySOL and database; builds the visual interface based on InteliJ IDEA development tool to realize the real-time monitoring and fault warning of elevator operation, providing the basis for fault diagnosis and preventive maintenance of the elevator.

Keywords: elevator; fault monitoring and early warning; hybrid deep learning;

1. Introduction

As our country in recent years to "industrial 4.0" and "made in China 2025" as the background of intelligent mechanical equipment renovation project, the implementation of the elevator industry iot technology application more common, using sensing can collect more and more different kinds of data, the number of explosive B, such as the state of running data, mechanical parts of vibration signal data, etc. At the same time, in addition to the large amount of data generated in the process of use, the corresponding data generated in the production and later maintenance process of the elevator is also quite huge. The surge of data volume brings both challenges and opportunities[1-2]. It has become an urgent knowledge for relevant management departments and industry experts and scholars to mine the potential knowledge hidden in the huge elevator data, supervise the operation status of elevators and give early warning of the elevator failure[3]. In this context, the development and maturity of new generation technologies such as big data, Internet of Things and deep learning provide new ideas and methods for processing these massive data through technological innovation[4-6].

Through the analysis of the elevator operation data of the elevator control system and mechanical system running state of real-time fault diagnosis and timely warning, help the elevator management personnel find elevator fault and develop targeted solutions, solve the traditional monitoring method is not found in time, fault location is not accurate[7]. At the same time, through the construction of distributed cluster, it can provide high data processing throughput and computing efficiency, so that the system built in this paper can meet the needs of large quantities of elevator monitoring at the same time, which has important economic and social significance to improve the quality of elevator transportation and the safety of elevator operation[8].

For the monitoring and warning of the main elevator (control system, mechanical system) and corresponding faults, based on the basic type of wire rope defects, specifically analyzes the main characteristics of wire defects, expounds the basic principle of magnetic leakage detection and the basic design idea of excitation device, and monitoring and warning results to provide reference for related research.

2. Elevator common fault analysis

2.1. Basic elevator structure and common mechanical faults

Elevator is a typical mechatronics equipment, which consists of functional components such as control, driving, transmission and bearing capacity[9-10]. Generally, the elevator system can be divided into individual subsystems, as shown in Table 1.

Table 1. Main components and devices of the 7 subsystems of the elevator

systematic name	Main components and devices
Towing system	Traction machine, traction wire rope, guide wheel, reverse rope wheel, base, etc
Guidance system	The guide rail of the car, the guide rail in the team and its guide rail frame, guide boots, etc
The sedan-door system	Car frame, car body, weighing device, car door, layer door, linkage mechanism, door lock, door opening machine, etc
Weight balance system	Weight and weight compensation devices, etc
driving system	Motor, power supply system, speed feedback device, motor speed control device, etc
Navar	Control device, position display device, control panel (cabinet), etc
Safety protection device	Speed limiter, safety pliers, buffer and end station protection device, overspeed protection device, power supply system fault and fault phase protection device, protection device beyond the upper and lower limit working position, layer door lock and car door electrical linkage device, etc

The elevator failure has internal reasons and external performance. The internal reason refers to the failure of the elevator parts, and the external performance is that the elevator is in some state of failure. The monitoring

range of component failure is too large, and the realization cost is very high. In fact, for the elevator safety supervision department, elevator owners, elevator maintenance companies, more attention is paid to whether the elevator is in some state of failure.

When the elevator fails, the specific fault type can be inferred from the various state signals of the elevator."Elevator, escalator and automatic sidewalk data monitoring and recording specification" and "elevator remote alarm system" two standards gives the basic logic of the elevator fault judgment, but does not reflect "monitoring the elevator is running normally, and whether the trouble is trapped" the actual need of the elevator safety supervision, therefore, according to the elevator safety operation logic and technical inspection professional knowledge research design elevator fault knowledge base. The elevator fault knowledge base consists of the elevator operation status set and the fault judgment logic. The elevator operation state set includes the basic state signal and the extended state signal, which can be acquired by the main controller communication or collected by an independent sensor. In the independent sensor collection mode, the basic state signal and the extended state signal can be collected by switching quantity, analog amount and sensor module, as shown in Table 2.

Table 2 Elevator status set and independent sensor acquisition method

Status signal		Independent sensing and acquisition method
Basic state signal	Coupe switch status	Switch volume collection
	Hall door switch status	Switch volume collection
	Up flat layer signal	Switch volume collection
	Lower flat layer signal	Switch volume collection
	Base station signal	Switch volume collection
	Upper limit switch signal	Switch volume collection
	Lower limit switch signal	Switch volume collection
	Passenger detection signal	Sensor perception
	rate signal	Sensor perception
	System power status	Analog acquisition
	Standby battery status	Analog acquisition
Extension of the state signal	The alarm bell signal	Switch volume collection
	Safe loop status	Switch volume collection
	Door lock circuit state	Switch volume collection
	Maintenance status	Switch volume collection
	Fire status	Switch volume collection
	The driver state	Switch volume collection

Judging the operation state of the elevator and the specific fault type under the fault state are not directly obtained from the collection module information of the elevator operation parameters, but based on the elevator

operation fault reasoning strategy. The information of operation speed, operation direction, whether there is someone in the car, whether the upper and lower limits touch, the parking station and the closing of the car door are obtained through the elevator operation parameter acquisition module, which is the basis for judging whether the elevator is running normally and the type of fault in the abnormal state. For elevator safety supervision and emergency rescue services, the basic fault set, including the stop ladder outside the door, operation timeout, flat opening timeout, opening during operation, top, bottom, overspeed, system power failure, standby power failure and distress, basically meet the requirements. The basic fault types of the elevator and the reasoning logic of each fault are detailed in Table 3.

Table 3. Basic fault set of elevators

Type	Criteria
Tiring	There are passengers in the car & (outside the door stop ladder | running timeout! Flat door timeout | top | squat)
Stop the ladder outside the gate	No flat layer & the speed is zero
Run timeout	Speed is not zero & running time exceeds allowable value
Open the flat layer and timeout	Flat layer & does not open within the permitted time
Open the door in operation	Speed is not zero & the sedan door opens
At the top	Upper limit switch triggers
Squat bottom	Lower limit switch triggers
Exceed the speed limit	Speed exceeds the allowable value
System power failure	Power off, phase absence, misphase
Backup power failure	Undervoltage

2.2. Analysis and detection of elevator steel wire rope defects

2.2.1. Analysis of the elevator steel wire rope defects

Wire rope is an important mechanical component often used for traction, lifting and bearing in engineering. In the process of long time work, wire breaking phenomenon may occur due to fatigue and bending. On September 13,2012, on the construction site of Donghu Jingyuan Community in Wuhan, an elevator filled with painting workers suddenly broke, and the box body fell directly to the ground, killing 19 people. The occurrence of wire rope is extremely dangerous

Injury to the safety and stability of the elevator operation. Safety has always been the focus of people in the process of the elevator operation, and the safe operation of the elevator is the primary premise of its application. The following are some common elevator wire rope defect analysis:

1) Wear and broken wire

Reason: During long-term use, the friction between the wire rope and the guide rail and pulley will cause the wire rope to wear; if the elevator operating environment is poor (such as moisture and dust), the wear speed may be accelerated.

Consequences: the durability of the wire rope decreases, the bearing capacity is weakened, and the broken wire increases. When serious, it may cause the wire rope to break and be dangerous.

2) Corrosion

Reason: wire rope exposed to wet or corrosive gas environment (such as seaside, chemical plant, etc.), or long-term maintenance and cleaning, will lead to corrosion of wire rope.

Consequences: Corrosion will increase the risk of wire rope fracture, affecting the safety of elevators.

3) Broken stock of wire rope

Reason: During using the steel wire rope, some steel wire may break due to fatigue, wear and other reasons. Especially, the joint part of the wire rope is prone to problems.

Consequences: the bearing capacity of the wire rope decreases, affecting the normal operation of the elevator, and even leading to the failure of the elevator.

4) Stretching and elongation

Reason: The wire rope may elongate under excessive load or long time use.

Consequences: the tension of wire rope affects the smooth operation of the elevator and increases the burden of the elevator system.

5) Bend and distortion

Reason: Excessive bending or distortion of the wire rope can cause the deformation of the internal structure, usually in the asymmetry of the guide rail system or the installation of the wire rope.

Consequences: The flexibility of the wire rope is reduced and may cause rope fracture or failure in severe cases.

6) Wear or misplaced wheel slot

Reason: the part of the elevator pulley and the wire rope, if the wheel groove is worn or misplaced, it will lead to uneven force of the wire rope.

Consequences: The wear of wire rope is intensified, and kinink or fracture may occur.

7) The relaxation of the wire rope

Reason: if the elevator wire rope does not adjust the tension for a long time, there may be a relaxation phenomenon.

Consequences: the elevator operation may produce unstable phenomenon, affect the passenger experience, and even lead to the elevator out of control.

2.2.2. Design of magnetic leakage detection system of steel wire rope

The elevator wire rope through the traction wheel, connected to the heavy device, the car, with the growth of the use time, the wire rope will have different degrees of damage, usually the following two types of damage: LF type and LMA type. LF refers to the local defect-type damage, such as the broken wire and local deformation. LMA type refers to the cross-sectional area loss and damage, such as corrosion, wear, diameter shrinkage, etc., which is characterized by the reduction of the cross-section area of the wire rope. If the wire rope broken wire, corrosion, wear and other faults will inevitably cause the instability of the whole system, if not handled in time, it may even cause the wire rope broken in the process of elevator operation, which poses a major threat to the safety of passengers. It is a very important work to monitor the wire rope, and the destructive magnetic leakage detection method of the wire rope is a relatively novel and practical defect detection method.

As shown in Figure 1, the magnetization characteristic curve of the wire rope under different magnetic field strength.

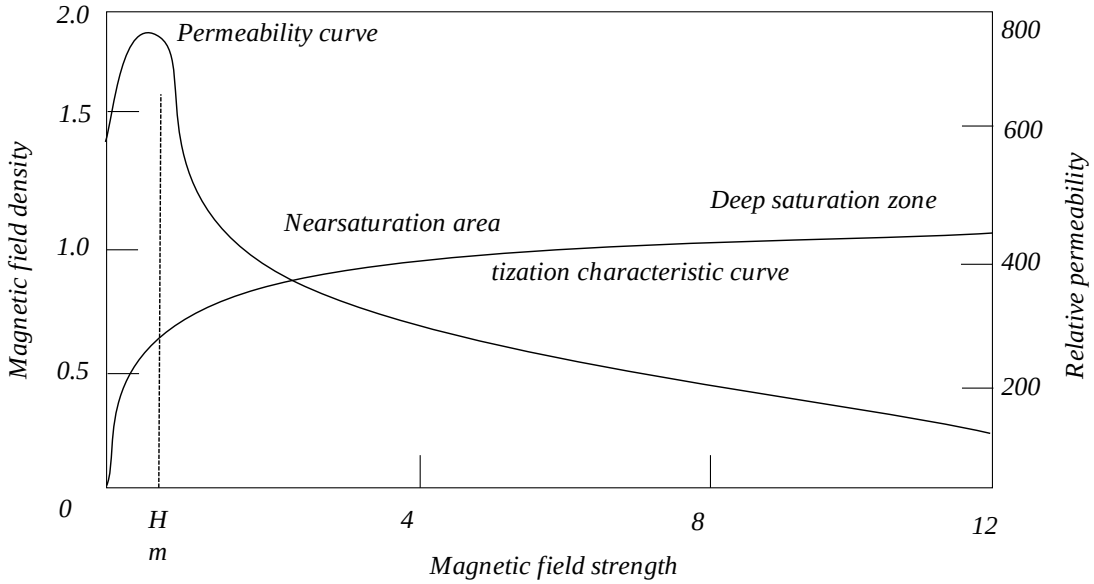

Figure 1 Magnetization property curve

Hall elements have the ability to sense a magnetic field and can convert the magnetic field signal into a voltage signal, a phenomenon called the Hall effect. Hall element is based on the hall effect principle of a detection device composed of matrix conductor sheet material, when the application of the external magnetic field is vertically distributed on the surface of the element, and a constant circuit through both ends of the hall element, element will form charge accumulation to form the hall potential, and the hall potential and magnetic field strength, the current is proportional relationship.

Hall elements are usually processed and applied in the form of integrated circuits, and the constant current source is integrated inside the element. From FIG. 4-4, the integrated Hall elements have three pins, namely power supply VCC 1-, ground 2-GND and voltage output 3-Vout. From the above formula, it is also known that the output voltage is linearly related to the strength of the external magnetic field so the change of the external magnetic field strength can be inferred by detecting the voltage output of the Hall element.

It is composed of an excitation device that can excite the wire rope and a detection element that can be more sensitive to the magnetic field changes. The main purpose of the exciter is to magnetize the wire rope to the saturation state. Only in the saturation state can enough detected magnetic field can be leaked, so that it can be detected by the detection device. The following explains the design criteria from the following aspects: the design of magnetic circuit mode, there are many kinds of exciters, but the appropriate excitation structure should be selected according to the actual measurement environment. The DC excitation has the characteristics of large detection depth, and the magnetic field strength can be adjusted, but at the same time, due to the serious DC excitation loss, so the exciter heat is serious, and the DC power supply is difficult to obtain in real time. The cost of AC excitation is relatively small, and the structure is simpler, but there is also the excitation surface heating phenomenon.

The excitation device with permanent magnet as magnetic source is characterized by light quality, simple structure, small volume and convenient carrying, while the magnetic field strength is fixed and lack of flexibility; the excitation structure can ensure that the wire on the surface of the wire rope is excited to saturation, which can accurately determine the specific location of the wire defect, so it has achieved considerable development. The project is to use a multi-loop permanent magnet magnetic exciter, its structure is shown in Figure 2

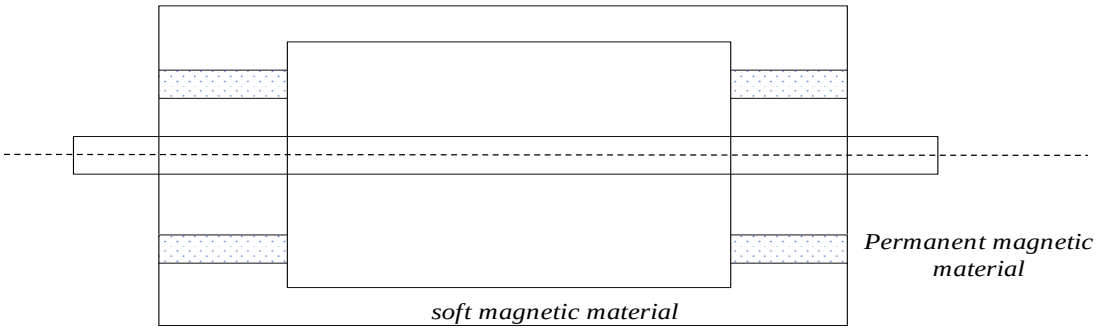

Figure 2 Structural diagram of the excitation device

In figure 2, the magnetic source of the exciter is a permanent magnet material, in the whole excitation circuit, the excitation effect is the inner ring and the rope surface gap δ, its size determines the gap conductivity G δ, which is important for the rope excitation to saturation, assuming that Dmw is equal to the diameter of the rope when the actual area of the tested rope is Sw, its value can be expressed by formula (1)

$$\mathrm{D_{mw}} = \sqrt{\frac{4S_w}{\pi}} \qquad (1)$$

The air gap q can be expressed as

$$\delta = \frac{D_t - D_{\mathrm{mww}}}{2} \qquad (2)$$

$$G_\delta = \frac{\mu_0 I_m \theta}{\mathrm{In}(1+\frac{\delta}{r})} \qquad (3)$$

It can be concluded from the above formula that the size of $\frac{\delta}{r}$ plays a vital role in the permeability of the air gap, and the increase of this value will inevitably lead to the decrease of the gap, which is also the most direct way to improve the excitation effect of excitation materials.

The process of wavelet removal can understand the separation of low frequency and high frequency components in the signal, and can accurately peel off the transient abnormal information hidden in the normal signal, so it has its own unique advantages in retaining the original signal to remove the noise signal.

Before the wavelet transform processing, the choice of wavelet basis function, number of decomposition layers and threshold are first determined. Appropriate wavelet basis function is the key to the accurate operation of wavelet transform, and in order to achieve the accuracy of decomposition, the basis function should have standard orthogonal characteristics, so Db 4 wavelet can be selected in this simulation.

The fault signal of wire rope breaker collected by Hall element is simulated by simulation signal. The specific waveform diagram is shown in Figure 3. As can be seen from the time domain diagram, due to the influence of noise, the prominent fault feature information cannot be found from the time domain waveform due to the influence of noise. In this paper, Db 4 wavelet function is used to analyze and process the simulation

signal.

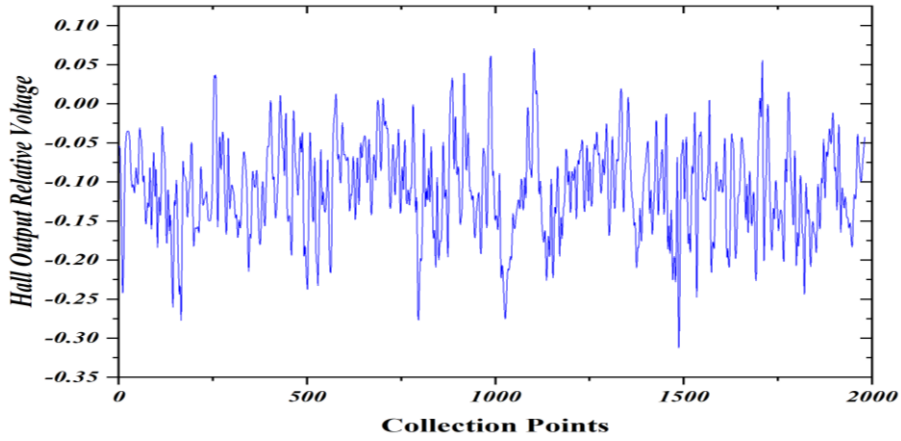

Figure 3 Time-domain wave pattern of the simulation signal

After the first decomposition, As can be found from Figure 4 (1), With an amplitude around the number of sampling points, 1000, But at 1500,1800, The specific fault information cannot be accurately judged, After the second decomposition, The reduction of the amplitude at the above point, There was no significant change in the amplitude at 1000, This also shows that there may be a broken line phenomenon, After breaking it down 3 times, The results are shown in Figure Figure 4 (3), The noise component of the signal has been excluded, Can be clearly seen that there are distinct peaks with troughs at 1000, With no significant changes in the other positions, Finally, we have concluded that, Ffunction at 1000, Inspection should be emphasized.

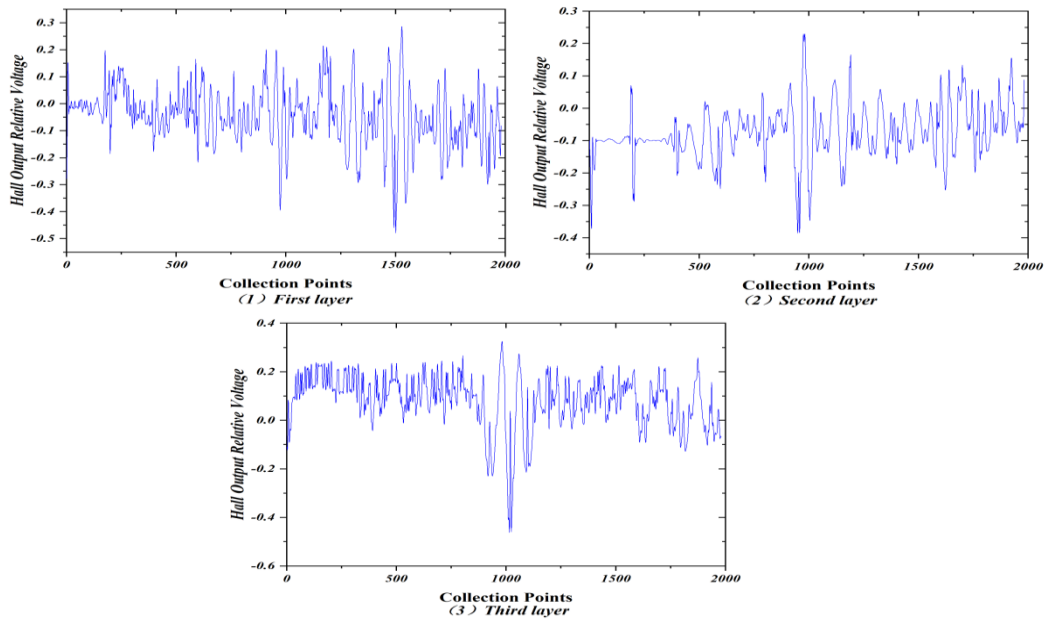

Figure 4 Model diagram of each layer after decomposition of three layers

3. Demand analysis and architecture design of elevator fault monitoring and early warning system

3.1. Overall system architecture design

According to the requirements and based on the modular idea, the system is divided into the following four modules: data acquisition and transmission module, data distribution module, data and business logic processing

module, and result visualization module.

3.2. Data acquisition and transmission module design

1) Selection of transmission technology. Elevator operation signal acquisition has the characteristics of high sampling frequency, large data volume and high real-time acquisition. However, the Ethernet is deployed in a wired way, with simple network access, low deployment cost and its transmission speed, and the processing information volume is huge, which matches the characteristics of high real-time elevator data acquisition and large data volume. Therefore, this paper will use the Ethernet mode for data transmission.

2) Overall scheme design. The system collects the vibration signal data of the elevator running state signal and the xz axis through the sensor. For example, the data of whether the flat layer reaches the station is obtained through the light sensor sensor, the data of whether the car hall is jammed through the light screen sensor on the car door, and the vibration data of the car is obtained through the vibration acceleration sensor. The obtained raw data is extracted from the real-time database after conversion, waiting for the subsequent fault diagnosis and fault warning module call of the distributed processing cluster, so as to conduct elevator operation safety monitoring and real-time monitoring and early warning of car vibration state. After the signal feature value is processed, the human history database will be stored for the analysis of subsequent modules.

3) Acquisition system design. The hardware part of the system acquisition module mainly includes four parts: sensor, CP2104 module (TT serial port to USB interface) elevator control board and wired Ethernet transmission module.

Ethernet based data acquisition of Ethernet includes multiple distributed server terminals and downmachines. The server terminal is used to process the data signals transmitted by Ethernet, and the lower computer is responsible for collection, and the upper computer is responsible for data processing and storage. The upper computer uses TCP / IP protocol to complete the digital signal of the elevator operation data collected by the data transmission sensor between the lower computer and the elevator control board module to transmit the digital signal to the elevator control board module. Connect the router through the network cable and set the corresponding IP address to transfer data with the server cluster.

4) Collect the data content. The main data collected in this system is the elevator operation state data and the car vibration acceleration data. The model of the vibration acceleration sensor selected for this system is EVA-625. Due to the small size of EVA-625 and convenient installation, the vibration acceleration signal in x and 3 directions can be measured simultaneously.

5) Transmission format design. The system directly transmits the data to the local server cluster through the data format set by the sensor. The format mainly consists of five parts: starting code, address code, data flow, end code, and check code.

3.3. Data distribution module design

Real-time elevator flow data has the following characteristics: fast data acquisition speed, many types, large volume. When processing these data, it is necessary to first screen the invalid data segments in the original data, and then distribute the data to a distributed cluster for processing. In order to make the data distribution module have large throughput and distributed expansion, Fink1.8, Kafka2.11Flume1.90 is selected in this paper. The data flow processing engine that builds the cluster. After the elevator operation signal data is collected by the

sensor, it is first transmitted and stored to the local database. Then, Fume will monitor and pull the log files of the local database in real time. Then Kata receives and stores the data flow log files, and finally processes and analyzes the data flow through the Fink cluster.

3.4. Results for visualization module design

Architectural design. Compared with C / S architecture, B / S architecture has good systematic scalability and can add new functions according to user needs. In the actual production, due to B / S, the Web technology of the structure has been gradually developed and improved, and the number of clients developed on the browser has also gradually increased. The system provides the relevant data interface in the back-end service processing module, and the decoupling between the front-end and the back-end reduces the dependence on the front-end function, and facilitates the reuse and maintenance in the later stage. The front end sends the request to UR through HTTP to obtain the back-end resources. The back end sends the data from the front end back in JSON format, and the front end parses the data into JavaScript objects, and enders and displays the page considering the convenience and aesthetics of interacting with users. Figure 3 shows the overall architecture of the front-and rear-end separation of the typical elevator fault monitoring and early warning system based on the Internet of Things,

2) Visual module function design. Based on the idea of modularity, the system is divided into five functional modules, namely, the elevator geographical location visualization module, the elevator data management module, the relevant unit management module, the fault monitoring module of the elevator control system and the fault warning module of the elevator car system.

3) Design of the database. The system stores the typical fault monitoring and diagnosis information, the information of elevator fault warning and the information of elevator related units, and according to the analysis establishes the E-R model of the relationship between the tables in the database. To store the system data through the database, one is to facilitate the system data management, the other is to meet the traceability of the data and the high efficiency of the query analysis.

4. Conclusion

With the rapid rise of the number of elevators in China, the connection between elevators and daily production and life is more and more close. How to ensure the normal operation of elevators and timely diagnosis and early warning of faults has become the focus of the government and relevant scholars. At the same time, the rise of the Internet of Things technology has brought advanced intelligent perception technology, so the number and real-time elevator operation data that can be collected have been greatly improved, and the variety is becoming more and more diverse. In this context, this paper monitors and gives early warning to the corresponding faults in the main components of the traction elevator (control system, mechanical system), and visually displays the monitoring and early warning results. The main research contents are as follows:

(1) This paper analyzes the main characteristics of the broken wire defects from the basic type of wire rope defects.

(2) The basic principle of magnetic leakage detection and the basic design idea of the excitation device are expounded. After the wire rope is excited to saturation, there will be a magnetic field leakage at the broken wire position, and then the specific location of the broken wire defect can be detected through the magnetic

sensitivity characteristics of the Hall element. Considering the actual signal in the process of acquisition is often affected by the surrounding environment noise components, take the wavelet transform of signal processing method to dry the collected signal, by setting the threshold selection waveform containing characteristic information for analysis, so as to accurately determine the location of wire defects specific information.

(3) Design an elevator fault detection and early warning system. The system collects the elevator car vibration acceleration signal through sensors and uses Ethernet transmission to build a cluster data flow processing engine using Fume, Kafka and Flink to aggregate and distribute the data and store it in MySOL, database.

(4) Based on the InteliJ IDEA development tool, the visual interface of the system is built to realize the real-time monitoring, fault warning and other functions of the elevator operation, providing the basis for the fault diagnosis and preventive maintenance of the elevator.

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