

Research Article

Robot Remote Monitoring and Fault Diagnosis Based on Industrial Internet of Things

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In order to realize the remote monitoring of robots, a remote monitoring platform for industrial robots is designed based on the browser/server (B/S) architecture. Through this platform, users can check the real-time running parameters and running status of robots in any place with network. The Industrial Internet of Things scheme of remote platform system is proposed to adopt three-layer structure: on-site “perception layer,” information “transmission layer,” and remote data service center. The data acquisition controller of the whole system and the core part of the sensor layer is designed. The data acquisition controller adopts the embedded platform design, which can be directly connected with the control cabinet of the industrial robot to read the running status of the robot in real time, monitor the alarm and warning data, and it is transmitted to the local server and remote service center in the first time. At the same time, the robot can receive the control command of the server for remote debugging and fault maintenance. Aiming at the data model of industrial machinery parts, a fault prediction method based on BP neural network algorithm is proposed. According to the needs of the target algorithm and the analysis of the measurement results, an attempt is made to obtain a more feasible fault diagnosis and early warning method. Through the remote monitoring system, fault early warning and corresponding troubleshooting methods are realized.

1. Introduction

As more and more industrial robots are applied to all aspects of national production, the demand for remote monitoring and diagnosis of industrial robots is becoming more and more urgent. Industrial robot is an integration of many advanced technologies and high-tech equipment such as mechatronics, mechanical engineering, power electronics, sensor technology, and computer technology [1]. The daily maintenance cost of industrial robots is high, and it also has high requirements for the technical level of daily maintenance personnel. Especially when the robot fails, it is often necessary to contact the robot manufacturer to send professional maintenance personnel to the site for diagnosis and maintenance. The shutdown and production phenomena caused by routine maintenance tasks and unavoidable failures of user enterprises will bring huge economic losses to user enterprises. Serious equipment failures may even pose a threat to the personal safety of nearby workers. In

addition, when robot manufacturers provide robot maintenance services, maintenance technicians cannot know the detailed operation data of the faulty robot before and after the failure, which may greatly prolong the diagnosis and maintenance period of the robot and further increase the loss of users and enterprises.

The remote monitoring and diagnosis system of industrial robots can monitor the running status of industrial robots in real time and prompt maintenance personnel for equipment maintenance when abnormal status of robots is detected, which can effectively avoid the occurrence of some faults. After a fault occurs, the industrial robot remote monitoring and diagnosis system can provide the robot manufacturer with detailed operation data before and after the fault occurs at the first time, assist maintenance experts to provide remote diagnosis services, greatly reduce the diagnosis and maintenance cycle of the robot, and reduce the loss of users and enterprises. After a specific robot diagnosis model is configured, the system can also provide some

online fault diagnosis services. It can be said that the remote monitoring and diagnosis system of industrial robots can guarantee the safe, stable, and efficient work of industrial robots and is of great significance to the transformation of manufacturing industry to automation and intelligence.

With the development and progress of computer technology and network technology, the popularization and improvement of public communication network platforms, especially the popularization and application of Internet of Things technology, an online remote monitoring, diagnosis, and service system based on robot network characteristics has been established. The challenge of how to build an efficient service network bridge between robot manufacturing enterprises and application enterprises lies in front of leading domestic robot manufacturing enterprises. Based on the technical standards of the Internet of Things, system architecture, communication protocols, and the key technologies of the remote monitoring, diagnosis and service system of the Internet of Things robot, the construction of a remote monitoring, diagnosis and service system for the Internet of Things robot is a necessary measure to solve the above problems. Using the remote service system, robot service providers can greatly reduce the number of on-site services and maintenance costs and improve the benefits of service providers. On the other hand, robot user enterprises can reduce the average failure time of robots and improve enterprise productivity. At the same time, the remote diagnosis and analysis system can also predict the potential faults of the user enterprise robot to the maximum extent and reduce the incidence of faults.

2. Related Work

The Industrial Internet of Things (IIoT) is applied to various links of industrial production and industrial management using intelligent terminals with perceptive ability, ubiquitous mobile computing mode, ubiquitous mobile communication network, and other technologies. The Industrial Internet of Things realizes “intelligent industry” by improving the efficiency of manufacturing, reducing labor costs, ensuring product quality, and reducing external pollution [2, 3]. At present, the system and architecture of the Industrial Internet of Things are still different in the industry, but generally speaking, it is mainly divided into the perception layer, transmission layer, and application layer. The main difference between the Industrial Internet of Things and the Internet of Things technology application in other industries lies in that the Industrial Internet of Things is usually used in a relatively limited factory environment. Therefore, the communication process of the Industrial Internet of Things is often short-range and requires real-time transmission and high reliability [4]. The requirements for the network transport layer are as follows: (1) accurate time synchronization; (2) communication accuracy; and (3) strong adaptability to the factory production environment. Since entering the 21st century, with the progress and development of computer science, sensor technology, embedded technology, and network communication technology, the research of remote monitoring system

supported by these key technologies has gradually become a research hotspot. The mature application of remote monitoring system is undoubtedly in intelligent home, intelligent agriculture, medical, and other industries [5, 6]. However, in industry, the remote monitoring system is not as widely used as intelligent home and intelligent agriculture.

With the rapid development of intelligent industrial technology, various production equipment will also have new remote monitoring application requirements, and the research and development of remote monitoring systems have also encountered unprecedented historical development opportunities. Due to the emergence of big data processing and cloud platform technology, the application of equipment monitoring system should no longer be limited to the simple monitoring level but should become an effective means of supervision and management resources. The future development direction of remote monitoring technology presents a trend of integration, productization, intelligence, and specialization [7, 8]. The present remote monitoring system can have the following functions: production data detection, management, and fault diagnosis; summarize and analyze the detected real-time information and instructions given by operators in the production process and store them as real-time information and historical data, respectively; real-time comparison is made between the information obtained by the monitoring equipment and the standard dataset in advance by the system, and the failure and danger warnings [9] are issued and displayed for the equipment that does not meet the requirements.

The fault diagnosis of industrial robots is very important for the efficient operation of robots. Many scholars have carried out extensive and in-depth research on this technology. The currently used industrial robots can be mainly divided into fault diagnosis based on model analysis, fault diagnosis based on signal processing, and fault diagnosis based on diagnostic knowledge [10, 11]. The first two methods are usually used for fault diagnosis of ordinary robots, and the third method is mainly used for fault diagnosis of robot components. The key point of fault diagnosis based on model analysis is to establish an accurate mathematical model of the object to be diagnosed, input the same signal to the controller of the object to be diagnosed and the corresponding mathematical model, and compare the observable parameters of the object to be diagnosed with the corresponding information obtained by the model to obtain a residual index. The residual index is input into the decision system as the fault feature to diagnose the fault. Fault diagnosis based on model analysis can be further divided into state estimation method [12, 13], parameter estimation method [4], and equivalent space method [14] according to the different generation modes of residuals. The state estimation method uses observer and filter to diagnose faults. Parameter estimation method is to infer the change of physical parameters in the actual system by detecting the change of relevant parameters of the model, so as to diagnose the fault of the system. The equivalent space method is to establish an equivalent mathematical model of the actual system and realize fault detection and separation by

comparing the model with the output of the system. The fault diagnosis method based on model analysis is convenient and fast. The disadvantage is that the robot is a complex nonlinear system, and it is very difficult to establish an accurate mathematical model, which also restricts the use of this method. The operation of the robot is accompanied by the generation of various signals, and the signals of the robot will change correspondingly after the occurrence of faults. Through signal analysis and feature extraction of relevant signals of the robot, fault diagnosis of the system can be realized by combining with certain prior knowledge [15]. There are many methods of signal analysis, which can probably be divided into two categories: one is the traditional method, including amplitude analysis, Fourier transform, and correlation analysis; the other refers to modern methods, including Wigner–Ville analysis [15], spectral analysis, wavelet analysis, Hilbert–Huang transform, and so on [16, 17]. The traditional method can only be used for stationary signal analysis, but the modern method can also get good results for nonstationary signal analysis. The characteristic values such as variance, amplitude, frequency, and kurtosis can be extracted through signal analysis of robot-related signals. As long as the relationship between characteristic values and faults is found, the faults of robots can be diagnosed. Knowledge-based fault diagnosis methods [18, 19] can be subdivided into expert system-based fault diagnosis methods, fault model-based fault diagnosis methods, and neural network-based fault diagnosis methods. The fault diagnosis method based on the expert system needs to collect some data of the robot, synthesize the empirical rules in the knowledge base for inference, and quickly determine the faults of the robot [20]. The expert system is composed of knowledge base, learning system, and reasoning mechanism. The performance of the system depends on the correctness of the knowledge system. Therefore, updating knowledge base frequently can improve the accuracy of diagnosis. The fault diagnosis method based on the fault model mainly uses the method of constructing a fault tree, and the fault location can be determined by analyzing the fault tree step by step from the state of the system fault [21]. The neural network-based fault diagnosis method uses fault instances and diagnosis experience to train the neural network [22], so that the neural network can learn the mapping relationship between faults and symptoms, so as to realize the diagnosis of robot faults through some symptoms of the robot.

For the failure of robot actuator, the following studies were mainly carried out. A data-driven method was proposed to detect the wear state of industrial robot joint motion pair, and the wear degree of joint motion pair was explained by comparing monitoring data and nominal data using KDE and Kullback–Leibler distance [22]. The vibration and noise of robot joints were analyzed by neural network to achieve fault prediction, and the RBNN was better than SMNN in fault prediction [23]. Discrete wavelet transform was used to preprocess vibration signals of each joint of the robot, and then artificial neural network was used to classify faults [24]. In the discrete time domain, the observation system was constructed to output the nonlinear

state observer of joint position and velocity, which increased the linear feedback and delay nonlinear compensation effect of the observation error [25] and generated residual errors of sensor and actuator fault detection from the observation error, so as to carry out fault diagnosis of the robot joint. An intelligent state monitoring system based on vibration signal analysis was used to monitor the gap faults of industrial robot joints [26]. They used discrete wavelet transform to analyze vibration signals and extract significant features related to faults and used artificial neural network (ANN) to classify faults.

3. Overall Design of Robot Remote Monitoring Based on Industrial Internet of Things

3.1. Overall Approach to the Industrial Internet of Things.

The remote monitoring system is based on the Industrial Internet of Things, and the system mainly includes video monitoring, positioning monitoring, working parameter monitoring, and other functions. The robot remote monitoring system collects the robot field operation information (such as GPS positioning data, on-site video information, and robot working parameter information) through the vehicle-mounted terminal and then uses the mobile Internet to connect to the Internet to send the processed data back to the data control center. The data control center uses server-side software to receive data and store them in the database. The client displays the data from the remote end in real time. The industrial Internet of Things remote monitoring system adopts the network remote data distribution method, which is a client/server mode. The vehicle terminal can be regarded as a terminal, the central host can be used as a server, and each server can be used as multiple terminals. Running on the Internet based on the TCP/IP network protocol, users can realize upper and lower computers and multilevel networks. Through GIS technology and C/S technology, real-time positioning of robots, analysis, and statistics of robot operation data can be realized, and scientific predictions and guidance decisions can be provided for agricultural production. The system transmits the orbit data back to the monitoring center by means of GPS positioning and mobile Internet. The system composition is shown in Figure 1.

Industrial robot is a complex nonlinear dynamic system, which is made up of a series of joints and links. When the robot is running, its speed, acceleration, torque, and other parameters are mutually compatible. In order to analyze the dynamic characteristics of robot, a lot of research has been done and the Newton–Euler method has been put forward. The Newton–Euler method is based on two basic mechanical relations, the first is Newton’s equation of the translational motion of the center of mass, and the second is Euler’s equation of the rotational motion of the link.

$$\begin{aligned} T_x &= m\alpha_x, \\ \tau_x &= T_x\alpha + \omega \times T_x. \end{aligned} \quad (1)$$

For a particular link I , Newton’s equation can be written as

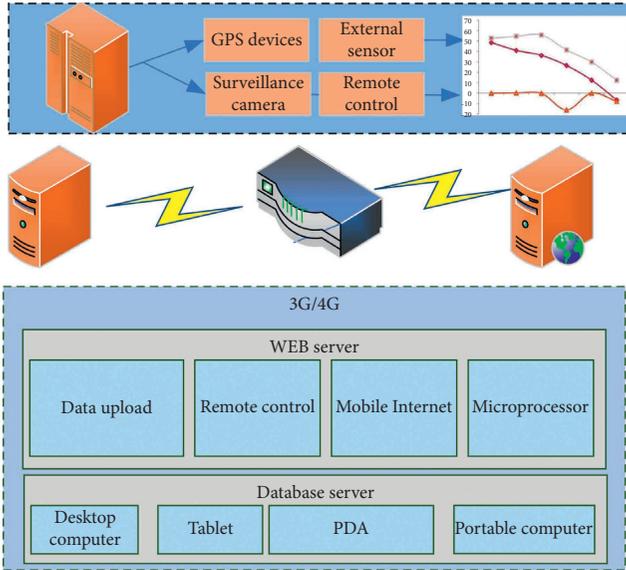


FIGURE 1: Robot remote monitoring composition of the Industrial Internet of Things.

$$\lambda_I + T_{I-1} \times f - f_{i+1} \times T_{h,i,r} = T_I. \quad (2)$$

3.2. Overall System Architecture. The whole industrial robot remote monitoring and diagnosis system is divided into three layers, which are data acquisition and control system of field “perception layer,” information network system of “transmission layer,” and remote monitoring and diagnosis service system of robot production enterprise. The schematic diagram of the whole system is shown in Figure 2.

The “cognitive layer device” is directly attached to the industrial robot, and the “cognitive layer” sensing data acquisition system includes the auxiliary wireless sensors installed on the robot and the key components of the data acquisition controller. They are responsible for robot operation data, provide data to the robot, and have local and remote data transmission capabilities.

The remote monitoring and diagnosis service platform software is the background data processing center of the whole system, which is responsible for connecting all the robot data acquisition controllers with the local monitoring platform software of the user enterprises. The remote monitoring and diagnosis service platform is a web data publishing software designed based on B/S mode and installed on the web server. In this way, service engineers can log in to the web browser anytime and anywhere to remotely check the running status of enterprise robots of each customer. The remote monitoring and diagnosis service platform is equipped with remote data collection, remote monitoring, remote commissioning, remote diagnosis, remote fault prediction, remote data analysis, and other functional modules. On the one hand, the remote platform is connected to the data acquisition controller (wired Ethernet or DTU (data terminal unit)) for remote monitoring and commissioning. On the other hand, the remote platform communicates with the

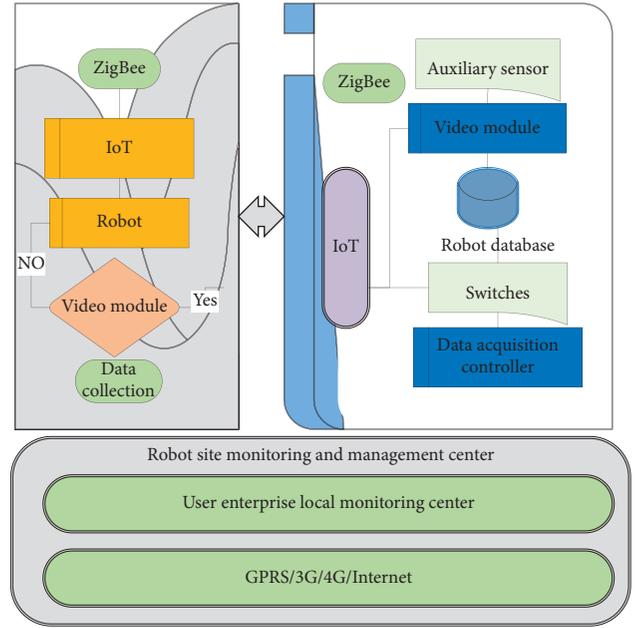


FIGURE 2: On-site monitoring and analysis service system.

local monitoring platform at the same time, reads the configuration information of the robot and data acquisition controller as well as the historical state data in the local database, and performs remote data analysis and processing.

An industrial IoT wireless video surveillance system is installed on the working robot. When the operation robot is working in the field, through the mobile Internet remote monitoring center, the robot management can monitor the current operation of the robot and control the current operation of the robot in real time, such as whether the operation robot is working, whether the robot has operation quality, and so on. Schematic diagram of realization principle of the video monitoring system and technical route of the video monitoring system are shown in Figure 3. First, the camera of the working robot collects images (multichannel video signal acquisition, at least 2 channels of signals), and the collected images are transmitted to the video acquisition module of the on-board processor, and then the processor compresses the images. It is transmitted to the 3G/4G network through the wireless network transmission module and then entered the Internet data server, and the client application program receives the data from the server and decodes it.

Video monitoring network is a communication network based on TCP/IP. The core protocol of the transport layer is TCP/UDP. The selection of network video transmission protocol is also concentrated on the transport layer and is based on TCP/UDP. In order to solve the problems of jitter, delay, and packet loss in the process of real-time data transmission in the network environment, the IETF's AVT (Advance Vehicle Technology) working group has formulated relevant real-time video transmission protocols, namely, RTP (real Time Protocol), RTCP (real Time Control Protocol), and RTSP (real Time Streaming Protocol). It is designed to provide powerful guarantee for real-time streaming media transmission in TCP/IP network.

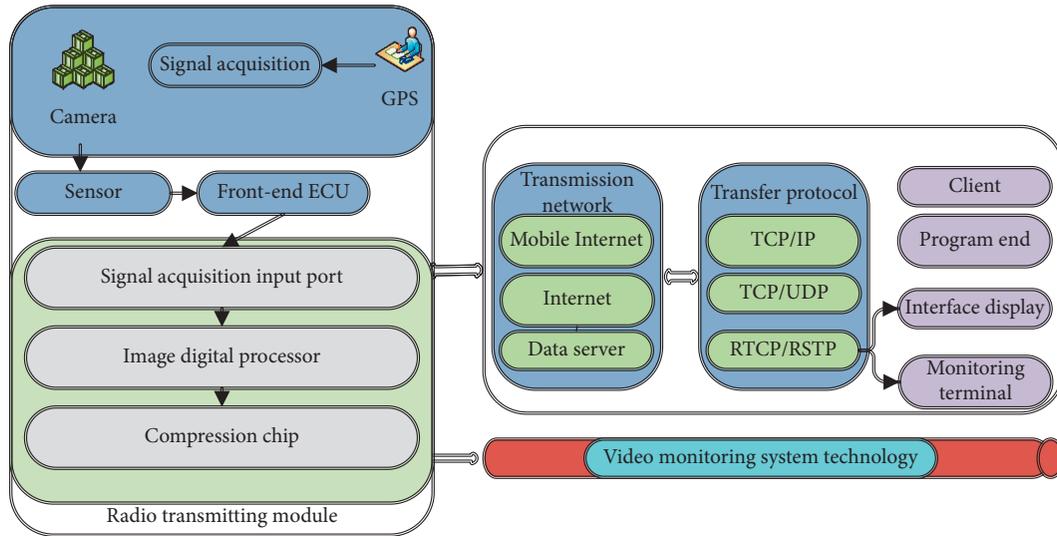


FIGURE 3: Technical route of video monitoring system.

4. Remote Monitoring Fault Diagnosis Method

Combined with the important components of industrial robots and the requirements of monitoring system data management, the industrial machine monitoring system can be designed according to the function of solid module, which can be divided into five entities, including basic equipment information, servo motor, servo driver, driver, and alarm information. The relational structure of the basic information table of industrial robots is shown in Table 1.

The relational structure of industrial robot driver information table is shown in Table 2.

The state quantity of industrial robot is periodically obtained by the state monitoring system module, including the state quantity to be obtained from the controller including axis information (current value, position instruction, instruction value, encoder value, each axis speed, motor speed, deviation value, current value, etc.), each I/O port signal state, and step detailed information state. In the teaching state, the teaching speed grade and the current operation coordinate system are obtained; in the reproduction state, the reproduction speed grade is obtained, and various state quantities obtained are periodically stored. The fault diagnosis and early warning module diagnoses various state quantities, and when the state is detected to be abnormal, it will enter the fault processing module. Users can query the amount of state they want to display on the mobile terminal, then access the data storage module, process the relevant data information regularly, and present the amount of state information that users need to see on the mobile terminal.

The fault early warning diagnosis method based on analysis model, through theoretical research and analysis or a lot of experimental analysis, excavates the internal relationship between the corresponding diagnostic equipment object and fault information and establishes the analysis model of the equipment to be diagnosed. Then, through the analysis model, the expected state and actual

TABLE 1: Basic information of industrial robot.

Attribute	Variable name	Data type	Maximum length
ID	Robot ID	Int	20
Name	Name	Int	30
State	Status	Char	10
Model	Model	Char	30
Serial number	Serial number	Char	30

running state of the diagnosed device in normal running state are analyzed, and the parameter residuals in normal running and actual running of the diagnosed device are used as the main fault information for fault warning and diagnosis. The specific methods include equivalent space method, parameter estimation method, and state estimation method. The fault early warning diagnosis method based on signal processing has some difficult uncertainty between the characteristics of the detected parameter signal and the fault of the equipment, which may be missed or misdiagnosed. In addition, the fault warning and diagnosis method based on signal processing takes many known detection parameters signal characteristics as the standard, which is not easy to carry for different types of equipment. Industrial robots come in many forms and types. At the same time, the load of each joint axis changes constantly during the working process, which affects the detection parameters. In addition, in order to realize joint fault alarm and location of industrial robots, it is usually necessary to extract the characteristics of detection parameter signals of each joint axis of industrial robots. For compact industrial robots, the distance between joint axes is relatively close, and joint axes usually work together, which will lead to the interaction of detection parameter signals between joints and bring a lot of trouble to the signal-to-noise separation and feature extraction of digital signals. Therefore, for industrial robots, the above problems not only affect the accuracy of fault warning diagnosis but also bring difficulties to the location tracking of specific fault joints.

TABLE 2: Industrial robot driver information.

Attribute	Variable name	Data type	Maximum length
ID of the industrial robot to which it belongs	Robot ID	Int	30
Serial number	Code	Int	20
State	S Tatus	Char	10
Model	Model	Char	20
Serial number	Serial num	Char	30
Produce time	Time	Char	20
Input voltage	Input voltage	Char	20
Output voltage	Output voltage	Char	10
Number of input phase	Input phase	Char	10
Output phase number	Out phase	Char	10
Rated input current	Rated input current	Char	20
Rated output current	Rated output current	Char	20
Input frequency	Input frequency	Char	20
Output frequency	Output frequency	Char	20

Prediction is the use of searchable historical data to estimate the value of data T not produced in the future. Given the time series (x) , we know that the historical data can predict the future value of $n + M + K$ ($k > 0$):

$$T_{N+M+K} = f(T_N, T_{N+1}, \dots, T_{N+M}). \quad (3)$$

We choose to use the mature BP (backpropagation) neural network to build the model. BP neural network is the most commonly used feedforward neural network, which does not need to understand the mathematical equation of the input and output model, but constantly adjusts and optimizes the weight parameters of each node of the network through the change of a large number of input and output data, so as to improve its own network. The most commonly used learning rule of the network is the fastest descent method, which uses backpropagation to continuously adjust the weights and thresholds of each node in the network to minimize the sum of the squares of error between the network output and the expected output.

Before the neural network training, the data are first scaled, also known as normalization, to transform the data into $[0, L]$ interval, and the transformation formula is as follows:

$$T_N = \frac{T_N - T_{\min}}{T_{\max} - T_{\min}}. \quad (4)$$

Some normalized data are shown in Table 3. For industrial remote monitoring and fault diagnosis of network robots, some normalized data are shown in Table 3, which are obtained based on monitoring formulas (1)–(4).

Firstly, the weight between the hidden layer and the output layer is adjusted, and the fastest descent method is used to calculate the error gradient on the weight and then adjust in the opposite direction.

$$\lambda_I = F(\mu_I(N)) \sum_{j=1}^M \mu_j \omega_{Ij}. \quad (5)$$

5. Example Verification

The basic parameter setting of BP neural network training in this paper is as follows: a total of 140 groups of training data and 40 groups of test data are selected in this paper. The hidden layer excitation function is RELu, the training times are 600 times, the training goal is 0.01, and the Learning_rate is 0.003. The important parameters affecting the network output capacity include hidden layer number, output excitation function, and training function. Sigmoid is used in the output excitation function, and train function is used to train the network. The validation set of Validation_samples was used to evaluate the trained network model. Below are two diagrams without algorithm optimization. Figure 4 shows the BP neural network training diagram, and Figure 5 shows the error variation diagram.

The optimized BP neural network model was built by using the above parameters to predict the mean square error of test data of 0.0023, which was better than the desired target of 0.01. It can be seen that the design of fault prediction effect in this paper has preliminarily reached the requirements of actual prediction.

Mechanical collision simulation was carried out on the robot simulation model, and it took a total of 10 seconds to control the robot to move from the position shown in Figure 6 to the position shown in Figure 7. Joint 1 to joint 6 of the robot are, respectively, from the base to the end of the manipulator.

Two commonly used signals, block and Doppler, were used to simulate the noise reduction of CEEMDAN and wavelet packet threshold combined with the denoising method. The mutation characteristics of block signals and the random characteristics of Doppler can simulate the nonlinear and nonstationary characteristics of bearing vibration signals to a large extent. Figure 8 shows the waveform of block signal, white noise, and block signal with noise.

TABLE 3: Data of gear box at work (partial data).

State	Vibration 1	Vibration 2	Vibration 3	Vibration 4	Torque	Vibration 5	Vibration 6	Vibration 7
Normal	0.154	0.772	0.854	0.723	0.968	0.745	0.653	0.611
	0.163	0.713	0.616	0.766	0.987	0.695	0.838	0.764
	0.154	0.764	0.904	0.721	0.99	0.782	0.741	0.813
	0.221	0.804	0.661	0.703	0.981	0.763	0.633	0.751
	0.283	0.744	0.742	0.734	0.955	0.703	0.825	0.731
Fault	0.078	0.742	0.734	0.728	0.722	0.726	0.743	0.686
	0.081	0.748	0.746	0.743	0.724	0.737	0.762	0.732
	0.071	0.741	0.768	0.745	0.732	0.713	0.714	0.743
	0.072	0.742	0.723	0.735	0.723	0.742	0.702	0.705
	0.075	0.741	0.745	0.753	0.747	0.734	0.768	0.716

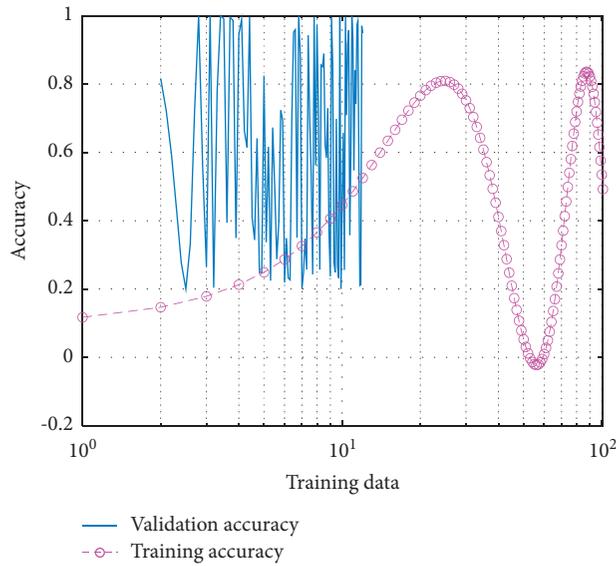


FIGURE 4: BP neural network training process diagram.

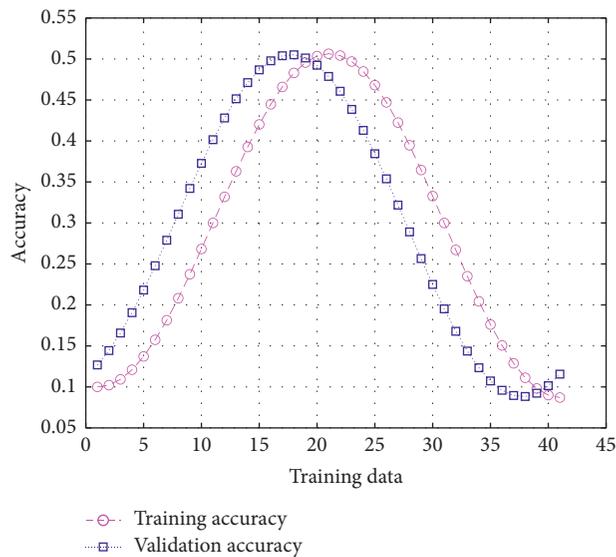


FIGURE 5: Error variation diagram.

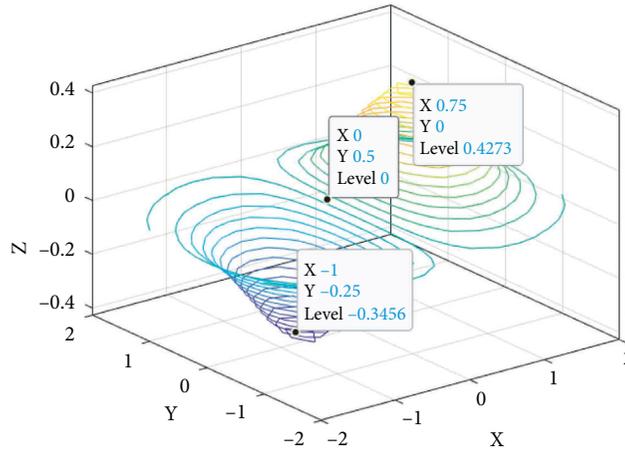


FIGURE 6: Initial position of the robot.

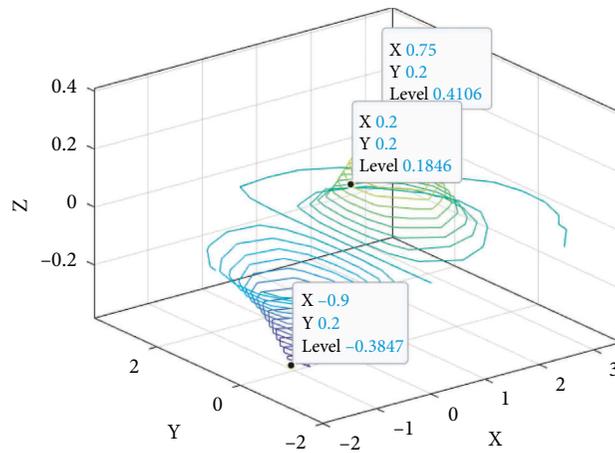


FIGURE 7: Final position of the robot.

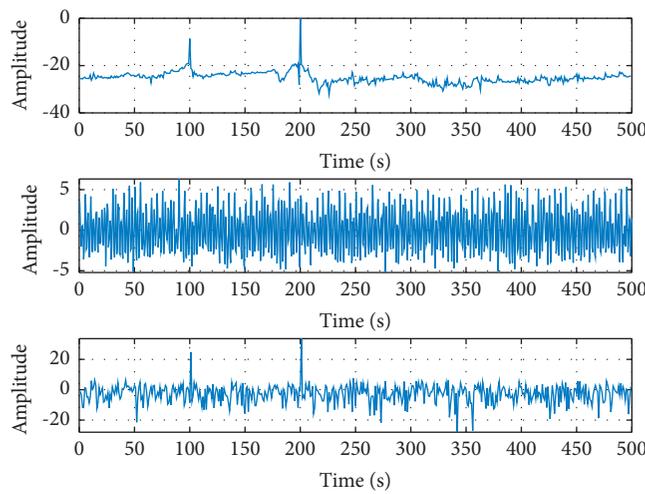


FIGURE 8: Block signal, white noise, and block signal with noise.

6. Conclusion

Wireless video surveillance equipment is installed in the large robot, and the wireless video surveillance equipment sends the robot work to the management command and dispatch center through wireless digital transmission equipment. Managers can monitor the current operation of the robot and control the current operation of the robot in real time. The realization result included video image collection, video image transmission, video image display, and video image monitoring system application. The key technologies of Android platform, wireless communication, data acquisition, and artificial neural network algorithm in the monitoring and early warning system are studied. In the process of system design, the uninterrupted communication technology based on TCP/IP protocol is introduced, which realizes the communication application that the Android platform can obtain data for a long time, and provides the function of data dependence for fault warning, which makes the system more stable and practical. The remote monitoring system established in this paper has insufficient visibility, so it focuses on solving the visibility problem in the process of information configuration, such as adding animation demonstration and other means, so as to make the monitoring means more diverse.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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