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Research Article

Study and Application of an Elevator Failure Monitoring System Based on the Internet of Things Technology

Wei Yao,[1] **Vishal Jagota**,[2] **Rakesh Kumar**,[3] **Danish Ather**,[4] **Vishal Jain**,[5] **Suhail Javed Quraishi**,[6] **and Jonathan Osei-Owusu**[7]

[1]*Jiangsu Vocational College of Electronics and Information, Huai'an, Jiangsu 223005, China*
[2]*Madanapalle Institute of Technology and Science, Madanapalle, India*
[3]*Department of Computer Engineering and Applications, GLA University, Mathura, India*
[4]*Department of IT and Engineering, Amity University in Tashkent, Uzbekistan*
[5]*Department of Computer Science and Engineering, School of Engineering and Technology, Sharda University, Greater Noida, Uttar Pradesh, India*
[6]*CSE Department, Chandigarh University, Mohali, Punjab, India*
[7]*Department of Biological, Physical and Mathematical Sciences, University of Environment and Sustainable Development, Somanya, Ghana*

Correspondence should be addressed to Wei Yao; yaowei788@163.com and Jonathan Osei-Owusu; josei-owusu@uesd.edu.gh

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To prevent the occurrence of elevator safety accidents, in this study, an Internet of things-based elevator failure monitoring system is investigated. First, it introduces the Internet of things technology, preprocesses the relevant data, and extracts the features of the elevator operation data continuously collected by the elevator sensors. The objective of this paper is to study the application of IoT in elevators. *Method*. The Relief-F algorithm is used to evaluate the potential influencing factors. The results show that, as the batch size increases, the accuracy rate will gradually increase, but after more than 20, the accuracy rate will decrease. When the batch size is 20, the training result is the best. It can be seen that, as the time step increases, the accuracy of the prediction will be significantly improved. When the time step is 24, the prediction accuracy is the highest; after 24, the prediction rate will decline. In the diagram of the influence of learning rate on the model, the blue line indicates that the learning rate is 1.0, the red line is 0.1, and the black line is 0.01. With the increase of the iteration times, the effect is the best when the learning rate is 0.1. This system has high research value and broad application prospects and can make up for the current lack of monitoring in the elevator industry.

1. Introduction

With the rise in global population in recent years, the process of urbanization has been accelerating and people's demand for convenient life has increased, making the elevator more and more widely used. From residential to the commercial lives, use of elevator is widely seen. Hence, there is an urgency to develop a system that has high research value as well as has application aspects. Versatile design along with the safety parameters is much needed in the industry [1–3]. China's annual elevator demand still maintains a 5%–7% growth, mainly due to the abolition and renewal of old elevators, which cannot meet the requirements of safety, energy saving, environmental protection, secondary technical supervision, and new regulations and policies [4]. With the increase in the number of elevators, the elimination and renewal of old elevators is also imminent. This will undoubtedly increase the workload of maintenance personnel and may lead to missed inspections and false inspections of some elevators; therefore, neither the property nor the public can understand the elevator operation and potential risks in time [5]. In the sector, innovative design is crucial, as is taking safety precautions into account. The rules governing security come first. The elevator's capacity to

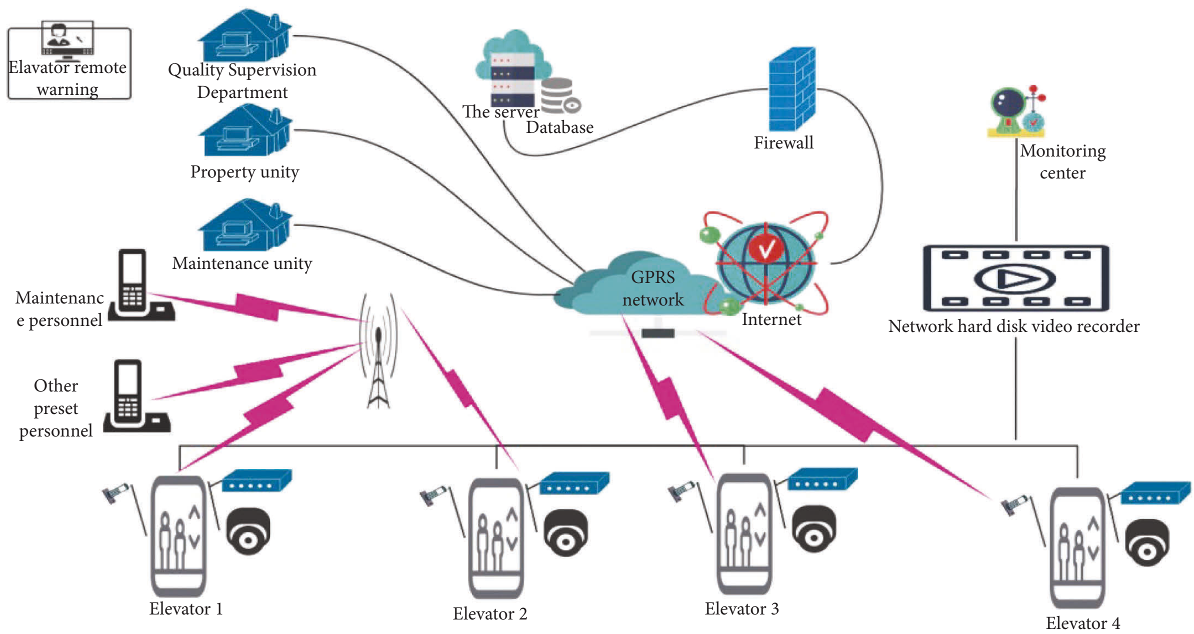

Figure 1: Elevator fault monitoring system based on Internet of things technology.

support several passengers' combined weight must be ensured at all costs. After installation, you must do a maximum efficiency test and note this in the elevator so that people are aware of how much it is capable of carrying. Additionally, alarm systems for elevators are required in case of emergencies or malfunctions. Additionally, you must do safety inspections on the location where the elevator will be put to make sure it is sturdy enough. To prevent any mishaps from happening, it is also crucial to make sure that only authorized individuals and maintenance staff have access to the elevator equipment. According to the American Council for an Energy-Efficient Economy (ACEEE), using more energy-efficient elevators might significantly save buildings' operational expenses. At present, elevators are limited to the basic monitoring of the car, such as video surveillance and regular inspections by maintenance personnel. These are subjective factors, which cannot objectively reflect the aging degree and failure rate of the elevator from the data aspect [6]. It combines the advantageous technologies such as television audio and videotape technology and Internet of things technology to realize the supervision functions such as elevator state early warning. The system diagram is shown in Figure 1 [7]. In order to realize the supervisory features, such as the elevator state early warning, an elevator fault monitoring system based on the Internet of things technology is proposed in this paper. An elevator monitoring platform based on the Internet of things is built; it combines the beneficial technologies such as television audio and video camera technology and Internet of things technology, so as to enhance the property management company's capacity to manage elevators using pertinent communication and Internet of things technologies. Experiments reveal that, in addition to the elevator's current condition, the status of its prior stage also affects the likelihood that it would fail. Using artificial intelligence (AI), IoT-enabled elevators may successfully transport people and commodities vertically. It is the process of modernizing the elevator's critical components in order to accept new technology and performance [8, 9]. IoT is revolutionizing elevators in addition to allowing users to ascend and descend buildings efficiently and comfortably. IoT-enabled elevators could successfully transport people and goods vertically by using machine learning (AI). It involves updating the elevator's essential parts to accommodate new technologies and efficiency. In addition to enabling customers to move effectively and comfortably up and down buildings, IoT is revolutionizing the elevator industry. Today's smart elevators gather data, analyze traffic patterns, and could even serve as effective marketing tools. The IoT solutions for elevators from Robustel are made to help equipment manufacturers and maintenance businesses correctly control the operation of their machinery.

Smart elevators of today collect data, analyze traffic patterns, and may even be used as useful marketing tools [10, 11]. Robustel's elevator IoT solutions are designed to aid manufacturers and maintenance companies in properly controlling the operation of their equipment. Connecting one's Robustel equipment towards the Robustel Cloud Management System (RCMS) enables simple network and connection, including provisioning management [12, 13].

2. Literature Review

Kuang et al. researched the use of the Hi3515 high-performance processor in the elevator monitoring system as a solution to this issue. Linux kernel, which was to realize the tailoring of Linux functions, the realization of each functional module, the development method of embedded applications, and the writing of the driver based on the chip,

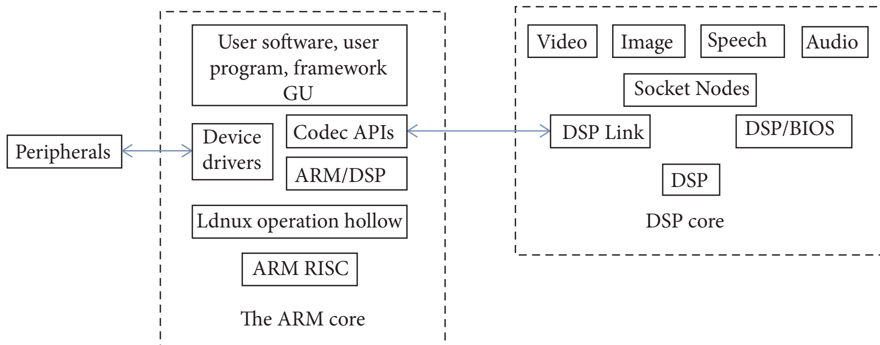

Figure 2: Technical framework diagram of Da Vinci software.

were studied by the authors [14]. Feng et al. studied the logic function of the whole system and how to obtain the multimedia data in the elevator in real time. The realization of these business logics is a key problem that needs to be solved in the subject of this thesis [15]. Zhang studied and developed the technical framework of Da Vinci software used in the front-end monitoring system. The principles and implementation methods of the technical framework of Da Vinci software were studied to find out the entry point that can be applied to this system, so as to shorten the development time and development cost of the system. The Da Vinci software's technical foundation is applied to the front-end monitoring system. The Da Vinci software framework compared the available video and voice codecs to find a video and voice codec scheme suitable for the system, and others tried to search for information related to computer connections to study the transfer efficiency of this system. These studies were done to determine the entry point that can be applied to this system, reducing the time and expense of the framework. The Da Vinci software framework is shown in Figure 2 [16]. Liu et al. compared the existing video and voice codecs to find a video and voice codec scheme suitable for the system [17]. Van et al. searched for computer network-related knowledge to study the transmission characteristics of video and voice stream under RTP/RTCP, which can realize the smooth transmission of video and audio on 3G networks [16]. Lin et al. studied the programming of the embedded Web server for porting the BOA server in the hi3515 embedded environment [18, 19]. Ge et al. mastered the writing of CGI scripts and realized the modification of system-related parameters through CGI scripts [20]. Liu et al. pointed out that the front-end monitoring subsystem is an unattended method and its remote configuration and maintenance plan needs to be considered [21]. Jinkui analyzed the shortcomings of the current elevator monitoring system. An elevator safety monitoring program based on unified platform management for the current system is proposed to change the discrete and inefficient state of elevator management, ensuring simple and efficient daily management and maintenance [22]. Xie et al. used a high-performance communication media processor with a hardware acceleration engine, which can meet the current applications of collecting audio and video instead of the ARM chip plus video codec module, making the system more streamlined in both software and hardware design, which is conducive to the rapid development of products [23]. This study suggests conducting research on an Internet of things-based elevator defect detection system in light of recent findings. IoT technology offers improved productivity of staff as well as reduces human labor [24]. First, it introduces the Internet of things technology, preprocesses the relevant data, and extracts the features of the elevator operation data continuously collected by the elevator sensors. The Relief-F algorithm is used to evaluate the potential influencing factors. The results show that, as the batch size increases, the accuracy rate will gradually increase, but after more than 20, the accuracy rate will decrease. When the batch size is 20, the training result is the best. This will surely increase the workload of maintenance workers and may result in skipped or inaccurate inspections of some elevators, preventing the property and the general public from understanding the operation and potential threats of the elevator in a timely manner. Currently, elevators can only be monitored in the most basic ways, such as through video surveillance and routine maintenance checks.

3. Methods

3.1. Introduction to Internet of Things Technology. The Internet of things (IoT) refers to a network of physical items, or "things," that are embedded with sensors, software, and other technologies with the purpose of connecting and sharing data with other devices and systems over the Internet [25, 26]. These devices range from simple household goods to high-tech industrial equipment. The IoT has emerged as one of the most crucial 21st century technologies in recent years. Because of the capacity to connect mundane products such as household appliances, autos, thermostats, and baby monitors to the Internet via embedded devices, continuous conversation, processes, and things are now possible [27, 28]. Because of the rise of cloud platforms, businesses and consumers may now receive the equipment they need to significantly increase without having to manage it all [29, 30]. The Internet of things is a network of physical devices, which usually represents the ability of physical network devices to perceive and collect data from the world around us. Almost any physical object can be converted into an Internet of things device, which in the usual sense represents the physical network device's ability to perceive and collect data from the world around us, then share the data through the Internet, and finally process the data through the cloud, which can be applied to different scenarios and businesses. IoT-enabled elevators can successfully transport passengers and freight vertically by utilizing artificial intelligence (AI). It is the process of modernizing the elevator's vital components so that they can handle new technology, function more efficiently, boost safety, and ensure up-to-date maintenance. IoT-enabled elevators can successfully transport passengers and goods vertically by utilizing artificial intelligence (AI). It refers to the process of updating the elevator's critical components to accept new technology [31–33]. The Internet of things (IoT) technology provides elevator operators with new views and tools for more effective observation, analysis, and reaction. IoT elevator systems provide several operational and user benefits, including the reduction of time- and money-consuming upgrades. Additionally, user wait times have lowered [34, 35].

3.2. LSTM Algorithm. The long-short-term memory network is usually called "LSTM", which is a special RNN that can learn long-term dependence [36]. It is invented by Hochreiter and Schmidhuber and refined and popularized by many people in many works. It works very well on a variety of issues and now is widely used. All recurrent neural networks have the form of a chain of repeated modules of neural networks [37]. The repeating module is a single tanh layer, much like in RNNs. The LSTM also has same chain-like design but uses a distinct repeating module structure [38]. It has four, instead of one, neural network layers, interacting in a very specific way. The long-short-term memory network, or "LSTM," is a unique type of RNN that has the ability to learn long-term dependency. Hochreiter and Schmidhuber are the inventors, and several authors have improved and popularized it in numerous works. It is now widely utilized and performs admirably on a number of concerns. Similar to RNNs, the repeating module is a single tanh layer. The chain-like design is also present, but it has a different recurring modular structure. Instead of just one neural network layer, it features four that interact in a very particular way. The LSTM concept is made to prevent issues with long-term dependency.

The LSTM model is designed to avoid long-term dependency problems. There are four main stages inside the LSTM:

(1) Forgetting stage: this stage is mainly to selectively forget the input from the previous node. To put it simply, it will forget the unimportant and remember the important [39]. The output $f(t)$ of the forgetting gate is then acquired using an activation function, often sigmoid. The likelihood of forgetting the hidden cell state of the previous layer is represented by the output $f(t)$ in this case since response $f(t)$ of the convolution is between [0, 1].The output expression of the forget gate is shown in equation (1).

$$f_t = \sigma\left(W_f \cdot \left[h_{t-1}, x_1\right] + b_f\right). \tag{1}$$

(2) Selective memory stage: this level "memorizes" only some of the input from the stage before it. The fundamental goal is to selectively memorize the input [40], write down what is significant, and leave out less critical information. There are two components to the input gate. The output of the first section, which makes use of the sigmoid activation function, is $I(t)$. The result of the second section, which employs the tanh activation function, is $c(t)$. To update the cell status, multiply the two outcomes together. The expression is shown in formulas (2) and (3).

$$i(t) = \sigma\left(W_i \cdot \left[h_{t-1}, x_t\right] + b_i\right), \tag{2}$$

$$\widetilde{C} = \tanh\left(W_c \cdot \left[h_{t-1}, x_t\right] + b_c\right). \tag{3}$$

(3) Renew cell state stage: the results of the previous forget gate and input gate will affect the cell state $C(t)$. How to get $C(t)$ from the cell state $C(t-1)$ is shown in the following formula:

$$C_t = f_t * C_{t-1} + i_t * \widetilde{C}. \tag{4}$$

(4) Output stage: which output will be considered the current condition will be decided at this stage. Based on the status of the cell, this output is produced. First, run a sigmoid layer to determine which part of the cell state will be output. Then, the cell state is processed through tanh and multiplied by the output of the sigmoid gate. The expression is shown in formulas (5) and (6).

$$o_t = \sigma\left(W_o\left[h_{t-1}, x_t\right] + b_o\right), \tag{5}$$

$$h_t = o_t * \tanh\left(C_t\right). \tag{6}$$

3.3. Analysis of Fault Prediction Model Based on LSTM

3.3.1. Data Preprocessing. The data of the fault prediction module in this paper mainly come from the elevator monitoring system, elevator fault history records, and elevator history maintenance records. The specific content is shown in Table 1.

In the process of collecting elevator data, there will be missing and redundant data. Data preprocessing is required before use [41]. First, perform a preliminary cleaning of elevator data: delete fields with constant data collection indicators, delete data with empty values in the entire record, and remove field values that are not related to the model, such as elevator use location and maintenance personnel name. Then, the data are processed in the next step, which includes the following aspects:

Table 1: Data source table.

Data source	Data content	Data type
Elevator monitoring system	Elevator real-time operation data and elevator historical operation data	Elevator operating speed, floor information, car vertical acceleration, car horizontal acceleration, door switch status, machine room temperature collection equipment number, etc.
Elevator fault history records	Contents and status recorded in case of elevator failure	Failure time, elevator number, failure content, elevator manufacturer, elevator maintenance unit, maintenance measures, failure mode, whether people are trapped, maintenance personnel, and other data
Elevator history maintenance records	Data and contents recorded during elevator maintenance	Use unit, use location, elevator number, rated load, grid input voltage, traction machine status, speed limiter status, car lighting, fan, emergency light, and other data

Correct the missing values of the data, which adopts two methods of the homogenous mean value interpolation and manual interpolation. The homogenous mean interpolation is to classify the samples and then use the mean of the samples in the class to impute the missing values. The manual interpolation is to fill the vacant value with the subjective estimated value, which may not completely conform to the objective facts, but in many cases, the effect of the manual interpolation according to the field experience will be better. Correct the abnormal data: for example, the elevator maintenance time appears in the impossible time period and the elevator operation status appears outside the specified range. Deal with duplicate values: for example, when an elevator maintenance worker performs one maintenance on the elevator, two identical maintenance records may be generated. Deal with inconsistent data: the data of the elevator are inconsistent with the actual data. Carry out feature coding: for example, use custom tags to complete quantization coding for maintenance status, door opening and closing status, up and down directions, etc. Smooth the noise: the methods include binning method, regression method, and clustering method. Perform data integration and standardization processing on the data: because the various acquisition parameters are different and their respective metrics are different, these data cannot be directly manipulated. They need to be standardized before they can be used in the algorithm. This can improve efficiency and performance.

3.3.2. Feature Extraction. The elevator's sensors will continuously collect elevator operation data, and the collection module will store the collected data in the system at regular intervals. These data will be used as basic data to provide support for failure prediction. There are many potential factors that affect the normal operation of the elevator, including not only the operating state of the elevator itself but also a series of factors such as external environmental factors and human influence. These data have many dimensions and complex relationships and may be related to each other. Larger dimensions will have an adverse effect on subsequent data analysis. Some dimensions will have a reverse effect. Through feature selection, the data dimension is reduced, the redundant parameters that play a negative role in the failure prediction are reduced, and the contribution of each parameter to the failure prediction is clearly distinguished. Then, the key factors, secondary factors, and irrelevant factors are analyzed. For the above problems, this paper will use the Relief-F algorithm to screen the related factors of elevator failures and get the factors that play a major role in the prediction of elevator failures [42]. The Relief-F algorithm is used to handle with multi-category problems. In the process of the Relief-F algorithm, each time a sample R is randomly taken from the training sample set, and then d neighbor samples of R are found from the sample set of the same type as R, and d neighbor samples from the sample sets of different classes of each R are found. Then, the weight of each feature is updated [43].

3.3.3. Specific Steps of Relief-F Algorithm. According to the analysis of the subsystems that make up the elevator, the main types of elevator failures are divided into 7 types, plus the normal state; the total state of the elevator can be roughly divided into 8 parts, which are normal state, traction system failure, guidance system failure, door system failure, electrical control system failure, weight balance system failure, electric drive system failure, and safety protection system failure. Based on this, the category set $C=${normal state, traction system failure, guide system failure, door system failure, electrical control system failure, weight balance system failure, electric drive system failure, safety protection system failure} is determined [44–46]. According to relevant data sources, after preprocessing the real-time monitoring system, elevator historical failure records, and elevator maintenance records, 21 state parameters that characterize the elevator operation can be obtained, which are traction machine three-phase power supply current, traction machine three-phase power supply voltage, vertical vibration acceleration, horizontal vibration acceleration, car running noise, door opening and closing noise, machine room noise, elevator load, vertical acceleration, vertical deceleration, host motor temperature, machine room temperature, host gearbox temperature, brake coil temperature, running time, running times, elevator alarm times, equipment status, total number of floors, up and down status, and door switch status; then, the attribute set $F=${traction machine three-phase power supply current, traction machine three-phase power supply voltage, vertical vibration acceleration, horizontal vibration acceleration, car running noise, door opening and closing noise, machine room noise, elevator load, vertical acceleration, vertical deceleration, host motor temperature, machine room temperature, host gearbox

Table 2: Category set code table.

Category	Code
Normal state	C1
Traction system failure	C2
Guidance system failure	C3
Door system failure	C4
Electrical control system failure	C5
Weight balance system failure	C6
Electric drive system failure	C7
Safety protection system failure	C8

temperature, brake coil temperature, running time, running times, elevator alarm times, equipment status, total number of floors, up and down status, door switch status} is determined [47]; and finally, the category set is coded, as shown in Table 2.

A sample set is created, and 1000 data from the database are selected as sample data, with 8 categories and 21 attributes. The Relief-F algorithm is used to evaluate the potential influencing factors. Then, the number of sampling times and the number of neighbor samples are set, the samples are calculated according to the algorithm, and the weight of each attribute is obtained. The attribute weight is shown in Figure 3.

The threshold is set to 0.2, and the preliminary factor screening is performed on the above analysis results, and 16 attributes are obtained. The Pearson correlation coefficient is further used to determine the correlation between attributes, and the set threshold needs the second screening. The final selected attributes are {traction machine three-phase power supply current, traction machine three-phase power supply voltage, vertical vibration acceleration, horizontal vibration acceleration, car running noise, door opening and closing noise, machine room noise, elevator load, vertical acceleration, vertical deceleration, host motor temperature, machine room temperature, host gearbox temperature, brake coil temperature, running time, running times, elevator alarm times, equipment status, total number of floors, up and down status, door switch status}. Through analysis, we can get the main factors of elevator failure and eliminate some irrelevant factors and negatively related factors. Based on the results of this analysis, these attributes can be used to more accurately judge the status of the elevator.

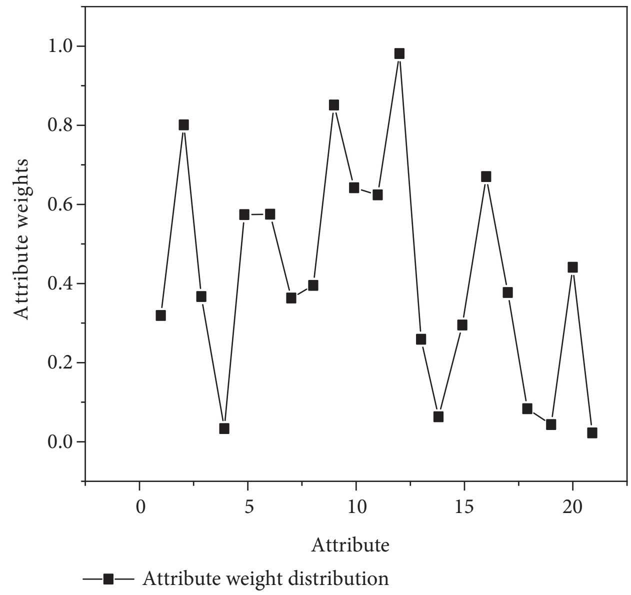

Figure 3: Distribution of attribute weights.

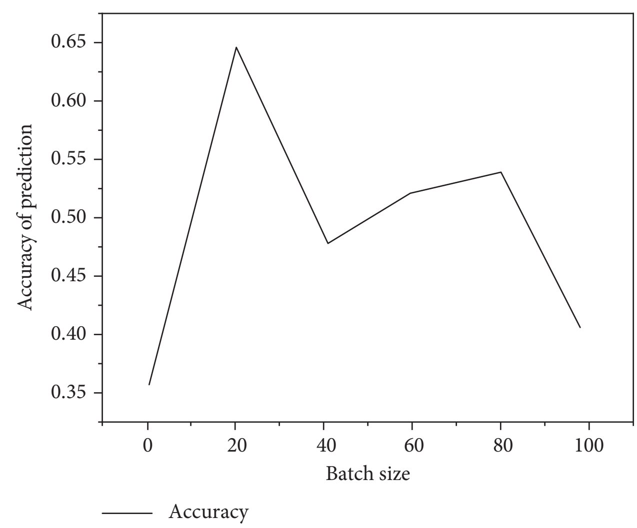

Figure 4: Accuracy under different batch sizes.

4. Results

The selection of batch size in the process of tuning is as follows: first, start small and gradually increase the batch size. As the batch size increases, the accuracy rate will gradually increase, but after the size is more than 20, the accuracy rate will decrease. It can be seen from Figure 4 that when the batch size is 20, the training result is the best.

It can be seen from Figure 5 that the optimization of the model can also start from the time step. The time step represents the length of the sequence that the LSTM can use and is a response to the length of the data association. As shown in Figure 5, as the time step size increases, the prediction accuracy rate will be significantly improved. When the time step size is 24, the prediction accuracy rate is the highest. After 24, the prediction rate will decrease.

5. Discussion

The experiments show that, in addition to the current status of the elevator, the status of the previous stage also plays a role in the prediction of elevator failure. Therefore, the long-short-term memory network combined with the method of extracting strong correlation factors can predict the failure of the elevator. In general, the system is technically feasible in terms of hardware and software.

In terms of hardware, the sensors, acquisition terminals, and gateways required by the system are available on the market and can be easily obtained. From the perspective of software, various technologies are relatively mature and their functions are relatively clear. As a result, the failure of the

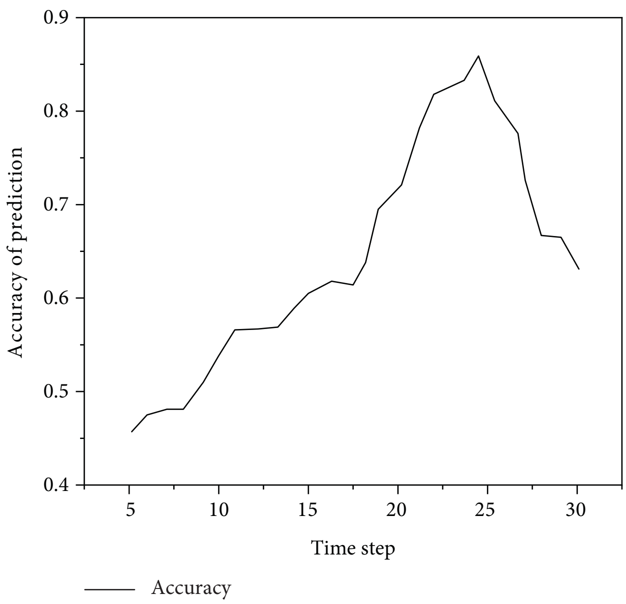

Figure 5: Accuracy rate under different time steps.

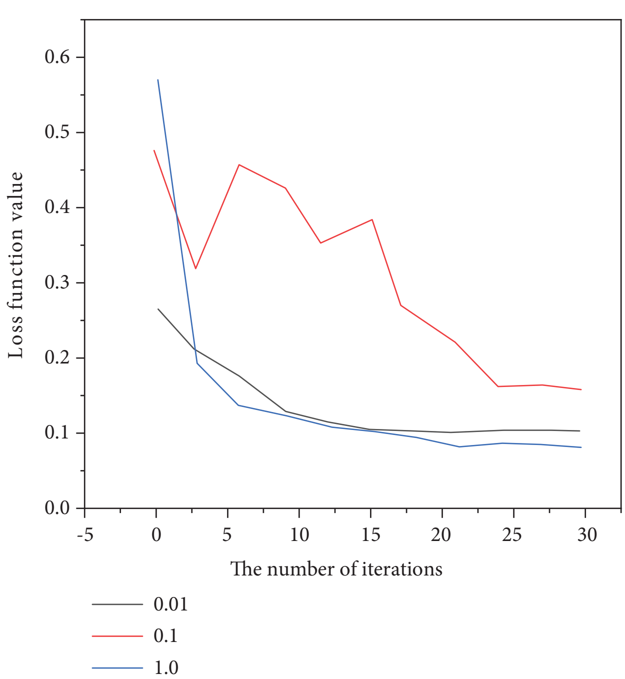

Figure 6: Loss function curve under different learning rates.

elevator can be predicted using the long-short-time memory network as well as the approach of extracting significant correlation variables. The effect of the learning rate on the model is obtained, as illustrated in Figure 6. The blue line indicates that the learning rate is 1.0, the red line is 0.1, and the black line is 0.01. With the increase of the iteration times, the effect is the best when the learning rate is 0.1.

6. Conclusion

A new elevator fault monitoring system based on the Internet of things technology is proposed in this paper, and an elevator monitoring platform based on the Internet of things is built, so as to improve the property management company's ability to supervise elevators through relevant Internet of things technology and communication technology. The experiments show that, in addition to the current status of the elevator, the status of the previous stage also plays a role in the prediction of elevator failure. Therefore, the long-short-time memory network combined with the method of extracting strong correlation factors can predict the failure of the elevator. The desire for convenience has grown as a result of the recent increase in world population, which has accelerated urbanization efforts and increased use of elevators. The use of elevators is commonplace in both residential and commercial settings. The need for a system that has both strong research potential and practical application is urgent. Hence, the sector urgently needs a versatile design while still considering safety precautions.

Our future studies will focus on implementing the Da Vinci software architecture and real-time audio transmission technology.

Data Availability

The data presented in this work can be accessed through the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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