Requirements analysis and overall design of escalator condition monitoring and early warning system

Zhuangzhuang Zhang[a,1], Yifei Tong[a,*], Xiyang Jiang[b,2], Li Yang[c,3]
[a]Nanjing University of Science and Technology, Nanjing 210094, Jiangsu,China; [b]Special equipment safety supervision inspection institute of Jiangsu province, Nanjing 210036, Jiangsu, China; [c]Taizhou University, Taizhou 225300, Jiangsu, China.

ABSTRACT

Escalators are becoming more and more popular in daily life, bringing a lot of convenience to people. However, in recent years, the frequent safety accidents of escalators have caused people's concern. How to ensure the safe operation of escalators, timely diagnosis and early warning of faults has become a focus of research for many elevator manufacturers and operation and maintenance personnel. The traditional regular inspection of escalators causes waste of human and material resources. The rapid development of Internet of Things technology and sensor technology has brought new development direction for the operation condition monitoring of escalator parts. Under this background, the escalator condition monitoring and early warning system is designed and constructed, and the results are displayed visually through the user interaction page.

Keywords: Escalator, IoTs, fault diagnosis

1. INTRODUCTION

1.1 Research background

Since the beginning of the new century, with the rapid development of China's economy, the acceleration of urbanization and the increasing proportion of aging population, escalators, as a convenient way of life, have been warmly sought after by people. Nowadays, escalators are widely used in subway stations, airport waiting rooms, high-speed railway stations and other important transportation hubs, as well as large shopping malls, hospitals and other places with dense traffic. Escalators have been deeply integrated into modern cities, bringing great convenience to People's Daily life and travel.

Although escalators have developed into mature commercial products after more than 100 years, the frequent escalator safety accidents in recent years have aroused wide attention from all aspects of the society after being spread by the news media. On January 23, 2020, an escalator accident[1] at a bus hub in Chongqing resulted in one person being slightly injured and many people falling down. The reason was that the escalator stopped suddenly in the downward running process, causing the passengers to lose their weight and fall down. Taking Shanghai Metro as an example, there are 16 total lines, 4000 escalators in use, and a daily passenger flow of more than 30 million people. According to statistics[2], passenger injury accidents occurring on escalators account for 60% of subway passenger injury accidents, and the injury accidents caused by escalators are on the rise.

The lack of monitoring data for escalators[3] makes it difficult to assess potential failure risks, and escalator failures often occur during periods of high load with large passenger loads. Once the escalator breaks down, it will affect the daily operation of stations, shopping malls and other places on the one hand, and may cause harm to passengers on the other hand. The traditional fault diagnosis of escalator is highly dependent on manual experience. Operation and maintenance personnel determine whether parts and components are faulty according to the vibration, temperature, sound and other signals generated on the site of the escalator. However, this method has poor universality for complex signal processing and is often difficult to achieve accurate maintenance.

*tyf51129@aliyun.com; [1]1446227876@qq.com; [2]jiangxiyang@163.com; [3]ly562339471@foxmail.com

Seventh International Conference on Mechatronics and Intelligent Robotics (ICMIR 2023), edited by Srikanta Patnaik, Tao Shen, Proc. of SPIE Vol. 12779, 127791B · © 2023 SPIE · 0277-786X · Published under a Creative Commons Attribution CC-BY 3.0 License · doi: 10.1117/12.2688931

1.2 Escalator structure

Escalator is a kind of fixed mechanical equipment that transports passengers up or down between different levels of various buildings through circular running steps. It includes a chain conveyor of special structure and two belt conveyor of special structure. The main components of escalator[4] include the driving host (including motor, reduction box, brake, etc.), drive and cascade sprocket, traction chain, main drive shaft, cascade, cascade guide rail, cascade chain tensioning device, handrail belt, truss structure and electrical system, etc. At the entrance, passengers climb the steps, the escalators do a horizontal movement, and then form a ladder structure to transport passengers to different floors; Near the exit, the steps gradually disappear into a horizontal structure, allowing passengers to exit the escalator. These motion processes are mainly realized by the main wheel and auxiliary wheel moving along the two step guide rails respectively. Fig. 1. shows the simple structure of the escalator.

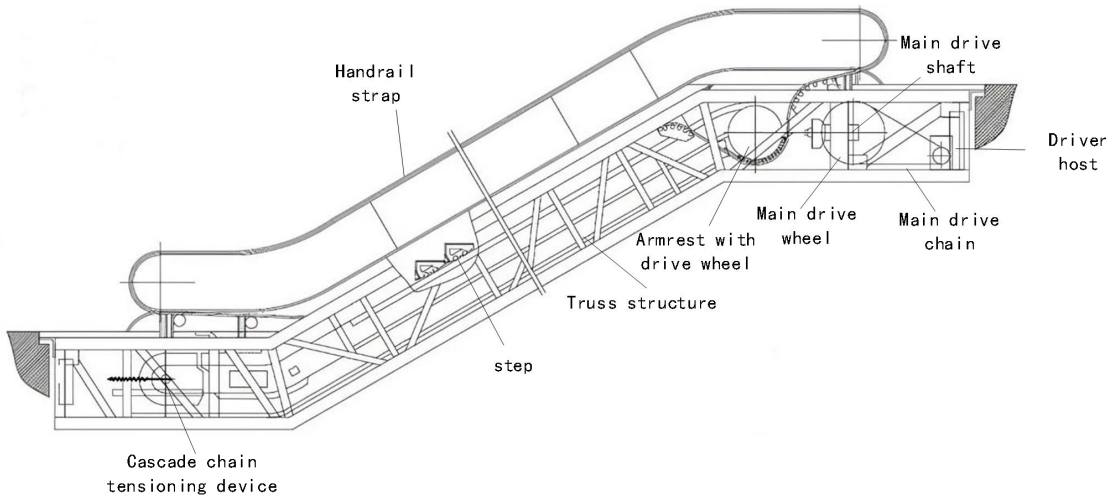

Figure 1. Structure of escalator

Escalators can be structurally divided into two categories: control systems and mechanical systems. Among them, the mechanical system of escalator is relatively complex and has many parts. With the increase of service time, the mechanical failure caused by the aging or failure of parts will become more and more frequent. There will be vibration, noise and other phenomena caused by minor faults, which will affect the comfort of passengers. A serious failure could threaten the safety of passengers.

The driving device consists of motor, reduction box, brake, drive sprocket, main drive shaft and other components, usually located at the upper end of the escalator, the role of the driving device is to drive the power of the main engine through the drive sprocket to the cascade device and armrest belt device, drive the cascade and armrest belt synchronous operation, the drive sprocket through the chain and the reducer connected to obtain power. The ladder is arranged on the guide rail in accordance with a certain line, driven by two traction chains, which bypass the upper end of the drive sprocket and the lower end of the ladder chain tensioning device, and form a closed loop through a number of straight and curved sections of the upper and lower end. Handrail straps on both sides of escalators run at the same speed as the steps to help passengers stand on their hands.

2. ANALYSIS OF SYSTEM FUNCTION REQUIREMENTS

At present, there are problems[5] such as low data collection efficiency and low information management level of escalator. The following aspects should be taken into consideration when designing the escalator condition monitoring and early warning system: the escalator data[6] collected through the system should be authentic and accurate, and the error should be within the controllable range; In addition, after data collection, it is necessary to upload the data to the server in a timely and fast manner to prevent data accumulation in the network resulting in system crash; Finally, various intelligent methods should be adopted to improve the digitization and information level of escalator operation and maintenance management.

2.1 Fine data collection

Data collection is an important basis for system construction, as well as a data source for state monitoring, fault diagnosis and maintenance. During operation, the escalator relies on the coordination of multiple parts such as the driving main engine, driving sprocket, handrail belt, etc. If only the state information of local positions is monitored, the running state of the whole escalator cannot be truly reflected. Aging of handrail belt, failure of reduction box and other adverse effects will directly affect the service life of escalators. The purpose of condition monitoring is to accurately reflect whether all parts of escalators are within the normal range during operation, and to respond quickly when abnormal operating conditions occur. The refined escalator data collection and monitoring mode enables the management personnel to know the running status of various parts in the escalator in time, reduces the frequency of on-site inspection of the maintenance personnel, and thus improves the operation and maintenance effect. Therefore, the system must carry out refined state monitoring on the key components of the escalator to reflect the real running state of the escalator.

In case of mild fault of the escalator, in order to ensure that the system management personnel[7] can quickly communicate with on-site personnel and take necessary measures for adjustment, it is necessary to ensure that the server system can timely receive the operating status information of the escalator, which requires the system to upload the data collected from all parts in a timely manner. The management of escalator running status information is the key to escalator information management. Only when escalator monitoring data is uploaded into the network and transmitted to the escalator status monitoring and early warning system, can the management personnel be helped to grasp the escalator running status remotely, avoid frequent on-site maintenance, and make escalator operation and maintenance management more convenient and efficient.

2.2 Data storage and analysis

Data is the basis of condition monitoring and fault diagnosis. It is necessary to save the data to the database during system operation. Data management is an important part of system design. The database[8] is a warehouse that stores and manages data according to a certain structure. When developing the escalator condition monitoring and early warning system, relevant data should be stored in the database in a certain format. Then, the powerful function of the database can be used to process the data conveniently according to the needs of the system.

After the running status information of escalator parts enters the database, the system needs to analyze the data. Data analysis is the key to escalator fault diagnosis. Potential fault information can be extracted from a large number of irregular data to find out the inherent law of the state change of each escalator component, so as to take necessary measures to intervene in the fault. Condition monitoring and fault diagnosis are the core functions of the system. By extracting the running features of escalators and describing them with appropriate mathematical models, the changing trend of the running state of escalators can be mastered and the functions of condition monitoring, fault diagnosis, performance prediction and maintenance of escalators can be realized.

2.3 Intelligent diagnosis and remote monitoring

As escalator is a complex rotating machinery[9], the traditional condition monitoring and fault diagnosis technology is difficult to meet the needs of escalator system. The traditional fault diagnosis method based on detection data processing can realize the fault diagnosis of simple mechanical equipment, but when the structure of the mechanical system is complex, it will inevitably increase the type and number of sensors, so that the operation and maintenance personnel have to spend a long time to process a large number of data, which is not conducive to the timely diagnosis and removal of mechanical faults. In addition, due to the large and complex escalator system, it is difficult to obtain a fine condition monitoring and fault diagnosis mathematical model. Due to the continuous upgrade of computer hardware equipment and the development of artificial intelligence technology, fault diagnosis technology based on deep learning does not need to establish accurate mathematical model of equipment, and is an increasingly popular diagnosis method.

On-site escalator monitoring and diagnosis will be limited by manpower, technology and region, and cannot meet the needs of the site. With the rapid development of Internet of Things technology, remote monitoring technology has gradually entered the field of equipment operation and maintenance. By establishing escalator monitoring center, functions such as remote monitoring, fault diagnosis and early warning of escalator can be realized. The escalator monitoring center receives the escalator running status data sent from the bottom through the communication network, and monitors and diagnoses the data. At the same time, it can also be linked with the escalator. If there is a fault, it can

quickly provide remote alarm service, and the management personnel can give the escalator maintenance guidance remotely, so as to realize the purpose of remote operation and maintenance.

3. ANALYSIS OF SYSTEM PERFORMANCE REQUIREMENTS

The system should meet the performance requirements of accuracy and timeliness, ease of use and easy maintenance, scalability, reliability, so as to ensure the long-term stable and efficient operation of the system.

3.1 Accuracy and timeliness

Changes in temperature and humidity may affect the accuracy of data collected by the sensor. The internal situation of the escalator is complicated, so the sensor should be stable to changes in temperature and humidity to ensure a high accuracy of the collected data of the escalator. The time interval of the data collected by the sensing terminal should be dynamically adjusted to make use of the network resources of the system at a reasonable transmission rate and transmit the data to the remote server through wired communication technology to maintain the timeliness of the data.

3.2 Ease of use and maintainability

The target users of this system are escalator management personnel. The user visual interface should be simple, intuitive, maneuverable and easy to use. At the same time, the system should be developed in a modular way to improve the independence of each module, convenient for technical personnel to carry out necessary maintenance of each module of the system, conducive to information management and reduce costs.

3.3 Expansibility

In practical applications, with the increasing of business volume, the system needs to constantly cope with new business requirements. At this time, the extensible system can help system managers to cope with such challenges. In the sensing terminal, open data interface should be provided to ensure that the system can expand new functional requirements; At the same time, open technology is used to design the system client, so as to facilitate the system expansion and upgrading and communication with the outside world.

3.4 Reliability

The system needs to collect escalator information continuously for a long time. The bottom sensor and collector should have good reliability to ensure that there will be no large deviation when the system is powered on for a long time. In addition, the remote communication transmission of data should have a low frame loss rate to prevent excessive data from being discarded due to failure to pass the validity test.

4. OVERALL SYSTEM DESIGN

The escalator condition monitoring and early warning system constructed in this paper is designed on the basis of the Internet of Things structure[10], and its main work can be divided into three parts: collection of the running state of all parts of the escalator (perception layer), remote transmission of data through Ethernet (network layer), data processing and realization of escalator condition monitoring, fault diagnosis and early warning function (application layer). The sensing layer collects the vibration acceleration of the driving host and the main driving shaft, the temperature of the handrail belt and other information through the sensor network. The network layer sends the collected data from the bottom layer to the application layer through the information transmission technology, and the application layer analyzes the data and saves it to the database. In the application layer, the concept of modularity is adopted to decouple front-end and back-end services, and the escalator management system is developed through B/S architecture to realize the requirements of remote condition monitoring and fault warning.

4.1 Systematic architecture design

With the development of the Internet of Things technology, sensors shine in the mechanical equipment signal acquisition, providing a new development opportunity for escalator fault diagnosis. Various sensors are used to monitor the running

state of the escalator, analyze and judge the location and cause of the failure, and send out early warning information to enable the escalator operation and maintenance personnel to intervene in time and restore the equipment to normal state.

On the basis of the Internet of Things, applying the theory and method of artificial intelligence to the fault diagnosis of escalator can extract more abstract and deeper features from the complicated operation data and dig the complex connection between data and the fault of escalator parts. In particular, deep learning, computer vision and other tools have made breakthrough achievements in mechanical equipment fault diagnosis, which has been paid more and more attention by experts and researchers in the field. In escalator fault diagnosis, deep learning can extract valuable features for fault diagnosis by means of autonomous learning, and get rid of the previous method of feature extraction using expert experience and manual work. Therefore, the research on applying deep learning technology to escalator condition monitoring and early warning system is of landmark significance. Intelligent diagnosis direction is a new way of escalator fault diagnosis.

After receiving the data from the sensor, the data collector sends the data to the application layer server through the communication transmission technology, and transmits the information obtained by the acquisition terminal quickly, securely, stably, and accurately over the wired or wireless communication transmission network. Network layer communication technology develops rapidly and has many types, including Ethernet[11], 3G/4G, WIFI, NB-IoT, etc. In the process of escalator operation, a large number of wireless signals generated by passengers' mobile phones and other communication devices are easy to interfere with wireless transmission mode, so wireless communication technology is not suitable for escalator data transmission. At the same time, the working time of escalators is long, and a large amount of operation information will be generated every day, which has certain requirements for data transmission rate and volume. Through the analysis and comparison of the advantages and disadvantages of various Internet of Things communication technologies, Ethernet can better meet the needs of escalator acquisition and transmission system to transmit information.

The escalator status monitoring and early warning system based on the Internet of Things constructed in this paper is shown in Fig. 2. From bottom to top, it is successively composed of data acquisition and transmission module, business logic processing module and front-end user interaction module.

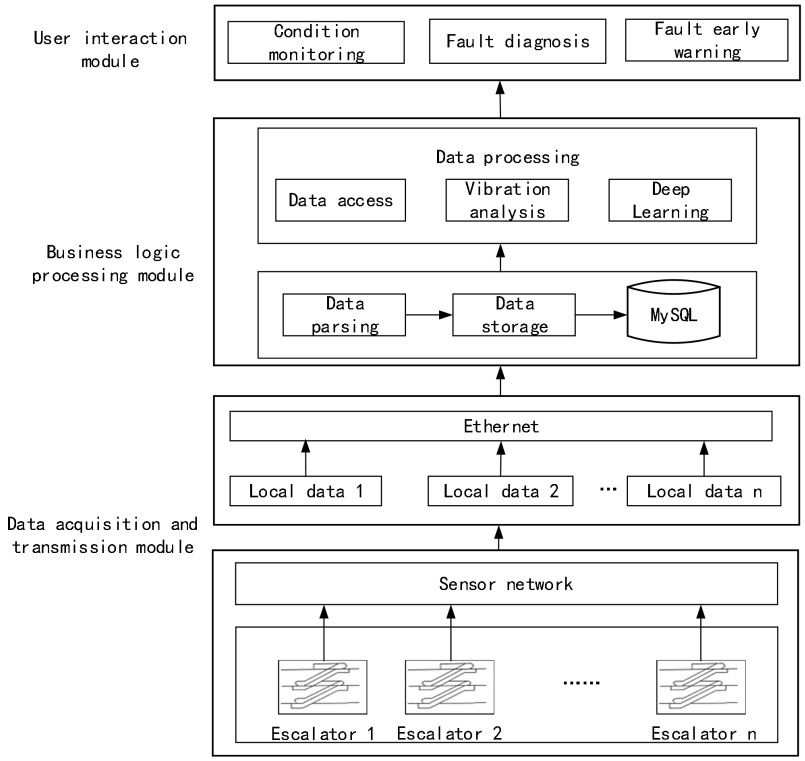

Figure 2. System architecture design drawing

4.2 System overall workflow

When early damage occurs to escalator parts, the signal is weak, so it is usually difficult to make accurate identification and diagnosis by intuitive means such as listening to the ear and touching the hand. According to the structural characteristics of all parts of the escalator and the change mechanism of the running state after failure, the characteristic changes before and after failure can be captured by installing sensors. For the change of the running state of the driving host, the main driving shaft, the step chain tensioning device and other parts, the vibration signal is collected by vibration sensor[12], and the vibration signal is analyzed according to the vibration analysis theory. When the armrest belt and the friction driving wheel slip due to poor matching, the temperature of the armrest belt will rise suddenly in a short time. Through the temperature sensor, the temperature of the armrest belt will be monitored in real time, and the abnormal temperature will be warned when it rises.

The system workflow is shown in Fig. 3. The sensing layer obtains the operating state data of the escalator drive host, main drive shaft, lower tensioning shaft and handrail belt through the sensor network, and the data collector sends the power or non-power signals collected from the sensor and other underlying devices to the upper computer. The transport layer sends data to the application layer through the network transmission technology, parses the data and saves it to the database. The vibration signal is processed by vibration analysis method and deep learning theory, and the results are visualized through the web page.

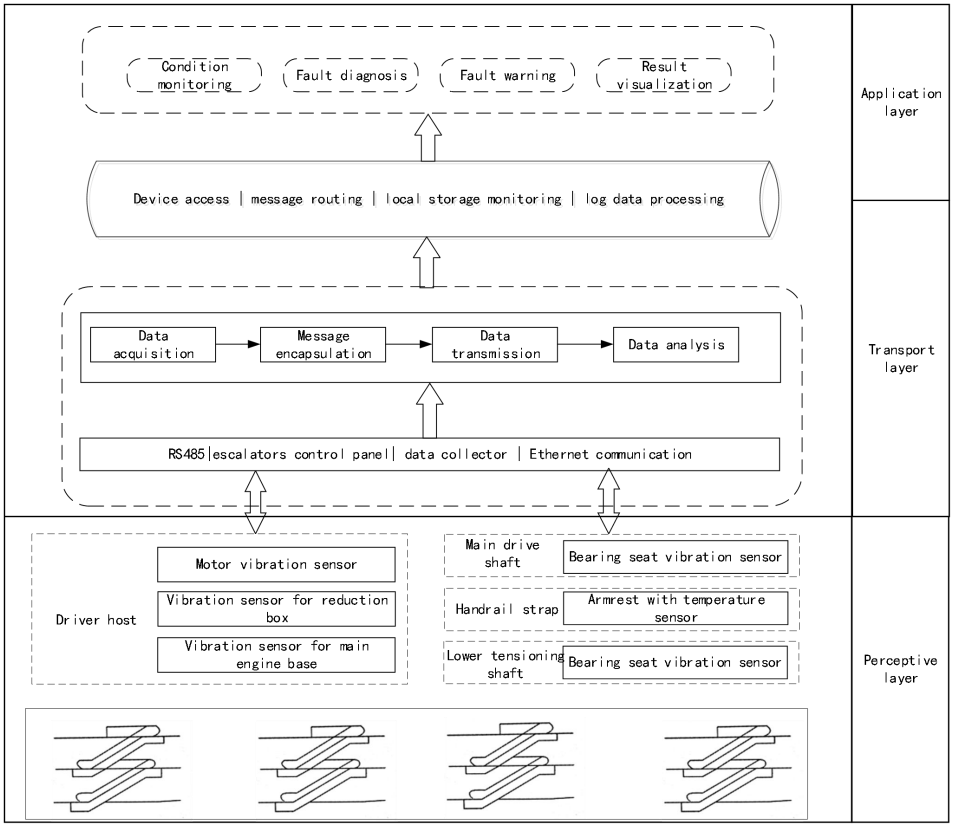

Figure 3. System working process diagram

5. RESEARCH SIGNIFICANCES

5.1 Theoretical significance

With the rapid development of the Internet of Things technology, sensor technology and data transmission communication technology used in monitoring the running status of escalators have developed rapidly in recent years, and more and more new technologies have been applied to the operation and maintenance management of escalators.

Experts in related fields pay more attention to video surveillance when doing research on escalator faults, and the status change trend of escalator internal parts is also an important link in escalator monitoring. In this paper, the Internet of Things technology, sensor technology and escalator parts are studied in depth, and the application of the Internet of Things technology to the escalator condition monitoring and early warning system has certain reference significance for the intelligent operation and maintenance management of the escalator and the information construction.

5.2 Practical significance

The Internet of Things technology has incomparable advantages for escalator condition monitoring. Sensors are installed on some key components to realize continuous collection of escalator operation information, and remote data transmission with high security and reliability can be realized through Ethernet transmission technology. Finally, data processing and analysis are carried out and results are displayed. The condition monitoring and early warning system can accurately monitor the health condition of each escalator. If abnormal conditions occur, they can be dealt with promptly and quickly, so as to prevent the adverse effects that may be caused by the operation of the escalator under the condition of disease, and ensure the long-term stable and healthy operation of the escalator. In addition, the introduction of information and intelligent technology improves the effect of escalator operation and maintenance management, and the fine monitoring helps to extend the service life of the escalator.

ACKNOWLEDGMENTS

This work was financially supported by the Program of Science Foundation of Jiangsu Province Special Equipment Safety Supervision Inspection Institute (NO.KJ (Y) 2023034).

REFERENCES

[1] Luo, H., Zhang, D. P., Analysis and Enlightenment of an Escalator Emergency Stop Accident, China Elevator. Papers 32(03), 53-55(2021).
[2] Fan, J. Q., Discussion on the Importance of Intelligent Video Monitoring System to Improve the Safety of escalator, China Elevator. Papers 33(12), 40-43(2022).
[3] Zhang, C. J., Liu, S. Z., Ren, H. P., Legacy risks and additional risks of Escalator Safety Protection Measures, China Elevator. Papers 33(19), 59-62(2022).
[4] Hui, T. Y., Shi, X. L., Liu, X. Y., Reliability Analysis and Research of Escalator Drive Station Based on FMECA, China Elevator. Papers 30(04), 57-63(2019).
[5] Wang, H., He, J. F., Application Research of Escalator Condition Monitoring and Intelligent Early-Warning Diagnosis System, Modern Urban Rail Transit. Papers (S1),114-119(2021).
[6] Wang, X. C., Research on Intelligent Warning and Fault Diagnosis System of Escalator, Modern Manufacturing Technology and Equipment. Papers 57(10), 98-101(2021).
[7] Yang, Y. C., Li, X. P., Sun, K. M., et al., Design and Application of Intelligent Monitoring System for Escalator in Subway Station, China Elevator. Papers 32(13), 12-14(2021).
[8] Li, L. M., Application Scenarios of relational database and NOSQL Database, Electronic Technology and Software Engineering. Papers 234(16):184-187(2022).
[9] Wang, X. X., Geng, X., Design and Implementation of Remote Fault Diagnosis System for Rotating Machinery Equipment, Industrial Control Computer. Papers 33(11), 53-54+57(2020).
[10] Fu, C. T., Hu, J. Y., Chen, J. X., et al., A kind of escalator monitoring System based on Internet of Things, Internet of Things Technology. Papers 10(10), 15-17(2020).
[11] Wu, Z. W., Liu, J. L., Yu, F. G., Overview of on-line Monitoring and Fault Diagnosis Technology of Escalator, China Special Equipment Safety. Papers 38(11), 1-7+13(2022).
[12] Chen, J. X., Wang, L., Tai, S. L., et al., Braking Parameter Detection of Escalator Based on MEMS Acceleration Sensor, Automation & Instrumentation. Papers 37(07), 63-67(2022).