Sensors and Materials, Vol. 34, No. 5 (2022) 1757–1769
MYU Tokyo

S & M 2926

Remote-control System for Elevator with Sensor Technology

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(Received December 30, 2021; accepted March 22, 2022)

Keywords: elevator, sensor, IoT, remote control, feasibility evaluation

Elevators are essential in high-rise buildings. Their principle is simple but they have many devices and functions for safe operation and effective management. The development of new technologies based on the Internet of Things (IoT) and high-rise building technology allows improved elevator systems with remote control and intelligent operation. Many studies have proposed new functions for safety management, efficient operation, and effective data collection and storage. However, remote-control technology is required for advanced elevator systems, especially those based on recent technologies such as the IoT and sensor technology. Therefore, a study was carried out to provide the required basic information on what should be sensed, which sensors should be used, and where they should be installed in a remote-control elevator system. For this study, we designed a questionnaire to define the issues with the help of experts. The replies to the questionnaire were analyzed using the Delphi method, and the results suggest that 18 major tasks must be performed when designing an elevator system appropriate for remote-control and intelligent operation. We propose the monitoring items, related sensors or devices, and their installation locations for an intelligent elevator system. A design based on the results of this study is expected to contribute to the development of an improved intelligent and remote-control elevator system. The results enable subsequent research on the technological requirements of the equipment and the establishment of maintenance and management strategies for the proposed elevator system.

1. Introduction

With the popularity of high-rise buildings, elevators have become an indispensable vertical transportation tool for modern life.[(1–3)] An elevator system includes various equipment that is sometimes integrated into the resource planning system of an enterprise. Traditional elevator systems have problems such as difficult maintenance, unclear operational instructions, and limited inspection capability[(4)] as they comprise complex mechanical and electrical systems for

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https://doi.org/10.18494/SAM3827

ISSN 0914-4935 © MYU K.K.
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traction, guidance, the carriage, the doors, balance, drive control, operation control, and safety protection. The modules of fault warnings and emergency stops are the most important in an elevator system and require various sensors to monitor the operation in real time.[5]

Owing to its complexity, an elevator system requires the Internet of Things (IoT) with diverse remote sensing devices[6,7] with reliable data acquisition and transmission to control the elevator system. The IoT allows the use of remote sensing devices as well as intelligent control of the elevator system with sensing technology; thus, it has become an important part of the maintenance, repair, and operation of systems and the replacement of traditional systems. Because IoT-based systems reduce the cost of labor and materials and improve the efficiency and safety of elevators, manufacturers and customers of elevators are adopting them rapidly. Thus, elevator systems based on the IoT and sensing technology have attracted much research interest regarding the statistical analysis of related data and intelligent operation.[8] Such research results are applied in the use of IoT technology in the real-time monitoring of fault diagnosis, spontaneous alarms, and maintenance;[9] the data logging of remote elevator monitoring systems;[10] a cloud monitoring system with video information and mobile terminals;[11] an intelligent multisensory module for remote monitoring;[5] and a system for preventing people from being trapped in elevators.[12]

However, there is not yet a basic principle for the software and hardware settings or a maintenance standard for elevator systems that use remote-control technology with the IoT, big data, and AI applications. Therefore, we propose the important components for designing an elevator system using recent technology. To this end, we carried out a questionnaire survey and analysis with the Delphi method for the feasibility assessment and implementation of sensors in the remote control of an elevator system. The results provide industry and users with a reference to improve the efficiency of the maintenance and the safety of elevator systems.

2. Methods

2.1 Elevator system

2.1.1 Architecture of remote monitoring system for elevator

A remote monitoring system comprises monitoring equipment, a transmission device, a controlling device, computing equipment, data storage equipment, and sensing equipment.[13] The architecture of the system is shown in Fig. 1. The functions of each component of the architecture are described in Table 1 and the data collected by the components are shown in Fig. 2.

2.1.2 Technical standards and interface

In accordance with the technical standards of the International Organization for Standardization (ISO), we adopted the IoT global standard initiative (IoT-GSI), the M2M service layer as the network communication standard protocol, and the International Organization for

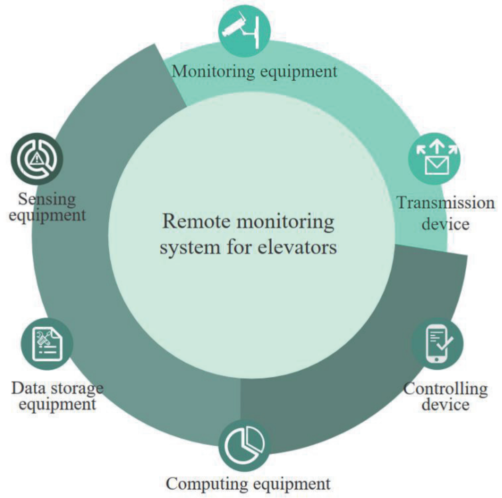

Fig. 1. (Color online) Architecture of the remote elevator monitoring system.

Table 1
Main functions of components of elevator system.

Component	Functions
Monitoring equipment	Obtains visual images and sound for further use
Transmission device	Sends measured and recorded data from elevator to data storage equipment
Controlling device	Measures and monitors system to automatically control operation
Computing equipment	Computes data to issue instructions for control
Data storage equipment	Stores all collected information in data storage device for retrieval, calculation, and further analysis
Sensing equipment	Detects operating data of equipment including date, time, temperature, vibration, and stopping

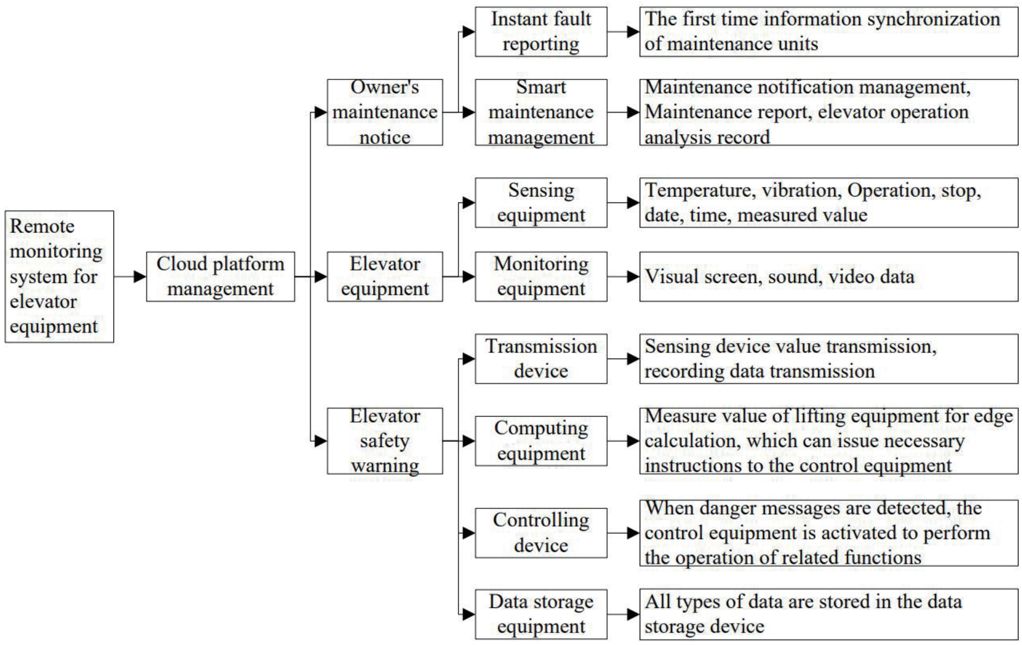

Fig. 2. Data collected by each component of the elevator system.

Standardization/International Electrotechnical Commission (ISO/IEC) standard established by ISO International Telecommunication Union Telecommunication Standardization Sector (ITU-T). We also followed the network architecture and the required standards of ISO/IEC JTC 1/WG 7 Sensor Networks (WGSN) of ISO and IEC. The standards of the Institute of Electrical and Electronics Engineers (IEEE) and the 3rd Generation Partnership Project (3GPP) were also considered in this study. The technical standards adopted are shown in Fig. 3.(14)

2.1.3 IoT cloud platform for remote monitoring

The cloud platform plays an important role in IoT applications.(12) Enterprises can monitor and operate equipment remotely through an IoT platform as a service (PaaS). The cloud platform of the IoT is used for equipment maintenance and innovative services based on the analysis of equipment usage behavior. The platform is composed of connection management, device management, and device cloud units.(14)

Connection management: Owing to the variety of IoT sensing devices, the formats and forms of data produced by different devices are inconsistent, which causes difficulties in analysis and processing. The IoT PaaS module allows the integration of data in different formats provided by different devices, thereby ensuring the interoperability of the devices.

Device management: Device management is necessary for monitoring and diagnosing connected equipment to ensure an appropriate lifetime of the equipment or appropriate real-time operating conditions such as the battery life, connection/offline status, firmware/software update status of the machine, and sensors. It makes necessary preventive decisions to improve the effectiveness of the equipment.

Device cloud: A device cloud collects and stores the data from the equipment or connected endpoints. It converts time series data into a form accessible by mobile applications and sends it to a web app for further analysis.

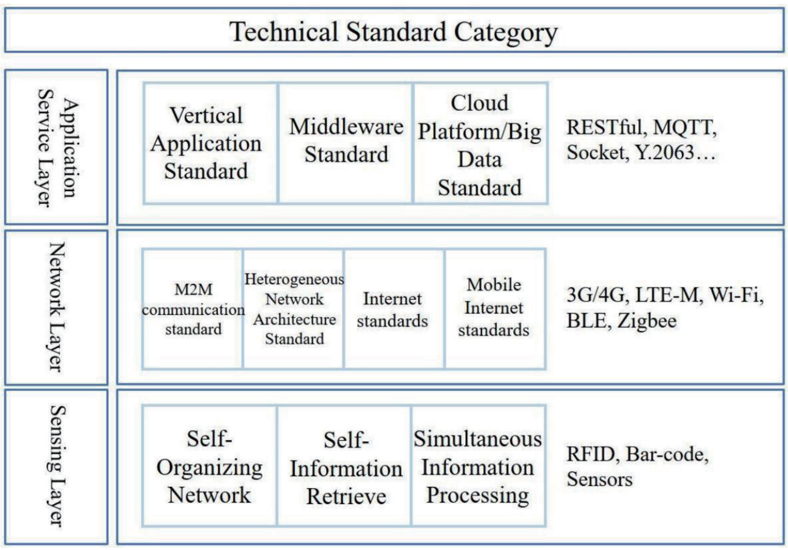

Fig. 3. (Color online) Technical standards in this study.

2.1.4 Data analysis and forecasting

The integration of sensor networks and the analysis of big data are required for the successful application of IoT devices. The former is responsible for collecting information and finding the best route to transmit it, whereas the latter enables various uses of the collected data to establish an appropriate maintenance strategy. The strategy must consider the following subjects for the efficient management of data analysis and forecasting in the IoT system.(14)

<u>Tracking and managing the data model of the IoT</u>: To create applications based on big data, the tasks of all components must be assigned in a designed system. This model defines which data are to be collected such as measurements from sensors, the amount of data, and the storage options.

<u>Platform for processing and storing data</u>: To collect data and manage the increasing amount of data, efficient and flexible expansion of the distributed storage with an appropriate computing architecture is required. Hadoop and MapReduce are currently the most common technology platforms for data management.

<u>Rule engine of managing devices and data analysis</u>: The management of devices, equipment, and data analysis requires a visual interface and platform, allowing a rule engine to be established for flexible browsing of the status and the effective buildup of the user interface. The rule engine generates activities based on individualized schedules.

<u>Autonomous cloud platform and data center</u>: A software-defined network, the IoT, and cloud computing are the key technologies and form the backbone of the IoT system.

Each international organization is responsible for establishing standard protocols for the above-mentioned strategy and the required networks as shown in Fig. 4.

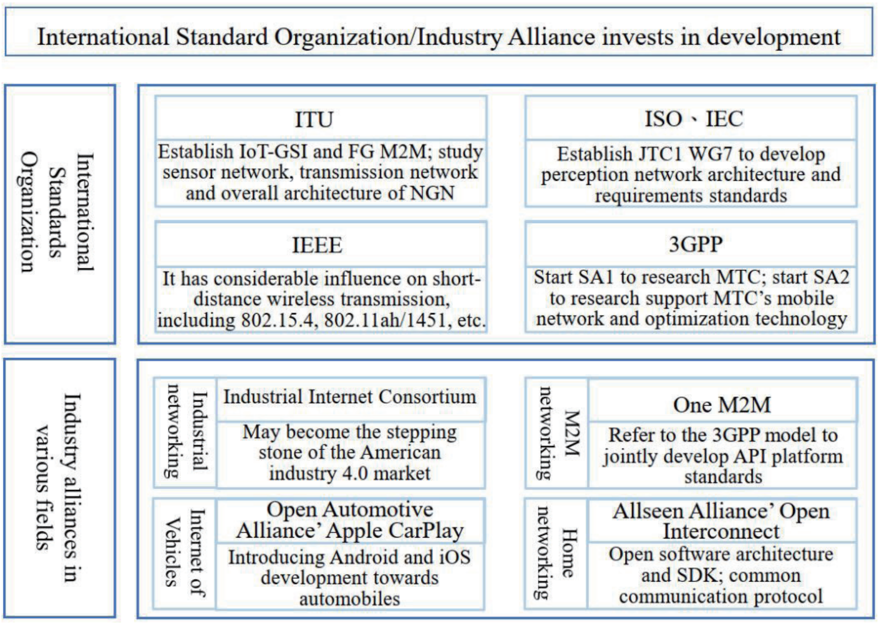

Fig. 4. (Color online) ISO/industry alliances actively involved in the development of the IoT industry.(14)

2.2 Questionnaire survey

A questionnaire based on the Delphi method was designed.[15] It contained 11 items asking about necessary platforms and technologies (Section A), problems to be solved (Section B), and necessary research and regulations (Section C). The content of the items is described in Table 2. Each item was scored according to the Likert five-point scale, with 5, 4, 3, 2, and 1 corresponding to "strongly agree", "agree", "no opinion", "disagree", and "strongly disagree", respectively. Seventy-seven correspondents replied to the questionnaire survey, among whom 44 were industry experts, 26 were academics, and seven were from the public sector.

Table 2
Questionnaire on elevator remote monitoring system given to experts.

Item	Contents
A-1	Interoperable information platform: In the data structure required by an elevator remote monitoring system, manufacturers should introduce a common open communication protocol so that they can communicate with each other and exchange required information.
A-2	Opening and integration of communication technology: Professional elevator manufacturers should try their best to open up relevant information on the communication technology level without affecting company confidentiality, so as to integrate remote monitoring platform protocols in the future.
A-3	Use of common technical components: Elevators involve various components for remote monitoring. To reduce costs and shorten maintenance time, manufacturers should cooperate in the development/use of common components.
A-4	Remote monitoring and recording: Elevator remote monitoring systems must perform 24 h uninterrupted monitoring and have equipment to record monitoring data.
B-1	Alleviating staff shortages: Remote monitoring technology of elevators can moderately reduce the frequency of maintenance with appropriate supporting measures through electronic management. This can alleviate the impact of the declining birthrate and reduce the shortage of professional elevator maintenance staff.
B-2	Remote monitoring, setup cost: The research and development of elevator remote monitoring technology have matured. The setup cost of remote monitoring will decrease with the increased adoption of technology.
B-3	Manufacturer's operating and maintenance costs: When an elevator uses remote monitoring technology, the manufacturer can effectively control the operating status of equipment in the cloud through remote monitoring. This allows the maintainer to enter the site for troubleshooting and repair only when necessary, effectively reducing the manufacturer's operating and repair costs.
B-4	User maintenance costs and failure waiting time: When an elevator uses remote monitoring technology, it can determine possible hardware failures based on collected data before they occur and take early countermeasures. This can reduce the cost and time required for repairs in the event of failure. This can effectively reduce the burden on users and reduce inconvenience caused by the inability to use the elevator during maintenance.
C-1	Revision of relevant laws and regulations: In promoting the use of remote monitoring technology for elevator equipment, it is necessary to integrate the opinions of industry, government, education, and research and cooperate with the revision of laws and regulations for their smooth implementation.
C-2	Promotional seminars and publicity: The use of remote monitoring technology for elevators requires promotion and publicity seminars for owners, users, and property managers. This will be very helpful for the wide promotion of elevators using remote monitoring technology.
C-3	Technical studies: Technical studies for the elevator industry and property management industry can be helpful for promoting the use of remote monitoring technology in elevators.

3. Results

The geometric means and interquartile ranges of the item scores were obtained to determine the concentration and dispersion measures of each item score. The results are shown in Table 3, where Q_1 and Q_3 denote the upper and lower quartiles, respectively.

All items of the questionnaire passed the interquartile test with $QD \leq 0.5$. This implies that all experts agreed on the 11 items. The geometric mean of A-4 is the highest with a value of 4.73, which shows that the experts agreed that elevator systems require a remote-control system. Experts were also in agreement with the other issues raised in the questionnaire, indicating that each suggestion in the questionnaire survey should be adopted as part of a maintenance strategy for elevator systems. On the basis of the results of the questionnaire survey, we summarize the system architecture of the remotely monitored elevator system in Fig. 5. The system comprises five components for data collection, the web interface, data pooling, the cloud platform, and applications.

Table 3
Analysis of results from questionnaire survey showing expert consensus.

Item	Geometric mean	Q3	Q1	Quartile difference (*QD*)	Kendall's W	Expert consensus
A-1	4.53	5	4	0.5		High consensus
A-2	4.60	5	4	0.5		High consensus
A-3	4.38	5	4	0.5		High consensus
A-4	4.73	5	5	0.0		High consensus
B-1	4.48	5	4	0.5		High consensus
B-2	4.47	5	4	0.5	0.56	High consensus
B-3	4.42	5	4	0.5		High consensus
B-4	4.49	5	4	0.5		High consensus
C-1	4.58	5	4	0.5		High consensus
C-2	4.45	5	4	0.5		High consensus
C-3	4.43	5	4	0.5		High consensus

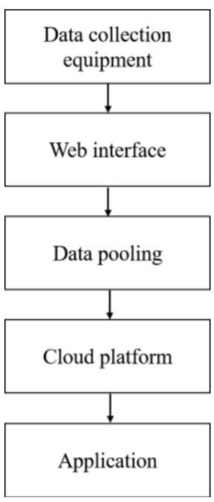

Fig. 5. Architecture of remote elevator monitoring system.

Data collection is carried out by different data collection channels including sensors, I/O devices, and devices that collect digital and analog signals, and calculations on the data are performed in real time. These data are transmitted to the controlling device of the elevator as shown in Fig. 6. The collected data are processed for transmission to the control equipment as described in Fig. 7.

We compiled 18 detection items related to the elevator remote monitoring system, as presented in Table 4, which lists the sensors and devices that detect the events and the pertaining operations that collect the related data in the remote elevator monitoring system.

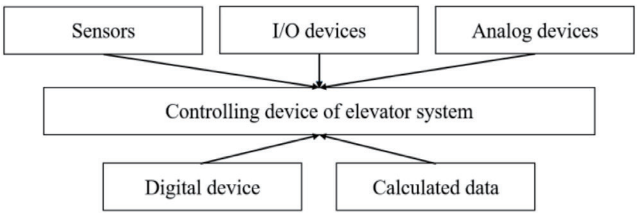

Fig. 6. Integration of data into the controlling device of the elevator system.

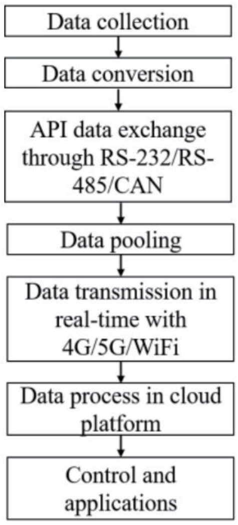

Fig. 7. Data processing of the elevator system.

Table 4
Detection items, tasks after detection, operating sensors/devices, and installation locations of remote elevator monitoring system.

Item	Task	Sensors/devices	Installation	Detected event
Disconnection of main power supply	Main power supply disconnection or reverse signal	Main contactor	Control panel	Normally open/closed
		Reverse-phase detection sensors	Control panel	Normally open/closed
		Main control board	Control panel	Main power detection
		Programmable logic controller	Control panel	Input/output contacts
Ascending and descending speed of elevator	Signaling when overspeed switch of speed governor is actuated	Overspeed switch of speed governor	Machinery room, elevator path	Normally open/closed
Brake function of elevator carriage	Signaling for car safety gear to activate interlock switch	Detection switch of safety gear actuation link (shared type)	Below and above elevator carriage	Normally open/closed
		Detection switch of safety gear actuation link (independent type)	Under elevator carriage	Normally open/closed

Table 4 (Continued)

Item	Task	Sensors/devices	Installation	Detected event
Brake function of main engine	Provides detection signal of brake detection switch without actuation command of control system	Electromagnetic brake detection sensor, normally open/closed (drum type, disc type)	Machinery room (including machinery-room-less type)	Normally open/closed
		Electromagnetic brake detection sensor, normally open/closed drum type	Machinery room (including machinery-room-less type)	Normally open/closed
Operation of main safety circuit on control panel	Detection switch disconnection signal connected in series to safety circuit	Safety circuit detector for main control board	Control panel	Safety circuit disconnection
		Signal transmission board on elevator carriage	Elevator carriage	Safety circuit disconnection signal (connected in series to safety circuit in pit)
		Safety circuit switches installed in elevator path	Elevator path	Safety circuit disconnection (connected in series to safety circuit in pit)
		Safety circuit switches installed in elevator hall and outer door on elevator carriage	Elevator hall	Safety circuit disconnection (connected in series to safety circuit in pit)
Opening and closing function of inner door on elevator carriage	Abnormal opening when carriage fails to reach position, and detection signal from switch for carriage door fully open and fully closed detection	Door position detection switch	Elevator carriage	Normally open/closed
		Closed door detection switch	Elevator carriage	Normally open
		Mechanical safety edge, light curtain safety edge	Elevator carriage	Normally open/closed
		Light curtain safety edge	Elevator carriage	Normally open/closed (high and low potential)
Overloading function of elevator carriage	Detection signal for long-time operation of carriage overload detection	Overload detection sensor (micro switch)	Elevator carriage	Normally open/closed
		Overload detection sensor (differential transformer)	Elevator carriage	Differential voltage
		Pressure gauge	Machinery room	Normally open
Safety circuit function of elevator carriage	Detection switch disconnection signal connected to safety circuit of carriage	Door closed detection sensor	Elevator carriage	Normally open
		Emergency exit detection sensor	Elevator carriage	Normally open
		Safety gear actuation detection sensor	Elevator carriage	Normally open/closed
		Emergency stop switch in operation panel or carriage	Elevator carriage	Normally open contacts

Table 4 (Continued)

Item	Task	Sensors/devices	Installation	Detected event
Limit switch function at top and bottom of elevator path	Signaling that top limit and bottom limit switches are actuated	Limit switch (installed separately at top and bottom of elevator path)	Elevator path	Normally open/closed
		Proximity switch (shared between top and bottom of elevator path)	Elevator carriage	Normally open/closed
		Non-contact type absolute positioning system	Elevator carriage	Digital transmission of absolute position
Opening and closing function of outer door on elevator carriage	Detection signal to detect that inner door and outer door must be opened or closed synchronously	Interlock switch	Outer door of elevator carriage	Normally open
		Linkage cable detection switch	Outer door of elevator carriage	Normally open
Safety circuit function in pit	Detection switch disconnection signal connected in series to safety circuit in pit	Emergency stop switch	Machinery pit	Normally open
		Switch for detecting looseness of tension wheel cable	Machinery pit	Normally open
		Buffer actuation detection switch	Machinery pit	Normally open
		Detection switch of tension wheel for balance steel cable	Machinery pit	Normally open
Pressure of hydraulic system (applicable to hydraulic type)	Detection signal of long-time overload operation or detected pressure greater than 150% of normal pressure	Safety valve pressure detection sensor	Machinery room	Pressure detection (normally open/closed)
		Pressure gauge detection sensor	Machinery room	Pressure detection (normally open contacts)
Height difference between inner door threshold and outer door threshold	Detection signal for abnormality of implantation detection switch	Implantation detection sensor	Elevator carriage	Height difference detection (normally open/closed)
		Non-contact type absolute positioning system	Elevator carriage	Digital transmission of absolute position
Running up time and running down time of elevator carriage	Detection signal of control system running over time and stopping running	Microcomputer main controller	Control panel	Program logic timer
		Timer relay	Control panel	Normally open/closed
		Programmable logic controller	Control panel	Input/output
Tightness of main cable (applicable to hydraulic type)	Detection signal of abnormal slack of main wire rope or chain	Detector switch for main cable slack	Under elevator carriage	Normally open/closed
		Detector switch for main cable slack	End of main cable	Normally open/closed
Moving elevator cars to evacuation floor	Detection signal that elevator carriage has been recalled to evacuation floor but elevator carriage has not arrived at floor within time limit	Microcomputer main control board	Control panel	Program logic
		Programmable logic controller	Control panel	Program logic, input/output contacts
		Emergency recall button	Elevator hall	Normally open/closed
		Fire signal reception switchboard	Administration room	Normally open/closed (dry contact)

Table 4 (Continued)

Item	Task	Sensors/devices	Installation	Detected event
Switching working platform on and off	Detection signal for unexpected mobile device switch activation of working platform	Unexpected device movement detection switch	Above elevator carriage	Normally open/closed
		Detection switch for switching working platform on and off	Work platform	Normally open/closed
Stopping elevator at nearest floor during power failure	Enabling control system to detect mains power failure, start nearby floor stop function	Microcomputer main control board	Control panel	Program logic
		Programmable logic controller	Control panel	Control panel
	Detection signal when elevator carriage fails to be leveled within limited time	Implantation detection switch	Elevator car	Implantation detection (normally open/closed)
		Uninterruptible power system	Machinery room	Power supply feedback

4. Discussion

The defined function of the elevator system in this study is different from that in other studies. Previously, Zhou *et al.*[9] proposed safety monitoring and operating modules for an elevator. An *et al.* developed a system to access the controlling device through web browsers for data querying, video monitoring, and alarm management.[8] In the system designed by Marinov *et al.*, the sensor unit monitored the position of the elevator using an inertial navigation system in combination with a barometric altimeter.[5] The system proposed by Zhu *et al.* used a video detection algorithm that enabled accurate and efficient monitoring.[11] The system proposed by Suárez *et al.* was implemented in a cloud platform to receive the data from the equipment of an elevator without collecting, processing, and transmitting the data for actual operation.[12] Although the results of the previous studies have improved equipment for the efficient operation of elevators, they did not consider remote control of the elevator system using the improved equipment. For the remote control of an elevator system, it is necessary to process a significant amount of data collected from a variety of sensors because there are many items to be sensed and monitored. The data allow effective judgments for the implementation of remote control. Thus, it is necessary to define the items required for the remote control of an elevator system.

Compared with the above-mentioned studies, the novelty of our research is that we propose 18 major tasks to effectively design a system that uses multiple sensors to monitor and control the operation of an elevator through data collection, processing, and transmission. The details of the monitoring items, the related sensors or devices, and their installation locations are presented as the results of this study, which will help enhance the reliability of intelligent elevator operation. The proposed design is expected to prolong the interval between the manual maintenance of elevators, reducing the time and cost of maintenance and improving the safety and service quality.

5. Conclusions

The development of new sensor technologies, the IoT, and machine learning has contributed to the realization of intelligent machinery systems. It also enables enterprises to use remote monitoring to operate systems. Elevator systems also require improved technology based on the IoT, big data, and AI technology for better maintenance and operation. Traditional elevator systems have problems such as the need for frequent manual inspection and the lack of operation data collection. When remote control is successfully applied, equipment failures can be predicted accurately to improve the safety of elevators and reduce the maintenance cost and time. It also allows the use of intelligent systems that control and maintain elevator systems autonomously. Therefore, we proposed an intelligent and remote-control system for an elevator with appropriate data collection, processing, and transmission by using multiple sensors implemented in the system. We explored the feasibility of introducing remote-control technology in an elevator system and proposed a framework for designing such a system using the results of a questionnaire survey and the Delphi method.

On the basis of the results, we defined 18 detection items to consider for the design, which include the required data with the relevant tasks, the sensors and devices to collect the data, and installation locations in the elevator system. The items include many functions for disconnecting the main power supply, controlling the speed of the elevator, operating the main safety circuit, opening and closing the elevator doors, checking the overloading of the elevator, examining the flatness of the elevator track, inspecting the function of the hydraulic system, detecting the position of the elevator, and so on. We also proposed the sensors and devices required that will help develop an improved intelligent and remote-control system for an elevator. The results of this study are expected to lead to subsequent research on the technological requirements of the equipment for sensing, monitoring, data processing, computing, and data storage. Further research is required to establish maintenance and management strategies for the proposed elevator system.

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