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Research Article

Elevator Leveling Failures Monitoring Device and Method

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Elevators are highly susceptible to safety incidents in the event of leveling failures, so the ability to monitor related failures must be strengthened. This paper proposed a new elevator leveling failures monitoring device and method in which elevator signals are obtained from the elevator CAN bus interface, transmitted to a remote monitoring platform via NB-IoT, and stored in our private data center. The leveling sensor sensing signal, the door signal, the car call signal, the target floor signal, and the running signal are obtained by analyzing the data extracted from the elevator. Logical analysis could be used to determine the elevator's running status and leveling-related failures. The device and method could identify and also predict leveling-related failures and have advantages in terms of universality, accuracy, and economy.

1. Introduction

In recent years, the number and service time of elevators have increased significantly; meanwhile, elevator failures have inevitably increased [1, 2]. As a result of this situation, elevator monitoring technologies and systems have been designed and implemented in the industry. Remote monitoring systems developed by elevator giants, represented by Otis's ONE™ system [3] in America, Mitsubishi's MelEye system [4] in Japan, and KONE's E-Link™ system [5] in the United Kingdom. These systems continuously monitor the elevator's running status in order to detect or even predict elevator failures in real time. However, these systems are expensive, and because the manufacturers do not publish the protocols [6–8], we do not know how the system monitors, what data is used for monitoring, or what the data structure is, implying that these systems are limited in universality as they could only be applied to their own brand of products. The promotion of monitoring systems has been stymied by these issues.

When the elevator is leveled normally, the car pedal and the external hall door pedal are in the same plane, and elevator leveling helps to facilitate peoples' coming in and out while reducing unnecessary damage to the elevator [9]. The incorrect judgment of elevator car position not only affects elevator efficiency, but it may also cause a series of leveling-related failures. When an elevator car position is incorrectly obtained, the consequences are severe if an accident occurs. Skog et al. [10] used signal processing to achieve elevator safety warning and monitoring. Abnormal stops were identified by monitoring the deceleration of the elevator. Luo and Feng [11] established a failure-tolerant control strategy based on neural networks and used a photoelectric encoder to realize elevator leveling. Lai and Liu [12] could analyze and calculate the target images of the elevator car floor and the elevator floor, and obtain the difference in viewpoint between the two to determine whether the elevator leveling failure occurs and alarms in time. However, these studies are relatively isolated on the leveling failure and do not investigate the internal causes or combine with the elevator's running status. In addition, some scholars have also proposed their own approaches, such as an additional leveling gauge [13] or altimeter [14] being available to monitor leveling failures. In essence, they all install sensors in the elevator shaft, which has the disadvantages of complicated installation, high cost, and the possibility of sensor false alarms, making it difficult to promote the application.

In this paper, we obtained elevator data through the CAN bus interface between the elevator controller and the control box inside the elevator, obtained the leveling sensor sensing signal, target floor signal, and operation signal of the elevator through data analysis, and used logic analysis to determine the elevator's running status and leveling-related failures. Since elevator data is transmitted in real time to the remote monitoring platform, prompt intervention could be requested in the event of leveling failures.

The failure monitoring device and method have the following advantages:

(i) universality. Modern elevators generally use the CAN bus interface, and the device and method described in this paper are not limited by the brand and model of the elevator

(ii) accuracy. Since the running data of the elevator is truly collected through the elevator serial port, and the system logically combines the leveling related failures of the elevator by itself; the failure judgment has a high success rate and is characterized by accuracy

(iii) economical. Since a large number of sensors are not used to collect elevator running data, but the elevator data is collected from the CAN bus interface, the construction cost is low and the installation is easy, which is conducive to the promotion of the system

(iv) it is possible to identify and also predict failures. When the faulted floor is the target floor or passing floor, its leveling sensor signal will show corresponding abnormal variation, thus enabling identifies and prediction of different types of leveling failures

2. Architecture and Methods

2.1. Elevator Data Collection Scheme and Transmission Method. Elevator floors are getting higher and higher nowadays, such as in residential community elevators, which are often above 30 floors. Regardless of the brand or model of elevator, data is usually transferred between the controller and the car communication board using a serial method, such as the CAN bus interface [15]. In this paper, we obtained the running data from the CAN bus interface. The specific connection method of the data collector designed by our research group [8] is shown in Figure 1.

In addition to power and ground (Vcc and Gnd), the elevator CAN bus has two data lines, Can+ and Can-. The data collector gets the elevator signal from the elevator CAN bus interface, and then transmits it to the remote monitoring platform via the NB-IoT module after processing by the microcontroller. Compared with commonly used wireless communication methods, NB-IoT has lower device costs, longer battery life, and expanded coverage [16]. It is especially advantageous for meeting wireless communication requirements for long time, light weight, high stability, and wide coverage, which is consistent with our needs. Once a failure is detected, maintenance personnel can be notified in time to intervene. The elevator monitoring system is shown in Figure 2.

2.2. Elevator Signals Could Be Obtained. Typical elevator CAN bus data includes the STEP elevator used in the experiment, including index, time, name, ID, type, format, Len and data. Although the exact form of the raw CAN bus data varies between elevators, our approach to extraction and analysis remains consistent. In general, the analysis approach is based on the principle of control variables, for example, comparing the data of an elevator at rest on the 1st floor with that of an elevator at rest on the 2nd floor, without interference from other states such as doors and running, to find the data representing the floor. Based on the above principle and methods, the following elevator signals could be obtained by analyzing the elevator CAN bus data.

Door signal is sent from the car to the elevator controller, includes the door closed and door opened signals, which represent the door closed or opened in place, respectively. And door movement signals, which are sometimes refined to opening and closing signals to indicate that the door is in movement.

Car call signal is sent from the car to the elevator controller. Under normal circumstances, whenever a car call signal is generated, it means that someone is summoning the floor inside the elevator.

Target floor signal, generally sent from the car to the elevator controller, is usually in the form of a bit to indicate the target floor. For example, 01 means the first floor is calling, 10 means the second floor is calling, and 11 means the first and second floors are calling at the same time.

Running signal is sent from the elevator controller to the car to indicates that the elevator is running up or down. The elevator's running signal is reset (low level), indicating that the elevator has stopped in place.

Leveling sensor signal is sent from the car to the elevator controller, indicating the sensing relationship of the leveling sensor to the baffle. This includes the upper sensing signal, when the leveling sensor's upper sensing node detects the leveling baffle, the upper sensing signal is activated. Similarly, there are signals with lower sensing, full sensing, and no sensing. These signals are contained in the leveling data frame's 7th byte (from high to low), beginning with 00 01. The format of these signals varies depending on the elevator's up/down/static state. With the work of data analysis, the leveling sensor signals for the STEP elevator used in the experiment are shown in Table 1.

3. Results and Discussion

We use leveling sensor signal to determine the elevator failure method as follows. Following normal elevator leveling, the car pedal and the external hall door pedal are in the same plane, and the acquisition of the car position is critical to determining the elevator leveling status. At present, elevators generally rely on the floor encoder and leveling device to determine the car's position. The leveling device generally includes leveling sensor and leveling baffle; the leveling sensor is installed on the car and runs up and down with it, while the leveling baffle is installed at a fixed position in the elevator shaft. The specific installation is shown in Figure 3.

Elevator leveling sensors generally have photoelectric sensing type and magnetic sensing type, both of which are used to determine the elevator position through the sensing

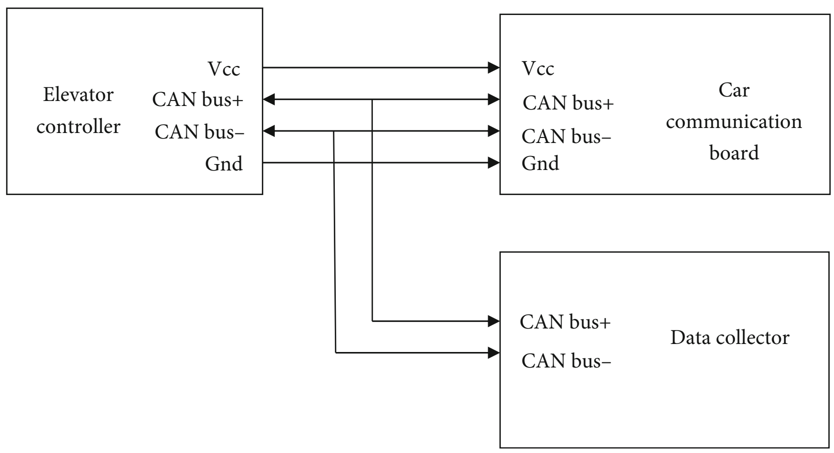

Figure 1: Connection diagram of the data collector and elevator serial interface [8].

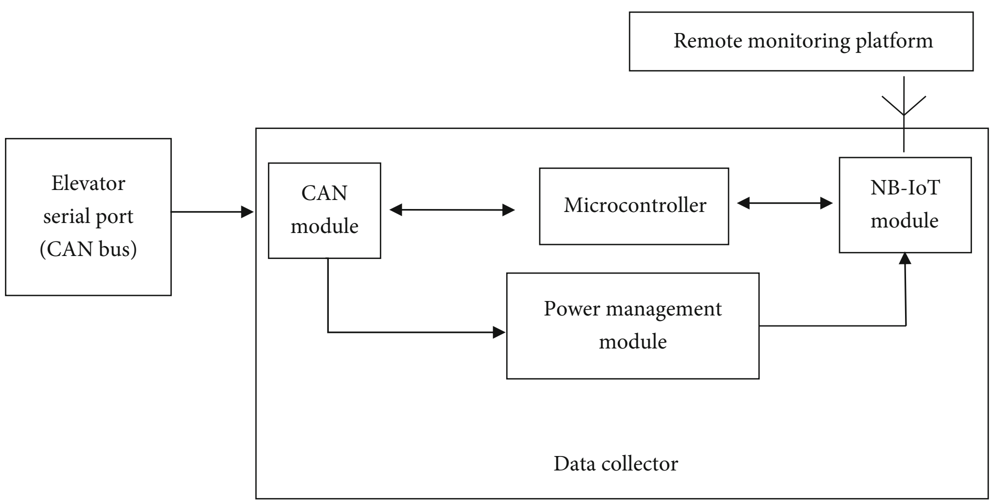

Figure 2: The structure diagram of the monitoring system.

Table 1: Correspondence between leveling sensor sensing signal and elevator running status.

Elevator/leveling sensors	No sensing	Lower sensing	Upper sensing	Full sensing
Static	00	04	08	0C
Upward	01	05	09	0D
Downward	02	06	0A	0E

(Note: The high level of the leveling sensor signal may be 0 or 1, 2 ...... its specific number has no effect on the leveling signal judgment, this paper is unified to 0.).

signal between the leveling sensor and the leveling baffle. The photoelectric sensing type sensor, which is widely used today, has two sensing nodes, upper and lower. When both sensing nodes detect the baffle, the elevator door could be accurately aligned with the elevator exit to allow personnel safe access.

Take the 2nd floor leveling sensor signal as an example in the upward movement (the downward situation is similar to the upward direction). When the elevator is inside summoned from the 1st floor to the 2nd floor, the variation of the leveling sensor signal of the 2nd floor (as the target floor) is shown in Table 2. When the elevator is inside recruited from the 1st floor to the 3rd floor (or higher floors), i.e., the 2nd floor as the passing floor; the variation of the leveling sensor signal is shown in Table 3.

However, leveling failures still occur from time to time due to signal loss, leveling baffle displacement, etc. At this time, the variation of the leveling sensor signal will differ from that shown in Tables 2 and 3.

3.1. Leveling Stopping Failure. If the target floor leveling baffle falls off or cannot be sensed, the elevator will not stop and open the door normally, but will instead continue to run up/down to find the leveling state, which is referred to as "leveling stopping failure" below.

When the leveling stopping failure occurs on the 2nd floor as the target floor, after the elevator enters the leveling range of the 2nd floor, it will not stop and open the door normally due to the lack of leveling full sensing signal, but it will be static for a short time and leveling at the floor

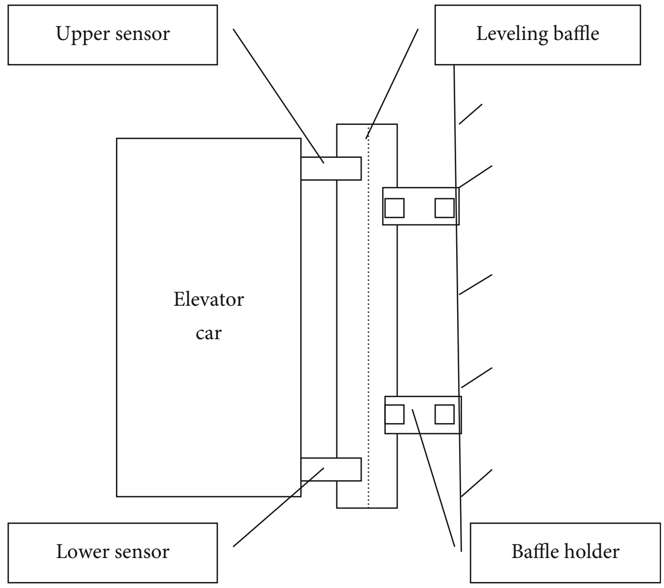

Figure 3: Elevator leveling sensor installation schematic.

Table 2: Variation of leveling sensor signal of the target floor (2nd floor) under normal condition.

Content of the 7th byte	The 7th byte means	Corresponding elevator running status
01	Upward and no sensing	The elevator enters the 2nd floor range, but has not yet sensed the 2nd floor leveling baffle
09	Upward and upper sensing	The upper sensor starts to sense the 2nd floor leveling baffle
0D	Upward and full sensing	Full sensor sensing, still running upward
0C	Static and full sensing	Elevator leveling normaly

Table 3: Variation of leveling sensor signal of the passing floor (2nd floor) under normal condition.

Content of the 7th byte	The 7th byte means	Corresponding elevator running status
01	Upward and no sensing	The elevator enters the 2nd floor range but has not yet sensed the 2nd floor leveling baffle
09	Upward and upper sensing	The upper sensor starts to sense the 2nd floor leveling baffle
0D	Upward and full sensing	Full sensor sensing, still running upward
05	Upward and lower sensing	The elevator continues to go upward; the upper leveling sensor leaves the leveling baffle, and the lower leveling sensor is still in sensing
01	Upward and no sensing	The leveling sensor completely leaves the 2nd floor leveling baffle

nearby. Correspondingly, the leveling sensor signal variation will change from “01-09-0D-0C” to “01–00”. That is, more “00” and missing “09”, “0D” and “0C”. The specific meaning could be correlated to Tables 1 and 2. Similarly, it is possible to predict the leveling failure. When the leveling stopping failure occurs on the 2nd floor as a passing floor, the 7th byte of the leveling data will change to: “01-01”, continuously going up and no sensing, missing “09” “0D “05”, but since the 2nd floor is not the target floor, the elevator will still running upward normally. Elevator data is transmitted to the data center of the monitoring system in real time through the data acquisition board, so that in the event of leveling without stopping failure, failure judgment and prediction could be made based on the sequence variation of signals.

Traditionally, leveling stopping failure could only be identified when the elevator reaches the floor with failure, which means the passengers have to experience the leveling failure. With the elevator monitoring system, however, once

Table 4: Variation of leveling sensor signal at the target floor (2nd floor) in case of leveling alignment failure.

Content of the 7th byte	The 7th byte means	Corresponding elevator running status
09	Upward and upper sensing	The upper sensor starts to sense the 2nd floor leveling baffle
0D	Upward and full sensing	Full sensor sensing, still running upward
05	Upward and lower sensing	The elevator continues to go upward; the upper leveling sensor leaves the baffle, and the lower leveling sensor still senses
04	Static and lower sensing	Elevator static for a short time
06	Downward and lower sensing	The elevator reruns and goes down to find the full sensing state
0E	Downward and full sensing	Full sensor sensing, still running downward
0C	Static and full sensing	Elevator ends running downward, and the inner door opens

Table 5: Variation of leveling sensor signal at the target floor (2nd floor) in case of leveling cycling failure.

Content of the 7th byte	The 7th byte means	Corresponding elevator running status
01	Upward and no sensing	The elevator enters the 2nd floor range but has not yet sensed the 2nd floor leveling baffle
09	Upward and upper sensing	The upper sensor starts to sense the 2nd floor leveling baffle
05	Upward and lower sensing	The elevator continues to go upward; the upper leveling sensor leaves the baffle, and the lower leveling sensor senses
04	Static and lower sensing	Elevator static for a short time, lower leveling sensor senses
06	Downward and lower sensing	The elevator reruns and goes down to find the full sensing state
0A	Downward and upper sensing	Elevator running downward; lower leveling sensor leaves the baffle, and upper leveling sensor senses
......	......	......
……	……	……

Table 6: Variation of leveling sensor signal at the passing floor (2nd floor) in case of leveling cycling failure.

Content of the 7th byte	The 7th byte means	Corresponding elevator running status
01	Upward and no sensing	The elevator enters the 2nd floor range but has not yet sensed the 2nd floor leveling baffle
09	Upward and upper sensing	The upper sensor starts to sense the 2nd floor leveling baffle
05	Upward and lower sensing	The elevator continues to go upward; the upper leveling sensor leaves the baffle, and the lower leveling sensor still senses
01	Upward and no sensing	The leveling sensor completely leaves the 2nd floor leveling baffle

the data is abnormal as described above, it will be detected in real time by the system, and it only requires the elevator to pass through the floor to determine the failure and provide an early warning. Taking a 30-floor community building as an example, the probability of which the failure floor happens to be the target floor is only about 3%, while 97% of the failures could be detected in advance, thus passengers experiencing the relevant failure could be greatly reduced.

3.2. Leveling Alignment Failure. If the leveling baffle is misaligned due to loose screws or other factors, it will usually move down relative to the normal position due to gravity. When the

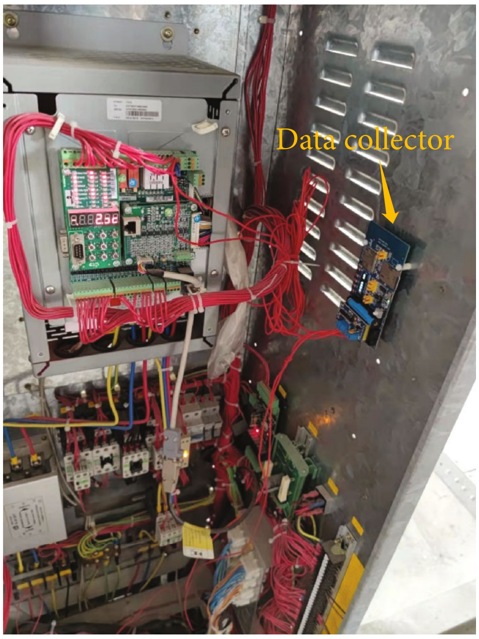

Figure 4: The installation of the data collector in the actual elevator.

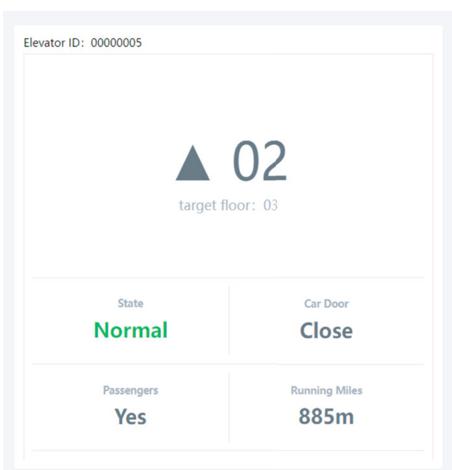

Figure 5: Elevator in normal condition.

elevator reaches the normal levelling range, due to the downward shift of the leveling baffle, the leveling sensor is lower sensing instead of full sensing, and the elevator will not open the door but continue to go down to find the full sensing state of the leveling sensor. Because of the deviation from the leveling range, the floor encoder will judge that the elevator is not in a leveling state, and the outer door will remain closed and the power off. In this case, "leveling alignment failure" described below occurs. Take the 2nd floor as the target floor as an example, when the 2nd floor leveling baffle moves down and leveling alignment failure occurs, the variation of the leveling sensor signal is shown in Table 4.

It can be seen that when the elevator has a leveling alignment failure due to the leveling baffle moving down, there is a variation of "09—0D—05—04—06—0E—0C" (Table 4) compared to the normal leveling sensor signal variation of "09—0D—0C" (Table 2). When the failure occurs, the inner door opens, while the outer door remains closed, which could result in trapping if there are passengers inside.

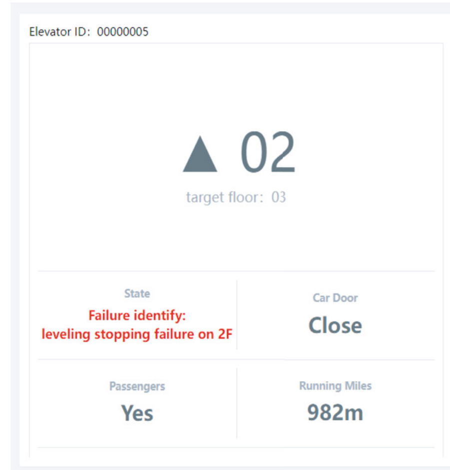

Figure 6: Failure identify.

The leveling sensor signal is transmitted in real time to the monitoring system's data center, and the elevator leveling alignment failure could be identified based on its variation sequence and timely maintenance could be carried out.

3.3. Leveling Cycling Failure. The elevator opens only when the leveling sensor finds the full sensing state. However, if the leveling baffle becomes shorter due to corrosion, fracture, or other reasons, and the length is less than the distance between the upper and lower sensing nodes of the leveling sensor; the sensor would be unable to reach the full sensing state, and the elevator would move up and down in the normal leveling range cycle, unable to leveling the floor. It is the "leveling cycle failure," which is described as follows:

As an example, consider the 2nd floor. If the leveling baffle on the 2nd floor becomes too short to allow the leveling sensor to reach its full sensing state, the procedure of the elevator inside summoned from the 1st floor to the 2nd floor is as follows: After the elevator senses the upper leveling sensor, it continues to go up normally to the lower leveling sensor, but the upper leveling sensor no longer senses the baffle at this time. After a brief pause, the elevator moves downward to find the full sensing state. When the lower leveling sensor is sensing, the upper level sensor is no longer sensing the baffle. After a brief pause, the elevator moves up. So on and so forth, cycling upward and downward until the leveling full sensing state is reached. The variation of the 2nd floor leveling sensor signal under this failure is shown in Table 5.

This is a rare occurrence, but when it occurs, the elevator will cycle up and down in the vicinity of the failure floor leveling range without opening the door, causing serious physical and mental harm to passengers. Furthermore, since it is the normal operation logic of the elevator to look for the full sensing state, the elevator will not actively determine the failure.

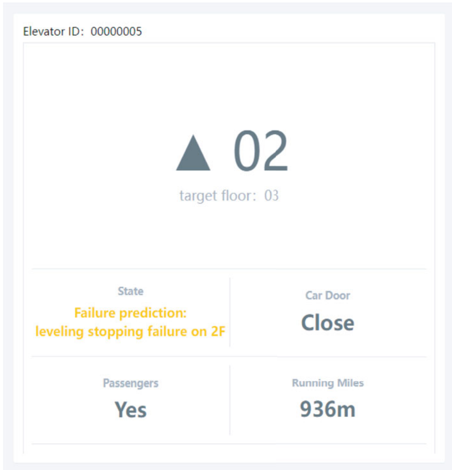

Figure 7: Failure prediction.

The leveling sensor is missing full sensing “0D” between upper sensing “09” and lower sensing “05.” Once the monitoring system detects such an anomaly in the data, it could identify the leveling cycling failure and issue an alarm.

Similarly, the leveling sensor signal could be used to predict the leveling cycling failure. When the 2nd floor is used as a passing floor, that is, when a passenger runs from the 1st floor to the 3rd floor (or higher) and passes through the 2nd floor, the leveling sensor signal variation shown in Table 6.

Compared to the normal state of Table 3, it can be found that the leveling sensor is missing the full sensing “0D” between the upper sensing “09” and the lower sensing “05” in Table 6. Once the monitoring system detects such anomalies in the data, it could make failure predictions and notify maintenance personnel to intervene in advance.

3.4. The Leveling-Related Failures Monitoring Method. To summarize, the judgment method of leveling-related failures is as follows. When the elevator arrives at a particular floor, it first determines whether it is the target floor or the passing floor based on the target floor signal, and then obtains the sequence of leveling signal variations for the current floor and compares it to the variations under normal condition in Tables 2 and 3. If the variation differs from the normal state, it is possible to conclude that the elevator has a leveling failure.

Furthermore, the specific failure type is determined, and the corresponding identification or prediction is generated in conjunction with Tables 4–6. What is more, if a new type of unknown failure emerges, we could add its sequence variations to the monitoring system and constantly update and optimize the failure judgment strategy. The above description is for the monitoring method when the elevator is in the upward movement; the specific signal when the elevator is in the downward movement is different (as shown in Table 1), but the method is the same.

The installation of the data collector in the actual elevator is shown in Figure 4, which can be corresponded to Figure 1, where the data collector connects the CAN+ and CAN- data lines of the elevator and sends them to the remote monitoring platform via the NB-IoT module. In the experiment, we used the leveling stopping failure of the 2nd floor as an example. The elevator’s running status and level-related faults can be reflected visually. The page of the monitoring platform when the elevator is in the normal state is shown in Figure 5. The page of the monitoring platform for identifying the leveling stopping failure is shown in Figure 6. The page of the monitoring platform for predicting the leveling stopping failure is shown in Figure 7. The experimental results support the efficacy of our device and method.

4. Conclusions

This paper extracts the elevator’s door signal, car call signal, target floor signal, running signal, and leveling sensor signal, and then monitors leveling failures by analyzing the real-time variation sequence of the elevator leveling sensor signal. Whether the elevator is leveling normally is determined. If a leveling failure occurs, the type of failure is identified based on the leveling variation. Based on the failure judgment, timely maintenance is possible.

The device and method are not limited by elevator brand and signal, so they have advantages in universality. Furthermore, raw CAN bus data is collected by data collectors and stored in our private data center, and it could accurately identify failures by logical analysis and is inexpensive because no additional sensors are required. Since the monitoring of the elevator’s CAN bus interface, leveling failures can be identified and predicted once the leveling sensor signal show the corresponding abnormal variations.

Data Availability

Raw CAN bus data is collected by the data collector and stored in our private data center. If you would like more detailed information about CAN bus data, please contact our corresponding mail and state your intention and purpose. We will sincerely consider your request at our discretion and try to accommodate you.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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