The Real-Time Elevator Monitoring System Based on Multi-sensor Fusion

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Abstract. In recent years, the number of elevators has increased dramatically as the increase of high-rise buildings. The safety monitoring of elevators, a matter of people’s security, becomes more and more important. This paper proposed a real-time elevator monitoring system, which can rapidly and accurately diagnose the faults and abnormal states of the elevator based on the real-time operation data acquired from multi sensors. The proposed multi-sensor fusion algorithm effectively ensured the stability and reliability of the system. The real-time monitoring result was easily accessed using web client on various platforms via the local network, which also can be sent to the cloud platform realizing the remote access. The test result of the system demonstrated its usefulness.

1. Introduction
With the rapid development of the construction industry in China, elevators as the transport devices in high buildings become more and more popular [1]. The safety of elevators is increasingly demanded since the accident of elevators would cause loss of life and property. According to statistics, in 2017, there were a total of 56 elevator accidents in China, resulting in 41 people killed and more than 20 people injured [2]. In order to rapidly and accurately diagnose the faults and abnormal states of the elevator, reducing the incidence of accident, the real-time elevator monitoring system is critical.

In most conventional cases, elevators were maintained periodically by the engineers from the elevator company which is high-cost, time-consuming and labour-intensive. This method is subjective and passive leading to the incapability of finding faults of the elevator in time. Therefore, more and more elevator monitoring systems have been proposed. Hsu et al. [3] proposed the machine learning procedure for developing the diagnosis method for the failure detection of elevator doors. Zhang et al. [4] developed a method of fault diagnosis for elevator door based on multi-agent system technology. Liao et al. [5] introduced the virtual instrument technology into the elevator diagnosis field, demonstrating a safety monitoring and alarm system. Gao et al. [6] used a smart phone which was authorized to access the elevator internal system to real-time monitor the vibration and noise of the elevator. These researches mostly focused on the door’s faults of the elevator. However, the diversity of the faults of the elevator need more dimensional data. In the paper, we described a real-time elevator monitoring system based on multi-sensors fusion algorithm, ensuring detecting most of common faults in the elevators.

2. System overall design
The overall design of the proposed system was shown in Figure 1. The system installed on the top of the elevator car moved up and down with the elevator. The sensors in the system acquired all kind of
real-time data from the moving elevator. The computing center as the kernel module processed the data by using the proposed fusion algorithm, then presented the results on the web-client by which the human-computer interaction could be realized. Furthermore, the above results would be transferred to the cloud via the message queuing telemetry transport (MQTT) protocol and file transfer protocol (FTP), achieving the remote monitor of the elevator.

3. **Hard system design**

The hard system composed of computing module, power module, network module and sensor module was designed as Figure 2. The algorithm and software were running on the computing module. The power module was responsible for supplying power to the system in a variety of environments. The network module made the system link to the Internet, ensuring the data communication and remote access. The sensor module consisted of multi sensors such as magnetic switches, network camera, barometer and accelerometer, acquiring the real-time data of the elevator.

![Diagram of the hard system](image)

Figure 2 The design of the hard system.

The actual hard system described in Figure 3 was developed according to the above design. The system can be powered by 220V alternating current via the power module composed of air switch and switching supply which could ensure electricity safety and voltage conversion, respectively. Huawei
portable WIFI was used as the network module in the system, ensuring the access to Internet via WIFI. Jetson Nano with high computing performance was selected as the computing module equipped with RJ45 network port and the expansion board for multi sensors mounting. There were three magnetic switches in the system being used to detect the opening/closing status of the elevator door and determine the elevator was on the levelling floor or on the first floor. BMP-180 and MS5611 were responsible for acquiring the air pressure and acceleration along the direction of elevator motion, respectively. The original network camera of the elevator was connected to the RJ45 port to acquire the video data inside the elevator car.

4. Algorithm and software

The algorithm and software architecture of the proposed system was presented in Figure 4. The temperature and barometric data from BMP-180 were used to compute the altitude of the elevator. The altitude and the signal of “first-floor-status” were fused to get the relative altitude which was subsequently fused with the signal of “levelling-floor-status” to calculate the floor num of the elevator. On the other hand, the acceleration data from MS5611 were fused with the relative altitude to acquire the speed and the up/down information of the elevator.

The monitoring algorithm was carried out based on the status data of the elevator. The deep learning detection model based on the YOLOv4 [7] was constructed in the algorithm to process the video data for detecting whether there were people and foreign objects (such as animals and battery powered vehicles) in the elevator car. The door switch was fused with the other information of the elevator to
diagnose the common faults, for example, the door opened and closed repeatedly, or the door opened while the elevator moved, or the door cannot open when the elevator stopped on the levelling floor. The other faults such as the abnormal speed of the elevator (e.g. greater than the normal value) and stopping at the non-levelling floor, can also be diagnosed from the above-mentioned algorithm. The monitoring results composed of images and text data were stored in the database of the software background which can be accessed from the web client or the cloud.

5. Experiment

Experiments were carried out in the actual elevator environment where the total number of floors is 18. The sensors of the proposed system were installed on the elevator. Meanwhile, the model DS-2CD3525FV2-L network camera of the elevator purchased from Hikvision was connected to the system to acquire the video data. The partial sensing data was described in Figure 5 which revealed the principle of the proposed fusion algorithm. The barometric data (Figure 5a) and the signal of “levelling-floor-status” (Figure 5b) indicated the relationship between the barometric value and the floor num. There were peaks in the acceleration data (Figure 5c) when the elevator started to move which were used to determine the up/down information of the elevator. The differential of the barometric data and the integral of the acceleration data were used to calculate the speed of the elevator.

![Figure 5](image-url)

Figure 5 The partial sensing data in the experiments. (a) The barometric data; (b) The signal of “levelling-floor-status”; (c) The acceleration data.

The developed web client in the experiments showed the monitoring results of the elevator. The screenshot of the running client was presented in the Figure 6. The status information of the elevator such as the floor num, the speed, the up/down status, the door opened/closed status can be accessed easily from the client. In addition, the status of the elevator car was monitored via the video data, real-timely being presented in the client. Furthermore, the fault status on the client would change to the corresponding fault information once faults were emerging on the elevator, ensuring the timeliness and the accuracy of status-presenting.
6. Conclusion
The real-time elevator monitoring system based on multi-sensor fusion was developed in this paper. With the help of this system, the running status and the common faults of the elevator can be efficiently identified, improving the efficiency and safety of the elevator management.

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