MEASUREMENT SCIENCE REVIEW, **25**, (2025), 15-21

sciendo

ISSN 1335-8871

MEASUREMENT SCIENCE REVIEW

Journal homepage: https://content.sciendo.com

Elevator Operation Health Diagnosis using Vibration Region Segmentation Algorithm via Internet

Hsiung-Cheng Lin*, Yan-Hao Peng

Department of Electronic Engineering, National Chin-Yi University of Technology, Taichung, Taiwan
hclin@ncut.edu.tw, yanhao951206@gmail.com

Abstract: The safety of elevator operation is an indispensable issue in the elevator industry. The most important factor affecting the elevator performance is car vibration. For this reason, vibration analysis is considered an important topic for elevator maintenance as it can be used to detect potential problems before breakdown. Currently, vibration measurement is typically performed using vibration analyzers operated by personnel, resulting in a time-consuming process and experience-dependent interpretation. While there are some machine learning algorithms that are used to diagnose elevator condition, their computational complexity still makes it difficult to translate into a real-world application. Therefore, in this study, the elevator condition diagnosis model is developed using a simple vibration region segmentation method. Based on the elevator operation characteristics, the cut-off point is determined by the abrupt acceleration variation condition to define the acceleration segment region. With the binarization process, the digital array is used at each time of acceleration variation to evaluate the state of elevator operation. Normally, the elevator operation can be divided into five segments, e.g., start up, acceleration, steady state, deceleration, and stop. The rule for determining the critical point for segmentation is thus formulated based on an abrupt acceleration change. If the number of segmented areas exceeds five, it can be considered as an abnormal case. To develop the system, the elevator vibration data is collected by a 3D accelerometer and then processed in the PC using the proposed algorithm. The results are then transferred to the cloud for online monitoring. The experimental results show that the proposed model is quite simple but effective for elevator diagnosis and maintenance.

Keywords: elevator, diagnosis, vibration, segmentation, accelerometer

1. Introduction

Elevator vibration has become an increasingly common and frequent problem with the rise of high-rise buildings around the world. Abnormal elevator vibrations can lead to elevator car riding discomfort. In a serious situation, they can cause high levels of dynamic stress in the elevator structure, damaging the elevator system or even risking serious safety accidents. Underlying sources of elevator vibration include misaligned guide rail joints, rope sheaves, eccentric pulleys, systematic resonances in the electronic control system, vibrations generated by gears and motors, etc. [1]-[3]. The vibration can originate from the elevator rope, for example, which can resonate with the natural frequency of the building. To avoid resonance, a vibration suppressor can be a solution to change the natural frequency of an elevator rope [4]-[5]. For this reason, some studies have particularly focused on the vibration characteristics of wire-ropes [6]-[9]. However, there is still a lack of effective and simple evaluation methods to reveal the relationship between the vibrations and elevator performance [10]. Therefore, the development of preventive measures related to elevator vibrations is an indispensable task in the industry [11].

Based on the one-dimensional characteristics of the vibration signal, an elevator operation fault monitoring method using a one-dimensional convolutional neural network was proposed [12]. The elevator vibration signals were preprocessed by value decomposition (SVD) and wavelet transform. The wavelet transform was then used to extract wavelet energy features from the original vibration signals. Although the processing required less complex feature extraction processes, it was still not comprehensive enough to achieve the expected goal. Also, the selection of different layer parameters during the network process required several attempts to achieve better performance results. Alternatively, based on a case of elevator vibration, abnormal vibration of the elevator was found through on-site investigation, instrument test, and vibration mechanism analysis [13]. It was found that elevator vibration is determined by the characteristics, mechanism of vibration and on-site situation. It proposed a series of methods that can be used to improve the comfort of the elevator. To detect abnormal states of elevators, an anomaly detection model was developed using vibration analysis of horizontal vibration signals and the Isolation Forest algorithm [14]. In this study,

DOI: 10.2478/msr-2025-0003

**Corresponding author: hclin@ncut.edu.tw (H.C. Lin)*

the Weiszfeld algorithm was used to estimate gravity acceleration from the decomposed acceleration signal of elevators. In addition, Kalman filtering was introduced to reduce error accumulation. However, the fault detection of elevator door systems was not sufficiently considered, relying only on an unsupervised learning process. Therefore, it was difficult to fully explore the deep data information.

In order to obtain reliable and sufficient data for training the fault diagnosis model, a numerical model of the vertical elevator vibration with three degrees of freedom was created [15]. The obtained equations of motion were used as constraints to obtain simulated vibration data by a physics-informed neural network. Then, the Enhanced Relational Graph Convolution Network was used for elevator fault diagnosis. Experimental validation showed that the accuracy of the proposed model reached 96.61 %. However, it may not be applicable in a real environment due to the highly complex processes involved. Alternatively, a hybrid method combining the Weight-Minkowski method and the Distance-Improved GRA evaluation method was developed for the condition evaluation of the elevator operation [16]. First, the relationship between the vibrations and the performance was analyzed. Based on the characteristics of the vibration data, the sensitive ones were selected as evaluation indexes to determine the actual health status of the elevators. The disadvantage is that the results of the performance analysis are highly dependent on the selected data. Accordingly, it may be difficult to transfer them to industrial applications. Furthermore, a denoising method based on a deep residual U-Net was introduced to mitigate the noise in the vertical vibration signals of elevator cars [17]. The proposed convolutional neural network was successfully constructed with skip connections and a multi-scale convolutional structure. Although it has high potential for practical applications, it was only suitable for the case where significant noise occurs due to the elevator car vibrations.

2. DESCRIPTION OF THE SYSTEM STRUCTURE

The proposed system structure is shown in Fig. 1, and the system hardware installed in the elevator car is shown in Fig. 2. The system is implemented based on three performance sides, i.e. data acquisition, data processing, and personnel operation. First, in data acquisition, a 3D accelerometer (LSM6DSR) is used to detect the elevator car vibrations, i.e. acceleration, during elevator operation. Secondly, the acquired vibration data is sent to the data acquisition microprocessor (dsPIC33CK64MP506) via I2C. On the data processing side, the collected data is transmitted to the data processing microprocessor (dsPIC33CK64MP506) via RS485 to process the elevator diagnostic model. The processed data is then saved to a USB flash drive via the file management chip (CH376). SRAM is used to temporarily store the acquired data before sending it to a USB flash drive, using SPI as the communication protocol between the microprocessor and SRAM. On the other hand, system critical data is stored in EEPROM and I2C protocol is used for communication between EEPROM and microprocessor. A real-time clock is used to record the system working date and time. On the personnel operation side, the personal computer (PC) can receive the USB data and then run the proposed diagnostic model. The results obtained from the model implementation are then sent to the Microsoft SQL server via the router using TCP/IP.

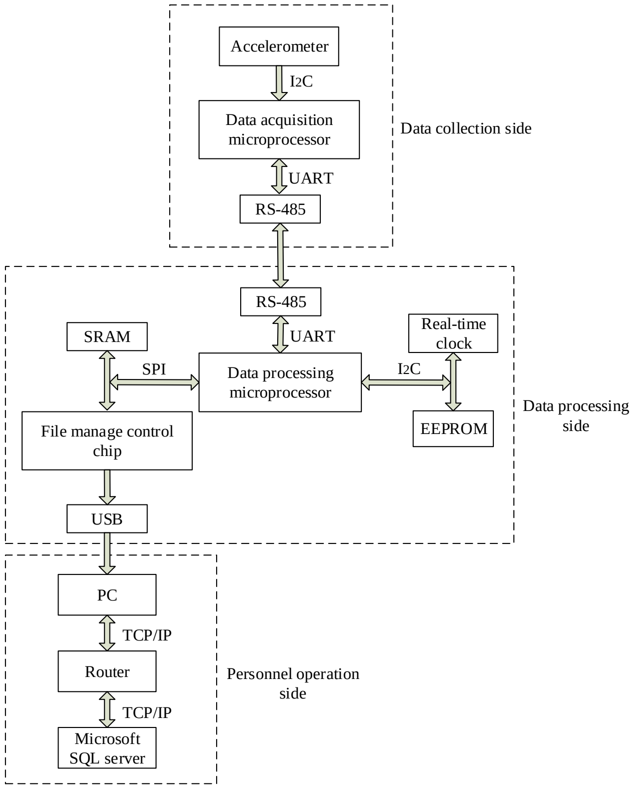


Fig. 1. System structure.

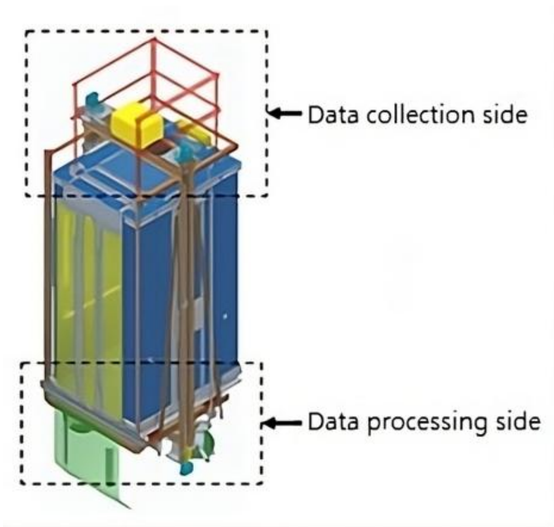
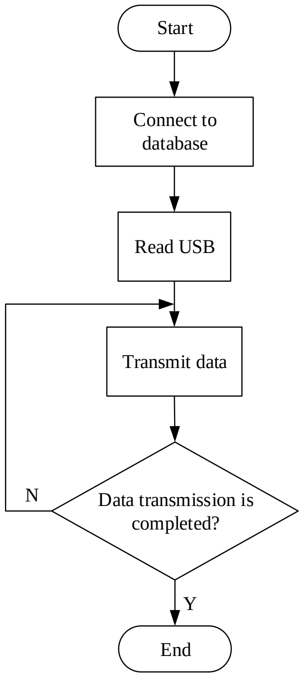


Fig. 2. System hardware installation.

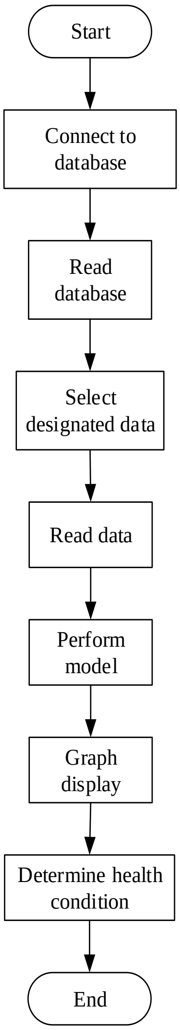
3. THE PROPOSED MODEL

A. *The system processing flowchart*

The system processing flowchart is shown in Fig. 3. It is divided into two tasks: (1) The acquired data stored on the USB flash drive is transferred to the cloud database. (2) The acquired data is read from the database for model performance.



(a) Data transmission process.



(b) Data reception and processing.

Fig. 3. Model processing.

Fig. 3(a) shows the vibration data transferred to the database as follows:

1. Start the connection with the database.
2. Read USB data.
3. Transfer the data to the database. Assume the data file path is 2022/03/25 with the file name: 14-28-06, so the classified file is named T220325142806. In other words, T220325142806 stands for year: 2022, month: 03, date: 25, hour: 14, min.: 28, sec.: 06.

Fig. 3(b) shows the vibration data received from the database as follows:

1. Connect the database.
2. Read the database.
3. Select the designed data file.
4. Read the designed data file.
5. Display a graph and determine the health status.

B. The principle of vibration region segmentation algorithm

In reality, the elevator acceleration value can change abruptly from one status to another, including four situations such as zero to negative, negative to zero, zero to positive, or positive to zero. Based on these phenomena, the cut-off point, which is considered as the turning point, is determined by the abrupt acceleration variation jerk $j(t)$, which is used to segment the acceleration region.

The jerk $j(t)$ is expressed as

$$j(t)=\left|\frac{\Delta a(t)}{\Delta t}\right| = \left|\frac{a(t2)-a(t1)}{t2-t1}\right| \quad (1)$$

where $a(t)$ is the elevator acceleration value at time t, i.e. in the time domain. $a(t2)$ and $a(t1)$ are the elevator acceleration values at time $t2$ and $t1$, respectively, and $t2 > t1$.

With the binarization process using n sampled points, $j(t)$ can be converted into a discrete form $j(n)$. The segmentation value DJ_i using the cut-off point of the acceleration region is defined as

$$DJ_i = \begin{cases} 1, j(i) = 0 \text{ and } j(i+1) > 0, \text{or } j(i) > 0 \text{ and } j(i+1) = 0 \\ 0, \text{ else} \end{cases} \quad (2)$$

where $1 \le i \le n,$ and $i, n \in$ positive integer

Based on the array structure, the digital array $DJ[n]$ is defined using the data set of DJ_i, expressed as

$$DJ[n] = [DJ_1, DJ_2, \ldots\ldots, DJ_n] \quad (3)$$

To evaluate the elevator operation status, TQ is defined as the total amount of DJ_i contained in $DJ[n]$, expressed as

$$TQ = \sum_{i=1}^{n} DJ_i \quad (4)$$

where $i, n \in$ positive integer.

4. Results

A. Data transmission and reception

(a) Data transmission processing

The data transmission processing procedures based on Fig. 3(a) are described as follows:

1. Enter the operation main panel, as shown in Fig. 4.

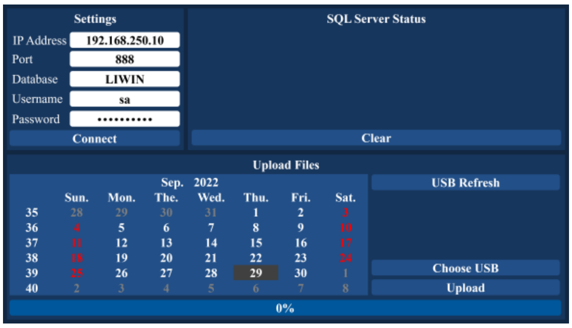


Fig. 4. Main front panel of data transmission.

2. Click "Connect" to connect the database, as shown in Fig. 5.

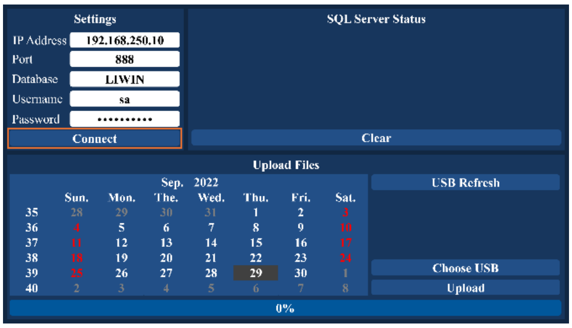


Fig. 5. Connection with server.

3. Click "Choose USB" to read the acquired data, as shown in Fig. 6.

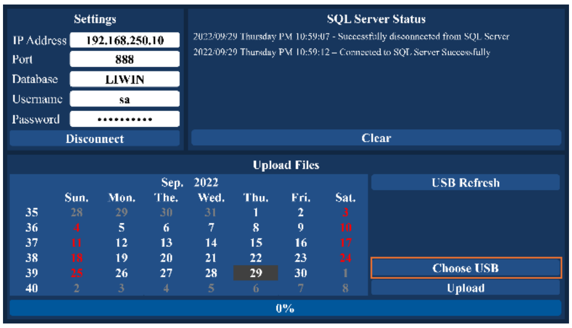


Fig. 6. Selection of USB.

4. Click "Upload" to upload the data file, as shown in Fig. 7.

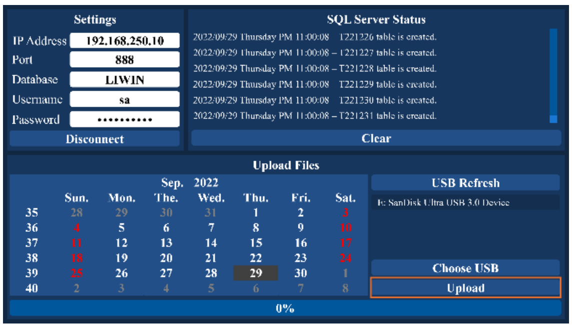


Fig. 7. File upload.

5. The upload process is completed (100 %), as shown in Fig. 8.

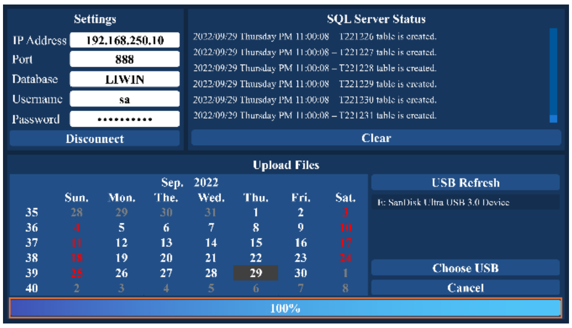


Fig. 8. File uploading progress.

(b) Data processing

On the server side, the data processing procedures based on Fig. 3(b) for are demonstrated as follows:

1. Enter the server main panel, shown in Fig. 9.

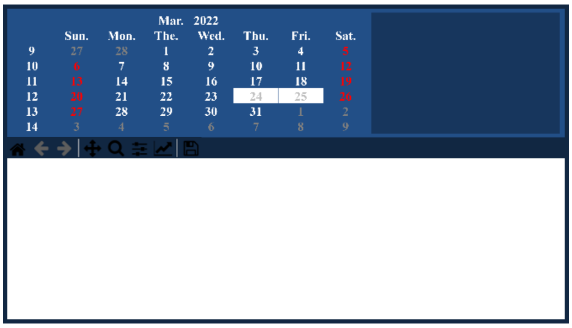


Fig. 9. Server front panel.

2. Select the desired date, as shown in Fig. 10.

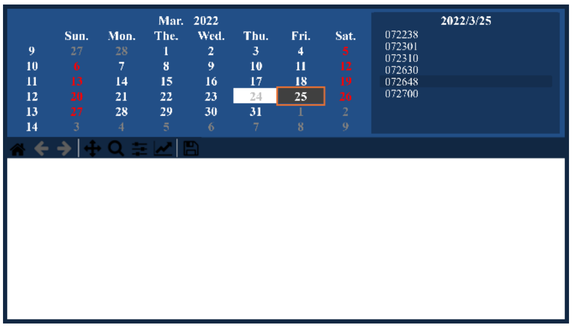


Fig. 10. Selection of desired date.

3. Select the desired file, as shown in Fig. 11.

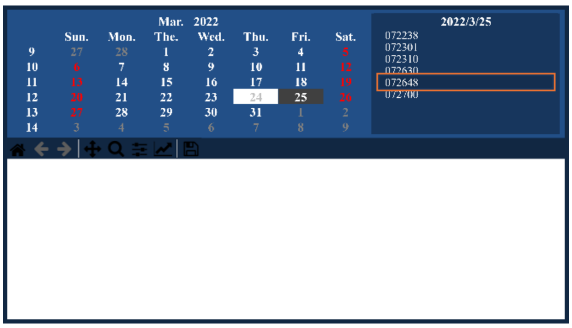


Fig. 11. Selection of desired file.

4. Display the vibration data and calculate the moving distance, speed and jerk of the elevator car, as shown in Fig. 12.

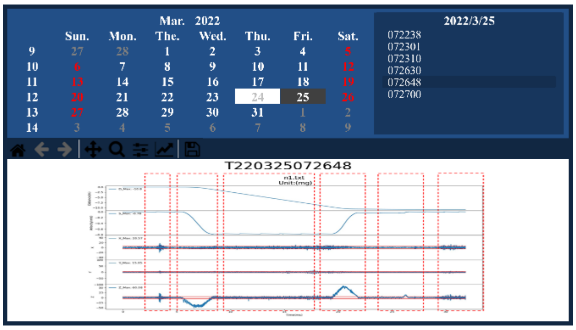


Fig. 12. Display of vibration data.

B. Experimental results

In this study, both normal and abnormal cases were recorded and analyzed during the elevator ride, as shown in Fig. 13 - Fig. 18. Each figure shows the crucial elevator operation curves in terms of Acceleration X (mg), Acceleration Y (mg), Acceleration Z (mg), Distance (m), Velocity (m/min.) and Jerk (m/s^3), respectively, from top to bottom. Note that 1 g = 9.8 m/s^2 = 1000 mg. In reality, the elevator moves mainly in the vertical direction, so only the Z acceleration is used for the analysis of the proposed model. In Fig. 13 and Fig. 14, the elevator was moving up to different floors in a normal situation, i.e. three and four floors in total. It can be seen that the elevator travel time in Fig. 14 is relatively longer than in Fig. 13, i.e. 20 sec. compared to 14 sec., as a higher floor is reached. Nevertheless, both cases have the same acceleration and deceleration intervals, i.e. 4 sec. and 3.5 sec., respectively.

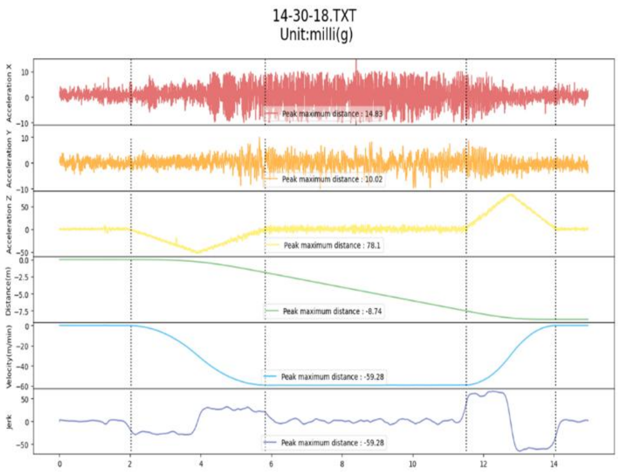


Fig. 13. Normal elevator operation within three floors.

In the abnormal cases, Fig. 15 - Fig. 18, there are more than five segments to be identified than in the normal case. In Fig. 15 and Fig. 17 the elevator is going down and it is going up in Fig. 16 and Fig. 18. It can be seen that Fig. 15 and Fig. 16 have excessive vibration segments, i.e. six and nine, respectively. Fig. 17 and Fig. 18, on the other hand, have more segments, eleven and twenty-one, respectively. Obviously, in all cases, an unexpected vibrations occur more frequently than usual during elevator operation.

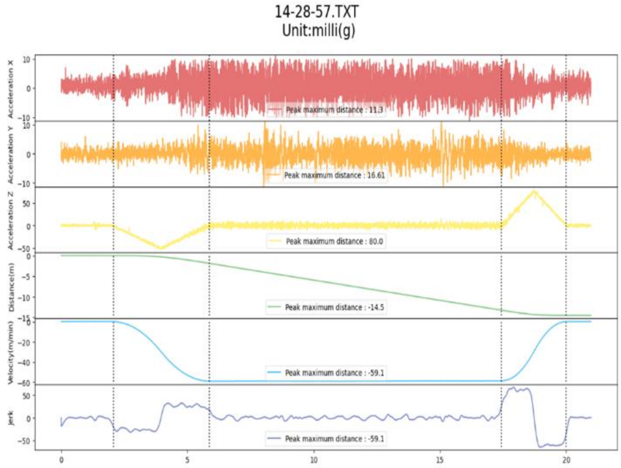


Fig. 14. Normal elevator operation within four floors.

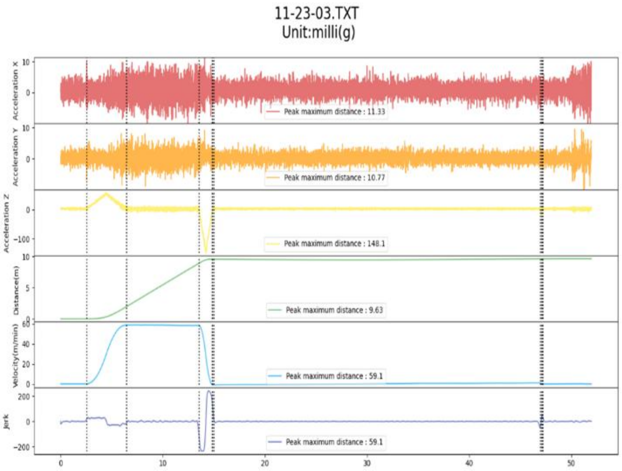


Fig. 15. Abnormal elevator operation with six segments.

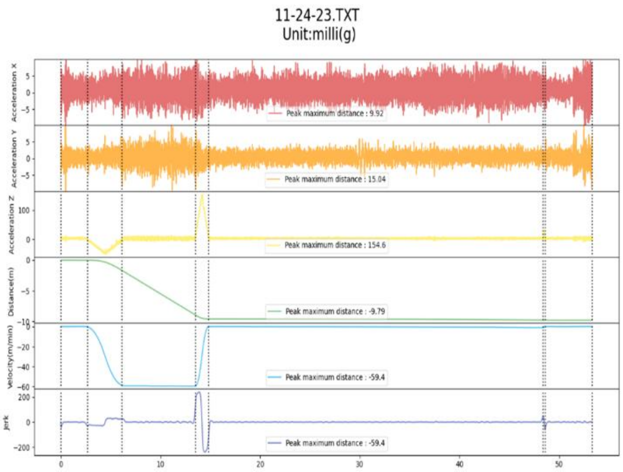


Fig. 16. Abnormal elevator operation with nine segments.

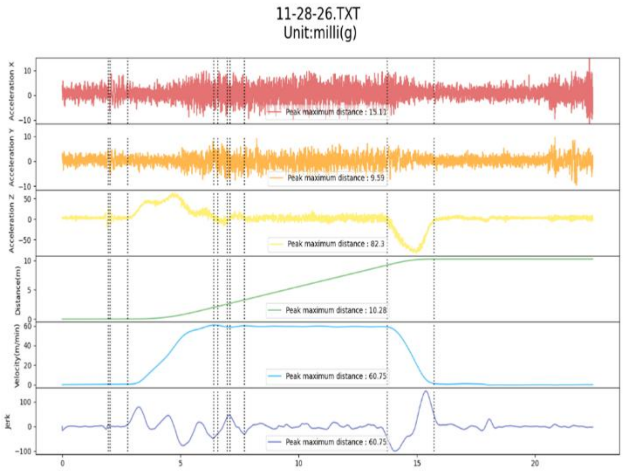


Fig. 17. Abnormal elevator operation with eleven segments.

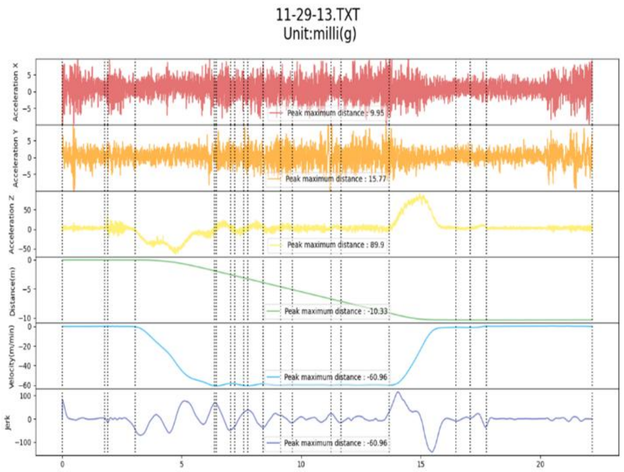


Fig. 18. Abnormal elevator operation with twenty-one segments.

The above experimental results from Fig. 13 - Fig. 18 are summarized in Table 1. It can be seen that TQ = 4 occurs in the first two cases (Fig. 13 and Fig. 14), which means that the elevator is in a normal situation. In contrast, the TQ exceeds 4 in the other four tests, e.g. 5, 8, 6 and 20 in Fig. 15 - Fig. 18, which puts the elevator in an abnormal operating condition. In Fig. 18, the situation is worst due to the highest TQ (= 20). Clearly, it shows that the more risks to the elevator, the more segments are identified.

Table 1. TQ in experiments.

Figure	TQ	Segmented region num.	Elevator health status
Fig. 13	4	5	Normal
Fig. 14	4	5	Normal
Fig. 15	5	6	Abnormal
Fig. 16	8	9	Abnormal
Fig. 17	10	11	Abnormal
Fig. 18	20	21	Abnormal

The comparison between the EVA625 Elevator Vibration Analysis System (Physical Measurement Technologies, Inc., USA) and the proposed system is shown in Table 2. It shows that the proposed system is generally superior to the EVA625.

Table 2. Comparison between EVA625 and the proposed system.

Item	EVA-625	The proposed system
Samples per second (sps)	256	1000
Resolution	0.6 mg	0.061 mg
Storage speed	Slow (15 s)	Fast (10 s)
Operation mode	Manual	Automatic
Long term record	No	Available
Analysis software	Available	Available
Installation method	Standalone	Complex

5. CONCLUSIONS

Although commercial elevator vibration analysis instruments such as the EVA625 are now widely used in the industry, determining the health of the elevator still depends on the experience of the personnel. In order to accurately recognize the elevator health status, the proposed vibration region segmentation diagnostic model has been developed and successfully implemented. In this model, the jerk is considered as a key factor to determine the elevator health status. Based on the definition of the jerk, the critical vibration segment points can be easily found. During the binarization process, the number of vibration segments, i.e. TQ, can be directly calculated and used to diagnose the elevator operating condition. Since only a simple arithmetic operation is required in the TQ calculation, the model performance becomes simpler and more effective. In addition, important data such as acceleration in the X, Y and Z-axes, moving distance, velocity and jerk can be monitored online via the Internet. The acquired vibration data can also be transmitted to the server for real-time tracking and analysis. For further research in the future, it is suggested that AI algorithms can be used to analyze and find the relationship between elevator faults and vibration sources.

REFERENCES

[1] Hirose, I., Kimura, H., Ogawa, K. (2015). Suppression of transverse vibration of elevator rope using vertical vibration of counterweight. *Transactions of the JSME (in Japanese)*, 81 (827), 15-00102. https://doi.org/10.1299/transjsme.15-00102

[2] Peng, Q., Jiang, A., Yuan, H., Huang, G., He, S., Li, S. (2020). Study on theoretical model and test method of vertical vibration of elevator traction system. *Mathematical Problems in Engineering*. https://doi.org/10.1155/2020/8518024

[3] Wu, S., He, P., Gong, X. (2021). Analysis of transverse vibration of wire rope in flexible hoisting system. *Journal of Vibroengineering*, 23 (2), 283-297. https://doi.org/10.21595/jve.2020.21487

[4] Wu, H., Zhang, D., Cheng, Q. (2019). Modeling and parameters analysis of longitudinal vibration of high-velocity elevator hoisting system. *ICIC Express Letters, Part B: Applications*, 10 (2), 97-103. https://doi.org/10.24507/icicelb.10.02.97

[5] Kimura, H. (2016). Free vibration analysis of a string with vibration suppressor (When the position of vibration suppressor is opposite to the pulled position). *Mechanical Engineering Journal*, 3 (1), 15-00554. https://doi.org/10.1299/mej.15-00554

[6] Teshima, N., Sasaki, Y., Onishi, S., Nagai, M. (2002). Vibration characteristics of wire-rope in the high speed elevator (Numerical analysis by the difference method). *Transactions of the Japan Society of Mechanical Engineers Series C*, 68 (675), 3202-3208. https://doi.org/10.1299/kikaic.68.3202

[7] Qi, X., Zhang, R., He, Q. (2019). Modeling and analysis of transverse vibration of traction rope of high speed traction elevator. *IOP Conference Series: Materials Science and Engineering*, 538, 012036. https://doi.org/10.1088/1757-899X/538/1/012036

[8] Miura, N., Matsuda, T., Higashi, Y., Ono, H., Nguyen, X. T. (2023). Method of estimating the lateral vibration of an elevator rope from the vertical vibration of a compensating sheave. *Journal of Asian Architecture and Building Engineering*, 22 (3), 1533-1544. https://doi.org/10.1080/13467581.2022.2086876

[9] Yang, D.-H., Kim, K.-Y., Kwak, M. K., Lee, S. (2017). Dynamic modeling and experiments on the coupled vibrations of building and elevator ropes. *Journal of Sound and Vibration*, 390, 164-191. https://doi.org/10.1016/j.jsv.2016.10.045

[10] Ahmed, R., Assad, A., Abdelkader, E. M., Zayed T., Nasiri, F. (2020). Stochastic-based deterioration modeling of elevators in healthcare facilities. In *2020 International Conference on Decision Aid Sciences and Application (DASA)*. IEEE. https://doi.org/10.1109/DASA51403.2020.9317250

[11] Zhang, J., Wang, S., Wang, W. (2009). Explicit model predictive control and its application in vibration control of elevator mechanical system. *Information and Control*, 38 (1), 105-109.

[12] Jia, M., Gao, X., Li, H., Pang, H. (2021). Elevator running fault monitoring method based on vibration signal. *Shock and Vibration*. https://doi.org/10.1155/2021/4547030

[13] Wang, D. (2022). Analysis and solution of abnormal vibration of elevator box based on information technology. In *2022 International Conference on Artificial Intelligence in Everything (AIE)*. IEEE, 306-309. https://doi.org/10.1109/AIE57029.2022.00066

[14] Wang, Z. (2025). Elevator abnormal state detection based on vibration analysis and IF algorithm. *International Journal of Advanced Computer Science and Applications*, 16 (1). http://dx.doi.org/10.14569/IJACSA.2025.0160177

[15] Wang, Q., Chen, L., Xiao, G., Wang, P., Gu, Y., Lu, J. (2024). Elevator fault diagnosis based on digital twin and PINNs-e-RGCN. *Scientific Reports*, 14, 30713. https://doi.org/10.1038/s41598-024-78784-7

[16] Wei, Y., Wang, X., Lin, Z., Shi, M., Feng, B. (2023). Performance evaluation for an elevator by analyzing the vibration data of the car. In *2023 9th International Symposium on System Security, Safety, and Reliability (ISSSR)*. IEEE, 321-330. https://doi.org/10.1109/ISSSR58837.2023.00055

[17] Xie, P., Zhang, L., Li, M., Lau, S. F. S., Huang, J. (2024). Elevator vibration signal denoising by deep residual U-Net. *Measurement*, 225, 113976. https://doi.org/10.1016/j.measurement.2023.113976

Received May 14, 2024
Accepted March 4, 2025