

Equipment Vibration Condition Monitoring Technology Based on Spectrum Image Deep Learning Models

Kim, Gun Sik ¹, Kim, Deog Hyeon ², Lee, Jae Min ³, Hwang, Ju Heon ⁴, Park, Jin woo ⁵

^{1,2} *Equipment Control Engineering 1 team, Hyundai Motor Company, 44259, Ulsan, Korea*
 6505602@hyundai.com, dhkims@hyundai.com,
 dlwoals1222@hyundai.com, yd93013@hyundai.com, jin4417@hyundai.com

ABSTRACT

We created a system that predicts failures in advance by analyzing the equipment spectrum for rotating equipment in the Hyundai and Kia Motors. we extracted and trained equipment spectrum images in various ways, and made it possible to know what kind of failure there is when a new spectrum is received.

1. INTRODUCTION

With the advent of the 4th industrial revolution, the management method of the most important 'production facilities' in the automotive industry is also changing. As with the human body, a 'Equipment' with a characteristic that deteriorates over time requires more resources for diagnostic activities than direct repair (in the case of the human body, treatment). In addition, unlike the human body, the equipment does not have the ability to heal naturally, so it requires artificial conservation activities for the health condition.

The maintenance methods of production facilities are largely divided into break down maintenance, preventive maintenance, and predictive maintenance. (1) Break down maintenance is a method of maintenance after operation until failure occurs, and it can be applied to facilities that have replacement parts or have no effect on additional damage to production or safety. It is the cheapest when applied properly, but it is an unsuitable maintenance method for equipment that is important to production and quality. (2) Preventive maintenance determines the basic maintenance time by statistically analyzing past failure data. It is suitable for items whose performance changes over time, such as filters and seals. However, it can cause over-maintenance and is vulnerable to breakdowns that occur between maintenance intervals. (3) Predictive maintenance is a maintenance method based on the equipment condition. It can be operated until just before breakdown and maintenance costs can be

minimized. Sudden failure can be prevented, and secondary damage caused by failure can be avoided, thereby increasing the lifespan of equipment. However, it requires an initial investment and additional skill acquisition. And it is difficult to respond to equipment that has a various & sudden failure mode before the cause is identified. (Fig.1)

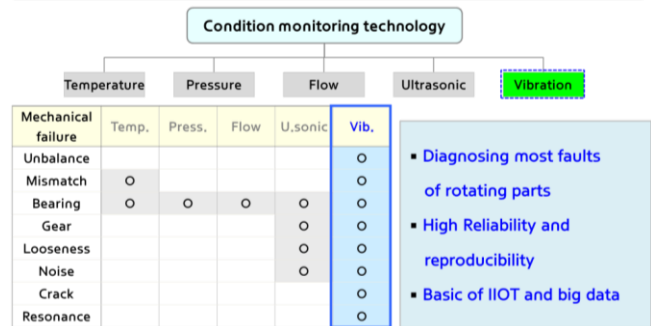


Fig.1 Condition monitoring technology

In this paper, in order to supplement the vibration-based equipment condition predictive maintenance system, the actual user (1) does not require additional investment or technology acquisition, (2) responds appropriately to sudden equipment failures, and (3) cyclically Methods for how the system operates are discussed. In addition, we intend to deal with the demonstration of equipment spectrum analysis through deep learning image analysis technology.

In Hyundai/Kia plants, a system for monitoring the vibration status of major rotating equipment is applied(Vibration system specification: fMax based on acceleration: 5000Hz or more, number of lines 3200 or more, hanning window applied). However, due to limited vibration analysis experts, many difficulties arise in (1) 'recognition' of the equipment state and (2) 'analysis' of the equipment state. To this end, we developed a system that can quickly 'recognize' and 'analyze' the equipment status even if you are not an expert in vibration analysis. The equipment vibration spectrum image is designed so that it can be easily known which equipment is abnormal among various equipment and what kind of

First Author et al. This is an open-access article distributed under the terms of the Creative Commons Attribution 3.0 United States License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

problem there is through the deep learning model. In addition, this paper intends to discuss ① equipment maintenance history management system, ② spectrum image collection program, ③ spectrum image learning program, ④ automatic spectrum analysis program, ⑤ analysis result visualization, and mailing service to complement the system. Individual programs are integrated and managed as one integrated program. In addition, each program utilized an open-source library that can be easily found on the Internet.

Predictive maintenance is the best way to maintain equipment where utilization management is important in a factory. For predictive maintenance, first of all, equipment data, history management, data analysis are the most important. Among the solutions for this, there are ultrasound, temperature, and current, but among them, vibration analysis is the most reliable. Therefore, Hyundai/Kia plants are already operating vibration monitoring systems. However, since 2013, the number of facilities to which vibration monitoring is applied has been increasing rapidly, while the number of analysis experts is limited, so an effective method to monitor the condition of equipment is needed.

2. BACKGROUND

2.1 Reasons for choosing an image deep learning model

Recently, in the vibration monitoring industry, time-series data prediction technology using deep neural networks has been widely used. However, it is almost impossible to apply a time-series deep learning model because the characteristics are repeatedly changed in the case of facilities that are frequently stopped/restarted or maintained. Therefore, in order to recognize the equipment state first, we managed it with a relatively simple algorithm such as the average vibration trend and vibration alarm level for each section, and developed a deep learning model of equipment vibration spectrum image for equipment state analysis. (Fig.2)

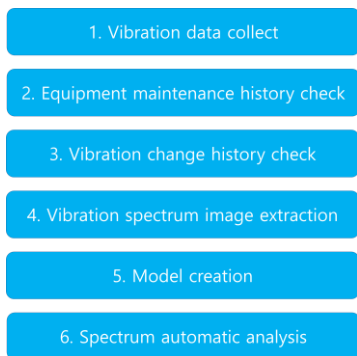


Fig.2 Deep learning system introduction

2.2 Data processing and Model development

Typically, vibration analysis engineers analyze the spectrum based on equipment rotation speed and equipment

information (bearing model number, pulley and motor specifications, etc.). However, in this case, even a small change in the initial equipment information may be useless. Therefore, we applied a deep learning image classification model that can analyze images based on the overall vibration spectrum shape even if the equipment information changes slightly. As a result of analysis by cause of defects due to the increase in vibration during operation of the vibration monitoring system since 2013, the pattern of equipment vibration increase due to mechanical failure was somewhat limited, and the vibration spectrum showed the same pattern. Utilizing these points, (1) equipment maintenance history management system (2) spectrum image collection program (3) spectrum image learning program (4) spectrum automatic analysis program (5) analysis result visualization and notification service program A total of 5 individual programs developed and integrated

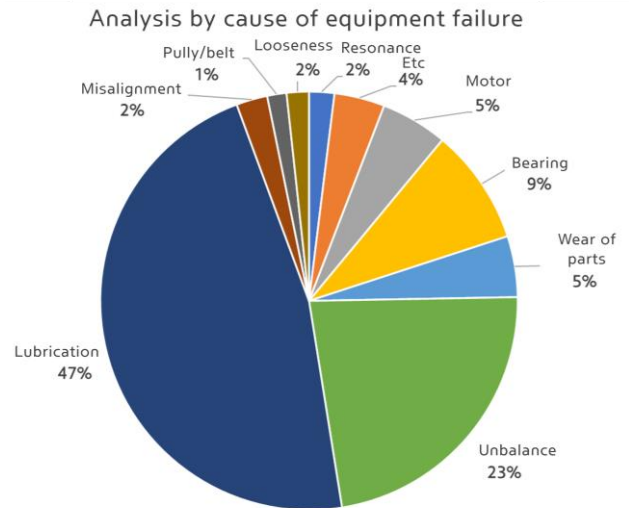


Fig.3 Analysis by cause of defects according to the rise in vibration

3. DEVELOPING DEEP LEARNING MODEL

3.1 Equipment maintenance history management system

In order to collect images for spectrum learning, the maintenance history management system can be used first. The existing vibration system and mail service were utilized so that the equipment maintenance department could easily notify changes to facilities (repair, replacement, etc.). The items necessary for equipment maintenance history management are as follows. ① Repair date ② Equipment ID and equipment name ③ Equipment type ④ Defect cause ⑤ Repair details and result ⑥ Vibration reduction degree

Based on the above information, it is possible to establish criteria for what actions to be taken when certain types of defects are present in which equipment

3.2 Spectrum image collector

Based on the maintenance history collected earlier, it was possible to know when and what changes occurred in the total vibration value and vibration spectrum for the equipment. It will take a lot of time if people try to collect spectrum images one by one for spectrum image learning. Therefore, a program was developed that automatically extracts the spectrum image by inputting only the equipment name, date, and repair history. The Spectrum image collection program was designed so that only the equipment number, maintenance work date, and work details were entered, and the spectrum image of the equipment vibration value was extracted automatically to perform labeling for learning(Fig.4). The spectrum image label types applied in this study are as follows.[bearing initial defect, bearing defect step 3-4, belt, looseness(fan), looseness (motor), poor lubrication, misalignment, normal vibration, sensor error, Unbalance]. The number of spectral images for each defect type used for training is the same

※ Velocity measurement condition: 0~100Hz
 1600 lines , measure time : 3.2s, hanning window
 Acceleration measurement condition: 0~5kHz
 3200 lines, measure time: 0.64s, hanning window

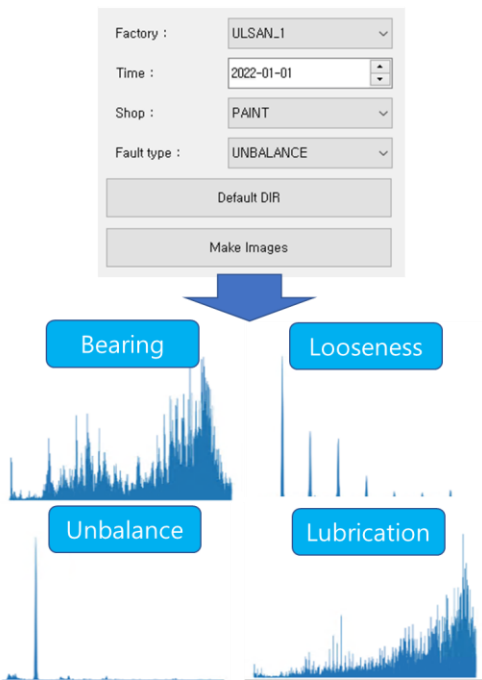


Fig.4 Vibration spectrum pattern by equipment defect

3.3 Spectral Image Learning Program

The next is the process of learning and modeling the collected and labeled spectrum images. The program was developed using Python open-cv2 and keras CNN. First, the spectrum pixel size is unified and the labeled images are stored in one image array. Then, the image value (X) and the labeling value (Y) are divided into a training data group and a test data group. Afterwards, the model network is as follows.

Model – Convolution2D – MaxPooling – DropOut – Convolution2D – MaxPooling – DropOut - Convolution2D – MaxPooling – DropOut – Flatten – Activation Function(relu) – DropOut(0.5)- Activation Function(SoftMax) – compile

The structural representation of the deep learning network is shown in (Fig.5)

Since the spectrum image was relatively easy to distinguish, high accuracy was easily obtained.(Fig.6)

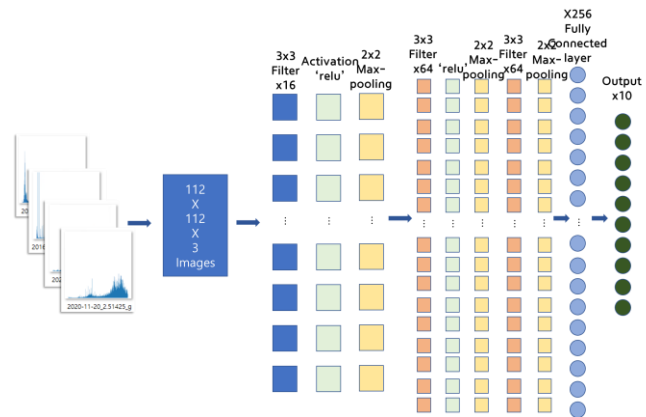


Fig.5 spectrum prediction model CNN architecture

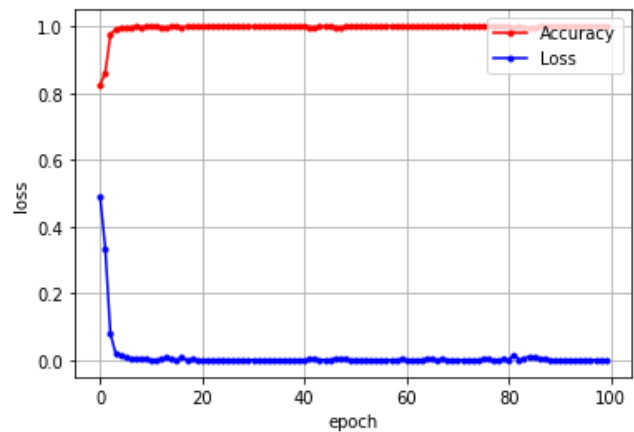


Fig.6 Accuracy-Loss graph according to the number of training iterations

3.4 Spectrum automatic analyzer Figures

Spectrum automatic analyzer uses the learned model. Load each learned model, save the spectral image you want to analyze in the temp folder, and input it into the loaded

model to extract the ‘Predict’ value(Fig.7). The equipment selection criteria were those with a high current vibration value compared to the currently set total vibration value alarm level and a equipment with a high vibration value increase ratio.

3.5 Analysis result UI, mailing service

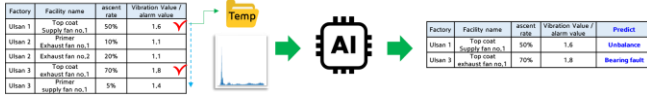


Fig.7 AI equipment defect prediction process

Fault type	Precision	Recall	F1 score
Lubrication	14/15 : 93.3%	14/14 : 100%	0.965
Unbalance	14/14 : 100%	14/14 : 100%	1
Bearing	12/12 : 100%	11/12 : 91.6%	0.956

Fig.8 Model Performance Scorecard

◎ Test conditions: Among the facilities monitoring vibration, the detection results for each type of defect found after operating the deep learning model. ('22 January~)

※ The remaining defects are excluded from the statistics because they occur only in very small amounts.

Test spectrum images: 30 in total (14 poor lubrication, 14 unbalance, 12 defective bearings)

Test result: Lubrication F1 score 0.965 / Unbalance F1 score 1 / Bearing F1 score 0.956 (Fig.8)

Interpretation of results: Since the shape of the spectrum images was very different, it was possible to extract a high-performance model without difficulty.

3.5 Analysis result visualization and mailing

The result value extracted by automatic spectrum analysis is tabulated and sent to the screen. The tabled data can be inquired with a UI program written in PYQT (Fig.9). In addition, an automatic e-mail service is installed so that you can check the status immediately after going to work every morning. After selecting a equipment with a large range of total vibration fluctuations and performing automatic spectrum analysis, the table is converted into a table and the analysis result table is sent to a pre-set email address. After that, the equipment analysis results are again included in (1) maintenance history management to strengthen the model

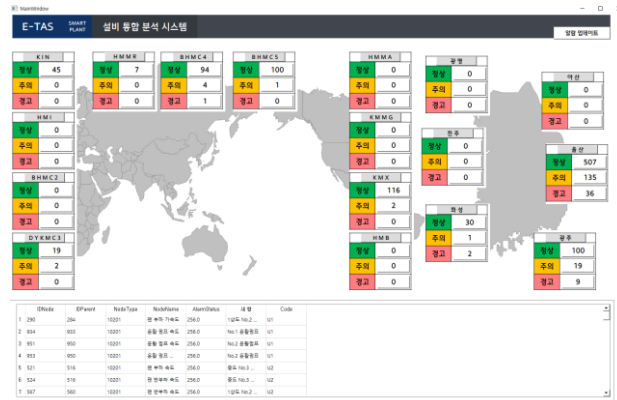


Fig.9 Global vibration monitoring system

4. CONCLUSION

Through this study, it was confirmed that the following effects can be obtained while using the equipment condition prediction/monitoring system.

- (1) Vibration analysis became possible through the use of the system by personnel other than vibration analysis experts through the development of the vibration spectrum analysis model.
- (2) It was possible to reduce the fatigue of vibration analysis by automating the repetitive tasks of existing vibration analysis experts.
- (3) The faster cognitive analytics process allowed us to respond to unexpected disruptions in days or hours.
- (4) Automated mailing and reporting programs helped increase the efficiency and reliability of the vibration analysis system.
- (5) It can be applied to other legacy vibration analysis systems in addition to the previously developed systems.

REFERENCES

Razvan-Gabriel Cirstea (2018). Correlated Time Series Forecasting using Deep Neural Networks: A Summary of Results. arXiv:1808.09794

Shuai Zheng (2017). Long Short-Term Memory Network for Remaining Useful Life Estimation. IEEE ICPHM. 978-1-5090-0382-2/16

Khan, S. and Yairi, T (2018). A review on the application of deep learning in system health management. Mechanical Systems and Signal Processing, 107, pp.241-265.

Alex Krizhevsky(2012).ImageNet Classification with Deep Convolutional Neural Networks

When a work has three, four, or five authors, cite all authors the first time the reference occurs, e.g., “Zhang, Smith, and Patel (2002) found”. In all subsequent citations, include only the surname of the first author followed by “et al.” (Latin for “and others”) and the year of publication, e.g., “Zhang et al. (2002) found”.

Works by associations, corporations, government agencies, etc. are referenced by the name of the body that created the work, e.g., “the 2004 National Academy of Sciences [NAS] report”. When appropriate, abbreviations can be used in all subsequent citations, provided that there is enough information in the text citation for a reader to locate its source in the reference list without difficulty, e.g., “the report (NAS, 2004) showed”.

BIOGRAPHIES

Kim Gun-sik received the Bachelor degree in Electrical and Electronic Computers from Kyungpook National University, South Korea, in 2015. Since January 2015, he has been with Hyundai Motors. He acquired ISO 18436-1 category 3 in 2017.

Kim Deog-hyeon received the Master of Information and Communication Engineering, Gwangju Institute of Science and Technology, South Korea, in 2005. Since January 2014, he has been with Hyundai Motors. He acquired ISO 18436-1 category 3 in 2017.

Lee Jae-min received the Bachelor of Electrical Control, Soongsil University, South Korea, in 2008. Since January 2008, he has been with Hyundai Motors. He acquired ISO 18436-1 category 3 in 2017.

Hwang Ju-heon received the Bachelor of Electrical Engineering, Inha University, South Korea, in 2005. Since January 2012, he has been with Hyundai Motors. He acquired ISO 18436-1 category 2 in 2022.

Park Jin-woo received the Bachelor of Electronic Engineering, Dong-A University, South Korea, in 2002. Since January 2003, he has been with Hyundai Motors.