Nuclear power plant vibration automatic monitoring system using artificial intelligence

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1. Introduction

Within nuclear power plants, numerous facilities operate concurrently, interconnected via a complex physical infrastructure. The failure of any individual facility can lead to a cessation of the entire system, resulting in catastrophic consequences. The recent accelerated development of networking and sensing equipment enables system operations to monitor real-time device status, thereby contributing to optimal operation predicated on safety management and real-time conditions when integrated into power plant maintenance.

In particular, the application of artificial intelligence, specifically deep learning, an area of significant recent research, facilitates the automation of real-time state management. This automation not only reduces human effort but also prevents issues arising from human errors, thereby establishing a real-time, automated monitoring system based on data characteristics that may be challenging to discern. In this paper, we propose a method for enhancing the safety and reliability of nuclear power plants by developing a system capable of performing automated anomaly detection and predictive diagnostics through artificial intelligence technology.

2. Overall System Setting

The overall configuration of the monitoring system to be developed consists largely of an overall operation process, including a measurement system and a server system that stores data, and a diagnostic system that uses artificial intelligence to detect anomalies and predict life expectancy. In the overall system, the measurement system is directly connected to the sensing equipment to convert analog signals into digital signals, and the server system stores data collected from the measurement system and diagnostic results generated by the diagnostic system. The measurement system and the diagnostic system exist in a completely separate data space and operate by unilaterally delivering data from the measurement system to the diagnostic system.

2.1 Measurement System

The system proposed in this study utilizes a vibration sensor to monitor the state of rotating equipment within the power plant. Nuclear power plants necessitate the utilization of sensing equipment capable of operating under extreme conditions, such as high temperatures and pressures, to adhere to the API 670 specifications. Consequently, the measurement system under development should conform to the API 670 standard and aims to enhance event detection functionality by incorporating multiple voting functions. Furthermore, the miniaturization of the rack system enables its deployment in more adverse environments. Additionally, nuclear power plants employ digital filters to address noise interference due to the concurrent operation of various facilities, and order tracking via digital signal processing is utilized for precise measurement in high-speed rotors.

2.2 Data Server System

The monitoring system under development encompasses two primary data storage structures designed to retain the acquired data. The first structure constitutes a database dedicated to preserving analysis data, which employs a relational database to ensure data integrity and maintain the stability of monitoring and diagnostic performance. The second structure entails a database specifically engineered for storing raw signals procured from vibration sensors, utilizing a time series database to accommodate the management of substantial data quantities. Particularly within the context of nuclear power plants, where raw signals generate hundreds of gigabytes of data per second, the expediency of input and output is of critical significance. As a result, the database structure is meticulously optimized to circumvent bottlenecks, thereby facilitating real-time monitoring and enhancing the overall efficacy of the monitoring system.

3. Diagnostic System

The diagnostic system comprises two principal subsystems. The first is an artificial intelligence-based system that conducts anomaly detection and predictive diagnostics utilizing collected vibration data. The second is a monitoring subsystem that visually conveys information to users by leveraging sensing information and the outcomes derived from the artificial intelligence-based system.

3.1 Artificial Intelligence Analysis System

Artificial intelligence possesses the capacity to extract and learn inherent features of vibration data, which may be challenging for humans to recognize. Given the high performance through deep learning and the large quantities of data collected in nuclear power plants, the proposed system's performance can improve during operations. Furthermore, performance and stability enhancement techniques have been developed in comparison to traditional machine learning methodologies, facilitating the creation of artificial intelligence models optimized for nuclear power plant applications.

3.2 Deep Learning based Diagnostics

In this study, vibration anomaly detection is utilizing deep learning model. Numerous deep learning studies have been undertaken to abnormal detection in facilities by inputting vibrations. Specifically, a significant number of 1-D CNN-based anomaly detection models have been explored [1]. However, CNNs exhibit the drawback of potentially overlooking global characteristics due to their heightened ability to analyze regional features rather than the comprehensive characteristics of the data. Consequently, recent research has increasingly focused on Transformer-based deep learning models.

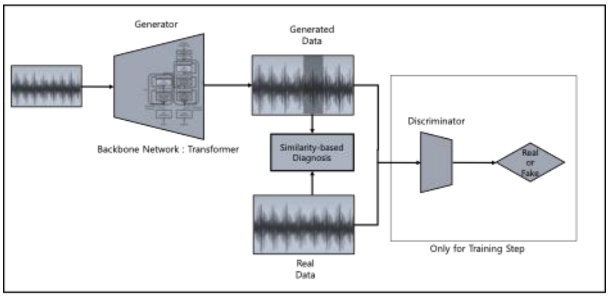

Fig. 1. An Overview of Anomaly Detection Algorithm Based on Transformer GAN

This study utilizes a Transformer-based model [2] with an attention mechanism that receives all vibration data simultaneously and analyzes the relationships between each temporal point. Specifically, anomaly detection is performed based on unsupervised learning by capitalizing on the differences in vibration patterns between normal and abnormal states of equipment. We construct a Transformer-GAN [3] architecture that receives vibrations, extracts features, and reconstructs the original vibration based on these features. As the model has learned only normal state characteristics, inputting abnormal state vibrations will result in discrepancies during process, outputting data that differs from the original. The algorithm measures the similarity between the model's output and the original data, determining that vibrations are generated in an abnormal state if the similarity exceeds a certain threshold. This structure enables the determination of abnormalities through an artificial intelligence model even in the absence of abnormal state vibration data, making it suitable for nuclear power plants where abnormal data is scarce.

While previous methods have also performed diagnoses based on data, most of these methodologies are predicated on shallow machine learning and mathematical approaches, necessitating fine-tuning for each device from which data is collected. In contrast, the method proposed in this study is based on deep learning and offers the advantage of maintaining consistent performance despite changes in the data collection source.

3.3 Automated Monitoring System

To facilitate plant managers' oversight of the entire system's operation, presenting information in a visual format is necessary. Specifically, the proposed system is designed to enable real-time monitoring, allowing for prompt responses to anomalies and changes in plant conditions.

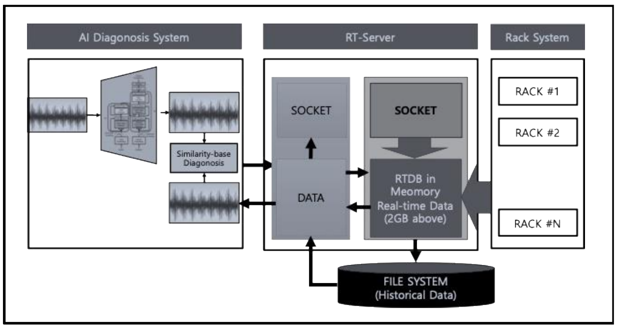

Fig. 2. An Overview of Total System

At the same time as the real-time nature of data monitoring, the diagnostic results of artificial intelligence can be visualized, and the results of warnings and artificial intelligence judgments can be shown based on the diagnostic results to complete an automated diagnostic system.

4. Conclusions

The system proposed in this paper is an intelligent system that can collect and store data generated from nuclear power plants, automatically perform abnormal diagnosis based on artificial intelligence, and provide visual information to users in real time. Furthermore, it is expected that this system will enhance the safety of nuclear power plants and reconsider the perception of the risks people have in nuclear power plants.

REFERENCES

[1] X. Xie; B. Wang; T. Wan, Multivariate Abnormal Detection for Industrial Control Systems Using 1D CNN and GRU, IEEE Access. Volume:8, 2020
[2] A. Vaswaniet al, Attention is All you Need, Advances in Neural Information Processing Systems 30 (NIPS 2017)
[3] Y. Jiang, S. Chang and Z. Wang, TransGAN: Two Pure Transformers Can Make One Strong GAN, and That Can Scale Up, Advances in Neural Information Processing Systems 34 (NeurIPS 2021)