A Digital Twin Approach to Diagnostics in Equipment Maintenance

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1. Introduction

To solve diversifying social issues, Mitsubishi Electric is working to provide integrated solutions that combine the strengths of both inside and outside the Group by consolidating its management foundation, which has been cultivated over the 100 years, and transforming its business model. We aim to create value by multiplying our strong components with our extensive field knowledge and advanced digital technology to realize a vibrant and comfortable society.

This paper describes a Digital Twin approach to diagnostics in equipment maintenance that utilizes Digital Twin as an example of technical development that supports integrated solutions. This technique will turn Mitsubishi Electric's field knowledge, such as equipment design knowledge and operational know-how, into formal knowledge through IoT and Digital Twin to achieve consistency and efficiency in diagnosing the causes of failures in equipment maintenance. This will reduce downtime for customers and contribute to solving social issues such as the declining birthrate and aging population, and the declining working-age population.

2. Social Issues Surrounding the Manufacturing Industry

According to the Ministry of Internal Affairs and Communications' WHITE PAPER Information and Communications in Japan(1), Japan's working-age population is expected to decline due to the declining birthrate and aging population. The ratio of the working-age population to the total population is estimated to decrease from 59.1% in 2020 to 53.9% in 2040, which will have a major impact on the Japanese economy and society. In addition, according to "World Population Prospects" of the United Nations Department of Economic and Social Affairs, the working-age population is declining worldwide: Europe, North America, East and Southeast Asia will face the same challenges as Japan.

Under these circumstances, the shortage of human resources and the aging population are having a major impact on the manufacturing industry as well. In particular, maintenance work, such as the inspection of equipment and diagnosis/repair of failed equipment, requires advanced skills and knowledge, but it also relies heavily on the tacit intuition and experience of skilled technicians. Due to the aging of skilled technicians, it has become difficult to pass on their skills to young technicians.

3. Issues at the Equipment Maintenance Site

At the equipment maintenance site, after an equipment failure occurs, maintenance staff go to the site to diagnose external and internal phenomena occurring in the equipment while referring to sensor data and other sources to identify the cause of the failure. In addition to using manuals, etc., the diagnostic work takes into consideration the installation environment and equipment state of each customer, so the design knowledge, experience, and intuition of maintenance staff have a significant impact on work quality. Therefore, although efforts are being made to train maintenance staff and to pass on technical knowledge, various issues arise when considering global service deployment, including differences in distance, language, and customs. As it becomes more difficult to secure human resources in the manufacturing industry, new initiatives utilizing advanced digital technologies such as AI, IoT, and Digital Twin will be necessary to maintain consistent work quality in the global market.

4. Use of Digital Twin for Equipment Maintenance Sites

"Digital Twin" refers to the concept of creating a real-world twin in digital space. The Digital Twin is attracting much attention in all industries, but the manufacturing industry in particular is expected to reap great benefits from it. With the introduction of IoT in recent years, efforts have been made to analyze and utilize the data collected from equipment and production lines in the cloud. By inputting the equipment state collected in real time from the equipment in this way into a model that reproduces the behavior of the equipment, the equipment and its state can be reproduced in digital space, almost the same as in the real world. This can be used to improve the quality of equipment maintenance work, improve work efficiency, reduce prototyping costs, improve after-sales service, and so on. For example, when some

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abnormality occurs in the equipment or manufacturing line during equipment maintenance, the state of the equipment or manufacturing line in digital space can be analyzed to identify the cause of the abnormality in real time. The difference from conventional data analysis is that the internal state of equipment is reproduced. The Digital Twin of equipment uses design knowledge to create a model of the equipment that reflects the real-world state. This makes it possible to analyze and explain in detail why the abnormality occurred using design knowledge. Thus, in the Digital Twin of equipment, it is important to build models using the design knowledge of equipment, thereby enabling solutions to be built that take advantage of the strengths of manufacturing companies. Therefore, we are developing a technique for applying the Digital Twin to equipment maintenance sites.

5. Digital Twin Approach to Diagnostics in Equipment Maintenance

5.1 Overview of diagnosis technique in equipment maintenance

Mitsubishi Electric has developed a technique for diagnosing equipment that utilizes Digital Twin to solve issues at equipment maintenance sites. This technique involves collecting sensor data representing the equipment state from the failed equipment and estimating the cause of the failure based on the sensor data. This technique leads to consistent quality of maintenance work and improves the efficiency of the work itself. Sensor data are values obtained by sensors installed inside and outside the equipment and are used for equipment control and maintenance. For example, sensor data varies depending on the equipment, such as temperature, current value, vibration, and pressure. This technique mainly uses sensor data that can be obtained from outside the equipment to estimate the causes of failures.

The technique consists of a model that reproduces the equipment state and a function for diagnosing equipment (Fig. 1). Using actual sensor data and the model, which reproduces the equipment failure state with Digital Twin, the function for diagnosing equipment calculates the candidate causes of the failure and their likelihoods. Maintenance staff receive these calculated candidate causes and start maintenance service on the equipment from the most probable cause. As a result, the function assists diagnosis based on design knowledge, leading to consistent work quality among maintenance staff. Furthermore, the sensor data from equipment in the real environment is constantly collected and stored in the cloud, making it possible to instantly diagnose the equipment using this data when a failure occurs. By the time maintenance staff arrive at the site, the results of the diagnosis have already been obtained, and they can quickly perform diagnostic work while referring to the results on PCs or tablet devices.

5.2 Equipment state reproduction model

The equipment state reproduction model maintains the relationship between the causes of failure and the sensor data representing the behavior of equipment during the failure (Fig. 2). It consists of three models: a physical quantity propagation model, a sensor value correlation model, and a state analysis model.

The physical quantity propagation model is a formula that expresses how a physical quantity such as the energy that drives equipment propagates between the components of the equipment. This model is used to simulate the behavior of equipment during normal conditions and during failure, and to acquire how the equipment's sensor data behaves during that time.

The sensor value correlation model retains the behavior of sensor data obtained from simulations using the physical quantity propagation model, i.e., the relationship between failures and the pattern of change in values. This model converts such knowledge into formal knowledge, such as the pattern of sensor data values that characterize a failure when it occurs.

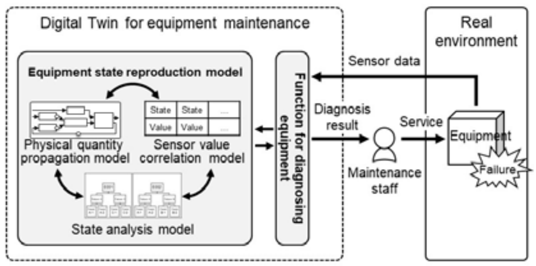

Fig. 1 Overview of diagnosis technique in equipment maintenance

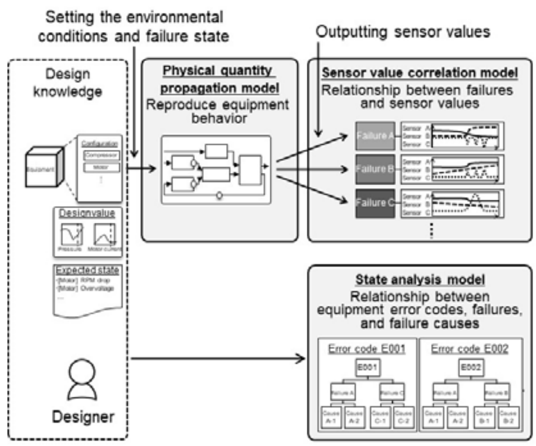

Fig. 2 Framework for equipment state reproduction model

The state analysis model expresses the phenomena that appear when equipment fails, and the relationship between error codes and failures. This model formalizes the knowledge of possible causes of failure when a certain error code occurs.

5.3 Function for diagnosing equipment

The function for diagnosing equipment estimates the cause of failure from the equipment state reproduction model and equipment sensor data (Fig. 3). This function inputs the error code obtained from the failed equipment and the sensor data before and after the failure and estimates its cause using the misdiagnosis reduction function and the sensor value pattern determination function.

The misdiagnosis reduction function uses the error code at the time of failure and the state analysis model included in the equipment state reproduction model to identify several causes of failure that could generate the error code. For example, if the error code is E001, failure A and failure C are extracted as candidate failure causes and passed to the sensor value pattern determination function. In this way, the misdiagnosis reduction function improves the accuracy of the sensor value pattern determination function by narrowing down the causes of failure from the error code using the state analysis model. On the other hand, there are cases where an error code is not generated depending on the failure condition. In that case, the misdiagnosis reduction function does not work, and only the sensor value pattern determination function is used for estimation.

The sensor value pattern determination function inputs the candidate failure causes and sensor data passed from the misdiagnosis reduction function and estimates the failure cause from the sensor value correlation model. Based on the candidates, a pattern of sensor data during failure is acquired for each candidate from the sensor value correlation model. The pattern obtained from the model is compared with the sensor data pattern of the failed equipment to calculate the degree of similarity. The investigation starts from the cause of failure with a higher degree of similarity, which enables more efficient diagnostic work.

6. Prototype System for Diagnosing Equipment

6.1 Overview of prototype system for diagnosing equipment

This cloud-based prototype system passes sensor data collected from equipment to the cloud, and presents the cause of failure and countermeasures to maintenance staff.

6.2 Cloud deployment model

This system consists of a model management platform, a service provision platform, and a data collection platform (Fig. 4). Each platform is built as a separate cloud system and is designed to be deployed globally across countries. The model management platform is a cloud system that manages the equipment state reproduction model. The service provision platform is a cloud system that provides maintenance staff with a function for diagnosing equipment. The data collection platform is a cloud system that constantly collects and stores sensor data from equipment actually in operation. The data collection platform and service provision platform are separated, which makes it easy to connect the service provision platform with existing data lakes and a new data collection platform. The model management platform is deployed in Japan, where models are created, and enables controls such as placing access restrictions on models and controlling export to other countries. The service provision platform and data collection platform are deployed in the country where the service is provided, taking into consideration the cross-border regulations on data that are being written into the data protection laws of each country, such as the General Data Protection Regulation (GDPR).

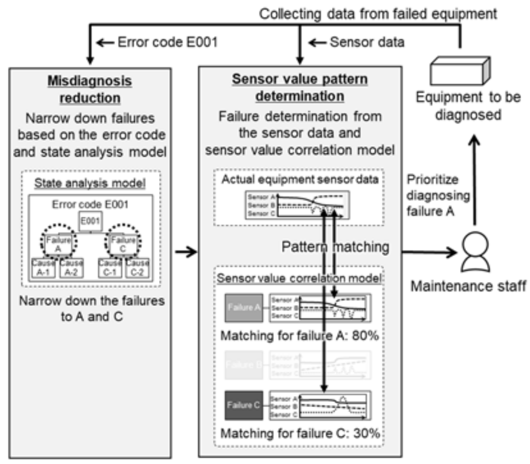

Fig. 3 Mechanism of function for diagnosing equipment

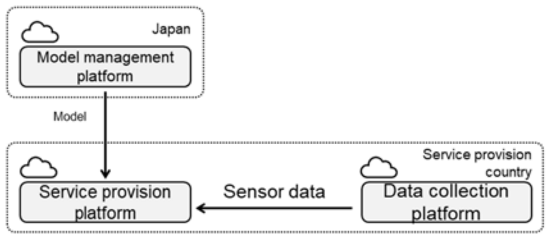

Fig. 4 Cloud deployment model

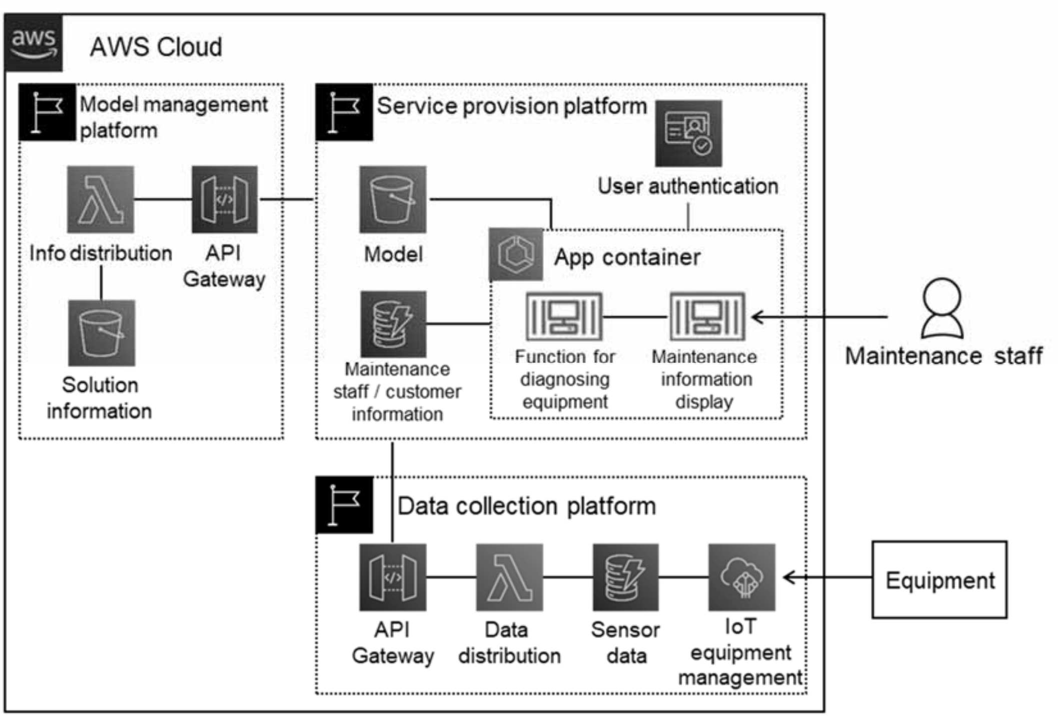

Fig. 5 Cloud architecture

6.3 Cloud architecture

This system is built as a cloud service on AWS *1 (Fig. 5). The model management platform, service provision platform, and data collection platform are each configured as a Virtual Private Cloud (VPC), and Application Programming Interface (API) Gateways are placed between the platforms to separate them. The function for diagnosing equipment and the maintenance information display function, which displays diagnosis results to maintenance staff, are configured as an application container so that they can be easily migrated according to the country where the service is provided. The maintenance information display function is a browser-based application that can be accessed from various terminals such as PCs and tablet devices by maintenance staff.

6.4 Building a prototype system

A prototype system was built for Mitsubishi Electric's equipment at the Information Technology R&D Center. Sensor data was acquired from the equipment and periodically stored in AWS. By installing a mechanism for generating failures in the equipment and diagnosing the equipment by generating specific failures, we confirmed that the causes of the failures can be estimated from the pattern of the actual sensor data and the sensor value correlation model.

7. Conclusion

This paper described a Digital Twin approach to diagnostics in equipment maintenance that utilizes Digital Twin as an example of technical development that supports integrated solutions. This technique turns field knowledge, such as equipment design knowledge and fault diagnosis know-how, into formal knowledge in the form of an equipment state reproduction model and reproduces the behavior of failed equipment as a Digital Twin. Then, sensor data during a failure is collected from equipment through IoT, and the cause of the failure is estimated from the equipment state reproduction model and sensor data. This initiative converts field knowledge into formal knowledge. We believe this technique can help solve industry and social issues such as the difficult of passing on skills due to the aging of skilled workers.

We will continue to promote technical development to realize integrated solutions that make use of our strengths, aiming to realize a vibrant and comfortable society.

References

(1) Ministry of Internal Affairs and Communications: WHITE PAPER Information and Communications in Japan 2021
https://www.soumu.go.jp/johotsusintokei/whitepaper/index.html

1 AWS is a registered trademark of Amazon Technologies, Inc.