Application of the IIoT to Equipment Maintenance

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As an increasing number of plant facilities are aging and with growing demand for environmental protection, condition-based maintenance (CBM) is needed in developed countries. However, identifying and managing the state of facilities depends largely on skilled field workers, and it is difficult to transfer their know-how to the next generation, hindering the widespread use of CBM. Yokogawa Electric Corporation has long been involved in plant operation and equipment maintenance, and is now planning to use the Industrial Internet of Things (IIoT) and artificial intelligence (AI) in these areas in order to promote CBM. Yokogawa's Sushi Sensor is a product based on this concept. This paper describes the functions and various technologies behind Sushi Sensor.

INTRODUCTION

Artificial intelligence (AI) and the Internet of Things (IoT) have become household terms and appear in the media almost every day, and people tend to have wild expectations and imagine that these technologies could work like fantasy. This paper discusses realistic applications of these technologies to plant operation.

Yokogawa Electric Corporation has long improved the efficiency and safety of production and plant operation. In this field it is necessary to monitor the operational state and to prevent risks based on highly accurate, reliable data. To do this, Yokogawa released the ISA100 Wireless-compliant field wireless products and has helped maximize the efficiency of plant operation and ensure security.

In recent years, as the environment surrounding the industry has changed, there is an increasing need in plants to improve the efficiency of maintenance work and protect the environment. These new requirements involve analyzing the trend of facility conditions and performing appropriate and timely maintenance, based on time-series data obtained from many measuring points. This paper describes the role of AI and IoT in meeting these requirements, focusing on the Industrial Internet of Things (IIoT) in terms of IoT since the target field is plants.

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APPLICATION OF THE IIoT TO MAINTENANCE

AI and IIoT

AI stands for artificial intelligence. According to the Japanese Society for Artificial Intelligence(1), John McCarthy, a computer scientist, defined it as "the science and engineering of making intelligent machines, especially intelligent computer programs." Research on AI started in the 1950s and an expert system was released in the 1970s. Although this system was able to answer easy questions, it clearly lacked the ability to solve complex problems in the real world(2).

The AI boom has come again, and there are growing expectations that it could solve difficult problems in the real world as deep learning and other types of machine learning are put into practice. Previously, it was necessary for humans to input domain knowledge by, for example, specifying the feature set containing the characteristics of knowledge (attributes). Therefore, AI only served as a support tool for humans. However, deep learning and other recent machine learning methods enable computer programs to build up knowledge by themselves. As a result, for example, AI specialized in Go (a board game in East Asia) can now beat human professional players(3).

Meanwhile, the IoT enables all things to be interconnected via the Internet. The industrial IoT (IIoT) is attracting attention because it is expected to be able to determine the state of instruments as existing infrastructure becomes old(4).

Problems in Industry

In many developed countries including Japan, many plants are more than 40 years old and their facilities have been rapidly deteriorating. In Japan, more than ten years have passed since the skill transfer problem (the “2007 problem”) occurred due to the mass retirement of veteran workers who had played a leading role in the field. Outside Japan, due to rapid industrialization, the training of workers is not keeping pace with plant construction and skill levels are falling.

In addition, there is a growing global need to ensure environmentally friendly plant operation.

How to Solve the Problems

Extending the service life of aging facilities not only saves costs in plant operation but also reduces impacts on the environment by eliminating scrap & build processes. To achieve this, it is necessary to precisely understand the state of facilities and perform appropriate maintenance. This maintenance method is called condition-based maintenance (CBM) (Table 1).

Taking measures to protect the environment is a part of fulfilling social responsibility. Breakdown maintenance (BDM) may cause hazardous substances to scatter or leak, resulting in environmental problems. Meanwhile, time-based maintenance (TBM) is expected to increase costs because it also includes facilities that do not need maintenance. In terms of environmental protection, it is desirable to shift to CBM.

However, CBM has not yet spread globally, as explained in the following section.

Table 1 Comparison of maintenance methods

Maintenance method	Description
BDM	Breakdown maintenance Perform maintenance only when instruments break down.
TBM	Time-based maintenance Perform maintenance at regular intervals.
CBM	Condition-based maintenance Examine and understand the state of facilities, and perform appropriate maintenance.

Factors Preventing the Spread of CBM

CBM needs a system that can process and use the information obtained in the field. However, existing maintenance work relies largely on off-line measurements and handwritten documents. The results of visual inspection in operator rounds are written down on paper and not digitized. When transcribing such notes, some of them may be omitted or written incorrectly. Although off-line measurements with handheld instruments are recorded digitally, these need to be centrally managed if they are to be used effectively. By addressing these issues, centrally managing data collected in the field and analyzing the long-term trend, the state of facilities can be precisely understood.

The state of facilities is judged based on measurements or visual observations in the field, using know-how that depends largely on the skills of individual workers, and veteran workers in particular. CBM requires fair, objective judgment criteria, but such standards have not yet been established.

This is because physical quantities that indicate the state of facilities are not always simple. A criterion for judging temperature or pressure measurements can be determined as a threshold because these measurements are numerical values. But is this approach applicable to vibration, which is often used for judging the state of rotary machines?

Vibration is recorded as a frequency spectrum and it is not easy to determine what factor to focus on, such as the frequency of each spectrum, amplitude, or distribution of a spectrum (Figure 1). Veteran workers have various knowledge; for example, they first focus on the band of hundreds of hertz or lower frequencies to judge whether the axis is misaligned, and then look at the band of 1 kHz or higher frequencies to search for signs of abnormality in the bearing. This judgment depends on individual skills, and such expert skills are treated as qualitative abilities and called “God’s eye” or “master’s skill.”

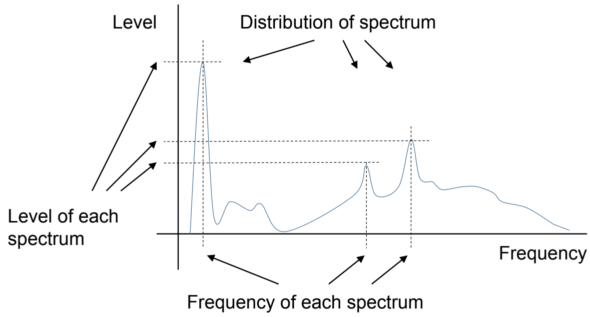

Figure 1 Example of vibration spectrum

The two main hindrances to enhancing CBM are as follows.

- Data are not managed for effective use.
- Methods of understanding the state of facilities depend on individuals, and problems regarding skill transfer and training are aggravating this issue.

Promotion of CBM

To apply the IIoT and AI to maintenance work, we will discuss how to promote CBM.

The IIoT can be defined as technology that transfers information about facilities and instruments in manufacturing as electronic data via the Internet, without human intervention. AI can be defined as technology that allows a computer to determine the criterion for judging the state of facilities, which human workers used to learn through experience and accumulate as know-how.

With these latest technologies, we can carry out CBM as follows.

(1) Use the IIoT to automatically measure the state of facilities and continuously collect and record digitized measurement data.

(2) Use AI to analyze changes in data, objectively judging the tendency of equipment degradation, and proposing

effective measures.

Yokogawa developed the Sushi Sensor to achieve these. The CBM solution using this product is explained below. The Sushi Sensor is a small wireless sensor for IIoT applications. It is mounted on instruments that are conventionally inspected during operator rounds, and measurement data are centrally managed, and recorded and analyzed continuously. As the first product, Yokogawa released the XS770A, which measures the vibration and surface temperature of instruments.

Note that "T" in IoT differs from "T" in the IIoT although both mean "Things." In the case of IoT, the target instruments are consumer appliances such as home appliances. In the case of the IIoT, the target instruments are industrial equipment such as motors, valves, and storage tanks. These operate in much harsher environments than consumer appliances. Therefore, sensors for IIoT applications are required to correctly measure and communicate even in harsh environments such as frigid and scorching environments, as well as in the presence of corrosive and inflammable gases.

There are many sensors for IoT or IIoT applications, and they have excellent environmental resistance. However, a closer look at the specifications reveals that their resistance to "severe" outdoor environments is only for farmland or other limited applications, and not where hazardous gases are present. Therefore, these sensors cannot withstand harsh plant environments (Table 2).

Table 2 Comparison of Yokogawa's Sushi Sensor and other companies' sensors

Product	Measured item	Application	Environmental resistance		Communication method
			Waterproof (IP66/IP67)	Explosionproof	
Sushi Sensor	Vibration and temperature	Equipment maintenance	✓	(In preparation)	LoRaWAN
A	Water in soil	Agriculture	✓ (Unknown standard)	–	LoRaWAN
B	Temperature, humidity, CO^2, etc.	Home automation	–	–	LoRaWAN
C	Temperature, etc.	Benchtop experiment	(No casing)		LTE

(As of June 2018, surveyed by Yokogawa)

Yokogawa's Technologies

For details of the technologies implemented in the Sushi Sensor, please see respective papers in this special issue. The key point is that Yokogawa has built various technologies into this small wireless sensor for IIoT applications, including for measurement of field conditions, power-saving communications, the cloud, and machine learning analysis. By seamlessly integrating these technologies, we can quickly apply IIoT-based CBM to plants.

The core technologies discussed in each paper are as follows:

- Hardware
  Environmental resistance, sensing in an integrated structure, power-saving
- Software
  User interface, power-saving
- Network (wireless)
  Low-power long-distance communication, public infrastructure
- Cloud
- Machine learning

To monitor trends, the XS770A measures the velocity and acceleration of vibration as well as the surface temperature of instruments. These data are easy to analyze, and their volume is low. For easy installation, the Sushi Sensor has an integrated structure containing batteries, sensors, and antennas. The bottom that comes into contact with the measured object must be metal in order to measure vibration and temperature. Meanwhile, the casing must be made of resin to allow radio waves from the built-in antennas to pass through. To satisfy both requirements, these two types of material are used as appropriate. Although the integrated structure is convenient, it must not be heavy because it would lower the resonance frequency, potentially affecting vibration measurements and making the measuring range narrower. The Sushi Sensor skillfully supports the internal parts to maintain the frequency measurement range. In addition, the built-in software compensates for the effect of weight on the resonance frequency.

For maintenance, sensors must be installed on a huge number of instruments, and so must be battery-driven in view of all the power lines to each sensor that would be needed otherwise. In addition, it is necessary to reduce power consumption and extend the battery life to reduce the frequency of replacing the batteries. Therefore, the Sushi Sensor is designed so that its battery life under normal usage is longer than the interval between periodical maintenance. Each functional block was designed to save power, and a smartphone is used as the user interface. This is achieved by near-field communication (NFC) which consumes little power; if the sensor had a display, it would consume more power.

The Sushi Sensor communicates with a smartphone via NFC while it uses LoRaWAN (wireless communication network for long distance) to transmit measurement data to the cloud. It was difficult to design a small, integrated sensor that contained two antennas, one for NFC and another for LoRaWAN, in the small body.

Although the Sushi Sensor must be easy to deploy and operate, this requirement could compromise security. For example, data could leak via neighboring devices that use the same communication standard. Therefore, the Sushi Sensor uses a security system using smartphones and the cloud. The security of wireless communications between the Sushi Sensor and the gateway is ensured by using an encryption key that is unique to each system. When acquisition via the network is allowed, the key is protected by encryption and password authentication. When acquisition via the network is not allowed, the encryption key can be acquired by using the NFC card, which is protected by the NFC security standard. We also use original security systems, such as restricting the time for which the encryption key is retained in a smartphone.

Another example of facilitating deployment and operation is a function that enables settings to be transferred from one Sushi Sensor to another when replacing a Sushi Sensor in the field. In the Sushi Sensor, settings are stored in the nonvolatile memory of the NFC function part. Even if the battery dies before replacement, a smartphone can read the settings and copy them to a new Sushi Sensor. The sensor also uses the cloud and machine learning to analyze and share measurement data. By leveraging machine learning and the characteristics of data fluctuations, the Sushi Sensor can detect unusual behaviors of target instruments and predict failure[5].

Future Development

This paper explained various technologies. Their applications and future development are discussed below. One application is expanding the scope of information used for data analysis. At an early stage, AI machine learning 1 is used to predict the time to possible failure of instruments, based on past data (Figure 2).

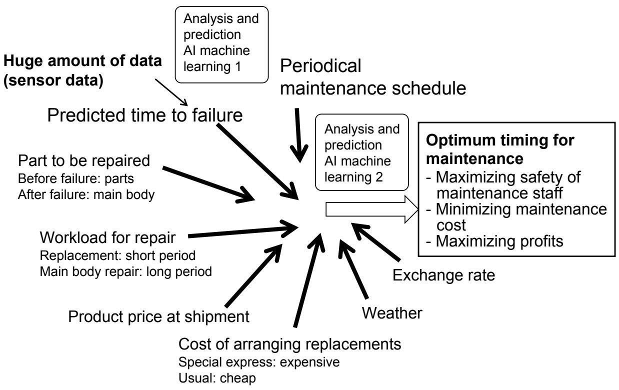

Figure 2 Expansion of scope of AI application

For example, when the price of replacements differs between quick delivery and normal delivery, AI machine learning 2 can be added to handle numerous, intricate conditions. Working together, machine learning 1 and 2 can derive solutions that maximize the profits of the entire plant.

The following case is also plausible. Assume that the data from a sensor shows that an instrument is likely to break down in several months, and its periodical maintenance is scheduled to take place after the predicted failure. If the instrument is repaired in advance, spillover effects can be avoided and costs saved, whereas an unplanned shutdown might cause a huge operation loss. Machine learning excels at considering multiple mutually related conditions and deriving solutions that minimize maintenance costs.

One solution in this case is to change the operating conditions and reduce the load on the instrument. The predicted failure may not occur until the periodical maintenance and operation may remain stable. By taking the output during the period into consideration, this solution may be able to maximize the profits of the entire plant. By offering such solutions and helping customers with all their operations from plant control to maintenance, Yokogawa can provide high added value. The company has long optimized plants as an instrumentation system vendor as well as a main automation constructor (MAC), and is now actively proposing Synaptic Business Automation[6] to customers. This concept aims to automate not only the control but also the operation of the whole plant, and all business processes, to attain total optimization.

CONCLUSION

This paper explained the trends and prospects of AI and IIoT technologies, and the use of these technologies in Yokogawa products.

The Sushi Sensor uses AI and IIoT technologies flexibly to deliver value to customers based on their various requirements. By offering value with this product, Yokogawa aims to help customers in the manufacturing industry to optimize their plant operation and whole business.

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* Sushi Sensor is to be released outside Japan soon. For details, please visit Yokogawa’s website.