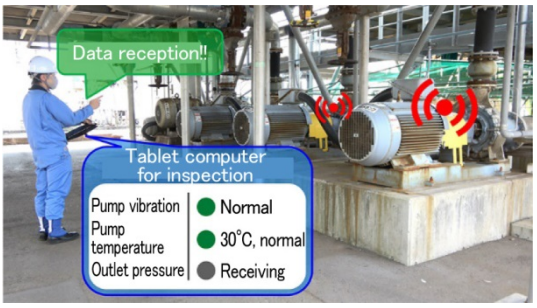
Smart Patrol Inspection System for Industrial Plant/Factory Facilities



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Energy industries such as electricity, oil, gas and chemistry face the problems of aging industrial plant facilities and the shortage of operators/maintenance personnel. The challenge lies in continuing to perform maintenance that is comparable to the current levels in terms of both quality and quantity despite the limited human resources. Given the situation, Mitsubishi Heavy Industries, Ltd. (MHI) has developed a smart patrol inspection system for industrial plant/factory facilities. It is mainly comprised of the wireless sensor, tablet computer and our original application software. Having been on trial or applied to patrol inspection inside/outside our company, this system produced a promising effect as indicated by about a 90% reduction in the time required for a patrol inspection of the water supply facility at our company. The use of this system can help with digitalization of patrol inspection processes, thus contributing to solving problems related to the maintenance of plant/factory facilities, as well as more advanced and labor-saving features and higher profitability.

1. Introduction

Energy industries such as electricity, oil, gas and chemistry are required to keep up with structural challenges such as advancement of the digital society and various environmental changes, while addressing the problems resulting from the aging of industrial plant facilities, aging operators/maintenance personnel and labor shortage, and difficulty in passing on the expertise/skills to the younger generation. Given the situation, the Japanese Ministry of Economy, Trade and Industry has encouraged demonstration trials for the use of digital technologies such as IoT (Internet of Things), AI (Artificial Intelligence) and robots for plant facility maintenance, and is proceeding with regulatory reform in order to facilitate such technological applications. Thus, the number of cases in which digital technologies were introduced to maintenance work is increasing[(1)(2)].

MHI has more than 30 plants nationwide that have facilities/equipment ranging from infrastructures such as electricity, gas and water supply systems to production equipment such as machine tools and cranes. Our daily maintenance work includes patrol inspection and regular maintenance. However, because of the aging facilities and the decline in the number of operators/maintenance personnel owing to their old age and retirement, we are confronted with the challenges of retaining/improving the quality of maintenance work and efficiency and reducing the required manpower.

In response to such challenges related to the maintenance of industrial plant/factory facilities, we have developed a smart patrol inspection system in order to make patrol inspection processes more advanced, more labor-saving and more profitable. By making use of wirelessly communicable sensors and tablet computers, this technology enables automatic collection of inspection data, inspection history management and automatic output of record files among others, thereby helping with digitalization of patrol inspection processes.

This report summarizes the smart patrol inspection system and its features, as well as the

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trial/application results obtained inside/outside our company. The future prospects are also presented.

2. Patrol inspection at industrial plants/factories and the challenges

Patrol inspection, or the inspection round, is carried out by each business operator as part of maintenance activities at industrial plants and factories. The procedural scheme is often based on legislation and in-house regulations. For example, according to the Regulation on Safety of General High-Pressure Gas, it is mandatory to check on the operating state of a high-pressure gas facility at least once a day during its operation, other than at the time of the startup/shutdown[(3)]. For thermal power plant facilities, the Amended Electricity Business Act came into effect in April 2017. In this act, the inspection system for safety management was reviewed with the aim of improving the safety capabilities of the business operator; the period subject to periodic inspection can now be extended to up to six years, if the maintenance management is carried out properly. One of the requirements in the assessment of safety capabilities is inspection of each facility component specified by the in-house regulations at a minimum frequency of once a day[(4)]. Patrol inspection is thus considered important and indispensable in enhancing the safety capabilities of facilities such as power plants.

What should be done during patrol inspection varies between business operators, depending on the facility of interest. However, it generally includes examination by five senses such as sight, hearing and touch and checking on the readings of on-site meters, aiming to identify an abnormality or failure at an early stage. Usually, an inspection record form is filled in by pen based on the obtained results and is kept in the archive as it is, after being checked by the administrator. The data are not digitized in many cases. Such paper-based styles of patrol inspection of facility conditions in which humans are used to determine the presence/absence of abnormalities by utilizing such five human senses are considered to suffice for maintenance needs. However, in the near future, it is very likely to become difficult to maintain the reliability of facilities with conventional inspection styles, because of the increased number of inspection sites within a facility owing to aging equipment and the labor shortage due to aging operators/maintenance personnel. These problems have been recognized in the field of electrical safety[(5)]. As we are also struggling with similar problems regarding the maintenance of our plant facilities, these problems are considered common to any industrial plants and factories. Therefore, our principal challenge for patrol inspection at industrial plants/factories lies in enabling a level of inspection that is comparable to the current levels in terms of both quality and quantity despite the limited human resources.

3. About our smart patrol inspection system

As a solution to the above-mentioned problems in patrol inspection, we have developed a smart patrol inspection system (with the related patents pending). **Figure 1** is a conceptual diagram of the system structure. Our system mainly uses five types of devices: wireless sensor, logging box, portable wireless meter, tablet computer, and administrative PC. We thus help with smartification and digitalization of patrol inspection processes. This chapter describes the features of our smart patrol inspection system including these devices.

The most important device in this system is the wireless sensor. It measures the voltage, electric currents, contact signals, surface temperature, readings of the thermometer/barometer, and physical quantities such as vibration. It then sends the measurement data and sensor identification ID to the tablet computer. Being battery-powered, the sensor has an advantageous feature of easy attachment to the existing equipment as a retrofit without requiring wiring for the power supply.

The device that enhances this wireless sensor function is the logging box. It receives data from the wireless sensor and stores them in the internal memory area. The stored data are then transferred to the tablet computer during patrols of the site. Our system thus realizes regular data logging regardless of the frequency of patrols.

The portable wireless measuring instrument can measure the noise, vibration and surface temperature, and uses its built-in communication module or external communication adapter to send the measurement data to the tablet computer.

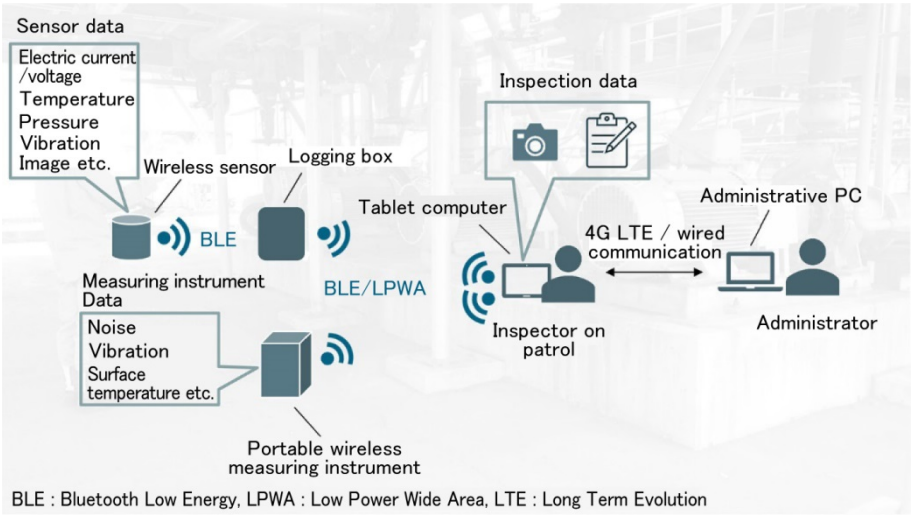

Figure 1 Conceptual diagram of our smart patrol inspection system

Tablet computers are used at the patrol sites by inspectors. They operate even in an environment in which LTE (Long Term Evolution) communication with the administrative PC is not possible, there is no need to worry about the availability of communication connections. The simultaneous use of multiple tablet computers is also possible. The tablet computer is installed with our originally developed application software that supports the smartification and digitalization of patrol inspection processes (**Figure 2**). The functions of the software include collecting data from the wireless sensor and the portable wireless measuring instrument, selecting the results of inspections such as visual examinations for the presence/absence of abnormalities, and taking photographs and notes. It is also possible to search/browse the linked information of equipment such as the drawings and procedural manuals required during patrol inspection, thereby enabling to support not only inspection but also maintenance including performance check-up and lubrication.

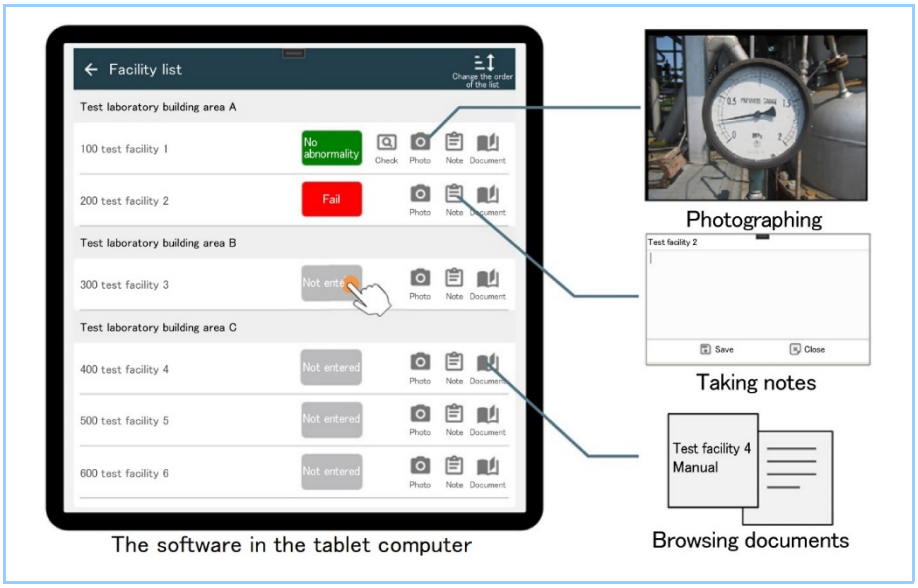

Figure 2 An example of the functions of the software in the tablet computer

The administrative PC is expected to be installed primarily in the office for use by a administrator. We have developed/implemented the application software that makes it possible to manage master data such as inspected equipment names, conditions and inspection history, browse inspection results, display trend graphs, approve inspection records, and automatically output reports (**Figure 3**).

In order to minimize the offer price and lead time of the system, we decided to use off-the-shelf products for wireless sensors and portable wireless measuring instruments. However, as their specifications for communication and the architecture of accompanying software differ depending on the product or supplier/maker, just combining them causes decoupling of the user

interface, leading to a decline in the usability. Therefore, we have built an environment in which processing for versatility or processing specific to a device (that is, a sensor or portable measuring instrument) such as extraction of byte sequences and four arithmetic operations is put in a block, and processing of each device type is implemented as a combination of blocks. Besides easy addition of sensors, this enables integrated data processing thanks to uniformly shaped sensor data. Moreover, the installation of the same platform in the tablet computers realizes an integrated user interface regardless of the product or supplier/maker, enhancing the usability.

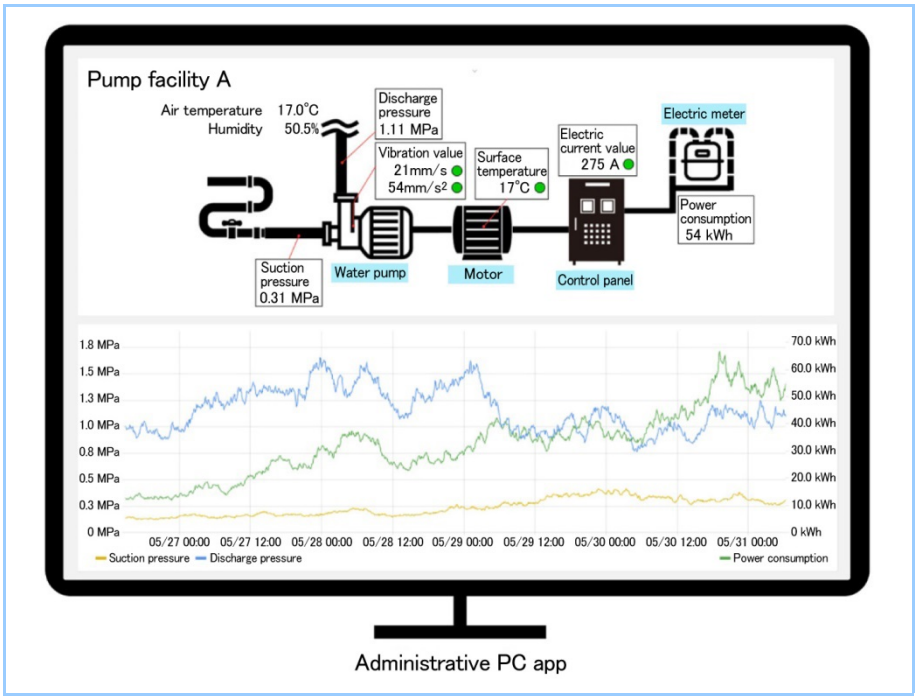

Figure 3 An example of the functions of the app in the administrative PC

4. Results of the trial/application to patrol inspection

With regard to the smart patrol inspection system that enables the automatic acquisition of sensor data and the digital management of inspection results, this section describes the results of the system trial/application to patrol inspection at our company plant and a power generation plant.

4.1 Results of the trial on the water supply facility at our company plant

Using a water supply facility of our company plant for a trial, we piloted the smart patrol inspection system. The facility intended for the trial is a water well system, which is mainly comprised of the following instruments/equipment: water pump, water supply pump, control panel, and water tank. It draws water from a well and supplies it to the plant. Our patrol inspection of this facility typically involves examination by humans five senses for any abnormalities in terms of appearance, noise, odor and vibration, as well as measurements to check electric current/voltage, discharge pressure and flow rate. In this trial, sensors for electric current and vibration, a sensor that takes a reading of the pressure gauge and such were attached to the pumps as retrofits, and reception of measurement data from these sensors using a tablet computer was undertaken. **Figure 4** gives an example of how these wireless sensors are attached. The trial results have indicated that sensor data can be received by a tablet computer with no problems, thus demonstrating the possibility of improving the efficiency of measurement inspection. Based on these results, we estimated the expected effect when the smart patrol inspection system was applied to this water well facility. **Figure 5** shows the estimation results. The time required for patrol inspection on the water well facility totals about 462 hours annually. If the measurement can be streamlined with this technology, it is expected to reduce the time by about 404 man-hours per year. The inspection with automated measurement allows us to focus more on examination by humans five senses using the time otherwise allocated to measurement, which is expected to lead to more advanced patrol inspection processes.

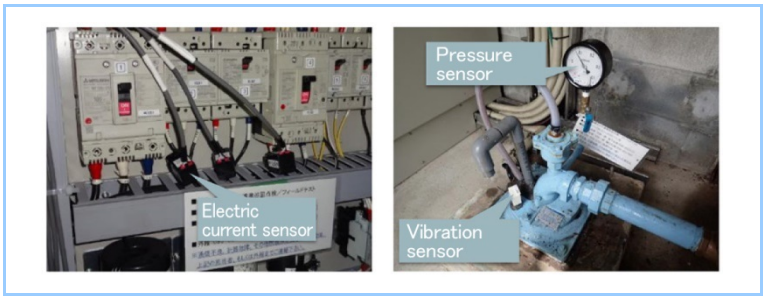

Figure 4 An example of how wireless sensors are attached to the water supply facility

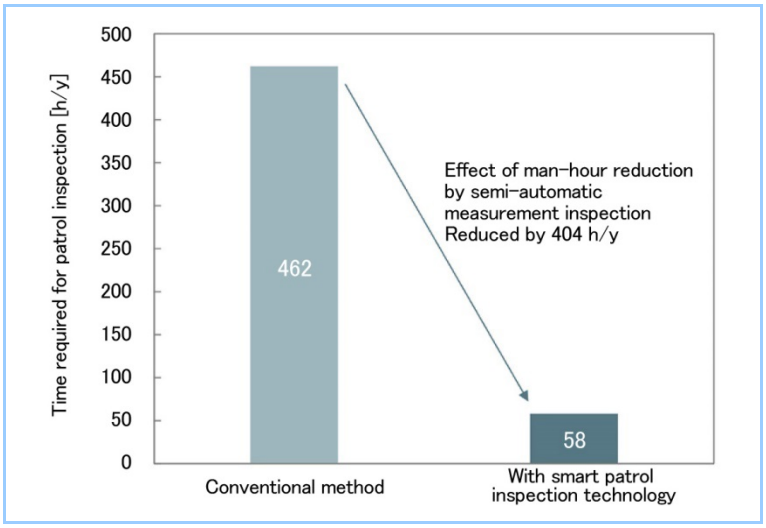

Figure 5 Expected effect when applied to patrol inspection on the water supply facility of our company

4.2 Results of the application to the water/electric meter reading at our company plant

Next, we present the results of the system application to water/electric meter reading at our company plant. Many of the plants take readings of the water/electric meters installed at various locations on the premises once a month, and the results are then aggregated accordingly. This work incurs a certain amount of cost. Therefore, by making use of the smart patrol inspection system, we built a system in which a tablet computer can collect meter readings using pulse-transmitting meters, pulse-reading sensors and logging boxes. This system was then applied to our water/electric meter reading work. **Figure 6** shows an example of how wireless sensors are attached to the water/electric meters. The introduction of this system has realized improvement of the efficiency of meter reading, especially at places where multiple water/electric meters are installed. An example of water meter data analysis is given in **Figure 7**. The line graph represents the average use of water per hour, while the bar graph represents the cumulative amount of water used every 24 hours. For example, the average use during the summer holiday is zero, so it can be deduced there are no water leaks in this water supply system. Thus, the acquisition of unconventionally dense data and their subsequent visualization enable the undertaking of more advanced analysis that was not possible before, as exemplified by checking the presence/absence of leakage in each water supply system.

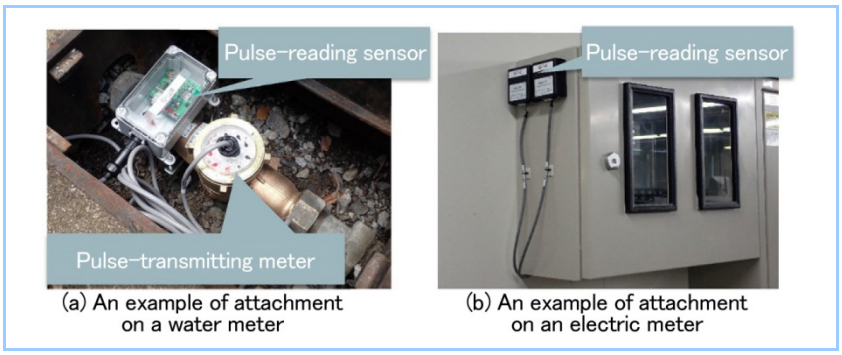

Figure 6 An example of how sensors are attached to the water/electric meters

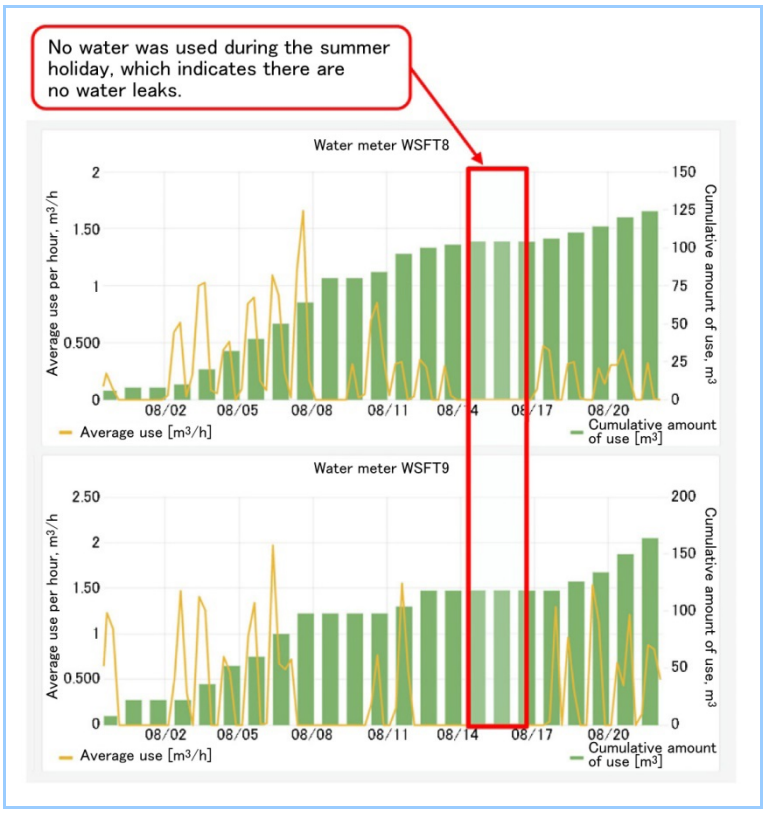

Figure 7 An example of visualization/analysis of water meter data

4.3 Results of the trial for patrol inspection at a power generation plant

We have also started trialing the smart patrol inspection system at a power generation plant, in addition to our company plant facilities. In power generation plants, the operating conditions of the main units such as turbines, generators and boilers are always monitored at the centralized operation room by means of the signals/data being sent to the control system using permanently installed sensors and communication cables. On the other hand, BOP (Balance of Plant) equipment such as pumps, fans and conveyers has a minimum number of permanent sensors or on-site meters in many cases. Therefore, when it comes to the maintenance of BOP equipment, patrol inspection of the site is of great importance.

In power generation plants, the range of equipment targeted to be inspected during patrols is wide in terms of both the number of pieces and types. The inspection tasks are therefore wide-ranging. Our ongoing system application trials include receiving data on the ground from vibration sensors attached to overhead cooling tower motors or fans and, if an area has numerous on-site meters, retrieving the data accumulated over the past one week in one time by installing the sensors to take readings of these meters and the logging box (**Figure 8**). Based on the trial results so far, we now have the prospect of automating tasks such as reading of on-site meters and improving efficiency. These effects will allow us to focus more on examinations by humans five senses and the maintenance of equipment and facilities, which is expected to lead to

retaining/improving the quality of maintenance work.

Figure 8 Trial of the smart patrol inspection system at a power generation plant

5. Future prospect

Lastly, our future prospect related to the use of a smart patrol inspection system are described.

5.1 Toward the advancement of maintenance work at industrial plant/factory facilities

Figure 9 shows the vision of future maintenance work for industrial plant/factory facilities. As the first phase, we intend to apply the smart patrol inspection system and other digital technologies to facility maintenance processes one by one, and increase the automation rate and efficiency of work, saving the required manpower and reducing costs. The following phase is to analyze enormous amounts of accumulated digital data using technologies such as AI to identify abnormal signs in or diagnose the condition of equipment/facilities. Lastly comes the phase in which early inspection based on the results of abnormal sign detection can prevent a failure, while daily inspection is streamlined in accordance with the diagnosis of conditions. In this way, maintenance work can be sophisticated by two approaches: TBM (Time Based Maintenance), which is prescribed by regulations such as legislation, and CBM (Condition Based Maintenance), which is performed according to data analysis results. We thus aim to minimize the life cycle cost while retaining facility reliability.

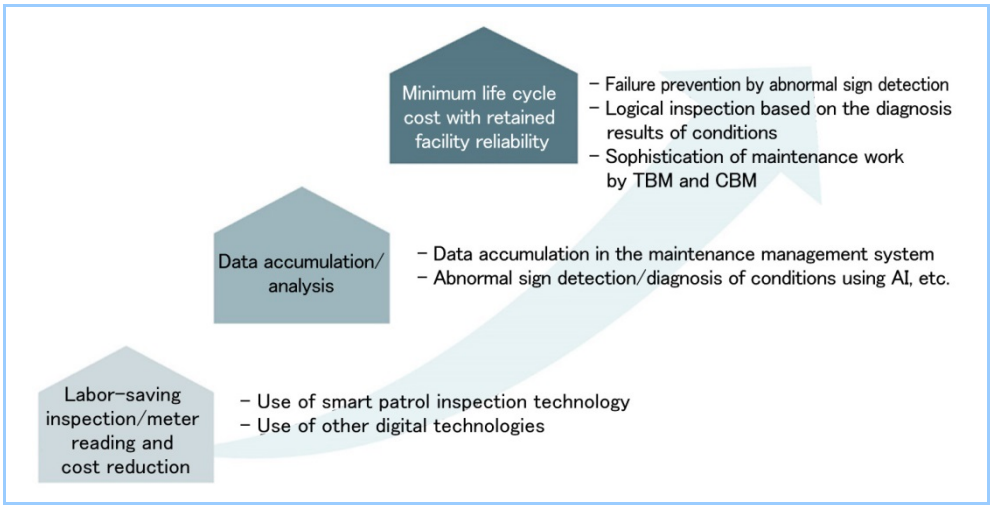

Figure 9 Vision of maintenance work for industrial plant/factory facilities

5.2 Provision of services in combination with digital solutions such as TOMONI®

In 2017, MHI started providing a service called TOMONI, which is a digital solution to realize the optimal operation of power generation plants and has been introduced to both Japan and overseas power plants[6]. TOMONI offers wide-ranging services. For example, it can remote monitor through communication connection with the control system of a power plant, or detect

abnormal signs by the MT (Mahalanobis-Taguchi) method. It can also support optimization of a power plant's O&M (Operation and Maintenance), performance enhancement and operability improvement by making use of the applications such as diagnosis of motor drive systems using clamp-type current sensors, as shown in **Figure 10**[7]. In TOMONI, operational data are transmitted from the power plant's control system to a cloud environment for visualization and analysis. However, as described before, the data handled by the control system are mostly the operational data of the main units with permanent sensors; though depending on the power plant, the amount of BOP equipment operational data that can be monitored by TOMONI is less than that of the main units. Therefore, by making use of the smart patrol inspection system, we are developing a system in which patrol inspection data (that is, operational and maintenance data) of BOP equipment are transmitted to TOMONI's cloud environment. Adding the patrol inspection data of BOP equipment to the operational data of the main units makes it possible to perform the visualization and analysis in which the operating conditions of more plant facilities are combined for consideration. It also becomes possible to use TOMONI applications such as abnormal sign detection and motor drive system diagnosis. Thus, by enabling our digital solutions to be used in a combined manner, we can offer services such as visualizing the conditions of more facilities and making pertinent maintenance proposals, which can be expected to result in enhanced reliability of plant facilities and reduced O&M costs (**Figure 11**).

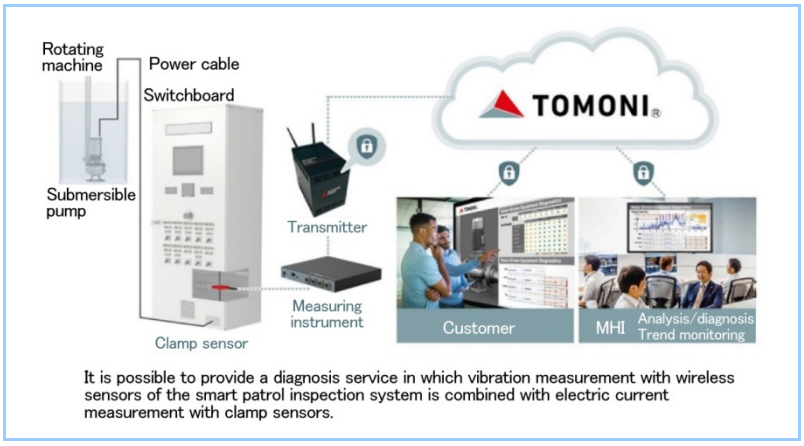

Figure 10 An example of services provided by TOMONI (motor drive system diagnosis service)

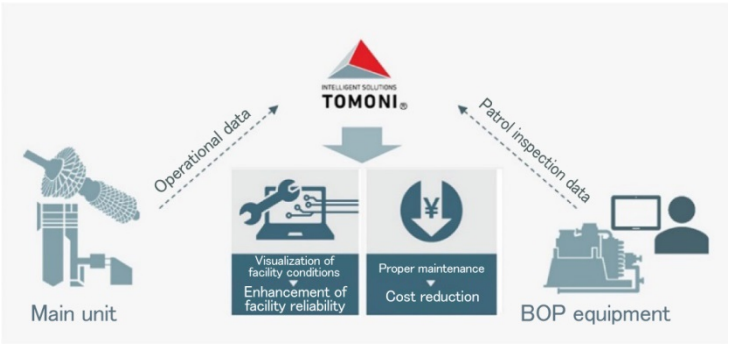

Figure 11 Conceptual diagram for provision of our services in combination with TOMONI

6. Conclusion

For patrol inspection at industrial plant/factory facilities, we have developed a smart patrol inspection system by which the data from wireless sensors attached to the equipment as retrofits can be automatically obtained and the inspection results can be digitally managed. The trial/application of the system to patrol inspection inside/outside our company produced the effect of improving the work efficiency.

While the facilities are aging, operators/maintenance personnel are also aging and the labor shortage is getting serious. Under such circumstances, the use of digital technologies is

indispensable in continuing to perform maintenance that is comparable to the current levels in terms of both quality and quantity despite the limited human resources. We consider that this system can help with digitalization of patrol inspection processes. The application for digitalization will be expanded to other patrol inspection processes at our company plants. The resulting outcomes and best practice will be shared with the customers as part of our services, thereby contributing to making industrial plant/factory facility maintenance processes more advanced, more labor-saving and more profitable.

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