Indication Monitoring Solution by Optical Fiber Temperature Measurement Utilizing AI

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At power stations, plants, and manufacturing factories, priority is given to safety and security, and guaranteed stable operations are required. Failures with machines and equipment, in particular, do not only affect power generation and manufacturing capacity but also cause significant losses due to the production of defective products. To solve these problems, Fujitsu has developed "FUJITSU Business Application Operational Data Management & Analytics (ODMA) Indication Monitoring Model for Optical Fiber Temperature Measurement," which is equipped with an indication monitoring function that utilizes AI. This product detects anomaly indications that could potentially lead to errors and failures by using optical fibers to detect the temperature of machines and equipment and to monitor their heat generation conditions. It also enables temperature measurements in confined spaces, which is a difficult task for conventional measuring instruments. This paper presents the developed optical fiber temperature measurement technology as well as its features and examples of its applications.

1. Introduction

Optical-fiber communications technology that enables high-speed communications has become an integral part of today's information society. When near-infrared laser light enters into an optical fiber, various types of scattered light can be observed depending on the properties and state of the silica glass making up the optical fiber. Three types of scattered light are known to occur: Rayleigh scattered light has the same wavelength as the entered light, Brillouin scattered light has a slightly shifted wavelength due to interactions with acoustic phonons or magnons, and Raman scattered light has at a shifted wavelength due to interactions with optical phonons.

Raman scattered light consists of Stokes and anti-Stokes scattered light, both of which occur as a result of transitions between phonon levels. Temperature can be determined from the intensity ratio between Stokes and anti-Stokes scattered light and from the Boltzmann distribution when assuming thermal equilibrium.[1)-6)]

On optical-fiber temperature measuring equipment that uses Raman scattering, pulsed laser light enters into the optical fiber. This generates backscattered light at different points along the optical fiber. The intensity of the backscattered light can be measured together with the propagation delay in the optical fiber. Intensity corresponds to the temperatures at each point while the propagation delay corresponds to the distance between each point in the optical fiber and incident point (**Figure 1**).

An optical fiber's heat resistance is dependent on its protective film to keep it at temperatures that are lower than those in which impurities in the glass thermally diffuse. For example, when a heat-resistant polymeric material like polyimide is applied, measurements can be performed in high-temperature environments at around 300°C.[7),8)] Optical-fiber temperature measurement technology using Raman scattering has found widespread use in diverse applications including fire detection in tunnels, temperature anomaly detection in power lines and various plants, and temperature distribution measurement within boreholes in oil-well drilling and geological surveys.[9)-14)]

At Fujitsu, we have carried out extensive development using optical-fiber temperature measurement technology such as for improving its spatial resolution and effectively laying optical fibers in server racks and areas around server rooms as a means of sensing to

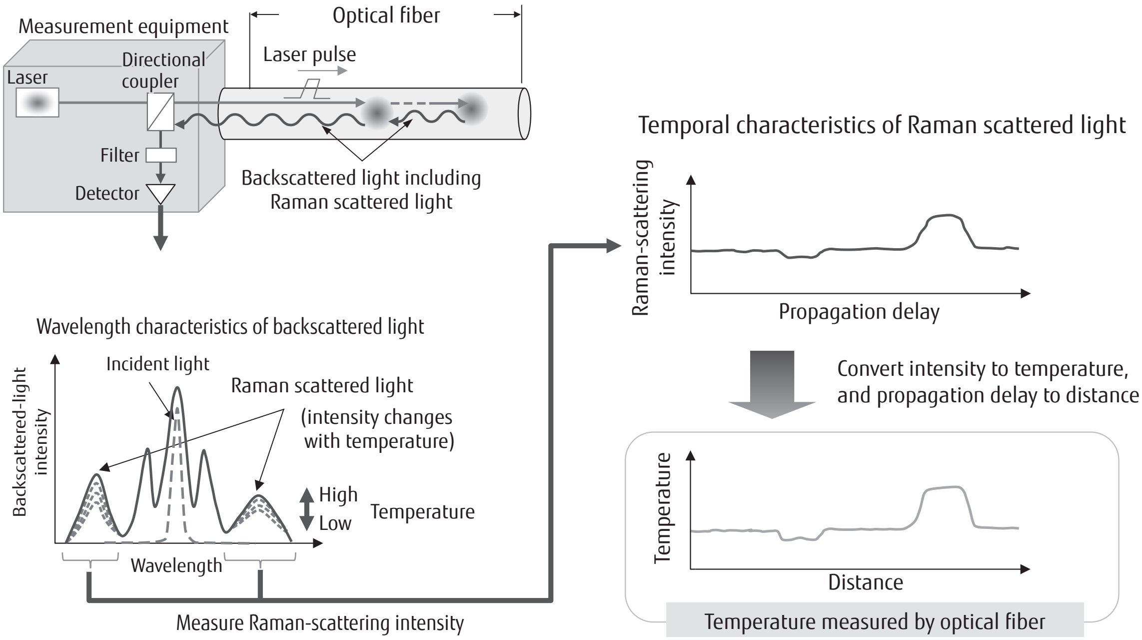

Figure 1
Temperature measurement technology using optical fiber.

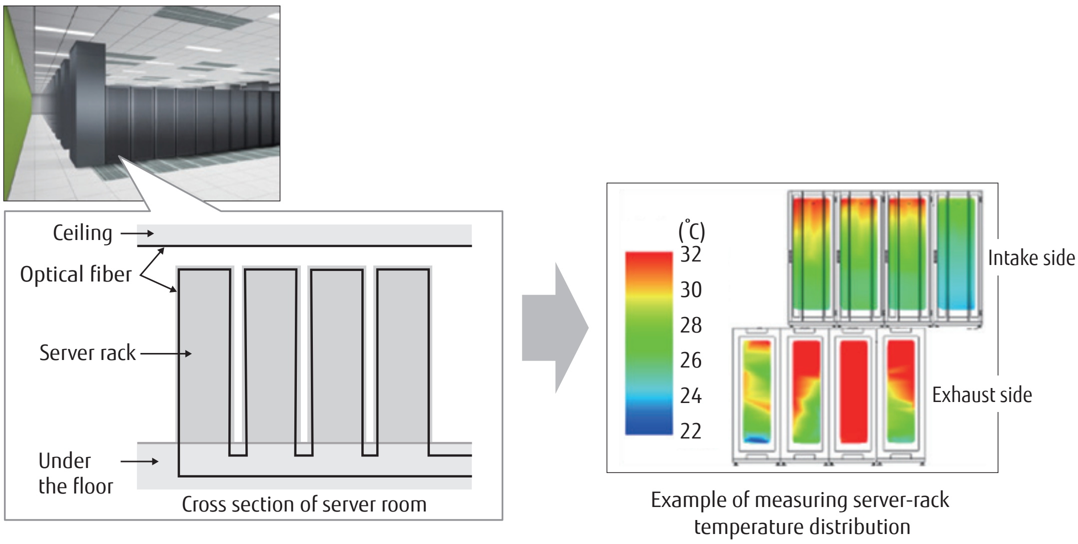

Figure 2
Temperature monitoring system for data centers using optical fibers.

effectively adjust temperatures within a data center (**Figure 2**).[15] We have also been conducting studies on providing new approaches and values to temperature measurement on the basis of technologies and know-how accumulated in conventional application fields of optical-fiber temperature measurement such as infrastructure, power stations, and chemical plants. The outcome of these studies was the provision of "FUJITSU Business Application Operational Data Management & Analytics (ODMA) Indication Monitoring Model for Optical Fiber Temperature Measurement," which is equipped with an AI-based indication monitoring function specialized for optical-fiber temperature measurement.

In this paper, we introduce the development of the technology behind this product and present application examples.

2. Development of temperature measurement technology

The intensity of Raman scattering used in temperature calculations is extremely weak at about 10^{-6} that of Rayleigh scattering having relatively strong intensity at the same wavelength as the entered light. It is, therefore, necessary to use a high-sensitivity detector having a photoelectron multiplier effect such as an avalanche photodiode. Doing so, however, will simultaneously multiply circuit noise in the form of shot noise. Consequently, since temperature is determined from the intensity of the scattered light, it is necessary to keep in mind that the ratio of scattered-light intensity to noise (SNR: signal-to-noise ratio) has a direct effect on the accuracy of the temperature calculated. In particular, the intensity of scattered light generated at points far from the measuring equipment is low due to transmission loss in the optical fiber, resulting in a small SNR and a drop in temperature accuracy.

It is common in temperature monitoring of critical facilities to establish threshold values for temperature for the purpose of detecting anomalies. Temperature measurement with low accuracy and large error can result in false positives and anomaly detection delays, so it is important to reduce the temperature error as much as possible.

To improve temperature measurement accuracy, it is important to enhance the SNR described above. One effective means of enhancing the SNR is to reduce noise. In this regard, noise reduction processing in general signal processing is usually achieved by filter processing that differs for each frequency band. In optical-fiber temperature measurements, filter processing handles the frequency characteristics of spatial distribution of scattered-light intensity and temperature. These are the measurement targets, and since the frequency bands of the signals to be obtained are unknown, it is difficult to apply simple filter processing. With this in mind, we developed a method that selectively reduces noise based on obtained signals using signal processing that incorporates statistical-analysis and data-analysis methods developed by Fujitsu. This method made it possible to measure temperature with greatly improved accuracy even at points far from the measuring equipment.

3. Development of AI algorithm for indication detection

Areas in which temperature must be precisely measured are extensive, ranging from infrastructure equipment to power stations, chemical plants, and manufacturing sites. Furthermore, in addition to methods for monitoring measured temperatures in terms of threshold values, there has been a growing need for more rapid detection of temperature changes that could not be detected using conventional methods. This is particularly important for overcoming the limitations of human monitoring and reducing the burden on humans and for achieving early detection of problems and anomalies. In short, the ability to quickly perceive problem locations that need attention is directly linked to production activities in a company, that is, for improving manufacturing quality and achieving stable facility operations.

Against the above background, Fujitsu developed an indication detection system that merges multipoint temperature data obtained from optical fibers with AI technology to enable the early detection of anomaly indications that differ from the usual temperature distribution. The system operates by capturing multipoint temperature data as a temperature distribution pattern and judging it as an anomaly when the measured temperature distribution departs from the usual pattern. Adding such advanced detection by AI technology to conventional monitoring based on threshold setting has enabled us to achieve a level of temperature monitoring previously thought unachievable (**Figure 3**).

While many existing AI technologies and algorithms detect changes, many conventional AI algorithms were unable to detect anomalies and alert people, and thus were unsuitable for practical use. Fujitsu attached importance to capturing temperature anomalies and detecting only anomalies without false positives. Consequently, instead of finding all temperature changes through AI-algorithm calculations, we developed an original indication-detection AI algorithm that focuses on detecting the “occurrence of temperature changes having particular risk.”

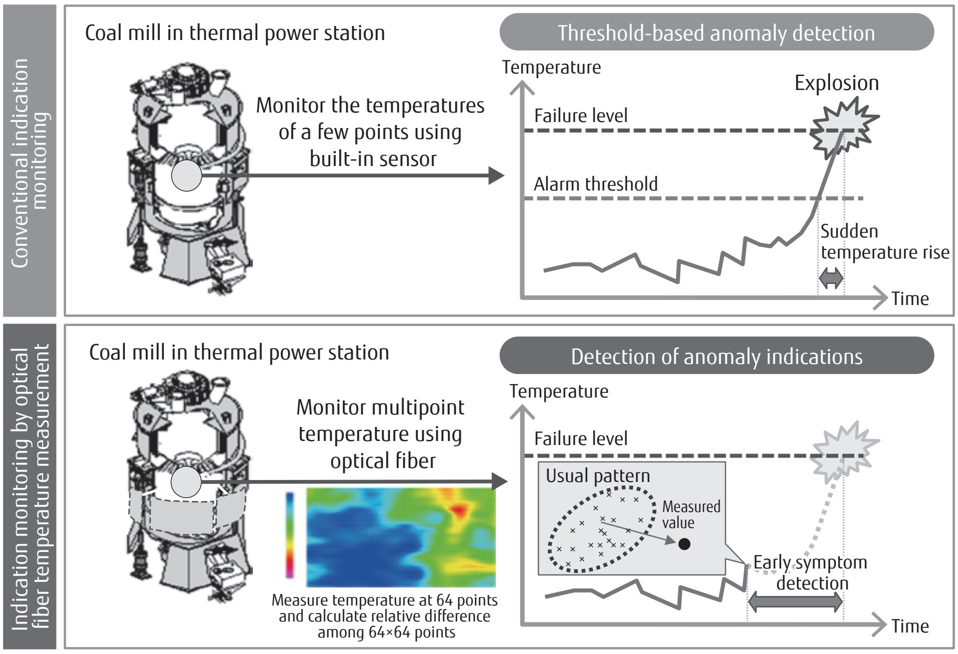

Figure 3
Concept of indication detection used in power-plant facilities.

The algorithm learns the relationships among temperature values measured at different points of one fiber from past data and calculates how a new change in temperature departs from learned states. The algorithm also incorporates many original ideas on the frequency and timing of learning and on the criteria for judging the need for relearning, and it can restrict detection to unusual changes in temperature that need attention and not simply spikes or dips in temperature. We developed this algorithm so that it could be used in actual plants and manufacturing sites and be adjusted any number of times as needed. The base technology supporting high detection accuracy by AI is the noise-reduction processing developed for the temperature-measurement function of this product. The accuracy and validity of detection using AI are greatly affected by the SNR of input data.

Given that this product is not configured to use a large number of independent sensors, no individual differences arise among multiple sensors, which means that the accuracy of the temperature data input into AI is stable. Moreover, as the product is combined with specialized AI analysis, there is no need to worry about selecting an AI algorithm for monitoring, performing data preprocessing, or assessing the results of AI analysis. In other words, this product enables the user to concentrate on where to lay the optical fibers, what to monitor, and what problems or issues to solve.

4. Application examples

We here introduce several examples of tests and trials that Fujitsu has undertaken with this product.

4.1 Thermal power station

A thermal power station includes many critical facilities related to heat, and to ensure stable operations, advanced monitoring and control techniques for each and every piece of equipment are essential. Above all, it is important to monitor temperature changes in fuel pipes, steam pipes, flues, etc. near boilers and turbines and to be continuously aware of facility conditions to detect any anomalies early. The use of thermocouples and thermal cameras is a common means of measuring temperature in power stations or plants. However, there are many areas in which sensor cables for making multipoint measurements cannot be effectively installed due to, for example, the need for explosion-proof measures and complex equipment shapes that make measurements difficult. In response to this problem, temperature measurement by using optical

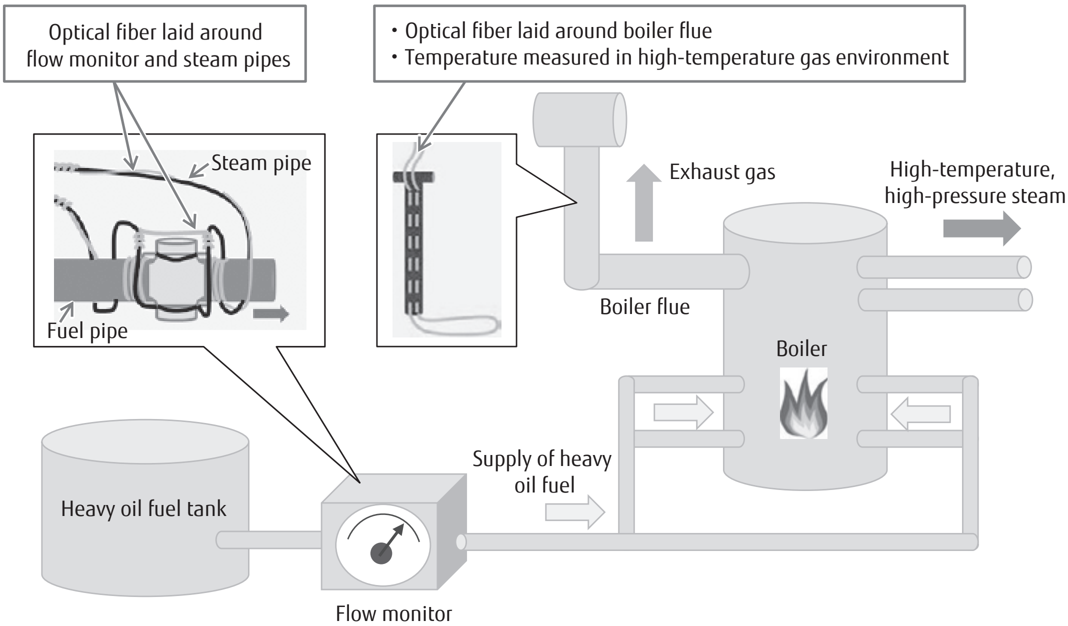

Figure 4
Installation of optical fiber in power-station facilities.

fibers enables temperature to be measured at 10-cm intervals over a length of several kilometers while also making the need for explosion-proof measures unnecessary since the measurement technology uses light instead of electricity.

In a joint field trial conducted with Tohoku Electric Power Co., Inc. from June 2014 to March 2015, Fujitsu continuously measured temperature changes in fuel pipes, steam pipes, and boiler flues at the company's Akita power station. The objectives were to confirm the feasibility of long-term use of this product in a harsh environment that included vibration in addition to high-temperature exhaust gases, and simultaneously, to detect any facility anomalies through the analysis of changes in temperature data obtained from measurements (**Figure 4**).[16),17)]

Trial results revealed that analysis of temperature data obtained from steam-pipe measurements could detect the liquefaction of steam and occurrence of retention within steam pipes. They also showed that comparing the temperature rise and fall timings between steam pipes and fuel pipes could successfully determine whether each type of pipe was in a normal state.

The temperature of the steam and fuel pipes at various points obtained by optical-fiber temperature measurements is shown in **Figure 5**. Examining the results in this figure, the fuel-pipe temperature (4) was initially kept constant due to the steam pipe. However, three minutes after a rise in temperature (in the interval between the dashed lines) of the steam-supply section (1), the temperature of the steam pipe (3) rose, and the temperature of the steam-return section (2) fell. In other words, these measurements revealed the occurrence of liquefaction and retention in the supplied steam. Additionally, it was found that applying a method for evaluating the overall distribution of temperature at various points enabled the early detection of anomaly indications.

In this trial, we also achieved temperature monitoring of boiler flues for 60 consecutive days despite the discharge of high-temperature exhaust gas reaching 120°C and continuous vibration. This result demonstrated that real-time temperature monitoring could be performed with this technology applied to it and that facility anomalies could be detected early even in a high-temperature, high-vibration environment.

Tohoku Electric Power is also using this product to monitor the state of oil-filled cables installed within specialized cable tunnels. In short, temperature-measurement technology using optical fibers enables optical fibers to precisely monitor the overall conditions

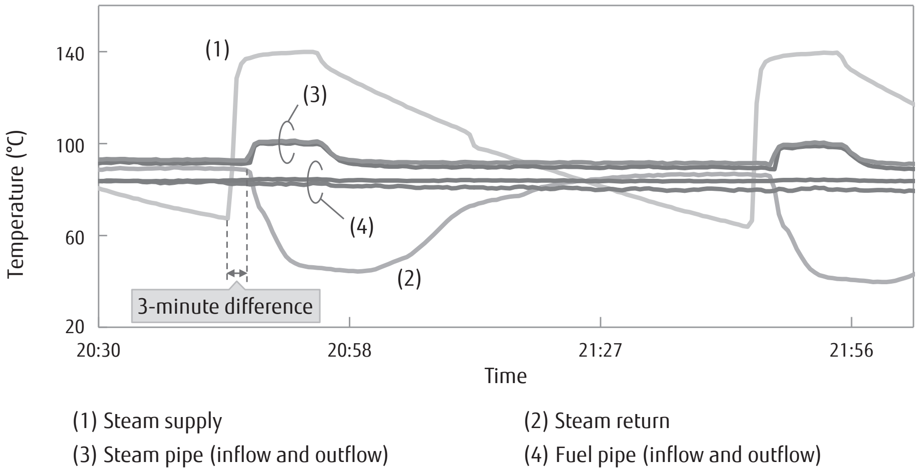

Figure 5
Results of pipe-temperature measurements from optical fiber.

of each oil-filled cable, thereby improving safety.

4.2 Manufacturing site

The use of this product for performing and enhancing quality control in production is expanding in the manufacturing industry. Manufacturing sites often include heating and drying processes that require working with heat, and in cases in which those processes are directly related to quality, it is extremely important that indications are detected from unusual changes in temperature through spatial temperature monitoring and/or AI. Missing such temperature changes can result, in the worst-case scenario, in a large amount of waste or defective products. However, there are also cases in which temperature management relies on the know-how of veteran on-site engineers and technicians with the result that many problems have not been quantified.

As a specific example, Fujitsu is applying its know-how in semiconductor-fabrication cleanrooms to the production of low-potassium vegetables at its Aizu-wakamatsu Akisai Plant Factory in Aizu-wakamatsu City, Fukushima Prefecture. This production site combines Fujitsu's know-how in quality management built up in semiconductor manufacturing and the temperature-measurement technology of this product to produce vegetables that can maintain freshness and taste over long periods.

Temperature highly affects the growth rate of vegetables making its management an essential element of a plant-cultivating factory. In the case of a non-uniform distribution of temperature in cultivation shelves, vegetable growth is subject to variation that will make it necessary to divide up shipment periods, switch locations for vegetable placement on shelves, etc. In an extreme case, variation in the growth rate of vegetables within a cultivation container can result in waste. In a plant factory having many spatially distributed structures such as cultivation shelves, a complete grasping of temperature distribution is difficult by using conventional technologies that use thermocouples or thermal cameras.

At Fujitsu, we have adjusted air-conditioning temperature, amount of airflow, circulator airflow direction, etc. and improved the uniformity of the temperature distribution by installing optical fibers as temperature sensors throughout the plant and visualizing the temperature distribution within the room (**Figure 6**). In this way, the technology contributed to achieving a uniform cultivation environment and improving yield.

The use of this technology at a manufacturing site is not limited to detecting anomalies or their indications through temperature measurement. It can also be used with the intention of visualizing the control know-how of veteran operators and achieving automatic control in combination with AI technology such as reinforcement learning on the FUJITSU Human Centric AI Zinrai platform.[18)]

When introducing a large number of new sensors, adjusting for individual differences takes time,

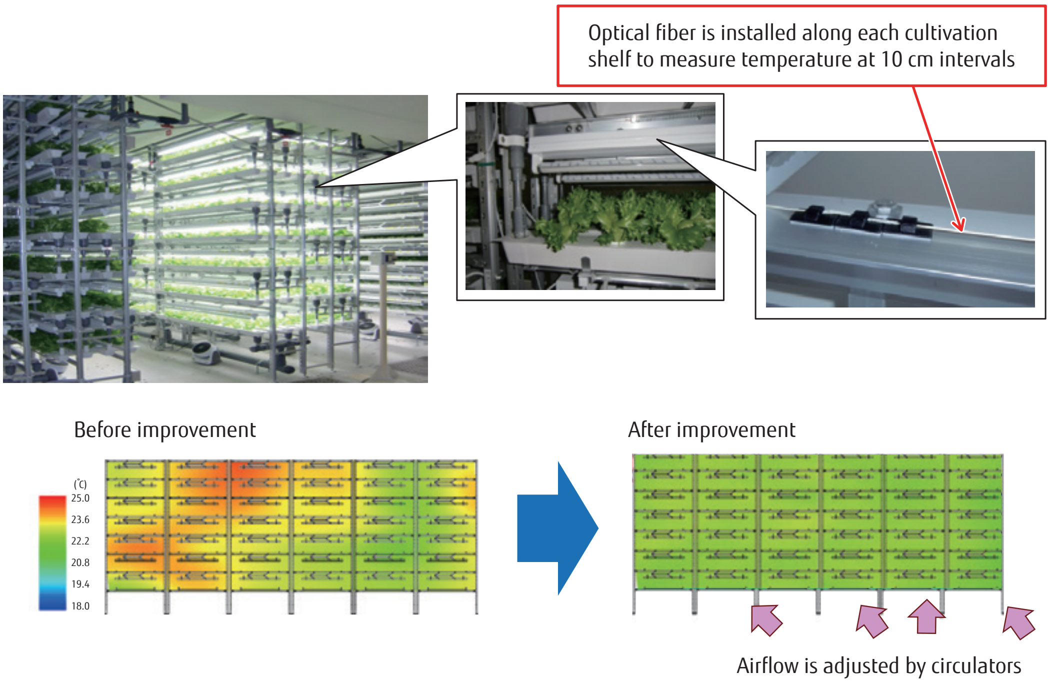

Figure 6
Achieving uniform temperature in cultivation shelves.

and monitoring the sensor devices' own state during an operation may be necessary. In contrast, our product enables precise and stable data collection at all times without having to worry about individual differences between discrete devices. In this way, it can be viewed as an infrastructure enabling advanced use of IoT technology at a manufacturing site.

5. Conclusion

Fujitsu's "ODMA Indication Monitoring Model for Optical Fiber Temperature Measurement" introduced in this paper achieves wide-range and detailed measurement of temperature and advanced monitoring by specialized AI. Its broad scope of application includes data centers, power/chemical plants, infrastructure equipment, and manufacturing sites.

Fujitsu places importance on the measurement and monitoring of temperature, and places even more importance on solving problems and issues related to temperature. It has accumulated specialized technology proposals for achieving such solutions on the basis of past experience and know-how. With respect to AI, our aim is to increase the precision of measurements by introducing even more advanced analysis technologies combined with diverse analysis tools and to provide an extensive lineup of functions in the future. Finally, we will continue to research and develop the application of optical fiber to areas deemed unfeasible in the past while pursuing solutions to especially difficult problems.

Achieving maintenance operations with advanced technologies like IoT and AI is an important theme, and a variety of technologies currently exist. For on-site operations in which false positives or errors are not acceptable, Fujitsu places great importance on accurate analysis and monitoring through the convergence of high-quality sensing (measurement) and specialized AI algorithms. Looking to the future, we are committed to expanding our on-site solutions and solution-proposal service.

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