Development of New Facility Condition Evaluation Method Using Information Content

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Abstract

We provide maintenance services that utilize Information and Communication Technology (ICT) and the Internet of Things (IoT) to improve the status monitoring and abnormality diagnosis of electrical equipment. This service provides equipment diagnosis solutions by analyzing measurement data. In recent years, a wide variety of large amounts of data have been collected from equipment, and the scale of data analysis is on the rise. To address this increase in the scale of analysis, we have developed a new statistical analysis method called "information content correlation analysis" using information content.

This method converts sensor data into information content, which is a common measure, and evaluates the progress of changes to perform equipment diagnosis. This function was developed based on the principle of not being dependent on the physical quantity of the sensor, and does not limit the target equipment or the sensor used. By utilizing this analysis method, it is possible to expand conventional sensor and data analysis, and improve condition-based maintenance service.

1 Preface

We deliver electrical equipment and systems to a wide range of public and industrial fields both in Japan and overseas, and are working to realize a better society through these social infrastructures. Large rotating machines are used for power generators, water treatment aeration blowers, and pumps. In addition, various rotating machines of different sizes are in operation in factories and plants, and their operation forms and usage environments are extremely diverse. In recent years, there has been a shift[1] to Condition Based Maintenance (CBM) using Information and Communication Technology (ICT) and the Internet of Things (IoT) in order to maintain the performance of these electrical equipment and improve its economic and management efficiency.

We have developed a condition monitoring method using information content as a new analysis technology to enhance CBM of existing equipment. This paper introduces the enhancement of equipment diagnosis by utilizing information content. In this development, we established a technology based on mathematical engineering through collaborative innovation activities with Hiroshima Institute of Technology in Hiroshima City and Math. Research Institute Calc for Industry in Hiroshima City[(2)-(4)].

2 Infrastructure Monitoring Using Sensors

With the spread of ICT and IoT, large-scale infrastructure facilities are being equipped with a large-content data measurement environment. By installing a sensing terminal in infrastructure facilities, the status values of the target facilities can be easily measured. However, in the case of sensing large facilities, the status information that can be measured from a single sensor is limited to the surrounding area of the installation location. Due to this physical constraint, it is common to use multiple sensors to measure appropriate physical quantities for each part and evaluate them for monitoring and diagnosis of large infrastructure facilities.

We are working on developing data analysis technology that combines a wide variety of measurement data and will cover the entire facility in the future. Correlation analysis has long been known as an analysis technique for numerically evaluating the relationships between multiple data. However, since the aforementioned infrastructure facilities handles a wide variety of physical quantities such as vibration, temperature, current, voltage, and sound, it is not easy to analyze the interrelationships between them. Therefore, the identification, quantification, and evaluation of correlations that are useful for status monitoring are currently limited to experienced engineers. Given this technical background, we have developed a new condition monitoring method that does not rely on physical quantities in data analysis from multiple disparate sensors in order to resolve the problem of analysis that relies on experiences.

3 Information Content

To evaluate the correlation between sensor data, we focused on information content. Information content is one of concepts where uncertainty or ambiguity of status is expressed(5). By applying this index of ambiguity of a state to the state evaluation, we have achieved advanced equipment diagnosis. In addition, since the information content is calculated from the statistical tendency of the data, analysis that is not strongly dependent on the physical characteristics of various sensors can be performed.

Fig. 1 shows the conventional data analysis of different types of sensors. In conventional analysis, the measurement data obtained from each sensor is analyzed and processed to evaluate the equipment status. At this time, numerical processing is performed on the physical quantity of the measurement data. Since the physical characteristics of the data differ for each sensor, processing (normalization) is required to standardize the scale when comparing sensors. However, physical characteristics have various patterns, and designing normalization is not easy. As a result, there were challenges in realizing a diagnosis that covers the entire equipment using a large amount of measurement information.

Fig. 2 shows the effect of information content. The data of the physical quantity measured by the sensor is converted into information content through statistical processing. This process makes the scale common to all sensors. As a result, the correlation can be evaluated using a common measure called information content. There are several definitions of information content. In this paper, we will introduce an example of average information content (hereinafter referred to as “entropy”).

Fig. 3 shows data analysis using information content. It is a flow of numerical processing from sensor data to information content. Since the measured data x periodically acquired from the sensor comes in a numeric string for a specified time, it is possible to obtain the statistic information $P(x)$. This statistic information is then converted into information content $H(x)$ by the entropy-based expression (1) below.

$$H(x) = -\sum_{x} P(x) \log P(x) \cdots\cdots (1)$$

The data $x1$ measured with the sensor is stable in regard to numerical variation. This numerical condition can be regarded as a fact that the “infor-

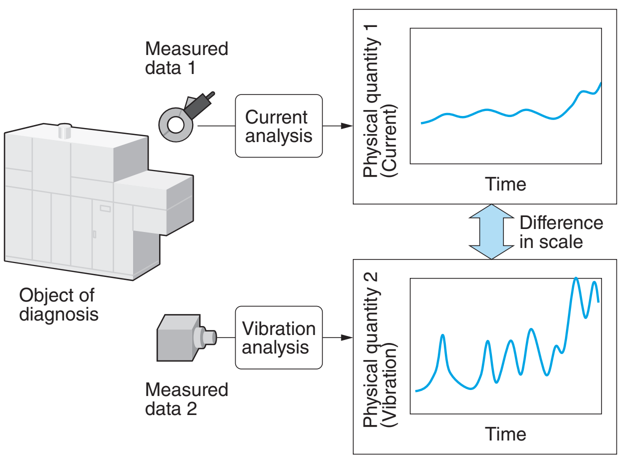

Fig. 1 Conventional Data Analysis of Different Types of Sensors

The measured values (numerical data expressing the physical quantity) are greatly changed by sensor types and physical characteristics. Accordingly, it is difficult to define a common scale by ordinary analysis. As a result, there have been challenges in regard to the realization of conditional evaluation based on the common scale.

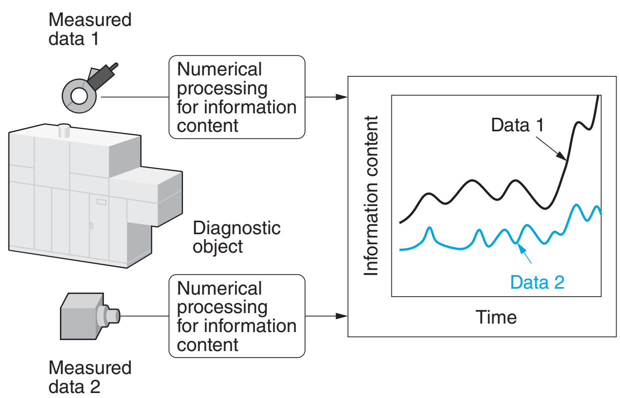

Fig. 2 Effect of Information Content

Physical content from each sensor is converted into information content. By this treatment, analysis becomes easy to do based on a common numerical scale even though different types of sensors are used. Analysis is possible and not dependent on any sensor types and physical characteristics.

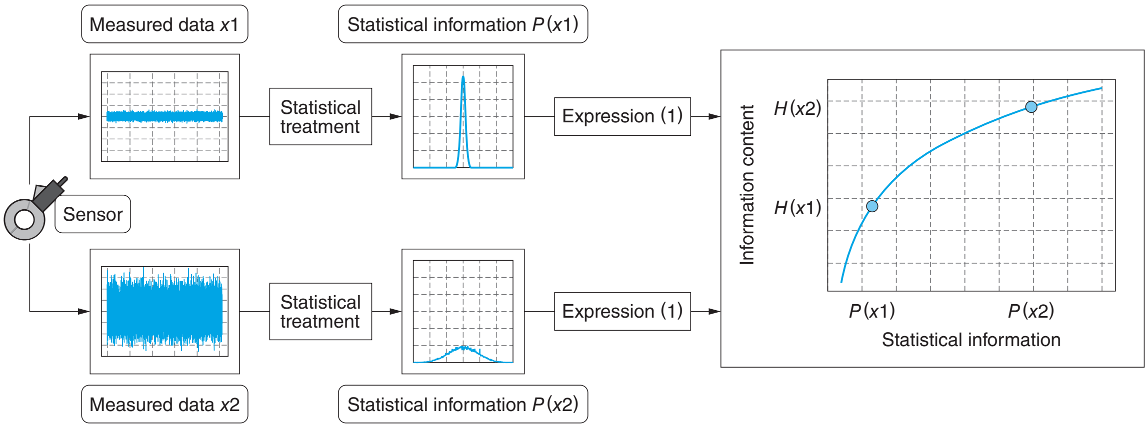

Fig. 3 **Data Analysis Using Information Content**

Based on statistical information of Sensor *x*, the information content is calculated from Expression (1). The information content brings a greater effect as the data is more unstable relatively. Utilizing this effect, data analysis and anomaly diagnosis are carried out for the sensor data.

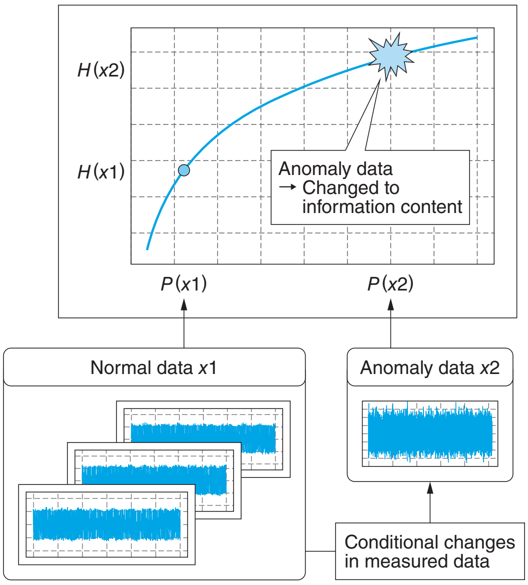

Fig. 4 **Equipment Condition Diagnosis Using Information Content Analysis**

Conditional changes in measured data are evaluated based on the scale of information content.

mation uncertainty" held by this data is low. Value $H(x1)$ is the quantified figure of this information.

Measured data $x2$ can be regarded as a fact that numerical variation is relatively high compared with $x1$ and it is recognized as an unstable condition. According to a viewpoint of the "information uncertainty", this instability can be regarded as a high value. In fact, Value $H(x2)$ indicates high numerals. Consequently, it is possible to conclude that quantification based on the information content can easily show the tendency of measured data.

Fig. 4 shows equipment condition diagnosis using information content analysis. Since the sensor periodically collects measurement data, the entropy is calculated each time. Normal data, which corresponds to a stable state of the equipment, has low "information uncertainty". Therefore, the entropy shows a low value. On the other hand, in an abnormal state, the measurement value becomes unstable, and the numerical values contained in the data become more uncertain. As a result, the entropy changes from the normal value. By monitoring and evaluating this change, the equipment condition can be diagnosed.

4 Equipment Condition Evaluation Method Based on Information Amount

Status monitoring and equipment diagnosis of large-scale infrastructure require sensing and analysis using a large number of different types of sensors. **Fig. 5** shows equipment diagnosis using a combination of different types of sensors. This is an example of condition monitoring using a current sensor and a vibration sensor. Current and vibration data are different physical phenomena, so the periodicity of the values, the measurement settings of the sensors, and the numerical level of the signals are different. Therefore, comparative evaluation is not easy.

In this analysis, the measurement data is converted into the amount of information described in **Section 3**, and the condition is evaluated using that value. At this time, the values of both the current data and the vibration data are calculated under the scale of "information uncertainty". Therefore,

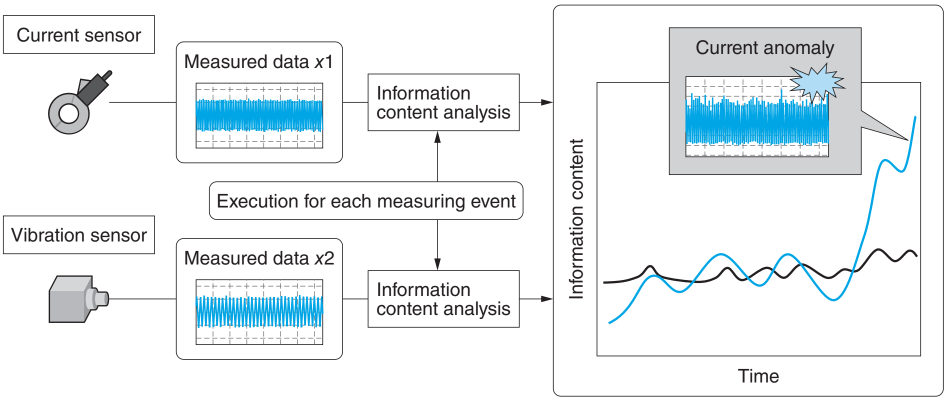

Fig. 5 **Equipment Diagnosis Using Combination of Different Types of Sensors**

Based in the information content, data of the anomaly sensor is evaluated with common index. Evaluation and diagnosis are carried out to overview the entire equipment of infrastructures through analysis of periodically measured data with the use of common index.

regardless of the sensor, the normal state takes a low value. However, as shown in the graph in Fig. 5, if an abnormality occurs in the current data, the value of the information contained in the current data increases. At this time, the data of the vibration sensor has the same information value as past measurements, so a relative numerical difference is created between the amount of information of the current and vibration. Through this process, it is possible to grasp that an abnormality has occurred in the current data among the many different types of sensors of the monitored equipment. In this case, engineers can view the results of the sensor analysis from the perspective of the value of the information, without knowing the physical properties of the sensor. This makes it easier to determine the priority of sensors that are important in the event of an abnormality, and allows them to move on to the task of investigating the condition and determining the cause.

As described above, we have established a technology that uses data analysis and equipment diagnosis using the amount of information to improve equipment monitoring service.

5 Postscript

We introduced a method for evaluating the condition of equipment using information from multiple disparate sensors. We are working to incorporate this technology into our equipment diagnosis services.

Going forward, we will continue to work on improving the maintenance, efficient operation, and functionality of infrastructure equipment through the development of data-driven condition monitoring methods obtained in response to the advancement of digitalization of social infrastructure.

《**References**》

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