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Belt Conveyor Monitoring System for Effective Maintenance Utilizing ICT

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Abstract:

In the raw material yard of steel works where iron-making materials are stored and conveyed, a number of belt conveyors are in operation. It is strongly required to find out abnormalities in belt conveyor equipment at an early stage and to prevent breakdowns, as the loss to production is large. However, the raw material yard is so large that it is difficult to install many various sensors for monitoring. Therefore, JFE Steel developed a belt conveyor monitoring system utilizing ICT (Information and Communication Technology). Demonstration test was conducted at JFE Steel East Japan Works (Chiba), and specifications necessary for wireless networks, which are indispensable for wide-area data collection, and the usefulness of image judgment system of belt shape defects were confirmed. And, a centralized monitoring system using a heat mapping display to evaluate correlation of multiple types of data was built.

1. Introduction

At coastal-type integrated steel works, the series of equipment from unloading and storage of raw materials through iron-making, steelmaking, rolling and other steel manufacturing process to shipment as final products is arranged on a large plant site. Many steel works in Japan were constructed during the period of high economic growth, and since these iron and steel production facilities range from ageing equipment to newly-introduced state-of-the-art equipment, various levels of equipment maintenance are required.

In an integrated steel manufacturing process, trouble affecting equipment or other problems has an enormous impact on operation. Therefore, early discovery of abnormalities and advance prevention of breakdowns of the equipment are strongly required. Since steel works basically operate under a 24-hour-a-day system, regular monitoring of the equipment while in operation and detection and correction of the signs of anomalies are necessary.

In the raw material yard, where iron ore, coal and other materials for steel production are unloaded, stored and conveyed, monitoring and maintenance of equipment has been considered difficult because the handling machinery for stacking and reclaiming raw materials and a large number of belt conveyors are arranged over a large site under a poor environment that includes outdoor conditions, dust, etc.

JFE Steel is promoting infrastructure improvement and technology development for wide application of data science technologies such as ICT (information and communication technology) and AI (artificial intelligence)[1, 2]. This paper introduces an equipment condition monitoring system which was developed using ICT for the numerous belt conveyors arranged in the raw material yard.

2. Outline of Belt Conveyor Monitoring System

Equipment management of raw material conveyors is extremely important due to the large loss of production if a breakdown occurs. Although there is a high need for monitoring by installing large numbers of sensors of various types, the cost of wiring for data collection is large, since the many conveyors in a raw material yard are arranged over a large site, and their total length ranges from several 10 km to as much as several 100 km in some cases. Therefore, wireless monitoring utilizing state-of-the-art ICT rather than a wired communication system had been demanded.

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A demonstration test of a new belt conveyor monitoring system was conducted at JFE Steel East Japan Works (Chiba), and collective monitoring of the data from multiple sensors and diagnosis of anomalies using image data were verified. **Figure 1** shows the outline of the belt conveyor monitoring system. The object of the system is the multiple belt conveyors of the iron ore system and coal system in the raw material yard. This centralized monitoring and anomaly diagnosis system collects and consolidate information from sensors installed at each conveyor to the raw material yard center by means of wireless communication. The sensors installed in the system include visible light cameras for detection of shape defects such as breakage of the conveyor belt edge, longitudinal rips, holes and scratches, vibrometers, thermometers and microphones for detection of anomalies in drive parts and pulley bearings, and visible light cameras, microphones, thermo-hygrometers and vibrometers for monitoring the condition of raw material clogging in chutes.

3. Construction of Wireless Network

3.1 Network Design for Raw Material Yard Environment

Various wireless communication schemes for construction of a wireless network in the raw material yard were studied [3, 4]. **Table 1** shows the feature of various frequency bands used in wireless communication. Generally, the transmission speed and communication range of wireless communication changes depending on the frequency band. Low frequencies have a slow transmission speed but a long communication range, and are also less affected by obstacles in the transmission route. Conversely, high frequencies enable high speed communication, but are weak against obstacles and have a short communication range. It may be noted that the transmission speed and range are also affected by the transmission power of the wireless standard and the features of antennas. For example, when using an antenna with high directionality in wireless communication by Wi-Fi, the transmission direction is limited, but long distance transmission of around 1 000 m is possible.

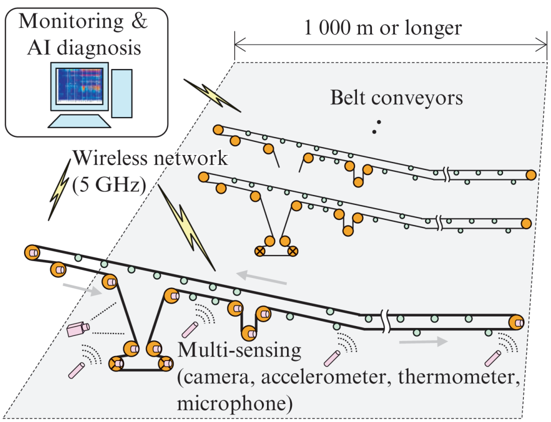

Fig. 1 Belt conveyor monitoring system

Table 1 Wireless communication scheme

	ZigBee IP, Wi-SUN	ZigBee	Wireless LAN (Wi-Fi)	
Frequency band	900 MHz	2.4 GHz	2.4 GHz	5 GHz
International standard	IEEE 802.15.4	IEEE 802.15.4	IEEE 802.11b/g	IEEE 802.11ac
Transmission speed (max)	100 kbps	250 kbps	54 Mbps	6.9 Gbps
Communication range	700 m	50 m	100 m*	100 m*

*Approx. 1 000 m with directional antenna

In monitoring of belt conveyors, it is necessary to transmit video data concerning the condition of the belt surface captured by visible light cameras. For this, a 5 GHz band wireless LAN which enables large volume transmission is considered effective, but because 5 GHz band wireless transmission has high straightness, more stable transmission is achieved by constructing a multi-hop network, as illustrated in **Fig. 2**, for locations where installation of multiple access points is necessary due to complicated raw material yard equipment. In other words, when monitoring multiple conveyors, the preferred configuration for long distance transmission along raw material piles is reliable transmission by one-to-one P2P (Peer-to-Peer) connection, and in places where access points are concentrated in a certain area, a configuration that optimizes the transmission route by multi-hop connection is desirable.

3.2 Basic Verification Test of Wireless Communication

A basic verification test was carried out to investigate the wireless communication environment in the raw material yard. The test conditions and test environment are shown in **Table 2** and **Fig. 3**, respectively. A straight transmission test and an over-pile transmission test, in which the antennas were located on the two

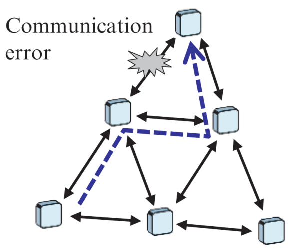

Fig. 2 Multi-hop networks

Table 2 Test conditions of wireless communication

Condition		Straight		Over pile
		P2P	1 hop	
A	High-directional antenna (3dB beamwidth: 9°)	200 – 1 000 m	–	–
B	Midium-directional antenna (3dB beam-width: 30°)	200 – 1 000 m	–	57 m
C	Non-directional antenna	100 – 1 000 m	100 m + 100 m 200 m + 200 m 500 m + 500 m	–

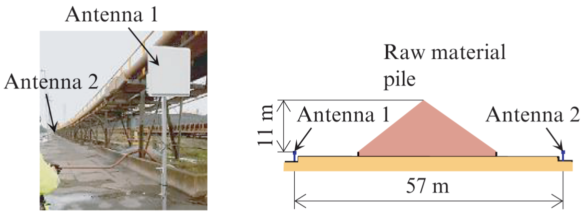

Fig. 3 Wireless communication test in raw material yard

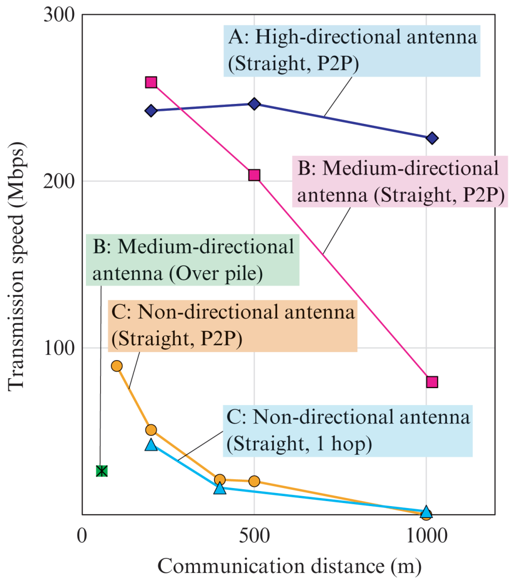

Fig. 4 Measurement results of transmission speed

sides of an 11 m high raw material pile, were conducted under different antenna conditions, and the transmission speed of 5 GHz band wireless communication was measured.

The results of the transmission speed measurements are shown in **Fig. 4**, where the communication distance is shown on the x-axis. The results revealed that the transmission speed changes remarkably depending on the directionality of the antenna, and an extremely high transmission speed could be achieved when using a high-directionality antenna, even over a long distance of 1 000 m. On the other hand, as a characteristic feature of medium- or non-directional antennas, which have poor directionality, the transmission speed became slower as the communication distance increased. Comparing one-to-one P2P connection and hop connection with one relay point, a slight decrease in the transmission speed was observed in the configuration with the relay point. In the case of transmission over a pile, which is an obstacle between the wireless access points, an extreme decrease in the transmission speed was confirmed in spite of the short distance between the access points.

The necessary transmission speed for monitoring of belt conveyors is estimated to be 20 Mbps. However, by using high-directionality antennas, it is possible to construct a communication network with a margin of more than 10 times the required speed in the wide range of the raw material yard. Furthermore, because 5 GHz band wireless is easily affected by obstacles, as demonstrated in the over-pile test, it is important to ensure transmission stability by using relays under conditions where the raw material yard equipment is complex, for example, at connection points between conveyors. If the access points are within a distance of 200 m, the necessary transmission speed can be realized, while also securing multiple transmission routes, by an appropriate arrangement of non-directional antennas.

4. Belt Anomaly Detection by Image

A model which detects conveyor belt shape defects by photographing the belt surface with a visible light camera was created, and its accuracy was verified.

The condition of belt photography is shown in **Fig. 5**. The camera used here is a dustproof, waterproof network camera, and is set to a shutter speed which enables blur-free photography of the belt, considering the speed of the belt conveyor. Because light will be inadequate if the shutter speed is too fast, the necessary light intensity was secured by setting up multiple lighting units, which were then adjusted for uniform brightness of the belt surface.

As a general technique for detecting shape defects

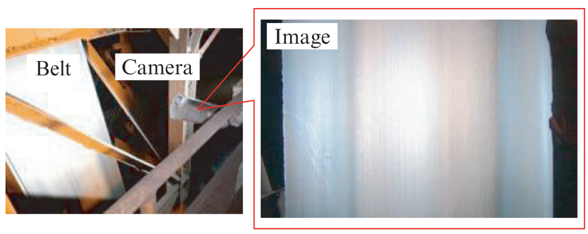

Fig. 5 Taking images of conveyor belt

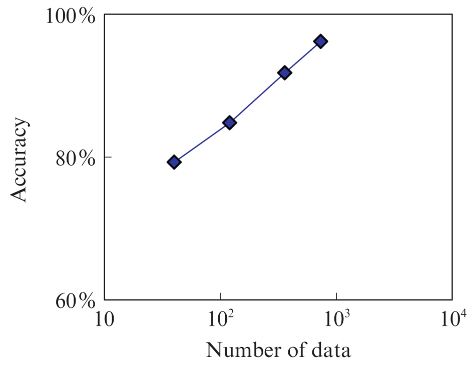

Fig. 6 Influence of number of data on judgment accuracy

from images, feature quantities are obtained by image processing, and a tree judgment is made [5]. However, considering the diversity of belt defective shapes and external disturbances due to photography under outdoor conditions, an anomaly judgment model was constructed based on a large volume of data.

For verification of the anomaly judgment model, the model was constructed by using the data for 80% of images photographed in advance, and the model judged the remaining 20% of the data, which were unknown to the model. Judgment accuracy was evaluated from the percentage of correct answers concerning whether an actual shape defect existed or not and agreement with its properties in the results of judgments of the image data by the model.

Figure 6 shows the judgment accuracy, which was evaluated by changing the number of image data used in constructing the model. It can be understood that judgment accuracy improves and more accurate judgment of defect shapes becomes possible as the number of data used in model construction becomes larger. In this study, satisfactory accuracy was confirmed, as the correct answer rate of the initial model was 90% or more, and it was also concluded that construction of a model with higher practicality would be possible by accumulating additional data.

5. Integrated Diagnosis of Different Types of Data

A diverse range of anomalies and trouble should be prevented in belt conveyor equipment, beginning with fires, but also including belt breakage, drive system stops and overflow of material from chutes. However, individual anomaly phenomena generally affect multiple types of sensor information and operating information. **Figure 7** shows a schematic diagram of this data correlation. For example, the conditions that must be known in order to prevent breakage of a conveyor belt include side tracking, fraying of the belt edge, holes (longitudinal ripping) and contact with pulleys (abrasion). However, it is thought that fraying of the belt edge shows a correlation not only with belt image data, but also with vibration of pulleys and vibration and sound in the drive system. Accordingly, anomalies can be detected with good accuracy in the sign stage by an integrated evaluation of the information from a number of sensors of different types, and the results can be used in efficient maintenance action.

In order to monitor a large number of sensors efficiently, the temporal changes in the degree of anomaly of each monitoring object are expressed by heat mapping corresponding to the magnitude of those changes. An example of a heat mapping display is shown in **Fig. 8**. Here, the *y*-axis shows the objects of monitoring, the *x*-axis shows time and one cell shows the anomaly score calculated in set time intervals.

As the anomaly score, statistical quantities such as the maximum value and average value are calculated for each sensor, or when an anomaly is detected in each image, the anomaly score is calculated as the degree of deviation from the normal condition. It is also possible to visualize the correlation of anomalies between sensors by showing deviation from the normal value by colors from blue (normal) to light blue, green and red (anomaly), in that order. Because many different types of data, such as belt shape defects, vibration, sound and temperature, can be checked at a glance in time-

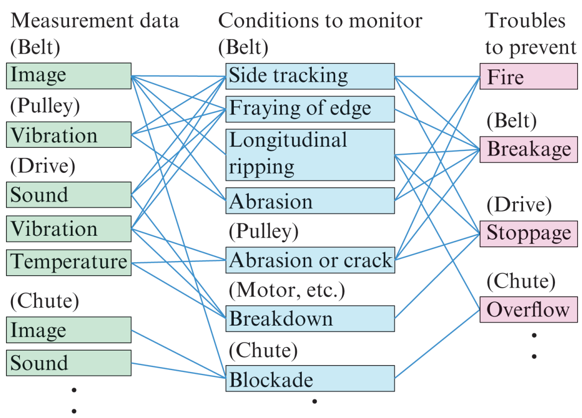

Fig. 7 Schematic diagram of data correlation

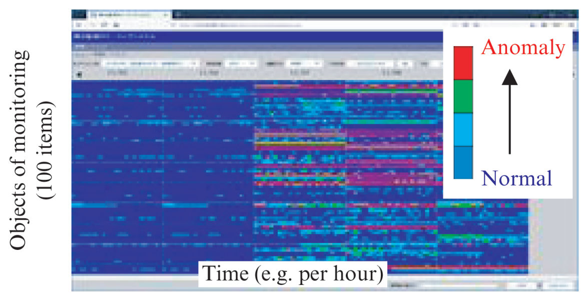

Fig. 8 Example of heat mapping display

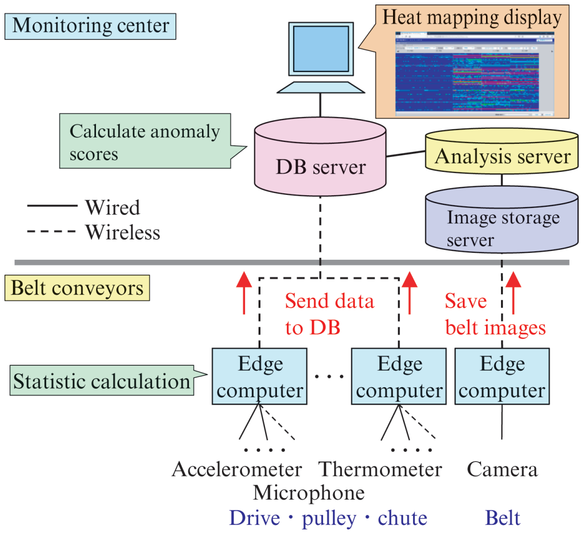

Fig. 9 System configuration of integrated monitoring

series order, heat mapping display is effective for evaluating the correlations of multiple sensors.

An outline of the integrated monitoring system is shown in **Fig. 9**. Information from the various sensors installed at the belt conveyors is collected by edge computers, and statistical quantities, etc. are calculated in a set time range, as necessary. In comparison with transmitting raw (unprocessed) time-waveform data as-is, the volume of data can be greatly reduced by preprocessing the data by the edge computers before data transmission. The system calculates anomaly scores from data in the database server, which are collected and consolidated by wireless communication, and displays the heat mapping. As outlined above, early detection of anomalies is possible by integrated monitoring of large numbers of data of different types.

6. Conclusion

A monitoring system utilizing ICT was developed for the belt conveyors of the raw material yard. The following knowledge was obtained.

(1) A demonstration test was conducted at the raw material yard of JFE Steel East Japan Works (Chiba), and the specifications necessary in a wireless network, which is indispensable for wide-area data collection, and the practicality of judgment of belt shape defect images were confirmed.

(2) An integrated monitoring system using heat mapping display, which is capable of evaluating large quantities of sensor information of various types, was constructed.

In the future, the authors intend to expand these technologies to various other types of equipment to promote stabilization of production by advance prevention of equipment anomalies.

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