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Development of Conveyor Belt Fire Detection and Monitoring System

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Raw material handling is a vital process in a steel-plant manufacturing execution system, and transportation of the raw materials plays a critical role in the entire manufacturing process. Therefore, the reliability of conveyor belt equipment should always be closely monitored. Fire is the greatest hazard associated with conveyor belt equipment; however, there are different kinds of root causes for fire events, such as belt friction, collapsing of pulley or idler bearing, smouldering fires of coal dust, excessively high temperatures, electrical sparks, etc.

A conveyor belt fire detection and monitoring system was proposed based on machine learning recognition technology to precisely detect temperature anomalies in conveyor belt equipment. The system includes heterogeneous sensor networks which are comprised of Distributed Temperature Sensing (DTS), Bearing Temperature Sensing (BTS), and Thermal Image Recognition (TIR). The experimental results show that the system can provide alert signals six minutes, at most, before an actual fire event occurs. Moreover, the accuracy of simulations can approach 100%, which satisfies the purpose of fire prevention.

Keywords: Conveyor belt, Fire detection, Heterogeneous sensor networks, Machine learning

1. INTRODUCTION

Raw material handling is a vital process in integrated steel-making firms. The transportation of raw materials is always dependent on conveyor belts. Therefore, the reliability and stability of conveyor belt systems is of high importance. Fire poses as one of the most severe hazards to conveyor belt systems. Since conveyor belts are ignited easily and spread fire rapidly, a conveyor belt fire detection and monitoring system to effectively prevent fire incidents must be developed[1-2].

Traditional fire detection systems are either unreliable due to the environment (misdiagnosed alarms and or alarm failure caused by dust or fog) or not sensitive enough. Hence, they are not suitable solutions for conveyor fire detection[3]. Linear heat detection can be activated under the fire or flames on a stationary belt, but it cannot prevent fires from occurring[4]. Carbon monoxide (CO) detection is becoming a method that can provide alerts before fire incidents, but it can only be adapted in enclosed systems (like tunnels) with correct setup conditions and proper air circulation[3,5-6]. Roller bearing temperature monitoring can accurately detect abnormal temperature fluctuation to monitor the status of belt drums or roller bearings, which can allow for early fire detection[7-8]. However, it can only function within the bearing.

This study describes the results of a newly proposed conveyor belt fire detection and monitoring system to evaluate the capacity of early fire detection within these systems. The front-end sensors were built by heterogeneous sensor networks which are comprised of Distributed Temperature Sensing (DTS), Bearing Temperature Sensing (BTS), and Thermal Image Recognition (TIR). In addition, the system detected temperature faults with an AI model built by machine learning algorithms based on sensor data.

2. EXPERIMENTAL METHOD

Figure 1 shows a workflow diagram of the system. It starts from data collection and analysis from heterogeneous data of the DTS, BTS, and TIR. Then, it proceeds to implement engineering and model building to detect and identify abnormal statuses. If abnormal events occur, the system will activate the water suppression system to prevent the fire incident.

There are three units in the proposed system: sensor networks, server, and control unit as shown in Figure 2.

Sensor networks consist of three kinds of front-end sensors that assist with the monitoring process, which are Distributed Temperature Sensing (DTS), Bearing Temperature Sensing (BTS), and Thermal Image Recognition (TIR). The server unit is responsible for data fusion from sensors and builds an AI model to identify abnormal conditions. Meanwhile, it also provides real-time feedback to users. If the model transmits the alert signal to the control unit, the PLC will activate the water pump and trigger water-suppression action until the alert is cancelled.

In this study, there are three main technologies of this system that will be completed:

1. Development of thermal image recognition and detection method for abnormal events.
2. Construction of a method for distributed temperature sensing systems to improve performance of anomaly detection systems.
3. Development of a method for bearing temperature sensing system to enhance the performance of anomaly detection systems.

2.1 Distributed Temperature Sensing (DTS)

The DTS technology is achieved by temperature sensor nodes with optical fibers. As Figure 3 shows, the ruggedized fiber optic based system has the capacity to detect fires rapidly by surrounding the conveyor belt and localizing the source to within 0.25 meters with ±0.5 degrees Celsius accuracy. However, there were occasional misdiagnosed alarms and failed alarms in the original DTS.

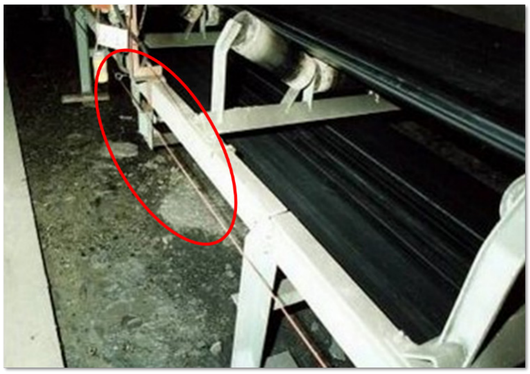

Fig.3. The deployment of fiber optics for DTS.

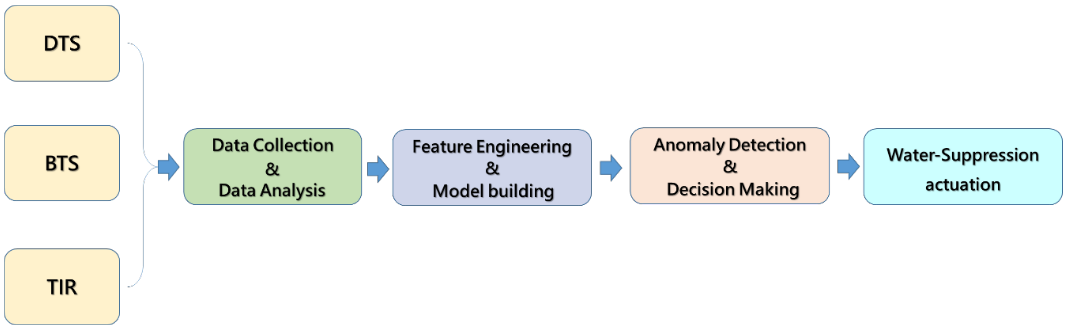

Fig.1. Flow of system working process.

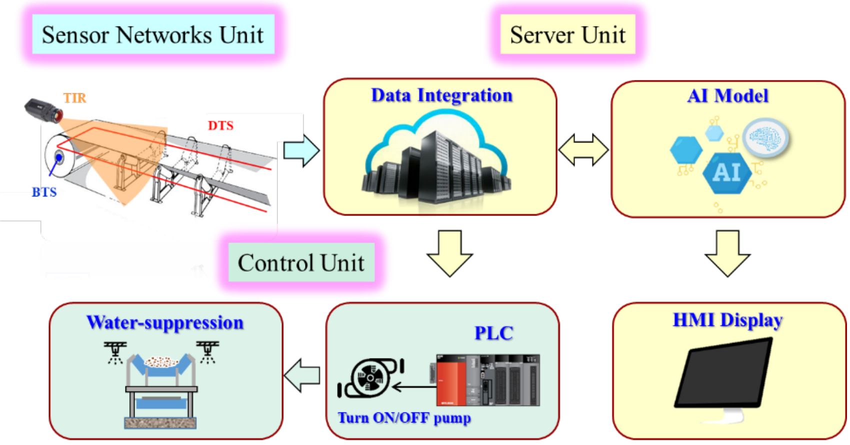

Fig.2. The structure and configuration of the system.

To address the problem above, the series of steps taken are shown in Figure 4. First, the raw data was captured, collected, and delivered to server units with abundant information such as time, location, data quality index, and temperature. After data preprocessing and normalization, the Dynamic Time Warping (DTW) algorithm is introduced to compute the similarity of the data to real fire incidents. DTW is an algorithm based on dynamic programming methods, which can be used to calculate the similarity of two time series, and the formula (2-1) is shown as follows:

$$D(i,j) = |V(i) - U(j)| + \min\{D(i-1,j), D(i-1,j-1), D(i,j-1)\} \quad \text{(2-1)}$$

Where, i and j are the sample point of time; $V(i)$ is the series data of temperature of real fire event, and $U(j)$ is the series data of current temperature.

2.2 Bearing Temperature Sensing (BTS)

This bearing temperature sensing has been designed for capturing and collecting roller bearings with thermocouples that are installed in conveyor belt equipment. The data includes time, roller code, drive/non-drive side, belt operation status, and temperature. All data information will be transmitted to the server unit via Modbus communication with the process shown in Figure 6. According to the time series data, the system applies the Weighted Moving Average (WMA) algorithm to predict the temperature trend to identify anomalies in the bearing status. Equation (2-2) is shown as follow.

$$T_p = W_1(T_r - 1) + W_2(T_r - 2) + W_3(T_r - 3) + \ldots + W_n(T_r - n) \quad \text{(2-2)}$$

Where, T_p is the next temperature value; n is the number of periods of moving average; $T_r - 1$ is the temperature value before 1 minute, $T_r - 2 \ldots T_r - n$ and so on. W_1 is the weight of the temperature value 1 minute ago; $W_2 \ldots W_n$ and so on. The equation helps to predict the next temperature value by using the historical temperature data and defining the threshold as the baseline for identifying the anomaly status.

Fig.5. The deployment of thermocouple for BTS.

Fig.4. The flow of DTS analysis and identification.

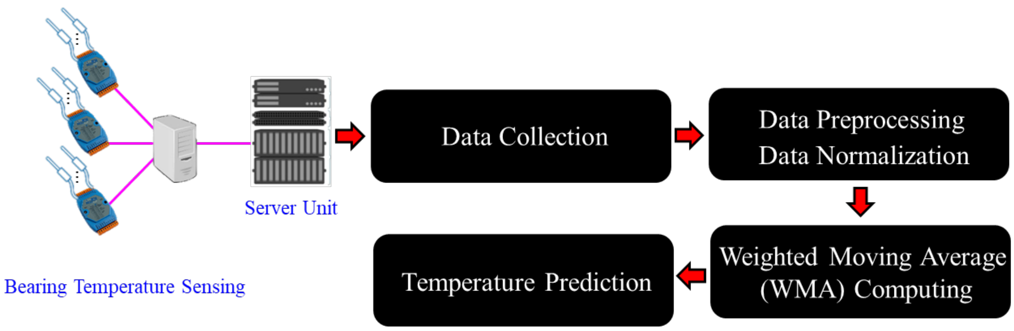

Fig.6. The flow of BTS analysis and identification.

2.3 Thermal Image Recognition (TIR)

The system carried out Thermal Image Recognition (TIR) by deploying the thermal camera (Fig.7) that can provide the thermal image with 336 x 252 pixels, detecting the temperature between 40 and 550°C. The TIR is an effective method for identifying the surface rising temperature within the thermal image. However, due to the inherent and environmental limitations of thermal imaging, it is not possible to directly determine the status of the system by retrieving the maximum temperature value of the thermal image. Considering the capacity and reliability of anomaly detection, Figure 8 shows the series of steps to achieve the target which are region of interest (ROI), color transformation (RGB to HSV), and filtering the noise by computing convolution. The decision function is defined as Equation (2-3). Then, the system computes the density index (D_i) to identify the results as Equation (2-4).

Fig.7. The deployment of thermal camera.

$$(f * g)(n) = \sum_{\tau=-\infty}^{\infty} f(\tau)g(n-\tau) \quad \text{......................} \quad (2\text{-}3)$$

$$D_i = \sum_j x(d_{ij} - d_c) \quad x(l) = \begin{cases} 1, & x < 0 \\ 0, & x > 0 \end{cases} \quad \text{......................} \quad (2\text{-}4)$$

Where, d_{ij} is the distance between two different groups; d_c represents the distance of detecting range of the image; $x(l)$ is the accumulation index.

This study proposed an identification method that consists of heterogeneous sensor networks which are Distributed Temperature Sensing (DTS), Bearing Temperature Sensing (BTS), and Thermal Image Recognition (TIR). Combining the features of various sensor networks and developing machine learning algorithms, the system was able to detect abnormal temperature rises with different root causes of the conveyor belt system. Based on the detection result, the system can provide real-time information to users. If the system delivers the alert signal to the control unit, the water-suppression system is activated to spray water with sprinklers and provide alerts on the HMI interface.

3. RESULTS AND DISCUSSION

In this study, for purposes of testifying the system performance and capability, we deployed the system in the raw material handling and transportation department. The proposed system was verified and evaluated for sensing ability, detection performance, and identification results.

3.1 Experimental Scenarios Testification

According to statistics, frictional heat seems be the primary cause of belt fires(9). Fires on belt conveyors are most often ignited by mechanical failures like frozen idlers which are even riskier in combination with coal dust. These frictional ignitions are a common source of belt fires. As a result, we simulated the heating scenarios (Fig.9) that are caused by friction to verify the system's capacity and performance.

3.2 System Verification of DTS

The scenario tests for the DTS are jammed rollers or friction of belts, that were carried out with the gas burner heating, and the heating length was 70 cm at

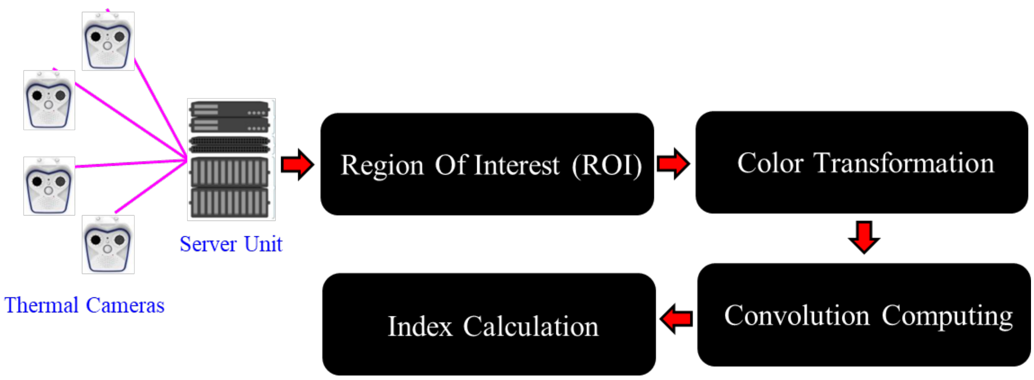

Fig.8. The flow of TIR analysis and identification.

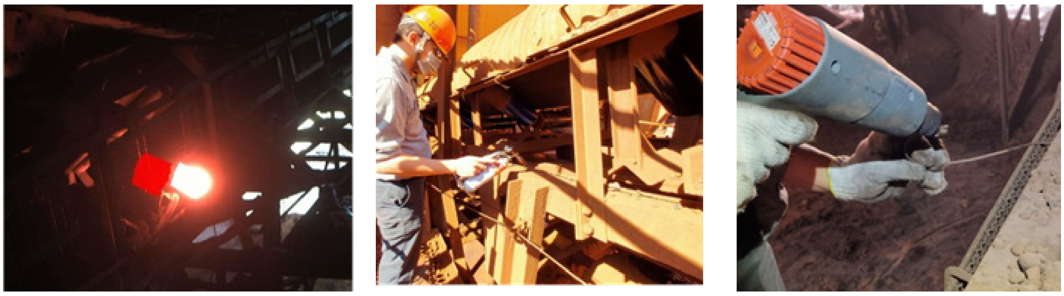

Fig.9. The friction simulation of heating scenarios.

about 100 degrees Celsius. The result showed that the system can accurately detect the area of abnormal temperature rise by introducing an AI model (Fig.10 and 11) and detect the abnormal status 2 to 6 minutes earlier than the original DTS system.

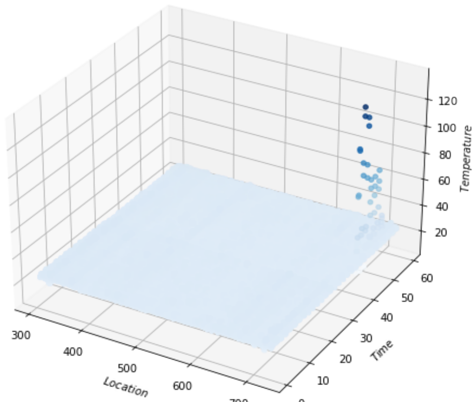

Fig.10. Abnormal temperature rise detection of DTS.

The results showed that the detection rate of the original DTS reached 95% accuracy, and the modeling DTS accomplish 100%. In addition, with 42 simulations, the modeling DTS could consistently alert earlier than the original DTS, as shown in Figure 12.

3.3 System Verification of BTS

The system test of BTS is simulated with seizing of bearings or collapsed pulley bearings, which are applied to heat the bearing with heat gun and hot liquid that range from 60 to 90 degrees Celsius. The system can detect and identify anomalies by introducing an AI model (Fig.13) and sending out alert messages 1 minute earlier than original BTS system (Fig.14).

With a total of 20 tests, the original BTS system and the modeling BTS system achieved 100% detection accuracy. However, there were a few times when the modeling BTS system sent out alerts earlier than original BTS system. The details are shown in Figure 15.

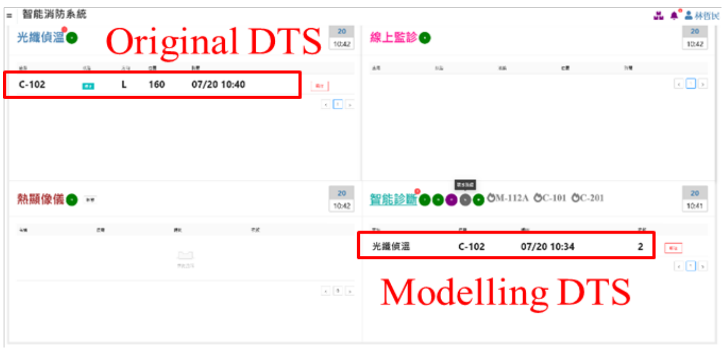

Fig.11. The System display of HMI (Modelling DTS alert 6 minutes eariler than Original DTS).

Number of tests	Accuracy rate	
	Original DTS	Modelling DTS
42	95%	100%

Alert delay (Original V.S. Modelling)	Number of tests
NA (Same time)	10
2-4 minutes earlier than **Original**	25
4-6 minutes earlier than **Original**	5

Fig.12. The statistics of simulation test of DTS of heating scenarios.

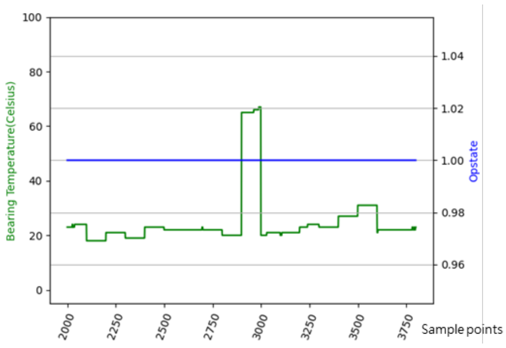

Fig.13. Abnormal temperature rise detection of BTS.

3.4 System Verification of TIR

The system test of TIR was tested with the friction between the belt and roller or friction between the belt and construction, and heating the conveyor structure to 180 Celsius degrees within 14 * 26 cm^2 area by using electric heating lamps. After three times of randomized testing on conveyor belts, the results showed that the system could identify and detect the area of abnormal temperature rises (Fig.16) and successfully deliver alerts to users (Fig.17).

The simulation result shows that the system could identify temperature rise abnormalities correctly and establish an AI model based on features of diversity of sensor information. Therefore, the results verify the system performance and the linkage of water suppression systems as shown in Figure 17.

The results of this study include:

1. Completion of the integration of heterogeneous sensor networks.
2. Building of the AI model for identification of temperature anomalies on conveyor belts.
3. Development of the conveyor belt fire detection and monitoring system.

4. CONCLUSION

This study developed a conveyor belt fire detection and monitoring system to detect and monitor temperature anomalies in conveyor belt systems to prevent fire

Fig.14. The System display of HMI (Modelling BTS alert 1 minutes earlier than Original BTS).

Number of tests	Accuracy rate	
	Original DTS	Modelling DTS
20	100%	100%

Alert delay (Original V.S. Modelling)	Number of tests
NA (Same time)	16
2-4 minutes earlier than **Original**	3
4-6 minutes earlier than **Original**	1

Fig.15. The statistics of simulation test of BTS of heating scenarios.

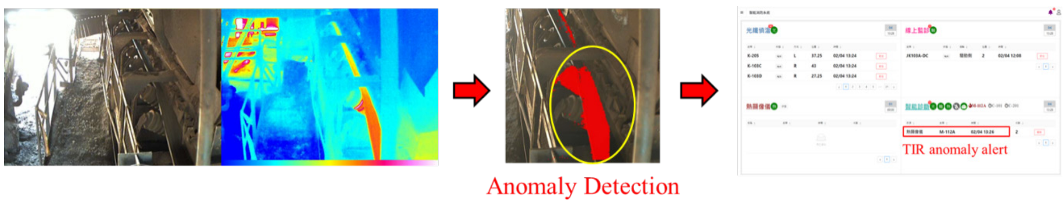

Fig.16. TIR result of heating test on belt.

Fig.17. The activation of water suppression system.

incidents from occurring. The system has been built and verified by the raw material handling and transportation department. Lastly, it can reach a 100% alarm signal accuracy with three different heterogeneous sensor networks.

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