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Development of Furnace Wall Inspection System

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Abstract*— In this study, the inspection system is developed. By this system, the incinerator which is target in this study will be inspected. As the development of software, the system to control the sensor and detect the crack was developed. As the development of hardware, the device which have rotary motion mechanism and liner motion mechanism was developed. In the future, the system developed in this study will really inspect the furnace wall of incinerator and used to maintain the facility.

***Index Terms*—Inspection system, defect detection, Kinect, incinerator, furnace wall**

I. INTRODUCTION

In this study, the system which inspect the defect of furnace wall is developed. The target is submerged combustion type waste fluid incinerator which process the waste fluid exhausted by plant as shown in Fig. 1. The present state of inspection is that the worker set up scaffolding and inspect by visual observation without using inspection device [1]. In this inspection, it is dangerous and severe work because the inside of incinerator is dark and high temperature, and the inspection precision is low because it is inspected by visual observation. There is already device which inspects the furnace wall in the market, but the device cost is very high and the cost per performance is low. It is difficult in a small, medium size company to introduce the inspection device.

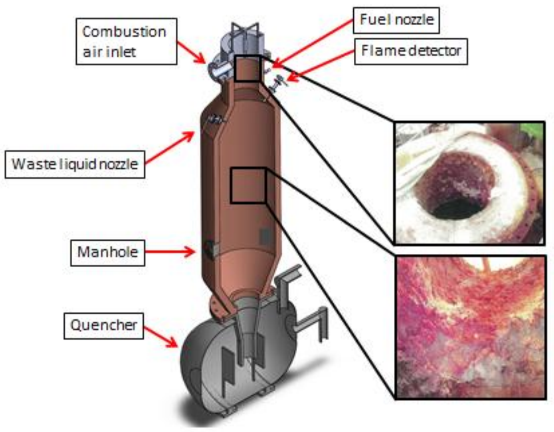

Fig. 1: Incinerator

The purpose is to develop the high cost performance system which can inspect the furnace wall with safety, easily and highly-precision condition by using sensor. The sensor can be bought for approximately $200 with enough precision. Thus, we use this sensor in this study. Moreover, developed system will be used in this plant in the future.

II. METHODS

In development of device, it is thought that the rotary motion mechanism and the liner motion mechanism is introduced to this device, in order to inspect the interior of incinerator. In this device, the internal sidewall's bricks of incinerator can be inspected by rotational motion and linear motion. As the sensor used in this study have depth sensor, the distance information obtained between the sensor and the target. The existence of defect can be detected by processing the distance information of the sensor function. The 3D image that obtained by data process and experimental measurement data was compared, and the evaluation of the proposed measurement system was done. The flow of development is shown in Fig. 2.

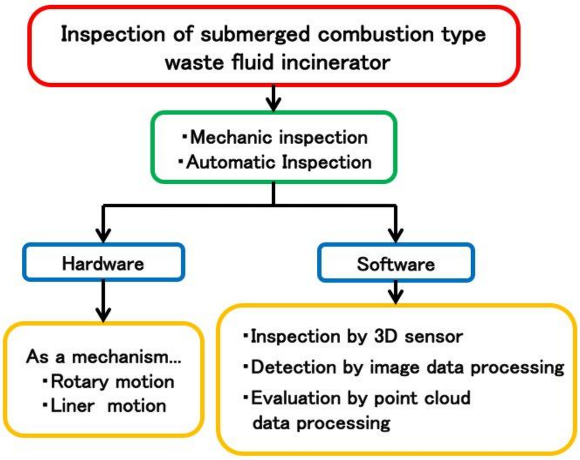

Fig. 2: The flow of development

The sensor used in this study is Kinect sensor (Fig. 3), which has the RGB camera, IR camera and the depth sensor. By control this sensor, the distance information between the sensor and the target can be acquired. Therefore, we can not only acquire the color image of the target but also detect the crack by comparing the distance information [2].

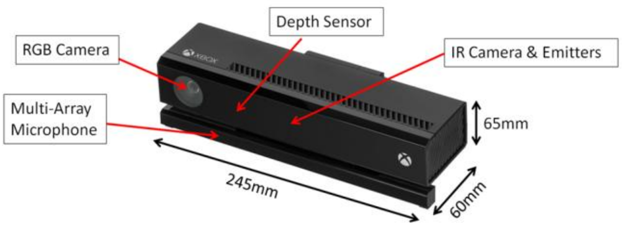

Fig. 3: Kinect sensor

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ROS is used as a software platform for developing applications. Here, ROS is defined in ROS Wiki as follows:

"ROS (Robot Operating System) provides libraries and tools to help software developers create robot applications. It provides hardware abstraction, device drivers, visualizers, message-passing, package management, and more." [3].

OpenCV (Open Source Computing Vision Library) is software library which have the functions of Image processing, Structural Analysis, Pattern Recognition, and so on.

By using CV_bridge package, ROS Image messages and OpenCV Images are converted [4].

PCL is abbreviation of "Point Cloud Library" and this software is a large-scale 3D point cloud operating open source program. The function of the model making, the filtering, registration and the object detecting is used in this study [5]-[7]. The system which inspect the inner incinerator wall state by using the Kinect sensor, the ROS and the OpenCV was developed. ・The 3D model of the inspected incinerator was made by using the PCL. ・The inspection device will be developed, which has the Kinect and the data processing systems.

III. DETECTING THE DEFECT

The system which inspect the inner incinerator wall state by using the Kinect sensor, the ROS and the OpenCV was developed and the 3D model of the inspected incinerator was made by using the PCL [8]. Each function of inspection device which has the Kinect and the data processing systems are described below.

A. Inspection by using Kinect sensor

The RGB color image and the infrared image were obtained by using Kinect sensor. By using this function, the inner wall of incinerator is going to be inspected without visual observation [9][10]. The results of image are shown in Figs. 4 and 5.

Fig. 4: RGB image

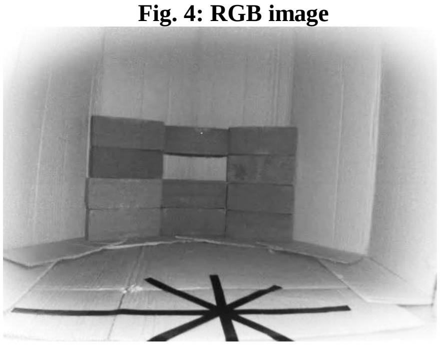

Fig. 5: Infrared image

B. Acquisition of the average distance

The average distance between the sensor and the wall in the incinerator was acquired. The sensor's depth sensing function was used in this measurement. The process is shown as follows:

I. The resolution of Kinect v1 is 640 × 480.
II. Measure the distance information of all points.
III. If this information is correct, the value of distance is summed in turn.
IV. Average distance is acquired by dividing the final value by 640 × 480.

The results are shown in Fig. 6 and Table 1. The actual distance is 500 mm between sensor and brick, and 1200 mm between sensor and crack. These data almost collect that the average distance becomes about 550 mm.

Fig. 6: Average distance

Table 1: Average distance

Average distance	555.8 mm
Actual distance (Sensor-Brick)	500.0 mm
Actual distance (Sensor-Defect)	1200.0 mm

C. Detection of the defect

The defect was detected by comparing the distance of the target. The process is shown as follows;

I. Acquire the average distance between the sensor and target.
II. The distance of all points in the range is compared with the average distance.
III. If the difference is larger than the threshold of distance, the point becomes red and this is defined as the defect.
IV. Usually, the information of average distance is displayed in the PC. If the defect is detected, the information of the distance at the defect and the difference between with average distance is displayed.

The result is shown in Fig. 7 and Table 2. In this result, the threshold is 50 mm.

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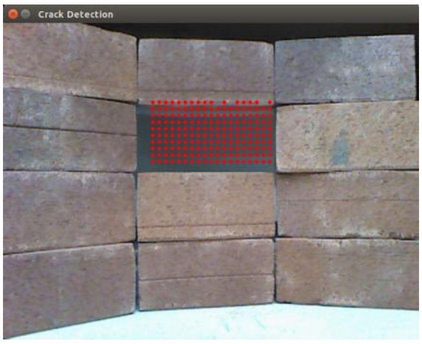


Fig. 7: Defect detection

Table 2: Crack detection

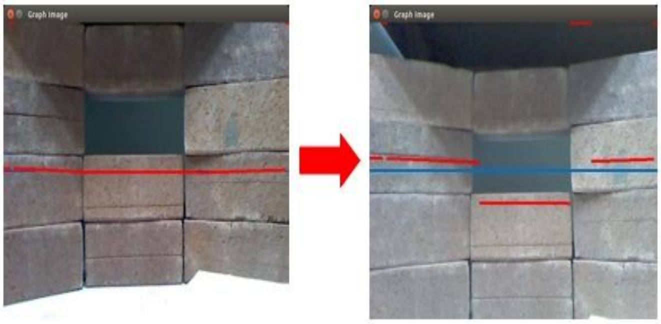
	Distance of the defect	Depth of crack
Actual	1200 mm	700 mm
Measured	1181 mm	698 mm

D. Visualization of the depth

The depth of defect was visualized by comparing with the average distance and the measurement target. The process is shown as follows:

I. The red line of Fig.8 (a) shows the distance measurement line.
II. The blue line is the measured average distance line (the reference distance) along the red line as shown in Fig.8 (a).
III. The measured distance is compared with the average distance (the current distance).
IV. If there are differences between the reference distance and the current distance, the defect depth is shown in Fig. 8 (b) as deviated red line.

The depth of the defect of the depth direction is seen in lengthwise direction. Then it is easy for us to see the depth.



(a) **(b)**

Fig. 8: Visualization of the depth

IV. DEVELOPMENT OF HARDWARE

A. About development of hardware

The purpose of hardware development is to inspect the inner wall of incinerator. From the problem of the shape of the incinerator, it is necessary for the inspection device to hang it from the upper part of incinerator. Then, the inner part of incinerator is going to be inspected by inspection device with the rotary motion and the liner motion mechanism. The flow of inspection is shown in Figs. 9 and 10.

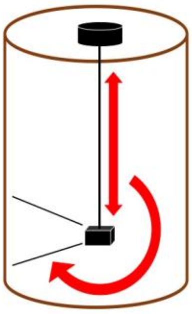


Fig. 9: Movement of the inspection device

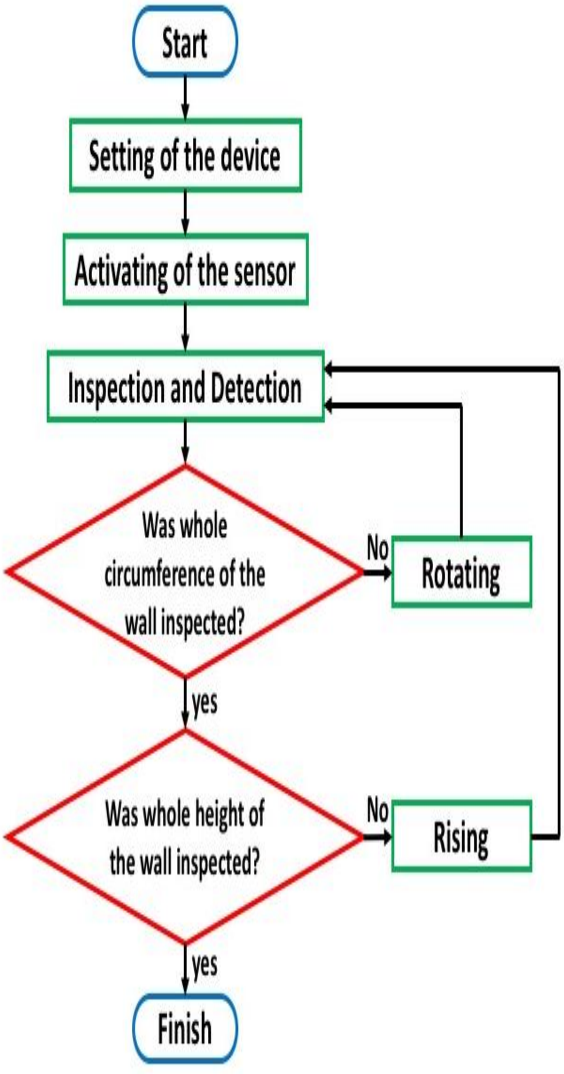


Fig. 10: Flow chart of the inspection

B. Design of the inspection device

In order to develop the inspection device, the mechanism was designed. The mechanical elements of the inspection device are shown in Table 3. Moreover, the 3D model of inspection device was designed. The models of inspection device with incinerator are shown in Figs. 11 and 12.

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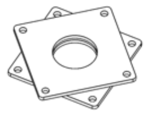
Table 3: Mechanical elements of the device

Mechanism	Model	Explanation
Turntable		Rotary motion mechanism for rotation the inspecting device.
Support stand		The base of inspecting device. This is designed in reference to a tripod.
Extendable rod		Liner motion mechanism for movement the sensor up and down which is attached to the lower part.
Winch		Liner motion mechanism for extension the extendable rod with the sensor.

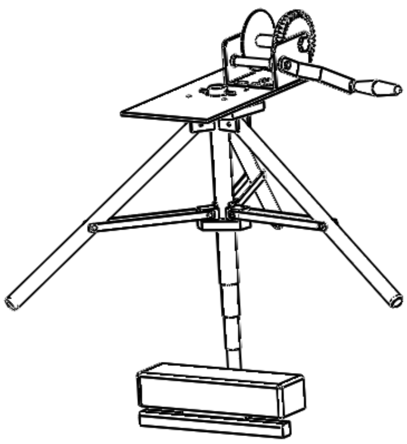


Fig. 11: 3D model of inspection device

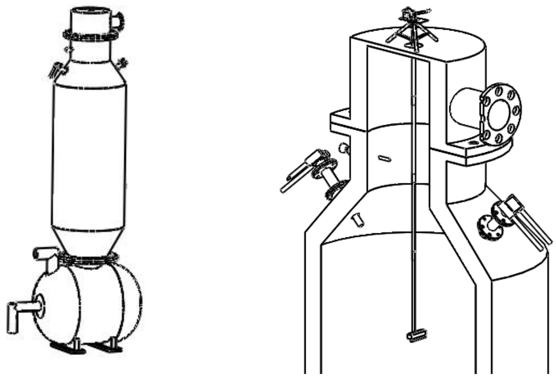


Fig. 12: Inspection device with incinerator

C. Production of the inspecting device

Based on the 3D model, inspection devise was produced shown in Figs. 13 and 14. The inspection test was carried out using a pseudo model of incinerator which consists of about 200 bricks as shown in Fig. 15.

Fig. 13: Setup of developed device on the incinerator

Fig.14: Setup of device inside of the incinerator

Fig. 15: Pseudo model of incinerator

The measured result by using developed device is shown in Fig. 16. By means of rotation and up-down functions, accurate 3D model can be constructed immediately. Therefore, the system can inspect the furnace wall with safety, easily and high-precision. As developing hardware, the inspection device can be produced.

Fig. 16: 3D model data of pseudo model of incinerator

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V. CONCLUSIONS

1) The system which inspects the furnace inside-wall by using Kinect sensor was developed.
2) The system which detects the defect automatically by using the sensor's depth function was developed.
3) The system which inspect the furnace wall with safety, easily and highly-precision condition could be developed.
4) As developing hardware, the inspection device was designed and produced.

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