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Development of steel bridge coating condition evaluation system using UV based active thermography and vision technique

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Abstract

This paper proposes an unmanned vehicle (UV) for steel structure coating condition assessment based on active thermography and vision techniques. The proposed UV can quantify and visualize the coating thickness, and detect and quantify defects on the coating. Once the UV moves over the steel structures, the line laser generates the heat energy on the structure surface. Corresponding heat responses are measured by a thermal camera and surface characteristics are captured by the vision camera as RGB images. The measured heat responses and RGB images are processed through signal and image processing. The coating thickness distribution is visualized and quantified the entire inspection area, and the defects on the surface and subsurface are detected and classified into four classes: corrosion, delamination, checking, and chalking. The uniqueness of this paper lies in (1) quantification and visualization of coating condition in a wide area, (2) improvement of accessibility of coating condition assessment instrument using the UV with magnetic wheels, and (3) world-first coating condition evaluation based on the coating thickness distribution and defect inspection using active thermography and vision technique.

1. Introduction

A coating is an important component to ensure the durability of steel structures. The coating plays an essential role in preventing steel surfaces from a defect such as corrosion, delamination, checking, and chalking with adequate coating thickness. A coating condition evaluation is composed of coating thickness inspection and defect inspection and the current standards adapt sample inspection and visual inspection methods. However, the current standard has some limitations to coating maintenance. The sample inspection measures the coating thickness distribution with small areas of 2~3 mm with manual and contact sensors, so it is difficult to detect locally occurring coating thickness under or excessive coating. In the visual inspection, it only can detect defects early because subsurface defect, which cannot be identified with the naked eye, such as subsurface corrosion and delamination is not included in the inspection scope. With the current coating condition evaluation technique, maintenance is carried out after the defect progresses or after the coating has fallen off. An appropriate time for maintaining the coating on the steel structure could be missed, and therefore the maintenance cost could increase.

In this paper, a coating condition evaluation system, which can visualize and quantify the coating thickness distribution and detect and quantify the coating defect, is developed to overcome the limitations of existing coating inspection techniques. The proposed system evaluates the coating condition based on the results of coating thickness. Active thermography with line laser as a heat source and vision techniques which acquires RGB images of the surface are used for the proposed system. The whole system has been made smaller and lighter by being mounted on the unmanned vehicle (UV) which has permanent magnets as wheels. The UV can attach to and move on the surface of steel structures, and has solved accessibility problems that may occur when inspecting large structures.

2. Development of UV based coating condition evaluation system

The UV based active thermography and vision technique is developed for coating condition evaluation on the steel structures. Here, a specially designed UV, a permanent magnetic wheel moving robot, was used for the system development, that can attach to the steel surface even in the upside-down state and precisely control the scanning speed. The coating condition evaluation is performed through a coating thickness inspection and defect inspection.

Once UV moves over the steel structures, the continuous line laser in the laser thermography module generates the heat energy on the coating surface and the heat responses are measured by an infrared (IR) camera. The heat response differs according to the coating thickness due to the heat transfer rate. The thinner coating thickness area shows lower heat response with a faster heat transfer rate and the thicker thickness area shows higher heat response. Further, when the defect exists such as corrosion, delamination, checking, and chalking, a difference in surface thermal energy occurs due to the different thermal conductivity between the defect area and the normal area. Analyzing the heat response from the IR camera can visualize the coating thickness distribution and the presence or absence of a defect.

Simultaneously with this process, the vision camera measures the surface characteristics in RGB format. The RGB image becomes RGB+IR, 4D image, with the thermal image data analysis result. The IR image after thermal data analysis only contains the presence of a defect, there is no information on the defect type or specific location, and the RGB image has the surface characteristics. The 4D image contains the thermal response and surface characteristics both. The defect detection and classification can be performed by inputting the 4D image to the YOLO v5-based artificial intelligence (AI) model. The AI model classifies the defect into four types: corrosion, delamination, checking, and chalking. After the defect detection and classification, the only detected area is quantified through image processing such as sharpening, grayscale, and binarization. As a result, the defect on the inspection area is detected, classified, and quantified.

3. Performance Validation of UV based coating condition evaluation system

The performance of the developed UV based coating condition evaluation system was validated through the lab-scale test and the field test on the steel box of the steel bridge. The coating thickness and defect inspection are performed on the lab-scale test and only coating thickness inspection is performed on the field test. The test result reveals that the coating thickness was quantified within 20 μm in the lab-scale test and 38 μm in the field test. The inspection area of the field test has no defect, therefore only coating thickness inspection was performed. Coating defect for corrosion specimen was quantified within 1 cm^2 without any false classification.

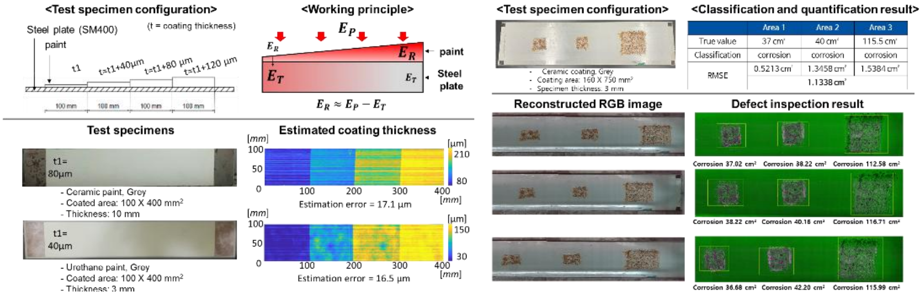

Fig. 1. Coating condition evaluation result on the lab-scale test

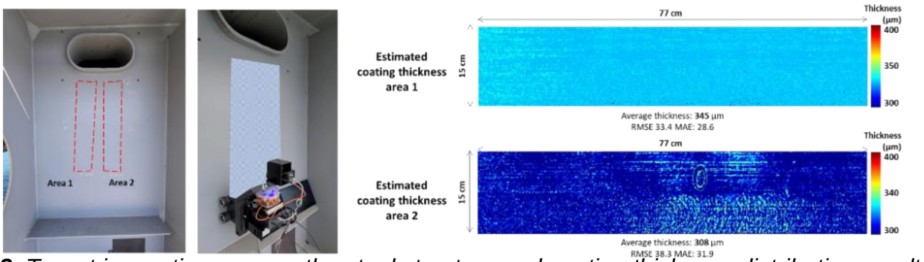

***Fig. 2.** Target inspection area on the steel structure and coating thickness distribution result*

4. Conclusion

In this paper, the coating condition evaluation system using UV based on active thermography and vision techniques is developed. In particular, the developed system has shown that it is possible to perform the coating thickness inspection and defect inspection simultaneously, and it is the world-first trial.

5. Acknowledgment

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