Estimating Deterioration of Wayside Equipment Using AI



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Introduction

Wayside equipment, such as signals and equipment boxes, is installed at various intervals along railway lines, requiring maintenance engineers to walk along the tracks to identify each piece of equipment and inspect its installation condition and visual deterioration level. With Japan's working-age population continuing to decline due to demographic changes, reducing the workload associated with maintenance management has become increasingly important.

To address this challenge, RTRI has developed a management support system that uses rapidly advancing AI technology to analyze images captured by cameras mounted on running trains, determine the kilometerage and types of wayside equipment, and output their visual deterioration levels and inclination angles[1]. By using this system, it is expected that part of the maintenance management work of wayside equipment conventionally carried out on foot can be replaced by camera-based inspection from onboard the train.

Management support system for wayside equipment

System overview

A schematic diagram of the proposed management support system for wayside equipment is shown in *Figure 1*. In this system, cameras are installed in the driver's cabs of commercial trains and other rolling stock to record forward-facing images of railway lines, and the captured data are analyzed using image processing and AI so that the condition of wayside equipment can be understood on a PC. For this purpose, the processing unit performs the following four steps on captured video images, such as the example shown in *Figure 2*: (1) estimating the kilometerage of each video frame, (2) recognizing wayside equipment in the images, (3) evaluating the visual deterioration level of the identified equipment, and (4) estimating the inclination angles of poles. As a result, the system can display both the kilometerage and thumbnail images of each piece of equipment captured in the video, thereby enabling users to diagnose the condition of

*1 How does AI evaluate deterioration?

In our system, we use an image classification AI model trained on a large number of images to identify visual features, such as the presence or absence of rust and surface damage. Based on these features, the model evaluates the condition of equipment from images in a manner similar to human visual inspection.

*2 What is the image segmentation AI "SAM"?

To extract only the pole region from an image, this method uses a technique called SAM (Segment Anything Model). SAM is an AI model that finds and segments required objects from within an image and is characterized by its ability to handle a wide variety of image types. Since it can be used without pre-training on a large number of images of specific equipment, it is particularly useful when dealing with categories as diverse as those found in railway equipment.

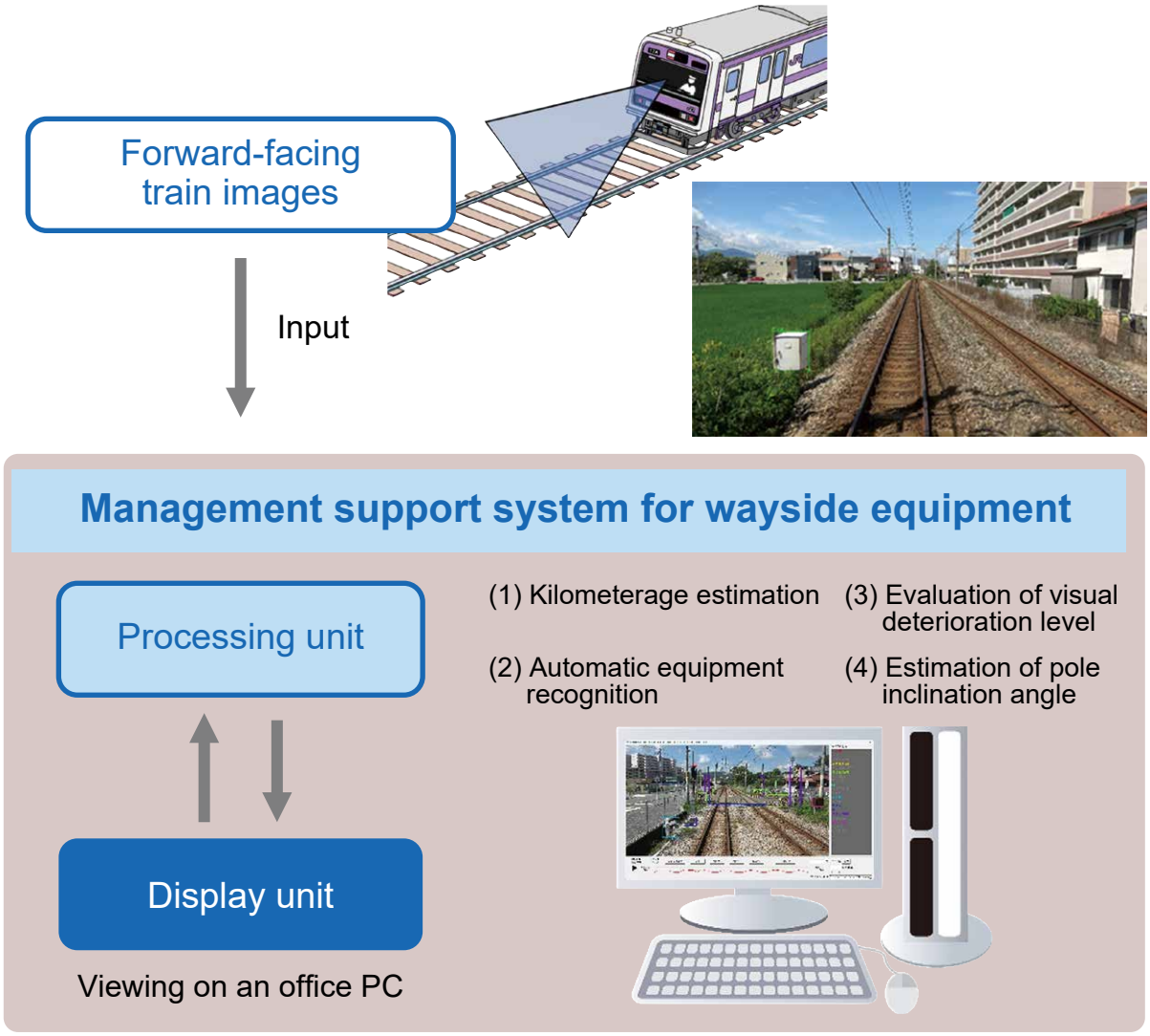


Figure 1 Overall schematic of the management support system for wayside equipment

equipment from the images. The details of these four processing steps are described below.

Kilometerage estimation

To make effective use of captured video images for maintenance management work, it is necessary to understand the kilometerage at which the locations and pieces of equipment appearing in the images are situated. Therefore, we use image processing to calculate the travel distance from the video and assign kilometerage information to each video frame. This approach enables all processing to be performed using images alone, without requiring external inputs such as those from GPS receivers or speed sensors, thereby simplifying the system configuration.

For kilometerage estimation from video images, we use a technique called optical flow, which calculates the motion of objects or feature points between consecutive images or frames. By applying optical flow



Figure 2 Example of forward-facing images captured from a train

to forward-facing images captured from a moving train, the travel distance and speed of the train can be obtained. To convert the calculated distance into kilometerage, two reference points with known kilometerage values, such as stations or wayside equipment visible in the video, are used, and kilometerage is then assigned to all frames.

Recognition of wayside equipment

Recognition of wayside equipment from video is performed using an object detection AI model. This AI program reads images or videos, recognizes objects, and displays their positions as rectangles called bounding boxes. In this study, we constructed an AI model trained on 18,000 forward-facing train images to recognize 22 categories of equipment. When the trained AI is applied to actual images, rectangles are drawn at the equipment positions, with different colors used for each equipment type, as shown in *Figure 3*.

Because kilometerage is assigned to each video frame in the preceding step, the proposed system can associate each detected piece of wayside equipment with its kilometerage, enabling efficient assessment of its condition.

Evaluation of visual deterioration level

Because wayside equipment is used outdoors for long periods of time, it inevitably deteriorates due to factors such as rain, snow, and ultraviolet radiation, which cause rust and peeling of paint. Therefore, periodic monitoring of equipment appearance and deterioration is important for

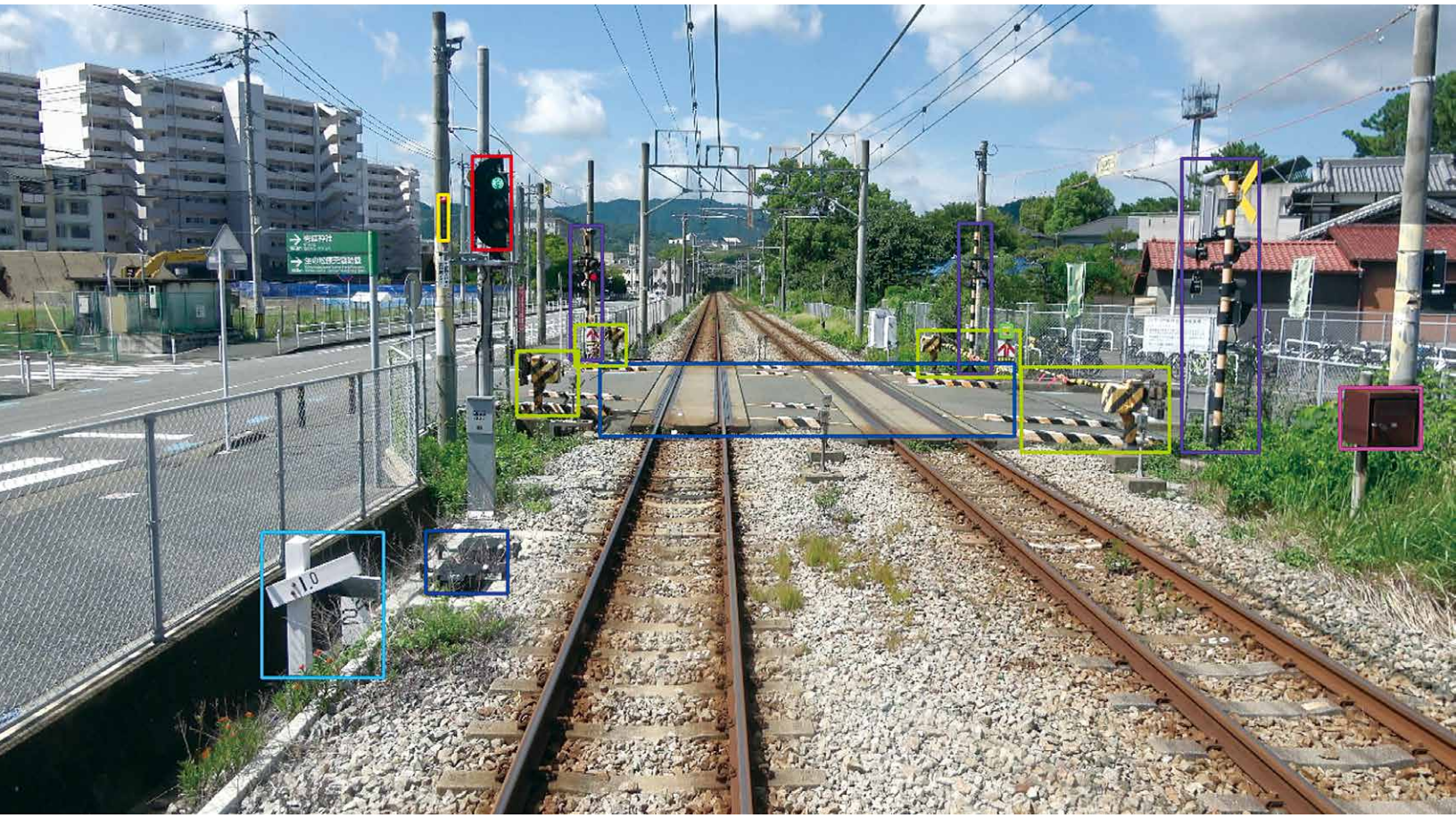


Figure 3 Example of AI-based recognition results for wayside equipment

maintenance management.

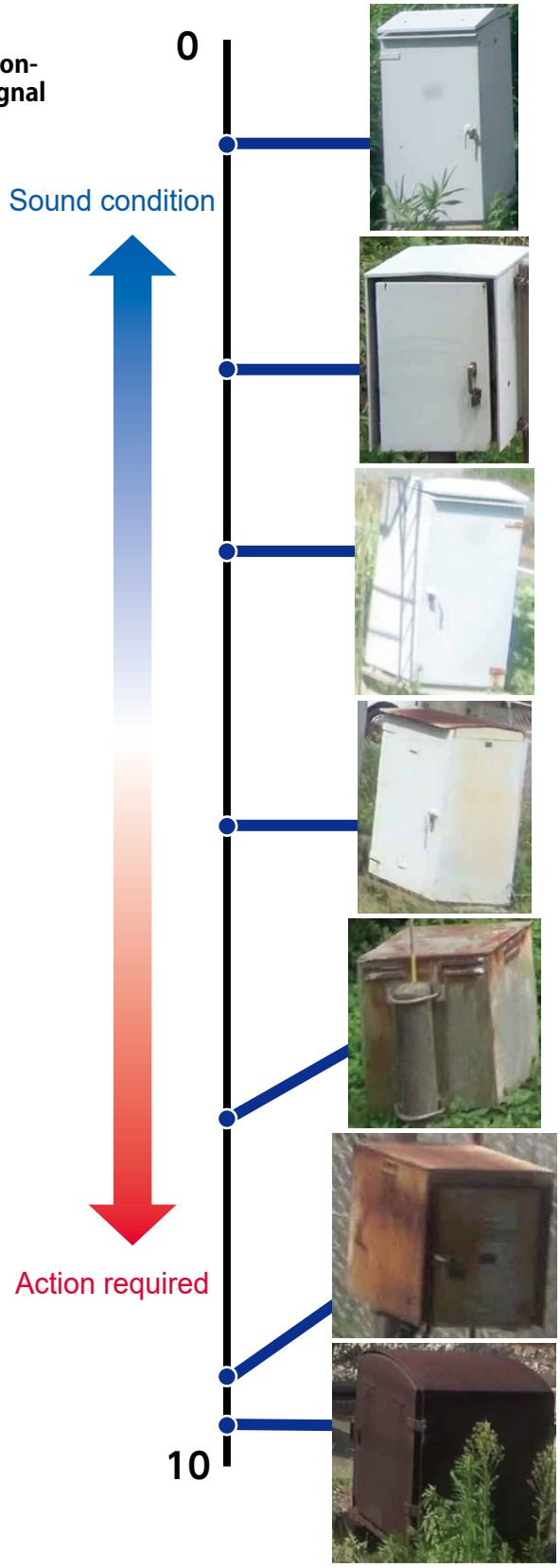
Currently, however, visual inspections are mainly conducted by maintenance engineers visiting sites and visually inspecting the actual equipment. This method relies heavily on human experience, resulting in variations in judgment among inspectors and requiring substantial time because maintenance engineers must travel to the site.

To address these issues, we have developed a method that automatically evaluates the degree of deterioration using images and AI [*1]. In the proposed method, the AI analyzes the surface condition of the equipment based on captured images and evaluates the deterioration level on a numerical scale from 0 to 10, where 0 indicates a sound condition and 10 indicates that replacement is required. By quantifying deterioration numerically, inspection results can be compared using a common standard regardless of who performs the inspection.

When the proposed AI-based deterioration evaluation was applied to images of signal equipment boxes, as shown in *Figure 4*, images with low numerical deterioration scores were found to be in good condition, whereas images with higher scores exhibited more advanced rust and corrosion. This confirms that representing deterioration levels numerically is effective for evaluating the condition of equipment.

Incorporating this automatic visual deterioration evaluation function into the system enables evaluation of the equipment condition in the office while reviewing a large number of equipment images, sig-

Figure 4 Results of deterioration-level evaluation for images of signal equipment boxes



nificantly reducing on-site inspection. Furthermore, automating the evaluation process can reduce variability among inspectors, leading to more reliable and efficient equipment management.

Pole inclination angle estimation

Estimation of pole inclination angle is a technique for determining whether equipment in-stalled along railway lines—for example, traction poles that support overhead lines and signal masts—is upright or leaning. Conventionally, the inclination angle has been measured manually using measuring instruments; however, this approach requires considerable time and effort when a large number of poles must be inspected.

In this study, we employ a method that uses AI to automatically calculate the inclination angle of equipment from images alone. This method uses images captured from vehicles running along the track and calculates the angle by means of AI and image processing. Because no additional measuring equipment is required, the method can reduce on-site work, which is a major advantage. *Figure 5* illustrates this process using a traction pole as an example.

To estimate the angle, it is first necessary to extract only the equipment region, such as a traction pole, from the equipment images recognized in the previous step. Equipment images usually contain background elements such as sky, vegetation, and buildings, which are unnecessary for angle calculation, therefore, accurately segmenting only the equipment is important. For this segmentation process, we use an image region extraction method based on an AI model called SAM, Segment Anything Model *2, 2).

After extracting the equipment region, the inclination angle is calculated by analyzing its orientation in the image using image moments. By calculating the image moments, the direction in which the object extends within the image can be determined, and thus the angle relative to the horizontal can be obtained. This calculated value serves as the estimated inclination angle.

Through this series of processing steps, the inclination angle of equipment can be efficiently estimated using only image data. Incorporating this technique can reduce on-site measurements while still confirming the soundness of equipment, thereby contributing to labor-saving in maintenance management and improved safety.

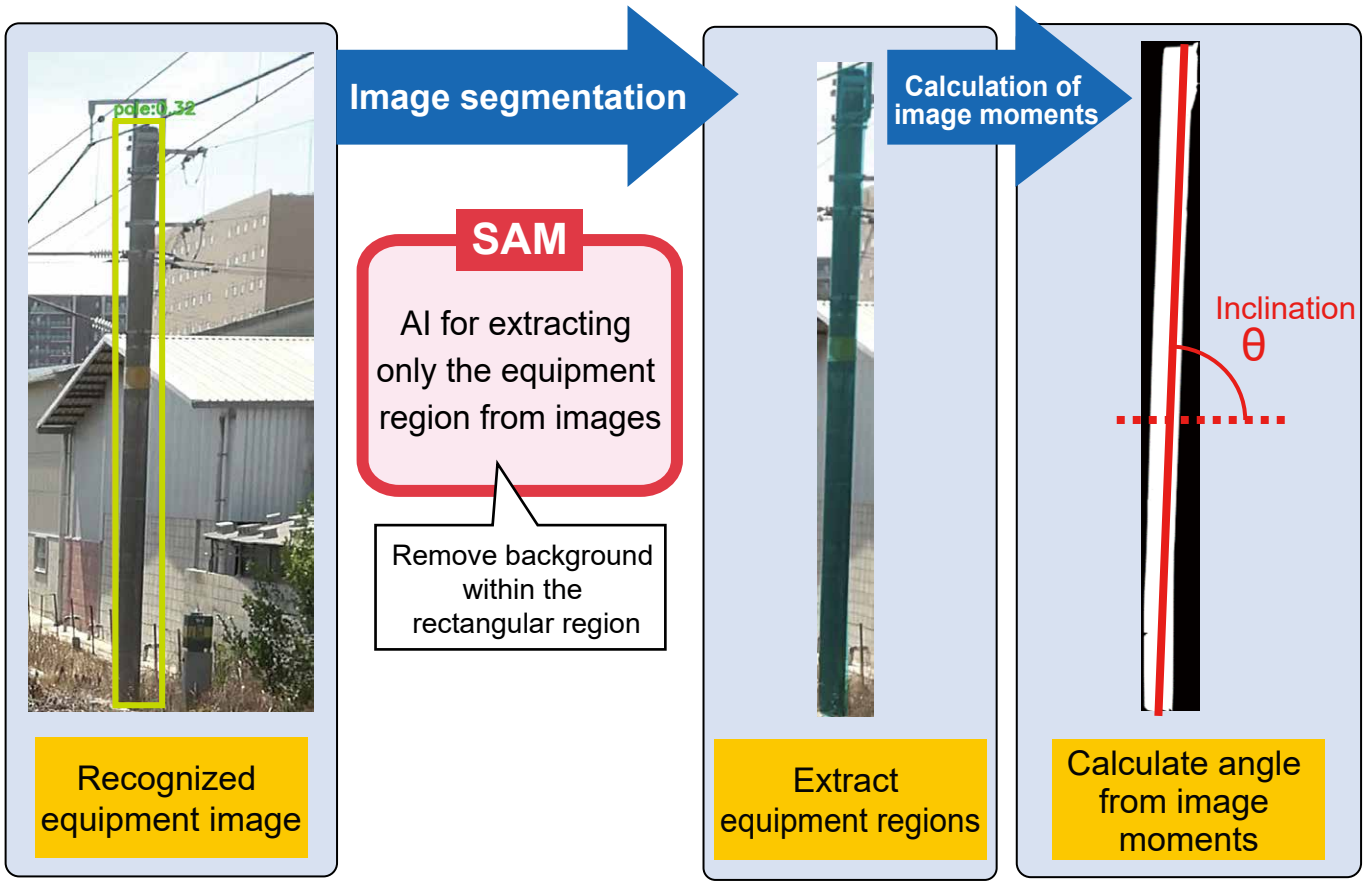


Figure 5 Flow of inclination angle estimation for traction poles

Conclusion

This study presented a management support system that utilizes forward-facing train images to reduce the workload associated with maintenance management work for railway wayside equipment. By applying AI to image processing, the system digitalizes part of the work that has previously relied on on-site visual inspections and thus enables more efficient equipment management.

In particular, we introduced a mechanism for evaluating the condition of equipment from images, enabling condition diagnosis such as estimation of visual deterioration levels and pole inclination angles. This demonstrates that equipment soundness can be assessed without on-site visits and the resulting information can support inspection and maintenance planning.

Going forward, we plan to continue improving the system in line with the needs of field users and to further contribute to enhancing the safety and efficiency of maintenance management work for railway equipment.

References

1) Mukojima, H., Nagamine, N., Yamanaka, K., Sakamoto, D., "Development of a Wayside Equipment Recognition System Using a Handheld Camera," Railway & Electrical Engineering, Vol. 32, No. 3, pp. 3–7, 2021 (in Japanese).
2) Kirillov, A., Mintun, E., Ravi, N., Mao, H., Rolland, C., Gustafson, L., Xiao, T., Whitehead, S., Berg, A. C., Lo, W. Y., Dollár, P., Girshick, R., "Segment Anything," arXiv preprint arXiv:2304.02643, 2023.