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DEVELOPMENT OF CONTACTLESS MEASUREMENT DEVICE FOR OVERHEAD CONTACT LINE

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Abstract

In order to reduce maintenance labor of overhead contact lines (OCL), a contactless measurement device for OCL was developed. This device is mounted on a roof of a vehicle of a train and measures static three-dimensional positions of wires of OCL and detects positions of OCL fittings without touching the OCL while the train is running. We proposed hybrid sensing method that combines stereo measurement by image processing with structure measurement by laser range scanners and it realized to measure OCL geometry with high-precision even in sections with complicated OCL structure. In addition, we developed position detection method of the OCL fittings that can cope with changes in height and stagger of OCL by using machine learning. Measurement data of OCL contactless measurement device is static position of OCL without influence of a probe such as a pantograph. With this device, the OCL static position can be measured continuously instead of at each support point or dropper point. For maintenance of OCL, the criterion of OCL is defined as a static position. The device is utilizable for OCL maintenance and it sophisticate maintenance of OCL. For example, this device realize the height difference measurement of the crossing section, which has been conventionally measured by maintenance workers. In addition, the device are utilizable for OCL fittings inspection. Maintenance workers can check the image of OCL fittings without on foot into the field. Furthermore the static position data of OCL can be used to create simulation model of OCL dynamic behavior. Using this model, it is possible to know the dynamic response of cases where various pantographs pass at various speeds. Running tests was conducted on commercial line, and the performance of the device was verified when running at a speed of 130 km/h. The results shown that the repeated measurement accuracy is within 10 mm, and the OCL fitting detection rate is 90 % or more.

Keywords: OCL, maintenance, OCL fittings, machine learning

1 Introduction

Overhead contact lines (OCL) are installed along a railway track for a long distance, and their inspection requires a lot of maintenance labor. In order to reduce maintenance works such as walking patrols and close-up inspections, automated inspection by railway vehicle is one of the solutions. Therefore, we developed a contactless measurement device for OCL [1]. This device can measure static positions of OCL wires. OCL static position measurement using this device replace manual inspection of overlap or crossing section configurations and reduce maintenance work. The device is mounted on a roof of a vehicle of a train and can measure static three-dimensional positions of wires of OCL and detect positions of OCL fittings while

the train is running. We proposed hybrid sensing method that combines stereo measurement by image processing with structure measurement by laser range scanners and it realized to measure OCL with high-precision even in sections with complicated OCL structure.
In this paper, we report prototyped OCL contactless measurement device can measure the three-dimensional position of the OCL wires and OCL fittings at 130 km/h speed on a commercial line. In addition, we developed position detection system of the OCL fittings that can cope with changes in height and stagger of OCL by using machine learning.

2 Specification of contact measurement device for OCL

2.1 Basic concept

Using a hybrid sensing method that uses two line cameras and two laser scanners together, the OCL contactless measurement device measures the three-dimensional position of not only contact wires, but also messenger wires and auxiliary messenger wires. In addition, the device measures position of OCL fittings. This is achieved by detecting OCL fittings from two images captured by the two line cameras.
Two laser scanners are installed on the left and the right of the vehicle and look up at the line from the roof, because the messenger wires are hidden behind a contact wire when the overhead line is directly above the laser scanner. Even if one laser scanner cannot detect the wire, the other laser scanner can detect the wire to ensure redundancy.
Two line scan cameras are installed on the right and the left sides in the traveling direction to continuously capture the image of OCL and perform stereo measurement of the wires, and the line scan camera can also capture images of the OCL fittings from both sides. When performing stereo measurement, even if the image is in backlight condition, it is possible to detect the position of the line. Even if one of the two cameras are in a backlight state with respect to the contact wire, the other camera is in normal light state. Therefore, at least one camera is in normal light state regardless of the sunlight direction.

2.2 Device configuration

We consider the hardware configuration of the OCL contactless measurement device for 130 km/h running. It is required to achieve both high-speed capturing and a wide depth of field. However, there are trade-offs between capture speed and depth of field. Increase capture speed decrease depth of field. As a countermeasure, it is proposed to mount two sets of cameras with different focus ranges to take images that are divided the lower and upper parts of OCL.
However, consideration of the aim of mounting this device on the roof of a commercial vehicle in the future requires to downsize the device. Therefore, it should be used only one set of cameras. In addition, the lower and upper parts of OCL fittings such as connectors and droppers are captured as separate images with different focus ranges. It is difficult to detect fittings and diagnose abnormalities without whole images of the fittings. On the other hand, the fisheye lens has a large image distortion but a wide depth of field. The distortion of the image can be corrected by image processing. Therefore, we used fish-eye lens without divide image.

Sizes of OCL fittings decided resolution of the image. It requires higher than 2 mm / pixel for detection and diagnosis of OCL fittings. It is necessary to use 8k line scan cameras because of wide field of view of fish-eye lens. In addition, at a resolution of 2 mm / pixel in the traveling direction, that is, at a scan rate of 18 kHz at 130 km/h, the exposure time per line is about 50 μs. The image data can be recorded uncompressed, only the central 6144 pixels image data of the 8k line scan camera was recorded due to the restriction of the data transfer bandwidth.
The pulse signal was obtained from the speed generator of the vehicle axis to calculate kilometrage. The kilometrage is recorded together with the image captured by the line scan cameras and the data measured by the laser scanners.
Figure 1 shows the OCL contactless measurement device. To capture clear image of OCL fittings, it is required that the elevation angle of the line scan cameras to the OCL are small. So that the line scan cameras were placed outsides and the laser scanner was placed inside. In addition, eight white LED lighting units were equipped. The weight of the device on the roof, excluding cables, is about 55 kg. The device is waterproof. However, it cannot use in rainy weather because water adheres to the lens cover surface and causing irregular reflection of the light.

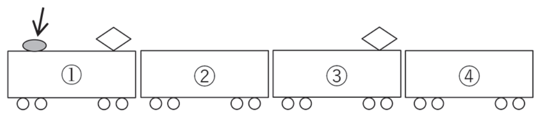
Figure 1 Contactless measurement device for OCL

3 Accuracy verification by field test

3.1 Outline of field test

In order to verify the OCL contactless measurement device accuracy, we installed the prototype device on a railway vehicle and run it on a conventional line to measure static position of OCL. We also measured the static height of the contact wire using the conventional method, and compared the two data. The accuracy of the device at low speed have been confirmed [1]. In the low speed verification, the device was mounted on a truck and measured on the OCL test bench in Railway Technical Research Institute. As a result, the error in the static height of the contact wire was within 2 mm.
In this section, we describe the field test performed to verify the measurement accuracy of OCL contactless measurement device mounted on a railway vehicle running at high speed. In the field test, the vehicle travelled several times in a section of about 40 km each way on a conventional line and recorded images. Table 1 shows the outline of test run. The maximum speed is 130 km/h. The OCL contactless measurement device was mounted on the roof of the first vehicle. Distance from the nearest pantograph is 13 m, and when the first car travelling at the head, the measurement can be performed with less effect of the uplift of the contact wire by the pantographs. In this paper, the measurement data obtained in the OCL contactless measurement device is treated as static structure measurement.

Table 1 Outline of test run.

Season	2 days in November
Weather	Sunny (both days)
Test section	40km, Three return trip / day
Speed	Max. 130 km/h
OCL type	Simple catenary
EMU configuration	OCL contactless measurement device 

3.2 Captured image

Figure 2 shows an example of a captured image of a section where the vehicle travels at 130 km/h in the running test. Although the distortion caused by the fisheye lens is observed, it is confirmed that equipment such as feeders, high-voltage power distribution lines, hinged cantilevers and catenary poles are recorded. The images of each component are focused and have enough resolution. We found out that proposed configuration of the device is suitable for OCL inspection.

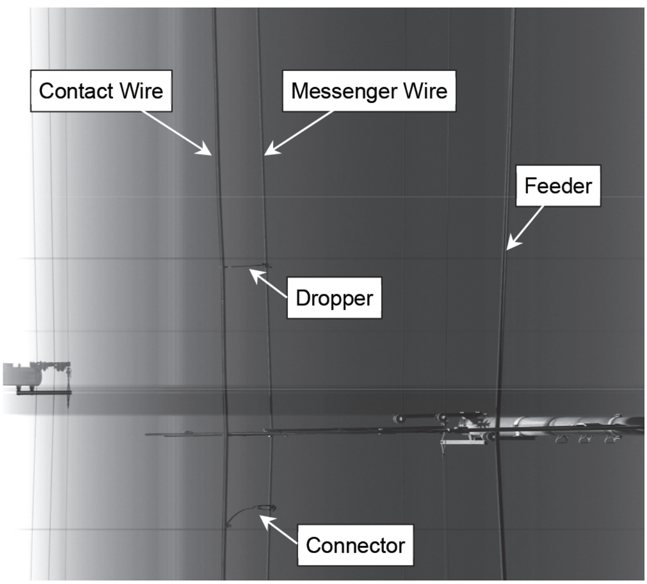


Figure 2 Example of captured image

3.3 OCL 3D structure measurement

After the test run, OCL 3D static geometry was measured with stereo measurement method. Figure 3 shows the measurement results of the height of the OCL in the test section running at 130 km/h, and Figure 4 shows the measurement results of the contact wire stagger in the same section. Figure 3 and 4 include the data obtained in the first and the second days of this test campaign, the measurement result of contact wire using a contact wire measuring instrument [2], and the contact wire inspection data measured from the inspection car that ran in the similar period of time. Note that the distance axis misaligned due to slippage of the wheels, etc., so axis was manually aligned based on the waveform.
The comparison between the contact wire position measured by the device on the 1st and 2nd days and the contact wire static height measured on a maintenance vehicle shows that difference is within about 20 mm. In test section, the train was running with the first car at the head, and that the effect of the contact wire lifts due to the pantograph located behind the device was small. The comparison between the contact wire heights measured by the device on the 1st and 2nd days shows that the contact wire heights agree within 10 mm, confirming that the repeat measurement accuracy is practically sufficient. Regarding the stagger of the contact wire, the comparison between those of the first day and the second day shows that they agreed within 20 mm. Since the contact wire stagger in the contactless measurements is not corrected the influence of the vehicle body rolling, it is considered that the repeat measurement accuracy is lower than the height of the contact wire.

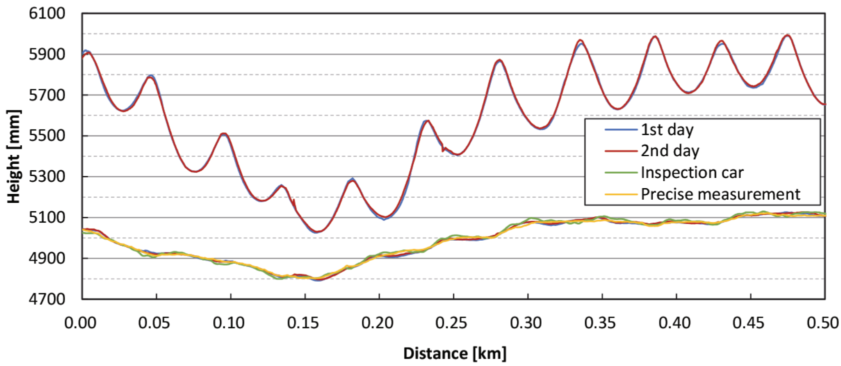


Figure 3 Static height of OCL

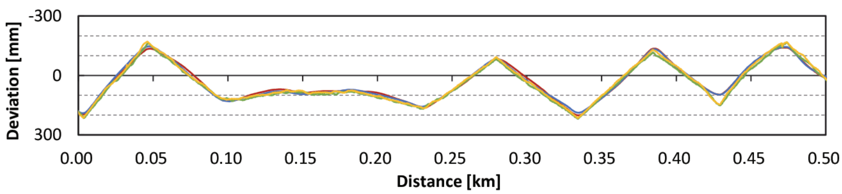


Figure 4 Static stagger of contact wire

4 OCL fittings detection

Dropper detection from the image of test section (approximately 1.6 km) of the simple catenary was performed by a machine learning algorithm. As learning data for machine learning, about 2000 annotated images were used, and a used transfer learning method. Detection processing was performed with area limitation. The limitation area was determined based on the wire position information.

Table 2 shows the detection results of dropper positions. The OCL contactless measurement device acquired OCL image by two cameras on the right and the left, if the OCL fitting can be detected from the image of either camera, it is determined to be detection (True Positive: TP). When neither camera detect the OCL fitting, it is determined to miss detection (False Negative: FN), and if false detection is made despite the absence of OCL fittings, it is judged as over detection (False Positive: FP). The judgement was made manually.

The precision (TP / (FP + TP)) and the recall (TP / (FN + TP)) are index of detection performance. The higher the recall value becomes, the less oversight is. Both the precision and recall were over 90 %, achieving highly accurate OCL fitting detection.

Figure 5 shows the position of the detected droppers and the three-dimensional positions of the OCL wires. By measuring the static three-dimensional geometry of a real OCL using the OCL contactless measurement device, we can digitize real OCL. The digitized OCL can be used as a simulation model to predict the behaviour when passing through a pantograph. It also is expected to be used as a tool to realize digital twins.

Table 2 Detection results of droppers

	Clipped Image
True number of droppers	94
True Positive	87
False Negative	7
False Positive	9
Precision	90.6 %
Recall	92.6 %

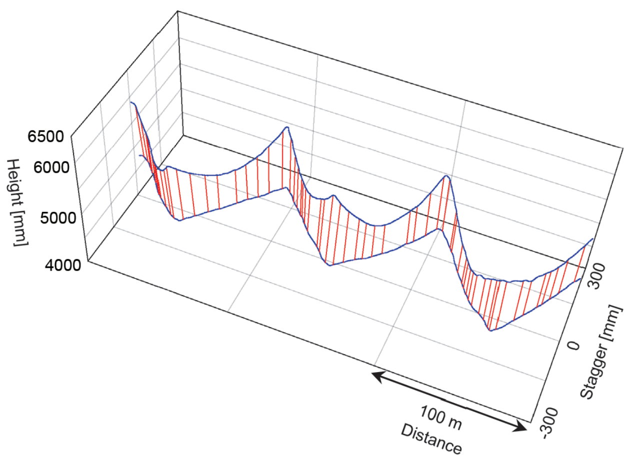


Figure 5 Measurement result of OCL 3D structure

5 Conclusion

We prototyped an OCL contactless measurement device and mounted on a vehicle of a train to perform a running test on a commercial line. Proposed “hybrid sensing method” realized the height and stagger measurement of OCL within 10 mm repeat accuracy of contact wire height at a speed of 130 km/h. In addition to this, we developed position detection system of the OCL fittings with machine learning algorithm. The detection rate of OCL fittings was over 90 %. Further research aims to develop diagnosis system of OCL fittings. Combined system with the OCL contactless measurement device and the OCL fittings diagnosis system will realize automated and frequent visual inspection of OCL. It will contribute to sophistication of OCL maintenance.

References

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