Contactless Measuring Method of Overhead Contact Line Positions by Stereo Image Measurement and Laser Distance Measurement

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A contactless measuring method was developed to measure static positions of overhead contact lines from vehicles, using stereo image measurement and laser distance measurement. Measurement experiments were conducted. By using the combination of two types of sensors, this method can make high detection performance and high measurement accuracy compatible. Moreover, since it is completely contactless, measurement of wires not in contact with the pantograph, such as the catenary wire and the auxiliary catenary wire, is also possible. This method automates the measurement and quantification of condition diagnosis of long contact lines, and should increase maintenance efficiency.

Keywords: stereo measurement, image processing, laser sensor, overhead contact line, contactless measurement

1. Introduction

Inspecting overhead contact lines (OCL) by electric inspection car is contributing to the efficiency of maintenance work. However, since only parts such as contact wires or pantographs which come into contact with the contact wire are inspected by these vehicles, inspection of other OCL equipment depends on visual or close inspections by maintenance workers. Automatic inspection technology is therefore being developed to encompass more kinds of equipment with a view to improving the efficiency and quality of maintenance work by quantification of measurement data.

First, a method was developed to enable contactless measurement of multiple contact wires, auxiliary catenary wires and catenary wires by a combination of the stereo image measurement by two line scan cameras and distance measurement by two laser range scanners mounted on the right and left sides of the vehicle roof. Measurement tests were performed at the RTRI test facility [1]. Results confirmed that measuring position by recognizing the wires correctly was possible. The applicability of the method was tested with an attempt to estimate tension from the shape of the wire in the span.

2. The measuring method

2.1 The outline of the measuring method

Stereo image measurement and laser distance measurement were considered as two possible methods for the contactless position measuring system, as they use devices easily mountable on a vehicle. Stereo image measurement uses two cameras for triangulation and the laser distance measurement uses a laser range scanner that can measure the distance to the reflection point of the laser beam. Table 1 shows the comparison of the performance between the two methods. Although both have advantages and disadvantages, it was expected that achieving high accuracy with stereo image measurement and high identification performance with laser distance measurement would be possible, thus development of the measuring method was commenced.

Figure 1 shows the measuring instrument configuration as viewed from the line direction. The frame was mounted across the roof of the vehicle (in the sleeper direction), while each side of the frame was equipped with one line scan camera and one laser range scanner (one of each on each side), and LED line lights were placed centrally, making it possible to collect data as the vehicle ran along the track. For tests, this frame was mounted on trucks or maintenance vehicles, while in practice, it will be mounted on electrical inspection cars and commercial trainsets.
Table 1 Comparison of stereo image measurements and laser range scanner measurements in terms of performance

<table>
<thead>
<tr>
<th></th>
<th>Stereo image measurement</th>
<th>Laser range scanner</th>
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<tbody>
<tr>
<td>Object identification performance</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Viewing angle</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Position accuracy</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Position resolution</td>
<td>High</td>
<td>Low</td>
</tr>
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</table>

2.2 Hardware configuration

(1) Laser range scanner
The laser range scanner is based on laser distance finding technology, which measures the distance to the laser light reflection point. It can measure the position of the objects on the scanning plane by scanning the laser beam radially. In theory, only one sensor is sufficient. However, for example, when the catenary wire is in a blind spot of the contact wire, one sensor is insufficient. Therefore, this system was designed to include redundancy by combining the outputs of two sensors, one on the right and one on the left.

(2) Line scan camera
The camera is the same kind as those used in copy machines, and its imaging elements are arranged on one line. It can obtain 2-D images by scanning the imaging line. For this case, a black-and-white camera of 8192 pixels was used. The maximum scan rate in the specifications was 43 kHz, making it possible to shoot at 2 mm interval at 300 km/h. However, considering data capacity and recording speed, 1 kHz scanning was selected, which is sufficient for the purpose of verifying the measuring method. In addition, the fish-eye lenses were used for wide viewing angles.

(3) LED line light
Similar to copy machines, white LEDs were arranged on one line. They were placed on the same plane as the line scan cameras, to shed intense light on the objects being scanned.

(4) Computers for data acquisition and data analysis
The laser range scanners and the line scan cameras were connected to the on-board data acquisition computer. The data was recorded in portable data cartridges. The cartridges were moved to the stationary computer for analysis, and post-processing.

2.3 Software flow

Figure 2 shows the flow chart of the developed measuring method. The left flow is for the laser range scanner, and the right flow is for the stereo image measurement. This method uses the rough positioning data of the wires obtained with the laser range scanner, and the high-precision stereo image measurements. The details of each item for which data was processed, are shown below.

(1) Wire detection process
The purpose of this process is to sort the target wires from other overhead equipment, using measured data from the laser range scanner. In order to exclude data picked up for other overhead equipment, such as suspensions, metal fittings, and ‘noise’ in the data due to the irregular reflection, only continuous data sets in the rail direction longer than a certain length in the region where OCLs should be present are collected. If gaps appear in the data, the wires are detected again by comparing data with similar characteristics, from before and after the blank in the data series.

(2) Wire distinguishing process
The purpose of this process is to distinguish the type of OCL and wire, once they have been isolated from other equipment, after the first process above. In addition, even...
when other OCLs are running either in parallel or crossing it over, this processing function makes it possible to distinguish the wire pair aligned in the vertical direction as one set of OCL.

(3) Wire detection from the image

The purpose of this process is to detect only the wire of interest from the image in which multiple wires appear. First, a calculation is made of the estimated area in the recorded image (Fig. 3 upper) that shows the wire of interest by using the rough positioning data from the laser range scanner, and by masking the rest of the image outside this area (Fig. 3 middle). Second, data for the line of interest can be extracted by finding the line which matches the direction it should be following based on the rough positioning data (Fig. 3 lower). Nevertheless when there are possibilities from the gathered images, stereo measurements are made for all the wires, and then results for the wire of interest are separated from the others, by identifying the set of data which has the smallest difference in relation to the rough positioning data.

Figure 3 shows OCLs (simulated with a rope) intersecting the contact wire scanned by the line scan camera on the OCL simulator shown in section 3.1. It was confirmed that the contact wire of interest can be correctly detected following the flow diagram in Fig. 2.

3. Verification by measurement tests

3.1 Measurement on the OCL simulator

Figure 4 shows the OCL simulator and the measuring instruments. The OCL simulator is an indoor compound OCL using the same components as a real OCL. The system height was about 1500 mm to ensure that the actual equipment would fit, whereas the dropper intervals were reduced to about 2 m, and the total length was about 13 m. In addition to the OCL, one compound OCL and one simple...
OCL simulating overlaps and one simple OCL simulating overhead crossing were installed. Furthermore, the three added OCLs were simulated with brown ropes with a diameter of about 15 mm. The measuring instruments were mounted on a hand truck below the OCL, and data was recorded while moving at about 1 km/h. The distance from the measuring instruments to the contact wire was about 1300 mm, approximately equal to the distance to the contact wire when the actual equipment would be mounted on the roof of an actual vehicle.

Figure 5 shows the 3-D position measurement results for the OCL. No. 1 is the existing actual OCL, No. 2 and No. 3 are the ropes simulating the overlaps, and No. 4 is the rope simulating the overhead crossing. It was confirmed that the type of OCL and the configuration of each wire were automatically recognized correctly. In addition, after comparison of the height measurement data of OCL No. 1 and direct measurement data using a special jig after executing the optical error correction for the line cameras, the error was found to be up to 2 mm for the contact wire, up to 3 mm for the auxiliary catenary wire, and up to 6 mm for the catenary wire. These results show that error increases with distance from the measuring instrument to the wire [2].

3.2 Measurement on the current collection testing equipment

RTRI has current collection testing equipment with an OCL extending to about 450 m, and it can measure current collection performance with a moving pantograph at a maximum speed of 200 km/h. For the experiment, the measuring instruments were mounted temporarily on the working vehicle, and measurements were collected during the day at a speed of about 3 km/h. The OCL is a simple catenary system and in the vicinity of the center of the equipment, where measurements can be made at high speed, the span length is 50 m, zigzag deviation is 200 mm to each side, and the system height is 960 mm, which represent standard conditions for a simple catenary system. Although conditions the preceding and following sections are significantly different from the standard conditions mentioned above, measurements were also made in these sections.

Figure 6 shows the measurement results. On current collection testing equipment similar to actual equipment, it was confirmed that it is possible to make 3-D positioning measurements of the OCL using the new method.

4. Application of wire positioning measurements – estimation of tension of the catenary wire for each span

4.1 The principle underlying tension estimation

An attempt was made to estimate the tension of each span along the catenary wire, applying the positioning measurements [3].

As schematically shown in Fig. 7, when the sag is sufficiently smaller than the span length, the height \( y \) of the catenary wire is approximately given by (1) that is expressed by a quadratic function of the distance \( x \) from the support point 1.

\[
y = \frac{4s}{l} x^2 \left( \frac{4s}{l} - \frac{h_2 - h_1}{l} \right) x + h_1
\]

Where, \( s \) is the sag ratio, \( l \) is the span length, \( h_1 \) is the height of the support point 1 and \( h_2 \) is the height of the support point 2. Furthermore, the sag ratio \( s \) is obtained by dividing the amount of sag in the span by the span length.

On the other hand, wire tension \( T \) is given by (2).

\[
T = \frac{\rho l^2}{8s} g
\]

Where, \( \rho \) is the mass of the OCL per 1 m, \( g \) is the gravitational acceleration.

Therefore, by determining the approximate curve of the quadratic function for the height of the catenary wire measured by the proposed measuring method using the least squares method for each span, and obtaining the
sag ratio $s$ from the coefficients of $x$ in (1), it is possible to calculate the tension $T$ from (2). Additionally, although it is possible to include the mass of fittings such as droppers and connectors in the mass of the OCL per meter, only the mass of the wires was considered in this case.

4.2 Validation test results

A compound OCL specified in Table 2 was installed in the current collection testing equipment and the catenary wire height was measured by using the proposed contactless measuring method. The tensions shown in Table 2 are the measured values obtained with tension meters at an end of the wires.

Table 3 shows the sag ratio for each span obtained from the catenary wire height and the tension of the catenary wire estimated from the ratio. Compared to 20.4 kN, the value of the tension meter, the error of the estimated tension was less than 3%. This is considered to be sufficiently accurate to diagnose abnormal tension.

5. Conclusions

A contactless measuring method was developed to measure OCL wire positions from vehicles, such as electric inspection cars, by combining stereo image measurements and a laser range scanner. Measurement tests on simulated complex OCLs, demonstrated that each OCL is automatically recognized correctly, that measurement errors for contact wire height were less than 2 mm by calibrating the optical system, and that outdoor measurements in sunlight were possible. Furthermore, when positioning measurement results were applied to estimate catenary wire tension, the error in tension values obtained, compared to those measured with a tension meter was less than 3%.

This paper describes the development of a position measuring method for OCL wires. The next step for this research will be to develop a measuring method for OCL fittings such as droppers and connectors. During experiments conducted in the course of this study, measurements were collected at very slow speed because of test equipment limitations. However when measurements are gathered at high speed, such as on conventional lines or Shinkansen lines, errors due to sensor vibration are expected to increase. Therefore, further research aims to develop a data collection method which takes vibration into account.

References


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