Visibility Checking Method for Railway Signals by Cab-mounted Camera

Nozomi NAGAMINE
Assistant Senior Researcher, Signalling Systems Laboratory, Signalling and Transport Information Technology Division

Masato UKAI
Senior Researcher, Signalling Systems Laboratory, Signalling and Transport Information Technology Division

An obstruction-warning signal is an important piece of signalling equipment used at level crossings in Japan. However, it is not possible to check the visibility of such equipment during train operating hours, because this would require service disruption. This paper therefore proposes a method which employs near infrared LEDs, and can check the visibility of obstruction-warning signals during in-service hours. It has been proved that the developed image processing method, using a near infrared camera and a pan-tilt camera by feedback control installed on a vehicle, can correctly detect specific signal blinking. The paper then gives results from functional field tests.

**Keywords**: image-processing, obstruction-warning signal, visibility check

1. **Introduction**

Obstruction warning signals alert drivers to the presence of an obstacle or abnormality, which calls for an emergency stop. Obstruction warning signals are therefore extremely important for safe train operation. It emits a flashing light signal as a result of the output from one or more other safety devices: obstruction-warning devices for level crossings, railroad crossing obstacle detection devices, clearance disorder alarms and rock-fall warning devices.

Train drivers however are unable to determine whether the device is working or not because it only produces a signal when the train needs to stop (contrary to fixed signals, which are signalling continuously). Consequently, train drivers must be able to discern obstruction-warning signals from more than 800 meters away from the facility at any given time and in any weather.

To guarantee this condition, obstruction-warning signal visibility checks must be carried out, in addition to those performed after installation or renewal of the devices. The latter is done by maintenance staff visual inspecting the devices in the course of periodic inspections. The challenge is to check their visibility during train operating hours because they only produce a signal when an abnormality has been detected. A new method has been studied bearing this in mind on the basis of quantitative checks which do not disrupt train operations and do not depend on subjective observations by maintenance staff [1, 2, 3].

For the purposes of this paper and to test the proposed method, a cab-mounted camera, an obstruction-warning signal, equipped with a blinking circuit to flash infrared LEDs and blink invisible light at specific times, a pan-tilt camera to capture the LED, and an image-processing algorithm to detect the blinking pattern of the LED, were developed. Results from functional field tests are reported at the end of the paper. It should be noted that the present proposed method may be applicable to other railway signals.

There are two kinds of obstruction-warning signals: “rotating” with five rotating flashlights, and “blinking” with vertically aligned blinking LEDs. Investigations for this paper used only “blinking” signals.

2. **Current testing and principles underlying visibility checks**

The visibility of newly installed or restored obstruction-warning signals is checked by flashing them from 800 meters away from the maintenance staff. However, over time, the construction or removal of buildings, growth of plants, and/or change in their facing direction potentially affect visibility of these signals making them no longer visible from 800 meters away. In order to prevent this, maintenance staff conduct visibility checks. Where visibility is lacking, maintenance staff install repeaters, adjust the angle of the signal, and/or prune plants forming the obstruction.

When visibility checks are conducted at level crossings, maintenance staff stationed at the visibility checkpoint check the visibility of the obstruction-warning signals which have been made to flash by other maintenance staff stationed at the level crossing. If the newly installed or restored devices are not visible from 800 meters away because of their facing direction, their angle is adjusted while the other member of staff stationed 800 meters away, using wireless devices for communication. The traditional method still depends on subjective inspection by the maintenance staff, and is therefore not a qualitative evaluation.

Moreover, it is difficult to flash obstruction-warning signals in the daytime because it could lead to confusion of train drivers. Maintenance staff therefore usually conduct testing at midnight, which makes work less effective. Considering these problems and the large number of existing obstruction-warning signals, there is a strong need to develop a more accurate and effective method for visibility checking.

As a result, an on-board visibility checking method was developed to try to resolve this problem. The main focus of this development was on work effectiveness and spatial continuity of visibility. On-board inspections can be performed from two types of car: inspection vehicles or trains in service. The advantage of inspection cars is that they can easily acquire mileage, and there are fewer constraints on the size of the devices. If a train in service is used, there are two ways to carry out testing: with the device
fixed on the train, or with a device brought on board by the maintenance staff. Either way, minimizing the size of the device is important, or in the case of the latter, the device should be portable. The advantage of using in-service trains is that additional measuring is relatively simple to perform in case of measuring mistakes.

Based on the above requirements, an on-board visibility check method is proposed and described in the next section.

3. Proposed Method

The proposed system checks legibility of radio waves or invisible lights emitted by obstruction-warning signals; this is one method for checking visibility in the daytime without disrupting train operations. In this case, the directionality of radio waves and invisible lights must be much greater than that of the original light dispersion. Unlike radio waves, invisible lights can be visible when using a special video camera. A black light was therefore selected for this research so that the maintenance staff could detect errors easily.

Black light spectrum goes from ultraviolet and to infrared. Given the potential hazardousness of ultraviolet rays, the infrared side of the spectrum was selected. Wave-lengths of 780 nanometers and over fall into the invisible range, however the longer the wavelength is, the more difficult it becomes to get the LED and less sensitive the camera becomes.

Considering the above, a near-infrared LED (850 or 940 nanometers in peak wavelength.) was finally selected. An infrared sensitive camera and lens were used as a receiver.

From 800 meters away regardless of the shape of arranged LED, the video camera only records the LED as a dot. In addition, sunlight contains also contains a large amount of infrared light. This peripheral light makes it difficult to recognize the LED light if it is simply lit. Furthermore, other lights with different wavelengths exist along the railway line in addition to obstruction-warning signals such as traffic lights, signs, neon lights from shops and streetlights. It must therefore be possible to identify the LED light among this background interference. In order to reduce the influence of interference, the near-infrared LEDs blink according to certain pattern, which is recognized by the image processing system.

Each obstruction-warning signal was assigned a different blinking pattern in order to distinguish them. Each obstruction-warning signal therefore sent a uniquely coded pattern to the trains to be decoded on board.

4. Selection of near-infrared LED

A study was made on LEDs whose peak wavelengths were 940nm and 850nm. Some people are able to faintly see LEDs emitting red light in the dark when the LED has a peak wavelength of 850 nm. In general, wavelengths visible to the naked eye are between 380 nm to 780 nm. Lights with a wavelength outside this range are therefore not visible to the naked eye. However, an LED with a peak wavelength of 850 nm outputs wavelengths other than 850 nm, because it has a certain bandwidth. The center of this bandwidth is 850 nm and the lower limit is 780 nm. Assuming that the spectral distribution characteristics are in accordance with the general Gaussian function, the characteristics can be expressed by (1) of the following equation. Sigma is the full width at half maximum (FWHM).

\[ f(x) = \exp \left\{ -\frac{(x - \mu)^2}{2\sigma^2} \right\} \]

\[ \sigma = \frac{FWHM}{\sqrt{2\ln 2}} \]

The peak wavelength is therefore 850 nm, FWHM = 45 nm, and \( \sigma \approx 19.1 \text{ nm} \). In addition, at the peak LED wavelength of = 940 nm, FWHM = 50 nm, and \( \sigma \approx 21.2 \text{ nm} \). Figure 1 shows the sensitivity characteristics of each wavelength. An LED with a peak wavelength of 940 nm has completely zero intensity at a wavelength of 780 nm, which is the upper limit of the wavelength visible to the naked eye. On the other hand, an LED of peak wavelength 850 nm outputs about 0.1% of its peak wavelength intensity at a wavelength of 780 nm. In other words, when the radiation intensity of the peak wavelength is 230 mW/Sr, that is about 0.23 mW/Sr at a wavelength of 780 nm. However, the sensitivity of the camera to a wavelength of 940 nm is about 1/2 of the 850 nm wavelength. An LED with a peak wavelength of 850 nm was therefore selected, and in order to avoid slight red emitted from the LED being recognized as red, a few white LEDs were added.

5. Device Structure

A prototype of the near-infrared blinking controller was developed. The LED peak wavelength was 850 nano-
meters. In order to adapt to the camera frame rate change (25 fps, 30 fps, and 60 fps), the blinking period can be set arbitrarily per 1 millisecond, and there were 8 possible blinking patterns available by using a dipswitch. In order to send 3 to 14-bit information when using the coding system, mentioned below, the prototype was made to allow a maximum of 32-bit code length in consideration of the header and the coding at the time of later expansion of the code length. A Programmable Logic Controller (PLC) was used as a controller. Figure 2(b) shows the controller. Figure 2(a) shows the light emitting unit which was made using the same mechanism as that of the current obstruction-warning signal (base plate, acrylic pillar, and cables).

6. Blinking pattern and Image recognition algorithm

Manchester coding [4] was used for the blinking code because it resistant to environmental change. Manchester coding is an embedding method for coding the clock rate in sending data, and its characteristic is that “0” and “1” do not continue for long. As a result, changes in the average level of the amount of received light do not affect the decoding threshold, and synchronization is possible without synchronous signals. It is therefore suitable for situations in which environmental conditions change significantly and signal intensity is not stable. The coding system for digital data in Manchester coding is, “0” input as “01,” “1” input as “10.” The binary system with “0” and “1” is defined as a transition, not a static value, and two definitions are established by assigning a logic level “0” and “1” (and vice versa) to the rising edge and falling edge respectively. In other words, blinking patterns are found by applying the clock signal and exclusive OR.

This coding, “0,” and “1” will appear with the same frequency, so it can be used with the average value of the data as the decoding threshold. Threshold adjustment is not necessary even in places where there are significant environmental changes or environmental noise, and it is easy to decode the received data. It is sufficient to find the average and to obtain the difference between the average and the observed data (or threshold processing with average value as the threshold) for the decoding procedure to obtain the digital data. Through the clock and exclusive OR process, digital data is decoded back to be original. When applied to image processing, if the k-th flame image is $F_i$, and its pixel value is $f_{i,j}(i,j)$, the average image between the k-th flame and the L-th flame is $f_{i,j}$, differential image of $f_{i,j}$ and $f_{i,j}$ is $g_{i,j}(i,j)$, and if $g_{i,j}(i,j)$ which binalized conforming with the code pattern $\sigma$ is $G_{i,j}(i,j)$, the formula is shown below, and the pixel only with the code pattern is $H_{i,j}$. In the end, k-th flame visibility check was conducted.

Results were interpreted to be a pass if test $\rho_i=1$, and fail if test $\rho_i=0$,

$$
\bar{f}_i(i,j) = \sum_{k=1}^{L} f_{i,j}(i,j)/L
$$

$$
g_{i,j}(i,j) = f_{i,j}(i,j) - \bar{f}_{i,j}(i,j)
$$

$$
\sigma = \sigma_1 \sigma_2 \cdots \sigma_L \text{ for } \sigma = [\pm 1, \pm 1]
$$

$$
G_{i,j}(i,j) = \begin{cases} 1 & \text{if } g_{i,j}(i,j) \times \sigma \geq 0 \\ 0 & \text{if } g_{i,j}(i,j) \times \sigma < 0 \end{cases}
$$

$$
H_{i,j}(i,j) = \prod_{k=1}^{L} G_{i,j}(i,j)
$$

$$
\rho_i = \sum_{\text{image height}} \sum_{\text{image width}} H_{i,j}(i,j)
$$

The figure below shows image processing decoding screenshots, Fig.3 (a) shows a part of the received data, Fig.3 (b) shows the average received data, and Fig.3 (c) shows the digital data generated from difference between received and averaged data.

![Fig. 3 Decoding process by image processing](image-url)
7. Synchronization with the near-infrared camera and LEDs

If the camera and light-emitting unit are asynchronous, the system may be unable to properly recognize the blink pattern due to deviation in the sampling timing of the camera and “rising or falling” edges of the flashing. For example, when the “camera sampling” and blinking periods are the same, if “sampling timing of the camera” does not match “the light emitting unit flashing timing”, as shown in the upper part of Fig. 4, the luminance data which the camera receives becomes uneven as shown in the middle of Fig. 4. A means to overcome the asynchrony between the camera unit and the light-emitting unit is to make the camera sampling frequency more than double that of the flashing of the light-emitting unit. However, since the time required for this type of inspection is at least twice that of the other method the inspection results are easily influenced by vehicle vibration. Consequently, as shown in the lower part of Fig. 4, shutter speeds of 1/500 sec and 1/250 sec were applied without changing the sampling frequency and the cycle of flashes. Field test results confirmed that the camera was able to obtain proper flashing signals without brightness unevenness.

Fig. 4 Relationship between sampling interval and shutter speed and received brightness

8. Scope control of the near-infrared Camera

8.1 Rail extraction algorithm

The rail near the camera can be observed with a comparatively strong edge, and it is almost straight because the curvature is moderate. Furthermore, the longer the distance between the rail and the camera, the narrower the gauge looks. An existing algorithm was used, in which the rails are represented as a combination of short line and curved segments [5]. From the far end of rail template specified with the near-field range processing, the next candidate rail-lines are drawn in consideration of the template’s curvature. The algorithm then chooses lines which match the rail image from those candidates. The farther from camera, the more divided the search area; repeatedly extracting the rail in the next area. Figure 5 shows the result of the rail extracting algorithm applied in practice. Figure 5(a) has raindrop noise, and Fig. 5(b) has halation because of the backlight, but the algorithm manages to detect the rails correctly in both conditions, and find the FOE.

Fig. 5 The result of rail extraction

8.2 Camera control method and Calibration

In order to be able to capture the vanishing point all the time, it is necessary to extract the rail from a wide-angle camera image, and acquire the target vanishing point. In order to track it and show it in the center of the screen, a wide-angle camera sends, as signal feedback, a signal toward the pan-tilt unit which is loaded with a zoom camera.

To control the camera view based on information from FOE, correspondence with FOE coordinates and pitch angle / yaw angle of pan-tilt unit must be maintained.

A calibration program was developed which, using a GUI can register one point on a wide-angle camera image and one point on a near-infrared image controlled at the pan-tilt unit by using coordinates as a guide reference. Figure 6 shows a screenshot of the calibration, in which the wide-angle camera view is on the bottom-left. The red square shows the area, which represents the same zoom rate as the near-infrared camera; the bottom-right image is the zoomed image, and near-infrared camera image in the upper-right hand of the Figure. Each image is adjusted to appear the same size, and the calibration coordinates are registered as leading coordinates in the program. At least four registered correspondence points are therefore necessary to ensure accurate calibration. The camera view control thus works accurately with coordinates extracted by the rail extraction algorithm.

Fig. 6 Calibration image on pan-tilt unit
9. **In-line testing**

9.1 **Temporary Installation**

A temporary experimental obstruction-warning signal was fixed to the pillar of a current obstruction-warning signal to evaluate the prototype emitter unit, controller, pan-tilt unit, and the blink detection algorithm. Measurements were taken during the daytime in order to check the effectiveness of this method. The test was performed on an actual line, and the light emitting units were installed from the starting point outwards.

As mentioned at the beginning of this paper when the obstruction-warning signal is not visible enough, repeaters are placed up to the level crossings. Figure 7 shows that "A" is a repeater of "C," and "B" is the repeater of "D." "E" does not have repeater, and Fig.8 shows the temporarily installed conditions of each of the test devices.

9.2 **On-track tests**

In-line tests were performed using a turn-back operation train. The device was installed on the assistant driver's side of the cabin on the outbound side. This was for evaluating the effects generated by the lights along the railway line. In the blinking pattern, each number from zero to seven was expressed with three bits, and each bit was translated into Manchester code such as "0" for "01" and "1" for "10," and then for sentence starter recognition, four start bits "1100" to coded six bits were added to complete the total 10 bit pattern. For example, "5" was expressed as "1100100110." Different patterns were assigned to the five prototype emitter units. The control signal was sent to the pan-tilt unit based on the FOE information derived from the computer analyzed image by wide-angle camera. Figure 9(a) shows how the device is set in the train, and Fig.9 (b) shows the system screen.

9.3 **Results**

Figure 10 shows the screenshot when the prototype emitter units A-E were detected. Figure 11 shows the results of the test, where the horizontal axis is mileage in kilometers, and the vertical axis is the prototype number. The "Filled triangle" is the kilometer point where the prototype-emitting unit was installed, and "Outlined triangle" is the kilometer point where the signal should be recognized. The "Lozenges" show the location where the system detected the prototype-emitter unit.

For units A, B, C, and D, visibility was successfully confirmed at the appropriate distance. The system even managed to recognize unit B from 600 meters ahead of where it should have been recognized. This is because unit B was a repeater, the distance involved was short, it was placed in an open place and was clearly visible. In addition, there was no influence from train vibration, and the camera view control worked well. Among the areas where visibility was accurately confirmed, there were a few spots which were not properly detected in each result. This was due to train vibration affecting the blink detection algorithm, so algorithm failed to function correctly and camera direction control was consequently inappropriate due to the failure of rail extraction algorithm. The zoom camera was not able to capture the unit from 100 meters to 150 meters away from every unit because it was too close to the camera.
10. Conclusions

An accurate and effective method was proposed in this paper for checking the visibility of obstruction-warning signals from the train. A new obstruction-warning signal was developed including a function which causes a near-infrared LED to flash in certain periods using a blinking circuit, an infrared camera with a pan-tilt unit which can track the LED even in curved sections, and an image processing algorithm which can catch the LED blink. On-track tests were performed to evaluate the method. Results confirmed the effectiveness of the basic function.

Future studies will be devoted to research into optimized blinking patterns and blink detecting algorithms, which enable continuous detection and reduce the number of misses in areas with multiple obstruction-warning signals. Investigations will also be made into an infrared light emission control system, which can detect a specific signal in such areas. Further work will be to develop a pan-tilt unit, which uses turnout information, and a method to link mileage on the visibility-checking screen to that of the obstruction-warning signal.

These technologies may be useful not only for obstruction-warning signals, but also for other signals, and may even be useful for communication between train and trackside installations.

References