Enhancement of Detection Functions of the 3DLR for Even Safer Level Crossing

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We have enhanced the detection functions of the 3D laser radar level crossing obstacle detection system (hereinafter referred to as "the 3DLR"). The 3DLR detects obstacles in level crossings by measuring the distance to objects using laser beams. Due to the demand for obstacle detection system with higher detection capabilities, we have worked to improve the functionality of the system and developed a falling down detecting function. The test was conducted in simulated environments and at on-site level crossings, and it was confirmed that the system could detect falling objects even in snowy regions, making it possible to improve the safety of level crossings and detect objects more accurately than ever before.

1. Introduction

The obstacle detection system for level crossings detects vehicles and other objects stuck in level crossings as obstacles to prevent trains from crashing into them. This system alerts train crew via railway signal equipment when detecting obstacles in level crossings. The train crew immediately stops the train when they receive the signal. In this way, the obstacle detection system for level crossings prevents level crossing accidents. This system has been widely deployed in Japan, mainly at level crossings with heavy traffic.

The 3D laser radar level crossing obstacle detection system (hereinafter referred to as "the 3DLR") measures the distance to objects using laser beams to detect obstacles in railway level crossings. Since delivering the first system to East Japan Railway Company (hereinafter referred to as "JR East") in 2005, IHI has sold a cumulative total of more than 2 800 systems in Japan, Europe and other countries. Based on the knowledge and experience accumulated so far, IHI has been working with JR East to improve the functionality of the system so that it does not prevent reliable train operation with higher detection capabilities. We have released the enhanced 3DLR in level crossings since 2019.

In order to enhance the functionality of the 3DLR, we modified the software using an original algorithm to improve the detection function. The enhanced 3DLR will be more helpful than ever in preventing accidents in which road users such as the elderly and wheelchair users are left stranded inside a level crossing. This paper introduces the 3DLR and describes the functions developed as part of its enhancement and their test results.

2. 3DLR

2.1 Overview of the 3DLR

Figure 1 shows a conceptual diagram of the 3DLR. The 3DLR is a system that emits laser beams from the top of a pole installed near a level crossing to measure the level crossing zone and obtain three-dimensional shapes in the level crossing in order to detect objects.

The 3DLR can detect objects wherever laser beams reach, and the zone where the detection zone is divided into multiple zones is wider than that of other systems. Other features of the 3DLR are installation and repair that do not require large-scale work as well as resistance to snow and other weather conditions and the high detection performance that can detect objects smaller than vehicles.

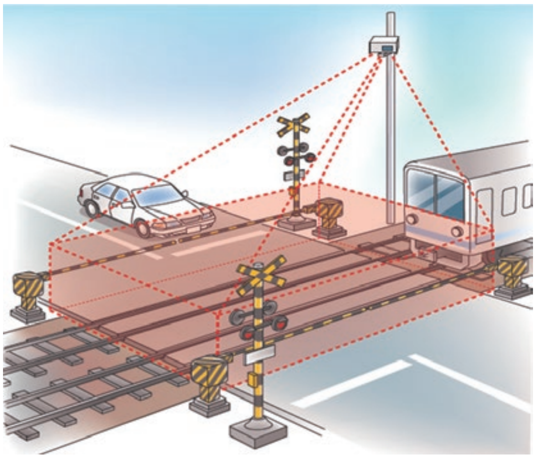

Fig. 1 Conceptual diagram of the 3DLR

2.2 Basic configuration of the 3DLR

Figure 2 shows the basic configuration of the 3DLR. The scanner (laser unit), installed on the top of a pole overlooking a level crossing, emits laser beams into the level crossing to obtain measurement data. If the 3DLR cannot perform its detecting function due to a large earthquake, environmental degradation due to bad weather, or other cause, the evaluation plate installed in the detection zone will be used for the diagnosis. The controller performs calculations using measured data obtained by the scanner and detects whether obstacles exist. The controller is often stored with a recorder for 3DLR data in the equipment box installed by the railway tracks. For setup or adjustment, a maintenance terminal will be connected to the controller.

2.3 Obstacle detection procedure and functions of the 3DLR

Figure 3 shows the operation principle of the 3DLR[(1)–(3)]. The scanner consists of a mechanism that emits and receives laser beams, and measures the distance to the object by the time it takes for the laser beams to return (time-of-flight method). The 3DLR scans the entire zone in the level crossing, emitting laser beams horizontally and vertically to calculate the distance to measured points. The 3DLR extracts measured points in the level crossing based on the reflection of laser beams and calculates the positions, speed, and size of objects such as vehicles. The 3DLR also has the following

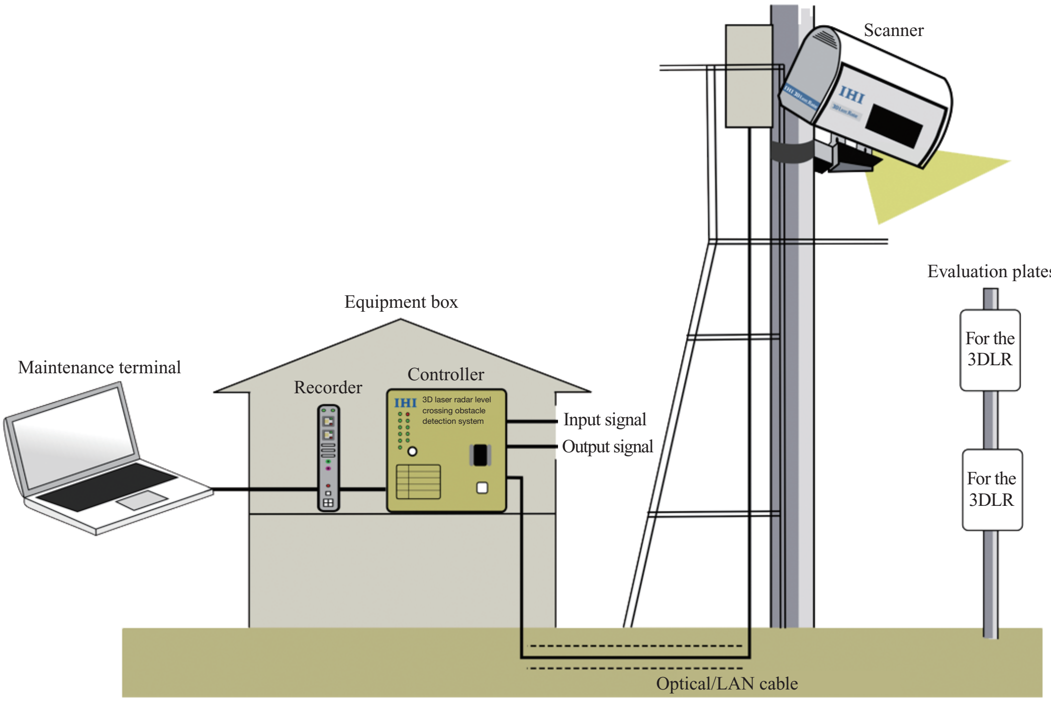

Fig. 2 Basic configuration of the 3DLR

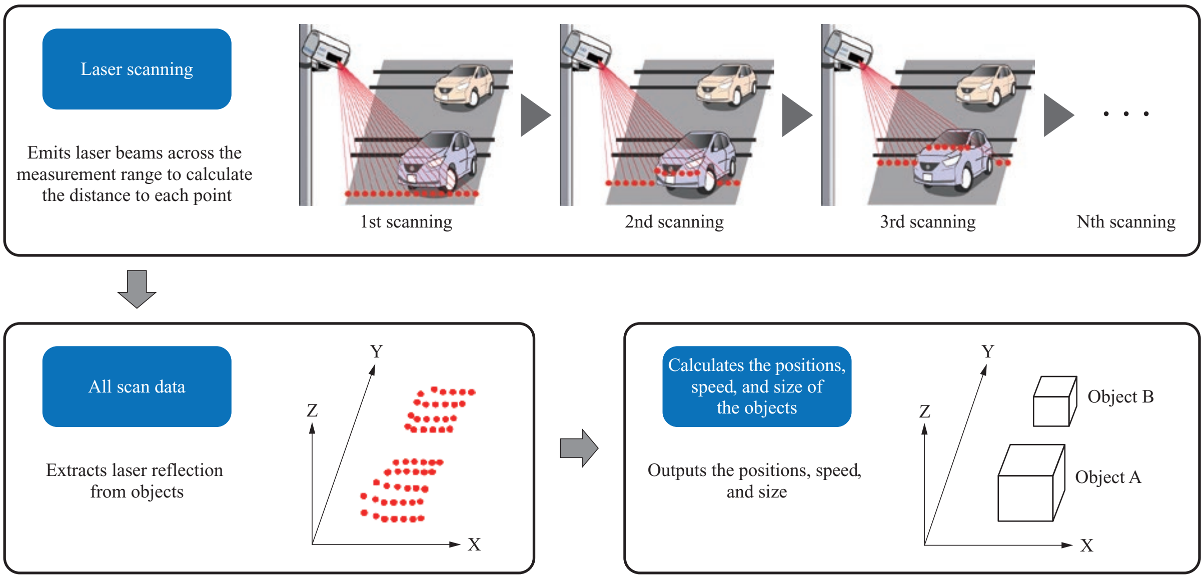

Fig. 3 Operation principle of the 3DLR

functions for more appropriate detection.

(1) Lower mask

Some objects such as accumulated snow, weeds, or small animals are detected as obstacles in level crossings even though they are not actually obstacles. The 3DLR has a function called a lower mask to avoid false positive of such objects and to prevent them from affecting normal railway operation. **Figure 4** shows a conceptual diagram of the lower mask. The lower mask sets a threshold at a certain height from the road surface so that it does not detect small objects below the threshold.

(2) Detection zone

The 3DLR emits laser beams from the top of the pole and scans the entire zone of level crossing to obtain data with a fan-shaped spread. **Figure 5** shows the state of measuring points throughout the entire zone in the level crossing. The 3DLR has a detection zone setting function to identify the zone in the level crossing from the obtained data. The 3DLR processes data to only detect objects within the detection zone. The 3DLR also divides the detection zone into multiple zones and obtains staying time information in each zone with respect to each object. With this algorithm, the 3DLR can detect not only the presence or absence of objects in a level crossing, but also only objects that are stuck there.

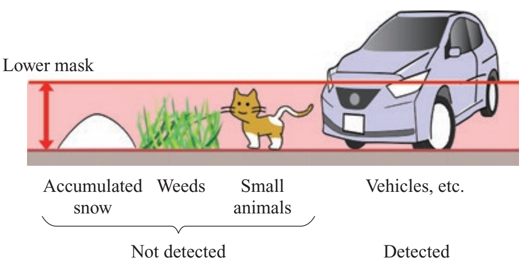

Fig. 4 Conceptual diagram of lower mask

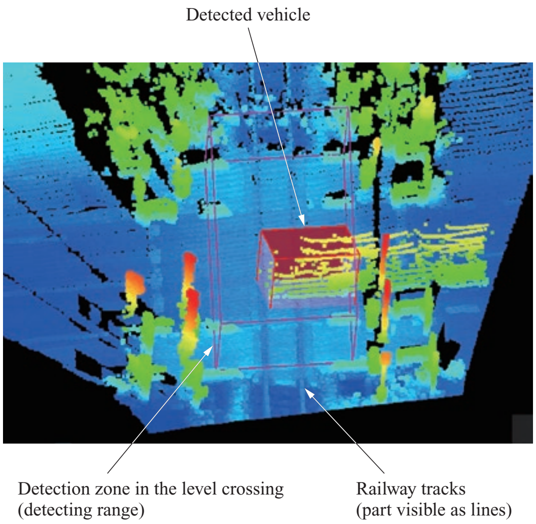

Fig. 5 State of the measuring points throughout the entire zone of a level crossing

2.4 Other functions of the 3DLR

(1) Diagnosis of failure function

The diagnosis of failure function assesses the state of the 3DLR in case parts of the 3DLR malfunction or measurement using laser beams fails, for example. The diagnosis of failure function constantly monitors the states of laser beam emitter/receiver, communication, and input and output signals. In addition, the diagnosis of failure function constantly monitors the position of the evaluation plate shown in **Fig. 2** and the reflection intensity of the laser beam. Therefore, it is possible to detect the case when the installation position of the scanner is displaced due to a large earthquake and so on, or the case when the laser beam is attenuated due to environmental degradation such as bad weather and measurement cannot be performed.

(2) Data recording function

The recorder shown in **Fig. 2** stores data that the 3DLR measures. By replaying the measured data, it is possible to investigate why the 3DLR detected an object even without a monitor camera.

3. Efforts to enhance the 3DLR

IHI released the 3DLR as a level crossing obstacle detection system in 2005. However, the elderly or other people prone to falling or wheelchair users continue to be involved in level crossing accidents. In this context, the "Committee for measures to prevent railway crossing accidents by elderly people," which consists of experts, railway companies, road administrators, the National Police Agency, and the Ministry of Land, Infrastructure, Transport and Tourism, proposed to study the installation of a level crossing obstacle detection system with high detection capabilities[4]. In response to such strong societal demand, in close cooperation with railway companies, we have enhanced the 3DLR in several ways including further improving the detection performance and system reliability. The following sections describe the functions developed to enhance the 3DLR and their test results.

3.1 Falling down detecting function

The falling down detecting function was developed because the lower mask described in **Section 2.3** used to have unreliable detection if a pedestrian fell in the level crossing. **Figure 6** shows a conceptual diagram of the falling down detecting function. The 3DLR tracks detected objects and measures their height. This height measurement function is used to improve the object detection performance by lowering the height of the lower mask only around that object if the tracked object gets lower[5]–[9].

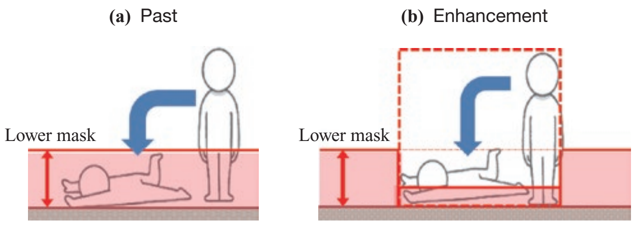

Fig. 6 Conceptual diagram of falling down detecting function

3.2 Road surface unevenness correction function

Level crossing surfaces may not always be even, but can be quite uneven. Although we had further improved the detection performance by introducing the falling down detecting function, this resulted in new challenges. For example, the 3DLR started unnecessarily detecting protruding sections on the road surface and detection became unreliable if a person fell onto an indentation. To address these issues, we developed a function to measure uneven shapes on the road surface in advance and correct the height of the lower mask according to them. **Figure 7** shows the correction of uneven shapes on the road surface.

The road surface unevenness correction function needs data on unevenness shapes in the level crossing beforehand. Therefore, a function was added to measure road surface in the zone of the level crossing with the scanner installed on the of the pole so that the uneven shape can be obtained from the measured data. **Figure 8** shows a histogram of the road surface height. Since the measured data contains objects such as pedestrians in the level crossing and vehicles passing through it, if the height of a certain point on the road surface is measured for a certain period of time, the histogram shape shown in **Fig. 8** will be obtained. Therefore, the software was modified to exclude measuring points at which pedestrians or vehicles are measured and only extract the road surface section of the level crossing to measure uneven shapes[(5)–(9)].

3.3 Automatic following function for changes of the road condition

The 3DLR does not detect a certain amount of accumulated snow due to the effect of the lower mask. However, it was found that the 3DLR increased false-positive of snow accumulation around vehicles or the feet of pedestrians after the falling down detecting function described in **Section 3.1** was introduced in snowy regions. To address this issue, we developed a function to automatically change the height of the lower mask according to the road surface that gradually changes due to accumulated snow, weeds or other elements. **Figure 9** shows the differences due to presence or absence of the automatic following function for uneven shapes on the road surface. **Figure 10** shows the lower mask that automatically follows road surface unevenness.

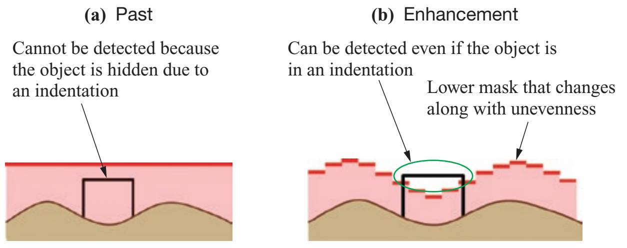

Fig. 7 Correction of lower mask according to the unevenness shapes of the road surface

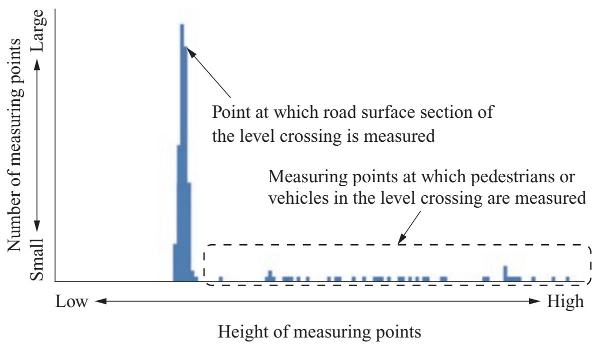

Fig. 8 Histogram of the road surface height

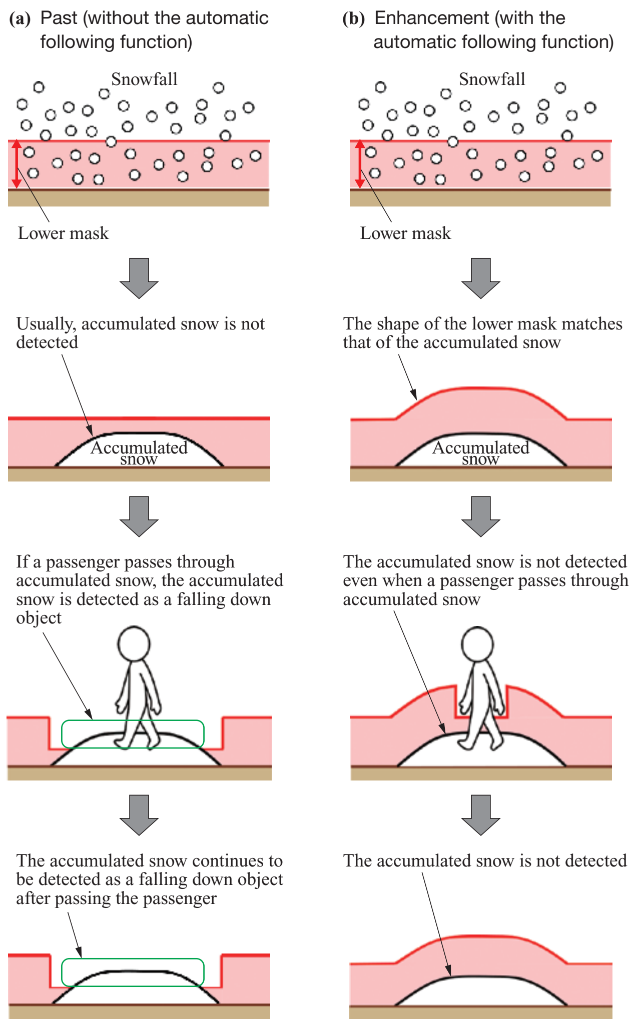

Fig. 9 Differences due to presence or absence of automatic following function

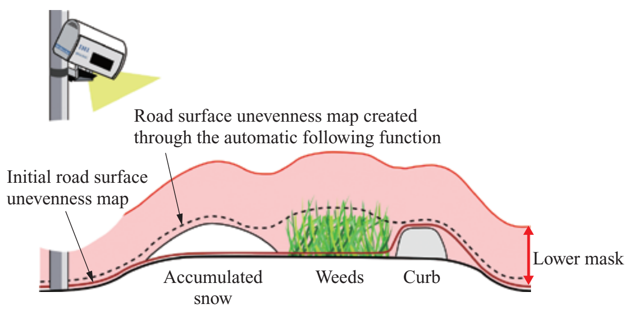

Fig. 10 Lower mask that automatically follows road surface unevenness

3.4 Noise reduction function

Figure 11 shows a conceptual diagram of noise reduction[(7)–(9)]. When laser beams are reflected, the 3DLR may mistakenly detect snowflakes as obstacles. This is likely to occur when many large snowflakes fall. Because the 3DLR repeatedly detects snowflakes in weather that meets this condition and affects normal railway operation, a function was developed to remove measuring points corresponding to snowflakes, etc. When laser beams hit snowflakes, the snowflakes are often detected as independent measuring points floating in the air. The new function removes such independently measured laser beam measuring points as noise.

3.5 Remote communication with the recorder

The 3DLR data is saved in the recorder. Railway operators had to visit the site to collect recorded data. To address this issue, a new recorder with a communication function was developed to remotely collect data. This function reduces the workload on railway operators. In addition, the railway operators can remotely monitor how the 3DLR is measuring objects in real time in case of failure and address issues more flexibly, which helps minimize influence on train operation.

4. Test of the developed functions

4.1 Falling down detecting function

We tested the environment of an on-site level crossing and tested the falling down detecting function by assuming the falling situations. **Figure 12** shows falling down detecting tests in various cases. In addition to simple falls, we tested cases that could actually occur. Specifically, we reproduced cases difficult to verify in real level crossings such as (a) fall of a person in a wheelchair, (b) a falling down object is shadowed by passing vehicles, (c) fall due to a collision with a cyclist, and (d) fall in a crowd, and verified the falling down detecting function. The results showed that the falling down detecting function properly detects falls that the previous 3DLR could not.

We also performed a falling down detecting test at an on-site level crossing to verify the falling down detecting function, considering the results obtained in the simulated environment. **Figure 13** shows the state of a falling down

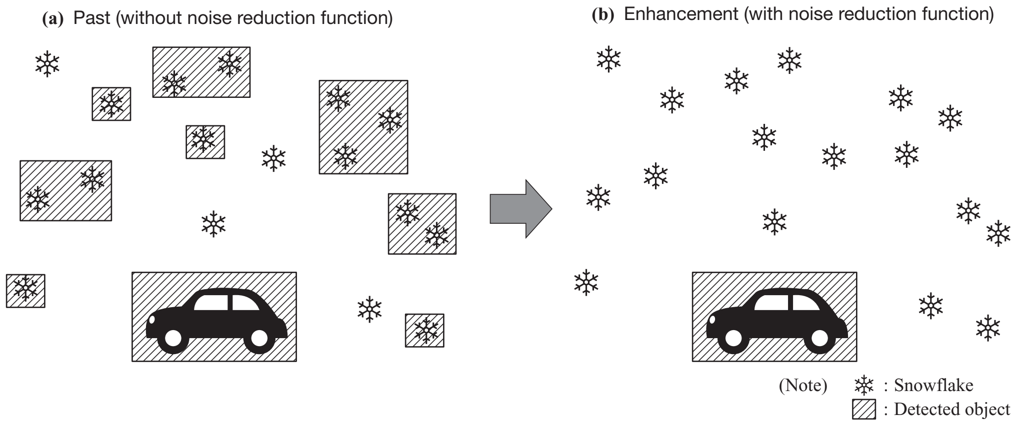

Fig. 11 Conceptual diagram of noise reduction function

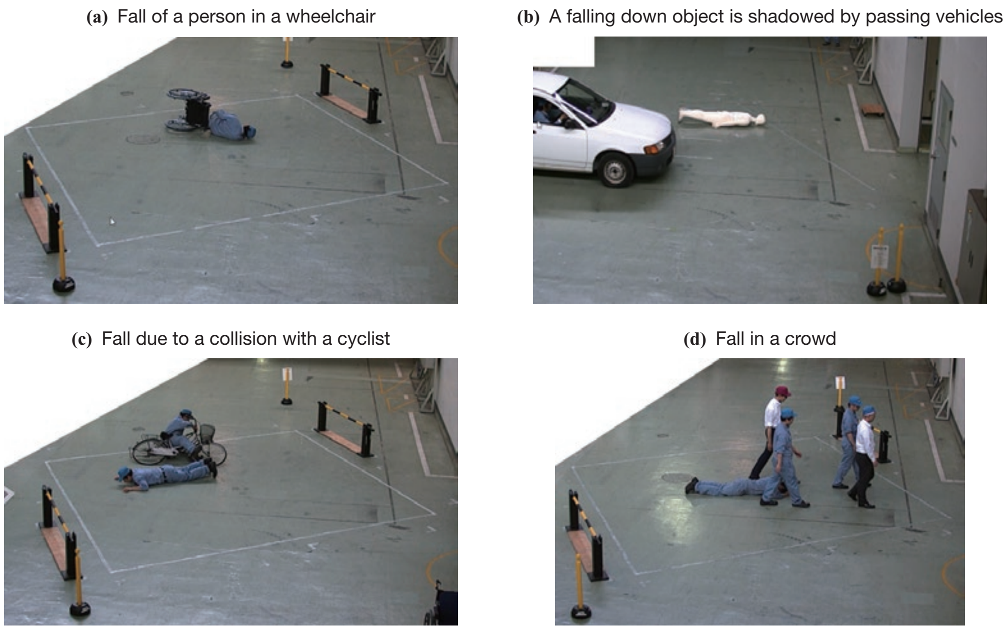

Fig. 12 Falling down detecting test in various cases

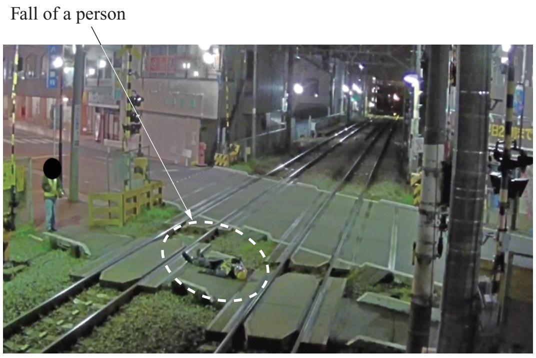

Fig. 13 State of falling down detecting test in on-site level crossing

detecting test in an on-site level crossing. **Figure 14** shows verification results of the falling down detecting test in the on-site level crossing. **Figure 14-(a)** shows the detection result of the previous 3DLR, where the fall is not detected. In contrast, **Fig. 14-(b)** shows the detection screen in a 3DLR equipped with the falling down detecting function. It was confirmed that the enhanced 3DLR detected the person who fell down on the rail surface, which was not detected with the previous 3DLR.

4.2 Road surface unevenness correction function

Figure 15 shows an example of creating data on the uneven shapes of the road surface for a level crossing that pedestrians and vehicles actually pass through. **Figure 15-(a)** is an

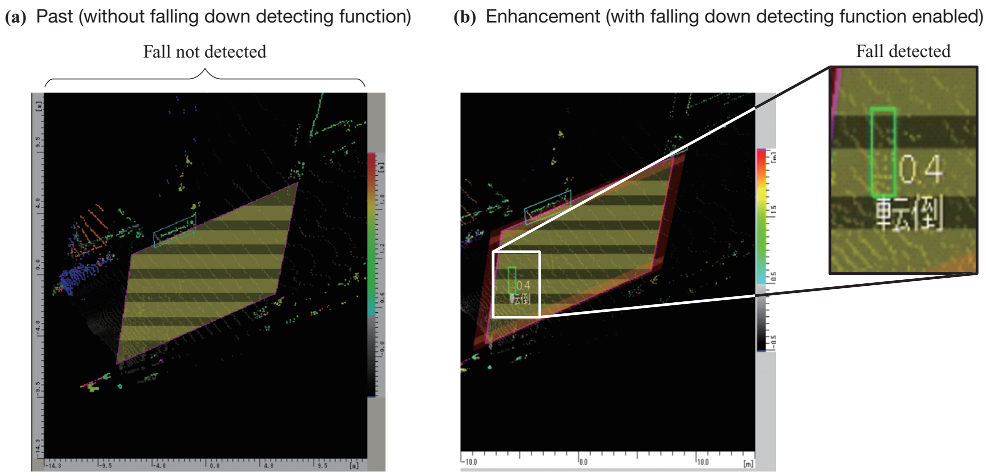

Fig. 14 Verification result of falling down detecting test in on-site level crossing

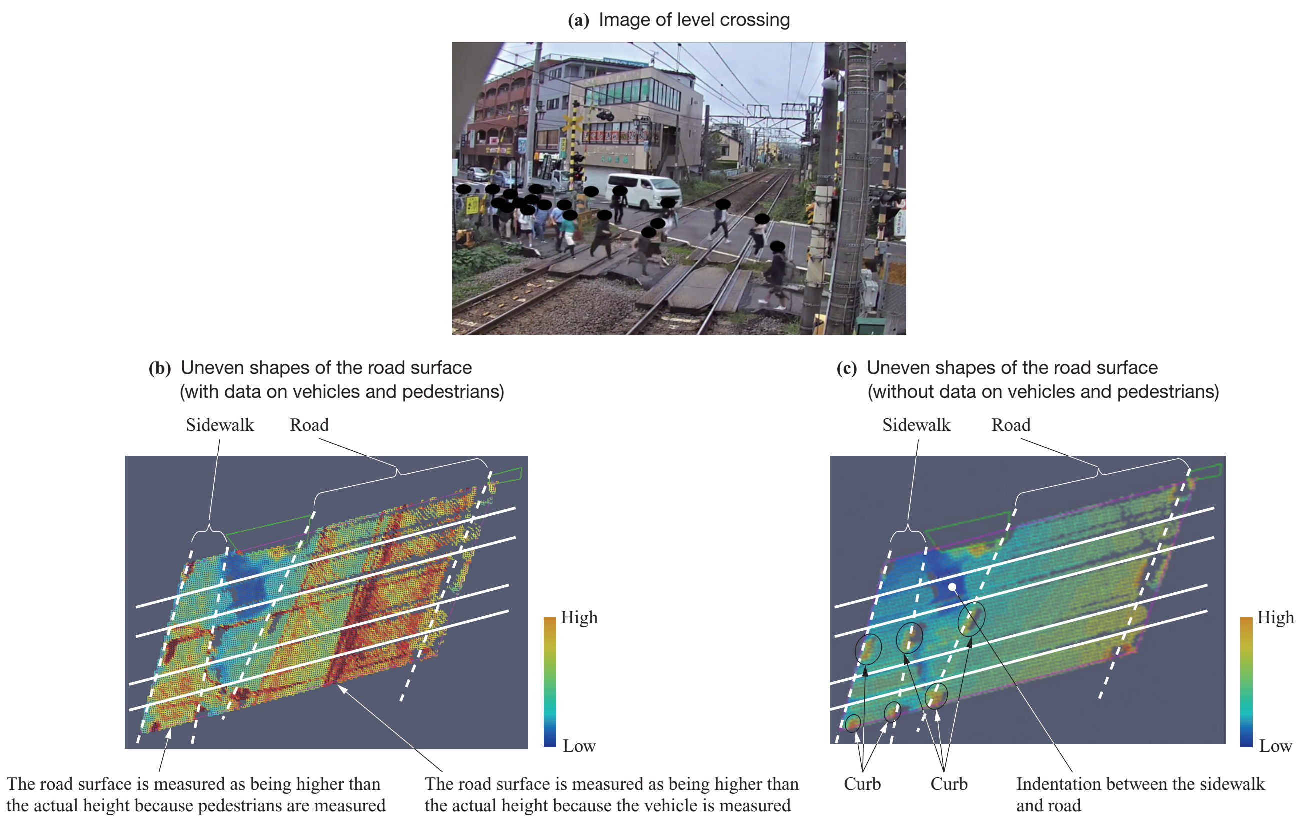

Fig. 15 Example of creating data on the uneven shape of the road surface

image of the on-site level crossing. **Figure 15-(b)** shows that uneven shapes higher than the on-site road surface were created because measured data contained measuring points such as pedestrians and vehicles. Therefore, we continued measurement for a certain amount of time and excluded measuring points where pedestrians and vehicles had been measured to only extract the road surface in the level crossing. This correction reproduced the shapes of curbs and the indentation between the sidewalk and the road in the level crossing to obtain the uneven shapes of the road surface shown in **Fig. 15-(c)**.

4.3 Automatic following function for changes of the road condition

We verified the automatic following function for changes of the road condition by using the 3DLR measured data obtained in level crossings in snowy regions. Of the obtained data, we used data from a week when a particularly large amount of snow had accumulated. **Table 1** shows the comparison result of how many times accumulated snow was detected. Five level crossings were selected for verification, considering the installation locations, traffic volume, types of snow melting machine, and other factors. (1) The previous system did not detect accumulated snow because the accumulated snow did not exceed the height of the lower mask. However, (2) the enhanced system (without the automatic following function) detected accumulated snow in the level crossings as falls in many cases because the falling down detecting function is enabled. (3) The enhanced system (with the automatic following function) did not detect accumulated snow even when the falling down detecting function is enabled, because the newly developed automatic following function automatically follows the uneven shape of the road surface according to the state of accumulated snow. We confirmed that the potential to introduce the falling down detecting function in snowy regions as well and validated the automatic following function.

Figure 16 shows the state of level crossing A when snow accumulated. **Figure 16-(a)** shows that a vehicle is in the level crossing with snow accumulated. The left image in **Fig. 16-(b)** shows how (2) the enhanced system (without the automatic following function) detected this situation. This system properly detected the vehicle but mistakenly detected accumulated snow as a fall.

In contrast, the right image in **Fig. 16-(b)** shows how (3) the enhanced system (with the automatic following function) detected objects in this situation. This system properly detected the vehicle without detecting accumulated snow. **Figure 16-(c)** shows the amount of change in the uneven shapes of the road surface from the initial state without accumulated snow. Whereas the amount of increase has not largely changed in the road section with a small amount of accumulated snow, the amount of increase is large in the sidewalk section with a large amount of accumulated snow. We confirmed that the 3DLR properly performed automatic following in line with road surface changes due to accumulated snow.

4.4 Noise reduction function

We obtained the 3DLR measured data in level crossings subject to the influence of snowfall during the snowfall period to verify the noise reduction function. **Table 2** shows the number of times obstacles were detected because of detecting environmental degradation due to snowfall and the amount of detection time. The previous system detected snowflakes at level crossings H and I, where environmental degradation due to snowfall occurred among the four level

Table 1 Verification results of level crossing under snowy regions

		(1) Previous system				(2) Enhanced system (without the automatic following function)				(3) Enhanced system (with the automatic following function)			
Falling down detecting function		Unequipped				Equipped							
Automatic following function for changes of the road condition		Unequipped								Equipped			
Level crossing name	Unit	No detection	Detection of accumulated snow	Detection of Snowflakes	Detection of other objects	No detection	Detection of accumulated snow	Detection of Snowflakes	Detection of other objects	No detection	Detection of accumulated snow	Detection of Snowflakes	Detection of other objects
Level crossing A	Time	0	0	0	0	0	5	0	0	0	0	0	0
Level crossing B	Time	0	0	0	0	0	8	0	0	0	0	0	0
Level crossing C	Time	0	0	0	0	0	24	0	0	0	0	0	0
Level crossing D	Time	0	0	0	0	0	39	0	0	0	0	0	0
Level crossing E	Time	0	0	0	2	0	0	0	22*1	0	0	0	19*1

(Note) *1: Steam from the snow melting machine was detected

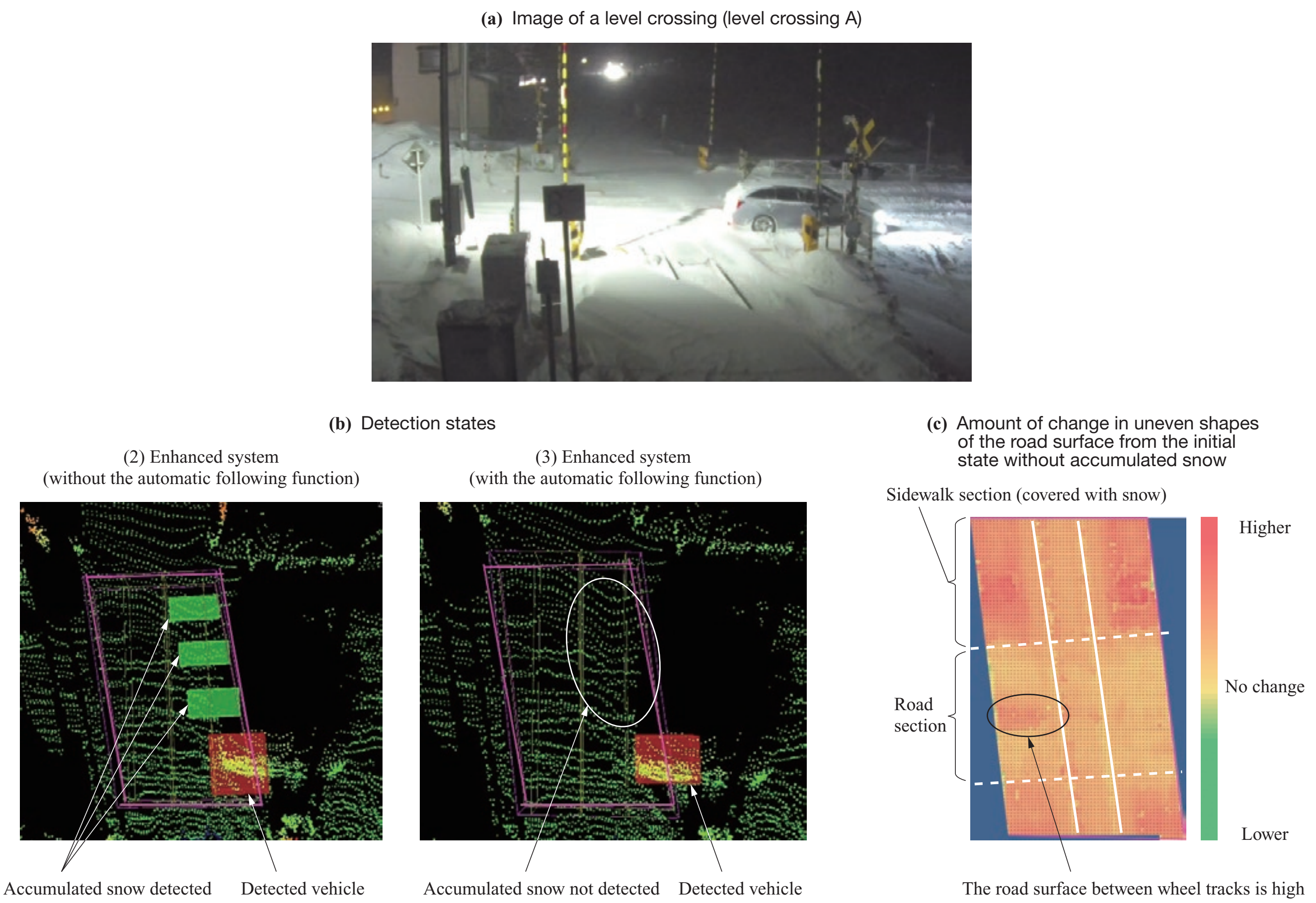

Fig. 16 State of the amount of change in uneven shapes of the road surface

Table 2 The number of times obstacles were detected because of detecting environmental degradation due to snowfall the and amount of detection time

		(1) Previous system		(2) Enhanced system	
Noise reduction function		Disabled		Enabled	
Level crossing name	Unit	No detection	Detection of snowflakes	No detection	Detection of snowflakes
Level crossing F	Time	0	0	0	0
Level crossing G	Time	0	0	0	0
Level crossing H	Time	0	9 1 296 s total	0	0
Level crossing I	Time	0	5 619 s total	0	0

crossings verified. The enhanced system with the noise reduction function enabled did not detect snowflakes at any level crossing, which confirmed the effectiveness of this system.

4.5 Remote communication function of the recorder

We installed recorders with the remote communication function at multiple level crossings to check if data can be remotely obtained. Railway operators remotely observed the occurrence of failures at the office without having to go all the way to level crossings when failures occurred in level crossings, which confirmed the effectiveness of the remote communication function.

5. Conclusion

In response to strong societal demand, we have enhanced capabilities of the 3DLR. As a result, the performance was successfully improved to detect falling down objects, which were difficult to detect in the past, by introducing a falling down detecting function and road surface unevenness correction function.

Although it was found that the falling down detecting function detected accumulated snow in snowy regions, we developed the automatic following function for changes of the road condition, making it possible to introduce the falling down detecting function in snowy regions as well. With these efforts, we can now provide a level crossing obstacle detection system that will further contribute to the safety of level crossings. We also believe that the noise reduction function and remote communication function with recorders allow us to better contribute to reliable system operation than in the past. We will continue to contribute to further safety enhancement of level crossings and the reliable operation of the 3DLR to respond to societal demands.

— Acknowledgments —

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