ENHANCEMENT OF DETECTION FUNCTIONS OF A 3D-LASER-RADAR-TYPE OBSTACLE DETECTION SYSTEM AT A LEVEL CROSSING

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ABSTRACT

East Japan Railway Company (JR-East) widely uses obstacle detection systems at level crossings in order to prevent collision accidents between running trains and passing automobiles. One type is the Three Dimension Laser Radar (3DLR), which uses LiDAR technology and has been installed into more than 800 level crossings in JR-East. As the current specification, 3DLR has a lower threshold of detection height. 3DLR do not detect obstacles from the ground surface to the lower threshold height in order to avoid wrong detection, which comes from surface irregularity such as grass-growing. However, it may also happen that a falling down person at level crossing cannot be detected due to the lower threshold. With an increasing demand for safety at level crossing, even a falling down person needs to be detected. Therefore, we have enhanced the detection functions of 3DLR by implementing two algorithms for the lower threshold. One is to follow up each object even below the threshold height so that a falling down person can be detected. The other is to vary the threshold height along with the shape of the ground surface of level crossing so that every object with more-than-threshold-height size can be detected. We have done the field test for about two years at a level crossing in Nambu Line and confirmed that the enhanced detection function with two algorithms work very well with the ability of detection of a falling-down object. JR-East has plan to start using the enhanced detection function of 3DLR in 2020.

Keywords: 3DLR, LiDAR, obstacle detection, level crossing.

1 INTRODUCTION

Prevention of railroad level crossing accidents is a major challenge for railway operators. In Japan, due to various measures to prevent level crossing accidents, the number of accidents has decreased to about 26% compared to 1988 [1], [2]. However, over the past few years, the number of fatalities in level crossing accidents has remained unchanged at around 100. In these, pedestrians account for the majority of fatalities (73%), so ensuring the safety of pedestrians at the level crossing is important. In addition, 40% of the fatal pedestrians are elderly people aged 65 and over, and there has been a high level of public concern [3].

At the same time, railway operators are introducing obstacle detection devices to prevent accidents at level crossings. Several types of obstacle detection devices have been introduced, such as lasers, loop coils [4], and millimeter-wave devices [5]. However, conventional obstacle detection devices are designed to prevent collisions between vehicles and trains, not to detect pedestrians.

In this study, we developed an enhanced obstacle detection system to improve the detection function of pedestrians at the level crossing.

2 OBSTACLE DETECTION DEVICES

In JR-East, there are three types of obstacle detection devices for level crossings as shown in Table 1 and Fig. 1. Laser type, Loop coil type, and Three Dimension Laser Radar (3DLR)

WIT Transactions on The Built Environment, Vol 199, © 2020 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/CR200041

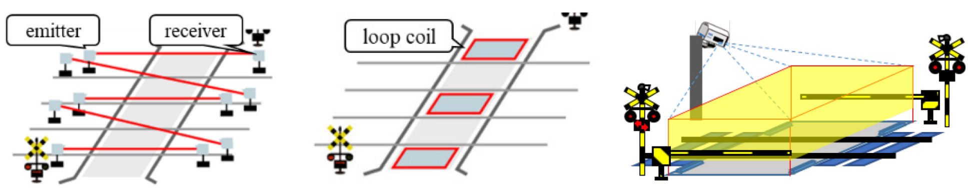
type. JR-East mainly install 3DLR type because it can detect more obstacles and therefore it is safer than Laser type and Loop coil type.

2.1 Principle of operation of 3DLR type obstacle detection system

Fig. 2 shows the principles of measurement of this 3DLR. 3DLR is one of the LiDAR system. 3DLR device emits a laser pulse to an object, and measures the time that it takes for reflected laser to return to the radar (time-of-flight method) to acquire a distance to that object [6]. Fig. 3 shows the object detection method used by the 3DLR. A laser pulse is emitted in a way that scans the entire area of a level crossing in the horizontal and vertical directions, and 3D coordinate values of each point are measured based on the laser reflected and returning to the 3DLR. The coordinates higher than the road surface are then extracted based on coordinate values of each point, and points distributed in close proximity to each other are recognized as "one group" [7]. Data on these groups of points are processed to calculate the positions and sizes of objects. By repeatedly executing this measurement process and performing related signal processing tasks, it becomes possible to recognize objects and identify the types of objects. Furthermore, speeds and moving directions are calculated based on the amount of temporal change in their positions.

Table 1: Types of crossing obstacle detection.

	Laser type	Loop coil type	3DLR type (3D laser radar)
Detection target	Ordinary vehicles	Larger vehicles than trucks, buses, etc.	Larger objects than 1 m × 1 m × 1 m cubic
Advantages	Lower implementation costs than other methods	Little exposed equipment	Easier to install than other methods
Disadvantages	Have some gaps which cannot be detected	Cannot detect small objects and pedestrians	Cannot detect objects in a bad weather such as heavy rain or snowfall. Higher equipment cost
Number of installations. (In JR-East)	1,460	570	800



(a) (b) (c)

Figure 1: Overview of obstacle detection system at level crossing. (a) Laser type; (b) Loop coil type; and (c) 3DLR type.

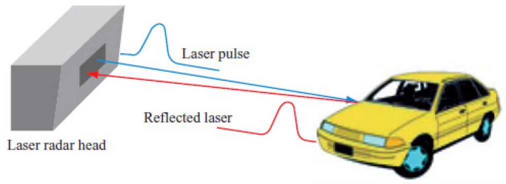


Figure 2: Measurement principle of 3DLR [6].

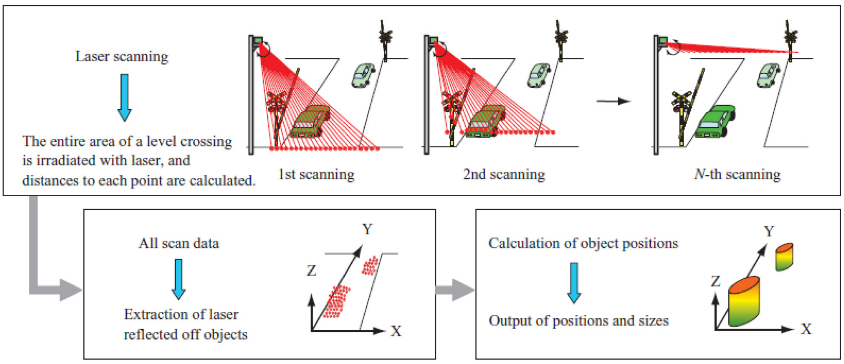


Figure 3: Object detection method [6].

3 PROBLEMS

3DLR can detect more obstacles and therefore it is safer than conventional Laser type and Loop coil type, but there are still some cases which are difficult to detect.

As shown in Fig. 4, we consider the following three cases:

- Case 1: Falling down while crossing. There have been cases where pedestrians have fallen down over due to unevenness near the rails in the level crossing as shown in Fig. 4(a). A falling down person, especially of an elderly person or in a wheelchair, is likely to lead directly to an accident because he/she takes much time to get up. Therefore, detecting a person who is about to fall down is considered to be important for accident prevention. With current 3DLR, detection after a fall down is difficult because the height of the fallen person is lower than the detection area.
- Case 2: Entering the track area. In some cases, moving from within the level crossing into the direction of the railroad tracks can lead to accidents because it is out of the detection area of the obstacle detection device as shown in Fig. 4(b). As it is very dangerous to go outside the railroad tracks, especially during warning at a level crossing, it needs to detect an object and output stop signal as soon as possible.
- Case 3: Stopping in front of the crossing bar. There is a case that the pedestrian was not able to cross the level crossing before the crossing bar closed and was left in front of the crossing bar and collided with the train as shown in Fig. 4(c). We assume that a vulnerable person such as an elderly person is unable to lift the crossing bar by themselves, or unable to reach the end of the level crossing and stops in front of the crossing bar. Currently, in many cases, the detection area is located 0.4 m away from the crossing bar, so that a person nearby the crossing bar cannot be detected.

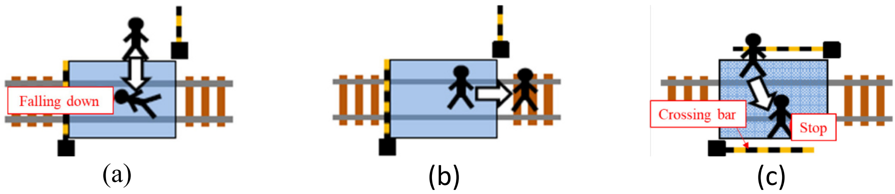


Figure 4: Pedestrian action pattern. (a) Case 1; (b) Case 2; and (c) Case 3.

In this study, we added a new algorithm to the object detection logic to improve the detection of pedestrian, which has not been possible to detect as shown the above three cases. For the development, we used the existing hardware and modified the software to improve the detection function at a lower cost.

4 EXAMINATION OF ALGORITHMS

Based on the action patterns of Section 3, we developed the functional specifications to be added in this study.

4.1 Function for Case 1 (falling down object detection)

A falling down object detection function was developed as a countermeasure for Case 1 in Section 3. In the current 3DLR, in order to prevent false detection due to grass-growing or bumps of the ground surface of the level crossing, an area is set up where an obstacle is not detected up to a certain height. Therefore, as shown in Fig. 5, it was difficult to detect the fall down of a person if the height was lower than the lower threshold height (0.5 m). Then, the lower threshold was set to 15 cm for the area only around the object being tracked, so that a person who has fallen down could be detected. Since the detection height is lowered only around the object, false detection of grasses and rain can be prevented.

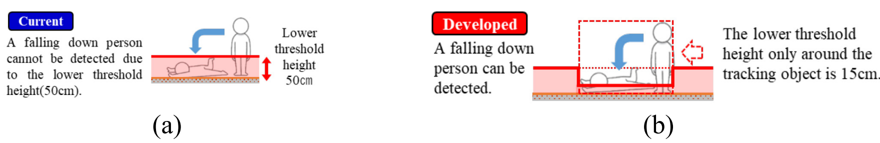


Figure 5: Falling down object detection function. (a) Current; and (b) Developed.

4.2 Additional function for Case 1 (map of ground surface of the level crossing)

In the current 3DLR, the lower threshold height was set at a certain level from the reference plane of the detection area, but it was treated as a constant value regardless of the shape of the ground surface of the level crossing. Therefore, as shown in Fig. 6, with the current function, it cannot detect pedestrians who have fallen down in the recesses. In this study, a map of the height corresponding to the ground surface of the level crossing was created and the lower threshold height was corrected by the height of a map along with the shape of the ground surface.

The map of ground surface of the level crossing is automatically created based on the data measured by the 3DLR. The detection area is divided into multiple square areas, and the height correction value of the ground surface is calculated for each area.

Figure 6: Map of ground surface of the level crossing. (a) Current; and (b) Developed.

4.3 Function for Case 2 and Case 3 (obstacle detection process for behavior judgment)

In addition to the current detection function, the following behavior judgment function was considered.

1. In order to detect pedestrians for Case 2 (Entering the track area), we set up a “detection area for track intrusion” in the direction of the track (refer to Fig. 7), and determine a “track intrusion” when an object moves from the detection area into the detection area for track intrusion.

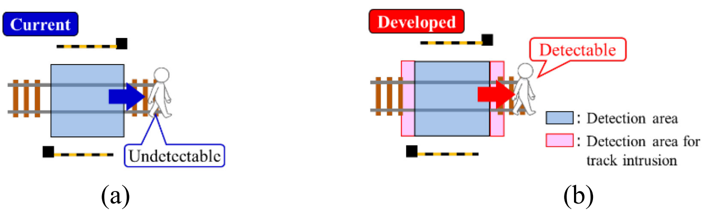


Figure 7: Detection of an object entering the track area from a level crossing. (a) Current; and (b) Developed.

2. In order to detect pedestrians for Case 3 (Stopping in front of the crossing bar), we set up a “detection area in front of crossing bar” (refer to Fig. 8). When an object moves from the detection area into this area, and it stays for more than the threshold time (5 seconds) during the warning of the level crossing, the function judges that it has stopped in front of the crossing bar. The reason why the behavior history is used for this judgment is to prevent false detection of some object such as reflectors of the crossing bar, and to exclude objects that exist in the area in front of crossing bar from the beginning.

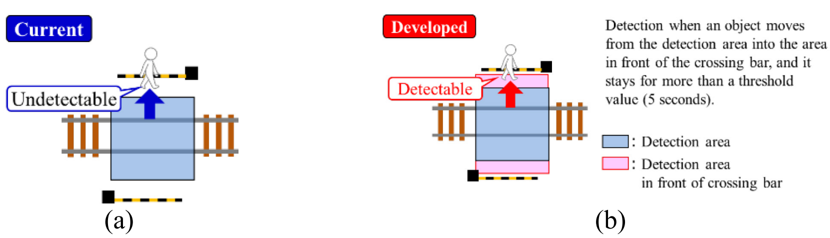


Figure 8: Detection of an object stopping in front of the crossing bar. (a) Current; and (b) Developed.

However, with regard to "Case 2 Detection of an object entering the railroad tracks from a level crossing", we wish to exclude the cases in which maintenance workers and vehicles enter the track area. But it is difficult to distinguish between them and other objects. In addition, the area that can be detected by a 3DLR is only in the vicinity of the level crossing, and it is difficult to continue tracking objects that have entered beyond the detection area. Therefore, it is necessary to keep issuing the "entering the railroad tracks" judgment for safety when an object is detected in the direction of the tracks. However, it is not possible to distinguish whether an object entering the railroad tracks continues to stay on the track or whether it has gone out of the tracks, so the judgment is continued. Therefore, it was decided to exclude Case 2 from this additional function.

4.4 Flow of detection and processing

Fig. 9 shows the software structure reinforced with the developed functions mentioned in 4.1 to 4.3. The height from the ground surface is corrected by "map of ground surface" as pretreatment. As a result, a pedestrian who has fallen down in the recesses can be detected in the later object detection process. In the object detection process, we added the "detection of falling down objects" function so that it can detect falling down objects continuously, and improved the current "object detection" and "object tracking" functions. In the last stage, we added a behavior judgment process (including "inter-area movement judgement" and "obstacle detection process for behavior judgement" processes) in parallel with the current obstacle detection process, and it has become able to detect of an object stopping in front of the crossing bar.

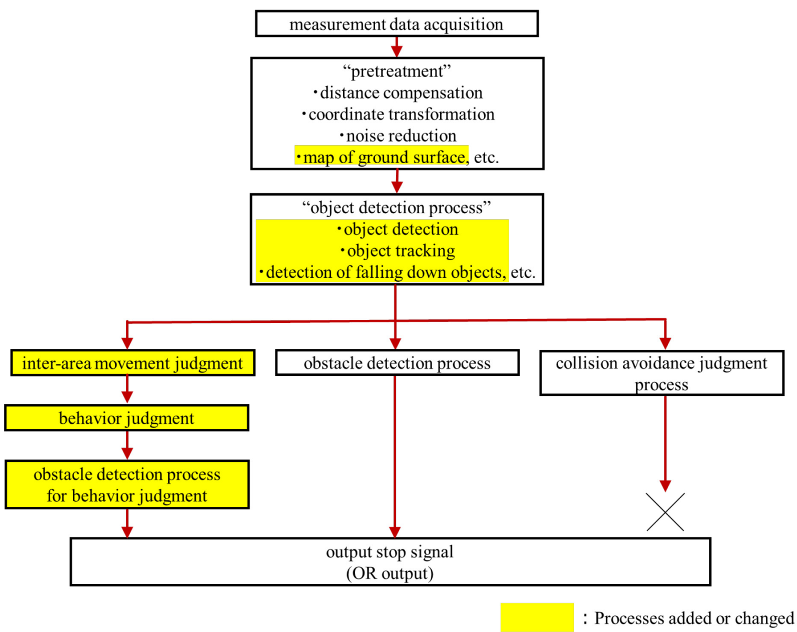


Figure 9: Software structure of 3DLR with developed functions.

5 FIELD TESTING AND EVALUATION

After confirming the operation of the additional functions mentioned in Section 4 in the factory, we conducted a field test at the Kuji level crossing next to Kuji station on the Nambu line in the Tokyo metropolitan area from March 2018 to February 2020. As shown in Fig. 10, this crossing is very busy with 6,000 pedestrians a day. As a result, even current obstacle detection device activates stop signals about 10 times a day, which affects normal railway operation.

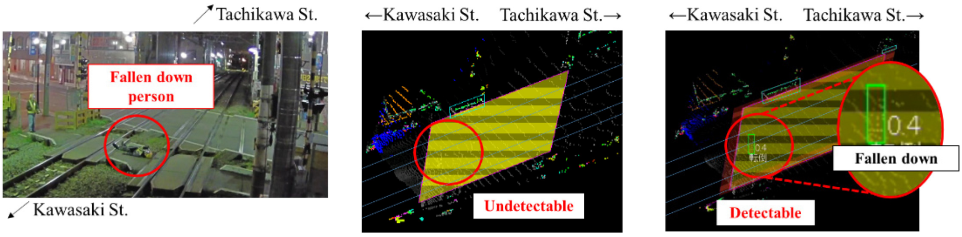
Figure 10: Kuji level crossing at the rush hour.

5.1 Results of the falling down object detection function

The results of the number of obstructions detected in the one-week field test are shown in Table 2. Obstacle detection device activates stop signal to approaching train if an object stays in the detection area for more than 5 seconds. We defined correct detections as the total number of obstacle detection that stay in the detection area for more than 5 seconds by checking the camera image visually. The number of correct detections and false detections increased when the falling down object detection function was enabled compared to the current function. This is because the lower threshold of the height of the detection area has been changed from 50 cm into 15 cm, thus spreading the detection area. This is especially true in a level crossing with many pedestrians, such as at the Kuji level crossing, where the detection time of multiple people as a single detection group increases, resulting in an increase in false detection. Fig. 11 shows an example of the test to compare the ability to detect a falling down object. Fig. 11(b) shows the detection screen of the current function and (c) shows the detection screen of developed function.

Table 2: Field test detection results.

No.	Effective function	Total number of detections	Correct detections	False detections
1	Current function	68	6	62
2	Current function ＋ Falling down object detection function	79	7	72

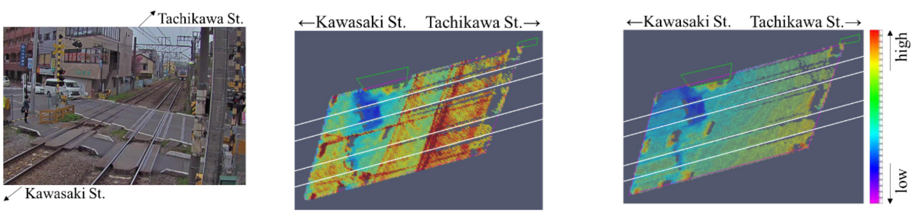


(a) (b) (c)

Figure 11: Falling down object detection status. (a) Camera image of a level crossing; (b) Detection screen-Plane view (current); and (c) detection screen-Plane view (developed).

5.2 Map of ground surface of the level crossing

In order to get the correct value of the height, the height data of each area for a certain period were aggregated, and then discrete data by vehicles, pedestrians, etc. were removed from those data. In Fig. 12(b), the height of the ground surface was corrected higher than the actual height due to vehicles and pedestrians. Fig. 13 shows the histogram of the measured height at this case. This shows the discrete data of vehicles and pedestrians apart from the data of the surface. On the other hand, in Fig. 12(c), by removing these discrete data as noise, it is confirmed a map of ground surface of the level crossing is produced correctly.



(a) (b) (c)

Figure 12: Map of ground surface of the level crossing (a) Capture of a level crossing; (b) Height map (w/o noise reduction); and (c) Height map (with noise reduction).

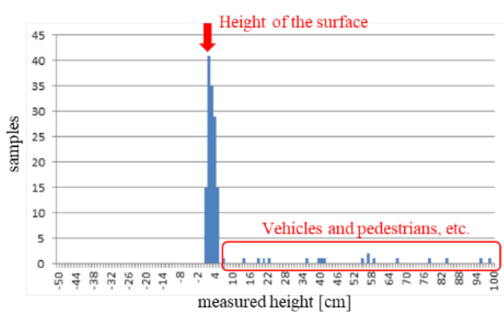
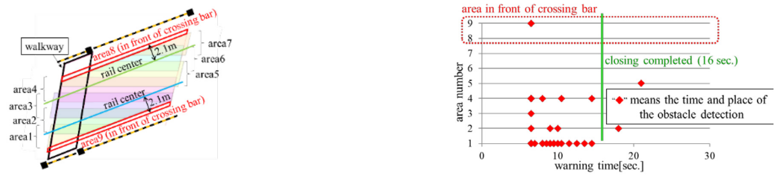


Figure 13: Histogram of measured height.



(a) (b)

Figure 14: Detection timing by area. (a) Detection area; and (b) Time and area of detection obstacle.

5.3 Obstacle detection process for behavior judgment

For Case 3(detection of an object stopped in front of the crossing), during the field test, the obstacle detection device sometimes misidentified that a detected object separated into two at the boundary between the detection area and the area in front of the crossing bar, and the timer of counting staying time was reset. This may be due to the unsuccessful handling of the object in the detection area and the area in front of the crossing bar, and further verification is required. Fig. 14 shows an example graph of the detection area and the time after level crossing start warning. This graph shows that there are no examples of pedestrians being detected in the area in front of the crossing bar (area 8 and 9) before and after the crossing bar is closed. Therefore, this function was found to be less effective in detecting pedestrians.

5.4 Evaluation

A field test was conducted at Kuji level crossing as described in Sections 5.1 to 5.3. It was confirmed that the falling down object detection function and the map of ground surface of the level crossing worked correctly, although the number of false detections slightly increased. We decided to adopt this function for operational use. On the other hand, it was found that obstacle detection process for behavior judgment of pedestrians stopping in front of crossing bar was not successful in taking over objects between the detection area and the area in front of crossing bar. In addition, there are few cases of detecting people staying in front of the crossing bar. For those two reasons, we have decided not to adopt this function for operational use.

6 CONCLUSION

In this study, we developed a new function of a 3DLR type obstacle detection system to improve the detection function of pedestrians at the level crossing. Three types of pedestrian action patterns that lead to level crossing accidents were extracted and countermeasure functions were examined. As a result, it was decided to implement two functions. One is to detect falling down objects by detection height being lowered only around the object. The other is to correct lower threshold height along with the shape of the ground surface by a map of the height corresponding to the ground surface of the level crossing. Regarding, the countermeasure against to entering in the direction of the track shown in Case 2, we decided not to implement this function due to difficulty of distinguishing maintenance activities. As for Case 3, we decided not to implement this function, either, due to less effectiveness of implementation.

Through the field test at Kuji level crossing, we confirmed that the falling down object detection function and the map of ground surface of the level crossing worked well and decided these functions to be put into practical use.

Based on the above results, JR-East plans to install these two functions to the existing 3DLR obstacle detection system for operational use from 2020.

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