3-D Laser Radar Level Crossing Obstacle Detection System

HISAMITSU Yutaka : Senior Engineer, Electrical System Department, Products Development Center, Corporate Research & Development
SEKIMOTO Kiyohide : Senior Engineer, Development Department, Infrastructure Division, Logistics Systems & Structures
NAGATA Kouichirou : Development Department, Infrastructure Division, Logistics Systems & Structures
UEHARA Minoru : Manager, Products Development Department, New Products Incubation Center, Corporate Research & Development
OTA Eiichi : Tokyo Electrical Construction and System Integration Office, East Japan Railway Company

Level crossing obstacle detection systems have been developed to prevent a train colliding with an object such as a vehicle stuck on the crossing. Increasing safety consciousness, however, has prompted railway companies to install more advanced systems than those that have been used conventionally. To cope with the demand for new devices, IHI developed a 3-D laser radar level crossing obstacle detection system which is not influenced by weather conditions or sunshine conditions, and which can accurately detect objects within the area of the level crossing in real time. Reliable detection can be achieved by installing just a single monitor that can cover the whole area of the crossing, thus surpassing the conventional system in sensing the obstacles in the crossing.

1. Introduction

To automate the operations of transport and working machinery, we conducted development activities to realize a sensing system capable of recognizing 3-D objects by applying laser radar technology. [1] We then applied the 3-D object recognition technology developed this way to the area of ITS (Intelligent Transport Systems) traffic control and safety in order to detect and measure moving vehicles (cars, trucks, etc.). By conducting vehicle detection experiments on test courses and actual environment experiments, we established the technology for detecting mobile objects and identifying vehicles based on the 3-D laser radar technology. [2]

To prevent accidents from occurring at level crossings, level crossing obstacle detection systems are installed mainly at the crossings where there is a large volume of traffic. The level crossing obstacle detection system detects an obstacle, such as a car stranded inside a crossing and notifies a train crew of the presence of an obstacle when a train approaches that crossing. As detection methods, the laser beam crossing type and the loop coil type have generally been used. These detection methods, however, have drawbacks : a limited detection range, complicated installation and maintenance work, etc. Given this background, the need for a more improved or advanced level crossing obstacle detection system has been increasing. [3]

The 3-D laser radar technology developed by IHI was considered a promising technology that might be able to fulfill this need. Based on this technology, we developed a level crossing obstacle detection system, improved it to make it fit for practical use, and conducted joint research activities [4], [5] with the East Japan Railway Company. As a result, we developed a 3-D laser radar level crossing obstacle detection system (hereinafter called this system) and made it practical. This paper describes the outline of this system, information on the system technology, and results of measurement carried out by this system.

2. 3-D laser radar level crossing obstacle detection system

Table 1 shows main specifications of this system, and **Fig. 1** shows the appearance.

2.1 Principles of measurement

A 3-D laser radar 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. **Figure 2** shows the principles of measurement of this 3-D laser radar.

Figure 3 shows the object detection method used by the 3-D laser radar. A laser pulse is emitted in a way that scans the entire area of a level crossing in the horizontal and vertical directions, and 3-D coordinate

Table 1 Specifications of 3-D laser radar level crossing obstacle detection system

Item		Unit	Specification
Detection object	Dimensions	m	Obstacle whose dimensions are 1.0 (W) × 1.0 (H) × 1.0 (D) or larger
Detection range	Horizontal angle of view	Degree	60
	Vertical angle of view	Degree	30
	Distance	m	5 to 30
Detection time		s	0.5 or less
Accuracy of position detection		m	± 0.1
Laser radar head	Dimensions	mm	570 (W) × 336 (H) × 300 (D)
	Weight	kg	17
Controller	Dimensions	mm	500 (W) × 350 (H) × 350 (D)
	Weight	kg	24

Fig. 1 Appearance of 3-D laser radar level crossing obstacle detection system

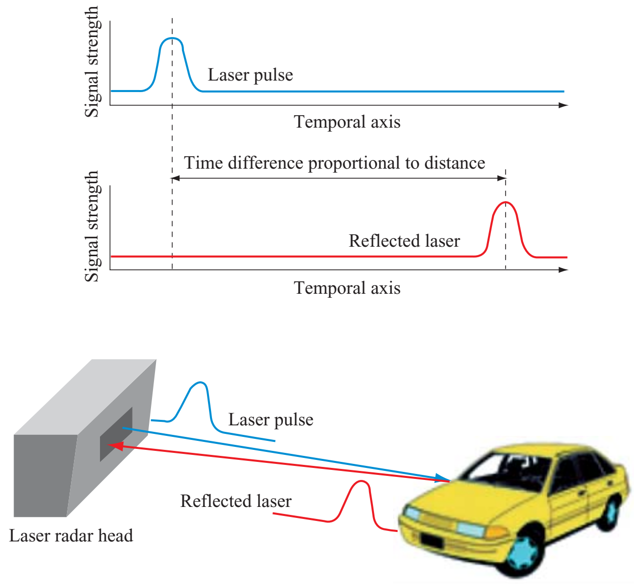

Fig. 2 Measurement principle of 3-D laser radar

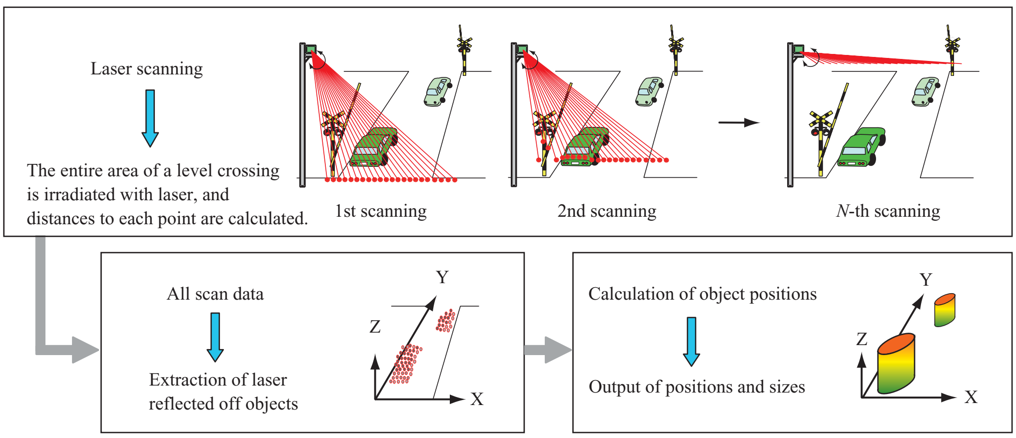

Fig. 3 Object detection method

values of each point are measured based on the laser reflected and returning to the 3-D laser radar. 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 of points." 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.

2.2 System configuration

This system consists of a laser radar head and controller, as shown in **Fig. 4**. The laser radar head processes laser pulses (laser diode) through polygon and swing mirrors to make the laser pulse scan the entire area of a crossing in horizontal and vertical directions twice every second. The laser reflected off objects is guided through high-speed, high-sensitivity photo diodes, and converted to electrical signals. The time interval counter measures a distance to an object based on the time interval between the trigger signal for emitting a laser pulse and the output of a laser receiving signal generated by a photo diode. The signal processing board controls the motion of polygon and swing mirrors, and measures the 3-D space data in which the origin is the position of the laser radar head, based on the time interval (distance) when the reflected laser has been detected, the rotation angle of a polygon mirror, and the angle of a swing mirror. These data are sent to the detection data processing section in the controller. In the detection data processing section, an object recognition process is executed, and whether a recognized object is an obstacle or not is instantaneously judged based on crossing alarm conditions and other judgment conditions. If a recognized object is judged an obstacle, an alarm is generated.

In this system, the hardware that executes detection processing tasks is made duplex; detection tasks are performed by two sets of hardware, and the result of a detection task performed by one set of hardware is collated with that performed by the other set of hardware in order to prevent a detection error or false judgment that may occur in the event of system abnormality or failure-a failsafe function. Furthermore, this system is provided with a fault diagnosis function of monitoring a change in the system conditions, including the occurrence of abnormality or malfunction,

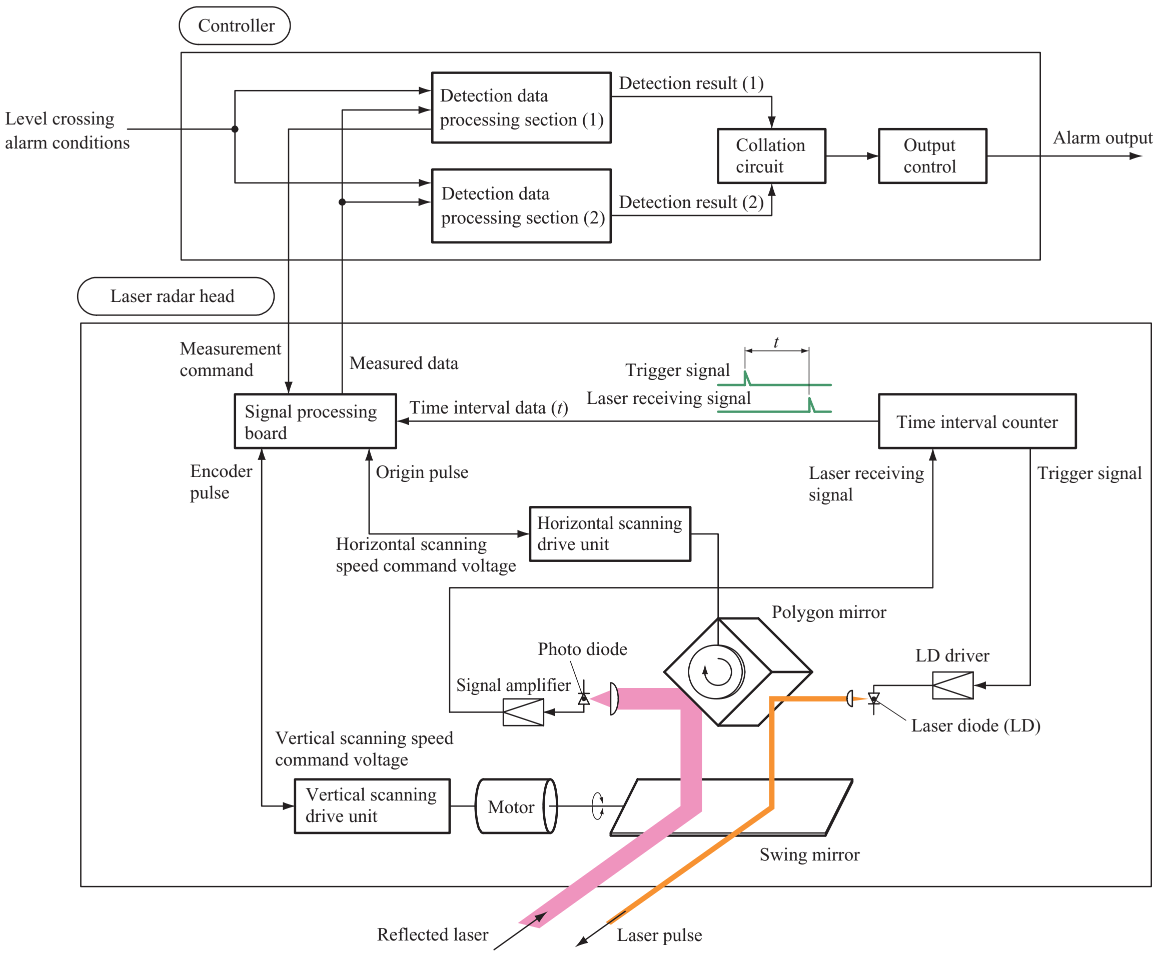

Fig. 4 Configuration of 3-D laser radar level crossing obstacle detection system

blocking of laser, postural change of the laser radar head, etc.

2.3 Features

Since conventional level crossing obstacle detection systems are designed with the laser beam crossing type, pairs of light receiving and emitting devices must be installed on both sides of a railroad track. If there are turnout switches or station platforms close to a crossing, there are cases where a level crossing obstacle detection system cannot be installed. For a level crossing obstacle detection system designed with the loop coil type, large-scale installation work must be done since detecting coils must be laid underground along the railroad track inside a crossing.

Features of this system are that the laser radar head is installed on a special concrete pillar erected outside a railroad track and that the entire area of a crossing (up to 20 m long and 10 m wide) can be monitored by a single piece of equipment. This makes the layout design and installation work much easier compared with conventional level crossing obstacle detection systems and, therefore, makes considerable space-saving and shortening of the work period possible. Level crossing obstacle detection systems designed with the laser beam crossing type are accompanied by various problems, including tampering with light receiving or emitting devices by passers-by, displacements of optical axes, fouling of light receiving or emitting devices as trains pass during rainfall, and so forth. Since this system is installed at a height of 4 m or higher from the road surface, it is free of these problems. In the case of a level crossing obstacle detection system designed with the loop coil type, maintenance work must be done with considerable toil if detection coils are broken. A great advantage of this system is that no breaking of wires occurs and maintenance work is easy.

3. Meeting the requirements for outdoor equipment

As a piece of outdoor equipment installed alongside a railroad track, a level crossing obstacle detection system is not permitted to stop functioning under any weather conditions as long as trains are in operation. This chapter describes the results of verifications carried out about whether this system meets the particularly rigorous performance requirements that outdoor equipment must meet, i.e., requirements for vibration and lightning protection properties, as well as the technologies used to adapt this system to various weather conditions.

3.1 Vibration resistance

To make the laser radar head resistant to vibration, a vibration analysis was performed on the support structures of components used in this system, appropriate vibration-resistance techniques were identified based on the results of this analysis, and components and structures were designed by applying the techniques. The components and structures designed this way were tested based on JIS E 3014 “Parts for railway signal-Vibration test methods.” The laser radar head and controller were set on a vibration table and secured in position. By operating the laser radar head and controller, a resonance test/vibration functional test and vibration proof test were conducted. After a maximum vibration level of 2.8 G (duplex amplitude, about twice as large as a vibration value specified by JIS) was applied for 38 minutes, 3-D distance measurements were made, and it was verified that the laser radar head and controller function normally and deliver the specified measurement performance.

3.2 Lightning protection properties

To verify the effects of lighting damage caused by an indirect lightning strike or the effects of an electrical surge caused by a trolley wire current in an AC electrified section, an impulse voltage test and impulse current test were conducted. In conducting these tests, a test circuit shown in **Fig. 5** was used, and a lightning damage protector and lighting protection transformer were connected to a power supply line of this system.

An impulse voltage (voltage waveform 1.2/50 μs, peak value 1 to 30 kV) was applied to a power supply line in common mode when a measurement operation is ongoing, and the effects of the impulse voltage on components in this system were examined. At a maximum peak value of 30 kV that is equivalent to a voltage withstand value of components used in level crossing signal equipment, it was verified that the impulse voltage is discharged via a protective device to a ground point so that this system functions normally without being affected by the impulse voltage.

In the impulse current test, induction wires were wound on the laser radar head and controller during a measurement operation, and an impulse current (current waveform 8/20 μs, peak value 10 kA) was applied. The number of wire turns (1 to 9 turns) was changed to change this impulse current value. An impulse current of 40 kA was applied to the laser radar head, and a maximum current rating 90 kA specified for testing equipment was applied to the controller. It was verified that the laser radar head and controller function normally when each current is applied. It was demonstrated from the test results that this system functions normally without being affected by a lightning current (10 to 20 kA) occurring if lightning strikes near a crossing or by an electrical surge equivalent to a trolley wire current (2 kA) in an AC electrified section.

3.3 Environmental resistance

3.3.1 Temperature resistance

A heat transfer analysis was performed to evaluate the conditions of the laser radar head that operates in midsummer sunlight. Based on the results of this analysis, a three-ply structure housing was adopted for the laser radar head to inhibit a rise in its internal

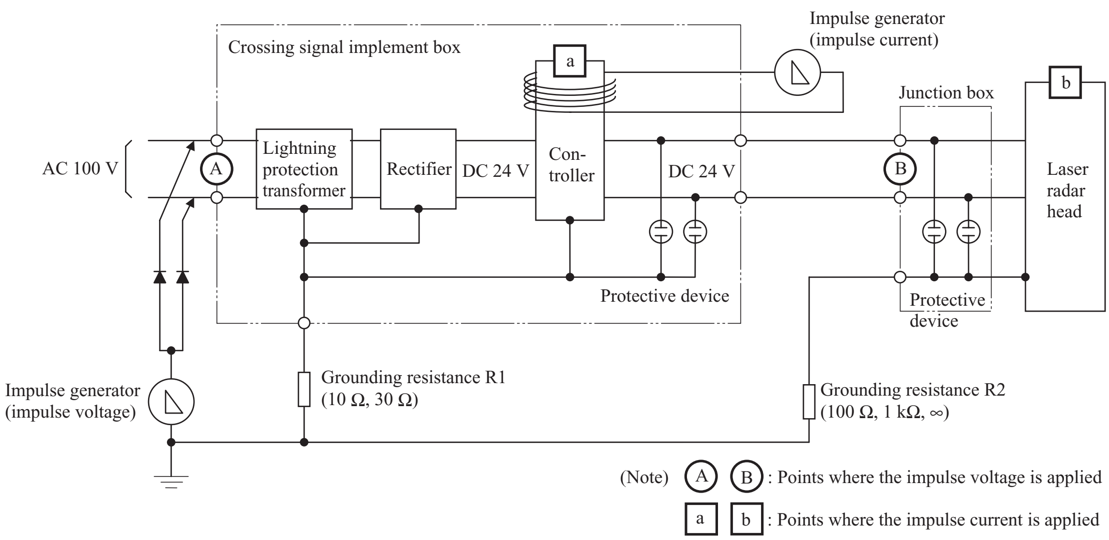

Fig. 5 Circuit of electromagnetic impulse testing

temperature. In addition, temperature distributions inside and outside this system at temperatures below the freezing point were evaluated, and the results were reflected in the capacity and layout design of a heater for heating the laser radar head window and moving parts inside the head. High- and low-temperature tests (at 60˚C and -20˚C) were conducted based on JIS E 3019 “High and low temperature testing methods for parts of railway signaling,” and thermal shock tests were conducted based on JIS E 3020 “Change of temperature testing method for parts of railway signaling.” It was demonstrated from the results of these tests that the performance of high temperature resistance of this system as a facility installed outdoors is high and satisfactory.

3.3.2 Snow and wind resistance

Housings were designed, including the shape of the roof for the laser radar head, to prevent the laser radar head window from being blocked by snow cornices or ice pillars and the functions of this system from being affected by snowfall. Outdoor tests were conducted in a snowy area to optimize the shape of the roof. To check the effects of wind pressure generated by typhoons or strong winds, fluid and structural analyses of the laser radar head were conducted. The results of analyses were reflected in the strength design of the laser radar head.

3.3.3 Others

To verify that this system performs given functions normally and flawlessly without being affected by a change in environmental conditions, including weather, sunshine, earthquake, etc., this system was installed inside the premises of our factory, and performance tests were conducted for a period of more than two years.

4. Case of measurement of level crossing obstacle

This system detects an object inside a crossing, tracks it as it moves, compares acquired data with predefined detection conditions (area to be monitored, crossing alarm conditions, obstacle detection conditions, etc.), recognizes an object stranded inside a crossing as an obstacle, and generates an alarm. **Figure 6** shows this

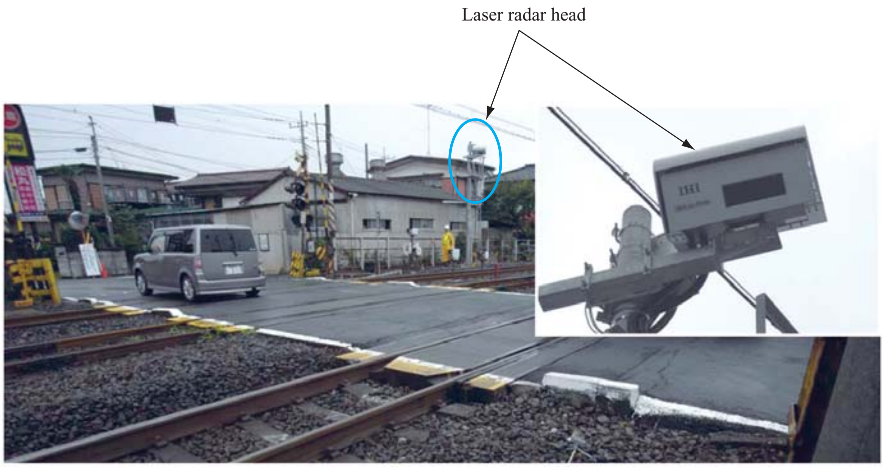

Fig. 6 Installation of 3-D laser radar level crossing obstacle detection system

system installed at a certain crossing which is 11.8 m long and 7.4 m wide, and has three railroad tracks.

Figure 7 shows how the data measured at this crossing is visualized. In **Fig. 7-(a)**, reflected laser light is presented in gray scales varying depending on the intensity of light reflected off an object. An object having high reflection intensity (an object located at a shorter distance) is shown white in color. In **Fig. 7-(b)**, distances from the laser radar head to objects measured are shown in different colors. An object located at a shorter distance is shown blue in color, while the one located at a farther distance is shown red. **Figure 7-(c)** shows an overhead image obtained based on distance and angle data (a crossing viewed at a position right above it) to coordinate conversion. Objects are shown in different colors, depending on the heights of each object. In **Fig. 7-(c)**, results of measurement taken when a car passes inside this crossing are shown; a part enclosed by a red quadrangle at the center is a car. If a car remains inside a crossing after a crossing gate starts to go down, the car is recognized as an obstacle and an alarm is immediately generated. Although this data was acquired during the daytime, this system is not affected by the presence or absence of sunshine and it does not require lighting equipment in the nighttime-a great advantage that conventional imaging systems using cameras cannot offer. This system allows correct measurement to be made during both the daytime and nighttime.

Furthermore, a maintenance operation terminal (notebook PC) can be connected to this system to input individual detection parameters, i.e., the shape of a crossing (length, width, road surface height, number of railroad tracks, etc.), and crossing alarm and obstacle detection conditions specified by each railroad company. Therefore, this system can be flexibly used with various different types of crossings.

5. Summary

A 3-D laser radar level crossing obstacle detection system (this system) for detecting an obstacle stranded inside a crossing, such as a car, and outputting an alarm was developed based on the 3-D laser radar technology and made practical. In December 2005, the first unit of this system was installed at the Nanbu-line Eidanmae level crossing (between Inadazutumi and Yanokuchi station) of East Japan Railway Company. This system has since been installed at many locations, and is now in operation at more than 200 crossings in Japan.

As a means of safety enhancement at crossings, we would like to further promote the introduction of this system to crossings and also expand the scope of application of the 3-D laser radar technology to uses other than the detection of obstacles at crossings, namely, the detection of vehicles in the area of road traffic, monitoring of suspicious objects in the area of security, etc. We believe that the technology used to make this system practical will be used as a fundamental technology and contribute to safety enhancement and security of society.

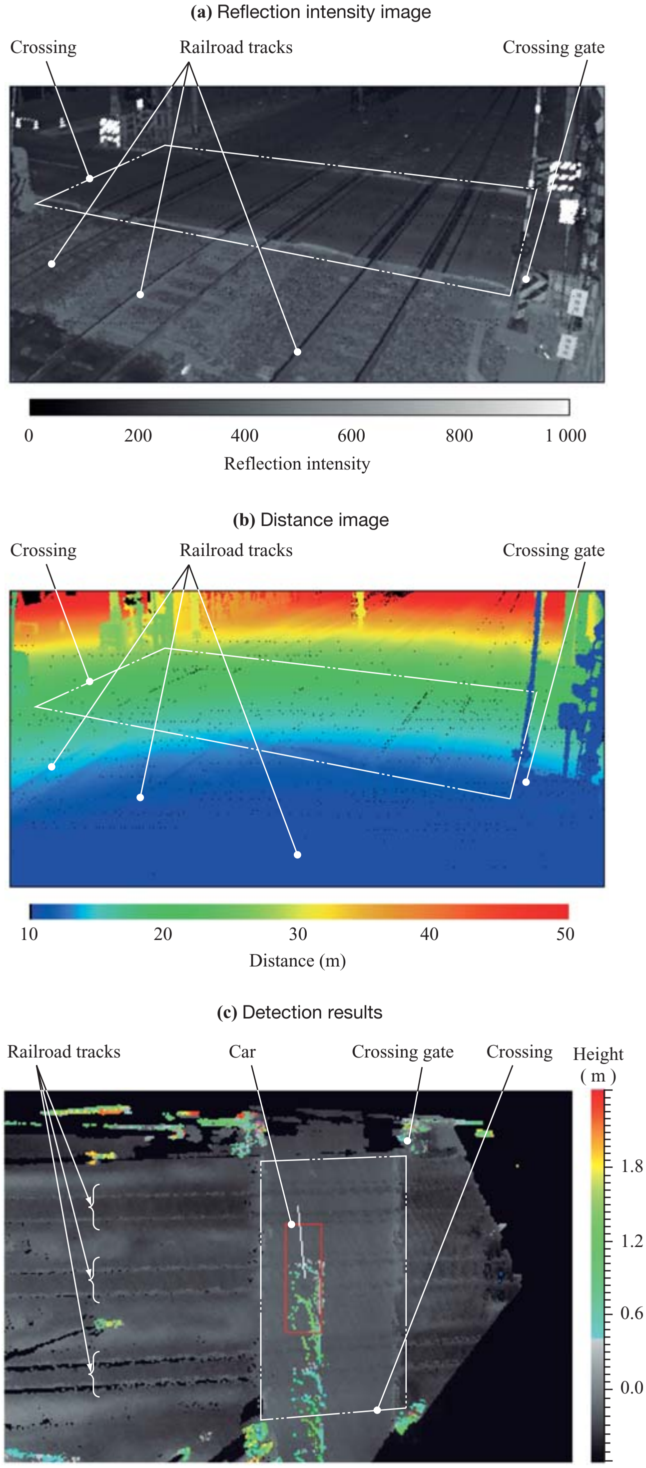

Fig. 7 Measurement results

— Acknowledgments —

In the process of making this system practical, we had a lot of cooperation and guidance from people and organizations concerned. We would here like to express our sincere appreciation to them.

REFERENCES

(1) K. Sekimoto, Y. Hisamitsu and M. Ishii : Laser-Based Shape Recognition System, Electronic Engineering Vol.40 No.1 (1998. 1) pp. 9 - 12

(2) K. Sekimoto, N. Kamagami, Y. Hisamitsu, K. Ono and K. Nagata : Development of 3D Laser Radar for Traffic Monitoring, Ishikawajima-Harima Engineering Review Vol.43 No.4 (2003. 7) pp. 114 - 117

(3) Y. Nakajima : Development and Implementation of Newest Detection System (Stereo Camera Type Falling Object Detection System and 3-D Laser Radar Level Crossing Obstacle Detection System) Signal Seminar, Text of 2006 (2006. 10)

(4) E. Ota, N. Yamaguchi, K. Sekimoto and K. Okajima : Verification of the Ability for Obstacle detection with a 3-D Laser Radar, The Institute of Electrical Engineers of Japan, Document of “Data from Traffic and Electric Train Seminar” TER-05-25 (2005. 5)

(5) E. Ota : Development Of 3-D Laser Radar Level Crossing Obstacle Detection System, Railway & Electrical Engineering Vol.17 No.7 (2006. 7) pp. 29 - 32