Development of an Alarm Device for Wrong Mounting of a Road-Rail Vehicle

Road-rail vehicles are operated with procedures taken to close tracks to normal train traffic, and safety with them relies on human attention. Unlike maintenance vehicles, road-rail vehicles do not have a rail shunting device. On the other hand, GPS technology has improved over time for greater accuracy and is expected to further improve in the future. We have thus developed an alarm device for wrong mounting of a road-rail vehicle that combines railway GIS (Geographic Information Systems) with the positioning function of D-GPS (differential GPS) that can be used at a low cost and good accuracy. The device activates an alarm if a road-rail vehicle is mounted on the wrong line or intrudes into a not-closed section. This alarm device is designed to crosscheck the vehicle location with closed track information gained from the ATOS server. We thus believe it will contribute to improving safety.

Keywords: Road-rail vehicle, D-GPS, Railway GIS, Inbound-outbound line judgment, Railway track closing

1 Introduction

In railway maintenance work, use of road-rail vehicles has been increasing in addition to use of maintenance vehicles that run only on rails (Fig. 1).

When using a road-rail vehicle, we conduct procedures for track closing. However, if the road-rail vehicle is mounted on the wrong inbound/outbound line or intrudes into a not-closed section due to omissions or misunderstanding by the person in charge, there is risk of a train entering the section occupied by the road-rail vehicle.

Fig. 1 Road-Rail Vehicle (left) and Maintenance Vehicle (right)

To overcome that risk, East Japan Railway Company (JR East) operates large maintenance vehicles that shunt track circuits to activate stop signal aspects on signals for protection in some line sections. But road-rail vehicles cannot be equipped with a rail clamp shunt device due to limitations in space and weight. We have thus developed an alarm device for wrong mounting of a road-rail vehicle (hereinafter “alarm device”) that warns the road-rail vehicle operator and the person in charge of track closing at handling errors such as when the road-rail vehicle is mounted on the wrong track or it exits from the closed track. This article will report on development of the alarm device.

2 Overview of Road-Rail Vehicles and Work

Road-rail vehicles have unique operation and structures. There are many types of road-rail vehicles that are specialized according to the work on track that they perform, and they are each outfitted differently. Considerations need to be made for protection of underfloor equipment when running on roads. Because they also run on roads, they need to be equipped with smaller and lighter onboard devices.

Points at which road-rail vehicles can mount the rails from the road are limited. Specifically, those locations include roads for construction work, maintenance vehicle depots and wide level crossings with light traffic (Fig. 2).

Fig. 2 Locations Where Road-Rail Vehicles Mount Tracks

3 Basic Functions Required for the Alarm Device

In development of alarm device, we made the following to be base functions, taking into account the operational and structural characteristics of road-rail vehicles. We also eliminated the need for installing any devices on the track or at the wayside.

(a) Detecting vehicle's position and converting it into kilometerage
(b) Obtaining information that track closing has started for the section occupied by the vehicle
(c) Activating alarm if the section occupied by the vehicle is not closed
(d) Indicating the current position (in kilometerage) and closed track sections for providing useful information as well as for the alarm function in case of wrong handling

3.1 Conditions Taken into Account for Equipping to Road-Rail Vehicles

To equip road-rail vehicles with the alarm device with those basic functions, we further considered the following conditions.
(a) No linkage to braking so as to prevent road-rail vehicles from being unable to move if GPS positioning becomes unavailable
(b) Avoiding vehicle modification as much as possible
(c) Downsizing to allow a variety of vehicle types to be equipped with the alarm device
(d) Operating only on the track: As a condition for running on the track, the PTO (Power Take Off) signal which a road-rail vehicle is input with while running on the track must be imported.
(e) Activation of the alarm after mounting the vehicle on the rail and before starting to move: When mounting a road-rail vehicle on the rail, track closing procedures are taken to also protect adjacent lines, so immediate judgment of which track the vehicle is on is not required. Taking mounting work into consideration, we initially set the judgment time at 120 seconds.

3.2 Setting Target Accuracy
To detect handling errors, we set positioning accuracy targets longitudinal and lateral to the track for the two jobs of mounting a road-rail vehicle on the rail (judgment of wrong mounting to line while mounting) and running a road-rail vehicle (judgment of intrusion into a section that is not closed) (Fig. 3).

(a) Accuracy needed for inbound/outbound line judgment
The interval between adjacent lines is usually 3.8 m or larger. To identify the line, positioning accuracy of at 2 m or less, approx. a half of the interval, is needed. We thus set this value as the target in the direction at right angle to the track.
(b) Accuracy needed for judgment of exit from a closed section
The section to be closed is set up with a slight margin added to the work area. We determined a margin of 30 m based on the situation in the area controlled by ATOS (Autonomous decentralized Transport Operation control System) and made that the target in the direction longitudinal to the track.

The initial target values may change during development, so we developed with the ability to change the setting.

4 Development of the Alarm Device
We developed the alarm device based on the aforementioned conditions.

4.1 System Configuration of the Alarm Device
To shorten the development period, we adopted existing hardware for the alarm device (Fig. 4). In the test system, obtaining PTO signals and track closing information was simulated.

30 m accuracy
Longitudinal to track
Track discrimination 2 m accuracy
Direction longitudinal to track 30 m accuracy
Judgment of intrusion into a non-closed section
Judgment of incorrect mounting
Fig. 3 Target Setting Accuracy

(a) Accuracy needed for inbound/outbound line judgment
The interval between adjacent lines is usually 3.8 m or larger. To identify the line, positioning accuracy of at 2 m or less, approx. a half of the interval, is needed. We thus set this value as the target in the direction at right angle to the track.
(b) Accuracy needed for judgment of exit from a closed section
The section to be closed is set up with a slight margin added to the work area. We determined a margin of 30 m based on the situation in the area controlled by ATOS (Autonomous decentralized Transport Operation control System) and made that the target in the direction longitudinal to the track.

The initial target values may change during development, so we developed with the ability to change the setting.

4.2 Programming for the Alarm Device
4.2.1 Overview of D-GPS
We examined use of RFID that is widely used in the distribution industry and ATS beacons installed on the track as methods of identifying the location of the road-rail vehicle. However, those had issues such as how to install onboard sensors and maintenance of wayside equipment.

D-GPS (Differential GPS) is a method to improve accuracy of GPS that has been increasingly used in the past few years. Among six GPS error factors already known (Table 1), four error factors cause similar behaviors with nearby receivers. D-GPS achieves better positioning accuracy than independent positioning by adjusting error at the GPS receiver based on error at reference stations with known locations (Fig. 5).

D-GPS receivers are of a size that allows them to be equipped to road-rail vehicles and do not require installation of equipment other than a D-GPS receiver. They also have an advantage in that correction information can be acquired free of charge.

Table 1 GPS Error Factors and Generally Recognized Accuracy

<table>
<thead>
<tr>
<th>No</th>
<th>Error factor</th>
<th>1σ(m) of distance measurement error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Effect on independent positioning</td>
</tr>
<tr>
<td>1</td>
<td>Orbital information</td>
<td>2.1m</td>
</tr>
<tr>
<td>2</td>
<td>Satellite clock</td>
<td>2.1m</td>
</tr>
<tr>
<td>3</td>
<td>Ionospheric transmission error</td>
<td>4.0m</td>
</tr>
<tr>
<td>4</td>
<td>Tropospheric transmission error</td>
<td>0.7m</td>
</tr>
<tr>
<td>5</td>
<td>Multipath</td>
<td>1.4m</td>
</tr>
<tr>
<td>6</td>
<td>Receiver performance</td>
<td>0.5m</td>
</tr>
</tbody>
</table>

UERE: User equivalent range error

Standard HDOP 2.0

Horizontal positioning error (2 dms)

4.2.2 Building Logic to Avoid Judgment Error

Individual D-GPS positioning data sometimes includes errors greater than the target of 2 m. As shown in Table 1, the accuracy of D-GPS is usually thought to be around 6–8 m even in good satellite placement. Thus, in this development, we studied how to eliminate from the positioning data values with a large error.

We believed we could find a correlation between GPS accuracy and the number of acquired satellites and DOP values (dilution of precision). So, we compared these to the measured offset distance from the true center of the track. But we could find no obvious correlation.

Then, we plotted measured D-GPS data of fixed point locations in a planar diagram and in time-series. Fig. 6 and Fig. 7 show examples of D-GPS positioning of 600 points in 10 minutes. Those examples show that GPS positioning data moved on a trajectory instead of in random movement.

In this example, there is a period of time with large error. When judging only by offset distance, GPS would judge in this period that the vehicle was on the inbound line even though it was actually on the outbound line. We adopted combination of judgment with root-mean-square values in this development as that can eliminate measurement values with large errors.

4.2.3 Calculation of Kilometerage Using Railway GIS and GPS Positioning

Data of railway GPS at every 20 m of kilometerage of main track is longitudinal and latitudinal data. Based on the longitude and latitude found by GPS, the system chooses the nearest two points as the benchmarks from the GIS database. By dropping perpendicularly from the positioning point to a straight line connecting two benchmarks, the kilometerage of the intersection is made to be the measured kilometerage, and the length of the perpendicular line is made to be the offset distance (Fig. 9).

4.2.4 Obtaining ATOS Closed Track Information and Crosschecking with Planned Work

The ATOS central unit has a function of managing track closing for maintenance work. In the central unit, the track closing schedule for the night's work is registered in advance, and actual start and finish time of track closing is recorded as the history when the respective procedures are taken.

The developed device retrieves the track closing information registered in the central unit per work number. Then it crosschecks the registered track closing information and the obtained information to judge 1) track closing is not yet started, 2) track closing has started or 3) track closing is finished.

5 In-Factory Test Overview and Results

We checked the developed logic by activating the alarm device on a plane simulating the tracks. The check was conducted on the roof of the factory where GPS reception environment was good. After the check, we evaluated the effect of shielding simulating structures and buildings near the tracks.

The judgment display for the alarm device 120 seconds after having the device mount the track is shown below (Fig. 10). The device alarm activated if it mounted the wrong line and did not activate if it mounted the correct line.
First, we conducted a test for correct procedures of track closing and operation of the road-rail vehicle (Fig. 14).

(a) Judgment at mounting the road-rail vehicle on the line

The track closing plan was input to the alarm device on the outbound line in advance. After arriving at the point with the device and turning the device on, we selected the track closing plan and waited. After setting the track closing conditions, we moved the road-rail vehicle from the waiting point to the mounting point, input the PTO signal, and then had the alarm device make judgment. The device indicated it was on the outbound line as planned.

(b) Moving within the closed track area

Then, we moved within the input closed track area. The alarm device displayed no alarm, and only the kilometerage changing along with movement.

(c) Dismounting and release of track closing

Finally, the road-rail vehicle moved to the dismounting point. We cancelled PTO signal input, moved the vehicle off the track from the crossing, and then deactivated the set track closing. The device did not activate the alarm when deactivating track closing.

Next, we checked the performance with shielding set (Fig. 12).

Positioning data deteriorated due to shielding, but the alarm device did not go into a situation of constant inability to judge where it would be useless. We thus decided to confirm the in-factory test results in field tests.

### Field Tests

In order to confirm that the device makes correct judgment as in the in-factory tests, we installed the alarm device to an actual road-rail vehicle and checked it on tracks for correct and incorrect handling.

We chose two test points open to the sky and one test point shielded on the Yamanote Line and Tohoku Line.

6.2 Judgment Results in Wrong Handling

Next, we conducted a test for incorrect track closing procedures and operation of the road-rail vehicle in the same order as in 6.1.

(a) Mounting the vehicle on the wrong line

Disregarding the plan for mounting the vehicle on the outbound line, we mounted the vehicle on the inbound line. The alarm device indicated incorrect mounting and activated the alarm.

(b) Intrusion into a not-closed section

After mounting the road-rail vehicle on the line, we moved the vehicle toward the end of the closed track area. Approaching the end, the device indicated it was 30 m to the end of the closed track area. Moving further, the device displayed a warning that it was out of the closed track area. When we moved the vehicle from out of the closed track area into the area, the warning turned off.

(c) Wrong release of track closing while working

When we deactivated track closing, the alarm device immediately activated an alarm.
6.3 Field Test Results

The field tests confirmed that the alarm device correctly judged what line the vehicle is mounted on and intrusion into a not-closed section. The closed track area and kilometerage were displayed, and kilometerage changed according to movement of the road-rail vehicle. This display can normally be used for navigation, and it immediately shows the reason when an alarm is activated.

While we fixed output time for inbound/outbound line judgment at 120 seconds in the in-factory tests, we changed the setting to output judgment results as soon as possible in the field tests for shorter judgment time.

7 Expansion of Line Judgment Logic to Station Yards

Tests confirmed that the alarm device can judge location of the road-rail vehicle and whether it is in the closed track area. If it can further recognize travel on crossovers (from outbound line to inbound line via crossover, etc.), the scope of application can be expanded to trace complex movement of larger maintenance vehicles in railyards. Using the logic utilized up to now and railway GIS, we verified logic to judge whether a road-rail vehicle moves from the inbound line to the outbound line and vice versa or it stays on the same line.

7.1 Advance Verification in Factory of Running on Crossover

When running on a crossover, the offset distance from the original line increases. When GPS positioning disturbance occurs, that distance increases too, so the increase of distance by running on a crossover and due to GPS disturbance must be distinguished.

On the assumption that the following three methods were best, we collected and verified data on behavior while travelling from one line to another.

(a) The alarm device compares GPS positioning data to the individual GIS data for running on the inbound line, a crossover and the outbound line.

(b) The alarm device can calculate the offset between the center of the track it is on and its own current position. Applying logic to avoid judgment error described in 4.2.2, the device compares the data of running on the line with that of travelling from one line to another using the root mean square of the offset distance from the original line.

(c) The alarm device measures the angle to the direction of vehicle travel, and that angle is used for judgment. Inbound and outbound lines usually are laid in parallel while crossovers connect inbound and outbound lines diagonally according to the size number of the turnout.

7.2 Field Tests of Running on a Crossover

We carried out the check of behaviors in running on a crossover in a good environment for data reception with little interference such as shielding (Fig. 15). With a GPS antenna placed at the center of a trolley, we collected data while moving. The height of the antenna above the rail surface was 1.5 m.

In the field tests, we measured data of running on a straight line and on a crossover 10 times each for three GPS models in two days. As disturbance in the GPS positioning environment is difficult to set on-site, we compared two examples from the positioning data: at satellite changeover while measuring data on the straight line and at running on a crossover.

7.3 Test Results of Running on a Crossover

A planar plot (Fig. 16) and time-series data (Fig. 17) are shown below for data of running on a straight line with the outbound line as the reference line.

During the measurement period, the GPS positioning accuracy was generally very good. The data of running on a straight line in Fig. 16 and Fig. 17 shows data in a case with satellite changeover during measuring as an example of relatively poor conditions for distinguishing running on a straight line from running on a crossover.

Root-mean-square values increased temporarily during measurement and then recovered. But we found no clear correlation to the offset from the reference outbound line and the angle of the road-rail vehicle to that line at that time.

Next, a planar plot (Fig. 18) and time-series data (Fig. 19) are shown below for data of running on a crossover with the outbound line as the reference line.

In Fig. 18, the edge of the tongue rail is indicated as a vertical line.
We have developed an alarm device that can be installed to road-rail vehicles and needs no wayside equipment. The device can judge correct/wrong line mounting when mounting on the line, calculate kilometerage while running on a main line and judge intrusion into a not-closed section.

The device identifies the line name, judges inbound/outbound lines and calculates kilometerage based on D-GPS positioning data and railway GIS data registered to the device. By adopting logic that eliminates measurement values including large errors, the device could make correct judgment on whether a road-rail vehicle was mounted on the correct line or a wrong line other than the planned line. The required time for judgment was less than 120 seconds. As the calculation of kilometerage followed the travel of the road-rail vehicle, the device could issue appropriate alarms for intrusion into a not-closed section based on crosscheck with track closing conditions. The calculated kilometerage can also be used to improve convenience in normal operations such as travel to the work site.

We further confirmed that the logic could be expanded to judgment of running on crossovers in travelling from/to adjacent lines. However, this function was not introduced to the alarm device this time.

We gained good results in the in-factory and field tests. In the future, we will conduct development for the following items not covered this time. We will also check effectiveness and operability in actual work.

(a) A method of effectively checking and correcting error in railway GIS data used for inbound/outbound line judgment
We will develop a method of verifying and correcting railway GIS data from the trajectory of the road-rail vehicle.

(b) Obtaining and crosschecking information on track closing
We will develop a server that obtains and crosschecks track closing conditions from the maintenance work management database of ATOS.

(c) Incorporating logic for judging running on crossovers
By incorporating the logic for running on crossovers described in 7, we will expand the judgment logic to use in the station yard.

Reference: