Development of a Platform Detection System Using Ultrasonic Sensor*

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Abstract
We have developed an on-car platform detection system using ultrasonic sensors. If a crew member tries to open the train doors when all or part of the train is not at a platform, this system could prevent passengers from falling from the train. But irregular reflection of the ultrasonic waves, due to the roughness of the slab of platform, caused unstable detection. Therefore, we have improved the system.

Key words: Platform Detection System, Ultrasonic Sensor

1. Introduction

If a train stops when part of the train is not alongside a station platform and train doors open, serious accidents could occur such as passengers falling to the track. To prevent such accidents, we developed the platform detection system that we are now using on the Keihin-Tohoku-line. In this paper, we will explain an outline of the platform detection system and its improvement after initial installation.

2. Development of the platform detection system

2.1 Concept of the system

To prevent accidents such as passengers falling to the track due to doors opening when the train is not alongside a platform, the platform detection system should have the following functions.

1) Function to check whether the train is stopping at the platform properly.
2) Function to ensure door locking at locations without a platform.
3) Warning for the crew if an attempt is made to open the doors in an unsafe location.

The first of these functions could be implemented by the following methods.

a) Detection of platform directly using sensors on the vehicle.
b) Detection of a marker located near the train stop target at each platform using sensor on the vehicle.
c) Check based on data from tracking the location of the train.

We introduced a direct platform detection method using ultrasonic sensors that would not require any equipment on the ground, only the sensors on the vehicle, and could be implemented simply compared with other methods.

The following is the action of the platform detection system. In this system, several ultrasonic sensors will be installed on both the right and the left sides at the ends of the first and last cars of the train set. When the train is stopping at the station, if the sensors at both the front and the rear of the train are located in front of the slab of the platform and receive ultrasonic waves reflected by the slab, the system will then permit the doors on each car to

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open on the same side as those sensors. If any sensor does not receive ultrasonic waves, the system will ensure locking every door on the same side as this sensor and prevent doors being opened, even if the conductor operates the door-open switch by mistake. Figure 1 and 2 illustrate the action and the configuration of the platform detection system.

2.2 Detection of platform using ultrasonic sensor

To detect a platform, the system would use ultrasonic sensors having functions both of transmission and receiving. When an object is present, the sensor will receive the reflected ultrasonic waves and measure the distance to the object based on the time from transmission to receiving of the ultrasonic waves. To prevent errors due to difference in temperature, the distance should be calculated based on the adjusted sonic speed determined by measuring the temperature with a built-in thermometer. Figure 3 illustrates the principle of distance calculation and Formula (1) shows the calculation formula.

These sensors, installed on both the right and the left sides at each end of the train, emit ultrasonic waves laterally toward the right and the left directions. If the train has stopped alongside the platform, each sensor will receive ultrasonic waves reflected by the slab of the platform, and the system will judge the presence of the platform and whether the train is stopping at the platform properly.

\[
L = (331.5 + 0.6t) \times \frac{T}{2}
\]

(1)

t : temperature (C)
T : receiving time of the reflected ultrasonic waves (s)

Fig. 3 Principle to measure distance using ultrasonic waves
We should consider the detectable area for each sensor, number of required sensors, and sensor installation position (the height and distance from side of car body). On each railway company, the limits of height of the platforms are standardized. Still, in each station, height of the platforms will vary somewhat. In the same way, the space between a car body and the slab of the platform would be required to be within specific limits. So the detection range and installation position of sensors should be designed suitably for making accurate detection possible. Our research showed that two sensors should be mounted in each location (both the right and the left sides of the front and rear ends of the train) to fit both higher and lower platforms.

Furthermore, the sensor should distinguish the reflection waves from the slab of the platform from waves reflected by other structures such as electrical poles. We have adjusted the detectable area in the horizontal direction within approx. 400mm. Figure 4, 5, 6 and 7 show installation of the sensors.

2.2 Interlock logic to prevent foul opening of doors

Some interlock logic must be put into the system to prevent doors being opened when the train is stopping at locations without a platform. For the purpose of this function, the detection signals from both the front and the rear sensors should be transferred to the control units installed in the control cabs at both ends of the train (Fig.8), so that both signals will be coupled by AND logic. When the output signal of the AND logic is FALSE, the control units will separate the conductor’s door-open switches on the side of the train where there is non-detection from the control circuits. In this situation doors will never be opened although the conductor may operate these switches. If the output signal is TRUE, these switches will be connected to the circuits (Fig.9).
2.4 Man-machine interface devices

Some devices will be installed to give the conductor warning if the door-opening control is operated when the train is not in a safe location for opening. One is an indication lamp and another is a warning buzzer installed near the conductor's door-open switch located at both the right and the left side in each cab (Fig. 10). When the train is stopping at a location without a platform, if the conductor operates the door-open switch by mistake, the indicator lamp will turn on in red, and the warning buzzer will sound for 5 seconds. Usually, with this system, it will make it possible to prevent doors from being opened by the conductor when in an unsafe location.

There is also a forced door-open button installed. If both the conductor's door-open switch and the forced door-open button are operated simultaneously, the system will make it possible to open all doors on this side, although some sensors on this side may not have detected a platform. When doors temporarily cannot be opened due to problems such as a detection error of the sensors or trouble in the control units even though the train stops correctly at the platform, the conductor can open the doors using the Force open button.

3. Implementation of sensors

3.1 Occurrence of unstable detection

In the trial use of the platform detection system on two series 209 train sets of the Keihin-Tohoku line from November 2004 to September 2005, ultrasonic waves reflected irregularly on dents and uneven side surfaces of the slab of platforms (Fig. 11), causing unstable detection at several stations. Specifically, the sensors sometimes would detect the platform and other times not, even when the train was stopped at the specified position. Figure 12 shows the image of unstable detection.

![Image of unstable detection](Image)

Ultrasonic waves are irregularly reflected on the dents and uneven side surface of the platform

Fig. 11 Irregular reflection of ultrasonic waves
3.2 Processing of the detection signal inside the sensor unit

The installed sensors repeatedly emit ultrasonic waves at an interval of 40ms and output detection signals to the control units when the reflected waves are received from a distance within the detectable area. But the signals turn on and off frequently due to noise and other factors, creating unstable output when sensors output detection signals simply according to the detection of the reflected waves. Hence, we made the sensors to judge that a platform is found and to output signals only when the sensors detect reflected waves within the detectable area six or more times out of the ten times ultrasonic waves are emitted just before judgment. Figure 13 illustrates the processing of the detection signal inside the sensor unit.

As described before, two ultrasonic sensors are installed in pairs on the right and the left sides, but they make judgment and output signals independently. The final judgment of the presence of a platform is made when either or both of the paired sensors judges that a platform is present.

3.3 Countermeasures against unstable detection

In order to prevent such unstable detection, we renovated the side surface of the platforms of the stations where unstable detection was observed (20 locations at 15 stations on the Keihin-Tohoku line, Fig.14 and 15).
3.4 Addition of an algorithm of the delay into signal processing

The previously mentioned actions were taken for unstable detection on the Keihin-Tohoku line, but further system development not dependent on platform shape is required if we are to consider expanding use to other line sections. According to a survey of the timing for opening operation of doors by the conductor based on an analysis of data from the trial use from November 2004 to September 2005, we found that approx. 95% of operations to open the doors were done within six seconds after the train decelerated to less than 5 km/h (Fig.16).

And upon analyzing how long the unstable detection continued when it occurred within six seconds after the train decelerated to less than 5 km/h, we found that approx. 70% of such unstable detection continued for 0.5 second or less and approx. 90% for 1.5 seconds or less. We also found that unstable detection continued for 2.8 seconds at the longest (Fig.17).

Thus we devised an improvement of the algorithm inside the sensor units so the sensors can keep the output of the detection signals for a specific time after detection to prevent unstable detection (Fig.18).

In our system the sensors were installed at the front end of the car body, namely there is some distance from the sensor to the end of the first door, so that when the train is running it takes a little times form the time the sensor pass the end of the platform to the time the end of the first door pass it. Then we can set the value of the delay (the time to retain the output of the detection signal) within this time-lag. In order to estimate the maximum acceptable value of the delay we assumed the most difficult condition. Practically the door open operation is limited when the train is stopping, this time-lag is minimized in case of the door operation after stopping by emergency brake (Fig.19).
In such a case, if the delay is long, the sensors might output a platform detection signal even if the front of the train is at a location without a platform. Therefore, we decided to set the acceptable maximum value of the delay of the detection signal in consideration of the distance from the installation position of the sensor (at the front end of the car body) to the end of the first door and of the maximum deceleration of the train. To put it concretely, theoretical maximum delay is given by Fig.20.

Then the actual value of the delay should be the sum of the calculated theoretical maximum time and some time to spare.

While the results of that calculation show that we can set the value of delay to 2.0 seconds for series 209 trains, we decided to set it to 1.7 seconds due to considerations for other series train. Table 1 shows the acceptable value of delay for each series of trains.

<table>
<thead>
<tr>
<th>Series</th>
<th>Distance between sensor and door (mm)</th>
<th>Deceleration (km/h/sec)</th>
<th>Acceptable delay (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>209</td>
<td>2,110</td>
<td>3.6</td>
<td>2.05</td>
</tr>
<tr>
<td>205</td>
<td>1,900</td>
<td>3.5</td>
<td>1.97</td>
</tr>
<tr>
<td>211</td>
<td>2,670</td>
<td>3.5</td>
<td>2.34</td>
</tr>
<tr>
<td>E217</td>
<td>3,020</td>
<td>4.2</td>
<td>2.27</td>
</tr>
<tr>
<td>E231</td>
<td>2,140</td>
<td>4.2</td>
<td>1.91</td>
</tr>
</tbody>
</table>

### 3.5 Verification of effect of improved sensors

We had carried out some verification tests of the ultrasonic sensors with delay processing to check their effect, from the end of August 2006 through February 2007, and had installed recorders on two series E231 trains on the Yamanote line (Fig.21, 22 and 23).

As the result of the test, improved sensors showed good records with unstable detection never occurring at all during a half-year test, even though these two trains made approx. 63,000 stops at stations (Table 2). So we found them effective to improve detection accuracy.
Since the improved sensors will be expected to improve detection accuracy, they were then used for the Series E233 trains on the Keihin-Tohoku line instead of the original ones. We also changed the shape of the sensor unit to fit into the car body in consideration of appearance (Fig. 24).

We have now developed the platform detection system, and this system is applicable to commuter trains that consist of fixed trainsets. So, in order to expand the system to suburban lines and regional lines, we started development of a new system that can also work on cars that are coupled and uncoupled. We made a trial device last year.

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### Table 2 Results of test

<table>
<thead>
<tr>
<th>Train set</th>
<th>Times of stopping at the stations</th>
<th>Times of unstable detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>33916</td>
<td>0</td>
</tr>
<tr>
<td>No.2</td>
<td>29203</td>
<td>0</td>
</tr>
</tbody>
</table>

References

(1) Hirotoshi Hata, "Development of Platform Detectors Using Ultrasonic Sensors", R&m Japan Railway Rollingstock &Machinery Association, January 2004