Wrong-Way Driving Detection System on Expressways

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In recent years, serious accidents caused by wrong-way driving on expressways have become a problem. Expressway administrators have taken measures to prevent vehicles from running the wrong way particularly at entrances and exits, but no effective measures have been taken on the main lanes. We have developed software that detects wrong-way driving vehicles using the loop-type vehicle detectors already installed on expressways. Further, we have developed a system that notifies the expressway control center when a wrong-way driving vehicle is detected. In this paper, we present the false detection suppression algorism that has been field tested to improve accuracy, and report on the results of accuracy evaluation of the detection system.

Keywords: expressway, wrong-way driving detection, loop-type vehicle detector, false detection suppression algorithm, field testing

1. Introduction

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) reported that wrong-way driving incidents, resulting in stopping of the vehicle or an accident, occurred at a rate of approximately 200 per year, or about once every two days.(1) In 2018, fatal and injury-causing accidents accounted for 9% of all accidents that occurred on expressways; while of all wrong-way driving accidents, fatal and injury-causing accidents accounted for 44%. The latter proportion is about five times the former.(2) Against this background, MLIT is implementing measures to counter wrong-way driving, with the aim of eliminating serious wrong-way accidents by 2029.(3)

Up until 2018, expressway administrators introduced wrong-way driving prevention measures, which were physical and visual measures, typically signs erected at diverging and merging points as well as at entrances and exits, ahead of other locations. Indeed, wrong-way driving incidents occurring at these points accounted for approximately 60% of the total.(1) These measures were effective in reducing the number of wrong-way accidents at diverging, merging points and entrances and exits by approximately 60%, and overall wrong-way accidents decreased by approximately 40%. However, the number of wrong-way accidents occurring on main lanes increased from 2016 to 2018 by approximately 20%.(2)

It is presumably important for the prevention of wrong-way accidents to quickly discover wrong-way vehicles and take action such as stopping them. At present, however, sensors designed to detect wrong-way vehicles on expressways have not been installed on a wide scale.

Therefore, noting vehicle detectors already provided on main lanes of expressways throughout the nation, Sumitomo Electric System Solutions Co., Ltd. has developed a wrong-way driving detection technology that uses loop-type vehicle detectors. In an experiment conducted in 2017, the technology was evaluated for its wrong-way driving detection accuracy and proved to be capable of detecting wrong-way vehicles with high accuracy.(4)

In actual operation, it is assumed that the wrong-way driving detection system notifies the expressway control center*1 when detected wrong-way vehicles. If the system falsely notifies the wrong-way driving, it will interfere with the operations of the expressway control center. Hence, it is necessary to verify the wrong-way driving notifications.

This report explains the basic mechanism of the wrong-way driving detection system; example measures for false detection; and the results of practical field tests.

2. Wrong-Way Driving Detection System

This chapter discribes an example configuration and the features of the wrong-way driving detection system developed by Sumitomo Electric System Solutions and the wrong-way driving detection mechanism.

2-1 Example configuration of the wrong-way driving detection system

Device configurations of wrong-way driving detection systems are roughly divided into two types. One is the control center notification type, by which a wrong-way driving information apparatus notifies the expressway control center and other pertinent sections of wrong-way driving. Its configuration is shown in Fig. 1. The other is the standalone type, by which, upon detection of wrong-way driving, the vehicle detector directly alerts the wrong-way driver, using a variable message sign or the like. This report explains the former, the control center notification type.

The wrong-way driving detection system of control center notification type is comprised of loop-type vehicle detectors with a wrong-way driving detection function, a vehicle detection intensive transmission apparatuses*2, and a wrong-way driving information apparatus. The loop-type vehicle detector and vehicle detection intensive transmission apparatus measure the driving speed, vehicle length, and direction of travel, and so detect wrong-way driving. The wrong-way driving information apparatus collects wrong-way driving detection results from IP communication-based loop-type vehicle detectors and vehicle detec-

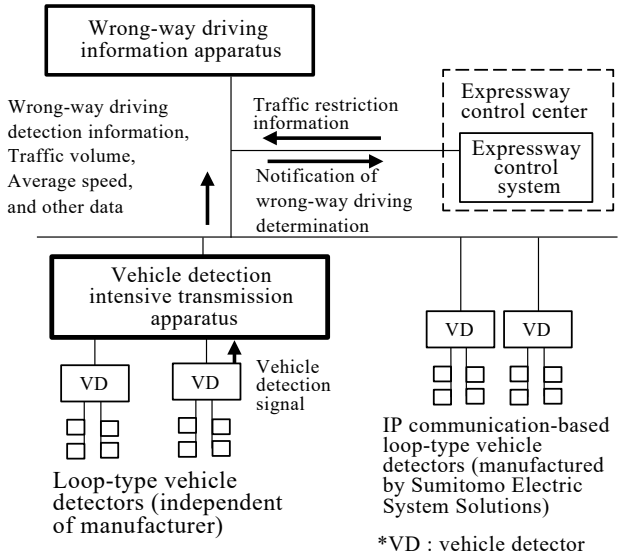


Fig. 1. Example of wrong-way driving detection system configuration (central capturing type)

tion intensive transmission apparatuses. Furthermore, this apparatus, in conjunction with the expressway control system,*3 judges the validity of wrong-way driving detection results from the information such as construction restriction or the traffic jam. When determined to be valid by the wrong-way driving information apparatus, wrong-way driving detection results are informed to the express control center. In collaboration with other relevant organizations, the expressway control center takes suitable actions, including information provision and traffic restriction to prevent accidents.

2-2 Features of the wrong-way driving detection system

The loop-type vehicle detectors adopted for wrong-way driving detection perform at a vehicle detection accuracy of 99.7%,[5] which is little affected by weather in principle. Accordingly, the vehicle detector detects vehicles stably and with high accuracy. Therefore, it has been installed as a facility to measure the traffic volume on the expressway, basically one or more locations in each direction between each interchange of the intercity expressway.

The IP communication-based loop-type vehicle detector manufactured by Sumitomo Electric System Solutions enables wrong-way driving detection simply by updating the built-in software. Consequently, one of its advantages is that it does not require a sensor to be newly installed for wrong-way driving detection.

Moreover, wrong-way driving function can be added to Sumitomo Electric System Solutions existing Vehicle detection intensive transmission apparatus merely by updating the software, and even other manufacturers' existing vehicle detectors can be connected to it in order to detect wrong-way driving. Of course, the conventional traffic volume measurement capability remains available even after the software is updated.

2-3 Mechanisms of wrong-way driving detection

Figure 2 illustrates the configuration of a loop-type vehicle detector. When a vehicle passes over a loop coil buried under an expressway, the coil's inductance changes, enabling vehicle detection.

The signal generated by the loop coil over which the vehicle passes first (hereinafter referred to as the "upstream loop") is combined with the signal generated by the loop coil over which the vehicle passes subsequently (hereinafter referred to as the "downstream loop") to compute the vehicle's direction of travel and speed.

Figure 3 presents detection patterns that the vehicle detector outputs when a vehicle passes over it.

Figure 3 (a) shows a vehicle detection pattern for a vehicle driving in the right direction (hereinafter referred to as a "right-way vehicle"). The vehicle is detected in order from the upstream loop to the downstream loop. In contrast, a wrong-way vehicle is detected in order from the downstream loop to the upstream loop, as depicted in Fig. 3 (b). The wrong-way driving detection mechanism detects the wrong-way vehicle utilizing vehicle detection signals generated in reverse order relative to those of right-way vehicles.

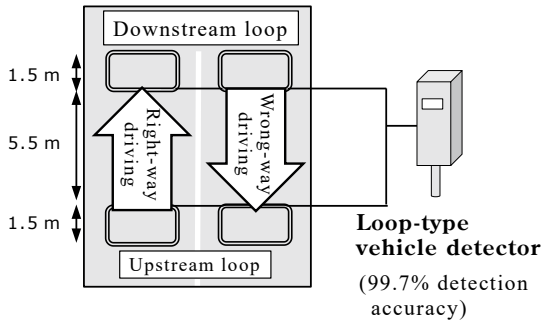
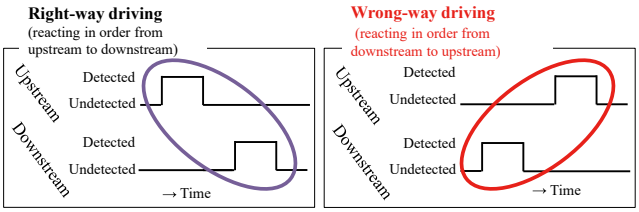


Fig. 2. Example of loop-type vehicle detector configuration



(a) Right-way driving detection pattern (b) Wrong-way driving detection pattern

Fig. 3. Detection patterns of vehicle detector

2-4 Challenges regarding the wrong-way driving detection system

To prevent wrong-way driving accidents, wrong-way driving information should be notified to the expressway control center immediately after detection. Nevertheless, in actuality, it can be assumed that some vehicles may be erroneously detected as wrong-way vehicles depending on their behavior, because there are various traffic flows, lane-changing and congestion.

The expressway control center that controls traffic on expressways carries out various tasks on a 24-hour-a-day basis. It receives reports from general drivers about fallen

objects on expressways, monitors diverse problems such as accidents and fires, and provides information on occurrences of traffic congestion.

When a wrong-way driving incident occurs, the expressway control center is required to promptly identify the location of the wrong-way vehicle, notify the Expressway Traffic Police Unit and other pertinent organizations, and display alerts on variable message sign about the wrong-way driving. If erroneous reports due to false detection are issued frequently, it will greatly hinder the operation of the expressway control center.

For the wrong-way driving detection system, it is important to avoid erroneous reports due to false detection, as well as to detect wrong-way vehicles.

3. False Detection of Wrong-Way Driving and Suppression of False Detection

This chapter describes the mechanisms behind the occurrence of false detection and the algorithm used to suppress false detection.

3-1 Mechanisms behind the occurrence of false detection

False detection of wrong-way driving by a loop-type vehicle detector is caused, for example, by a vehicle driving at low speed and making a lane change.

The loop-type vehicle detector detects whether there is vehicle by each loops, upstream loop and downstream loop. The direction of vehicle is determined by this combination. Therefore, it can be assumed that the system may erroneously detect a wrong-way vehicle based on successive detection signals generated by two right-way vehicles.

The upstream and downstream loops are installed at a distance of 5.5 m from each other, as illustrated in Fig. 2. Each loop coil is 1.5 m in width in the direction of travel.

When the traffic is heavy, vehicles drive at low speed, coming close to each other at a short following distance. Under these congested conditions, vehicles tend to change lanes. It can be assumed that if a vehicle only passes over a downstream loop and the following vehicle passes over the upstream loop in the same lane, as depicted in Fig. 4, the wrong-way driving detection pattern will be occurred, resulting in false detection of wrong-way driving (Figs. 4 and 5).

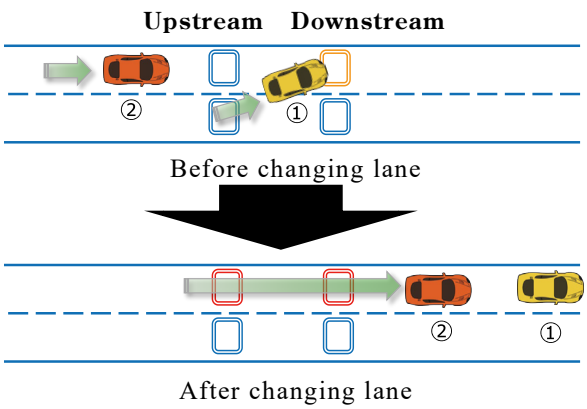


Fig. 4. Examples of false detections caused by lane changes

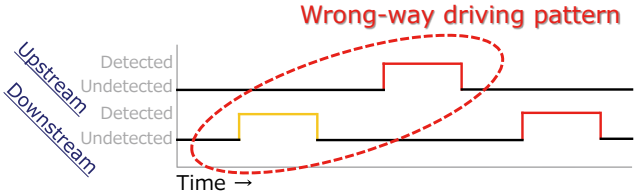


Fig. 5. Schematic of vehicle detection signals occurring false wrong-way driving detection during congestion

3-2 False detection suppression algorithm

In actuality, when traffic is congested and there are many vehicles on each lane, it would be difficult for any drivers to drive in wrong-way.

Based on this assumption, Sumitomo Electric System Solutions devised a method of suppressing false detection of wrong-way driving, whereby congestion is identified using traffic volume, average speed, and other data measured by vehicle detectors or the vehicle detection intensive transmission apparatus.

However, the system may not restrain false detection without the judgment of the congestion state catching up with it when it becomes the congestion state by the sudden change of the traffic condition in short time. Therefore, we further simulated the vehicle detection pattern. As a result, we concluded that it is impossible to drive the right-way vehicle in the same lane for a short time before and after a driving wrong-way vehicle, thus took measures that evaluate the continuity of the vehicle detection signal.

4. Practical Field Testing

This chapter describes the overview and results of the verification conducted on an actual expressway.

4-1 Effectiveness verification

Using actual vehicles, the basic performance of the wrong-way driving detection system was verified.

As for the effectiveness verification settings, test

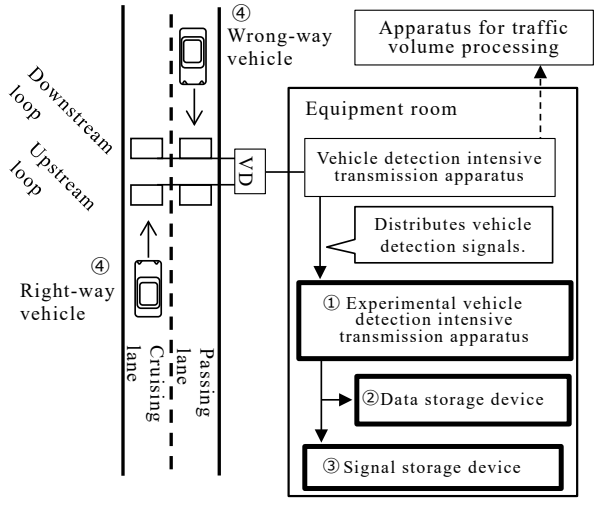


Fig. 6. Equipment configuration for effectiveness verification

driving was conducted in a closed section set up for construction work on actual expressway lanes, using existing loop-type vehicle detectors and test vehicles (4.5 m long) (see Fig. 6).

Equipment Configuration

① Experimental vehicle detection intensive transmission apparatus: A device prepared by additionally providing a wrong-way driving detection function to a vehicle detection intensive transmission apparatus manufactured by Sumitomo Electric System Solutions
② Data storage device: A device designed to store the results of wrong-way driving detection and traffic volume data sent from ①
③ Signal storage device: A device used to store vehicle detection signals
④ Test vehicles: approx. 4.5 m in vehicle length (two vehicles)

Table 1 presents the driving patterns of the test vehicles. These driving patterns were configured based on traveling conditions assumed for general vehicles.

Table 1. Driving patterns of test vehicles

No.	Driving situation	Description	Detection result
1	Wrong-way driving against normal traffic flow	Wrong-way driving against normal traffic flow should be detected as wrong-way driving.	Correct
2	Lane change at the beginning of congestion	Lane changes made at the beginning of congestion should not be detected as wrong-way driving.	Correct
3	Lane change in congested traffic flow	Lane changes in congested traffic flow should not be detected as wrong-way driving.	Correct
4	Driving between lanes	Wrong-way driving straddling the line between lanes should be detected as wrong-way driving.	Correct
5	Making a U-turn after wrong-way driving	A wrong-way driver becomes aware of his/her wrong-way driving and makes a U-turn. This should be detected as wrong-way driving.	Correct
6	Steering clear of a wrong-way vehicle	A right-way vehicle encounters a wrong-way vehicle on a lane and avoids a collision by driving near a loop, and then the wrong-way vehicle drive on that loop. In this situation, the wrong-way driving should be detected.	Incorrect ↓ Correct detection achieved after parameter adjustment

The results of the effectiveness verification are explained as follows. With No. 1, one vehicle drove the wrong-way while the other vehicle was driving the right-way on the adjacent lane. The system detected the right-way and wrong-way vehicles with 100% accuracy. No.2 was tested one vehicle changing lane from the adjacent lane following the other vehicle, which was driving in the lane. The two were detected as right-way vehicles and neither of them was detected as a wrong-way vehicle. For No. 3, firstly, data determined to show congestion was inputted into the system, followed by driving in the same way as in No. 2. Based on the congestion determination, the system suppressed false detection. With No. 4, in which one vehicle drove over the line between the lanes, the wrong-way vehicle was detected on at least one lane. The wrong-way vehicle in No. 5 was detected as wrong-way driving when it passed over the loops. Subsequently, when the vehicle made a U-turn and passed over the loops, the system detected it as a right-way vehicle.

No. 6 verified a detection situation where a right-way vehicle passed over the upstream loop and made a lane change. This was immediately followed by a wrong-way vehicle driving on the same lane. The system failed to detect the wrong-way vehicle. The vehicle detection signals acquired from this situation were analyzed in-house. As a result, it was verified that the wrong-way vehicle could be detected correctly through adjusting parameters used for the evaluation of the consecutiveness of signals.

4-2 Preliminary verification based on real traffic

Next, preliminary verification was conducted in real traffic flow to confirm whether or not false detection occurred and to take measures to prevent false detection.

(1) False detection of wrong-way driving due to congestion occurring in a short period of time

During a practical field test, false detection of wrong-way driving occurred when the tail of the traffic jam in a short period of time due, for example, to a traffic accident. Traffic volume data acquired in this instance is presented in Fig. 7.

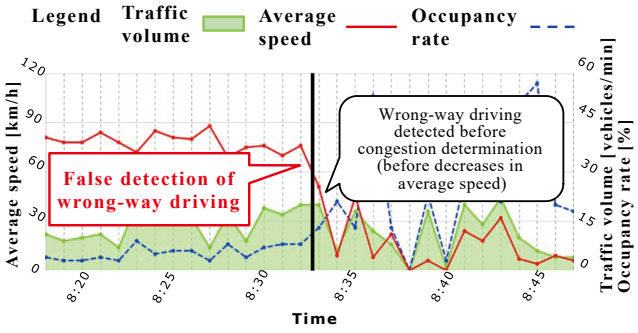


Fig. 7. Graph showing traffic volume present at the time of false detection

Before the false detection occurred, the average speed remained between 70 km/h and 80 km/h. In two minutes, the average speed decreased from 77 km/h to 10 km/h. Based on the pattern exhibited by the detection signals, it was inferred that when a column of vehicles in congestion rapidly lengthened, a vehicle stopped immediately after it passed over an upstream loop; then, it moved again and passed over the downstream loop; immediately after this, the following vehicle entered the upstream loop zone; as a result, the system determined this as wrong-way driving.

The traffic volume data acquired when the false detection occurred was analyzed. The analysis results revealed a characteristic trend emerging immediately before decreases in speed, which was also seen in traffic volume data presenting similar decreases in speed. Consequently, the wrong-way driving information apparatus was taken measure to suppress the notification of the wrong-way driving detection information to the expressway control

center when the wrong-way driving information apparatus finds this trend.

4-3 Field test results

The wrong-way driving detection system with updated software incorporating false detection suppression measures used in the preliminary verification was field tested. Table 2 outlines the test and presents the test results.

Table 2. Field test results

Period	Dec. 1, 2020 to Jan. 15, 2021 (46 days)
Number of detection locations	103 (approx. 55.8 km)
Number of passing vehicles	55 million
Number of detected wrong-way driving	12
Number of false reports about wrong-way driving	0
Number of lane-restrictions	7
Number of congestion occurrences	118 (55.7 h in total)

A cumulative total of 55 million vehicles passed over loop-type vehicle detectors during the verification period of 46 days, and there was a total of 12 wrong-way driving detections. All detected wrong-way vehicles were construction work vehicles in restricted-lane zones, which were blocked notifications to the expressway control center. Additionally, we confirmed with expressway administrators that no wrong-way vehicles were reported for the field-testing locations during the field test period.

Regarding the 12 detections detected as wrong-way driving, we checked all traffic restriction information entered during the test period. At least one wrong-way driving detection was identified with each lane restriction event. These detections seem to be construction work vehicles moving in reverse in order to collect materials used to implement traffic restriction*4 when the restriction was removed.

Meanwhile, traffic congestion occurred 118 times, totaling 55.7 h during the test period. During these times, no false detection of wrong-way driving occurred, proving the effective working of the measures incorporated to counter false detection during congestion.

The traffic volume was lower than in previous years as a result of the impact of the novel coronavirus. Therefore, during the field test period, congestion following rapid decreases in vehicle speed did not occur. Consequently, we were unable to verify the false detection suppression performance with regard to false detections arising from congestion occurring in a short period of time during the test period. However, the false detections that occurred during the preliminary verification period were confirmed to be suppressed by in-house reproduction test.

5. Conclusion

We improved the accuracy of the wrong-way driving detection system through verification, taking false detection suppression measures to address false detection cases other than those initially assumed.

Moreover, we were able to verify suppression of wrong-way driving notification by lane restriction.

Therefore, we believe that the wrong-way driving detection system has achieved the performance that meets the requirements of the road control center. We hope that widespread use of the wrong-way driving detection system will help reduce serious accidents caused by wrong-way vehicles.

Lastly, we are deeply grateful to people for valuable cooperation in the field testing.

Technical Terms

∗1 Expressway control center: Conducts road traffic control and information provision operations, including monitoring expressway traffic conditions and dealing with accidents and fires on a 24-hour-a-day basis.

∗2 Vehicle detection intensive transmission apparatuses: A device that computes traffic volume per unit of time, average traffic speed, and time occupancy rate using vehicle detection signals sent from older models of vehicle detectors, and transmits them to apparatus that is processing various traffic data.

∗3 Expressway control system: A system that supports traffic control conducted at the expressway control center by acquiring real-time expressway-related information from various equipment installed on expressways and providing information based on the acquired information.

∗4 Materials used to implement traffic restriction: Equipment and materials such as traffic cones, barricades and safety lights used when implementing traffic restriction to ensure safe work in the regulated zone.

References

(1) MLIT, "KOSOKUDORODENOGYAKUSOTAISAKUNIKANSURU YUSHIKISHAIINKAI," No.1, https://www.mlit.go.jp/road/ir/ir-council/reverse_run/index.html (accessed 2021-5-6)

(2) MLIT, "KOSOKUDORODENOGYAKUSOTAISAKUNIKANSURU YUSHIKISHAIINKAI," No.5, https://www.mlit.go.jp/road/ir/ir-council/reverse_run/index.html (accessed 2021-5-6)

(3) MLIT, "(Press Release) KOSOKUDORONIOKERUANZEN · ANSHINKIHONKEIKAKU," 2019-9-10, https://www.mlit.go.jp/report/press/content/001307543.pdf (accessed 2021-5-6)

(4) T. Nagai, T. Kawamoto, T. Shimoyama, J. Tohyama, H. Nakagawa, M. Goto, "Experiment to Detect Wrong Way Driving by Loop Coil Type Vehicle Detector on Expressway Main Line," IEICE Technical Report. Vol.118 No.200, IEICE, pp.11-14, ITS-18-17 (2018)

(5) East Nippon Expressway Co., Ltd., West Nippon Expressway Co., Ltd., "KOTSURYOKEISOKUSETSUBIHYOJUNSHIYOSHO No.17112," SHISETSUKIZAISHIYOSHOSHU DENKI," p.10 (2017-7)

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