# Development of Guidance Technology to Safe Driving Behavior


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## Abstract

Recently, the diffusion rate of vehicles equipped with Advanced Driver Assistance System (ADAS) has been increasing, but depending on a driver's ability, responses to the assistance system may be delayed so that a driver may not be able to avoid accidents. Therefore, this paper proposes a method of notification to guide the driver to safe driving behavior in potentially hazardous situations.

In the proposed method, "driving behavior to be executed by the driver (speed, wheel angle) are determined" by performing a route search to avoid potential hazards from prediction results of hazards that might occur in the future based on the external environment and state of host vehicles and from driving information of the host vehicles such as speed and wheel angle. Furthermore, only if the difference between the determined driving behavior and the actual driving behavior exceeds a certain threshold, the notification is made to guide to the "driving behavior to be executed" so as to guide to safe driving.

This paper introduces the proposed method where the effectiveness of the determination of the driving behavior to be executed was confirmed by verification using simulator and an actual vehicle and issues of the notification to guide to the driving behavior to be executed could be identified.

## 1 Introduction

Recently, the diffusion rate of vehicles equipped with Advanced Driver Assistance System which assists drivers to drive safely on the vehicle side has been increasing [1]. In such a situation, in order to reduce accidents, the driver assistance system which warns drivers in the situation where hazards are obvious has been developed. However, depending on a driver's ability, responses to the system may be delayed. Consequently, the driver may not be able to avoid accidents [2]. Therefore, in order to further reduce accidents, we are working on the development of safe driving support system in potentially hazardous situations (**Fig. 1**). In this system, in order to predict hazards that might occur in the future based on the "external environment" and the state of "host vehicle" and guide the driver to safe driving, it is necessary to "guide safe driving behavior to be executed by the driver" and "provide support for approaching the guided safe driving behavior to be executed".

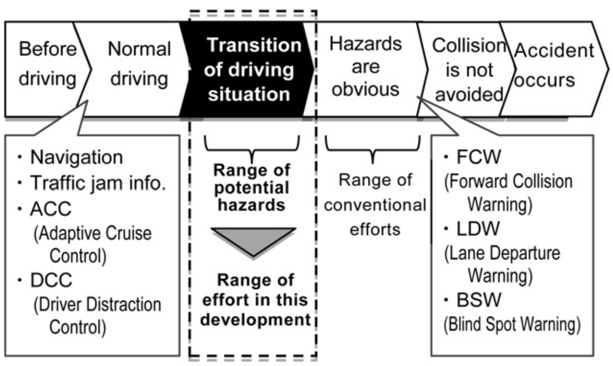



**Fig. 1 State Transition to Occurrence of Accidents and Range of Effort in this Development**

## 2 Issues and efforts

In this system, in order to avoid lapsing into the state that "hazards are obvious", it is necessary to guide to safe driving behavior, and ① "Determination of driving behavior to be executed by the driver" and ②"Notification to guide the driver to the driving behavior to be executed" become issues against potential hazards. The next paragraph shows an approach to these issues.

**<Approach to issues>**

① "Determination of driving behavior to be executed by the driver"

The amount of operation based on the driving operation plan to be executed is calculated from "prediction results of hazards" and "driving information of the host vehicle".

② "Notification to guide the driver to the driving behavior to be executed"

If the difference between the driving behavior (vehicle speed, steering angle) determined in the above item ① and "the actual driving behavior" exceeds a certain threshold, the necessity of notification will be determined and notification will be executed.

**Fig. 2** shows a process image of the item ① and item ②.

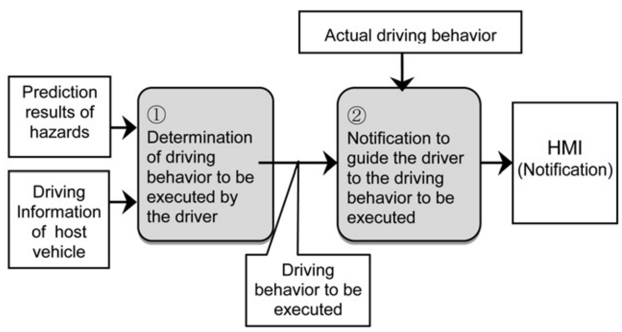



**Fig. 2 Process Image**

The next section and after introduce details of the developed technology and confirmatory results of effectiveness.

## 3 Development of "determination of driving behavior to be executed by the driver"

This section introduces details of development and verification results for Section 2. ① "Determination of driving behavior to be executed by the driver".

### 3.1 Developed technology

As one of the route search methods to avoid obstacles required for determining driving behavior to be executed by the driver against potential hazards, DWA (Dynamic Window Approach) [3] which is advocated by D. Fox, et al. has been known. This is an obstacle avoidance method to search the space where high speed movement is possible while avoiding the nearest obstacle by use of a kinetic model (translation, rotation angle) of a mobile robot (**Fig. 3**).

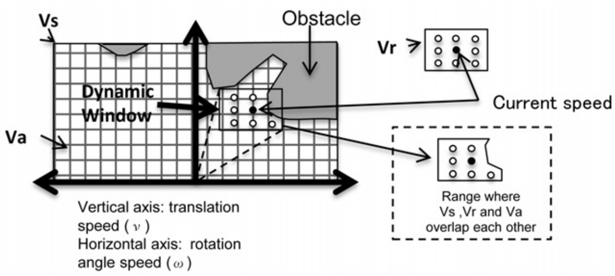



**Fig. 3 Space Search Image of DWA**

In DWA, a search is conducted by Dynamic Window calculated from AND of three Windows (Vs, Vr and Va in **Fig. 3**). The first one is "controllable range (Vs)" and indicates the range of maximum / minimum value of control input (translation, rotation angle) which the mobile robot may take. The second one is "dynamic controllable range (Vr)" and indicates the range of maximum / minimum control input (grid pattern area in **Fig. 3**) which is calculated based on the current speed and maximum acceleration speed on the specification and which the mobile robot may take by the next time. The third one is "acceptable control input due to obstacles (Va)" and (Va) indicates the range of control input which is calculated from the detection result of obstacle sensor and maximum deceleration value of the robot. In the range, safe driving is possible.

By calculating only the range in which the above three ranges of control input (Windows) overlap each other (dotted line area in **Fig. 3**), control input (translation speed ($v$) and rotation angle speed ($\omega$)) can be determined in consideration of safety and the kinetic model of the robot.

Sampling of control range of Dynamic Window is performed at each constant value. In order to calculate optimal control input, the following evaluation function G is used at the sampling. By determining the values of $v$ and $\omega$ so that G takes a maximum value, control input that is capable of driving to a destination with high speed while avoiding obstacles can be sequentially calculated.

$$G(\boldsymbol{v},\boldsymbol{\omega}) = \sigma\big(\alpha \cdot heading(\boldsymbol{v},\boldsymbol{\omega}) + \beta \cdot dist(\boldsymbol{v},\omega) + \gamma \cdot velocity(\boldsymbol{v},\boldsymbol{\omega})\big)$$

As for the evaluation function G, the first term, heading ($v,\omega$) is the value obtained by subtracting the angle of the difference between direction of the robot and direction of a destination at the time of control input from 180 degrees. When going straight to the goal, the evaluation value becomes larger. The second term, dist ($v,\omega$) represents the distance to the nearest obstacle at the time of control input. As the distance from the obstacle becomes larger, the evaluation value becomes larger. The third term, velocity ($v,\omega$) uses the value of v of control input. As the speed is faster, the evaluation value becomes larger. Furthermore, $\alpha$, $\beta$ and $\gamma$ are weight parameters of each term and $\sigma$ is a smoothing function to smooth control input values.

In this development, based on the above DWA, we extracted issues to determine the behavior to be executed by the host vehicle in order to avoid potential hazards. **Table 1** shows the issues.

**Table 1 Issue of Conventional Method (DWA)**

| Objectives of this development | What DWA can do | Issues | |
|---|---|---|---|
| Determine behavior to be executed by "host vehicle" | Determine behavior to be executed by "mobile robot" | Reflect vehicle driving model [4] | 1 |
| Determine behavior to avoid "potential hazards" | Determine behavior to avoid "the nearest obstacle" | Consider "plural and moving obstacles" | 2 |

Improved DWA → IDWA

For the above issues, as shown in **Fig. 4**, we developed the method (Improved Dynamic Window Approach = IDWA) of determining the "driving behavior to be executed" in response to plural obstacles and moving obstacles by reflecting a vehicle driving model [4] based on DWA and predicting the degree of hazard from location information and migration probability of plural obstacles (cars parked on the street, people)

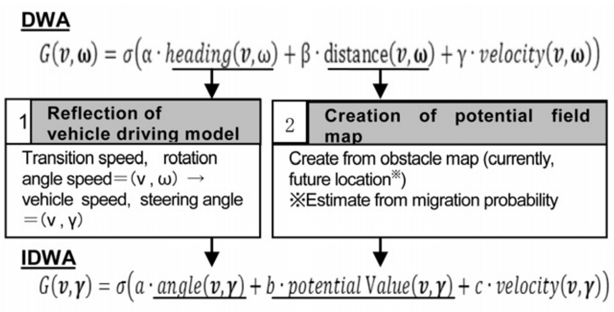



Fig. 4 Evaluation Function after Improvement (IDWA)

Next, **Fig. 5** shows algorithm for "determination of driving behavior to be executed by the driver" which was developed by use of IDWA and **Fig. 6** shows a process flow of IDWA.

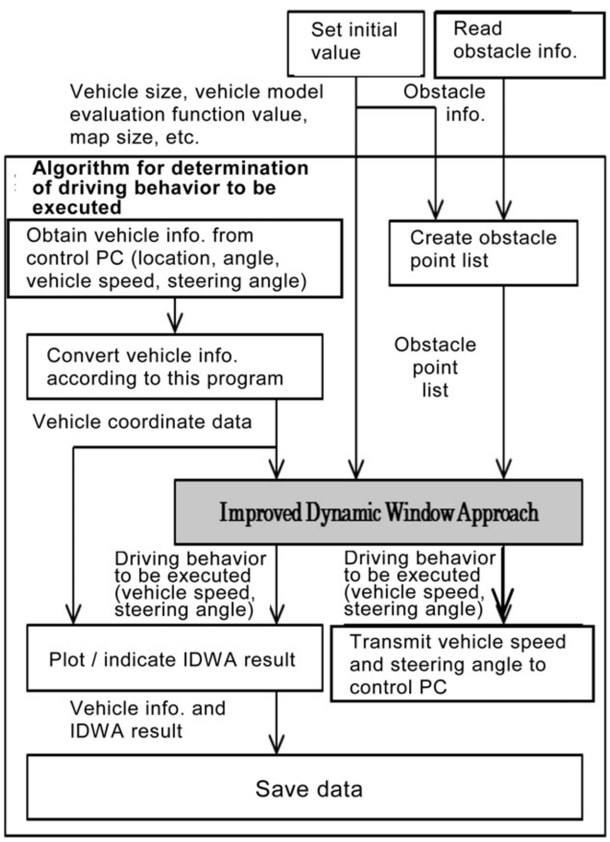



Fig. 5 Algorithm of "Determination of Driving Behavior to be Executed"

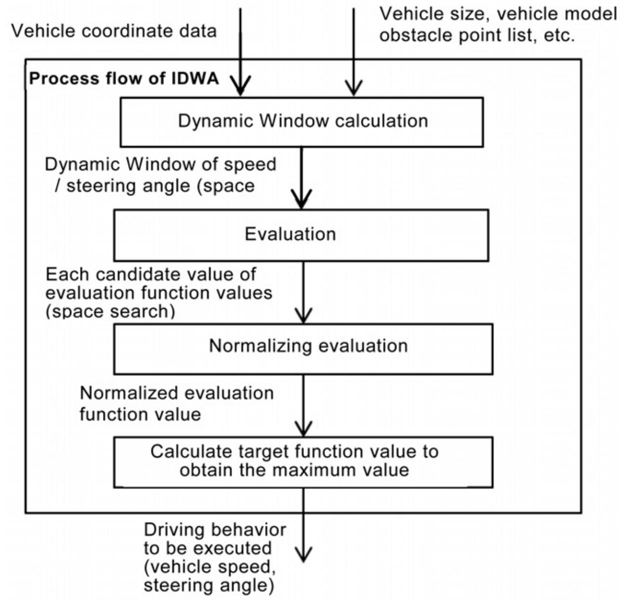



Fig. 6 Process Flow of IDWA

### 3.2 Simulation and evaluation of developed algorithm

Simulation and evaluation were conducted in order to confirm if it is possible to determine driving behavior to be executed (calculate vehicle speed and steering angle) according to the developed algorithm.

① **Simulation**

For Process Flow of **Fig. 6**, determined driving pattern (vehicle / obstacle information) is used as input so as to verify if it is possible to determine driving behavior to be executed.

② **In-vehicle evaluation**

In the algorithm in **Fig. 5**, actual driving pattern is used as input (vehicle information examples: GPS, vehicle speed and steering angle, obstacle information examples: camera recognition result and digital map data) so as to evaluate if it is possible to determine driving behavior to be executed.

### 3.3 Simulation environment

**Fig. 7** shows simulation environment in Section 3.2 ①.

The calculation result is displayed as output on the PC.

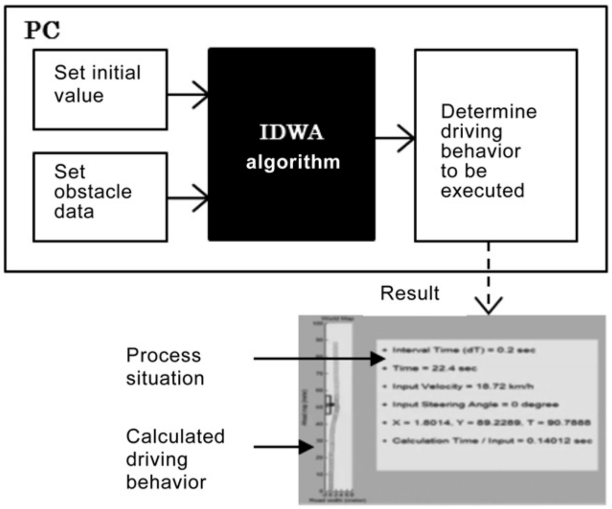



Fig. 7 Simulation Environment

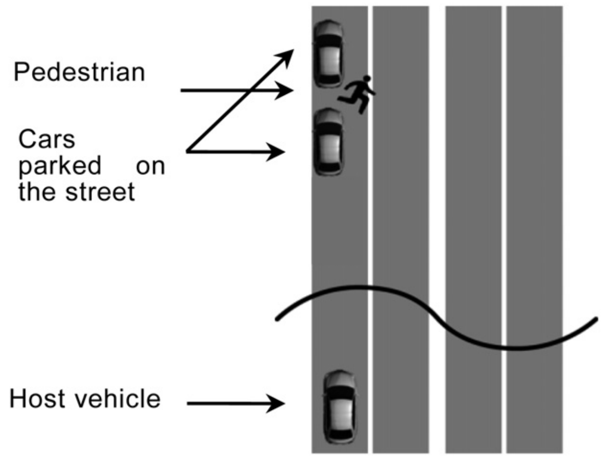



Fig. 8 Potentially Hazardous Scene (dashing out from between the Cars Parked on the Street)

## 3.4 Verification / judgment conditions and simulation result

For verification and evaluation of developed algorithm, **Table 2** shows verification conditions common to Section 3.2 ①②, **Fig. 8** shows potentially hazardous scenario to be assumed and **Table 3** shows judgment conditions. As the scene of this development, "driving at the point where two vehicles are parked on the street in the city and a pedestrian might dash out from between the cars" is assumed.

Table 2 Verification Condition

| Parameter | Verification condition |
|---|---|
| The number of obstacles (vehicle) | 2 vehicles |
| The number of obstacle (pedestrian) | 1 person |
| Vehicle speed | 15 km/h |
| Interval of calculation (dT) | 0.2 seconds |
| Maximum acceleration speed (maxA) | 5 m/s |
| Maximum steering angle (max Gamma Rate) | 20 degree/s |

Table 3 Judgment Condition

| |
|---|
| Do not collide with obstacles (parked car, person) |
| Always keep the distance of 1 meter or more between the host vehicle and the cars parked on the street |
| Always keep the distance of 2 meters or more between the host vehicle and the pedestrian |
| Drive from start to goal |
| Do not move to the oncoming lane<br>※However, this excludes some cases where the above distance should be kept when avoiding obstacles. |

**<Simulation result>**

**Fig. 9** shows the result of "driving behavior to be executed" calculated by using driving pattern (vehicle / obstacle information) determined for Section 3.2 ① as input, and **Table 4** shows the judgment result.

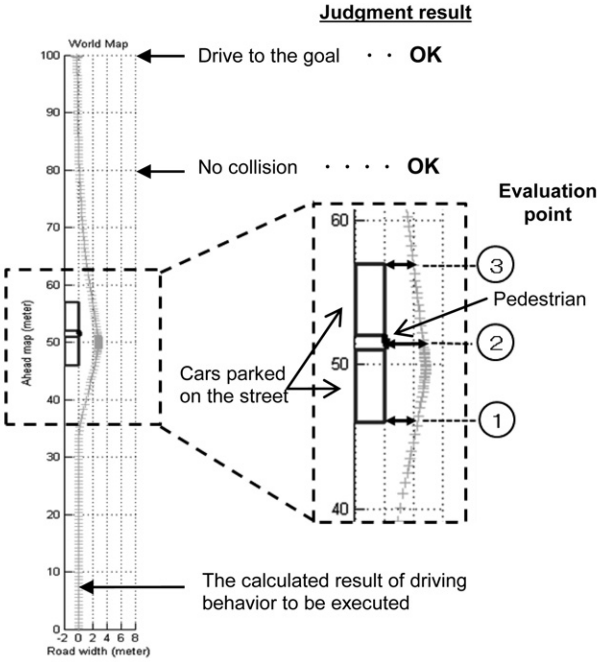



Fig. 9 Simulation Result

Table 4 Judgment Result of Simulation

| Judgment point | Judgment conditions | The minimum distance from obstacle (the center of vehicle − the radius of vehicle) | Judgment result |
|---|---|---|---|
| ① | 1.0 m | **1.5 m** | **OK** |
| ② | 2.0 m | **2.0 m** | **OK** |
| ③ | 1.0 m | **1.4 m** | **OK** |

The calculated result satisfied all judgment conditions and driving behavior to be executed was determined. **Fig. 10** shows time series log data of **Fig. 9** as reference (solid line indicates vehicle speed and dotted line indicates steering angle).

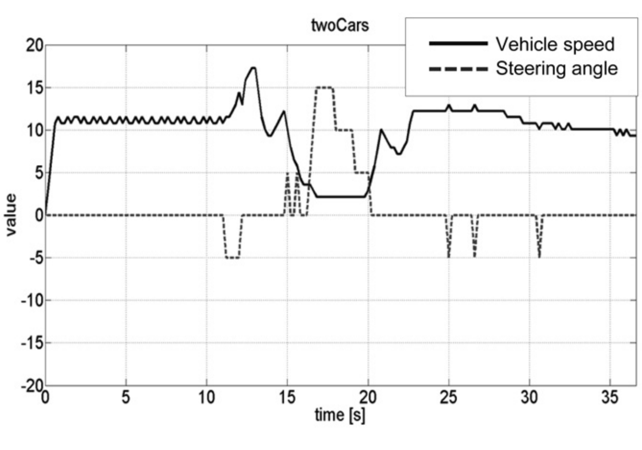



Fig. 10 Simulation Result (Timing to be Executed)

### 3.5 Verification environment by actual vehicle

**Fig. 11** shows system configuration of in-vehicle verification.

This is a verification environment for the purpose of confirming if it is possible to determine driving behavior to be executed under actual vehicle environment, like the simulation. Calculated results (vehicle speed, steering angle) are displayed as output on the PC. The difference with the simulation is, as described in Section 3.2, that driving behavior to be executed is determined by using the actual amount of operation (vehicle speed, steering angle) as input.

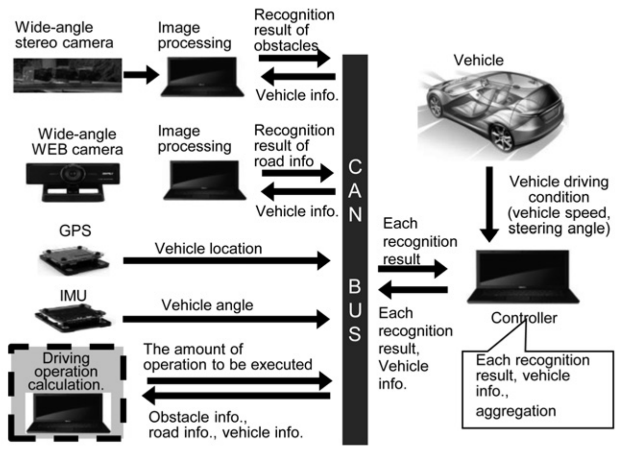



Fig. 11 Verification Environment by Actual Vehicle

**<In-vehicle evaluation result>**

**Fig. 12** shows the "result of driving behavior to be executed" calculated by using actual driving pattern as input for Section 3.2 ② and **Table 5** shows the judgment result.

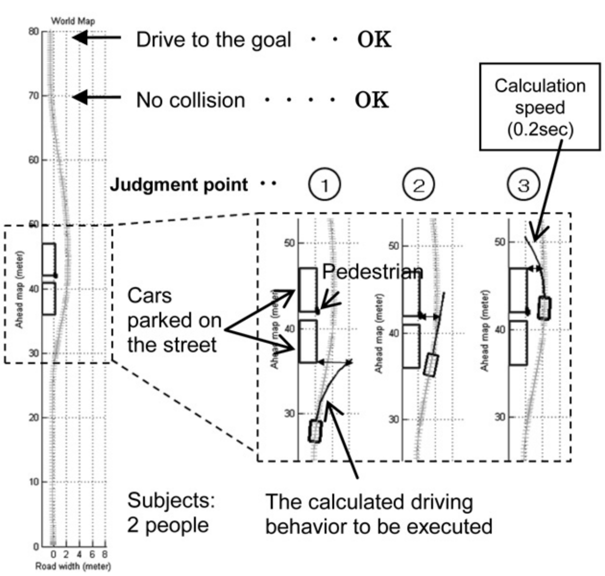



Fig. 12 In-vehicle Evaluation

Table 5 Judgment Result of In-vehicle Evaluation

| Judgment point | Judgment conditions | The minimum distance from obstacle (the center of vehicle － the radius of vehicle) | Judgment result |
|---|---|---|---|
| ① | 1.0 m | 2.5 m | OK |
| ② | 2.0 m | 2.0 m | OK |
| ③ | 1.0 m | 1.0 m | OK |

As a result, even when using actual driving pattern as input, the calculated result satisfied all judgment conditions and driving behavior to be executed could be determined. **Fig. 13** shows time series log data of **Fig. 12** as reference (solid line indicates vehicle speed and dotted line indicates steering angle).

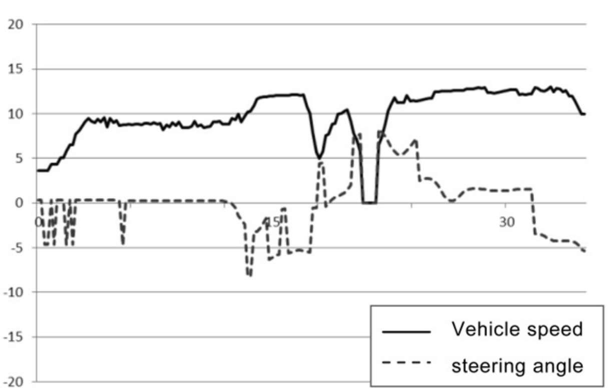



Fig. 13 Result of In-vehicle Evaluation (Timing to be Executed)

## 4 Efforts for "Notification to guide to the driving behavior to be executed"

This section introduces details of efforts and evaluation results in Section 2. ② "Notification to guide the driver to the driving behavior to be executed".

### 4.1 Process for notification to guide to driving behavior to be executed

As shown in **Fig. 14**, "driving behavior to be executed" and "actual driving behavior" are compared with each other, and if vehicle speed or steering angle exceeds a certain threshold, "notification to guide the driver to the driving behavior to be executed" (judgment of notification / determination of notification details) will be made.

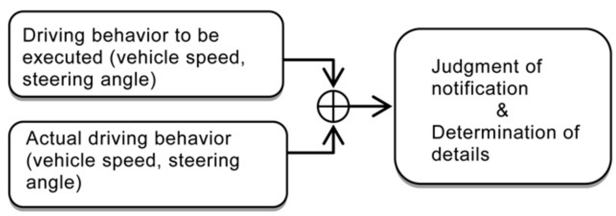
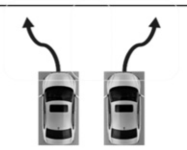



Fig. 14 Notification Process to Guide to Driving Behavior to be Executed

### 4.2 Verification environment / conditions by actual vehicle and results

In order to confirm the effectiveness of the "notification to guide the driver to driving behavior to be executed", in-vehicle evaluation was conducted. **Table 6** shows each threshold (speed, steering angle) to conduct the "judgment of notification" and details of the notification. Verification environment is the same as that of in-vehicle evaluation in Section 3.5 and verification conditions are the same as **Table 2**.

Table 6 "Threshold to Determine Notification" and "Details of Notification"

| Driving behavior | Threshold | Details of notification |
|---|---|---|
| Vehicle speed | ±2.5 Km/h | Warning message and recommended speed are displayed   |
| Steering angle | ±5° | Recommended steering angle is displayed  |

**<In-vehicle evaluation result>**

**Fig. 15** shows "actual driving behavior" (driving route) by the driver and **Table 7** shows the judgment result.

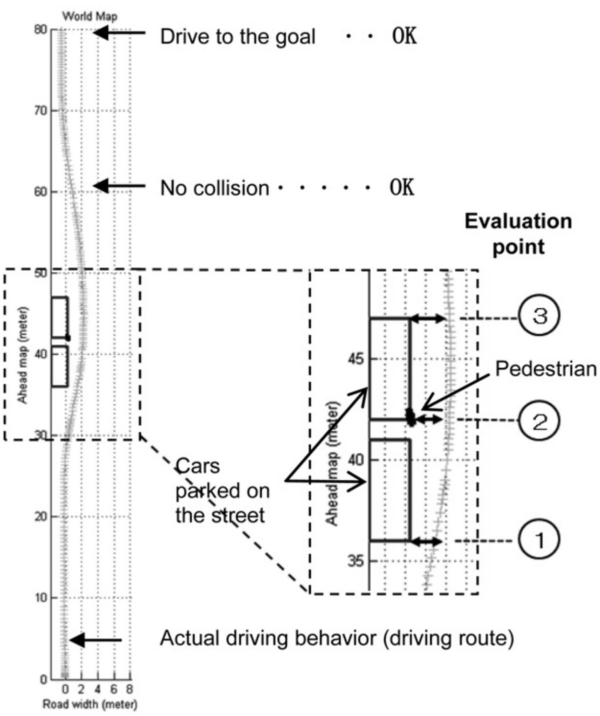



Fig. 15 Result of In-vehicle Evaluation of Notification to Driver

Table 7 Judgment Result of In-vehicle Evaluation

| Judgment point | Judgment conditions | The minimum distance from obstacle (the center of vehicle − the radius of vehicle) | Judgment result |
|---|---|---|---|
| ① | 1.0 m | **0.9 m** | **NG** |
| ② | 2.0 m | **1.5 m** | **NG** |
| ③ | 1.0 m | **1.0 m** | **OK** |

As a result, the driver did not satisfy a part of the judgment conditions (judgment conditions ① and ② in **Table 7**) and drove a hazardous route . Actual driving pattern (vehicle speed, steering angle) was used as input and the notification was executed if the difference between the "driving behavior to be executed" and the "actual driving behavior" exceeded a certain threshold. However, the driver did not follow the notification.

### 4.3 Consideration

Consideration for in-vehicle evaluation result described in Section 4.2 and obtained issues are described. As for the result that the driver drove a hazardous route, we consider that "the executed notification was not effective". Firstly, in terms of "recognition" in the process of human information processing, since the method of this notification was made by using "only visual display" and a center display showed the information, we consider that the driver could not afford to see the notification.

Furthermore, in terms of "judgment (decision -making)", although the notification was executed, the driver felt that "it was not necessary to keep the distance from obstacles". That is, we can consider that the driver judged that "it was not hazardous", was not convinced by the details of notification and did not follow them. Therefore, in order to guide the driver to safe and secure driving, we identified the following points as issues, ① "combination of the method and details of notification to raise recognition" and ② "further convincing the driver of potential hazards".

## 5 Conclusion

As efforts for "determination of driving behavior to be executed by the driver", we developed the method considered to be effective and conducted verification by using a simulator and an actual vehicle. As a result, the effectiveness of IDWA which had been developed for determination of driving behavior to be executed could be confirmed.

In the future, we will further conduct verification for "the notification to guide the driver to the driving behavior to be executed" in light of the issues (Section 4.2 ① and ②) obtained this time relative to our proposed method. Furthermore, we will perform evaluation for driver's acceptability and proceed with the development.

We will work on the development of safe driving assistance system which aims to allow the driver to drive in a safe condition at all times for early practical use.

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Reference


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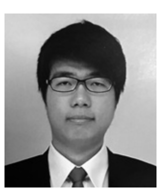

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