Collision Risk Assessment of Right Turns at Intersections Based on Driving Behavior for ADAS (First Report) - Risk Prediction System Based on a Car Navigation System -

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Abstract

It’s necessary to support drivers by the actual system to reduce the pedestrian-vehicle accidents when turning right. Therefore, we focused on a method to assess the collision risk with the driving behavior indices of right turns at intersections in our previous study. Using a car navigation system as an actual system, we implemented a calculation method of driving behavior indices to evaluate collision risk with a car navigation system as an actual equipment. In order to obtain the driving behavior indices, as a car navigation system is restricted to acquire the data required, we computed the difference between the calculated value on the system and the theoretical value calculated with an actual data. The driving behavior indices can be calculated using a car navigation system by changing the method of setting the centerline pass point (right turn start point) and the target arrival point (right turn end point) from the comparison result of the errors.

I. Introduction

In Japan, the largest number of traffic fatalities occur during "walking". It is necessary to prevent pedestrian-vehicle accidents to reduce the number of traffic fatalities. Right turn at an intersection is one of the typical accident scenarios of pedestrian-vehicle accidents. In addition, it is reported that the safety check of drivers is insufficient compared to other scenarios because there are many types of traffic participants including pedestrians, leading vehicle and oncoming car when the vehicle turns right [1]. Therefore, it can be said that turning right at an intersection is a difficult driving scene due to the factors of traffic participants, and it is required to be supported to prevent accidents from occurring. One way to prevent pedestrian-vehicle accidents is to predict the unsafe state that may cause a collision with a pedestrian and assist the driver in selecting appropriate driving behavior. This will prevent the unsafe state of driving and avoid collision with pedestrians. To realize such support, the system is required to be able to assess the future collision risk with the current driving behavior or the state of intersection and also the support should be implemented and assessed in an actual system.

We aim at realizing the above assistance system (risk prediction system). We focused on the driving behavior indices which reflect the characteristics of the driving behavior related to the collision risk where the pedestrians are walking near the intersection when the vehicle is turning right. These indices, however, were defined under a controlled environment and they are required to consider the constraints of the actual system if these are implemented in an actual environment. We have two options for in-vehicle units and any devices such as a car navigation system, a driving recorder and a smartphone. Among these, car navigation systems are originally designed to support drivers. They have sensors such as GPS receivers, gyro sensors, and map information and can acquire vehicle speed because it is connected to the vehicle. Therefore, the car navigation system is a reasonable device to assess risk prediction because it can use these information. In addition, the acquiring information is more accurate than other in-vehicle devices. From the above, we considered that the car navigation system is the most suitable in-vehicle device. The purpose of this research is to implement a function to calculate driving behavior indices in the car navigation system and compute them as defined. If we prove this, we can calculate the collision risk from the driving behavior indices and this can be utilized for risk prediction.
In this study, we focused on the indices (vehicle speed and curvature of trajectory during a right turn) [2] proposed in our previous research. The driving behavior indices indicate the collision risk of the right turn at a signal intersection. We utilized a Naturalistic Driving Study (NDS) data to consider the target intersections. We selected right turn scenes with “signal intersection” and “no traffic participants” from the NDS data. We implemented the function to calculate the collision risk with a car navigation system as an actual system and examined it to manufacture for the market.

First, chapter II describes the constraints of the driving behavior indices at right-turn intersections, which was proposed in our previous research, and the design of the method to calculate the indices on a car navigation system. Chapter III describes the driving experiment and evaluation method to evaluate the designed method. Chapter IV describes the evaluation results, Chapter V discuss the results and Chapter VI summarizes the findings obtained in this study.

II. Design

A. Driving Behavior Indices

The previous study focused on a particular scene without other traffic participants (e.g. leading and oncoming vehicles) during a right turn at a signal intersection. This study also targets the same scene. The proposed driving behavior indices are the curvature index of vehicle trajectory $\phi_{cl}$ and the centerline passing speed $V_{cl}$. $\phi_{cl}$ is calculated based on a position where a vehicle passed the centerline and a target destination point of the intersection. $V_{cl}$ is the speed when the vehicle crossed the centerline. The curvature of the trajectory $\phi_{cl}$ of right turns is represented by the equation (1) on Fig. 1. $\theta_{dst}$ in the formula represents the angle between the front direction of the vehicle and the target destination point, $D_{dst}$ represents the distance from the center of gravity of the vehicle to the target destination point, and $FL_{hr}$ represents the distance from the vehicle's center of gravity to the vehicle's front-end. In addition, when a vehicle passed the centerline means the point of time a vehicle enters the opposite lane. A driving experiment showed that collision risk against pedestrians can be assessed with the two indices under a controlled environment.

$$\phi_{cl} = \frac{\theta_{dst}}{D_{dst} - FL_{hr}}$$  \hspace{1cm} (1)

![Fig. 1: Model scene for $\phi_{cl}$ definition](image)

B. Calculation Algorithm on Car Navigation System

The data of the vehicle including speed and driving direction, decision of turning right, start and end points of right turns are required to compute the indices described in the previous section. Deciding whether the vehicle will make a right turn or not and identifying where the start and end points of the right turn are after a right turn has been made is easy. However, the calculation method for driving behavior indices on a car navigation system needs to decide whether the vehicle will make a right turn and set the start and end points of a right turn in real-time. We used features of a navigation system to identify these elements in real-time. First, we used the route information of the system to decide whether the vehicle will make a right turn at an intersection. As for the start points of a right turn, we set the start point as a point where the driver started to turn their steering wheel to the right as shown in Fig. 3 because the centerline passing point is a consequence of the drivers commencement of steering. For the end point, it is defined as a point on the crosswalk. However, it is difficult to predict the position where the vehicle will pass the crosswalk in advance. Therefore, we set the end point of right turn as a point certain distance away from the center of intersection in the right turn direction. The distance will be identified using the information from the map database. To make the result close to the definition as possible, the distance
from the center of intersection used in this research was measured and set in advance. Fig. 4 shows the flowchart of this calculation process. We set 2 m for $FL_{hv}$ because the front length of a general vehicle is approximately 4 m.

Fig. 2: Car navigation system related chart

Fig. 3: Start and end points of right turns

Fig. 4: Calculation flowchart

III. Methods

A. Target Intersection

We used an NDS data to examine and consider the suitable type of intersection for the driving experiment. The NDS data utilized in this research was a driving behavior database (Driving Behavior DB) in various environments that were collected as part of the “Smart Mobility System Research, Development and Demonstration Project” which was a consigned project of the Ministry of Economy, Trade and Industry of Japan.
First, we extracted right turn scenes from the driving behavior DB. This data records the data such as the use of the right turn blinker, speed, the change of the intersection link. The right turn scenes were extracted based on these information. These scenes include right turns that are not applicable for the driving behavior indices. Therefore, we extracted manually the right turn scenes that there were no other traffic participants other than the vehicle with a viewer tool. Table 1 show the intersection size and crossing angle of the extracted right turn scenes. Here, the roads are classified according to the number of lanes. The roads are classified into three types; road with no centerline, one lane on each side, and two lanes or more on each side. In addition, the intersection angles are classified as less than 80 °, 80 ° to 100 ° and more than 100 °. The intersection angle is calculated clockwise on the direction of the vehicle at the intersection entrance. That is, if the intersection angle is 60 °, the vehicle will turn an obtuse intersection and if it is 120 °, the vehicle will turn an acute intersection. From these results, we selected the intersection which crossing angle is approximately 90 °, the number of lanes of entrance road is one or two and the number of lanes of the exit side road is one as the target intersection.

<table>
<thead>
<tr>
<th>Total N = 55</th>
<th>Exit road of intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entrance road of intersection</strong></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

**Note**: 0: Road with no center line, 1: Road with 1 lane on each side, 2: Road with 2 or more lanes on each side

### B. Driving Experiment

The purpose of the experiment is to calculate the driving behavior indices with a car navigation system and to evaluate the accuracy of the calculated indices. We set a test route which includes four different intersections on a public road. The vehicle used for the experiment was NOAH (Toyota Motor Corp.), and a test driver ran ten rounds on the test course. There was no right turn lane only at intersection C. We acquired the navigation sensor data so that we can utilize the same data with a car navigation system and a PC to calculate the indices according to the definition. Table 2 shows the properties of the intersections in the test course.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Entrance road of intersection</th>
<th>Exit road of intersection</th>
<th>Distance from CoI [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>1</td>
<td>10.40</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>1</td>
<td>7.60</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
<td>10.45</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>1</td>
<td>10.30</td>
</tr>
</tbody>
</table>

**Note**: 0: Road with no center line, 1: Road with 1 lane on each side, 2: Road with 2 or more lanes on each side

### C. Comparison of Calculated Results

We compared the driving behavior indices computed with the proposed method for a car navigation system and the indices computed according to the definition to evaluate the proposed method. To calculate the indices according to the definition, we used a viewer tool on a PC to play the driving data and set the start and end points of a right turn manually by looking at the camera images.

We compared the result from the car navigation system and the PC, and verified if the result was accurate. We evaluated the root mean square error (RMSE) from the comparison of the PC and the navigation system result. We investigated the distribution of the driving behavior indices $V_B$ and $\phi_B$, and evaluated the variation of the errors.

### IV. Result

We acquired the data that the test driver ran the test course for ten rounds. However, we could not acquire data of a right turn without any other traffic participants at the intersection at intersection A and B due to the high-
volume traffic. We compared the correct values and the calculated values from the navigation sensor data of the ten right turns acquired on each intersection C and D.

Table 3 shows the average RMSE ratio of the driving behavior indices calculated with the proposed method to the indices value computed according with the definition. Fig. 6 shows the distribution of the driving behavior indices’ RMSE ratio for each intersection C and D. RMSE ratio of $V_{cl}$ ranged from -15% to 20% in both intersections and the average was approximately 10%. RMSE ratio of $\varphi_{cl}$ were all positive at intersection C, but there were both positive and negative at intersection D. Compared to $V_{cl}$, the RMSE ratio of $\varphi_{cl}$ and the indices that consists $\varphi_{cl}$ ($D_{dst}$ and $\theta_{dst}$) were large.

Table 3: Error of driving behavior indices calculated by car navigation system

<table>
<thead>
<tr>
<th>Intersection</th>
<th>$V_{cl}$ [m/s]</th>
<th>$\varphi_{cl}$ [rad/m]</th>
<th>$D_{dst}$ [m]</th>
<th>$\theta_{dst}$ [rad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>12.9%</td>
<td>54.3%</td>
<td>20.5%</td>
<td>57.3%</td>
</tr>
<tr>
<td>D</td>
<td>11.0%</td>
<td>64.8%</td>
<td>33.7%</td>
<td>63.6%</td>
</tr>
</tbody>
</table>

Fig. 6: Difference of driving behavior indices between a car navigation system and the definition

V. Discussion

With regard to $V_{cl}$ calculated with a navigation system, the start points, which were set by the system, were points where the vehicle has not reached the centerline. For this, it is considered that the result became higher compared to the result according to the definition because the driver had not yet lowered his speed at the points set as the start points. $\varphi_{cl}$ is composed of $D_{dst}$ and $\theta_{dst}$ therefore we discuss about $\varphi_{cl}$ with these two indices. There was a large variation of errors for $D_{dst}$, which is the distance from the point vehicle passing the centerline to the target arrival point, the deviation was about 6 m in some cases compared to the value computed according to the definition. These deviations were caused by the difference of the start and end points compared to the definition. The right turn start points are defined as points where the vehicle passed the centerline, but the car navigation system recognized them as moments when the drivers start turning the wheel to the right. The system recognized wrong start points when the driver turned the wheel to get close to the centerline before turning right as shown in Fig. 7 (1). In addition, the system recognized that the steering turned right when the driver started to enter the right-turn lane at intersection D. The car navigation system has judged the end point as a point constant distance away from the center of intersection toward the right-turn direction. However, there was a constant difference between the definition as shown in Fig. 7 (2). It is assumed that the error of $D_{dst}$ derived from these differences in setting the start and end points. Next, the $\theta_{dst}$ was often calculated larger than the definition. The car navigation system judged the moment when the car started heading toward the right turn direction as the start point. However, according to the definition, the start point is the point when the car passed the centerline and this means the car is already heading toward the right-turn direction to some extent. Therefore, it is suggested the difference in setting the start point led to the error of $\theta_{dst}$.

Fig. 6 shows the RMSE ratio of $V_{cl}$ and $\varphi_{cl}$ at intersections C and D and it shows that $V_{cl}$ had a similar tendency, but $\varphi_{cl}$ did not. There was only positive values at intersection C, but there was both positive and negative values at intersection D. RMSE ratio of $\theta_{dst}$ was negative, meaning that $\theta_{dst}$ was smaller than the value according to the definition, at intersection D because the car system failed to set the start point according to the definition and set the start point when the driver started steering when he entered the right-turn lane. The wrong start point was distant from the end point compared with the correct point, and this made $\theta_{dst}$ smaller.
From the above, we discussed that the errors between the indices calculated with the proposed method and that computed according to the definition were due to the setting of the start and end points. The system recognized a wrong position as the right turn start because the steering wheel was turned in situations not considered. The system can recognize the correct right turn start point if we narrow down the area to calculate the start point based on the intersection size included in the digital road map and set a sufficient threshold to detect the start point without misdetection of other situations such as a lane change to the right-turn lane. In addition, the desirable right turn end point could be set on the track of the vehicle by setting a constant offset toward the vehicle trajectory from the intersection center as shown in Fig. 7 (2). Furthermore, the end points were set at a position certain distance away from the intersection link in this research, but if the distance is calculated from a map data, we will be able to support various intersections. If the above is satisfied, the accuracy will be improved.

VI. Conclusion

It is necessary to support drivers with an actual system to reduce pedestrian-vehicle accidents when turning right. Therefore, we focused on the model to calculate collision risk from driving behavior indices during right turns in the previous study. A car navigation system, which is an in-vehicle device, is the most suitable as the actual system, and is implemented with the calculation method of the driving behavior indices. The car navigation system with the method implemented succeeded to compute driving behavior indices.

Moreover, the errors between the indices calculated with a car navigation system and the indices calculated according to the definition with a PC were approximately 10% for the speed index. From this result, we considered that a car navigation system can compute collision risk with the driving behavior indices and the risk prediction system is more feasible. However, the curvature index had a large error of approximately 65%. This error was due to the setting of the start and end points of right turn. We will improve the system to be acceptable to use with the following:

- The car navigation system set the moment when the steering wheel turned to the right as the right turn start point, but it recognized wrong situations such as lane change to the right turn lane and drivers getting closer to the centerline before commencement of right turns. We will narrow down the range to decide the start point and set a sufficient threshold for the turning angle of the vehicle.
- The intersection right turn end point is currently located at the center of the intersection exit, but we will shift it towards the vehicles’ trajectory. We measured the distance of intersection for the intersections included in the experiment to obtain high accuracy, but the actual system will compute the end points depending on the intersection’s size using the map data.

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References
