Do Not Pass Warning System based on Vehicle-to-Vehicle Communication for Curved Roads

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Abstract. This paper proposes a do not pass warning (DNPW) system based on vehicle-to-vehicle (V2V) communication for curved roads. The existing DNPW systems are applicable only to straight roads but not to curved roads. We propose a method to calculate the DNPW zone on a curved road based on the actual relative distance while considering the curvature of the road. Furthermore, we examined whether vehicles were present on each lane of a curved road by using the turning radius. We verified the applicability of the proposed DNPW system by comparing the DNPW zone calculated using the proposed system with that calculated through simulations. The proposed DNPW system can provide a DNPW zone according to a vehicle's speed and location where the vehicle overtakes.

Keywords: Vehicle to Vehicle(V2V), Do Not Pass Warning(DNPW), Curve Road, Overtaking

1 Introduction

With the rapid increase in the number of vehicles, traffic accidents have also increased markedly. According to the data from Korea and overseas, more than 80% of traffic accidents occur owing to the driver's negligence [1][2]. Overtaking is one of the most dangerous driving behaviors, which could lead to various types of accidents, including deviation from road lanes, changes in lanes, and rear-end collisions. Traffic accidents due to overtaking account for 7% of the total traffic accidents in Korea [2][3]. With the advancement of vehicle technologies, a number of studies have been conducted to reduce traffic accidents, and the development of active safety systems. Along with this advancement, studies on combining communication technologies such as vehicle-to-vehicle (V2V) with active safety systems have been actively performed. In particular, in North America, a safety service based on V2V communication has been proposed through the vehicular safety communication applications (VSC-A) project [4]. DNPW is one of the service of VSC-A. DNPW

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operates in dangerous situations when a vehicle approaching from the opposite lane overtakes the preceding car on a two-lane road. A number of studies have been conducted on overtaking on a straight lane including DNPW of VSC-A [5][6]. However, these algorithms applicable to straight lanes are not suitable for curved roads. Therefore, DNPW systems on a curved road should consider the actual relative distance on the road.

In this paper, we propose a DNPW system that considers the curvature of roads. We also analyze the applicability of the DNPW system to curved roads under various conditions.

2  System Design

The DNPW system informs the driver of a host vehicle (HV) whether overtaking is possible depending on the oncoming vehicle (OV) on the opposite lane when the ahead vehicle (AV) is overtaken. When the HV attempts to overtake, a DNPW zone is calculated using the locations of the AV and OV as well as the current speed. If the OV is located within the DNPW zone, the system generates a warning signal. Fig. 1 shows the flow chart of the proposed DNPW system.

![Flow chart of the proposed DNWP system.](image)

Using the curvature radius of a curved road, the actual relative distance termed as the arc relative distance (ARD) was calculated [7]. In the calculation of the DNPW zone, a particular zone was divided into five sections. The first section corresponds to the acceleration distance to be covered by the HV in order to overtake, which is defined as $Distance_1$ and calculated using Eq. (1). The second section is the distance until overtaking is complete, which is defined as $Distance_2$ and calculated using Eq. (2). $ARD_0$ in Eq. (2) refers to the relative distance with the AV when the HV overtakes it. The third section is the distance to be covered for returning to the original lane after overtaking; this is defined as $Distance_3$ and calculated using Eq. (3). $a_y$ in Eq. (3) represents the lateral acceleration according to vehicle speed and $y_d$ denotes the width of the lane [8]. The fourth section corresponds to the driving distance of the OV while the HV is overtaking, which is defined as $Distance_4$ and calculated using Eq. (4). The fifth section is the safe distance with respect to the OV after the HV overtakes; this distance is defined as $Distance_5$ and calculated using...
Eq. (5). $T_\mu$ in Eq. (5) represents the speed and deceleration at the time of stop. The DNPW zone can be calculated by using the expression in Eq. (6).

$$Distance_1 = V_{HV-1} \cdot t_a + \frac{1}{2} a_{HV} \cdot t_a^2$$  \hspace{1cm} (1)

$$Distance_2 = \frac{ARD_{O} - Distance_1}{V_{HV-O} - V_{AV}}$$  \hspace{1cm} (2)

$$Distance_3 = C_xV_o \cdot \frac{\sqrt{y_d}}{a_y}$$  \hspace{1cm} (3)

$$Distance_4 = (T_1 + T_2 + T_3 + T_4) \cdot V_{OLRV}$$  \hspace{1cm} (4)

$$Distance_5 = \frac{V_{HV-O} \cdot T_{\mu,HV} + V_{OLRV} \cdot T_{\mu,OLRV}}{2}$$  \hspace{1cm} (5)

$$DNPW \text{ Zone} = Distance_1 + Distance_2 + Distance_3 + Distance_4 + Distance_5$$  \hspace{1cm} (6)

### 3 Simulation and Results

#### 3.1 Simulation Scenario

Fig. 2 shows the simulation scenario for the verification of the proposed DNPW system. The vehicle-driving scenario was set by changing the speed and $ARD_O$ as shown in Table 1. The DNPW zone calculated using the equations for V2V-based communication for curved roads and that calculated through vehicle dynamic-based simulations were compared. The DNPW zone calculated through simulations considers the initial distance between the HV and OV. If the HV attempts overtaking when the initial distance between the HV and OV is smaller than the DNPW zone, a collision will occur. On the other hand, if the HV attempts to overtake when the initial distance between the HV and OV is larger than the DNPW zone, overtaking will be successful. In this study, the overtaking speed was set as the initial speed +20 [km/h].

![Fig. 2. Simulation configuration.](image)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Test Speed [km/h]</th>
<th>$ARD_O$ [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 1. Simulation scenario
3.2 Simulation Results

Table 2 shows the simulation results. In order to verify the proposed DNPW system, the DNPW zone calculated by the system was compared with that calculated through simulations except for the safe distance $Distance_s$. The experimental results showed that the DNPW zone calculated using the proposed system under each scenario has an error rate within a range of 0.7 to 1.6 [%] compared to the simulation-based DNPW zone, which showed similar results. This result verifies the usability of the proposed DNPW system.

Table 2. Comparison of DNPW zone for different scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Proposed system [m]</th>
<th>Simulation [m]</th>
<th>Error rate [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>245.1</td>
<td>241</td>
<td>1.6</td>
</tr>
<tr>
<td>2</td>
<td>379.8</td>
<td>376</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>891.3</td>
<td>885</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table 3 shows the DNPW zone calculated using the proposed DNPW system according to typical $ARD_o$ in scenarios 1 and 2. The DNPW zone presented as $ARD_o$ is changed to 2, 3, and 4[s]. The DNPW zone is displayed as ±10[%] of the value calculated using the proposed DNPW system.

Table 3. DNPW zone according to $ARD_o$.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Test Speed [km/h]</th>
<th>$ARD_o$ [s]</th>
<th>DNPW Zone[m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>2</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>276</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>326</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>2</td>
<td>399</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>504</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>609</td>
</tr>
</tbody>
</table>

Fig. 3 shows the DNPW zone calculated using the proposed DNPW system as a function of test speed in scenarios 2 and 3. Zone 1, which is wider than the DNPW zone, represents the safe area. The HV can overtake safely if the distance between it and the OV lies within Zone 1. Zone 2 represents the collision area. When the distance between the HV and OV lies within this zone, a collision occurs during overtaking.
4 Conclusion

In this paper, a DNPW system applicable to curved roads was proposed. The proposed DNPW system obtains the location and speed information of the host and surrounding vehicles using V2V communication, and calculates the relative distance on a curved road from the above information to generate a warning signal. We verified the applicability of the proposed DNPW system by comparing the DNPW zone calculated using the proposed system with that calculated through simulations. We also presented a range of DNPW zone calculated using the DNPW system for different scenarios. Finally, we calculated DNPW zones for various test speeds and locations where overtaking occurred.

In the future, we plan to investigate DNPW systems under various overtaking conditions and multi-vehicular environments.

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