RESEARCH ON DRIVER ACCEPTANCE OF LDA (LANE DEPARTURE ALERT) SYSTEM

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ABSTRACT

The purpose of this research is to identify whether the road departure accident reduction performance of the Lane Departure Alert (LDA) system is consistent with driver acceptance. If a vehicle deviates from the lane, the LDA system warns the driver and/or automatically steers the vehicle back into the lane to help avoid an accident. However, the system cannot perform as expected if the driver feels that the system is annoying and turns it off. Therefore, the consistency between the accident reduction performance and driver acceptance of LDA was studied by investigating driving behavior based on a new form of two-dimensional analysis using the distance to the lane boundary (DTLB) and the lateral velocity of the vehicle.

INTRODUCTION

In Japan, in 2013, single-vehicle accidents (such as rollovers and collisions with stationary objects or vehicles) and frontal collision accidents accounted for approximately 21% and 10% of fatal accidents, respectively. A high proportion of these accidents occurred when the vehicle departed from the road [1]. Reducing such road departure accidents is a major challenge in the development of technology to help achieve the ultimate target of zero fatalities and injuries from traffic accidents.

The importance of reducing road departure accidents has also been recognized at a governmental level. For example, in 2011, the National Highway Traffic Safety Administration (NHTSA) in the U.S. began assessments of lane departure warning (LDW) systems developed to help reduce these accidents [2]. Similar assessments have also been introduced in Europe and Japan.

In Japan, human factors such as drowsiness, distraction, and intoxication are involved in approximately 80% of road departure accidents (Figure 1) [3]. Furthermore, it was found that roughly 70% of drivers performed no steering or braking operations after departing the road in these accidents [3]. This suggests that many road departure accidents occur without the driver realizing that the vehicle is departing from the lane.

![Figure 1. Human factors of road departure accidents.](image)

The Lane Departure Alert (LDA) system was developed as a driver support system to help prevent road departure accidents. It uses a forward monitoring camera to recognize the markings that identify lane boundaries. If there is a high probability of lane departure, LDA warns the driver and/or performs control to steer the vehicle back inside the lane. When in operation, this system is reported to be an effective way of helping to prevent road departure accidents [4].
However, if LDA activates frequently in non-dangerous situations, the driver will feel annoyance and switch the system off. Since LDA can have no accident reduction effect if it is not switched on, it is important to design a system that is both effective at reducing accidents and that will not be turned off by the driver. This paper describes research into the feasibility of reducing both accidents with the LDA steering control and driver annoyance by investigating and analyzing driving behavior.

**RELATIONSHIP ANALYSIS OF LDA ACTIVATION FACTORS**

To study how to help reduce accidents while minimizing driver annoyance with the system, this section analyzes the relationship between the key LDA control factors. As shown in Figure 2, there are three control factors: the maximum lateral distance traveled out of the lane (A), the steering control magnitude (B), and the intervention timing (C). Since the maximum lateral distance traveled out of the lane must be restricted to help reduce road departure accidents, the research first examined a control target for this factor.

Figure 3 shows the distribution for the lateral distance traveled beyond the lane boundary in road departure accidents, as described in the 2007 Traffic Accident Investigation and Analysis Report by the Japanese Institute for Traffic Accident Research and Data Analysis (ITARDA) [3]. The bars in the graph show the number of road departure accidents and the line shows the cumulative distribution. This figure indicates that at least 80% of road departure accidents occur with lateral distance traveled out of the lane of 0.5 m or more. In other words, activating the LDA system so that the lateral distance traveled out of the lane is 0.5 m or less may be an effective measure for at least 80% of road departure accidents. Therefore, the development aimed to restrict the maximum lateral distance traveled out of the lane to less than 0.5 m using the functions of the LDA system.

**Figure 2. LDA control factors.**

**Figure 3. Distribution of lateral distance traveled out of lane in road departure accidents.**

Next, the research examined the relationship of the lateral distance traveled out of the lane with the steering control magnitude and intervention timing. To restrict the lateral distance traveled out of the lane, it is possible to either increase the steering control magnitude (proposal 1) or adopt the earlier intervention timing (proposal 2). In contrast, however, smaller steering control magnitude and later intervention timing are preferable conditions for minimizing driver annoyance with the system. As shown in Figure 2, this paper expresses the intervention timing using the
distance to the lane boundary (DTLB) variable. DTLB defines the direction toward the inside of the lane as a positive value, taking the lane boundary as the origin point. Figure 4 shows the results for proposal 1 (greater steering control magnitude) and the results for proposal 2 (earlier intervention timing). Each graph indicates how the maximum lateral distance traveled out of the lane (i.e., the minimum DTLB) varies with different steering control magnitudes and intervention timings, respectively. The simulations assumed the following conditions for calculation: a vehicle speed of 100 km/h, an initial lateral velocity (i.e., the speed at which the vehicle approaches the lane boundary) of 1.0 m/s, and a vehicle response delay for the steering control after lane boundary recognition of 0.5 s. The maximum lateral acceleration was set to 1.0 m/s² in accordance with the technical guidelines established by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) [5]. The intervention timing in proposal 1 was fixed at the DTLB of 0.2 m and the yaw acceleration in proposal 2 was fixed at 3.5 deg/s² in Figure 4.

**Figure 4. Results for proposal 1 (greater steering control magnitude) and proposal 2 (earlier intervention timing).**

When the steering control magnitude was increased with proposal 1, the reduction in maximum lateral distance traveled out of the lane (i.e., the increase in minimum DTLB) became markedly less pronounced after the steering control magnitude exceeded 4 deg/s². This is because the maximum lateral acceleration of the steering control has an upper limit, regardless of the speed by which the control starts up. For another reason, the ECU processing time, communication delay, and vehicle response time must be considered before the vehicle responds to the steering control after lane boundary recognition. As a result, the vehicle has already started to depart from the lane when the vehicle response occurs. In this case, adopting earlier intervention timing in proposal 2 should help to reduce the maximum lateral distance traveled out of the lane (i.e., increase the minimum DTLB). The maximum lateral distance traveled out of the lane decreases by the amount that the intervention timing is speeded up. The gradient in proposal 2 is linear. Therefore, based on the results for proposal 2, it was concluded that earlier intervention timing would be more effective than greater steering control magnitude in helping to reduce the maximum lateral distance traveled out of the lane.

**INVESTIGATION AND ANALYSIS OF DRIVING BEHAVIOR**

The previous section identified earlier intervention timing for the steering control as a potentially effective way of reducing the maximum lateral distance traveled out of the lane. However, adopting earlier intervention timing for the steering control may trigger LDA activation in non-dangerous situations, potentially annoying the driver. For example, the LDW assessment performed by NHTSA defines a warning that starts at DTLB of 0.75 m or more as too early and not in compliance with the assessment criteria [2]. The standard issued by the International Organization for Standardization (ISO) also contains the same requirement [6]. These requirements were probably established because a system that activates too early is unlikely to be accepted by drivers. Proposal 2 in Figure 4 indicates that to achieve maximum lateral distance traveled out of the lane of less than 0.5 m, the system must activate at DTLB of approximately 0.8 m when the lateral velocity is 1.0 m/s. However, this means that the system will activate from a position close to the center of the lane, which is highly unlikely to be accepted by drivers.
Therefore, this research examined this issue from another standpoint by investigating driving behavior using a new two-dimensional (2D) form of analysis that incorporates lateral velocity as well as DTLB. It was hypothesized that drivers would drive closer to the lane boundary when the lateral velocity is low but would tend to drive further away from the lane boundary when the lateral velocity is high. This hypothesis was then verified as described below.

Test conditions

Data was acquired by a forward monitoring camera. The DTLB and lateral velocity detected by the camera were then recorded. Table 1 shows the detailed test conditions.

<table>
<thead>
<tr>
<th>Item</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>Lexus GS</td>
</tr>
<tr>
<td>Market</td>
<td>Japan</td>
</tr>
<tr>
<td>Model year</td>
<td>2012</td>
</tr>
<tr>
<td>Camera</td>
<td>Originally equipped on the vehicle for the Lane Keeping Assist (LKA) system</td>
</tr>
<tr>
<td>Position of camera</td>
<td>Top center of windshield</td>
</tr>
</tbody>
</table>

Test method

Informed consent was obtained from at least ten test subjects, who were asked to drive the vehicle described in Table 1 in a normal driving style. The driving behavior of these drivers was then recorded. Table 2 shows an outline of the test scenario and Table 3 describes how the data was acquired.

<table>
<thead>
<tr>
<th>Item</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route</td>
<td>Mainly Aichi, Shizuoka, and Yamanashi in Japan Incl. both highways &amp; general roads</td>
</tr>
<tr>
<td>Drivers</td>
<td>More than 10 people</td>
</tr>
<tr>
<td>Driving style</td>
<td>Normal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle speed</td>
<td>Vehicle CAN</td>
</tr>
<tr>
<td>DTLB</td>
<td>Recognized by camera</td>
</tr>
<tr>
<td>Lane width</td>
<td>Recognized by camera</td>
</tr>
<tr>
<td>Lateral speed</td>
<td>Differential of DTLB</td>
</tr>
<tr>
<td>Road curve radius</td>
<td>Recognized by camera</td>
</tr>
</tbody>
</table>

The measured data includes different lane widths and curve radii. However, it is thought that the lane width and the size of the curve radius change the positional relationship between the vehicle and the lane marking. Therefore, the lane width and the size of the curve radius were categorized from (a) to (i) as shown in Table 4 and then analyzed. Since the inside of a curve is more likely to intersect with the driving region, the DTLB and lateral velocity at the inside of the curve were used. The “Curve G” value in Table 4 is the square of the vehicle speed divided by the curve radius.
### Table 4
Classification of recorded data.

<table>
<thead>
<tr>
<th>Curve G [m/s²]</th>
<th>Up to 0.5</th>
<th>0.5 to 1.5</th>
<th>1.5 to 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width [m]</td>
<td>From 3.25</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>2.75 to 3.25</td>
<td>d</td>
<td>e</td>
</tr>
<tr>
<td></td>
<td>Up to 2.75</td>
<td>g</td>
<td>h</td>
</tr>
</tbody>
</table>

#### Test results

In the test, normal driving behavior was recorded over total distance of 16,285 km. Most data was recorded at a speed of 50 to 60 km/h on general roads and at around 100 km/h on highways. In all regions where a lane marking was detected by the camera, 2D distribution of the DTLB and lateral velocity was plotted and the distribution indicated by color. The red areas indicate high frequencies and represent normal driving behavior. The blue areas indicate low frequencies. Figure 5 shows the plotted results for category (a) in Table 4.

According to Figure 5, the highest frequency is obtained at a lateral velocity of 0 and DTLB of 0.8. This has ellipsoidal distribution. When driving straight in the center of the lane, the driving behavior is likely to be close to the center of this ellipsoidal region.

An approximation was carried out using 2D normal distribution to analyze the distribution in Figure 5 statistically. First, the correlation coefficient between the DTLB and lateral velocity was calculated to be -0.0076. Since this indicates virtually no correlation, the probability density distribution \( f(v_y, D) \) of the 2D normal distribution was calculated following Equation 1, where, \( v_y \) is the lateral velocity, \( D \) is the DTLB, \( \sigma_{v_y} \) is the standard deviation of \( v_y \), \( \sigma_D \) is the standard deviation of \( D \), \( \bar{v_y} \) is the average of \( v_y \), and \( \bar{D} \) is the average of \( D \).

\[
f(v_y, D) = \frac{1}{2\pi \sigma_{v_y} \sigma_D} \exp \left[ -\frac{1}{2} \left( \frac{(v_y - \bar{v_y})^2}{\sigma_{v_y}^2} + \frac{(D - \bar{D})^2}{\sigma_D^2} \right) \right] \tag{1}
\]

To calculate the regions with the highest probability in which normal driving occurs, an ellipsoidal isopleth drawn between positions of equal values in the 2D normal distribution was used. The probability of data falling inside this ellipsoid was calculated following Equation 2 by integrating Equation 1 using the region inside the ellipsoid (S) defined when the exponential part of Equation 1 is set to \(-C^2/2\).

\[
P = \iint_S f(v_y, D) dS = \iint_S \frac{1}{2\pi \sigma_{v_y} \sigma_D} e^{-\frac{c^2}{2}} dD \cdot dv_y = 1 - e^{-\frac{c^2}{2}} \tag{2}
\]

This calculation was applied to the data in Figure 5. Figure 5 also shows the ellipsoid drawn when the result of Equation 2 is 99%. The actual proportion of data inside the ellipsoid is 98.2%, indicating that the margin of error for the 2D normal distribution model is 0.8%, which is regarded as a comparatively close approximation.

The 99% ellipsoidal isopleth indicates that virtually all driving behavior is within this ellipsoid. Therefore, Figure 5 shows that, as the lateral velocity increases, the ellipsoid (lower limit) moves further away from the lane boundary (DTLB=0). This result quantitatively verifies the hypothesis for category (a).
Categories (a) to (i) in Table 4 were analyzed in the same way. Figures 6 shows the 99% ellipsoidal isopleth results for each lane width. All results follow the hypothesis. In addition, Figures 6 also indicates an increasing trend for vehicles to depart from the lane as the curve radius becomes sharper and the lane becomes narrower, and at lower lateral velocities.

**Figure 5. Driver behavior analysis using 2D normal distribution.**

**Figure 6. Driving regions in each lane width and relationship with intervention timing.**
DISCUSSION

Driving behavior was identified in the previous section. The following section discusses the driving regions analyzed above and the consistency of the target maximum lateral distance traveled out of the lane (0.5 m). The required intervention timing to achieve maximum lateral distance traveled out of the lane of 0.5 m was calculated and the driving regions were plotted on the same graph (Figure 6). This graph assumes a vehicle speed of 100 km/h, a yaw rate gradient of 3.5 deg/s², and a vehicle response delay for the steering control after lane boundary recognition of 0.5 sec.

Figure 6 indicates that, as the lateral velocity increases, the target of 0.5 m is not achieved without earlier intervention timing. In addition, the driving regions analyzed above (i.e., the 99% ellipsoidal isopleth results) were plotted on the same graph. The DTLB lower limit values for the driving regions also increase in accordance with the lateral velocity. As a result, the figure shows that the required intervention timing almost entirely does not intersect with the driving regions. This means that it should be possible to achieve the target maximum lateral distance traveled out of the lane of 0.5 m when LDA control is started outside the driving regions.

From these results, the newly proposed 2D analysis of driving behavior using DTLB and lateral velocity shows that it may be possible to help reduce both accidents and driver annoyance with the system by adopting later intervention timing when the lateral speed is low, and earlier intervention timing when the lateral speed is high.

CONCLUSIONS

This paper studied how to help reduce both accidents and driver annoyance with the LDA system by investigating and analyzing driving behavior. The following results were obtained.

- Normal driving behavior was identified using a 2D analysis method incorporating DTLB and lateral velocity. It was found that drivers approached or crossed the lane boundary when the lateral velocity was low, but drove further away from the lane boundary as the lateral velocity increased.
- The normal driving position is affected by the size of the curve radius and the lane width. It was found that drivers tended to depart from the lane as the curve radius becomes sharper and the lane becomes narrower, and at lower lateral velocities.
- The possibility of intersection between the driving region and LDA activation falls when later intervention timing is adopted at low lateral speeds and earlier intervention timing is adopted at high lateral speeds. Based on this concept, it may be possible to help reduce both accidents and driver annoyance with the system.

This research assumed that activation of the system would not be invasive outside the 99% driving region. However, if strong steering control is applied in this case, the system is unlikely to be accepted by drivers. Therefore, further research is needed into the relationship between the steering control magnitude and driver acceptance.

REFERENCES