Driver Assistance System to Prevent Unnecessary Deceleration at Signalized Intersection by Indicating Deceleration Required Distance on Road

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ABSTRACT: This study examines a driver assistance system to prevent unnecessary deceleration at a signalized intersection. The assistance system presents the distance required to pass through signalized intersections without decelerating. The driving simulator experiments are carried out to evaluate the performance of the system. The system encourages the earlier deceleration and prevents the unnecessary deceleration. These effects contribute to reduce the fuel consumption. In addition, the assistance system shortens drivers’ reaction time to the emergency deceleration of the preceding vehicle in comparison with the conventional onboard monitor indication. This effect achieved the reduction of the collision risk to the preceding vehicle.

KEY WORDS: human engineering, driver behavior, driver support / Eco Drive, Signalized Intersection [C2]

1. Introduction

Automobile transportation causes serious problems such as the environmental destruction and the energy-resource depletion. Low or zero emission vehicles such as hybrid vehicles and electric vehicles become popular in the market. On the other hand, ecological driving such as earlier deceleration to the red signal contributes energy saving by human drivers instead of technologies. Generally, the automobile most consumes the fuel when a driver accelerates after the onset of the green signal. It is difficult to avoid the acceleration at the green signal by the above-mentioned solutions from the viewpoint of the vehicle and the driver. To solve these problems, it is effective to suppress the re-acceleration by preventing the unnecessary deceleration.

A driver assistance system, which informs the distance of the passage on the road ahead virtually assuming the AR (Augmented Reality) technology. The driving simulator experiments are carried out to evaluate the performance of the system.

2. Assistance System to Prevent Unnecessary Deceleration

This study assumes that the signal information on the signalized intersection ahead can be acquired by road-vehicle communication. The assistance system informs the driver visually of the deceleration required distance by assuming the HUD (Head-Up Display). The deceleration required distance which is denoted as \(d_d(t)\) is the distance which the vehicle will need to travel until the onset of the green signal assuming that the vehicle maintains the current velocity \(v(t)\). This distance is calculated by multiplying the present velocity by the time to the green signal TTG (Time To Green) as follows:

\[
d_d(t) = v(t) \cdot \text{TTG} \tag{1}
\]

If the distance to the intersection from the vehicle is longer than the deceleration required distance, the vehicle does not have to slow down. On the other hand, if the distance to the intersection is shorter than the deceleration required distance, the vehicle has to slow down to prevent unnecessary deceleration.

Figure 1 illustrates the schematic diagram of indicating the deceleration required distance on the road for the driver assistance. The deceleration required distance is indicated as a red colored rectangular as shown in Fig. 1(a). If the vehicle is on the rectangular as shown in Fig. 1(b), the rectangular is blinked to make the driver aware of the braking behavior. The blinking speed depends on how the deceleration is required. The faster blinking is corresponding to the higher deceleration.

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3. Effectiveness of Assistance System

3.1. Experimental Method

Driving simulator experiment is carried out with participants who travel a straight road through some signalized intersections. This study uses the CarSim DS 8.2.2 (Mechanical Simulation Corporation) as shown in Fig. 2 for the driving simulator experiment. This experiment evaluates the effectiveness when indicating the deceleration required distance on the road ahead virtually. The participants are required to drive with and without the assistance system.

Figure 3 illustrates the experimental conditions of signal timing. Here, TTI (Time To Intersection) means the predicted time that the vehicle arrives at the stop line (intersection entrance) by maintaining the present velocity. The TTI is simply calculated by the distance to the intersection \( d(t) \) divided by the vehicle velocity \( v(t) \). The standard condition of signal timing is based on TTG=TTI. In addition, the signal timing conditions are set to TTG=TTI±2s, ±4s, ±6s. The conditions in TTG<TTI mean that the deceleration is unnecessary with the present velocity as shown in Fig. 3(a). On the other hand, the conditions in TTG>TTI means that the deceleration is necessary as shown in Fig. 3(b).

The participants pass through several intersections, which include dummy conditions of TTG<TTI−4 (earlier green signal onset) and TTG>TTI+6 (later onset), and cannot expect the signal timing in a random order.

Indication image of the evaluation index is shown in Fig. 4. The evaluation index is indicated on the road ahead virtually by assuming the Head-Up Display (HUD), after the vehicle passes through the position of −167m (corresponding to 10s before arriving at the intersection with maintaining the vehicle speed of 60km/h).

The participants accelerate to 60km/h (=16.7m/s) from the stop situation. After the acceleration, the participants are required to maintain the velocity 60km/h until the beginning of the indices indication with the assistance system or they recognize the need of deceleration by themselves without the assistance system.

The seven males in their 20’s (Participant A through G) participated in the simulator experiment. All the participants gave their written informed consent before the experiment. The practice drive was conducted to familiarize themselves with the simulator driving and the indicating behavior of the assistance system. After the practice drive, the participants drove with the assistance system at first, then they drove without the assistance system. These two driving conditions, i.e. with and without the assistance system, were repeated twice to make all four trials for each participant.
3.2. Experimental Results

Figure 5 illustrates an example of the vehicle velocity with and without the assistance system (1st trial by Participant A) in the condition of TTG=TTI−2s (deceleration unnecessary condition). In this figure, 0s in the horizontal axis means the signal change timing from the red to green, and −8s corresponds to the start timing of the assistance.

The driver with the assistance system (solid line) maintains the vehicle velocity and enters the intersection, whereas the driver without the assistance system (dashed line) initiates the braking behavior during the red signal and accelerates after turning to the green signal (0s).

The positions of the vehicle versus time are shown in Figs. 6 (a) (with assistance) and 6 (b) (without assistance). In this figure, the solid line indicates the vehicle position, and the dashed line is the front end of the deceleration required distance. In fact, the evaluation index is not indicated on the road without the assistance system, so the index without the assistance system is shown for reference. 0m in the vertical axis means the stop line (entrance of the intersection).

The driver with the assistance system can recognize that the deceleration is not required because the vehicle does not reach the deceleration required distance. Therefore, the driver maintains the vehicle velocity and enter the intersection. On the other hand, the driver without the assistance system decelerates though the vehicle does not need to decelerate.

Figure 7 illustrates an example of the vehicle velocity with and without the assistance system (1st trial by Participant A) in the condition of TTG=TTI+4s (deceleration necessary condition). In this figure, −14s in the horizontal axis corresponds to the start timing of the assistance. The driver with the assistance system (solid line) decelerates earlier and maintains the velocity until turning to the green signal because the driver recognizes the minimum required deceleration, whereas the driver without the assistance system (dashed line) decelerates later, and the delayed deceleration makes the lower velocity and the unnecessary acceleration to recover the velocity.

The vehicle position with and without the assistance system in TTG=TTI+4s is depicted in Fig. 8. The driver with the assistance system can recognize that the vehicle arrives at the intersection by maintaining the present velocity before turning to the green signal. The driver, therefore, initiates the braking maneuver to escape from the deceleration required distance. After escaping the deceleration required distance, the driver finishes the deceleration. On the other hand, the driver without the assistance system decelerates later by approaching the intersection.
Figure 9 illustrates the average and standard deviation of minimum velocity with and without the assistance system. This figure shows the average of 14 trials (total of the two trials for the seven participants). The results in the deceleration unnecessary conditions are shown in Fig.9(a), and the deceleration necessary conditions are in Fig.9(b). In the deceleration unnecessary conditions, the drivers with the assistance system avoids the velocity reduction in each signal timing, while the drivers without the assistance system make the lower velocities as the later green signal timing. In addition, the assistance system in the deceleration necessary conditions suppresses the velocity reduction in comparison with the results without the assistance system.

Next, the fuel consumption is examined by the fuel consumption rate map in the DS software. The output of engine this study uses is 150kw, and the density of gasoline is 0.77kg/l. Figure 10 illustrates the average and standard deviation of fuel consumption with and without the assistance system. The results in the deceleration unnecessary conditions are as shown in Fig.10(a), and the deceleration necessary conditions are in Fig.10(b). The effects of the assistance system on the fuel consumption have same tendency to the minimum velocity. The assistance system improves the fuel economy not only in the deceleration unnecessary conditions, but also in the deceleration necessary conditions.
4. Comparison of Indicating Method

In the previous section, the effectiveness of the proposed assistance system is confirmed by comparison between the results with and without the system. In this section, the advantage of the proposed assistance system is examined by compared with the onboard monitor as the conventional assistance system. The DS experiment is carried out to examine the driver’s reaction in the emergency situation, such as the emergency deceleration of the preceding vehicle. The participants are required to follow the preceding vehicle with the two assistance systems, i.e. the proposed assistance system and the assistance system with the onboard monitor.

The indicated evaluation index for the onboard monitor is referred to as Deceleration Required Index (DRI). The DRI means the need of the deceleration that the vehicle arrives at the stop line by maintaining the current velocity. This index is calculated by the deceleration required distance \( d_d(t) \) divided by the distance from the stop line to the present vehicle position \( d(t) \) as follows:

\[
\text{DRI} = \frac{d_d(t)}{d(t)} = \frac{v(t) \cdot \text{TTG}}{d(t)} = \frac{\text{TTG}}{\text{TTI}} \quad (2)
\]

Figure 11 illustrates the image of the DRI indicator displayed in the ego vehicle. If the DRI is less than 1 as shown in the left side of Fig. 11, the vehicle does not have to slow down. If the DRI is more than 1 as shown in the right side of Fig. 11, the vehicle has to slow down to prevent unnecessary deceleration.

The participants follow the preceding vehicle with acceleration and deceleration on a straight road on one side lane. The evaluation index is indicated after the vehicle passes through the position of \(-222\text{m}\) (corresponding to \(20\text{s}\) before arriving at the intersection with maintaining the vehicle speed of \(40\text{km/h}\)).

Figure 13 illustrates a sample of velocity pattern of the preceding vehicle. The preceding vehicle accelerates from \(40\text{km/h}\) to \(60\text{km/h}\) with \(1\text{m/s}^2\). After that, the preceding vehicle makes an emergency deceleration with \(6\text{m/s}^2\) (Event). In addition, two dummy conditions, the ordinary deceleration (Deceleration) and no deceleration (Constant), are included in a random order to avoid the driver’s expectation of the emergency event. The event condition of signal timing is set to \(\text{TTG}=\text{TTI}-7\text{s}\).

The practice drive was conducted to familiarize themselves with the DRI indicator behavior. After the practice drive, the participants drove with the on-road indication at first, then they drove with the onboard monitor. These two driving conditions were repeated twice to make all four trials for each participant.

4.1. Experimental Method

The indication image of the onboard monitor is shown in Fig. 12. The above-mentioned seven males participated in the simulator experiment. All the participants gave their written informed consent before the experiment.

4.2. Experimental Results

Figure 14 illustrates an example of the ego vehicle velocity when the preceding vehicle makes an emergency deceleration (1st trial by Participant A). The solid line indicates the ego vehicle velocity with the on-road indication and the dashed line is the velocity with the onboard monitor. 0s in the horizontal axis

\[
\begin{align*}
\text{Constant} & \quad \text{Deceleration} & \quad \text{Event} \\
\text{Velocity [km/h]} & \quad \text{Time [s]} & \\
& \quad & \\
0 & \quad 30 & \quad 60 \\
10 & \quad 90 & \quad 120 \\
20 & \quad & \\
30 & \quad & \\
40 & \quad & \\
50 & \quad & \\
60 & \quad & \\
70 & \quad & \\
& \quad & \\
\text{Velocity [m/s]} & \quad \text{Time [s]} & \\
0 & \quad -5 & \quad 5 \\
5 & \quad -4 & \quad 4 \\
10 & \quad -3 & \quad 3 \\
15 & \quad -2 & \quad 2 \\
20 & \quad -1 & \quad 1 \\
& \quad & \\
\text{Preceding vehicle} & \quad \text{Ego vehicle (on-road indication)} & \quad \text{Ego vehicle (onboard monitor)} \\
& \quad & \\
\end{align*}
\]

Fig. 13 Sample velocity pattern of preceding vehicle.

Fig. 14 Vehicle velocity with emergency deceleration of preceding vehicle (1st trial by Participant A).
corresponds to the emergency deceleration timing of the preceding vehicle.

The on-road indication is helpful to shorten the reaction time and to avoid the emergency deceleration in comparison with the onboard monitor.

The average and standard deviation of reaction time of brake pedal operation is depicted in Fig. 15. The drivers with the on-road indication initiates the braking operation earlier than the onboard monitor. The on-road indication could reduce the reaction time of brake pedal operation with a significant difference under the 1% level.

Figure 16 illustrates the average and standard deviation of maximum deceleration. The on-road indication suppresses the maximum deceleration with a significant difference under the 1% confidential level. The on-road indication avoids the emergency deceleration.

The average and standard deviation of minimum value of the TTC (Time To Collision) to the preceding vehicle is depicted in Fig. 17. The on-road indication increases the minimum value of the TTC with a significant difference under the 10% confidential level. The on-road indication contributes the safety to the preceding vehicle emergency deceleration.

5. Conclusion

This study examines the driver assistance system which indicates the information on the deceleration necessity on the road ahead virtually. The driving simulator experiments are conducted to evaluate the proposed assistance system. The driving simulator experiment revealed the assistance system prevents the unnecessary deceleration and makes it possible to improve the fuel consumption. In addition, the proposed assistance system reduces drivers’ reaction time to the emergency deceleration of the preceding vehicle compared with the onboard indication. The on-road indication contributes the safety driving.

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