Abstract

This study examines a driver assistance system at a signalized intersection to improve safety and fuel consumption by indicating predicted signal aspects on the road. The driver assistance system informs the driver visually of the predicted signal aspects on the road by assuming the Augmented Reality (AR) technology. The predicted signal aspects are calculated by the current vehicle velocity and the signal phase. The driving simulator experiment is carried out to evaluate the driver assistance system. The assistance system encourages the earlier deceleration and prevents the emergency braking behavior. In addition, the assistance system avoids the unnecessary speed reduction and improves the fuel consumption. This effect depends on the assistance onset timing.

I. Introduction

Automobile transportation causes serious problems such as traffic accidents, environmental destruction and energy-resource depletion. Many traffic accidents occur not only at unsignalized intersections but also at signalized intersections. “Dilemma zone” may cause traffic accidents at signalized intersections [1]. The dilemma zone is an area in which it is difficult for a driver to decide to pass through or stop at the intersection when the green signal turns to the amber signal. In addition, the automobile most consumes the fuel when a driver accelerates after the onset of the green signal.

A driver assistance system, which informs passage possibility at a signalized intersection ahead through an onboard monitor, is commercialized using road-vehicle communication [2]. However, the assistance system with the onboard monitor may cause the driver’s distraction to be led to unexpected accident such as the rear-end collision to the preceding vehicle.

The assistance system that informs the driver of passage possibility indicating on the road is proposed to improve safety at the signalized intersection [3]. The assistance system which indicates deceleration necessity on the road is also proposed to improve the fuel consumption [4]. This study examines a driver assistance system which indicates the predicted signal aspects on the road to integrate the above-mentioned assistance systems for safety and fuel-saving driving. The driving simulator experiment is carried out to evaluate the assistance system.

II. Driver Assistance System

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 predicted signal aspects on the road by assuming the Head-Up Display (HUD). This study uses two evaluation indices for the driver assistance. One is GO index [3], and the other is NOGO index [4].

The GO index is composed of two distances, the entry possible distance and the passage possible distance. The
entry possible distance, which is denoted as \( d_e(t) \), is the distance which the vehicle will travel until the onset of the red signal assuming that the vehicle maintains the current velocity \( v(t) \). The entry possible distance is calculated by multiplying the current velocity by the time to the red signal TTR (Time To Red) as follows;

\[
d_e(t) = v(t) \cdot \text{TTR}
\]  

(1)

The passage possible distance, which is denoted as \( d_p(t) \), is the distance which the vehicle will travel until the onset of the green signal of the cross road, i.e. the end of all the red signals, assuming that the vehicle maintains the current velocity. The passage possible distance is calculated by multiplying the current velocity and the time to the green signal of the cross road TTGc (Time To Green) as follows;

\[
d_p(t) = v(t) \cdot \text{TTGc}
\]  

(2)

Fig. 1 illustrates the schematic diagram of indicating the GO index on the road for the driver assistance. The GO index is indicated as a green colored rectangular. If the distance to the intersection from the vehicle is shorter than the GO index as shown in Fig. 1, the vehicle can enter and pass through the intersection by maintaining the current velocity.

The NOGO index is the deceleration required distance which is denoted as \( d_d(t) \). This is the distance which the vehicle will travel until the onset of the green signal assuming that the vehicle maintains the current velocity. The deceleration required distance is calculated by multiplying the current velocity by the time to the green signal TTG (Time To Green) as follows;

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

(3)

Fig. 2 illustrates the schematic diagram of indicating the NOGO index on the road. The NOGO index is indicated as a red colored rectangular. If the distance to the intersection from the vehicle is shorter than the NOGO index as shown in Fig. 2, the vehicle has to decelerate to avoid the unnecessary speed reduction.

The above-mentioned two indices are integrated to indicate the predicted signal aspects when the vehicle arrives at the intersection. If the vehicle is on the GO index as shown in Fig. 3(a), the vehicle does not has to decelerate. On the other hand, if the vehicle is on the NOGO index as shown in Fig. 3(b), the vehicle has to decelerate to prevent the unnecessary speed reduction.

(a) Possible to enter (Not required to decelerate)  
(b) Impossible to enter (required to decelerate)

Fig. 3 Schematic diagram of indicating evaluation indices
III. Driving Simulator Experiments

A. Experimental Method

Driving simulator experiment is carried out with participants who travel a straight road through nine signalized intersections without a preceding vehicle. The distance between each intersection is 500m, and the participants travel a distance of 4,000m in one trial. This study uses the fixed-base driving simulator “DS-nano-” [5] as shown in Fig. 4. The participants are required to drive with and without the assistance system.

The duration of the green, amber and red signals are set to 62s, 3s, and 35s (including 2s of all the red signals), respectively, for all signals. The assistance onset timing may affect the effectiveness. Therefore, the assistance onset timing is placed at three positions. One is the position immediately passing one intersection before, which is referred to as the “early” condition. The other positions are 333m (middle) and 167m (late) before the intersection (corresponding to 20s and 10s before arriving at the intersection with maintaining the velocity of 60mk/h), respectively. Indication image of the GO/NOGO indices is shown in Fig. 5.

The participants accelerate to 60km/h 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 six males in their 20’s 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 (three onset timing conditions) at first, then they drove without the assistance system. These four driving conditions were repeated twice to make all eight trials for each participant.

B. Experimental Results

Fig. 6 illustrates an example of the vehicle position and velocity with and without the assistance system. The earlier assistance onset timing makes the earlier deceleration and the later approach to the intersection. The

Fig. 4 Overview of fixed-base driving simulator

Fig. 5 Indication image of evaluation indices

Fig. 6 Experimental results of time history
deceleration without the assistance system is latest and it makes the vehicle stop at the intersection. The earlier deceleration avoids the unnecessary speed reduction.

Fig. 7 illustrates the average and standard deviation of fuel economy in one trial with and without the assistance system. This figure shows the average of 12 trials (total of the two trials for the six participants). The earlier assistance onset timing contributes the fuel-saving driving. Even if the assistance onset timing is later, the fuel economy is improved in comparison with the drive without the assistance system.

The average and standard deviation of maximum deceleration in one trial with and without the assistance system is depicted in Fig. 8. The assistance system makes the vehicle decelerate ordinary and prevents the larger deceleration because the driver can recognize the passage possibility before turning to the amber signal. On the other hands, the driver without the assistance system decelerates after turning to the amber signal, and it makes the larger deceleration.

IV. Conclusion

This study examines the driver assistance system which indicates the predicted signal aspects on the road. The driving simulator experiment is conducted to evaluate the driver assistance system. The assistance system encourages the earlier deceleration and prevents the emergency braking behavior. In addition, the assistance system avoids the unnecessary speed reduction and improves the fuel consumption. This effect depends on the assistance onset timing, and the earlier assistance contributes the fuel-saving driving.

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References