Effects of steering control function on driver behavior while turning at an intersection

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ABSTRACT: A right turn accident at an intersection is caused by the driver overlooking a critical pedestrian. We investigated whether safety confirmation behavior for pedestrians will increase by performing steering assisted operations. In our experiment, we analyzed drivers’ gaze behaviors to confirm their safety confirmation behavior, without steering control and with steering control, in a right turn. In the experiment, the JARI-ARV, which can reproduce traffic participants such as pedestrians and oncoming vehicles by computer graphics (CG) was used. The JARI-ARV was equipped with a steering actuator, and steering control logic was also constructed.

KEY WORDS: Augmented reality, Driver assistance systems, Driver behavior, Intersection,

1. Introduction

Many accidents which occur in Japan happen at intersections, or around intersections. For intersections with traffic lights, there are many accidents when turning right. The number of injury casualties includes many bicycles, but for cases of fatal accidents many pedestrians are involved. Of all right turn fatalities, approximately 40% include pedestrians, therefore it is vital to take measures to prevent both deaths and injuries. (1)

Analysis of accident statistics shows that many of the pedestrian accidents are caused by the driver’s failure to detect a critical pedestrian. Fig.1 shows a summarized version of the analysis results (factor chain) at an intersection right turn, from a study (2) that analyzed factors of pedestrian collision risk (DREAM analysis) using near miss data. As shown in the figure, the following were suggested as the background of collision risk (near miss) with pedestrians:

- Incorrectly judging that the vehicle can be started without recognizing the potential hazard of a pedestrian crossing, to the right (the pedestrian in approach) (C2), and starting the right turn (A1).
- The background of the erroneous judgment above is the necessity of attention allocation (safety confirmation) (E2, E2) to oncoming vehicles and preceding vehicles, and that those were temporary obstacles to vision (K1), which caused drivers to make mistakes in recognition (B1).

This previous study also showed the driver tends to increase the priority of control in the direction of travel of the vehicle with respect to the safety confirmation regarding the right turn at the intersection shown in Fig.2.

![Fig.2 Visual task of a driver while turning right an intersection](image)

It has been confirmed that drivers’ safety confirmation can be encouraged by teaching information about these factors. (3)

In this current study, we performed preliminary investigation of the effects of automated steering functions on drivers’ safety confirmation behavior by using the Japan Automobile Research Institute’s augmented reality vehicle (JARI-ARV) (4) which can reproduce various traffic situations.

2. Instrumented vehicle

The JARI-ARV is an augmented reality (AR) driving simulator, which is coupled with a real passenger car (Fig.3). The instrumented vehicle has three LCDs (42 inch) and three video cameras on its hood. A driver can operate the vehicle by viewing a frontal scene projected to these LCDs that cover almost a 110-degree horizontal field of view. This display system is defined as “Video see-through” (5). The biggest advantage of the JARI-ARV is that a participant can drive without wearing any optical devices, such as a head mounted display (HMD). This is important to ensure natural visual behavior while driving in a simulated traffic setting.

![Fig.3 Instrumented vehicle](image)
environment.

Fig. 4 shows the configuration of the JARI-ARV. The forward view scenery is captured by a full HD video camera, and is sent to a workstation installed in the vehicle’s cargo space. The workstation combines the real view scenery with 3D CGs (Car, Moped, Cyclist, Pedestrian, etc.). A composite view, which consists of the real road and added virtual traffic participants, is then projected to the LCDs in front of the driver.

The representation of the virtual 3D objects (Fig. 5) is calculated based on the position and orientation of the instrumented vehicle, so that the position and orientation of the JARI-ARV are accurately collected by real time kinematic GPS.

While driving the JARI-ARV, the driver has novel visual experiences compared to standard car driving. The explicit difference is that traffic situations in front of the driver are shown on the three LCDs. This requires the driver to perceive depth information from 2D visual images. Therefore, the performance of vehicle control, especially while turning left or right, could be negatively affected by the visual displays. A less obvious difference is encountering virtual traffic participants. Although the virtual 3D CG objects have realistic features, they are not exactly the same as real traffic. This could lead to differences in the driver’s attention/reaction to the reproduced traffic participants in comparison with real humans or objects. Therefore, we compared the JARI-ARV with a same model vehicle, in terms of the driver’s vehicle control and reaction to other traffic participants, and no difference was found while turning right at an intersection (4).

Fig. 6 Configuration of steering control function

Fig. 7 shows a block diagram of the steering control function. In the Feedforward Controller, the steering angle necessary for basic turning is determined from the vehicle model, and in the Feedback Controller, the correction level is mainly determined from the point of sight model from the Target Trajectory, and the target steering angle is calculated from these two controllers.

3. Steering control System

The configuration of the steering control function is shown in Fig.6. The actuator unit was attached to the steering column of pinion type electric power steering. The Controller controls the actuator based on the value of torque and angle, and GPS that are detected by the sensor, and outputs the appropriate torque for ‘automatic’ and ‘assistance’. The driver can steer from the steering wheel because this function does not disturb the operation performed by the driver.
The target steering angle ($\theta_{\text{target}}$) is calculated from (1), (2), (3)

$$\theta_{\text{FF}}(t) = G_{\text{ratio}} \left(1 + AV(t)^2\right) \frac{l}{R_{\text{map}}(t)}$$  \hspace{1cm} (1)

$$\theta_{\text{FB}}(t) = G_{\text{ratio}} \left(y_{\text{map}}(t) - (y(t) + L\psi(t))\right)$$  \hspace{1cm} (2)

$$\theta_{\text{target}}(t) = w\theta_{\text{FF}}(t) + (1 - w)\theta_{\text{FB}}(t)$$  \hspace{1cm} (3)

where, $\theta_{\text{FF}}$ denotes the Feedforward Control outputs, $\theta_{\text{FB}}$ denotes the Feedback Control outputs, $G_{\text{ratio}}$ denotes the steering gear ratio, $A$ denotes the stability factor, $V$ denotes the vehicle speed, $l$ denotes the wheel base, $R_{\text{map}}$ denotes the curvature of trajectory, $y_{\text{map}}$ denotes the Target Trajectory, $y$ denotes the GPS position, $L$ denotes the front gaze distance, $w$ denotes the weighting, and $\psi$ denotes the yaw angle. The Angle Controller calculates the command torque from the target motor angle and the actual motor angle.

In this experiment, we prioritized the feedforward process rather than the feedback process. The reason is that it is a short section that is only a right turn, because there is no large error by controlling the initial position and angle under the experimental conditions, and the effect of corrective steering at the low speed is likely to be adversely affected. Fig. 8 shows the result of parameter tuning and actually running. The right turn from 25.0sec to 42.0sec controls the steering, and the error between the target trajectory and the actual trajectory is about 0.5m. (Fig.9) The target trajectory was created from a measurement result.

4.1 Objective

In a previous study, it was reported that priority is given to the driver's operation in the the direction of vehicle trajectory when turning right at an intersection, and the priority of the safety confirmation action is lowered.\(^{(10)}\) According the result, automatic vehicle control while turning an intersection can reduce driver’s workload concerning the vehicle control. Therefore, we hypothesized that the frequency and time of safety confirmation actions will be increased because of the decrease of visual workload for turning the vehicle.

As for driving assistance, only the steering control function was added. Driver’s accelerator and brake pedal control is the same as normal driving.

4.2 Methods

On a simulated city road test course at JARI, we reproduced a right turn in an urban area, as shown in Fig.10. Experiments were carried out as follows:

1) Drive following the preceding car on the right side of the road with two lanes in one direction. (the speed of the preceding car is 30km/h)
2) At the right turn intersection, the preceding car also accelerates and stops to make a right turn.
3) After stopping, press the steering control button installed on the left side of the driver's seat. (omitted in the case of manual steering)
4) Accelerate after safe confirmation of the preceding car, and continue to accelerate one’s own vehicle.
5) A Person is standing on the sidewalk of the intersection.
6) Decelerate and stop before the stop line. (Press the steering control button after stopping.)

![Driving course in the experiment](image)

Fig. 10 Driving course in the experiment

We conducted the experiment as the drivers each completed 12 trials of the test course, according to Table 1, for training and actual measurement.

<table>
<thead>
<tr>
<th>Circle No.</th>
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<tr>
<td>1</td>
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<td>2</td>
<td>Training (No CG participants) with steering control</td>
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<td>measurement with steering control</td>
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![Target Trajectory vs Actual Trajectory](image)

Fig. 9 Steering control (trajectory)
Participants were 5 male drivers aged 20 to 40 years old who gave their informed consent after the purpose and content of the experiment was explained beforehand.

4.3 Data analysis
We examined whether the steering control affects the safety confirmation behavior of the driver. For safety confirmation behavior, we focused on the time the driver was closely watching the pedestrian standing by the crossing (Person) and their gaze position, and analyzed these two factors.

An image acquired from a line-of-sight camera is shown in Fig. 11. The road and traffic light on the image are real, the vehicle and Person are CG, and the square points indicate the direction of the line of sight, and the objects indicated ahead of these square positions are called ‘Preceding Car’, ‘Person’, ‘Oncoming Car’, ‘Road’, ‘Other’, and are counted in every frame.

5. Results
We focused on the gaze target of the driver, as an example of the experimental result, and the time series is shown in Fig.12. In the time series, the right is automatic steering control mode, and the left is manual. The vehicle speed, steering angle, and the line of sight object are shown from above. From the graph of the line of sight in the third row, it can be confirmed that the time for confirming a Person has increased. As for the subjects as a whole, when we checked the time to confirm the Person and we summed up the results, the control was increased by 0.5sec comparing ‘with’ and ‘without’ control. (Fig.13)

Therefore, it may be considered that the steering assistance reduced the workload on a driver’s operation, and the time to perform safe behavior increased.

We then focused on the position where the driver confirmed the Person, and an example of an XY plot is shown in Fig. 14. Regarding the confirmed position, comparing with and without control, when driving ‘with control’ the Person is confirmed at the stage where the Y position is small, and the safety confirmation action is faster. Regarding the subjects, when looking at the difference between the Y position of the starting point and the Y position when confirming the Person (Confirm Y position), as shown in Fig.15, the ‘with control’ is approximately 1.4m shorter than ‘without control’, and the safety confirmation behavior of the driver is faster.
Regarding the position to confirm a Person, the trajectory is different for ‘with’ and ‘without’ control, and the case of ‘with control’ starts steering first. Therefore, it can be thought that the Person enters the field of view of the driver first and the driver confirms it faster. Therefore, we analyzed the position of the vehicle and the positional relationship of people when the driver confirmed the Person. As shown in Fig.16, the confirmation angle was calculated from Equation 4 from the yaw angle of the vehicle when the driver confirmed the Person and the position of the vehicle and the Person. The confirm angle (θ_c) is calculated from (4)
\[
\theta_c = \tan^{-1}\left(\frac{Y_p - Y}{X_p - X}\right) - \theta_{yaw}\tag{4}
\]
where, \(\theta_c\) denotes the confirm angle, \(X_p\) denotes the x coordinate Person position, \(Y_p\) denotes the y coordinate Person position, \(\theta_{yaw}\) denotes the yaw angle, \(X\) denotes the x coordinate Person position, and \(Y\) denotes the y coordinate Person position.

The angle was calculated from the yaw angle of the vehicle when the driver confirmed the Person and the coordinates of the vehicle and the Person. (Fig.17) When the value of the angle is small, the position of the Person is close to the front of the vehicle, indicating that the confirmation of the driver is slow.

The result is shown in Fig.18. There was an increase of 5.5 degrees comparing to ‘without control’ to ‘with control’. As a result, irrespective of the trajectory, it was found that the ‘with control’ has better confirmation of the Person at the earlier position than ‘without control’.

It is considered that the timing of performing the safety confirmation action is faster because the driver’s handling operation workload is reduced by the steering control, and the driver confirms the direction of vehicle trajectory at an early stage.

6. Conclusion

One of the factors of accidents that occur when pedestrians are not detected in a right turn at an intersection is that the driver prioritizes control of the direction of vehicle trajectory and reduces the priority of safety confirmation. The driving assistance that controls the direction of vehicle trajectory reduces the operation load of the driver. We hypothesized that instead of reducing the operation load of driving, the driver increased safety behaviors. As an experimental vehicle, the JARI-ARV was equipped with a steering actuator so that steering support could be performed, and control logic for steering was constructed. The steering control was automatic steering. Using this vehicle, we conducted an experiment of turning right at an intersection where there was a preceding car, an oncoming car, and a pedestrian on the sidewalk, under conditions of both steering control and manual steering.

As a result, in the case of steer control, driver's driving behavior is improved compared with manual steering.

1) The length of time to confirm a Person becomes longer.

2) The timing to confirm a Person becomes faster.

From this, it is suggested that the performance of a driver's safety confirmation behavior may be improved by reducing the operation workload of the driver's control of the direction of vehicle trajectory by providing driving support at an intersection right turn.
Providing such driving assistance can be expected to reduce traffic accidents at intersections, especially when turning right.

In the future, in addition to this steering control, we will conduct investigations on the influence of cooperative driving support and full automatic operation including acceleration/deceleration control, etc. We hope to propose the amount of effective driving support required for drivers’ safety confirmation.

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References

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