Investigation of driving behaviour reflecting drivers’ risk anticipation for pedestrian collision risk assessment of right-turns at intersections

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Abstract

The objective of this study is to discover driving behaviour features that indicate pedestrian collision risk of right-turns at intersections for collision risk assessment. Right-turns at intersections is a typical accident scene of vehicle-pedestrian accidents in Japan, and if the collision risk of this scene becomes measurable, driver-assistance-systems will be able to prevent those accidents. To realise the objective, driving behaviour reflecting drivers’ risk anticipation was focused on. Because collisions occur when drivers fail to anticipate risk correctly and driving behaviour is partially determined considering the drivers’ anticipation, collision risk could be evaluated based on the driving behaviour features reflecting risk anticipation. To discover the driving behaviour features, first, near-miss incident data with high collision risk behaviour was analysed. Features of drivers’ visual search and vehicle control were extracted as driving behaviour index candidates. Next, pedestrian collision risk scenes were experimentally reproduced and the relationship between the driving behaviour index candidates and collision risk were investigated. Evaluation indices based on drivers’ visual search behaviour features showed significant correlation with pedestrian collision risk. From the results, it was clarified that pedestrian collision risk is evaluable with driver’s visual search behaviour, and the visual search behaviour feature to realize the evaluation was identified.

Introduction

In Japan, among the fatal traffic accidents occurred in 2015, collisions with crossing pedestrians accounted for the most. Therefore, prevention of traffic accidents involving pedestrians is demanded to decrease the fatalities. If collision risk against pedestrians is evaluable in advance based on driving behaviour, driving-assistance-systems will be able to support the driver to select sufficient driving behaviour for collision avoidance and prevent collisions with crossing pedestrians. To realise such a system, a method to evaluate the collision risk against pedestrians based on driving behaviour is necessary.
Drivers select their driving behaviour (e.g. adjust vehicle speed, adjust margins between objects) not to collide with static objects and other traffic participants based on the risk anticipation of the traffic environment (Van der Hulst et al., 1999). If driving behaviour selected to avoid collision based on driver’s risk anticipation is identified, collision risk could be evaluated by comparing the present driving behaviour with the identified driving behaviour reflecting driver’s risk anticipation. To anticipate the transition of traffic environment and set driving behaviour targets based on the anticipation, drivers use visual information obtained from their eyes. From this fact, not only driving operation and vehicle behaviour but driver’s visual search behaviour is assumed to reflect the driver’s risk anticipation and has the possibility to evaluate collision risk based on the behaviour. Therefore, visual search behaviour as well as driving operation and vehicle behaviour is focused on in this study.

Attention selection of driving is classified into four modes (Trick et al., 2004). Among the four modes, habit and deliberation are known as top-down selection, which are driven by goals and expectation (Engström et al., 2013). Habitual attention is often allocated to places where the main hazards exist based on the driver’s experience, but in some situations if the attention allocation does not suit the actual situation it becomes critical. To avoid it, habitual visual attention is needed to be overridden by deliberate visual attention. To drive deliberate selection correctly and avoid the critical situation, sufficient risk anticipation of the situation is necessary. From this, it is suggested that the deliberate attention selection is related to risk anticipation. Therefore, when a driver is not anticipating the appearance of a pedestrian in a certain driving situation, it is assumed that the driver’s visual attention will not be deliberate but habitual and the collision risk against the pedestrian will be high.

The objective of this study is to discover driving behaviour features reflecting risk anticipation of the driver which can evaluate pedestrian collision risk for future driver assistance systems, focusing on driver’s visual search behaviour as well as driver’s operation and vehicle behaviour. First, candidates of driving behaviour indices are extracted by analysing near-miss incident database containing high risk driving behaviour focusing on driving behaviour that reflects driver’s risk anticipation. Next, the validity of the extracted driving behaviour indices is examined by a risk scene reproducing experiment using a real vehicle in a test course.

**Target driving scene**

The target driving scene in this study is right-turns at intersections with crossing pedestrians. Because vehicle-to-pedestrian collision during right-turns is a typical accident type in Japan and right-turn situation requires the driver to pay attention to many objects, this right-turn driving scene was selected as the target scene. In our previous research, environmental elements that affect driving behaviour of right-turns at signalized intersections with crossing pedestrians were clarified and 10 typical scene patterns were classified based on the clarified environmental elements (Shino et al., 2015). Among the classified typical scene patterns, the scene without...
any preceding vehicle or oncoming vehicle (Pattern D), as shown in Figure 1, was set as the target driving scene in this study.

Figure 1. Bird’s view of target driving scene (Pattern D).

Near-miss incident data analysis

The objective of this analysis is to extract driving behaviour indices reflecting driver’s risk anticipation which has the possibility to indicate pedestrian collision risk in right-turns at intersections.

Method

To achieve the previously mentioned goal of this analysis, first, hypotheses of driving behaviour features reflecting driver’s risk anticipation was formulated based on driving behaviours that drivers are expected to select when they have predicted the appearance of a crossing pedestrian at a crosswalk in a right-turn scene. Next, to examine whether the driving behaviour reflecting driver’s risk anticipation have relation with pedestrian collision risk, the near-miss incident database collected by the Society of Automotive Engineers of Japan (JSAE) (Nagai, 2013) was used. This approach using a near-miss incident database approach is a valid approach because the composition of near-miss incidents and actual traffic accidents were similar and the near-miss events could be collected in larger volume. The database used contained over 80,000 near-miss events recorded by an acceleration triggered event recorder equipped on taxis running in 5 cities of Japan. The database stored recorded video images of the cameras on board, vehicle data (e.g. velocity, acceleration, GPS signals) and driver operation data (e.g. brake pedal on/off, turn signal). Because the visual attention of the driver is focused on in this study, data with two cameras (front camera and driver face camera) as shown in Figure 2 was used.
Hypotheses of driving behaviour reflecting driver’s risk anticipation

Driving behaviour reflecting driver’s risk anticipation was extracted based on assumptions of driving behaviour that a driver will select to avoid collision in a situation where he/she anticipated the appearance of a pedestrian at an intersection. When a driver predicted the appearance of a crossing pedestrian in a right-turn situation, it is assumed that the driver will select their driving operation to avoid collision against the pedestrian with sufficient margin. As specific driving behaviour expected in the above situation, distributing visual attention to the ends of the crosswalk to find the pedestrian without any delay after the appearance and adjusting vehicle speed to maintain enough time to confirm the presence of the pedestrian can be listed. From the listed driving behaviour, distribution of visual attention to the surroundings and adjustment of vehicle velocity was focused on.

Result of database analysis

Figure 3 shows the time duration rate of each target that the drivers look during right-turns. The analysis period was from the timing when the vehicle crossed the centre line to the timing when the driver hit the brake against a pedestrian. The face direction of the driver in the above period was classified into 4 targets (traveling direction, oncoming direction, crosswalk and others) as shown in Figure 4. As a feature of the face direction during right-turns, a large time was turned towards the traveling direction. Looking long time towards the traveling direction will obstruct the driver from looking at other targets such as the crosswalk where pedestrians may appear and will lead to delay in crossing pedestrian perception. Figure 5 shows the frequency distribution of the velocity at the centre line. Incidents with velocity larger than 30 km/h accounted for more than the half. Crossing the centre line with high vehicle speed will shorten the time to check the appearance of pedestrians around the intersection and will lead to high pedestrian collision risk. From the analysis results, the face direction duration towards the traveling direction and the velocity at the centre line were extracted as driving behaviour indices.
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Figure 3. Time duration rate of face direction during right-turns.

Figure 4. Targets of face direction during right-turns.

Figure 5. Frequency distribution of velocity at centre line.
Risk scene reproducing experiment

Objective

Driving behaviour indices reflecting driver’s risk anticipation of pattern D was extracted based on analysis of the near-miss incident database. Although near-miss incident data classified as pattern D was analysed in this study, driving behaviour database contains data of various traffic environment conditions. Therefore, the objective of this reproducing experiment is to control environmental conditions by using a test course and examine the validity of the extracted indices.

Method and conditions

A reference measure $TTC_{\text{brake}}$ was defined to evaluate the validity of the extracted driving behaviour indices reflecting the driver’s risk anticipation. This $TTC_{\text{brake}}$ is the time-to-collision value against a crossing pedestrian at the driver’s braking manoeuvre timing calculated by the Equation 1 in the scene shown in Figure 6. $D$ and $\theta$ in Equation 1 is defined as Equation 2 and 3. The correlation between the $TTC_{\text{brake}}$ calculated based on a scene with a crossing pedestrian (risk scenario) driving data and the driving behaviour indices calculated based on a scene with no crossing pedestrian (non-risk scenario) driving data was evaluated.

$$TTC_{\text{brake}} = \frac{D-L}{V \cos \theta} \quad (1)$$

$$D = \sqrt{(X_{cp} - X_{hv})^2 + (Y_{cp} - Y_{hv})^2} \quad (2)$$

$$\theta = \tan^{-1}\left(\frac{X_{cp} - X_{hv}}{Y_{cp} - Y_{hv}}\right) - \psi \quad (3)$$

Figure 6. Model scene for $TTC_{\text{brake}}$ calculation.

To reproduce risk scenes without putting actual pedestrians at risk, the JARI-ARV (Augmented Reality Vehicle, Uchida et al., 2015) owned by the Japan Automobile Research Institute (JARI) was used. This vehicle has video cameras and displays on its hood and the driver can see the surroundings through the displays which show the...
images acquired by the video cameras. Due to this feature, this vehicle can reproduce risk scenes by superimposing computer graphic (CG) objects on real frontal images as shown in Figure 7. Using this augmented reality technology, it gives the driver the impression that the object such as vehicles and pedestrians really exist on the test field.

Figure 7. Augmented reality vehicle JARI-ARV (Top-left: Outer view of JARI-ARV, Top-right: Inner view of JARI-ARV, Bottom: Real front window image with superimposed CG objects).

Figure 8 shows the experiment course set in the test field of JARI. Non-risk scenario and risk scenario was reproduced at the target intersection with two lanes on each side and a traffic signal. The detail of the risk scenario reproduced is shown in Figure 9. Each driver drove the experiment course for a total of eight laps. Two laps for vehicle operation practice, two laps for CG scenario experience, three laps for non-risk scenario driving and last one lap for risk scenario driving.

Figure 8. Experiment course.
The subjects were 26 people (D01-D26) aged 22 to 42 years old who possessed a driving licence and drove on a daily basis. The subjects were explained about the nature of the experiment thoroughly and informed consent were obtained from each subject before the experiment.

The aim of this experiment is to reproduce risk scenes and obtain high collision risk driving behaviour data. However, it is rare to come across high collision risk incidents in daily driving. Therefore, to achieve the aim, 3 different driving conditions were set and each subject participated in the experiment with one of the conditions. The detail of each driving condition is as follows:

- Normal condition (D09-D17): Instruct subjects to drive as they do as usual.
- Hurry condition (D18-D26): Instruct subjects to drive with a hurry feeling.
- Absent-mind condition (D01-D08): Instruct subjects to drive with a secondary task (N-back task).

**Result**

In the risk scenario, 4 subjects did not hit the brake pedal although they noticed the crossing pedestrian and 1 subject was already pressing the brake pedal when he found the crossing pedestrian. Therefore, $TTC_{brake}$ could not be calculated for the previously mentioned 5 subjects. Figure 10 shows the average value of $TTC_{brake}$ for each driving condition. The variability between drivers were large and there was no significant difference between the driving conditions. From this result, although the driving condition was different between subjects, the subjects were treated as a single subject group regarding the variability as driver’s characteristics.
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Figure 10. TTC Brake result of each driving condition.

Figure 11 shows the relationship between the $TTC_{brake}$ calculated based on risk scenario driving data and the two driving behaviour indices extracted through the near-miss incident analysis calculated based on non-risk scenario driving data. The gaze duration rate (GDR) of traveling direction was calculated based on images recorded with the eye-tracking device. The analyse period was from the timing when the vehicle crossed the stop line to the timing when the driver reached the crosswalk. As the relationship shown in the figure, there were no significant correlation between the reference measure and driving behaviour indices.

Figure 11. Driving behaviour indices vs. $TTC_{brake}$
(Left: GDR of traveling direction, Right: Velocity at centre line).

Although the $TTC_{brake}$ was expected to be long when the GDR of traveling direction was low, there were cases with low GDR and short $TTC_{brake}$. Also, driving behaviour with high velocity at the centre line was assumed to be high collision risk behaviour but there were cases with relatively long $TTC_{brake}$ values. These instances indicate that the two indices partially represent the collision risk with crossing pedestrians but not sufficient for collision risk evaluation. From the fact that there were cases with relatively low collision risk driving with high velocity at the centre line, the drivers could perceive the pedestrian at an early timing and hit the brake to end up with a long $TTC_{brake}$ value despite the high vehicle speed. This suggests that there were some differences in visual search behaviour among high and low collision risk instances other than GDR of traveling direction.
Investigation of risk scenario driving behaviour

To reveal the difference of driving behaviour in high and low collision risk instances, driving behaviour data of the risk scenario was investigated. Figure 12 shows the crossing pedestrian position when the driver perceived it. The origin of the coordinate axes is the centre of gravity point of the test vehicle. The pedestrian perceived timing for each subject was set as the timing when the gaze point recorded by the eye-tracking device overlapped the crossing pedestrian in the camera image recorded. The driving behaviour data were classified into two groups (high risk driving behaviour (HR) and low risk driving behaviour (LR)) based on the median value (1.52 s). The figure shows that HR tended to find the crossing pedestrian near the vehicle front compared to LR. This result means that the drivers of HR were not able to find the pedestrian until the opponent got near to the vehicle front and this suggests that there was some difference in the visual search behaviour to find the pedestrian between HR and LR drivers.

Figure 12. Position of crossing pedestrian at perceived timing.

To identify the difference, visual search behaviour of the drivers was examined. During right-turns, drivers tended to look out through the side window for some time and then started to look out through the front window as shown in Figure 13. In Figure 14, the curved line shows the vehicle path which the driver drove and the circle represents the position where the driver started to look out through the front window. Compared to the driver of LR, the visual search behaviour of the HR driver differed at the point that they looked out through the side window longer and started to look out through the front window later after getting closer to the crossing pedestrian. From the examination of driver’s visual search behaviour, the timing when the driver started to look out through the front window was obtained as a feature having the possibility to evaluate pedestrian collision risk.
To evaluate pedestrian collision risk assessment based on the previously mentioned feature of visual search behaviour, a collision risk assessment index was formulated. Because drivers look out through the side window to check the trajectory they are willing to run in the near future, it was assumed that the target trajectory geometry and the behaviour looking out from the side window have relation and consequently have relation with pedestrian collision risk. Based on the assumption that the target trajectory could be expressed by the present vehicle velocity and the change in vehicle angle per unit distance, a collision risk assessment index, estimated yaw rate
$\gamma_{est}$ was defined as Equation 4 using the parameters in Figure 15. $D$ and $\theta$ of Equation 4 was defined as Equation 5 and 6. Figure 16 shows the relationship between $TTC_{brake}$ and estimated yaw rate $\gamma_{est}$ at the centre line when the target destination point was set as the boundary of the crosswalk like it is in Figure 15. There was a significant correlation between the two indices ($r = -0.65, p < .01$). From this result, it was confirmed that pedestrian collision risk was evaluable by an index based on visual search behaviour of a driver.

$$\gamma_{est} = \frac{\theta - \psi}{D - L} \cdot V \cos \theta \quad (4)$$

$$D = \sqrt{(X_{dst} - X_{hv})^2 - (Y_{dst} - Y_{hv})^2} \quad (5)$$

$$\theta = \tan^{-1}\left(\frac{X_{dst} - X_{hv}}{Y_{dst} - Y_{hv}}\right) - \psi \quad (6)$$

Figure 15. Model scene for $\gamma_{est}$ calculation.

Figure 16. Relationship between $TTC_{brake}$ and $\gamma_{est}$ at centre line.
Discussion

Visual search behaviour with high pedestrian collision risk is examined by applying the visual attention modes mentioned in the introduction of this paper. Drivers tended to look out through the side window towards the traveling direction for a long time and the confirmation of the crosswalk through the front window got behind and the perception of the crossing pedestrian was late ending up with a short time-to-collision. The attention allocation towards the traveling direction can be classified as a habitual visual attention because it is an attention selection mainly for making a right-turn which is an action the driver has done hundreds of times and over-learned. The visual attention to the crosswalk is assumed to be a deliberate attention since it is driven by the risk anticipation that a pedestrian may appear. From this application of visual attention modes to high collision visual search behaviour, it can be said that shift to deliberate attention got behind because of concentration to habitual attention and pedestrian collision risk became high, as assumed in the introduction. Therefore, it is suggested that the distribution and timing of habitual and deliberate visual attention affect pedestrian collision risk.

Conclusion

To discover driving behaviour features which can evaluate pedestrian collision risk for future driver-assistance-systems, driving behaviour indices reflecting the driver’s risk anticipation of a driving scene where no preceding vehicle and oncoming vehicle exists (Pattern D) was extracted based on near-miss incident analysis and the extracted indices were examined by a risk scene reproducing experiment using the JARI-ARV. The major conclusions of this research are as follows:

- The estimated yaw rate $\gamma_{est}$ was verified to be a valid pedestrian collision risk assessment index for right-turns at intersections classified as Pattern D.
- Pedestrian collision risk of right-turns at intersections was evaluable by an index related to driver’s visual search behaviour and it was suggested that distribution and timing of driver’s habitual visual attention and deliberate visual attention, which reflects the driver’s risk anticipation, affect the collision risk against pedestrians.

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References


