Research of Stop Assistance Considering Visibility of Intersection

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ABSTRACT: Crossing collisions caused by cognitive error often occur at unsignalized intersections. For the countermeasure, driver assistant systems that warn a driver against stop sign violation are researched and commercialized. However, if a driver is warned in spite of recognizing an intersection, he or she may feel annoyance and turn the system off. In this research, an index of intersection perception utilizing the saliency map was formulated in order to simulate the driver’s cognition. Then, an assistance method proposed gives a driver early alert only when an approaching intersection is difficult to notice. Applicability of this index was confirmed by a driving simulator, and effectiveness of the proposed assistance method was verified for subjects with the special eyeglasses emulating elderly person’s vision.

KEY WORDS: human engineering, warning system, visibility / intersection, adaptive warning, saliency map [C2]

1. Introduction

In Japan, fatal accidents were significantly decreased and 4411 people were killed in 2012, thanks to improvement of vehicle collision safety, legislation, education and spread of driving assistance systems caused by growing awareness for traffic safety (1) (2). However, much more effort is necessary in order to achieve the target of the Japanese government to reduce yearly “24-hour fatalities” to less than 3000 by 2015. In this traffic accident statistics, intersection collision between vehicles occupied 14.7% of fatal accidents, which was the 2nd largest factor behind pedestrian accident while crossing a street (26.7% of fatal accidents). 24.7% of the intersection accidents were caused by stop sign violation at an intersection. Furthermore, 53.2% of them were caused by 65 or older-year elderly people. Thus, it is found that the driver assistance for elderly people to avoid these accidents is important.

As one of the countermeasures, the assistance system that provides information at intersections and controls brake in case of danger has been commercialized (3). It was verified that such an assistance system is effective for elderly persons (4). However, if a driver is warned at each time in spite of recognizing an intersection, the driver feels annoyance and may stop utilizing the system at worst. In contrast to this, it is desirable that a driver is warned depending on driver’s cognitive status for intersection. However, it is currently difficult to physiologically measure driver’s cognitive status. Thus, an alternative method is proposed in this research, which estimates driver’s cognitive status utilizing visibility of the external environment. Then, applying this method, stop assistance method at intersection was developed, and the effectiveness was verified by utilizing a driving simulator (DS). In addition, experiments were conducted for subjects wearing the eyeglasses that can emulate vision of elderly persons as an alternative to directly evaluate them.

Previous research related to this research has been investigated, which studies driver assistance applying estimation of driver’s cognitive status. The assistance method for inattentive or drowsiness driving was proposed and the system was commercialized (5). The system detects driver’s face direction and eyelid closure, and earlier warning is issued if a driver does not face front or closes his/her eyes while approaching to a preceding vehicle. However, major causes of intersection accidents are oversight and making a wrong assumption, so the assistance method is not effective for the accidents. Intension of driving behavior is estimated by gaze direction in laboratory utilizing a DS, and they are unstable in the actual environments. Thus, it is difficult to put the research result to practical use. Estimation method of drowsiness utilizing vergence angle of eyes had been also researched (7). They detected transient state to catnap, so the accuracy is insufficient in urban area and it does not directly reflect oversight. Some researches estimate feeling of fatigue from brain waves (8), but it does not directly reflect oversight, either. A method directly detecting cognitive state of a traffic light has been researched (9). They detected transient state to catnap, so the accuracy is insufficient in urban area and it does not directly reflect oversight. Some researches estimate feeling of fatigue from brain waves (8), but it does not directly reflect oversight, either. A method directly detecting cognitive state of a traffic light has been researched (9). They detected transient state to catnap, so the accuracy is insufficient in urban area and it does not directly reflect oversight. Some researches estimate feeling of fatigue from brain waves (8), but it does not directly reflect oversight, either. A method directly detecting cognitive state of a traffic light has been researched (9). They detected transient state to catnap, so the accuracy is insufficient in urban area and it does not directly reflect oversight. Some researches estimate feeling of fatigue from brain waves (8), but it does not directly reflect oversight, either. A method directly detecting cognitive state of a traffic light has been researched (9). They detected transient state to catnap, so the accuracy is insufficient in urban area and it does not directly reflect oversight. Some researches estimate feeling of fatigue from brain waves (8), but it does not directly reflect oversight, either.

Therefore, it is found that the methods directly estimating driver’s cognitive state of intersections is currently far from practical realization, thus this research can be considered as a realistic approach at the current moment.
2. Assistance methodology

2.1. Assistance strategy

As aforementioned, a driver may feel annoyance if he or she is warned in spite of recognizing an intersection. Therefore, it is effective that warning is suppressed when a driver recognizes an intersection. However, it is difficult to directly measure driver’s cognitive status. Thus an alternative method to the estimation is proposed. As the driver’s cognition is formed by forward visual information, it can be indirectly estimated by analyzing the front image. Our proposed method quantifies visibility of an intersection from front camera image, and then warning timing is adapted corresponding to the value.

However, as visibility of image and driver’s cognitive status do not always coincide, warning is also issued by estimating driver’s status from the maneuver. Describing more specifically, when a vehicle cannot stop before an intersection due to the physical limitation or sudden braking compared with normal braking becomes necessary, it is judged that cognitive error may occur, and then warning is issued. Thus, assistance at the minimum timing is secured.

2.2. Development of visibility index of intersection

The key part of this proposal is to quantify intersection visibility. In this section, the quantification method is described, and the verification result is shown.

2.2.1. Design of visibility index

Visibility index for driver assistance at intersection is proposed. There are some researches on visibility of traffic environment. Human visibility has been modeled by Itti and his group based on physical structure of human retina (10). The image feature of a vehicle-mounted camera was researched in order to estimate visibility of road traffic signs (11). The method which estimates visibility of road traffic signs applying machine learning was also proposed (12). Human detects intersections by utilizing appearance features in the whole field of view. On contrast, just a few of the various types of information in intersections is utilized in the conventional researches. For example, road markers are very useful for human to recognize an intersection, but they are not utilized. Furthermore, despite background appearance affects the visibility, they are not considered in the researches. In consideration of these, we propose the visibility index of intersection which is formulated by ratio of sum of saliency values in various areas indicating an intersection to one in the whole image. Procedure of the quantification is described as follows;

1) Calculate value of the saliency map for whole image of intersection according to Itti’s method in the field of view (13).
2) Extract manually area of elements which indicate existence of intersection (e.g. crossing road area, road marker, stop sign) by bounding box, and calculate value of the saliency map in the each area (Sr, Sm, Si respectively).
   In this case, the areas were manually extracted. However, the computer can recognize the areas by image processing, so they can automatically extracted in the assistance system.
3) Summate them, and normalize it by saliency map value of the whole image Swi as equation (1). This St is defined as the intersection saliency index.

\[
St = \frac{Sr + Sm + Si}{Swi}
\]  
(1)

Fig. 1 shows an image sample of an intersection on screen of the DS. These yellow bounding boxes in the figure denote manually-extracted areas which indicate an intersection. Fig. 2 shows saliency map by Itti’s method for the image. Saliency is higher in an order of: red, yellow and blue color in the figure. Saliency of some parts in the intersection areas is high, but ones of background areas are higher than them. As the result, this saliency index becomes 0.15, which is not so high.

2.2.2. Verification of visibility index

It was verified that this index can properly express driver’s visibility by the experiment utilizing a DS (14).

A stationary DS with 3 screens and half of a vehicle body was utilized in this experiment as shown in Fig. 3. Fig. 4 shows a picture of the cockpit in the DS. An input switch to measure timing of the driver awareness and a display to provide assistance information are placed.

Field investigation was conducted at the high-accident intersections in order to design screen image of intersections in the experiment. About 2000 accidents at the intersections in
Kagawa prefecture of Japan were analyzed, and then 13 locations were selected for the investigation. Screen images of the DS were simulated to those pictures as much as possible. Fig. 5 is a sample picture of the high-accident intersection. Fig. 6 is the screen image simulating the intersection picture. It’s found that the image is reconstructed well.

The experimental subjects were 10 male students (average age of 23.3 years old) with a driver license. We had gotten informed consent from all study subjects before the experiments. They were instructed to drive straight while operating an accelerator pedal and a brake pedal.

We examined correlation between the intersection saliency index and the timing when drivers begin to notice intersections in order to confirm adequacy of the evaluation method of intersection visibility utilizing the saliency index. When the subjects identify intersection in the front direction, they were instructed to push an input switch on the steering wheel. Awareness timing to intersection TTIA is calculated from distance Li to the intersection when pushing a switch and subject vehicle speed Vs as the following equation (2). Though awareness depends on distance to the intersection, timing is used in association with warning systems here.

\[ TTIA = \frac{L_i}{V_s} \]  

This TTIA is assumed as an index of the timing when drivers identify intersections, and then correlation between TTIA and the saliency index St was analyzed. The intersection images to calculate St were obtained by trimming from the whole DS screen image so that they correspond to driver’s effective field of view at 20m from intersections.

2.2.3. Experimental result

Fig. 7 shows the relationship between the index St for each intersection and the awareness timing TTIA. The coefficient of correlation is 0.88, thus strong correlation between them is found. This result can be interpreted as the higher risk of the oversight the smaller saliency index St as the margin to notice an intersection becomes small when the awareness timing is late. In the experiment discussed later, sudden brake was actually caused by oversight or detection delay at the intersections with small saliency index. The result shows that awareness timing or risk of overlooking an intersection can be estimated by applying the proposed method.

2.3. Assistance method

We propose a method to adapt intersection assistance to driver’s cognitive status by applying the proposed saliency index. Fig. 8 illustrates the assistance method. It is sufficient to warn a driver only when intersection visibility is low. The warning may be issued at normal brake timing. In contrast, warning is not necessary if visibility is high. This method can reduce the annoyance for excessive assistance. This earliest warning timing is shown as the maximum time to intersection (TTI) in the figure. However, a driver may overlook an intersection in spite of high visibility. In the case, warning is issued at the emergency brake timing if no brake is operated by that time. This latest warning timing is shown as the minimum TTI. Thus, the warning timing is altered depending on the calculated saliency index St within the adaptive section.

![Fig. 8 Illustration of adaptive warning timing](Image)

This concrete procedure for the assistance is explained. Flowchart in Fig. 8 shows the procedure.

![Fig. 9 Flowchart of intersection assistance](Image)

Intersection locations are obtained from the GPS while driving as the commercialized assistance system (3). Front images are captured by a camera in the cabin at the timing of intersection alert, and then traffic stop signs and road markers are recognized by image processing (15)-(17). The proposed saliency index St is
calculated by utilizing this image information. When this index is smaller than a predetermined threshold $S_d$, warning is issued. The assistance is suspended when a brake is operated during the warning. Otherwise no assistance is provided. Even in this case, warning is issued when emergency brake at maximum deceleration is required during approaching to an intersection. This maximum deceleration means the maximum deceleration for general drivers during normal operation. Stopping distance $X_{maxg}$ at maximum deceleration $G_{max}$ is calculated as equation (3) in order to judge stop violation at an intersection. When the stopping distance becomes larger than or equal to current distance to the intersection $X_0$, a driver is warned.

$$X_{maxg} = V_0 T_1 + \frac{1}{2 G_{max}} V_0^2$$

where, $V_0$ denotes current velocity, $T_1$ is brake reaction time in normal situation.

3. Experiment

Effectiveness of this assistance method was experimentally verified by the DS.

3.1. Experimental method

Experiments were conducted by utilizing the aforementioned stationary DS. The subjects were 10 male students (average age: 22.5 years old) with a driver license. We had gotten informed consent from all study subjects before the experiments. They were instructed to drive on the straight road and stop at the intersections in the DS as shown in Fig.10. When the intersection visibility is low, warning is issued at 4 sec of TTI corresponding to the commercial assistance system (3). A conventional assistance which always warns at the timing was also evaluated. Then, when no brake is operated at timing of requiring emergency brake of 0.4 G, warning is issued. This threshold was set from experimental results. Sub-task was imposed in order to induce distraction, which is to read 2-digit-numbers displayed in the instrument panel every 3sec.

When a driver was warned, the illustration of a stop sign was presented to the subjects on the information display as shown in Fig. 11. And warning sound (1.5 kHz, interruption period of 0.35 sec, duty ratio of 50%) was also issued at the same time.

They wore the special eyeglasses that can simulate vision of an elderly-person in some conditions so that the young subjects can replace aged subjects. Fig. 12 shows the subject wearing the special glasses. Vision of the subject through the glasses is blurry as shown in Fig. 13. Experiment for elderly-persons was also tried. However, they could not adapt this driving maneuver of the DS, thus this emulation method was adopted.

7 scenes were utilized for the experiment, which is simulated to the actual pictures at the high-accident intersections. Size of traffic signs and contrast of road markers were adjusted so that the saliency indexes were diversified. (average: 0.0570, standard deviation: 0.0027, minimum: 0.0296, maximum: 0.1005) Samples of the adjusted graphics in the DS are shown. Stop sign was enlarged in order to maximize the saliency index of intersection in Fig. 14. Size of stop sign was reduced in order to make the saliency index medium in Fig. 15. Contrast of a road marker was reduced in order to minimize the index in Fig. 16.

4 combinations of experiments were conducted under the above conditions, which were with and without elderly-person glasses and with and without the assistance.

![Fig. 12](image12.jpg)  The subject wearing the glasses simulating elderly-person

![Fig. 13](image13.jpg)  Screen image of DS through the glasses

![Fig. 14](image14.jpg)  Intersection with maximum saliency index ($St=0.1005$)

![Fig. 15](image15.jpg)  Intersection with moderate saliency index ($St=0.0496$)

![Fig. 16](image16.jpg)  Intersection with minimum saliency index ($St=0.0296$)
3.2. Experimental result

Samples of the subject’s maneuver are shown. Fig. 16 shows time series graphs of velocity and deceleration when approaching the intersection which visibility is moderate ($St=0.061$) and the subject did not wear the elderly-glasses. Horizontal axis shows distance to the intersection. Data with and without the warning assistance are superimposed. In this case, there was no difference of profile between them. Fig. 17 shows the graphs in case that the intersection visibility is poor ($St=0.021$) and the subject wore the elderly-glasses. In the case, brake timing with the assistance became earlier than one without the assistance, and maximum deceleration was reduced. This sample data indicates that there is a difference in effectiveness of the assistance by conditions of the intersection visibility and the elderly-glasses.

![Graph showing the effect of warning assistance on deceleration](image)

Fig. 16 Subject’s maneuver without the glasses in the case of moderate visibility

![Graph showing the effect of elderly-glasses on deceleration](image)

Fig. 17 Subject’s maneuver with the glasses in the case of poor visibility

Evaluation values for the maneuver while approaching intersections were quantified by estimated TTI at the start of braking and maximum deceleration in braking. The former value reflects delay of visual perception of an intersection, and the latter value reflects panic brake maneuver caused by the delay of perceiving. Both evaluation values reflect risk of a mistake to stop at a stop sign. However, both of them were utilized to evaluate effectiveness of the assistance in order to verify which one is more adequate.

7 evaluation scenes were divided to 3 classes by the intersection saliency index $St$ (high class; $St$=1.01, 0.98, medium class; $St$=0.61, 0.58, 0.55, low class; $St$=0.28, 0.21). Then effectiveness of the assistance was analyzed for each class respectively.

Fig. 18 shows maximum deceleration when the subjects did not wear the elderly-person glasses. Significant differences between the evaluation values with and without the assistance were $p=0.76$ for the scene with high saliency, $p=0.28$ for the scene with medium saliency and $p=0.07$ for the scene with low saliency, which shows no significant difference at 5% level. However, the lower the saliency index becomes, the larger reduction effect of the maximum deceleration becomes with assistance compared with no assistance. Decreasing amounts of the deceleration were respectively -0.004 G, 0.026 G, 0.046 G, and the $p$ values were reduced accordingly. Thus, these data indicates that the more effectiveness is obtained for the smaller saliency index.

Fig. 19 shows maximum deceleration when the subjects wore the elderly-person glasses. Significant differences between the evaluation values with and without the assistance were $p=0.80$ for the scene with high saliency, $p=0.88$ for the scene with medium saliency and $p=0.016$ for the scene with low saliency, which shows there was significant difference at 5% level only in the case of low saliency. Decreasing amounts of the deceleration were respectively -0.005 G, -0.003 G, and 0.077 G. It is found that the effect of decreasing the deceleration was larger than one without the glasses.

Average of the maximum decelerations in the case of no assistance and no glasses was 0.29 G. In comparison, when wearing the glasses, it increased to 0.34G. Specially, the difference was widened to 0.10 G in the case of low saliency. Decreasing amounts of the deceleration were respectively -0.005 G, -0.003 G, and 0.077 G. It is found that the effect of decreasing the deceleration was larger than one without the glasses.

![Graph showing maximum deceleration with glasses](image)

Fig. 18 Maximum deceleration without the glasses

![Graph showing maximum deceleration with glasses](image)

Fig. 19 Maximum deceleration with the glasses
Fig. 20 shows the TTI at the start of braking when the subjects did not wear the elderly-person glasses. Significant differences between the evaluation values with and without the assistance were $p=0.97$ for the scene with high saliency, $p=0.02$ for the scene with medium saliency, and $p=0.01$ for the scene with low saliency, which shows there was significant difference at 5% level in the case of medium and low saliency. The TTIs were respectively extended by 0.01sec, 0.51sec, and 0.52sec with decreasing the saliency index. It is found that the assistance is effective unless the saliency index is high.

Fig. 21 shows the TTI when the subjects wore the elderly-person glasses. Significant differences between the evaluation values with and without the assistance were $p=0.74$ for the scene with high saliency, $p=0.29$ for the scene with medium saliency, and $p=0.000012$ for the scene with low saliency, which shows there was significant difference at 1% level in the case of low saliency. The TTIs were respectively extended by 0.06sec, 0.34sec and 0.94sec with decreasing the saliency index. It is also found that the assistance is effective only in the case of low saliency index. In the case of medium saliency, average of TTI was reduced by the assistance. It can be assumed that some incidental error occurred because there was no significant difference.

Effect of the elderly-person glasses for the TTI is also confirmed. Average of the TTI in the case of no assistance and no glasses was 3.61 sec. In comparison, when wearing the glasses, it decreased to 2.93 sec. Specially, the difference was widened to 1.18 sec in the case of low saliency, which shows the same tendency as the maximum deceleration.

Questionnaires were conducted for the proposed assistance method and conventional one with warning at each time after the experiments. The subjects additionally experienced the conventional assistance method that warned them at 4 sec of TTI each time. Then, they were asked to answer the questionnaires based on two criteria using a scale from 1 to 7 so that they could express subtle nuances in their evaluation. When evaluating annoyance, ‘7’ indicates the subject was annoyed by the warning and ‘1’, that the subject did not mind the warning. When evaluating effectiveness, ‘7’ indicates the subject found the warning effective and ‘1’, that the warning was not effective. In both cases, the subject could indicate ‘4’ as a neutral evaluation.

Fig. 22 shows the sensory evaluation scores about the annoyance. It is found that annoyance is significantly reduced by the proposed method. This $p$ value was 0.00067, which means there is significant difference at 0.1% level. Fig. 23 shows the sensory evaluation scores about the effectiveness. They are almost same scores, thus it is shown that effectiveness is not spoiled by the proposed method.

![Fig. 20 Time to intersection at the start of braking without the glasses](image1)

![Fig. 21 Time to intersection at the start of braking with the glasses](image2)

3.3. Consideration

Effectiveness of the assistance was verified by applying 2 kinds of evaluation value. Both results showed that the lower the saliency index becomes, the more effectiveness of the assistance increases. It indicates that it is possible to evaluate difference in effect of the assistance methods by utilizing these values. More significant differences for the TTI at the start of braking was shown, which means it is more appropriate as evaluation value representing risk of overlooking an intersection. On contrary, it is necessary to note to use the maximum deceleration as the evaluation value because braking maneuver seems unstable depending on driver’s skill.

It was proved that the proposed assistance method is effective in the case of degrading visibility by the elderly-person glasses from any results. Results of the questionnaire for subjects show that annoyance of the warning can be reduced while maintaining the effectiveness. This fact confirms the original hypothesis that the warning annoys a driver if it is issued even though a driver...
recognizes an intersection. Then, the proposed warning method can be the countermeasure.

4. Conclusion

The intersection collision avoidance system based on the visibility was proposed corresponding to traffic accidents often caused by elderly people’s overlooking. Saliency index of intersections applying the saliency map was formulated, and adaptive warning method according to the index value was proposed in order to reduce annoyance of warning at each time that is concern of the conventional assistance systems. Applicability of this index was confirmed by the DS experiments, and effectiveness of the proposed assistance method was verified by another DS experiments. As the results, it was confirmed that the annoyance can be reduced while maintaining the effectiveness. Visibility was degraded by the special glasses in order to substitute elderly persons in the experiments. It was also confirmed that brake start timing is delayed and sudden braking often occurs in these conditions. Furthermore, it was found that the more visibility degrades, the more effectiveness of the assistance is improved.

This proposed saliency index is expected to widely apply as a practical method to alternatively estimate driver’s cognitive status. Moreover, the environmental adaptive driver assistance can be applied to various situations, thus we will research another effective driver assistance systems applying this concept in the future.

References


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