An Investigation of Suitable Timing for a Vision-based Rearward Approaching Vehicle Notification System

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ABSTRACT

Systems for detecting and notifying drivers of vehicles in adjacent lanes have attracted considerable interest as a means of reducing driver workload which tends to increase when changing lanes. This paper presents the results of a study that investigated the relationship between the timing for issuing a notification about a vehicle detected in an adjacent lane and the related effect on drivers' trust in the system. The purpose of this study is to improve the perceived effect and value of such notification systems. Subjective evaluations were conducted using an experimental vehicle and a vehicle detection method employing a rear-mounted camera. Based on the evaluation results obtained, an investigation was made of a suitable timing for a system that notifies drivers about a rearward approaching vehicle when changing lanes.

1. INTRODUCTION

Vehicles equipped with a rear-view camera have become increasingly common in Japan in recent years. In the U.S., the National Highway Traffic Safety Administration (NHTSA) has proposed creating a new rule that would require all vehicles to be equipped with a rear-view camera. These developments suggest that the use of rear-view cameras can be expected to expand in the coming years.

Automobile manufacturers and auto parts makers are currently engaged in vigorous research activities on sensing technologies for use in driving safety support systems (DSSS). In particular, technologies for detecting vehicles in adjacent lanes are being actively researched for the purpose of preventing lane change accidents [1]. In view of this situation, we have developed a vehicle detection method using a single rear-mounted camera with the aim of expanding the application of DSSS to a wider range of vehicles [2].

The interface of DSSS that incorporate some type of vehicle detection technology is also being studied [3][4]. These examples of research studies dealt with certain issues inherent in vehicle detection systems. For example, consider a situation where the error rate for vehicle detection is extremely low. In this case, drivers may overly rely on the system, resulting in a greater possibility of an accident in the event a vehicle detection error actually occurs. Conversely, if vehicle detection errors occur repeatedly, drivers may not trust the system, with the result that the system

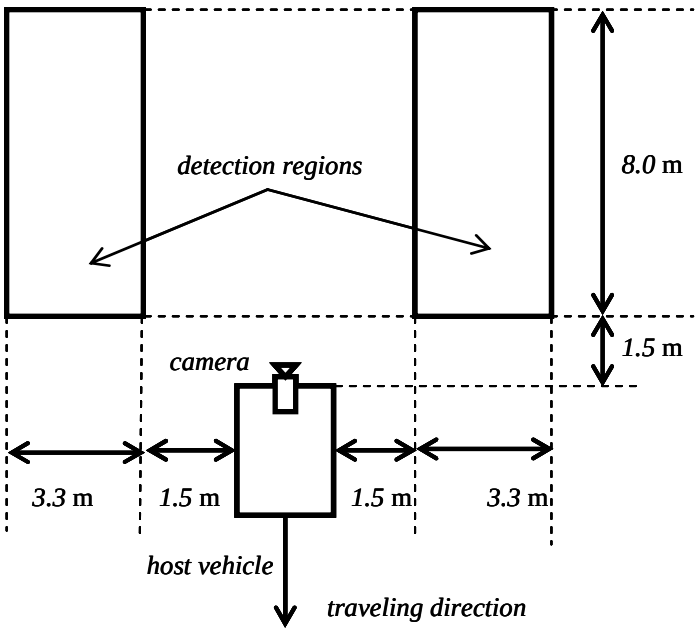

Figure 1. Position of detection regions

cannot deliver its intended benefits. Therefore, these interface studies were undertaken to examine how changing the way the detection results are presented to the driver might affect the level of drivers' trust in vehicle detection systems. However, the timing for presenting a notification to encourage drivers to be careful has not been thoroughly discussed in the literature yet.

It is assumed that the perceived effect of a system for notifying drivers of a rearward approaching vehicle will vary depending on the timing for issuing such a notification. That is because the relative positions of the host vehicle and rearward vehicle will differ depending on when a notification is issued.

In this study, a notification system was constructed by using the method developed previously for detecting a rearward approaching vehicle [2]. The timing for issuing a notification was varied in experiments to investigate how it might affect drivers' perception of the effect of the system.

2. RELATED WORK

The Japan Automobile Research Institute reported the results of a study on the behavioral characteristics of drivers at the time of changing lanes [5]. Based on their analysis of the time-to-collision (TTC) with a rearward approaching vehicle, they found that drivers changed lanes regardless of the distance between the two vehicles provided that TTC was at least 8 s and that they refrained from changing lanes when TTC was 4 s or shorter. When TTC was between 4 and 8 s, the results were mixed, with some drivers changing lanes while others refrained from doing so. These findings suggest that TTC of between 4 to 8 s represents a period when the driver's workload is especially heightened. Accordingly, in this study we investigated the effects of setting the timing for issuing a notification in this period.

3. VEHICLE DETECTION METHOD

As illustrated in Fig. 1, the vehicle detection method [2] developed previously judges whether or not a vehicle is present in either of two detection regions predefined behind the host vehicle. If a vehicle is

detected, its relative velocity can be estimated and used to vary the timing of the notification so as to match the TTC at that moment. Further details of the detection method are given in reference [2].

4. PROBLEM FORMULATION

The purpose of this study therefore was to investigate the effects of the notification timing in the period when the driver's workload for changing lanes is assumed to be especially high as mentioned in section 2. With the vehicle detection method [2] used in this study, the detection regions were defined as far as a distance of 9.5 m from the rear of the host vehicle, as shown in Fig. 1. Accordingly, vehicles at a rearward distance of up to approximately 9 m were the target of detection. With these detection regions, a notification sound can be issued at a maximum TTC of around 6 s when the relative velocity between the host vehicle and a rearward approaching vehicle is 5 km/h. The notification timing of the system used in this study was therefore varied in a TTC interval from 4 to 6 s. The effects of varying the notification timing in this interval on the participating drivers' subjective evaluations of the timing were investigated experimentally.

5. EXPERIMENT

5.1 Experimental Configurations

An experimental vehicle was setup and used in all of the experiments conducted in this study. The configuration of the experimental vehicle is shown in Fig. 2. The images captured with a camera mounted at the rear of the vehicle were fed into a PC. The computer activated the vehicle detection method [2] to detect any vehicles that were actually approaching

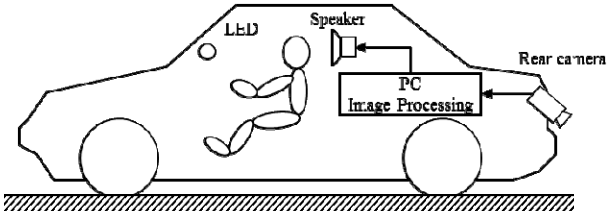

Figure2. Configuration of experimental vehicle

(a)LED Off (b)LED On

Figure3. Indicator to start lane change maneuver

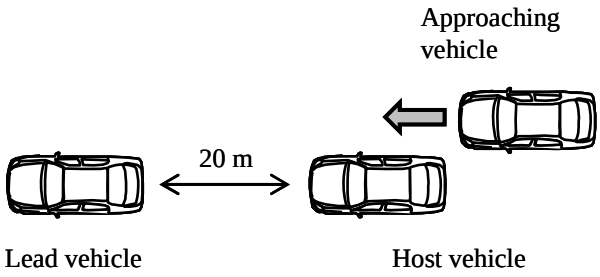

Figure4. Vehicle locations

from behind the experimental vehicle. When an approaching vehicle was detected, a notification sound was emitted from a speaker installed in the cabin. The "*notify.wav*" notification sound provided in Windows was used for that purpose. A light-emitting diode (LED) installed on the windshield served as an indicator for instructing the driver to start a lane change maneuver (Fig. 3).

In addition to the experimental vehicle and the rearward approaching vehicle, a vehicle was also positioned in front of the experimental vehicle, making a total of three vehicles altogether. This configuration simulated a vehicle following situation on a straight road in the evaluation experiments (Fig. 4).

5.2 Experimental Scenario and Driver's Task

The experiments simulated a vehicle following situation as illustrated in Fig. 4, with one lead vehicle positioned ahead of the experimental vehicle driven by a participant in the experiment. From the perspectives of safety and reproducibility, both the experimental vehicle and the lead vehicle were stationary and only the rearward approaching vehicle was moving. The participants were instructed to focus on the preceding vehicle in this experimental scenario that simulated a situation of following a vehicle ahead at a speed of approximately 50 km/h.

As shown in Fig. 3(b), the LED was illuminated at a certain given timing. The participants were instructed to begin a lane change maneuver the moment they noticed the illuminated LED. They were instructed to confirm that the condition around the experimental vehicle was safe, just as they would do in ordinary driving, and to turn the steering wheel if they judged that a lane change could be executed. If they judged that a lane change was impossible, they were told not to do anything.

5.3 Experimental Method

As described in section 4, the experimental configuration that provided a relative velocity of 5 km/h between the experimental vehicle and the rearward approaching vehicle allowed the notification sound to be issued at a maximum TTC of around 6 s. Table 1 shows the relationship between TTC and the distance between the two vehicles when their relative velocity was 5 km/h. Based on this relationship, the TTC was varied at 0.5 s increments between 4.0-6.0 s. The participants were asked to give their subjective evaluations of a total of five TTC notification timing patterns. The parameters of the vehicle detection program were pre-adjusted so that the notification sound would be issued according to the predetermined TTC.

A test engineer monitored the images captured by the rear camera and illuminated the LED upon confirming that the rearward approaching vehicle had reached the position of the TTC specified for a particular experiment. The participants were instructed to start lane changing when the LED was illuminated, if they thought it was appropriate to change lanes. On the other hand, if they thought that changing lanes was inappropriate then they should not do anything. To simulate a real lane changing situation, it would have been favored to leave the decision to start lane changing to the participant himself. However, this would make it difficult to assure the repeatability of the experiment. It is thought that the proposed method would induced a natural behavior of the participants

Table1. Relationship between TTC and inter-vehicle distance

TTC[s]	4.0	4.5	5.0	5.5	6.0
Distance[m]	5.55	6.25	6.94	7.64	8.33

5.4 Procedure

The experiments were conducted according to the following procedure.

- The purpose of this study was explained to the participants in advance, and their written informed consent was obtained before beginning the experiments.
- After confirming that the participants understood the purpose of the study, they were informed that the experiments simulated a situation of executing a lane change while driving straight ahead.
- As a practice exercise, all the participants experienced the illumination of the LED and the issuing of the notification sound at a TTC timing of

5.0 s.

● In the actual experiments, the LED was illuminated and the notification sound was issued while varying the TTC in 0.5 s increments between 4.0-6.0 s. The participants gave their subjective evaluations of each of the five notification sound timing patterns, which constituted one set of experiments.

● Three sets of experiments were conducted in total, and the scores were averaged to determine the final evaluation results of each participant. It should be noted that TTC was varied at random within each set of experiments.

The participants were 23 drivers (21 men, average age of 40.3 years; 2 women, average age of 38.5 years) who ordinarily drive a vehicle to commute to work or for some other purpose.

5.5 Evaluation Method

The purpose of the experiments was to evaluate how the participants perceived the notification sound issued by the system while inducing the start of a lane change maneuver within a TTC range of 4.0-6.0 s. The participants subjectively evaluated the timing of the notification sound on a five-point scale. In making their subjective evaluations, the participants were told to confirm that the condition around the experimental vehicle was safe, just as they would do when changing lanes in ordinary driving, as explained earlier in section 5.2. That was done by visually confirming the presence of a rearward approaching vehicle seen in the outside mirror or in the rear-view mirror in the cabin.

The evaluation criteria of each point score are explained below.

● 1 (early): The notification sound is annoying. In this case, the participant perceives that a lane change is possible because there is a sufficiently safe distance between the host vehicle and the rearward approaching vehicle.

● 2 (slightly early): a rating between 1 and 3.

● 3 (adequate): The participant perceives that the timing of the notification sound is effective. The participant perceives that the timing of the notification sound, when the distance between the host vehicle and the rearward approaching vehicle is close, is helpful in deciding to refrain from changing lanes.

● 4 (slightly late): a rating between 3 and 5.

● 5 (late): The participant perceives that the timing of the notification sound is not very helpful in deciding to refrain from changing lanes because the rearward approaching vehicle is already too close to the host vehicle at this point.

6. RESULTS

6.1 Overall Evaluation Results

The evaluation results of the 23 participants are shown in box plots in Fig. 5. The horizontal axis is the TTC in seconds and vertical axis shows the subjective evaluation ratings for each TTC. As an overall tendency, it is observed that the subjective evaluations of the participants change according to the TTC. Many of the participants evaluated the notification timing at TTC = 4.0 s as being “late” or “slightly late”. However, there were two participants who evaluated this notification timing as being “adequate”. These results will be discussed further in the section 6.2.

For notification timings at TTC = 4.5 s or 5.0 s, many of the participants tended to respond that the timing was “slightly late” or “adequate”. No participant evaluated the timing at TTC = 4.5 s as being “slightly

early" or "early", but four of the 23 participants responded that the timing at TTC = 5.0 s was "slightly early".

Many of the participants responded that the notification timing at TTC = 5.5 s was the most "adequate" of the five timing patterns used in the experiments. Moreover, the evaluation results for this notification timing showed the smallest dispersion. Compared with the timing at TTC = 5.5 s, the number of participants who responded that the timing at TTC = 6.0 s was "slightly early" or "early" increased, and the dispersion of the evaluation results also increased accordingly.

6.2 Individual Evaluation Results

Figure 6 shows the subjective evaluation results for all of the 23 participants. The horizontal axis is the TTC and the vertical axis indicates the evaluation ratings for each TTC. The evaluation results of each individual participant are shown as an approximation line. Two of the 23 participants responded that all of the notification timings were "adequate" regardless of the TTC. It is inferred that these two participants thought the system was effective simply because it issued a notification sound, irrespective of the TTC with the rearward approaching vehicle. On the other hand, it is observed that the subjective evaluation results for the other 21 participants change in relation to the TTC. All of these participants tended to evaluate the timing as being "late" when the TCC value was small and increasingly to respond that the timing was "early" as the TTC value became larger.

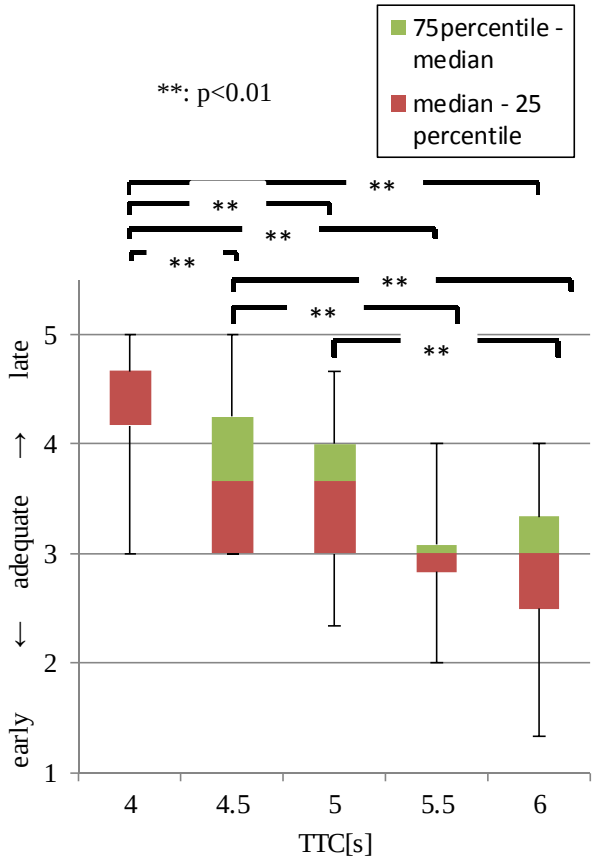

Figure5. Distribution of subjective evaluation results

7. DISCUSSION

First of all, we will discuss the overall evaluation results presented in section 6.1. As shown in Fig. 5, the five TTC patterns used in the experiments were paired to create ten combinations of patterns altogether. Of the ten pairs of patterns, the subjective evaluation results for eight combinations showed a significant difference ($p<0.01$). The two pairs of patterns that did not show a significant difference were the combinations of 4.5 s and 5.0 s and 5.5 s and 6.0 s. The only common point between these combinations was that the time difference was just 0.5 s. Presumably, the reason for that is because all of the participants were included in this comparison. An evaluation of the results for the individual participants will be discussed later.

Next, we will consider the subjective evaluation results for each TTC. For the notification timing at TTC = 4.0 s, the participants' evaluations were more concentrated at " late" or "slightly late" compared with the results for the other timing patterns. The

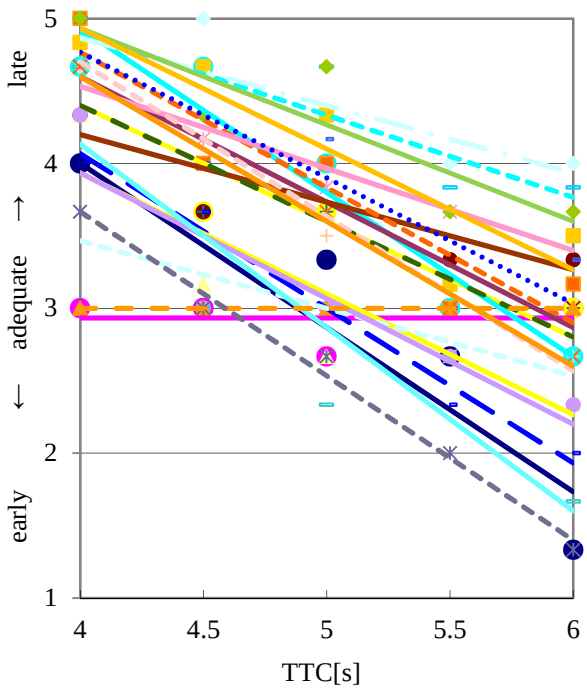

Figure6. Subjective evaluation results for all participants

The symbols in the figure plot the subjective evaluation results of the participants. The same symbols and colors are used for the same participant in the TTC range from 4.0 to 6.0 s. The straight lines of the same colors as the symbols are the approximation lines of the evaluation results of those participants.

Japan Automobile Research Institute reported that in their study no drivers changed lanes when TTC was 4.0 s or less [5]. In a similar way, the participants in the present study evaluated the notification at that timing as being "late". For that reason, a significant difference occurred between TTC = 4.0 s and TTC = 4.5 s, though the two timings differed by only 0.5 s.

For notification timings at TTC = 4.5 s and 5.0 s, many of the participants' evaluations were distributed between "slightly late" and "adequate". The dispersion of the results for these timings was larger and fewer participants responded "adequate" compared with the subjective evaluation results for TTC = 5.5 s and 6.0 s. We will next consider the subjective evaluation results for TTC = 5.5 s and 6.0 s. The Japan Automobile Research Institute reported that the mean and standard deviation of the time needed for drivers to change lanes was 5.58 ±1.29 s and that drivers estimated the relative positions of the two vehicles before executing a lane change maneuver based on the relative speed between their vehicle and the rearward approaching vehicle [5]. Accordingly, the number of participants in the present study who evaluated notification timings of 5.5 s and 6.0 s as being "adequate" probably increased because many of them judged that the risk of a collision with the rearward approaching vehicle would be high if they actually changed lanes. On the other hand, the number of participants who evaluated the notification timings at TTC = 4.5 s and 5.0 s as being "slightly late" presumably increased because many of them judged that the risk of a collision was clearly more definite.

We will now consider the evaluation results for the individual participants presented in section 6.2. All of the pairs of the five TTC patterns that were subjectively evaluated in this study showed a significant difference ($p<0.05$). This suggests that if TTC varies by 0.5 s, drivers' evaluation of the effect of a notification system based on the timing of the notification will probably vary.

Next, we will also analyze the approximation lines of the evaluation results of the 21 participants mentioned earlier. The mean and variance of the slope of the approximation lines of these 21 participants were -0.61 and 0.031, respectively, indicating that the individual difference was small. On the other hand, the mean and variance of the intercept were 7.04 and 1.03, respectively. Compared with the slope, an individual difference is evident ($p<0.05$). This presumably suggests that the participants had different expectations of the notification timing of the system when changing lanes. A close observation of the approximation lines

in Fig. 6 reveals that they could be divided into two groups. In one group the values of the approximation lines at TTC = 4.0 s are 4.2 or higher and in the other group they are less than 4.2. A significant difference ($p<0.01$) is thus observed between the two groups. At least for the 23 participants who participated in the present study, it can be inferred that their subjective evaluation of the effect of the notification system would probably improve provided that two patterns of notification timings were provided as system options to choose from.

8. CONCLUSION

This study examined the change in drivers' subjective evaluation of a notification system for a rearward approaching vehicle when the timing for issuing a notification was varied to match the time-to-collision (TTC) with the approaching vehicle. The following conclusions can be drawn from the experimental results.

(1) The experimental results confirmed that the subjective evaluations of the participating drivers changed when the notification timing was varied to match TTC.

(2) Notification timings at TTC = 5.5 s and 6.0 s were evaluated highly by the participants, based on the time needed to execute a lane change and the estimated speed and position of the rearward approaching vehicle.

(3) The results showed there were individual differences among the participants regarding the effect of the notification timing, but that such differences could be grouped together into two major groups.

The experiments conducted in this study were carried out under a limited driving environment. In order to analyze more thoroughly the timing for issuing a notification by a rearward vehicle detection system, it will be necessary to conduct experiments in real-world driving environments. Because of the parameters of the vehicle detection technology used in this study, experiments were conducted only at TTC values up to 6.0 s. In future work, it will also be necessary to conduct evaluation experiments using larger TTC values.

9. References

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