

Human Monitoring-Based Driving Support

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Abstract: From April 2004 to March 2007, a research project entitled “Situation and Intent Recognition for Risk Finding and Avoidance” was conducted. This project includes the following research topics: (i) estimation of driver’s state, (ii) driver behavior modeling, (iii) intelligent information processing methods for situation recognition and visual enhancement. This paper introduces several researches in which the author participated in the project on driver monitoring techniques and design of driver support based on the driver monitoring.

1. INTRODUCTION

In order to provide a driver with some support for proactive safety in an appropriate manner, a driver support system should be multi-layered and situation-adaptive. In this sense, it is important to detect mismatches between a traffic situation and driver’s intent in the situation.

From April 2004 to March 2007, a research project entitled “Situation and Intent Recognition for Risk Finding and Avoidance” was conducted under the support of the Ministry of Education, Culture, Sports, Science and Technology, Government of Japan (Inagaki, 2007). This big project in which approximately 30 researchers participated from eight organizations includes the following research topics: (i) estimation of driver’s state, (ii) driver behavior modeling, (iii) intelligent information processing methods for situation recognition and visual enhancement.

The author participated to the above project and conducted a research on driver support based on estimation of driver’s psychological state and his or her intent. This paper introduces several researches done in the project on driver monitoring techniques and design of driver support systems based on the driver monitoring.

2. APPROACH

2.1 A Framework

My framework in the project is shown in Fig. 1. The basic idea is that situation-dependent methods for estimation of driver’s state are necessary.

When a time-critical event (such as rapid deceleration of a forward vehicle) occurs, a driver may fail to implement safety control actions at appropriate timing. At this phase, major measures of driver’s attentiveness may be based on manual control inputs, such as the time to hit the brake. There may be no research topics on driver monitoring in this phase.

When the traffic condition is hazardous but not requiring driver’s immediate response, driver’s inattention may result in lack of “preparation.” For example, suppose the host vehicle (H) is following a forward vehicle (F) and another vehicle (A) is cutting in front of F (Fig. 2). In this case, F may decelerate rapidly in the near future for preventing a collision to A. In order to maintain safety of the host vehicle, the host driver may have to “prepare” to hit the brake. It can be assumed that this kind of “preparation” is required to professional drivers. If a system detects that such proactive actions are omitted, the system judges that the driver’s attention to driving is not adequate. Since such “preparation” may not be detected on the basis of manual control inputs, driver monitoring systems should be able to recognize driver’s motion. Another example in this phase is driver’s checking of the side mirror when he or she is trying to change lanes.

Even if the traffic condition is very peaceful, it is still necessary to detect driver’s inattentiveness to driving. The inattentiveness causes the driving potentially risky. Two types of inattentiveness may be distinguished (Delhi Delco Electronics Systems, 2003): (a) driver impairment (due to drowsiness, substance use, or a low level of arousal), (b) allocation of driver attention to non-driving tasks. Since there are many previous researches on drowsiness or fatigue, the former is not discussed in the project. The latter case can be discussed as a problem of “distraction.” Ranny et al. (2000) proposed four categories of distractions: “visual”, “auditory”, “biomechanical”, and “cognitive”. Among them, we have focused on the biomechanical and cognitive distractions.

(1) Cognitive Distraction. A driver is performing a cognitive task which does not require driver’s motion, e.g., thinking about something serious. Since we can assume that driver’s mental workload may increase when the driver is performing a cognitive subtask during driving, such situation can be detected with measurement techniques of mental workload.

(2) Biomechanical Distraction. A driver is performing a task which requires driver’s motion, e.g., looking at something irrelevant to driving, or taking something to eat/drink. In this

case, the inattention should be detected by observing drivers motion.

Reasons for focusing on the above two are as follows. First, auditory distraction has close relationship with the cognitive distraction. Typical example is talking on a cellular phone when the vehicle is running. Thus, we do not distinguish the auditory distraction from the cognitive distraction. Second, there have been a lot of researches on the visual distraction. There are several commercial products which have a function of identifying gaze point in a 3-D space (e.g. FaceLab and SmartEye).

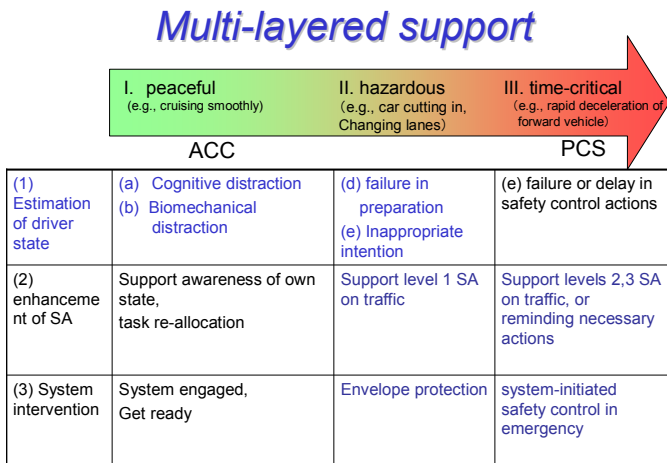


Fig. 1 A framework

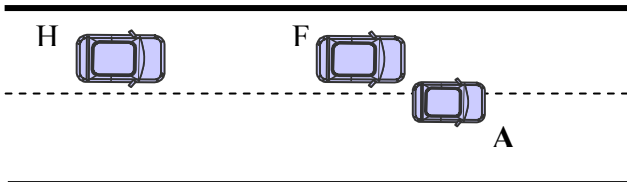


Fig. 2 An example of situations in which a driver in a host vehicle (H) should “prepare” to implement safety control actions (Vehicle A is cutting in just front of vehicle F)

2.2 Methods

In order to develop methods for estimation of driver’s state in a non-intrusive manner, data of driver behaviour are necessary. In the series of the research, data collections and/or experiments using a driving simulator were done.

Fig. 3 shows our driving simulator (DS). The simulator can record the following data automatically: steering angle, and strokes of acceleration and brake pedals. Moreover, the following sensors can be used simultaneously (Fig. 4):

(i) Tactile sensors. Sensor sheets are installed on the seat cushion and the seat back rest. The sensor sheets monitor load distributions on the seat and on the seat back rest. Driving posture and frequency of body movement can be speculated with the sensors.

(ii) Eye and head trackers. By combining the data obtained with these sensors, we can identify the point at which a driver is looking. Frequency of blinks may also be calculated.

(iii) A laser displacement sensor. Once a driver hits the brake, his or her pedal stroke is recorded in the simulator. In order to determine whether or not a driver is ready for hitting the brake pedal when the traffic condition is potentially risky, the instep position of the right leg is monitored with this sensor, which is installed near the acceleration pedal.

(iv) Finger/ear plethysmograms measurement system. Plethysmograms are used to evaluate driver’s mental workload. Several researches showed that maximum Lyapunov exponent derived by doing chaos theoretic analysis can be sensitive to the level of driver’s mental workload (e. g., see, Miao, et al. (2008))

(v) An infrared thermal imaging camera. The temperature at the driver’s nose-tip is measured with this camera. It has been shown that an increase in the mental workload may cause decrease in the tissue blood volume as well as the temperature at the nose-tip (e.g., Veltman, et al., 2005).

(vi) Video cameras. Driver’s facial expression and driving posture are recorded.

DS for driver monitoring in Univ. Tsukuba

- a flat, nearly straight
- up to 8 other vehicles
- other vehicles controlled from an external computer
- projected onto four 80" screens

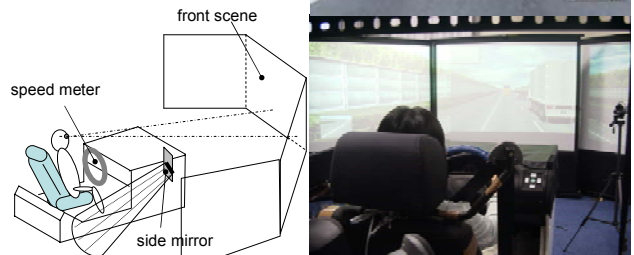


Fig. 3 A driving simulator

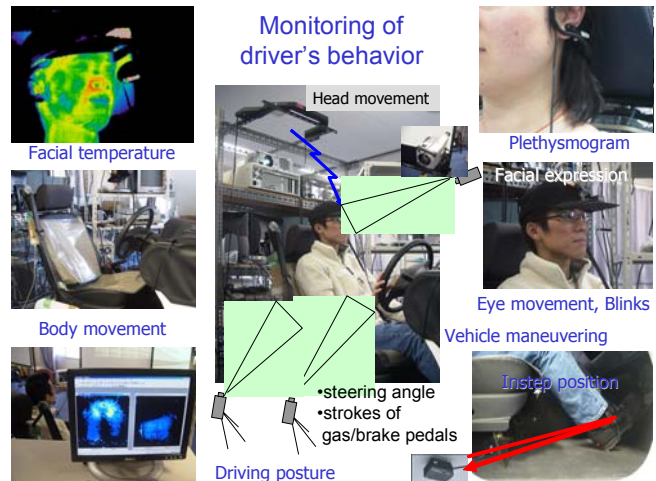


Fig. 4 Driver monitoring devices

3. DETECTION OF COGNITIVE DISTRACTION

In our researches on detection of cognitive distraction, the main task for participants is to drive safely on a cruising lane in the DS. A run lasts six minutes. Each participant may be asked to conduct a mental arithmetic (MA) subtask during driving as a source of the cognitive distraction. A driver is given one-digit number (from 1 to 9) every three seconds through speakers connected with a PC. He or she is asked to answer the sum of the latest two numbers verbally. In the subtask condition, the MA task is given during [2, 4] min after starting a run (MA period).

3.1 Eye movement

Itoh & Inagaki (2006a) found that there were two types of effects of performing a cognitive subtask on fixations: (A) shorter fixations were observed during an MA period, and (B) longer fixations during the MA period. Typical examples of these effects are shown in Fig. 5. Note here that either Type A effect or Type B effect may occur in one person depending on traffic conditions. For example, Type A effect occurred often when the traffic was relatively congested. On the other hand, Type B effect was observed mainly when the traffic is peaceful.

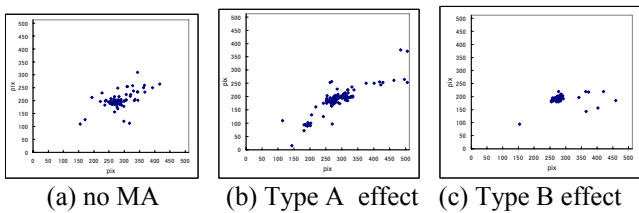


Fig. 5 Example of two dimensional distribution of fixation points (Itoh & Inagaki, 2006a)

Two categories were distinguished for the participants, according to types of the effects that they exhibited (Fig. 6):

- Group A. Type A effect was mainly observed. As a result, the number of “short” fixations (concretely speaking, fixations whose time lengths were shorter than 1.0 sec were regarded as “short”) increased significantly during an MA period (Fig. 6).
- Group B. Type B effect was mainly observed. The number of the short fixations decreased significantly during an MA period.

An algorithm for detection of performing the MA task has been developed. The basic idea underlying the algorithm is to regard that the driver is cognitively distracted if the number of short fixations exceeds a threshold if he or she is categorized in Group A (Fig. 7 (a)). On the other hand, the threshold is set at a lower part if the driver is categorized in Group B (Fig. 7(b)).

Table 1 shows a result of applying the algorithm to the experimental data. The result suggests that the eye fixations can be useful for detection of cognitive distraction at least for some types of drivers.

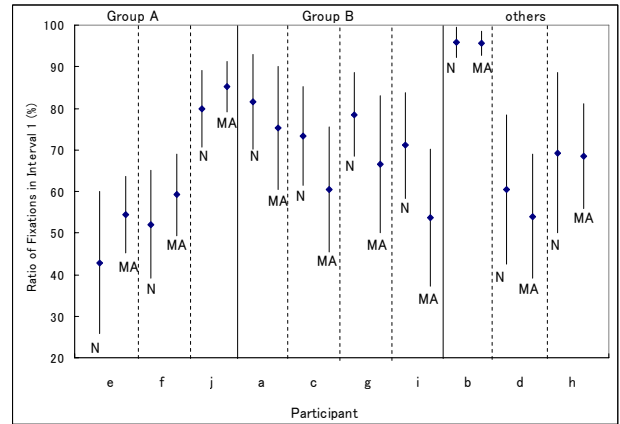
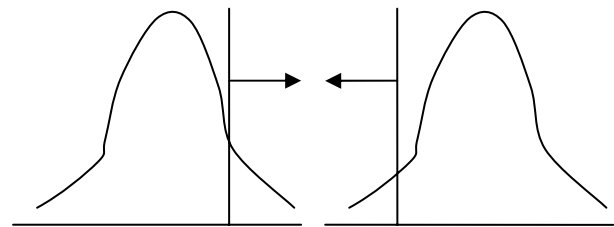


Fig. 6 Effects of performing MA task on the short fixations (Itoh & Inagaki, 2006b)



(a) Detection area for Group A (b) Detection area for Group B

Fig. 7 Basic idea of detection of cognitive distraction on the basis of eye movement data

Table 1 Performance of an detection algorithm based on fixations (Itoh, Inagaki, 2006a)

Participant	Group A		Group B	
	<i>e</i>	<i>c</i>	<i>g</i>	<i>i</i>
Hit rate	19/32 (59.3%)	24/32 (75.0%)	27/32 (84.4%)	28/32 (87.5%)
False alarm rate	3/64 (4.7%)	6/64 (9.4%)	11/64 (17.2%)	7/64 (10.9%)

3.2 Ear plethysmogram

Several researches show that the maximum Lyapunov exponent derived from ear or finger plethysmogram becomes high when the mental workload is high (e.g., see, Miao, et al. (2008)). Itoh & Inagaki (2007c) found that the maximum Lyapunov exponent may become high during an MA period at least for some particular persons (e.g., see, Fig. 8). The phenomenon was reproducible. Fig. 9 shows an example of time series of the mean (and the standard deviation) of the maximum Lyapunov exponent as a function of runs. In Itoh & Inagaki (2007c), two experiments, called Phases #1 and #2, were conducted. In the Phase #1 experiment, the traffic condition is peaceful. On the other hand, the traffic is relatively congested and some critical events, such as, steep cutting in of other vehicle, occur occasionally.

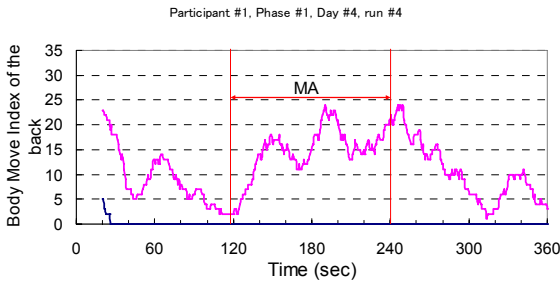


Fig. 8 An example of increase of the maximum Lyapunov exponent of an ear plethysmogram (Itoh, Inagaki, 2007c)

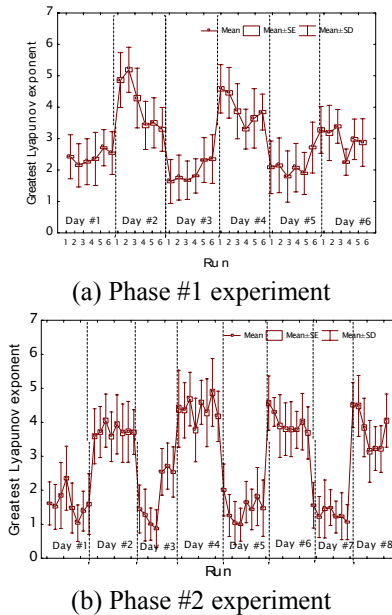


Fig. 9. An example of repeated observations of increase of the maximum Lyapunov exponent

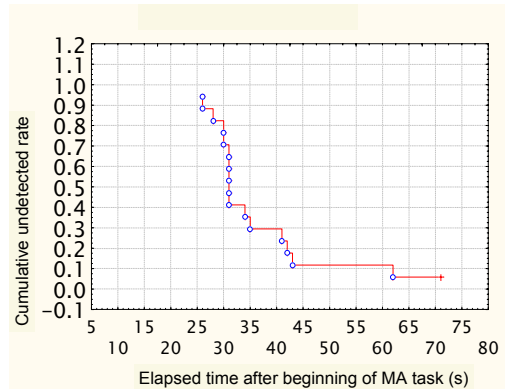
Itoh & Inagaki (2007c) developed a simple algorithm for detection of performing the MA task on the basis of the maximum Lyapunov exponent. The basic idea is similar to the one on the basis of eye movement. Table 2 represents the results of testing the algorithm with the experimental data for a participant. The hit rate is defined as the ratio of “time length of detecting performing the MA task” to the total time length of performing the MA task. The results showed that the performance of the algorithm is relatively lower than expected. This is because the maximum Lyapunov exponent is calculated with the data obtained in the latest 30 seconds. In this sense, the timing of the detection on the basis of the maximum Lyapunov exponent is inherently late.

Table 2 An example of detection of performing MA task on the basis of the maximum Lyapunov exponent (Itoh, Inagaki, 2007)

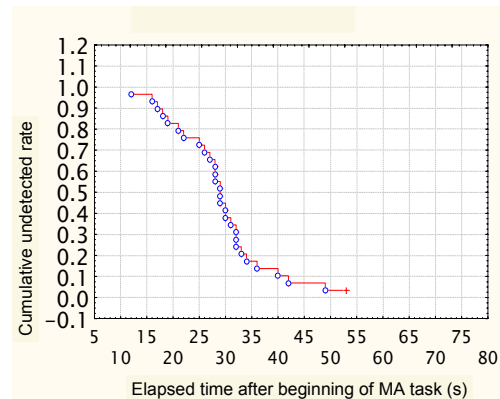
	Ear plethysmogram	
	Phase #1	Phase #2
Hit rate (%)	64.9	73.8
False alarm rate (%)	14.0	20.3

How long does it take to detect performing the MA task? Fig. 10 gives an answer. Fig. 10 represents the detection latency

on the data used in Table 2. According to Fig. 10, 50% of trials were detected within 30 seconds after starting the MA task.



(a) Phase #1



(b) Phase #2

Fig. 10. Detection latency

3.3 Temperature at the nose tip

It is known that the temperature at the nose tip decreases when mental workload becomes high. Itoh & Inagaki (2007a) also observed that the temperature at the nose tip decreased during an MA period, and that the temperature goes back to the original level after completion of the MA period. Fig. 11 shows an example. On the other hand, the temperature at the nose tip stayed at some degree when a driver was not imposed to perform the subtask during driving (e.g., Fig. 12).

The above tendency was common to most participants. However, the temperature may decrease not only when the mental workload is high but also when he or she feels nervous. As shown in Fig. 13, the temperature at the nose tip began to decrease even when the participant had not started to perform the subtask in the trial under MA condition.

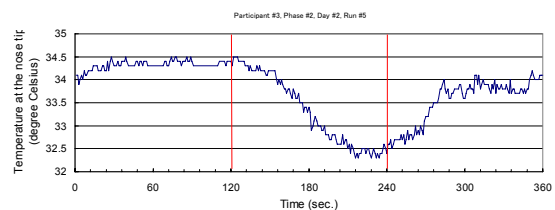


Fig. 11. Example of the nose tip temperature of Participant #3 (Phase #2, Day #2, Trial #5) (Itoh, Inagaki, 2007a).

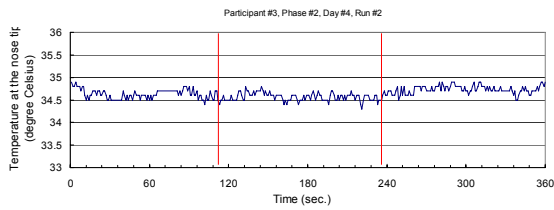


Fig.12. Disappearance of the effect on the nose tip temperature of Participant #3 (Phase #2, Day #4, Trial #2). (Itoh, Inagaki, 2007a).

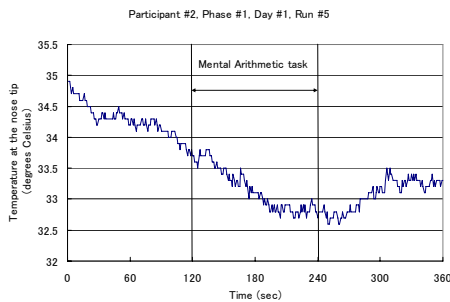


Fig. 13. Example of the temperature at the nose tip of Participant #1 under MA condition (Phase #1, Day #2, Trial #5) (Itoh, Inagaki, 2007a).

3.4 Data fusion

The results shown in the above sections suggest that no single index itself is enough to establish a highly reliable method of detecting cognitive distraction. Thus, data fusion is necessary for developing a reliable method.

There exist at least two approaches for the data fusion. One is to integrate individual judgments. In this approach, each judgment is derived from an index with a single sensor. A typical method of this approach is using a k-out-of-n logic. The other is to make a judgment via analyzing multidimensional sensor data. A typical example of this approach is using a discrimination analysis. Itoh & Inagaki (2007c) discusses on both approaches. However, it has not been clarified what is the best way to the data fusion. It is necessary to develop a full list of indices and methods which can be used to detect cognitive subtasks.

4. DETECTION OF BIOMECHANICAL DISTRACTION

Biomechanical distraction is one of important aspects of risky behaviour in driving. Itoh & Yoshimura (2007) developed a video analysis tool (see, Fig. 14) and found that there were various types of cognitive distractions. Typical example is taking something from the passenger seat (e.g., see Fig. 15).

There are many researches and techniques on detection of “looking aside” via analysis of face direction (e. g., see, Inayoshi & Kurita (2007), Nakagoshi, et al. (2006)). Driver’s body pose analyses methods are also developed by several researchers (e.g., see, Cheng & Trivedi (2006), Kamada, et al. (2006)). A feature of these approaches is that they are based on computer vision techniques. There are two problems here: cost and privacy. A camera is used just for analyzing the

posture or movement of driver’s face or body. Some drivers may not be happy to be taken their behaviour by camera.



Fig. 14 Video Indexing and Inspection System (Itoh & Yoshimura 2007)



Fig. 15 Example reaching to the passenger seat in the real world driving

A method on the basis of pressure distribution on the driving seat may overcome the above problems. A pressure distribution sensor on the driving seat can be general purpose as shown in the followings:

- (1)It can be used to determine whether the seat arrange is appropriate or not by analyzing the driving posture.
- (2)Physiological data, including the plethysmogram, can also be extracted from the seating pressure (see, Maeda, et al. (2007)).
- (3)Fatigue can also be detected by using a pressure distribution sensor (e.g., see, Furugori, et al. (2005)).

Moreover, it can be claimed that measuring pressure distribution on the driving seat may be more acceptable for drivers than taking pictures or movies by cameras.

Thus, it is worth developing a method of detection of biomechanical distraction on the basis of pressure distribution on the driving seat. Itoh (2008) tried to develop a method which analyzes the load centre position of a pressure distribution. Here is a brief review of their study.

A data collection is conducted in order to investigate whether unnecessary actions can be detected via analysis of load centre position of the back of the driving seat. With tactile

sheet sensors (called BIG-MAT by Nitta) installed on the seat cushion and on the back of the driving simulator, pressure distribution is measured continuously in time, in which the pressure distribution can represent driver's posture (Fig. 16). The load center positions (LCPs) on the seat and on the back have been obtained on the basis of the pressure data with 44 (row) x 48 (column) sensing units. In this paper, the LCP on the back (denoted LCP-B) is utilized for driver's action analyses.

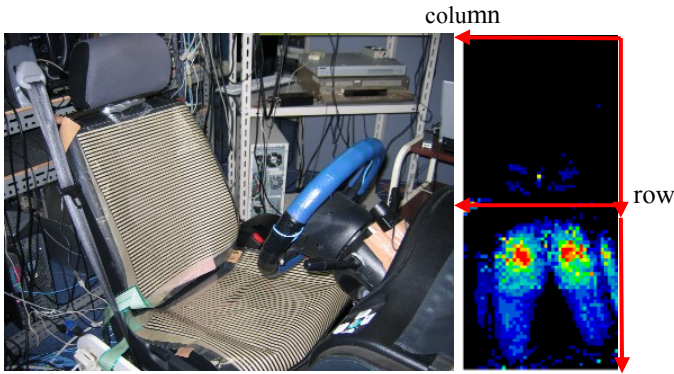


Fig. 16 Tactile sheet sensors for measuring pressure distributions

Five undergraduate students participated in this study. Participants were asked to drive safely in the driving simulator. The traffic is configured as peaceful. The participants were also required to perform actions which were unnecessary during driving. Five types of the actions were distinguished:

- C: to correct the driving posture (13 times)
- P: to take something on the cushion of the passenger seat, and to put it back (22 times) (Fig. 17(a))
- N: to operate a navigation system (9 times) (Fig. 17 (b))
- F: to pick up something under the participant's feet (7 times) (Fig. 17 (c))
- B: to take something on a backseat (10 times) (Fig. 17(d))

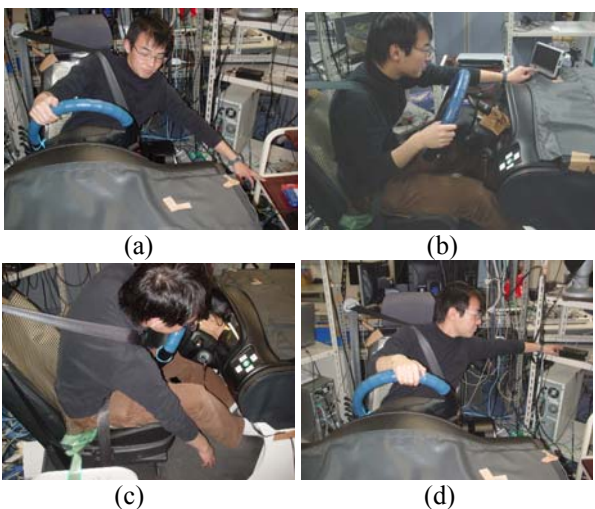


Fig. 17 Simulated movements as unnecessary actions during driving

The participant received ten runs for data collection. The number of movements in a run differed from run to run depending on the sequence of the movements. The minimum was seven and the maximum was 10.

In this study, pressure distributions on the seat cushion and on the back of the driving seat was measured. From the raw data, the load center positions were calculated. According to analyses of data obtained from the preliminary studies, pressure distribution on the back is affected significantly when a driver makes a movement.

Thus, an algorithm was developed for detecting driver's unnecessary actions. The detection procedure involves the following steps:

Step 1: Determine whether a driver is making a movement of something or not. The driver is regarded as making a movement when at least one out of two variances of the values of the column and the row of the LCP-B in the last 5 seconds is significantly greater than the reference value given in advance.

Step 2: If a movement is detected in Step 1, then go to Step 3. Otherwise, go to Step 1.

Step 3: Narrow the possibilities down to small number of candidates. This is done on the basis of the deviation direction of the LCP (Fig. 18). As shown in Fig. 18, (a) and (b) are not distinguished in this method.

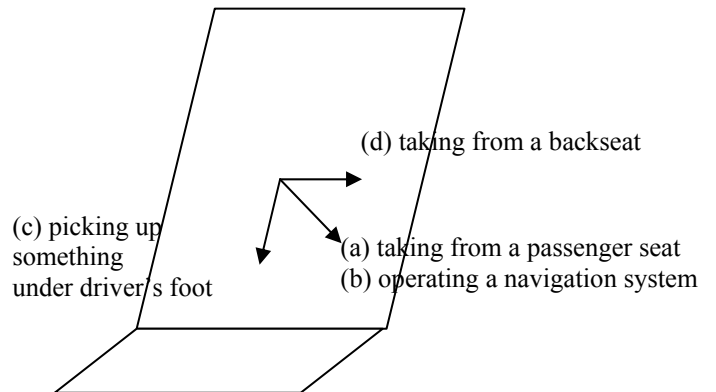


Fig 18 Deviation direction of the LCP-B (driver's seat is located on the right-hand side)

Table 3 shows the result of detection of driver's making a movement (Step 1). Detection of a movement when a driver is really making a movement was 100% for each driver. On the other hand, the numbers of false detection over 160 min (10 times 16 min run) were from 6 to 24 as shown in Table 3. Even though we need to reduce the number of false detection, driver's making of a movement can be detected effectively.

Fig. 19 illustrates how much each type of movement was detected in a sense that the particular type is included in a candidate set which had been narrowed as a result of Step 3 of the detection algorithm. As shown in this figure, narrowing candidate was successful in general. However, the detection rate on "picking up something from a backseat" was not high enough. Further improvement of the detection

algorithm should be done for developing a reliable detection system on driver's unnecessary actions.

Table 3 Detection of making a movement (Itoh, 2008)

Participant	#1	#2	#3	#4	#5
Hit rate	100%	100%	100%	100%	100%
# of false detection	16	24	6	11	6

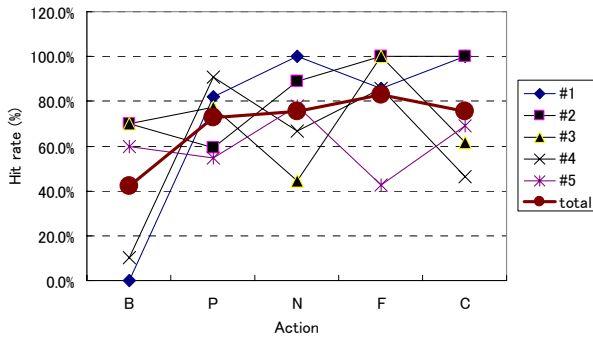


Fig. 19 Rates of hit in a sense that the particular movement is included in candidate set

As shown in the above, detection of the situation at which a driver is performing some unnecessary action would be done with our algorithm using the LCP-B. Since it is known that identification of the LCP-B can be done with 6-8 strain gages embedded in the back of a driving seat, the movement detection itself can be realized with low cost.

In order to improve the accuracy of identifying what a driver is performing, not only revising the algorithm shown the above but also analyses of two-dimensional pressure distribution measured with a pressure distribution sensor. For this purpose, a tactile sensor which can be embedded in a driving seat is necessary. Under the cooperation of Xiroku Inc., a novel sheet sensor has been developed as shown in Fig. 20. Examples of the data measured with the novel sensor are shown in Fig. 21. According to Itoh, et al. (2007), the hit rate and the correct rejection rate (1-false detection rate) were as shown in Table 4. Although further improvement is necessary, the new approach is potentially effective.

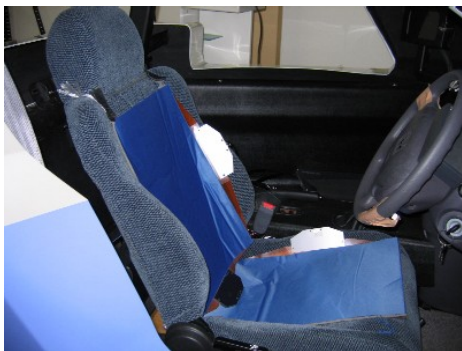


Figure 20 A novel sheet sensor

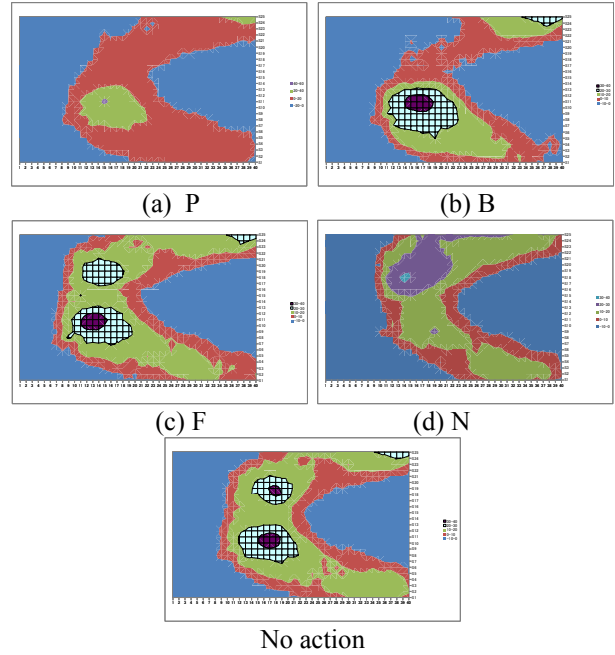


Fig. 21 Examples of pressure distributions (Itoh, et al, 2007)

Table 4 Hit rates in experiment 2 (Itoh, et al, 2007)

Class	No action	(a) P	(b) B	(c) F	(d) N	Total
Subject						
#2-1, 1 st	9/40	1/10	0/10	0/10	7/10	17/80
#2-1, 2 nd	6/40	0/10	8/10	0/10	8/10	22/80
Hit rate	18.8%	5%	40%	0%	75%	24.3%
#2-2, 1 st	28/40	10/10	1/10	0/10	10/10	49/80
#2-2, 2 nd	40/40	10/10	0/10	0/10	10/10	60/80
Hit rate	85.0%	100%	5%	0%	100%	68.1%
#2-3, 1 st	37/40	7/10	0/10	5/10	10/10	59/80
#2-3, 2 nd	40/40	10/10	1/10	1/10	10/10	62/80
Hit rate	96.3%	85%	5%	30%	100%	67.2%

5. EVALUATION OF PREPAREDNESS

Analyses of pressure distribution on the seat cushion can be applied to infer driver's "preparedness" for avoiding occurrence of an accident. For example, when a vehicle running on the next lane is going to cutting in just front of the host vehicle, the driver may have to prepare to hit the brake by putting his or her right leg over the brake pedal. In particular, detection of such "preparedness" is important when the driver has been used an adaptive cruise control (ACC) system because he or she may hesitate to hit the brake in order for avoid disengaging the ACC system (an ACC system is disengaged when a driver hits the brake).

Itoh, et al. (2007) collected data on the preparedness and developed a method to identify a driver posture from five possibilities shown in Fig. 22. Even though it is difficult for a person to identify a particular posture by just watching with analyst's eyes (e.g., see, the data shown Fig. 23). However, whether a driver is "prepared" to hit the brake or not can be distinguished if we apply pattern recognition methods, such as a liner discriminant analysis. The results of applying the method are shown in Table 5.

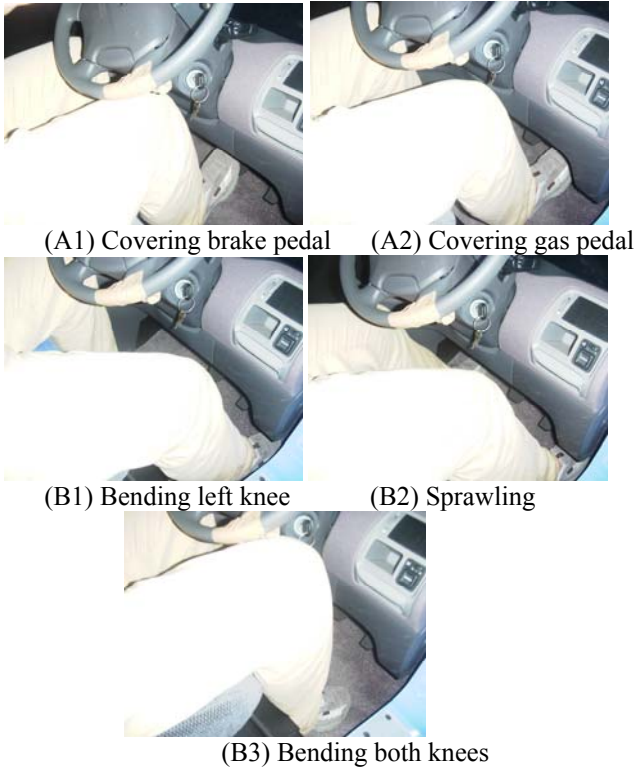


Fig. 22 Five Classes on Positions of Driver's Legs

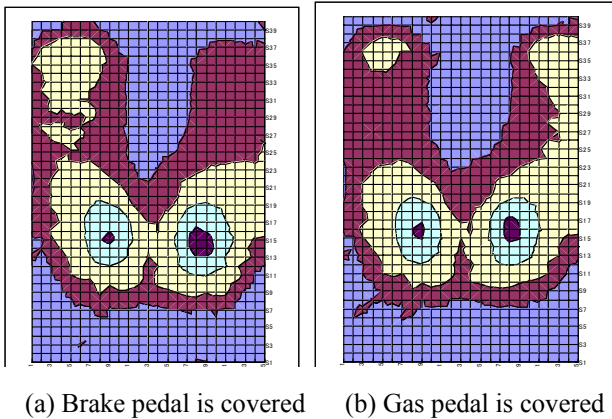


Figure 23 Pressure distributions on the seat cushion

Table 5 Linear discriminant analysis on preparedness to hit the brake (Itoh, et al., 2007)

Estimated \ Actual	"A1"	"A2"	"B1"	"B2"	"B3"
A1	10/10	0/10	0/10	0/10	0/10
A2	0/10	10/10	0/10	0/10	0/10
B1	0/10	0/10	10/10	0/10	0/10
B2	0/30	0/30	21/30	9/30	0/30
B3	0/30	0/30	0/30	0/30	10/10

6. INFERENCE OF DRIVER INTENT TO CHANGE LANES

Zhou, et al. (2008) collected driver behavior data when a driver who was driving a large truck tried to change lanes in

the DS. Fig. 24 shows an example of how the drivers check the side mirror when they are preparing changing lanes. According to the data, we can point out that the frequency of looking at the side-view mirror increases rapidly from approximately 10 seconds prior to starting the maneuver to change lanes. This tendency was common both to participants and to traffic situations. Zhou, et al. (2008) developed a model for inferring driver intent to change lanes (Fig. 25) and applied it to the data obtained from the DS experiment. A part of the results is shown in Fig. 26.

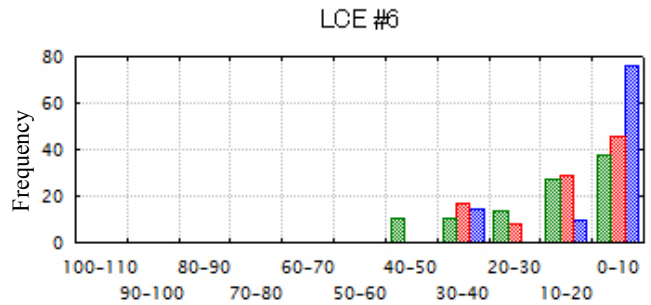


Fig. 24 Frequency of checking side mirror before starting the lane change maneuver (Zhou, et al., 2008)

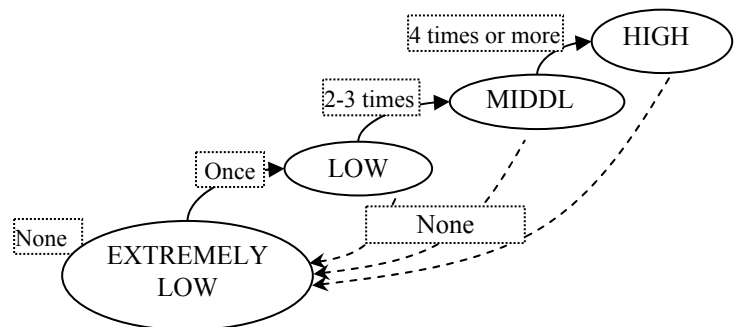


Fig. 25 A model for inferring driver intent to change lanes (Zhou, et al., 2008)

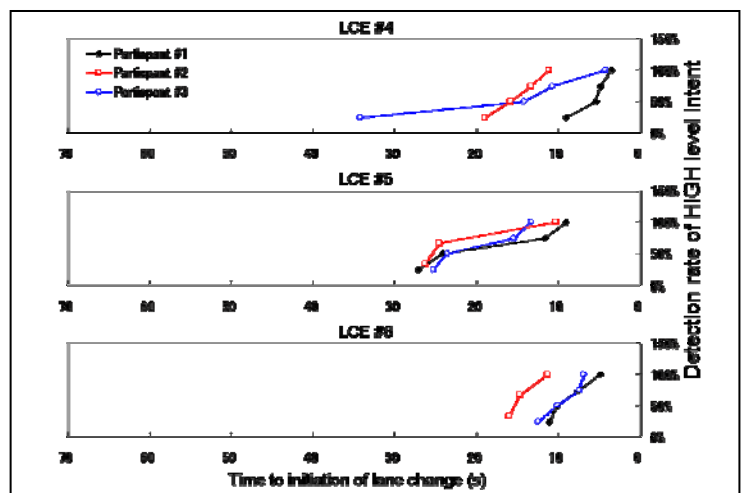


Fig. 26 Results of detecting lane change intent (Zhou, et al., 2008)

Zhou, et al. (2008) found that LOW level intent can be detected approximately 20 seconds before starting the lane change maneuver (Fig. 27). This result suggests that a truck driver may be inattentive if LOW is not detected when his or her vehicle is approaching the forward vehicle which will be passed in the near future. This interpretation is on the basis of Utsugi, et al. (2007) which shows that the time point of starting the lane change maneuver of a truck driver can be inferred with a statistical method.

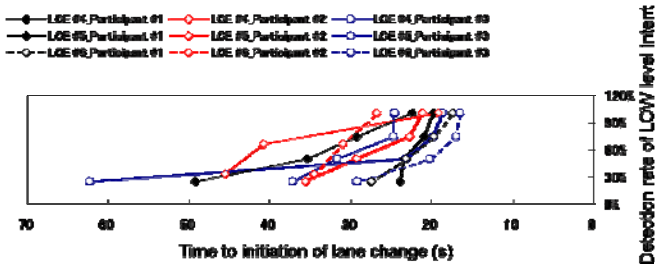


Fig. 27 Detection of LOW level of lane change intent (Zhou, et al., 2008)

Findings obtained in Zhou, et al. (2008) are supported by the data in the real world. Itoh & Inagaki (2007d) analyzed professional truck drivers behavior from video movie obtained in Itoh & Yoshimura (2007), pattern of the truck drivers' checking the side mirror in the real world is similar to that of ordinary drivers in the DS (Fig. 28). The detection algorithm proposed by Zhou, et al. (2008) is also useful. Fig. 29 shows an example of a cumulative curve of detecting HIGH intent for the real professional truck drivers.

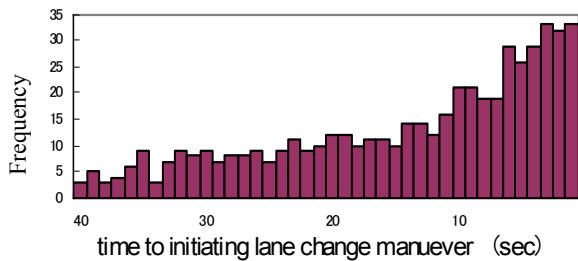


Fig. 28 Example of professional truck drivers' pattern of checking the side mirror (Itoh, Inagaki, 2007d)

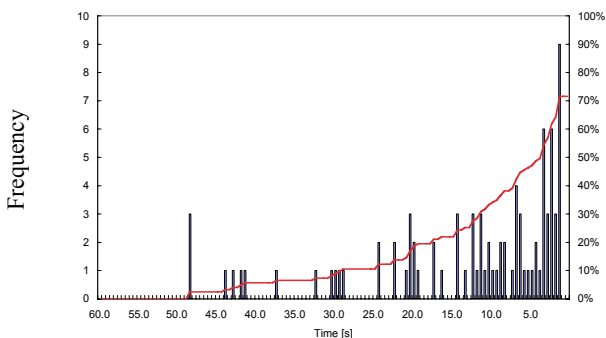


Fig. 29 Example of results of detecting HIGH intent from the real professional truck driver's behavior (Itoh, Inagaki, 2007d)

7. DRIVER-ADAPTABLE WARNING AND AUTONOMOUS BRAKING IN EMERGENCY

Suppose a driver is inattentive to driving. What should be done if a hazard has appeared? One possible answer to the question is to give some reminder for suggesting the driver to become attentive to the traffic situation. If, on the other hand, a driver is very attentive, what should be done under risky situation. Issuing some alert or other types of support may help the driver in case when he or she fails to react to the traffic in an appropriate and timely manner. However, early reminder or similar supports may annoy the driver when he or she is attentive.

One way to reduce annoying warnings is to adjust the timing of providing a support according to the driver's usual way of performing a task.

Itoh & Inagaki (2007b) examined effectiveness and a driver's acceptance of a driver-adaptable forward vehicle collision warning system. In this study, the alarm timing for a driver is set as his or her mean timing of hitting the brake pedal when the forward vehicle decelerates rapidly.

Fig. 30 illustrates the alarm thresholds for each participant obtained in Itoh & Inagaki (2007b). Even though the absolute value depends on drivers, dependence of the 1/TTCs on the lead vehicle's deceleration rate seems to be common to all participants.

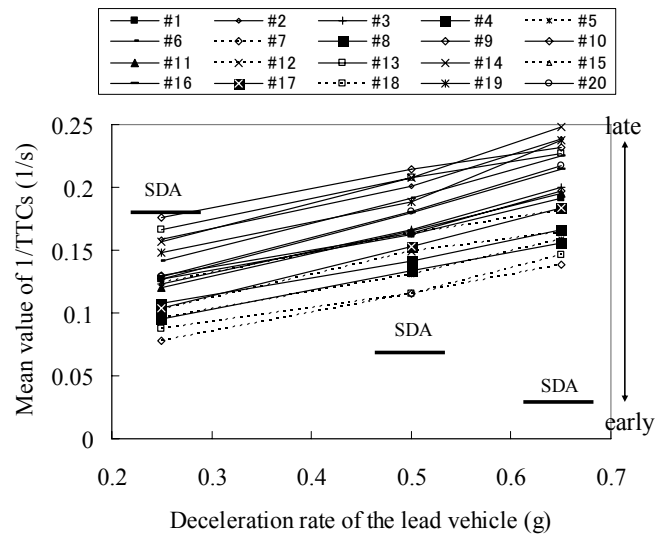


Fig. 30 Mean values of 1/TTCs at brake onset (Itoh, Inagaki, 2007b)

Fig. 31 represents the braking timing when a warning system based of driver's braking timing (DBT) is available. It is compared with the case in which Stopping Distance Algorithm (SDA) is used for providing a forward vehicle collision warning. The result shown in Fig. 31 may be interpreted as "using SDA is safer than using DBT." This interpretation is true if the alarm system never misses to issue an alarm. However, drivers using the alarm system based on SDA may fail to attain the safety if the alarm system misses. This is because the timing of driver's hitting the brake is

(unnecessarily) early under the SDA condition, especially when the deceleration rate of the lead vehicle is high. The earlier response under the SDA condition may be due to the change of drivers' policy on hitting the brake from "hit the brake when the situation seems to be dangerous" to "hit the brake when an alarm is heard." In fact, Inagaki, et al. (2005) showed that some drivers changed their policy on hitting the brake because of experiencing 'early' alarms, and that driver's braking was significantly delayed when the warning system failed to issue an alert.

On the other hand, Fig. 31 illustrates that overall trend of hitting the brake under the DBT condition is almost the same as that under the no alarm condition. This observation suggests that the driver's policy on hitting the brake did not change even when drivers used the alarm system based on DBT.

Moreover, DBT can be effective to reduce the number of rear-end collisions as shown in Table 6.

Note here that setting the timing as "just" the mean may not be optimal. Abe & Itoh (2007) showed that there exists more acceptable settings.

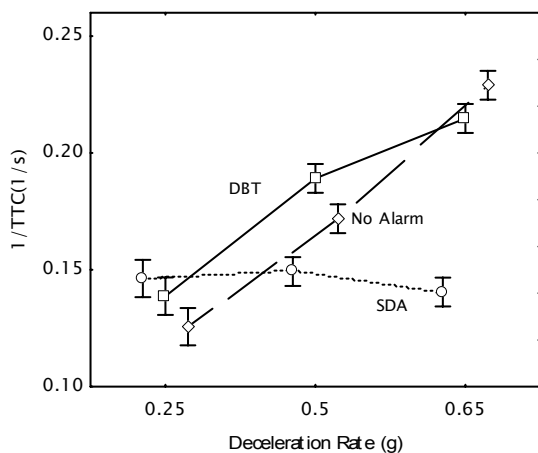


Fig. 31 Effects of warning systems on braking response time under distracting condition (each interval represented by an error bar means 95% confidence interval of the mean) (Itoh, Inagaki, 2007b)

Table 6 The number of rear-end collisions under distracting condition (Itoh, Inagaki, 2007b)

Deceleration Rate	No alarm	SDA	DBT
0.25 G	1/120	0/120	0/120
0.5 G	1/200	0/200	0/200
0.65 G	10/200	0/200	3/200

According to the above, it can be claimed that DBT is effective to avoiding accidents but free from driver's over-reliance. If we manage driver's commitment to driving by using the DBT-based or some other "driver-adaptable"

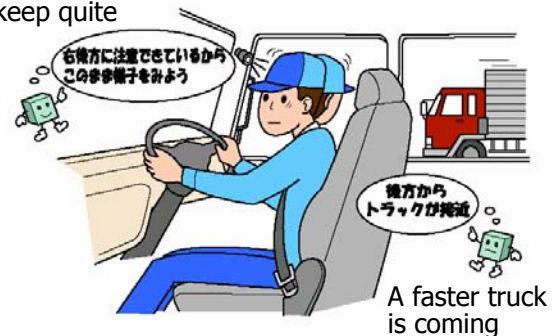
systems, a system in a car can decide by itself to execute strong automatic braking for "prevention of accidents." Note here that autonomous emergency braking which tries to "avoid" an accident is prohibited at least in Japan today. This is because some people are anxious about drivers' too much reliance on such autonomous safety systems.

8. DESIGN OF PROTECTION WHEN A DRIVER IS CHANGING LANES

Suppose a host truck is approaching to a slower forward truck. According to investigation by Itoh & Yoshimura (2007), truck drivers always try to pass the forward vehicle. How should a safety support system behave when a faster truck is coming from the behind just before the time point of starting the lane change maneuver by the driver in the host truck?

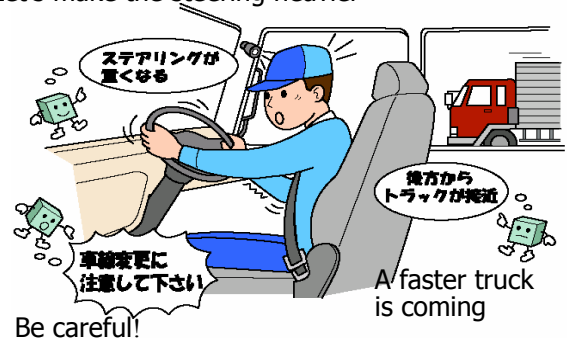
One possible answer is to keep quite if a driver looks attentive (Fig. 32 (a)). On the other hand, some support should be given if the driver looks inattentive to the truck coming from behind. This inference of driver's inattentiveness can be done by using a detection algorithm proposed by Zhou, et al. (2008). Two types of support can be provided: warning type and action type.

He looks attentive.
 Let's keep quite



(a) Driver is aware of the truck coming from behind

Let's make the steering heavier



Be careful!

(b) Driver is not aware of the truck coming from behind

Fig. 32 Driver-monitoring based adaptation of safety support

Inagaki, et al. (2007a) compared a warning type support and an action type support by conducting an experiment with a moving-based driving simulator (Fig. 33). In this study, the action type support is designed as "hard protection" which cancels out the driver's steering input completely when the

risk of colliding with the faster truck coming from behind. The results showed that the “hard protective” action type support is hard to be accepted by drivers (Fig. 34) even though the support can be effective to prevent crashes .



Fig. 33 A moving-based driving simulator

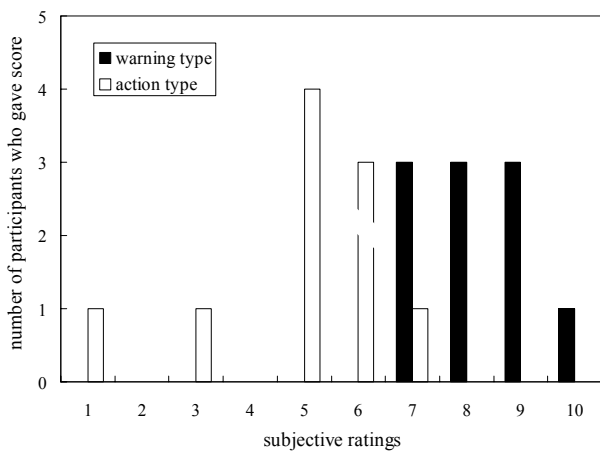


Fig. 34 An example of subjective ratings on drivers' acceptance of the support system (10: completely acceptable, 1: not acceptable) (Inagaki, et al., 2007a)

Inagaki, et al. (2007b) tested a “soft protection” instead of the hard protection, where the soft protection makes steering slightly heavier for informing the driver that the changing lanes may be dangerous. In this study, several situations including situations shown in Fig. 35 were given to participants. The result in terms of number of accidents is shown in Table 7. The results suggest that even the soft protection is effective to reduce the number of accidents.

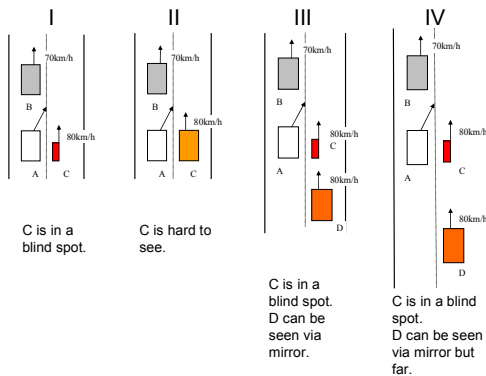


Fig. 35 Representative situations to be analyzed

Table 7 Number of accidents (Inagaki, et al., 2007b)

	No aid	Warning	Soft protection
Situation I	10/10	4/10	0/10
Situation II	0/10	0/10	0/10
Situation III	1/10	0/10	1/10
Situation IV	7/10	0/10	1/10

It is interesting that the number of accidents is not zero even though the soft protection is available. One interpretation is that the driver who caused an accident using the soft protection misunderstood the target of the support. Concretely speaking, he or she regarded that the protection was given for preventing a collision with vehicle D instead of vehicle C. In this sense, informing a driver what is a target of a support becomes important issue for design of the support system.

One way to solve the problem is adjusting the angle of the side mirror dynamically (Kuwana, et al., 2007) as shown in Fig. 36. Kuwana, et al. (2007) showed that this approach was effective to improve driver's recognition of a vehicle in a blind spot. Further studies are necessary to examine whether or not the dynamic changing of angle of the side mirror is effective for solving the problem of misunderstanding the target of the support.



(a) normal condition (b) rotated condition

Fig. 36 Dynamic angling side-view mirror (Kuwana, et al. (2007))

9. CONCLUSIONS

This paper showed an overview of the researches done by the author in the research project called “Situation and intent recognition for risk finding and avoidance”. Even though the researches focused their attention to professional drivers of large trucks, many techniques can be utilized for ordinary drivers in a small vehicle.

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