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A STUDY OF PERSONAL ADAPTIVE DRIVING SUPPORT SYSTEM USING A DRIVING SIMULATOR

Sueharu Nagiri[1], Yasushi Amano[2], Katsuhiko Fukui[3], Shun'ichi Doi[4]

Toyota Central Research and Development Labs., Inc.
41-1, Aza-Yokomichi Oaza-Nagakute Nagakute-cho Aichi-gun, Aichi-ken, 480-1192, Japan

1 Research-Domain 16, Tel.:+81-561-63-4569, Fax.:+81-561-63-6279 E-Mail:nagiri@vdlab.tytlabs.co.jp
2 Vehicle Control Laboratory, Tel.:+81-561-63-4569, Fax.:+81-561-63-6279 E-Mail:e0738@mosk.tytlabs.co.jp
3 Vehicle Control Laboratory, Tel.:+81-561-63-8419, Fax.:+81-561-63-6279 E-Mail:fukui@vdlab.tytlabs.co.jp
4 General Management Section of Mechanical Dep., Tel.:+81-561-63-6520, Fax.:+81-561-63-6518,
E-Mail:doi@vdlab.tytlabs.co.jp

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ABSTRACT

The social damage by a traffic accident is very enormous, therefore various countermeasures are taken for accident reduction. Most of accidents are caused by a human-error. Some researches and developments of the driving support system are executed to prevent this human-error. These systems early detects an error of a driver in "recognition" "judgment" "operation", then a sound and visual information are shown to the driver for the accident avoidance. This driving support system controls the vehicle by steering and braking when the driver can not avoid a collision. A driving simulator (DS) is an effective tool for the development of the driving support system and the evaluation of HMI (Human Machine Interface).

The authors have developed TRDS (Toyota Research Driving Simulator) to study the PADSS (Personal Adaptive Driving Support System). PADSS is able to detect an omission or deviation from normal operation by comparison the difference between current driving operations and beforehand accumulated one. On the basis of this detected result, PADSS assists the safety driving by the warning and vehicle control when a driver falls into dangerous situation. This paper describes TRDS and the analysis result of accumulated driving characteristics. Furthermore, some results of the PADSS are shown.

TRDS is constructed from the 6 DOF motion platform and the longitudinal motion device. The 6 DOF motion is constructed by link mechanism, which mounted on the longitudinal motion base. The range of longitudinal motion is ±4 m. The visual system is reflected with a liquid crystal projector from a viewpoint of a driver to the three flat screen installed in front 1.4m. FOV (Field Of View) of TRDS is 150 degrees.

The driving characteristics are accumulated while a subject drives to a destination of the neighbor town via a highway from a certain departure place. Subjects including two women are 12, and the trial number is 20 times. The characteristics of each subject in braking are automatically extracted during the experiment, and new data are added to a database after the experiment.

On the basis of braking characteristic of the accumulated individual subject, the authors carried out experiment of PADSS to show a warning for rear-end collision accidents. As a result of experiment, it was understood that the warning frequency is quite difference between each subject. There were many subjects who evaluated as the unnecessary about the rear-end collision warning. However, they had done hardy braking operation with the case which evaluated necessity of a warning. It is a future problem to decrease this unnecessary warning.

INTRODUCTION

In Japan, the fatalities by traffic accidents are slightly decreasing, but the accident numbers and the injuries are increasing year by year. Many driving support system are developing to reduce these traffic accidents [1], [2]. In such a system, it is often that the threshold is set based on average driver's operation. However, it is afraid that this setting is not an appropriate driving support to the driver with various operations. So, we are studying PADSS for each driver. The investigation of each driver's driving characteristics and a database are necessary for this system. A driving simulator is a good tool for the database accumulation and the study of the driving support system.

In this paper, the introduction of TRDS and developing system for PADSS are described by using its tool, and some experimental results are discussed.

DEVELOPED DRIVING SIMULATOR

System Construction

The appearance of TRDS installed at Toyota Central Research and Development Labs. is shown in Figure 1. In the blue shell on the 6 DOF motion system, only driving cockpit is accommodated. The 6 DOF motion system is able to move longitudinally ±4m. The system construction of TRDS is shown in Figure 2.

This TRDS has five components: common system, feel servo system, motion system, visual system, and support system. The main part of common system is the vehicle dynamics calculation by use of the real time simulation software CarSim. The vehicle dynamics of 19 DOF is calculated at 1 ms time interval, the results are used to the drawing a visual scene and the generation of acceleration given to the driver. The steering reaction torque is most important of the driving simulator. In feel servo system, this steering reaction torque is generated by use of the electric DC servo motor. The torque of this motor is controlled on the base of the front tire slip angle and steering angle. As for the motion and visual system, they are mentioned following section. The support system has three following functions. The first is the function to record the experiment data such as driver's operation and vehicle velocity. In these data, driver's eye movement is included, too. The second function judges the dangerous level whether vehicle collides to the forward vehicle or not. The third function is the warning to the driver when rear-end collision may occurs.

FIGURE 1 Appearance of TRDS (Toyota Research Driving Simulator)

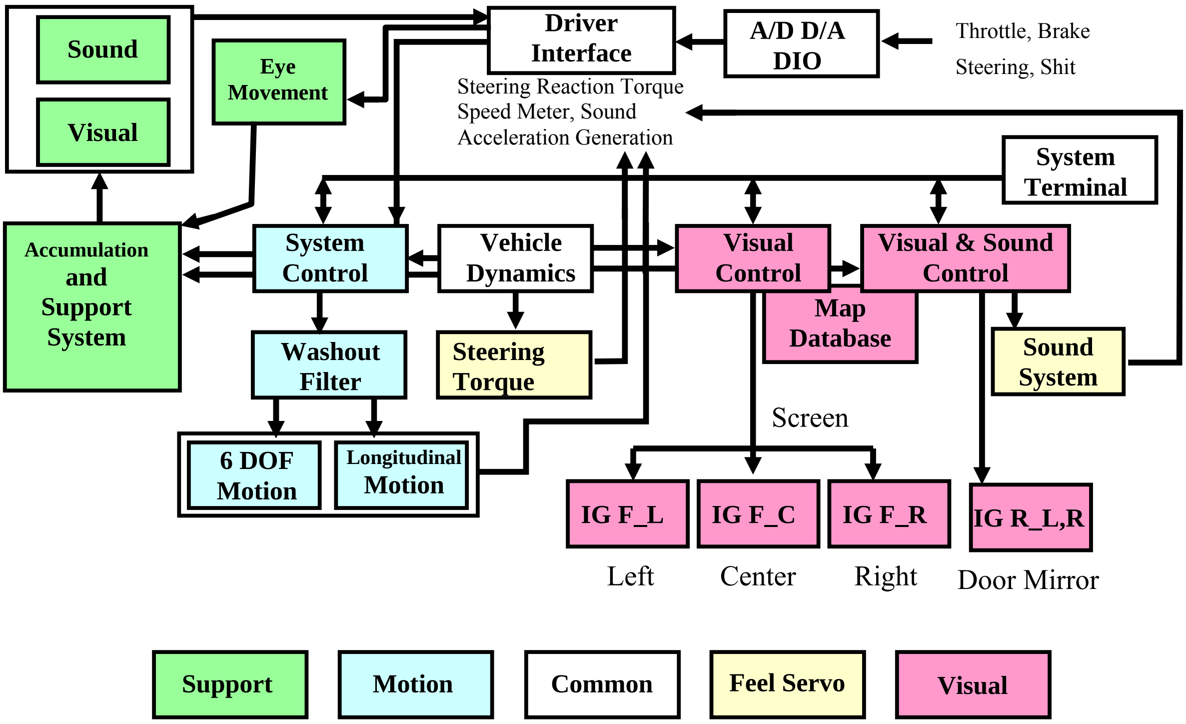

FIGURE 2 System Construction of TRDS

Motion System

The motion system is to reproduce the forces that occur through the vehicle change in motion such as steering or braking, etc. As for actual vehicle, longitudinal movement and lateral one are possible in a road freely. However, diving simulator can works only in a limited movable range. The specification of TRDS which we developed for PADSS is shown in Table 1. The motion system of TRDS is constructed of the 6 DOF motion and the longitudinal motion. The range of longitudinal motion is ±4 m. The 6 DOF motion is constructed from link mechanism, which mounted on the longitudinal motion base. The vehicle acceleration to move the motion devices is calculated by use of CarSim before described. The calculated vehicle accelerations are transported the motion generator to imitate the actual vehicle's motion.

Visual System

The visual system specification of TRDS is shown in Table 2. A computer graphic image from the image generator (IG) is projected by liquid crystal projector onto three flat screens installed 1.4m forward from the viewpoint of the driver. Figure 3 shows a scene of an interchange in the prepared visual database. A driving scene in a town area from the driver's viewpoint is shown in Figure 4. It is important the scenario making when conduct a test using the driving simulator. In TRDS, 32 other objects (vehicle, pedestrian) are able to move. The movements of these objects are generated by a scenario editor shown in Figure 5. Figure 5 (a) shows the whole route of a certain object, and figure 5 (b) shows some drive routes set in an intersection neighborhood. The scenario of an object is set by appointing speed of an arbitrary point on the road. There are 2 kinds of setting method as for the movement of these objects. The first setting moves regardless of the driver's vehicle, and another setting starts to move when driver entered a certain event range.

TABLE 1 Motion System Specifications of TRDS

DOF		6(Serge, Sway, Heave, Roll, Pitch, Yaw) + 1(Longitudinal)
Type		Link mechanism + Rail
Controller		Assembled PC
Range	Disp.	Serge: ±0.35m Sway: ±0.35m Heave: ±0.35m Roll: ±22degd Pitch: ±22deg Yaw: ±22deg Longitudinal: ±4m
	Acc.	Serge: 4.9m/s^2, Sway: 4.9m/s^2, Heave: 4.9m/s^2 Roll: 160deg/s^2 Pitch: 160deg/s^2 Yaw: 160deg/s^2 Longitudinal: 4.9m/s^2

TABLE 2 Visual System Specifications of TRDS

Image Generator		Lockheed Martin : REAL 3D PRO-1410 Ability : 1M polygons/s
Controller		Assembled PC
Projector	Front	Liquid Crystal Projector (3ch ; Left, Center, Right)
	Back	Liquid Crystal Display (2ch ; Left, Right)
FOV (Field Of View)	Front	Horizontal: ±75deg Vertical: +25deg - -13deg
	Back	Angle to view in a door mirror
Resolution	Front	Front View: XGA(1024*768pixels)
	Back	Back View: VGA(640*480pixels)
Frequency		60 Hz
Time Delay		50 - 60 ms

FIGURE 3 Visual Image of the Database

FIGURE 4 Driving Scene in Town Area

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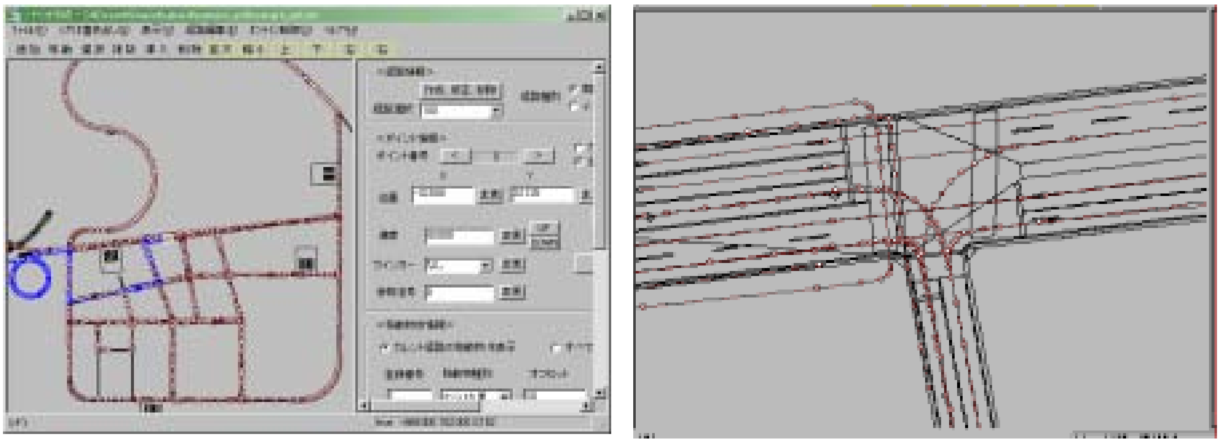


(a) Example of the Whole Route. (b) Some Routes in an Intersection Neighborhood.

FIGURE 5 Example of Drive Route by the Scenario Editor

DRIVING OPERATION DATA ANALYSYS

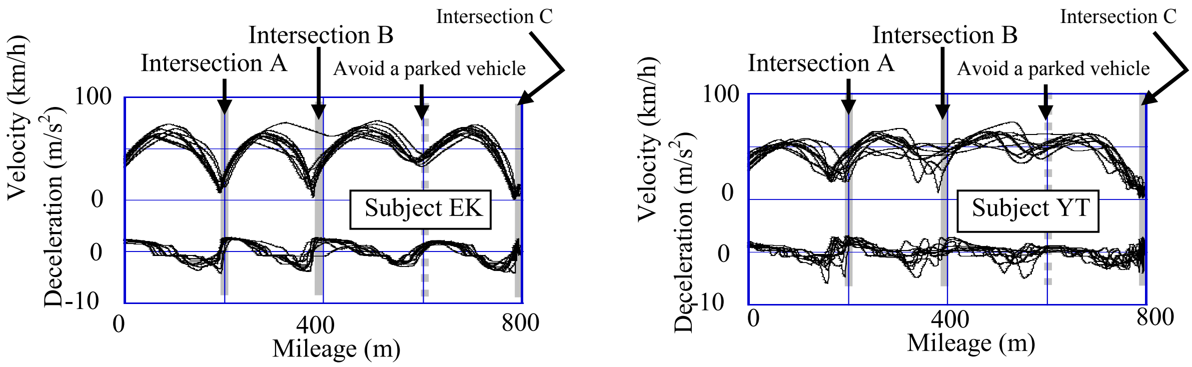
Experimental Method and Data Logging

A driving scenario for the accumulation of the driver's braking operation is a course to the destination in a parking lot of town EAST via expressway as a departure at a parking lot of the neighboring town WEST. After the driver's vehicle starts, a preceding vehicle leads him to the destination. The mileage is about 18 km, and it takes around 25 minutes. Of course, the other 32 vehicles except for own vehicle are moving in the same area. The subjects are 12 including 2 women.

In TRDS, own vehicle dynamics data and the other vehicle's data are recorded. Furthermore, identification number (ID) for identification is set at all roads and intersections, and the road ID and the distance to forward intersection are recorded. The judgment to collide with the forward vehicle is calculated by using these data. And a warning is output for a subject when a collision is predicted.

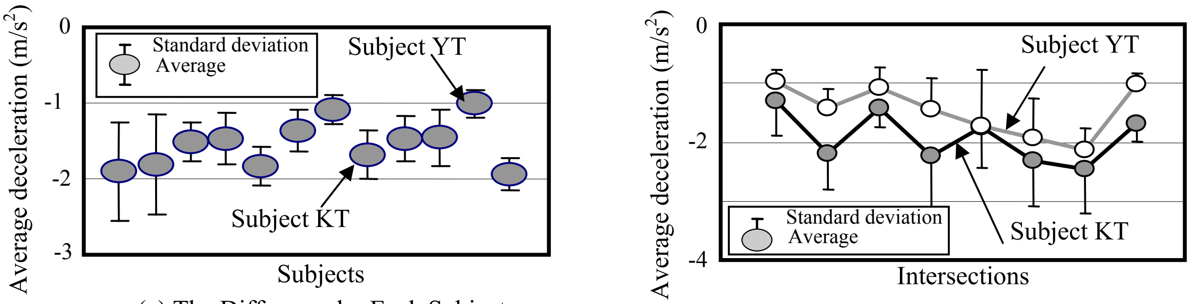
Analysis Results of the Braking Operation

The measured examples of vehicle velocity and deceleration in the 10 times driving are shown in Figure 6. Subject EK brakes consistently start to brake and almost similar deceleration over 10 drives. However, braking start point and deceleration are quite different for subject YT. As shown in Figure 6, the braking operations are different with each subject. Figure 7(a) shows the average and standard deviation of the deceleration at an intersection, Figure 7(b) shows the same statistics of 2 subjects at 8 intersections. From these figures, it is understood that the magnitude and standard deviation of the deceleration is different for each subject and each place. These results suggest necessity of PADSS.



(a) A Driver who Brakes in Same Driving (b) A Driver who Differently Brakes in Each Driving

FIGURE 6 Braking Operations at Some Intersections



(a) The Difference by Each Subject (b) The Difference by Each Intersection

FIGURE 7 Average Decelerations

PERSONAL ADAPTIVE DRIVING SUPPORT SYSTEM (PADSS)

System Concepts

A driving support system detects an error in "recognition" "judgment" "operation" of the driver and presents a sound or an image when it was judged to be dangerous [3], [4]. And the vehicle is controlled when he cannot avoid a collision by his operation. In such a system, it is often that a start timing of a warning and control are set based on the average driver's driving characteristics. However, because of the different braking operation as shown in figure 7 (a), it is thought that the warning with the mean value causes sense of incongruity. Therefore, we accumulate beforehand the step time from gas pedal to brake one (braking reaction time) and the braking magnitude for each driver at first. And, it is thought that the assistance by warning is appropriate to the driver when he may deviate from this accumulated data. The concept of PADSS is avoidance of the dangerous situation such as rear-end collision in the cause of the deviation from normal operation data based on accumulated data of each driver.

Personal Adaptation Method

In this section, it is described that the experiment method to warn based on an accumulated braking operation. The dangerous situation to warn is the rear-end collision. The judgment to warn is executed based on the equation shown in Figure 8. The own vehicle velocity V, the forward vehicle velocity Vf, the forward vehicle deceleration αf, and the headway distance D are data measured during in experiment. The braking reaction time T and subject's deceleration α are extracted from the braking operation database for each subject, and those are set at real time. The setting method of the braking reaction time T and deceleration α is shown in Figure 9. As for these parameters, 10% tile values of the extracted data are set for each driver. The 10% tile value is set as the situation that it seemed to come to deviate from normal operation of the subject. By this, this PAD SS can detect a delay of the recognition of an individual driver, judgment and operation.

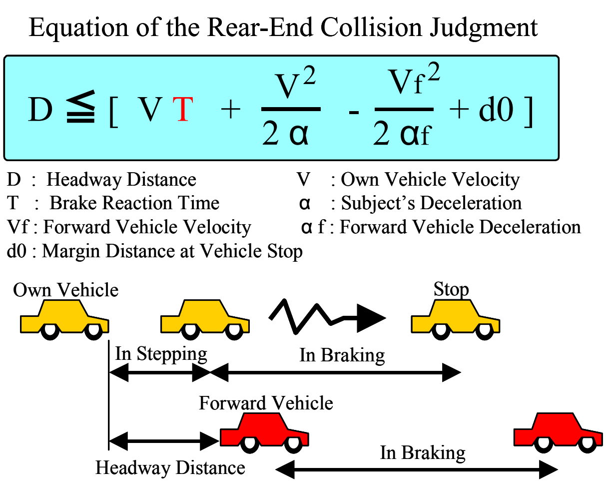


FIGURE 8 Rear-End Collision Judgment

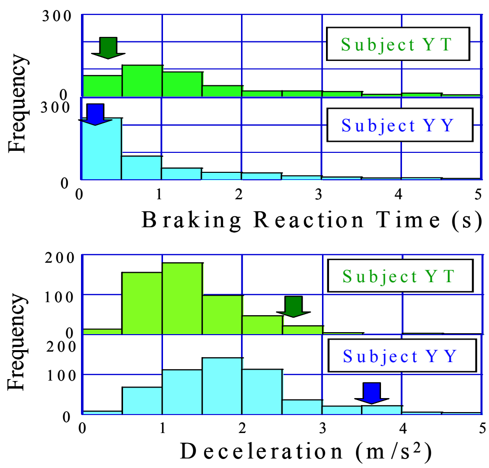


FIGURE 9 Setting Method of the Parameter for Each Driver

We constructed the system shown in Figure 10 to develop effectively the warning algorithm in PADSS. In this system, the installation of the collision judgment algorithm into PADSS and confirming the adequacy of the parameter to decide a warning timing are able to execute with a PC in the analysis room by using the recorded data during the experiment. The other vehicle's movement including own vehicle and the output situation of the warning are grasped visually when this algorithm is developed.

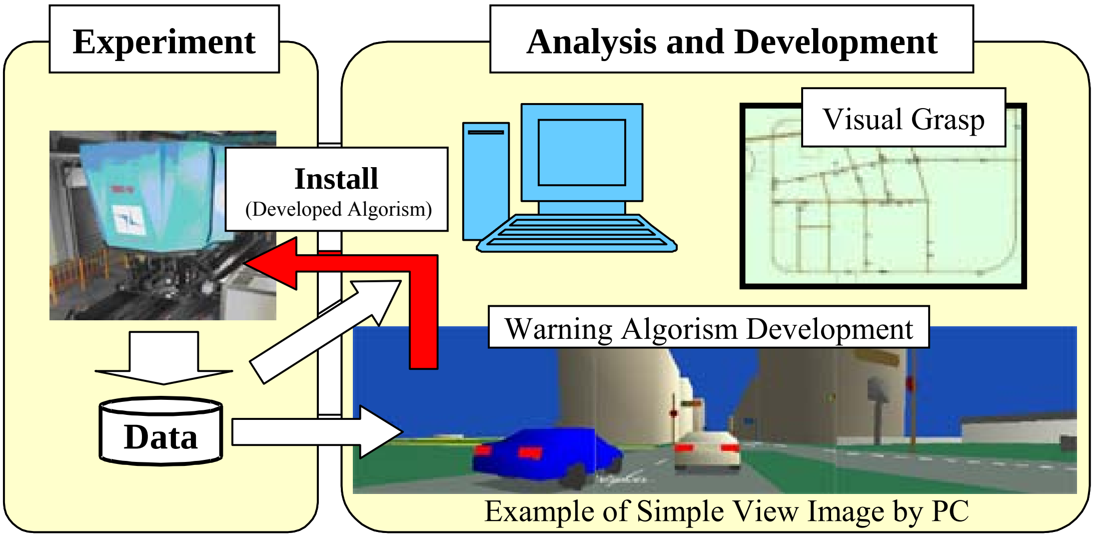


FIGURE 10 Constructed System for Experiment Data Analysis and Warning Algorithm Development

Based on the accumulated braking operation database, the effect of PADSS was examined by warning in some dangerous scenes. The driving course is almost similar to the experiment to investigate the individual driver's braking operation. The other 32 vehicles run the same area; the various dangerous situations are set newly. These dangerous situations are composed by an immediate departure of a parking vehicle or a sudden left turn of the forward vehicle without a turn signal. The subjects are the same 12 drivers. Three times driving with warning were experimented. In order to examine the necessity of the warning, subjective evaluation was executed simultaneously. The subjective evaluation is 4 levels shown in Table 3.

TABLE 3 Subjective Evaluations for the Warning

Level	Subjective Evaluation
1	Unnecessary
2	Slightly Necessary
3	Necessary
4	Very Necessary

Warning Output Results

The warning output frequency in 3 times driving is shown in Figure 11. The number of warning is quite different as for each subject; it is outputted from 2 to 44. As for subject HM with the most warning, he has heard about 15 times warning while he drives at 1 time. The discussion between the warning frequency and the driving characteristics is executed as follows. Figure 12 shows a frequency distribution and an accumulative frequency of the average deceleration concerning 2 subjects. These subjects are HK with 7 warnings and HM with 44 warnings; they are similar age and the same sex. From Figure 12, we cannot find the difference as for the strength of braking operation. Therefore, it seems that the almost same value is set with both subjects as for subject's deceleration α shown in Figure 8. Similar examination about braking reaction time T was studied, and it was most of the same values with both subjects. According to the equation in figure 8, a warning is outputted when headway distance is small, and a warning is not outputted when headway distance is large. Therefore we aimed to the headway distance at the time of braking start. The TTC (Time To Collision; headway distance / vehicle velocity) at the braking start are shown in

Figure 13. The subjects are the same as shown in Figure 12. Because of the result that TTC of subject HK is bigger than that of subject HM, it is understood that HK operates the braking earlier than HM. In other word, the difference of the warning output frequency depends on the TTC at the time of a braking start.

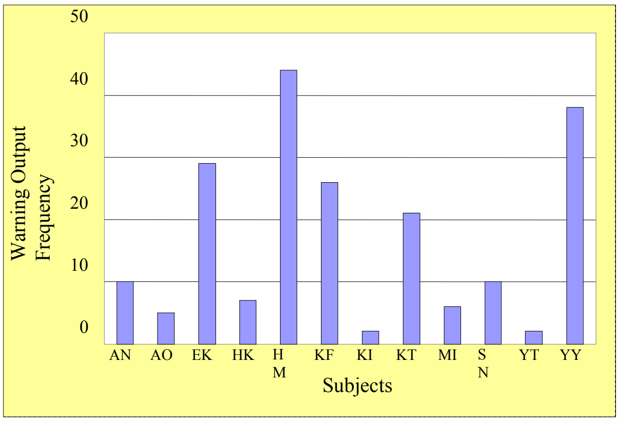
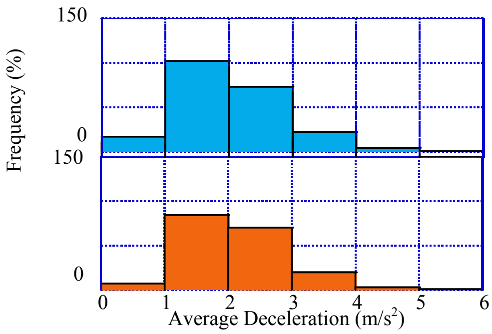
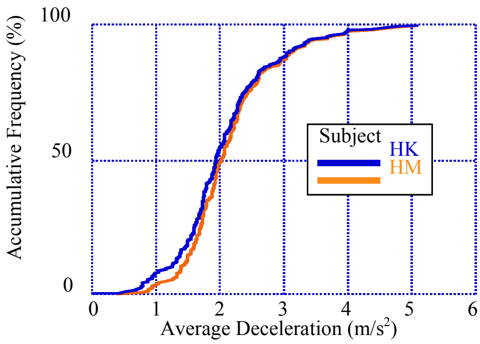


FIGURE 11 Warning Output Frequency



(a) Frequency Distribution



(b) Accumulative Frequency

FIGURE 12 Average Deceleration of the Subject with Different Warning Frequency

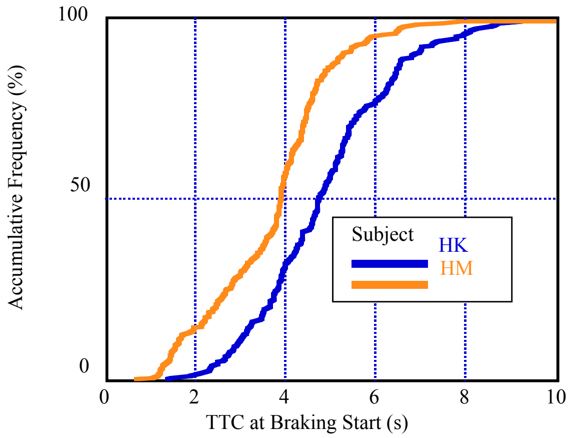


FIGURE 13 TTC at the Braking start of the Subject with Different Warning Frequency

Figure 14 shows the constitution of the subjective evaluation about subject AN and HM. The warning numbers of the subject AN are 10 shown in Figure 11, and that of the subject HM are 44. The subject AN feels necessary the warning about 70 %. However, the subject HM feels necessity of a warning only about 5 %. The trend of subjectivity evaluation for a warning except subject AN and HM seemed to be almost next. The subject with a few warning frequency felt that he was necessary same as AN. And the subject with many warning frequency did not feel necessity of the warning same as HM.

Figure 15 shows the relationship between the subjective evaluation and average deceleration when the warning is outputted. In the case of subjective evaluation 3 and 4 that subject felt the warning as the necessity, the average deceleration after the warning became larger than that of the subjective evaluation 1 and 2 with the feeling as unnecessary warning. In other words, it is understood that subject braked strongly when he felt the warning as necessity.

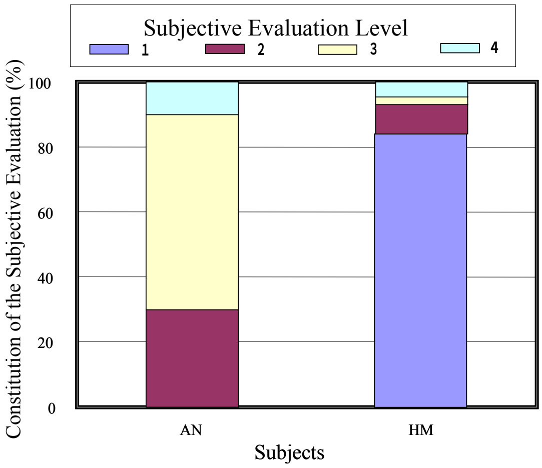


FIGURE 14 Subjective Evaluation

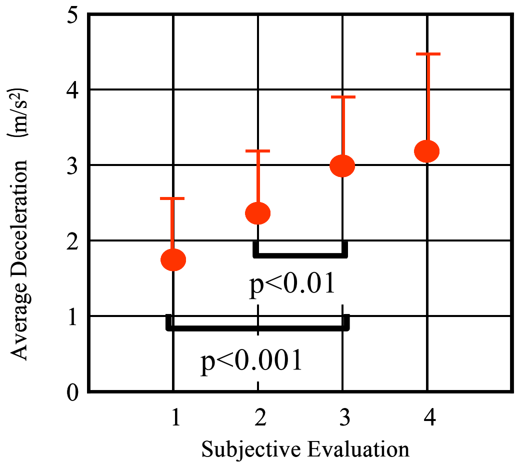
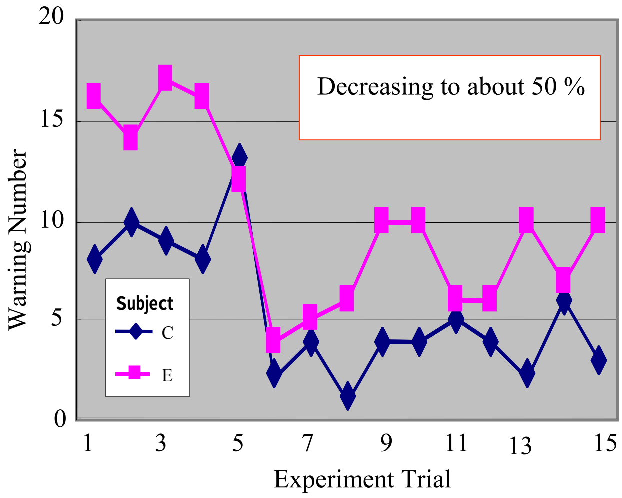
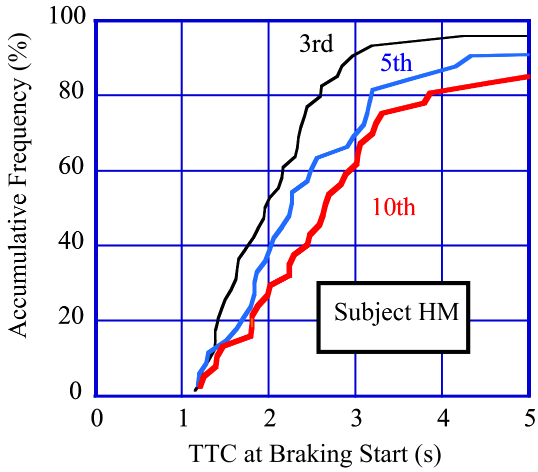


FIGURE 15 The Relationship between Subiective Evaluation and Deceleration

Next, the braking operation when the warning is repeated continuously in the urgent situation is described. The warning number for the experiment trial is shown in Figure 16. The subjects are EK and HM with many warning frequency. From this figure, it is able to understand that the warning number of both subjects decrease to about 50 % by continuing the experiment of PADSS. To investigate the reason why the warning number decreasing, we have examined the magnitude and the timing of braking operation. It was not different form the magnitude of the braking operation between the trial numbers of the experiment. Figure 17 shows the TTC at braking start while experiment trail 3, 5 and 10 of the subject HM. The TTC at the braking start becomes large with proceeding trials. The large TTC means the early braking start. Therefore, it is understood that the driver come to brake early by continuing the experiment with the warning in the urgent situation.



FUGURE 16 Warning Number during Experiment Continuing



FUGURE 17 TTC at the Braking Start during Experiment Continuing

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Warning Reduction Method Using the Analysis and Development System of TRDS

In this section, two results by the use of TRDS analysis system shown in Figure 10 are described. The first result is the study of warning algorithm to change the parameter during braking. The warnings shown in Figure 11 were outputted about 75 % while subjects were braking. Furthermore, they evaluated them as the unnecessary warning with most case. To reduce the unnecessary warning during braking, we improved the warning algorithm to change the parameter from 10% tile to 2% tile during braking. The studied result as for the subject HM with the most warning frequency is shown in Figure 18. The left bar graph shows the divided warning number whether he is during braking or non-braking. In case of this subject, he heard the warning 70% (=31/44) during braking. The center bar graph is the simulation result with improved warning algorithm on the basis of recorded data. These are the same data which recorded in the first 3 times experiments. The ratio of the warning during braking reduces from 70% to 43% (=10/23) by improved warning algorithm. From this previous study by using the simulation, it is estimated that the warning number during braking will decrease. The right bar graph in Figure 18 shows the verified experiment result by using the improved warning algorithm with change the parameter during braking. The warning numbers during braking decrease in the same way as beforehand executed simulation result. In addition, total warning numbers decrease from 44 to 24. This reason is the effect to continue the PADSS experiment as described before.

The second study by TRDS analysis system is the use of driver's gaze angle. It is often that subject feels the warning as the unnecessary when he is gazing to the forward vehicle. On the basis of the relation between subject's measured gaze angle and forward vehicle position, it is judged whether he is watching forward vehicle. It is very difficult that we develop warning algorithm with gaze angle by repeating the experiment. The subject's gaze angle is measured by image processing with the stereo-cameras which mounted on the dashboard to be shown in Figure 19. If the subject is gazing at the forward vehicle, the warning algorithm to change the parameter is developed by using TRDS analysis system. Left value 3 in Figure 20 is the warning number with gaze angle in the experiment, and right value 9 is warning number by simulation that it is estimated without gaze angle based on the same experiment data.

Like two examples described above, the analysis and development system of TRDS are able to confirm the experimental results and to develop the warning algorithm effectively.

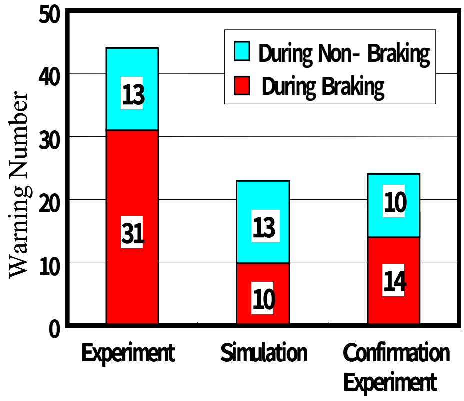

FIGURE 18 Warning Reduction by Parameter Change during Braking

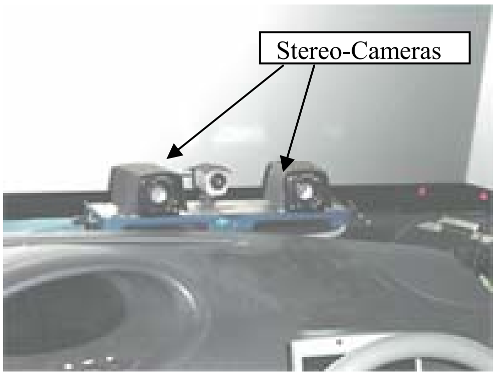

FIGURE 19 Mounted Stereo-Cameras to Measure the Subject's Gaze Angle

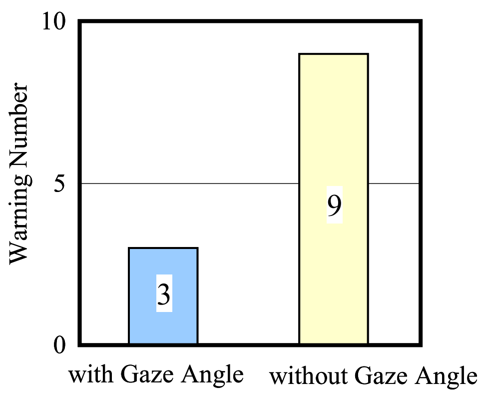

FIGURE 20 Warning Reduction by Using Gaze Angle

CONCLUSION

The driving simulator TRDS was developed to investigate the driving support system aimed for reduction of a traffic accident. TRDS includes the analysis of driver's behavior and the support system development on the basis of the accumulated data. As the analyzed result of the braking operation by TRDS, it was different with a driver and a place. Using this TRDS, the driving assistance PADSS which adapted to personal braking operation was developed. The number of warning is quite different as for each subject. The subject with a few warning frequency needed the warning, and the subject with many warning frequency did not feel necessity of the warning.

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