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QUANTITATIVE STUDY ON THE FEARFULNESS OF HUMAN DRIVER USING VECTOR QUANTIZATION

J. H. KIM[1)*], Y. W. KIM[2)] and K. Y. SIM[3)]

[1)]Power Business Team, Samsung Electro-Mechanics, 314 Maetan 3-dong, Yeongtong-gu, Suwon-si, Gyeonggi 443-743, Korea
[2)]EcoTopia Science Institute, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
[3)]School of Electricity, Electronics & Communication, Ulsan College, Ulsan 680-749, Korea

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ABSTRACT–This paper presents the quantitative evaluation of the fearfulness of the human driver in the case of the short range (time) on the highway. The driving situation is realized by using the driving simulator based on CAVE, which provides three-dimensional stereoscopic immersive visual information. The examinees' responses and personal information are categorized reasonably by applying the competitive learning algorithm. The characteristics of each group are analyzed. The following two situations are also compared: (1) the active approaching situation where the examinee drives the vehicle near the preceding vehicle, and (2) the passive approaching situation where the preceding vehicle nears the examinee's vehicle by gradually decelerating. The range time that the examinee feels fear in the active approaching case tends to be shorter than that in the passive approaching case.

KEY WORDS : Fearfulness, Range time, CAVE, Vector quantization

1. INTRODUCTION

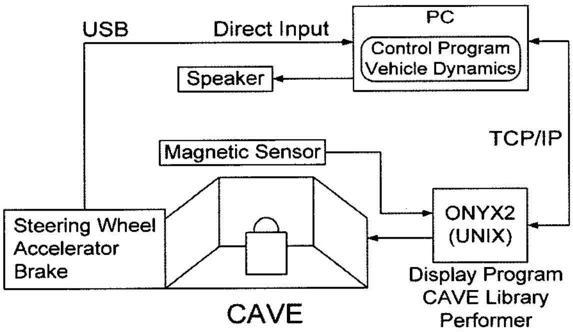
Recently, developments of the sophisticated driving assistance system have attracted a great amount of attention of many researchers. One of the difficulties of this lies in the consideration of the human factor. The human factor is known to consist of the aspects of physical motion, decision-making and emotion (or mental factor). The analysis of emotion of the human driver seems fairly behind the analyses of the other two aspects. The need for research of the human emotion in driving is now recognized as an important issue since the emotional states of the human driver, such as nervousness, fearfulness, stress and others, must be reflected in the design of the driving assistance system (Toda and Kageyama, 2003; Yagi *et al.*, 2003; Taguchi *et al.*, 1998; Ebe *et al.*, 1999; Konishi *et al.*, 2004; Kawashima *et al.*, 2002). As typical important examples, the Adaptive Cruise Control (ACC) and the proximity warning system to prevent 'the too short vehicle-to-vehicle distance (range)' can be pointed out.

These technologies try to reduce the driver's driving burden. Needless to say, the design of these systems must be established on the basis of the analyses of the human emotion, i.e. how the driver feels during the driving situation. From these considerations, we address the quantitative evaluation of the driver's fearfulness in the case of following a vehicle on the highway. The driver/passenger usually feels fear when the range between cars gets too short. This feeling seems subjective. However, it is expected that a kind of categorization of numerous measured data leads to the quantitative understanding of such a feeling. Although some researches on the analyses of the collision between vehicles have been found (Yamada and Wakasugi, 2001; Matsuki *et al.*, 2002; Mashimo *et al.*, 2002; Ohta, 1986; Ogawa *et al.*, 1998; Cheng *et al.*, 2003), they mainly focused on the relation with the road environment and the driver's mental aspect, i.e. the driver's subjective fearfulness has not been discussed in a quantitative manner as far as the authors know.

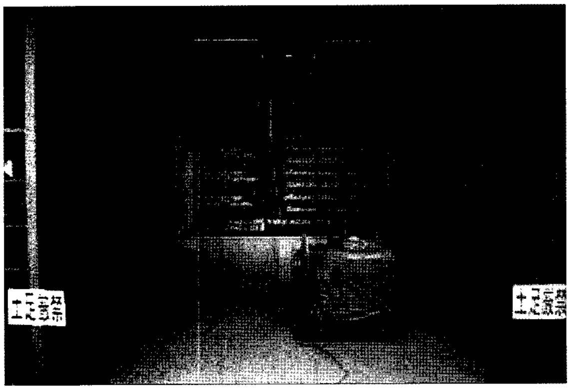
In this paper, we concentrate on the following two kinds of vehicle-following situations on the highway to analyze the fearfulness of the human driver: (1) active approaching situation where the examinee drives the vehicle near the preceding vehicle(note that the preceding vehicle runs at constant velocity), (2) passive approaching situation where the preceding vehicle nears the examinee's vehicle by gradually decelerating (note that the examinee cannot control the vehicle in this case, i.e.

**Corresponding author.* e-mail: kjhassk@hanmail.net

the examinee's vehicle runs at constant velocity). The driving situation is realized by using the three-dimensional Driving Simulator (DS) (Uno and Hiramatsu, 2001; Cho *et al.*, 2006; Matsuura and Morioka, 2001; Satoh *et al.*, 1998; Nagiri *et al.*, 2001; Kemeny *et al.*, 2003; Schultheis and Mourant, 2001) based on CAVE(Cave Automatic Virtual Environment), which provides stereoscopic immersive vision. Although our DS does not have any motion generators, the examinee can feel the real distance to the obstacles thanks to the effect of the stereoscopic immersive vision. The advantages of using DS are as follows: (1) The safety of the examinee is always guaranteed, (2) All environmental information can be captured without installing any sensor and (3) We are always able to repeat the same experimental scenario. These advantages are quite essential to capture the common characteristics of fearfulness. In order to evaluate the fearfulness in a quantitative manner, the vector quantization technique called Competitive Learning (CL) is introduced. In our analysis, the measured range (or range time; defined in section4) in which the driver feels fear and the driver's personal information such as age and mileage are grouped simultaneously by using CL. Then, we categorize the obtained data based on the vector quantization. Also, we compare the difference between the cases (1) (active following) and (2) (passive following) based on the results of grouping. Moreover, the relationship between the velocity of the vehicle and the characteristic of each group are investigated. These results give us the fundamental knowledge useful for the design of the driving assistance system.



(a) Configuration of the DS



(b) CAVE system

Figure 1. The developed driving simulator.

2. CONFIGURATION OF DRIVING SIMULATOR

The configuration and appearance of the developed driving simulator based on CAVE are shown in Figure 1. The display unit in the CAVE system provides the three dimensional virtual environment and it is controlled by ONYX2. The display program was developed by using the CAVE library and Performer. The simulator cockpit consists of a steering wheel, an accelerator and a brake in the CAVE system. The information on the driver's output to the steering wheel, accelerator and brake is transferred to the PC through a USB terminal. The vehicle position and motion are calculated based on these inputs and the vehicle dynamics implemented on the PC using the CarSim software. The results of the calculation are transferred to ONYX2 through the Internet (TCP/IP) and the 3D visual image based on the position and motion of the vehicle is displayed.

3. MEASUREMENT OF FEARFULNESS IN CASE OF SHORT RANGE

3.1. Experimental Environment and Conditions

The configuration of the straight highway used in this experiment is shown in Figure 2. The road is 10 km in length and two lanes each way. There are supposed to be only two vehicles in this environment. One of them is a sedan-type car the examinee rides in. The other one is the big truck that runs in front of the examinee and is controlled by the operator. The car of the examinee was supposed to have an engine with an 1800cc displacement. The two vehicles start at the same time. The truck runs only on the left side lane and the operator can change its

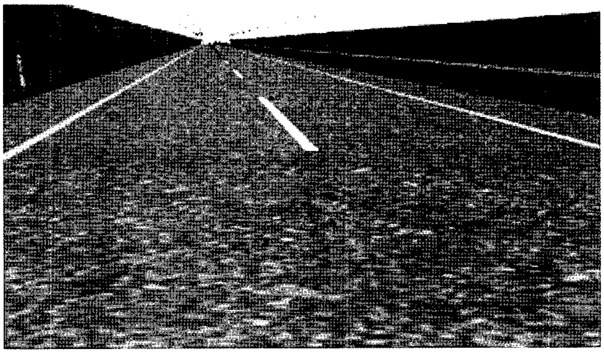


Figure 2. Highway environment.

speed. It is operated by the specified experimental scenario at each trial. We have examined thirty examinees. All examinees answered some questions such as daily driving behavior in real situation, driving preferences, and the Simulator Sickness Questionnaire (Been-Lirn Duh, 2001; Cobb *et al.*, 1999). The SSQ test is a way to find a driver who is likely to suffer from simulator sickness. Also, individual personal information on examinees such as age, sex, total mileage which is defined by the total driving distance before the executing experiment since the examinee acquires the driver's license, etc. were reported. The personal information of each examinee is listed in Table 1. The labels E_1 to E_{30} are assigned to examinees in this table.

3.2. Procedures of Experiments

Table 1. Information of each examinee.

Examinee	Sex	Age [years old]	Mileage [km]
E_1	Male	21–25	100000–
E_2	Male	21–25	1000–10000
E_3	Male	21–25	10000–50000
E_4	Male	21–25	1000–10000
E_5	Male	21–25	1000–10000
E_6	Male	21–25	50000–100000
E_7	Male	21–25	10000–50000
E_8	Male	21–25	0–1000
E_9	Male	21–25	0–1000
E_{10}	Male	21–25	0–1000
E_{11}	Male	21–25	100000–
E_{12}	Male	21–25	10000–50000
E_{13}	Female	18–20	0–1000
E_{14}	Female	18–20	0–1000
E_{15}	Female	26–30	10000–50000
E_{16}	Female	18–20	0–1000
E_{17}	Female	21–25	10000–50000
E_{18}	Female	21–25	10000–50000
E_{19}	Female	21–25	1000–10000
E_{20}	Male	21–25	10000–50000
E_{21}	Male	21–25	1000–10000
E_{22}	Male	56–60	100000–
E_{23}	Female	21–25	1000–10000
E_{24}	Male	56–60	100000–
E_{25}	Male	51–55	100000–
E_{26}	Male	61–65	100000–
E_{27}	Female	31–35	10000–50000
E_{28}	Female	31–35	0–1000
E_{29}	Female	31–35	100000–
E_{30}	Female	26–30	50000–100000

In this work, we focus on the quantitative evaluation of the driver's fearfulness in the case of following a vehicle on the highway. The following two driving situations are tested: (1) active approaching situation, and (2) passive approaching situation. They are explained in detail as follows:

- Active Approaching (AA)

In this situation, the preceding truck runs at some constant velocity specified by the operator. The examinee drives the vehicle near the preceding truck until the examinee feels fear. Then the examinee gives the signal to the operator when he/she feels fear. At the same time, the operator records the range between vehicles. This experiment was carried out for four different truck velocities, 60[km/h], 70[km/h], 80[km/h] and 90[km/h].

- Passive Approaching (PA)

In this situation, the examinee's vehicle runs at some constant velocity specified by the operator. This corresponds to the situation that the examinee sits on the passenger's seat (not on the driver's seat) in daily driving. Then the preceding truck decelerates until the examinee feels fear. The examinee gives the signal to the operator when he/she feels fear. At the same time, the operator records the range between vehicles.

This experiment was carried out for four different examinee's vehicle velocities, 60[km/h], 70[km/h], 80 [km/h] and 90[km/h]. Note that in our experiments, the range was defined by the distance between the rear end of the preceding truck and the position of the examinee. The number of trials for each situation is listed in Table 2. In Table 2, the preliminary experiment represents the trials

Table 2. Number of trials for each situation.

Velocity [km/h]	60	70	80	90
AA (Preliminary)	1	1	1	1
AA	5	5	5	5
PA (Preliminary)	1	1	1	1
PA	5	5	5	5

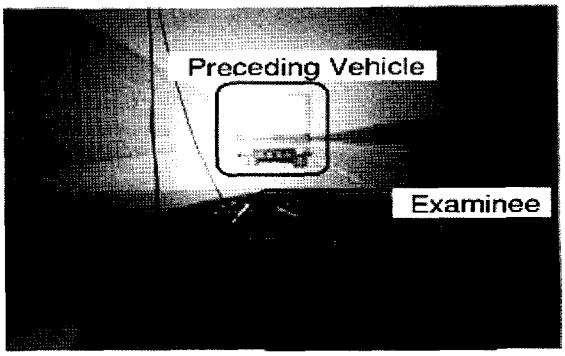


Figure 3. Sample view from examinee.

executed to familiarize the subjects with the DS and was not used for analyses in later sections. Also, the sample view from the examinee's position is depicted in Figure 3.

4. ANALYSES OF MEASURED DATA

4.1. Grouping by using Vector Quantization

Based on the setup described in section 3, the experiments in the AA and the PA were performed five times for each velocity. In order to secure the reliability of the analyses, three trial data samples from five data samples were selected at each velocity by eliminating the maximum and minimum values. As a result, twelve trial data samples for each driver in each task were used for analyses. In the following analyses, we often use the term 'range time' which is defined by the range divided by the velocity of the vehicle. Figure 4 depicts the distribution of data (12x30=360 data) in the AA in the space of age, total mileage and the range time.

In order to understand the characteristics underlying all examinees, the Vector Quantization (VQ) technique is applied to this data. Since the results in the AA have shown a clearer classification of examinees than the PA, we have classified examinees based on the data obtained in the AA. As the typical VQ technique, the Competitive learning (CL) algorithms was adopted (Ueda and Nakano, 1994). In the CL algorithms, the input data $x = (x_1, x_2, \ldots, x_k)$ (In our case, k=3) is presented to all Reference Vectors (RVs). We let ith RV denoted by $w_i = (w_{i1}, w_{i2}, \ldots, w_{ik}) \in R^k$. The distortion $d(x, w_i)$ between the RV and an input data was calculated. Then, a winning RV w_c with the minimum distortion is selected by checking the following criterion.

$$d(x, w_c) \leq d(x, w_j) \text{ for all } j \neq c \tag{1}$$

To reduce the distortion, the winning RV w_c is adjusted toward the current input data $x(t)$ as follows:

$$w_c(t+1) = w_c(t) + \eta(t)[x(t) - w_c(t)] \tag{2}$$

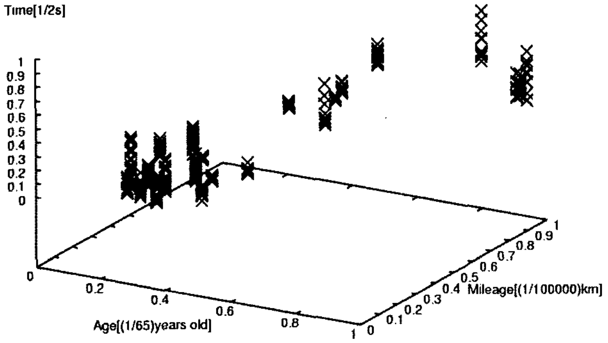


Figure 4. Distribution of data in the space of age, mileage and range time in AA.

Table 3. Initial values of the RVs for AA.

	Age	Mileage	Range time axis
w_1	0.250	0.250	0.125
w_2	0.750	0.250	0.125
w_3	0.250	0.750	0.125
w_4	0.750	0.750	0.125
w_5	0.250	0.250	0.375
w_6	0.750	0.250	0.375
w_7	0.250	0.750	0.375
w_8	0.750	0.750	0.375
w_9	0.250	0.250	0.625
w_{10}	0.750	0.250	0.625
w_{11}	0.250	0.750	0.625
w_{12}	0.750	0.750	0.625
w_{13}	0.250	0.250	0.875
w_{14}	0.750	0.250	0.875
w_{15}	0.250	0.750	0.875
w_{16}	0.750	0.750	0.875

The other losing RVs are unchanged. The nonnegative parameter $\eta(t)=1/(1+0.01n)$ ($<<1.0$), which represents the learning rate for the reference adjustment, decreases monotonically to zero as learning progresses. n denotes the learning times. In our work, the number of RV's was set to be sixteen. The initial values of these reference vectors are listed in Table 3. The distribution of them is also depicted in Figure 5.

The learning procedure in the CL was carried out so as to locally minimize the summation of distortion between the data and the corresponding reference vector.

After the learning procedure, all data were assigned to some reference vector. The values of the reference vectors after learning are listed in Table 4, and its distribution is depicted in Figure 6.

The CL algorithm has a drawback that an unreferenced vector called a 'dead node' sometimes may appear.

In this work, the existence of a dead node is ignored since all RV's do not need to be referred. The 'most

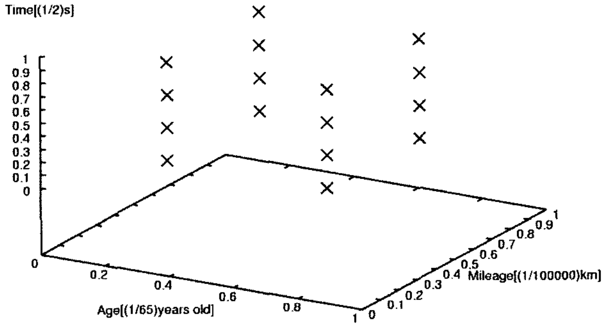


Figure 5. Initial distribution of RV for AA.

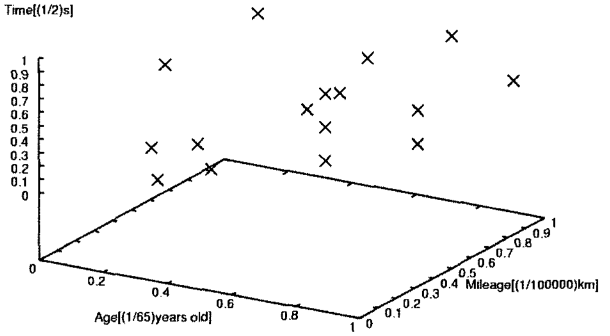


Figure 6. Distribution of RV for AA after learning.

Table 4. Values of the RVs for AA after learning.

	Age	Mileage	Range time axis
w_1	0.378	0.250	0.221
w_2	0.750	0.250	0.125
w_3	0.382	0.879	0.185
w_4	0.750	0.750	0.125
w_5	0.352	0.029	0.230
w_6	0.750	0.250	0.375
w_7	0.471	0.960	0.458
w_8	0.921	1.000	0.424
w_9	0.344	0.027	0.476
w_{10}	0.750	0.250	0.625
w_{11}	0.250	0.750	0.625
w_{12}	0.822	0.974	0.645
w_{13}	0.250	0.250	0.875
w_{14}	0.750	0.250	0.875
w_{15}	0.250	0.750	0.875
w_{16}	0.764	0.819	0.878

Table 5. Classification of examinees by using RV.

Examinee	RV	Examinee	RV	Examinee	RV
E_1	w_3	E_{11}	w_3	E_{21}	w_5
E_2	w_5	E_{12}	w_1	E_{22}	w_8
E_3	w_1	E_{13}	w_5	E_{23}	w_5
E_4	w_5	E_{14}	w_9	E_{24}	w_8
E_5	w_5	E_{15}	w_1	E_{25}	w_{12}
E_6	w_3	E_{16}	w_5	E_{26}	w_8
E_7	w_1	E_{17}	w_1	E_{27}	w_1
E_8	w_5	E_{18}	w_1	E_{28}	w_5
E_9	w_5	E_{19}	w_9	E_{29}	w_7
E_{10}	w_9	E_{20}	w_1	E_{30}	w_3

likely' RV to each examinee is listed in Table 5. Here, although the (twelve numbers of) data from the same examinee may be assigned to a different RV, the RV, which is mostly referred by data from the same examinee, is considered as the RV representing the examinee's characteristics in such a case.

Table 6 shows the results of the classification rearranged in the order of an RV. 'No. of Exs' represents the Number of Examinees' belonging to the category. Also, the maximum, minimum and average values of the age, the total mileage, the range time that belong to each group are listed in Table 6.

As listed in Table 6, seven groups can be identified by using the vector quantization technique. Now, the RVs w_8 and w_{12} are merged into one group since they have similar characteristics (especially in the age and mileage). Therefore, seven groups are reduced into six groups. Based on this classification, we have assigned the following five labels to each RV in order to intuitively represent the characteristic in the corresponding group.

- A(w_3), B(w_7) : Expert driver
- C(w_1) : Intermediate driver
- D(w_5) : Beginner driver
- E(w_9) : Sunday driver
- F(w_8, w_{12}) : Elderly driver

Table 6. Classification of examinees together with age, total mileage and range time.

R.V.	No. of exs.	Range time			Age			Total mileage		
		Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
w_1	8	0.16	0.95	0.45	22.5	32.5	24.38	25000		
w_3	4	0.17	0.90	0.36	22.5	27.5	23.75	75000	100000	87500
w_5	10	0.25	0.72	0.45	19	32.5	22.8	500	5000	2750
w_7	1	0.79	1.10	0.94	32.5	32.5	32.5	100000		
w_8	3	0.68	1.38	0.89	57.5	62.5	59.17	100000		
w_9	3	0.63	1.18	0.90	19	22.5	20.33	500	5000	2000
w_{12}	1	1.12	1.84	1.38	52.5	52.5	52.5	100000		

4.2. Analyses of Characteristics of Each Group

In this section, the characteristics of each group defined in the previous section are evaluated and analyzed. We have investigated from the following three viewpoints:

(1) The average and variance of the range time that the examinee feels fear in the AA.
(2) The difference in the range and the range time that the driver feels fear between the AA and the PA.
(3) The relationship between the velocity of the vehicle and the range (time) that the driver feels fear in the AA and PA.

4.2.1. Average and variance of range time in AA

The average and variance of the range time that the driver feels fear in the AA is listed in Table 7. In Table 7, the number in the parenthesis represents the number of examinees belonging to each group.

Note that in Table 7, since the variance of one examinee in group A was about 100 times as large as the average variance of other examinees, it was regarded as the abnormal data point and was removed from the list for analysis. In Table 7, the average of the range time is classified into two subgroups: (A, C, D) (short range time) and (B, E, F) (long range time). This classification clearly shows that the driving ability is strongly related to the range time that the driver feels fear. The variance of the range time is also classified in the same manner as the average. This coincidence is quite natural and represents that the accuracy of recognition of the range is degraded as the range becomes long.

4.2.2. Comparison of results in AA and PA

Next, the difference between the AA and the PA is investigated. The average and variance of the range time in these situations are listed in Table 8. As shown in Table 8, the average of the range time in the AA (Active Approaching) tends to be shorter than that in the PA (Passive Approaching) (except Group E). Since the examinee cannot control the vehicle in the PA, the examinee tends to feel fear at longer range between vehicles than the AA. This result agrees well with our feeling in the daily driving situation. As an exception, the Sunday driver (Group E) shows longer range time in the AA. This may be caused by the less reliable driving ability of the examinees in this group.

Table 7. Average and variance of range time in the AA.

Group (No. of Exs.)	Average [s]	Variance [$10^{-3}s^2$]
A(3)	0.36	0.17
B(1)	0.94	2.19
C(8)	0.45	1.43
D(10)	0.45	1.30
E(3)	0.90	2.90
F(4)	1.01	6.77

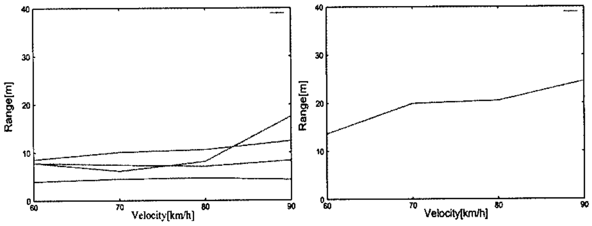
Table 8. Average and variance of range time in AA and PA.

	Active	Passive
Group (Count)	Average [s]	Variance [$10^{-3}s^2$]
A(4)	0.36	0.17
B(1)	0.94	2.19
C(8)	0.45	1.43
D(10)	0.45	1.30
E(3)	0.90	2.90
F(4)	1.01	6.77

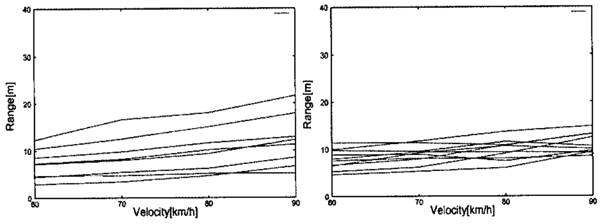
On the other hand, the variance of the range time in the PA tends to be longer than in the AA (except C and F). This result may be caused by the differences in the amount of concentration of the examinee between the AA and the PA, i.e. in the PA, the examinee shows less concentration on the task than in the AA.

4.2.3. Relationship between the velocity of the vehicle and range (time)

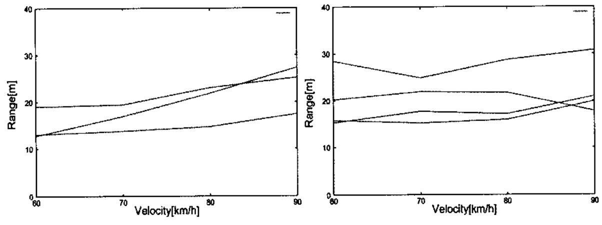
In the previous subsections, the average and variance of the range time were analyzed. In this subsection, the dependency of them on the velocity of the vehicle is



(a) Group A (b) Group B

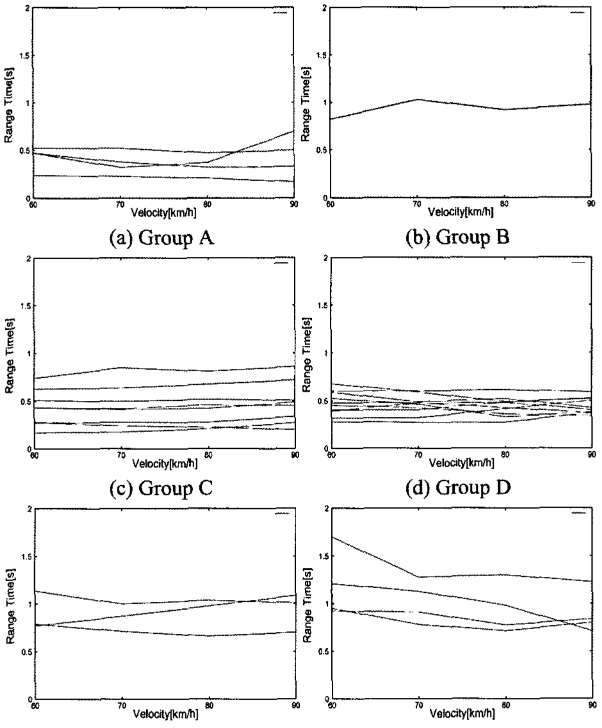


(c) Group C (d) Group D



(e) Group E (f) Group F

Figure 7. Relationship between velocity and range in AA.

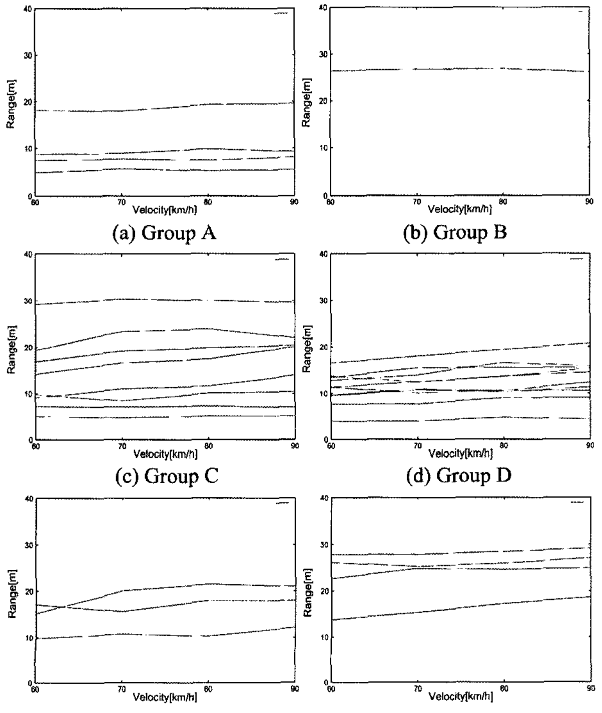


(a) Group A (b) Group B

(c) Group C (d) Group D

(e) Group E (f) Group F

Figure 8. Relationship between velocity and range time in AA.

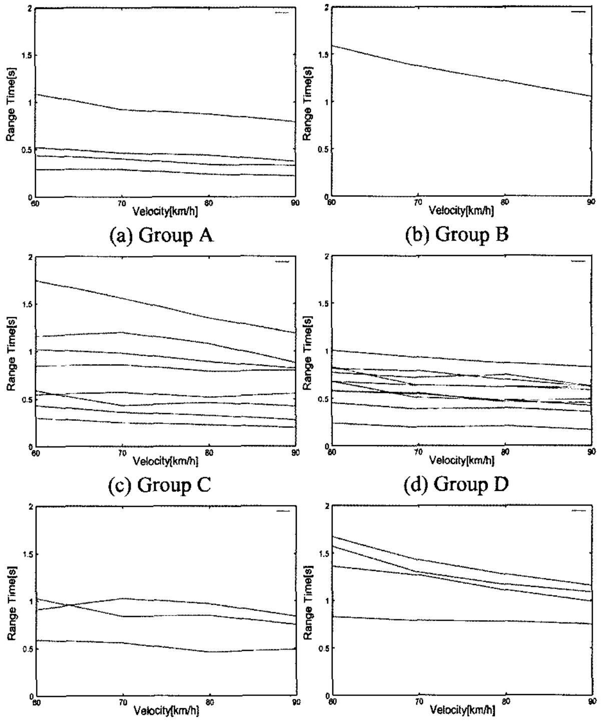


(a) Group A (b) Group B

(c) Group C (d) Group D

(e) Group E (f) Group F

Figure 9. Relationship between velocity and range in PA.



(a) Group A (b) Group B

(c) Group C (d) Group D

(e) Group E (f) Group F

Figure 10. Relationship between velocity and range time in PA.

investigated. Figures 7 and 8 show the results in the AA. The vertical axes in both figures represent the range and the range time, respectively. The horizontal axes represent the velocity of the vehicle. Also, Figures 9 and 10 show the results in the PA.

As shown in Figure 8, the range time that the examinee feels fear is almost constant in the AA. As a natural consequence, the range has a positive correlation with the velocity in the AA as shown in Figure 7. These results imply that the fearfulness of the human driver depends on the range time rather than the range itself.

In the PA, although we can see the positive correlation between the range and the velocity as shown in Figure 9, the magnitude of the correlation is smaller than that in the AA. Moreover, the range time has the negative correlation with the velocity as shown in Figure 10. This is a little surprising and may be explained by the situation that the examinee does not drive the vehicle. The viewpoint from psychology must be introduced to investigate this phenomenon.

5. CONCLUSIONS

This paper has presented the quantitative evaluation of the fearfulness of the human driver in the case of the short range (time) on the highway. The driving situation was realized by using the driving simulator based on CAVE, which provides three-dimensional stereoscopic immersive visual information. The examinees' responses and personal information were categorized reasonably by applying the competitive learning algorithm and the characteristics of each group have been analyzed. We have also compared two situations, i.e. (1) active approaching situation where the examinee drives the vehicle near the preceding vehicle and (2) passive approaching situation where the preceding vehicle nears the examinee's vehicle by gradually decelerating. It has been found that the range time the examinee feels fear in the active approaching case tends to be shorter than that in the passive approaching case. These results agree well with our natural feelings. The analysis in more complicated situations and the evaluation from viewpoint of psychology are our future work.

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REFERENCES

Been-Lirn Duh, H. (2001). *An 'Independent Visual Background' Reduced Balance Disturbance Evoked by Visual Scene Motion: Implication for Alleviating Simulator Sickness*. SIGCH'01. Seattle. USA.

Cheng, B., Taniguchi, T., Hatano, T. and Matsushima, K. (2003). Driver's behavior of headway setting in car following, *J. Society of Automotive Engineers of Japan* **57**, **12**, 28–33(in Japanese).

Cho, J. H., Nam, H. K. and Lee, W. S. (2006). Driver behavior with adaptive cruise control. *Int. J. Automotive Technology* **7**, **5**, 603–608.

Cobb, S. V. G., Nichols, S., Ramsey, A. and Johan, R. (1999). Virtual reality – Induced symptoms and effects (VRISE). *Presence* **8**, **2**,169–186.

Ebe, K., Okuwa, M. and Inagaki, H. (1999). Evaluation of driver's mental workload due to visual and auditory cognition. *R & D Review of Toyota CDRL* **34**, **3**, 55–62.

Kawashima, A., Kobayashi, K., Watanabe, K. and Numata, N. (2002). Modeling on the mental stress and automobile driving. *Society of Instrument and Control Engineers* **38**, **1**, 26–34(in Japanese).

Kemeny, A. and Panerai, F. (2003). Evaluation perception in driving simulation experiments. *TRENDS in Cognitive Sciences* **7**, **1**, 31–37.

Konishi, H., Kokubun, M., Higuchi, K., Kurahashi, T. and Umemura, Y. (2004). Risk rvaluation while driving by using hazard information. *R & D Review of Toyota CDRL* **39**, **2**, 16–23.

Mashimo, H., Furukawa, Y., Fukumaru, T. and Kaseyama, H. (2002). Experimental evaluation of driver's braking operation assistant system using brake motion warning. *J. Society of Automotive Engineers of Japan* **33**, **3**, 139–44(in Japanese).

Matsuki, Y., Matsunaga, K. and Shidoji, K. (2002). A study on driving characteristics of time headway keeping. *J. Society of Automotive Engineers of Japan* **33**, **3**, 157–160(in Japanese).

Matsuura, Y. and Morioka, T. (2001). An analysis of the difference threshold of driver's visual senses and bodily sensations on a simulator. *J. Society of Automotive Engineers of Japan* **32**, **3**, 95–99(in Japanese).

Nagiri, S., Amano, Y., Fuki, K. and Doi, S. (2001). The analysis of the driver behavior for the development of driver support system. *Toyota Central R & D Labs. Report*, 1–14.

Ohta, H. (1986). A quantitative estimation method of accident potentiality on the intersections. *Japanese J. Traffic Psychology* **2**, **1**, 11–24(in Japanese).

Ogawa, K., Ota, H. and Sugiyama, K. (1998). Traffic accidents in tunnels and drivers' subjective risk. *Japanese J. Traffic Psychology* **14**, **1**, 13–25(in Japanese).

Satoh, K., Wakasugi, T. and Hiramatsu, K. (1998). Accuracy and feeling of simulated cues on the JARI driving simulator. *Toyota Central R & D Labs. Report*, 35–43.

Schultheis, M. T. and Mourant, R. R. (2001). Virtual reality and driving: the road to better assessment for cognitively impaired populations. *Presence by MIT* **10**, **4**.

Taguchi, T. (1998). Evaluation of fatigue during car driving. *R & D Review of Toyota CDRL* **33**, **4**, 25–31.

Toda, A. and Kageyama, I. (2003). A study of psychological characteristics analysis for driver. *J. Society of Automotive Engineers of Japan*, **93-03**, 1–4(in Japanese).

Ueda, N. and Nakano, R. (1994). A new competitive learning approach based on an equidistortion principle for designing optimal vector quantizers. *Neural Networks* **7**, **8**, 1211–1227.

Uno, H. and Hiramatsu, K. (2001). Aged drivers' avoidance capabilities an emergent traffic situation. *J. Society of Automotive Engineers of Japan* **32**, **1**, 113–118(in Japanese).

Yagi, T., Yokomori, M. and Ymaguchi, S. (2003). The study of mental stress by sweating rates on the driver in the road traffic conditions. *J. Society of Automotive Engineers of Japan*, **93-03**, 9–13(in Japanese).

Yamada, K. and Wakasugi, T. (2001). A study on effectiveness of forward vehicle collision warning. *J. Society of Automotive Engineers of Japan* **33**, **1**, 119–124(in Japanese).

Yamashita, N. (1986). The cognition of risk and the evaluation of traffic desirability as the attitudinal predicting factor of behavior. *Japanese J. Traffic Psychology* **2**, **1**, 33–42(in Japanese).