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MODELING OF THE FEELING OF VISIBILITY REDUCTION BY THE RIGHT-A PILLAR OF A JAPANESE VEHICLE AND EVALUATION OF VISIBILITY USING THE K-MEANS METHOD

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Abstract. *There are many drivers who feel that the right-A pillar of a Japanese right-hand-drive car prevents visibility when turning right or left at an intersection. On the other hand, reports have shown that most pedestrian accidents are caused by delays in the drivers' ability to see the pedestrian, as determined by the drivers' eye movement. To ensure good visibility, vehicles must have a well-designed right-A pillar. Thus, it is important to develop a method for evaluating this visibility and to feed the result back into the design process. Here, a quantitative evaluation method based on drivers' eye movement data, as estimated by a least-squares approach, is developed and applied to evaluating commercial vehicles as having "good visibility" and "bad visibility" by the K-means method. This evaluation and modeling method can also be applied to other vehicles, including non-Japanese ones.*

Keywords: Eye fixation, Modeling, Obstacle feeling, Right-A pillar, K-means method

1. **Introduction.** In this paper, a method of quantifying the feeling of visibility reduction by the right-A pillar of a Japanese right-hand-drive car is presented and applied to commercial vehicles, such that vehicles offering good visibility can be designed. It has been shown that many drivers feel that this pillar reduces visibility when turning right or left at intersections [1,2]. On the other hand, a previous study has shown that most pedestrian accidents are caused by delays in the pedestrian being seen by drivers, as determined by drivers' eye movement [3]. A monitor system showing pedestrians or obstacles at a blind corner is under development, in order to improve the visibility during right or left turns at intersections [4-6]; however, this device is costly and takes a long time to be equipped onto commercial vehicles. An ideal solution for safety is to develop a vehicle with no pillar. However, this seems to be very difficult in practice because of its cost, the mechanical properties of materials, and the strength of the vehicle body. Therefore, it is important to design a right-A pillar that does not reduce visibility, as quantified through measurement of the driver's eye movement. Engineers can design such pillars more efficiently by using these data, thus improving the efficiency of a vehicle's design and development. A means of quantifying the visibility within vehicles will prove advantageous to designers. In addition, it is very interesting that the biometric, like eye tracking, is applied practically to modeling method from the point of the academic importance.

2. **Materials and Methods.**

2.1. **Hypothesis.** In this paper, we refer to the feeling of reduced visibility due to the right-A pillar as "obstacle feeling". Our two hypotheses concerning obstacle feeling are presented below.

<Hypothesis 1>

Eye-fixation duration near the right-A pillar increases if the driver strongly experiences obstacle feeling, because the direction in which the driver is looking is blocked by a right-A pillar. In addition, due to the obstacle feeling, the driver tends to move their eyes from the nearby pillar to the windshield by their seat and visually recognize obstacles such as oncoming vehicles. Thus, the longer the eye-fixation time near a pillar, the greater is the extent to which the driver experiences obstacle feeling. Figure 1 shows this situation. In Figure 1, circle shows that driver's eye fixation area and the size of circle indicates the eye fixation time. In Figure 1(a), the white-colored arrow represents the path of the driver's eye in case of a vehicle with good visibility. On the other hand, in Figure 1(b), the circles represent areas of long eye-fixation duration due to obstacle feeling and the gray-colored arrow indicates the eye movement of the driver. Figure 1(b) differs from Figure 1(a) in that the driver's eyes do not move toward the windshield by their seat because the right-A pillar is not designed to have good visibility.

<Hypothesis 2>

The factors affecting the visibility of the right-A pillar are the pillar's dead angle (Figure 2), the angle between the driver's facing direction and the right-A pillar, and the angle between straightforward and meter panel.

Following these hypotheses, we conduct experiments and modeling in this study.

2.2. **Experimental procedure.** An experiment was conducted to measure the eye movement and eye-fixation durations of drivers when driving a vehicle. Three individuals were selected as evaluators of this experiment. Each evaluator drove five types of C-segment vehicle (Sample vehicle A, B, C, D and E) and wore an eye-mark recorder (EMR-9 of NAC Image Technology, Inc.) [7], which could track their eye movements and eye-fixation times (Figure 3). Each of the C-segment vehicle used in this experiment had three measured parameters – the angle between the forward-facing direction and the right-A pillar, the dead angle of the right-A pillar, and the angle between the forward-facing direction and the meter panel. Obstacle feeling was verified in terms of correlations between the three parameters and the eye movement and eye-fixation time for each vehicle.

Eye movement and eye-fixation time were measured on the winding course in Ota-city Gunma, Japan. Informed consent was obtained from the evaluators before commencing

(a) (b)

FIGURE 1. Eye movement around a right-A pillar ((a): good visibility, (b): bad visibility). Circle shows that driver's eye fixation area and the size of circle indicates the eye fixation time. Arrow means the path of eye movement.

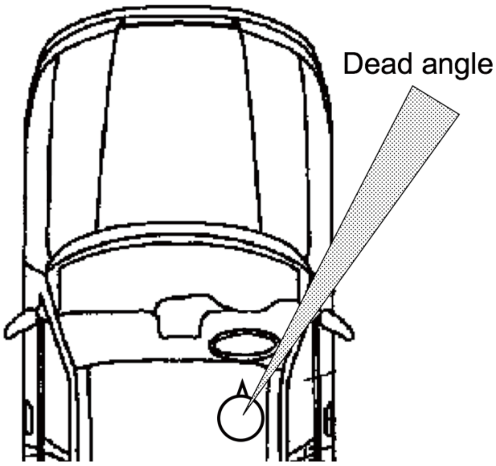

Figure 2. Definition of dead angle of right-A pillar

Figure 3. Eye-mark recorder (EMR-9)

the experiment. In addition, evaluators were taught not to move their head during driving, because this is the condition under which traffic accidents generally occur.

3. Results and Discussion.

In this section, result of experiment and modeling of obstacle feeling is discussed. It should be noted that the contents of §3.1, 3.3 and 3.4 are the same as previous study [8].

3.1. Experiment and sensory evaluation.

"Eye-fixation rate" is defined according to the following formula:

$$\text{Eye-fixation rate} = \frac{\text{EFT}}{\text{TT}} \tag{1}$$

where

EFT: eye-fixation time on the A-pillar and windshield by the driver's seat;

TT: total time of turning the steering wheel when driving each curve line.

Table 1 shows the eye-fixation rate while driving the course. This rate was calculated from the driving movie recorded by the eye-mark recorder, watched as a frame-by-frame playback.

Next, each driver subjectively evaluated the visibility around the right-A pillar of each vehicle. Each evaluator's score had units of 0.5 point, with a maximum of 4 points if they felt the car had the best visibility and 1 point if they felt it had the worst visibility. Table 2 shows the result; the differences between the scores of each evaluator are not larger than the standard deviation.

TABLE 1. Eye-fixation rate of each evaluator (unit: %)

Evaluator	Vehicle				
	S.V A	S.V B	S.V C	S.V D	S.V E
1	42.95	45.08	44.09	45.24	39.54
2	49.93	49.84	52.54	58.06	45.58
3	51.86	53.44	61.87	32.99	41.21

NOTE: S.V means sample vehicle

TABLE 2. Visual fixation rate of each evaluator (unit: %)

Vehicle	Evaluator			Average	S. D.
	1	2	3		
S.V A	2.5	2.5	2.0	2.3	0.1
S.V B	3.0	3.0	2.5	2.8	0.1
S.V C	1.5	2.0	1.5	1.7	0.1
S.V D	3.5	3.5	3.0	3.3	0.1
S.V E	4.0	4.0	3.5	3.8	0.1

NOTE: S.V means sample vehicle

TABLE 3. the value of "angle between forward-facing direction and right-A pillar", "dead angle of right-A pillar" and "angle between forward-facing direction and meter face" (unit: deg)

	S.V A	S.V B	S.V C	S.V D	S.V E
angle between forward-facing direction and right-A pillar	18.9	22.4	21.3	27.2	23.1
dead angle of right-A pillar	9.6	12.1	11.5	13.3	10.5
angle between forward-facing direction and meter face	9.2	11.6	8.8	14.1	7.8

NOTE: S.V means sample vehicle

3.2. **Modeling using experimental results.** The average eye-fixation rate, that is, obstacle feeling, was estimated by a least-squares method, and the dependent and independent variables were set as follows. Here, the suffix i indicates the number of the vehicles used in the experiment. For example, R_a means the angle between the forward-facing direction and right-A pillar of vehicle A.

<independent variable>

average eye-fixation rate: y_i

<dependent variable>

angle between forward-facing direction and right-A pillar: R_i

dead angle of right-A pillar: B_i

angle between forward-facing direction and meter face: L_i

Here, the value of "angle between forward-facing direction and right-A pillar", "dead angle of right-A pillar" and "angle between forward-facing direction and meter face" is shown as Table 3.

Now, matrix **A** is created based on Table 3,

$$\mathbf{A} = \begin{bmatrix} 18.9 & 9.6 & 9.2 \\ 22.4 & 12.1 & 11.6 \\ 21.3 & 11.5 & 8.8 \\ 27.2 & 13.3 & 14.1 \\ 23.1 & 10.5 & 7.8 \end{bmatrix}$$

and matrix $\mathbf{y}$ is created based on Table 1.

$$\mathbf{y} = \begin{bmatrix} 42.95 & 49.93 & 51.86 \\ 45.08 & 49.84 & 53.44 \\ 44.09 & 52.54 & 61.87 \\ 45.24 & 58.06 & 32.99 \\ 39.54 & 45.58 & 41.21 \end{bmatrix}$$

The eye-fixation rate ($\mathbf{y}$) is expressed as following equation.

$$\mathbf{y} = \begin{bmatrix} \mathbf{A} & 1 \end{bmatrix} \boldsymbol{w} = \mathbf{G}\boldsymbol{w}$$

$\boldsymbol{w}$ is calculated in the following equation:

$$\boldsymbol{w} = \left(\mathbf{G}^{\mathrm{T}}\mathbf{G}\right)^{-1}\mathbf{G}^{\mathrm{T}}\mathbf{y}$$

Thus, the estimated average eye-fixation rate ($\hat{\boldsymbol{y}}$) can be calculated using $\mathbf{G}$ and $\boldsymbol{w}$, which is acquired above.

$$\hat{\boldsymbol{y}} = \mathbf{G}\boldsymbol{w}$$

Modeling by the least-squares method estimates the average eye-fixation rate of 3 evaluator ($\hat{\boldsymbol{y}}$) according to the following equation:

$$\hat{\boldsymbol{y}} = (-2.3934)\boldsymbol{R} + 5.0427\boldsymbol{B} + (-0.3719)\boldsymbol{L} + 48.003 \tag{2}$$

where $\hat{\boldsymbol{y}} = [y_a, y_b, \ldots, y_n]^{\mathrm{T}}$, $\boldsymbol{R} = [R_a, R_b, \ldots, R_n]^{\mathrm{T}}$, $\boldsymbol{B} = [B_a, B_b, \ldots, B_n]^{\mathrm{T}}$, $\boldsymbol{L} = [L_a, L_b, \ldots, L_n]^{\mathrm{T}}$, n is the # of the vehicle and the coefficient of Equation (2) is the average of the coefficient of each evaluator's model.

Equation (2) is a linear model based on experimental data from the three evaluators and the interior dimension of experimental vehicles A-E. However, this equation can be generalized to any commercial vehicle whose interior dimensions are known. Equation (2) shows how $\boldsymbol{R}$ (the angle between the forward-facing direction and the right-A pillar), $\boldsymbol{B}$ (the dead angle of the right-A pillar) and $\boldsymbol{L}$ (angle between forward-facing direction and meter face) affect $\hat{\boldsymbol{y}}$ (estimated average eye-fixation rate). The coefficient sign of the equation means that the estimated average eye-fixation rate is small, meaning that obstacle feeling will be reduced if the dead angle is reduced. In addition, the estimated average eye-fixation rate is small, meaning that obstacle feeling will be reduced if the angle between the forward-facing direction and the right-A pillar and that between the forward-facing direction and the meter face are increased.

3.3. **Discussion – Correlation between the results of sensory evaluation and modelling.** Figure 4 shows the correlation between the estimated average eye-fixation times for five vehicles calculated by (2) and the sensory evaluations of the three evaluators. A linear model fits the subjective assessments in our case and eye-fixation time seems to be comparable with actual visibility.

3.4. **Discussion – Comparison between results of experiment and modeling.** R_i, B_i, and L_i are substituted into linear equation (2) and the estimated average eye-fixation rate is compared to that obtained by the experiment (Figure 5). Figure 5 indicates a strong correlation between these values (with $\boldsymbol{R}$ = 0.9611), such that the constructed linear model can be used to estimate the actual eye-fixation rate.

3.5. **Discussion – Applying the model to evaluating the visibility in other commercial vehicles and clustering of visibility.** The eye-fixation rates of vehicles A-E and F-J, which are C-segment vehicles that were not used in the experiment, were estimated according to the linear model (Figure 5). In order to classify these vehicles as "good visibility" or "bad visibility" vehicles, a clustering method was applied to the estimated visibilities of all vehicles by a least-squares method. In previous study [8], these

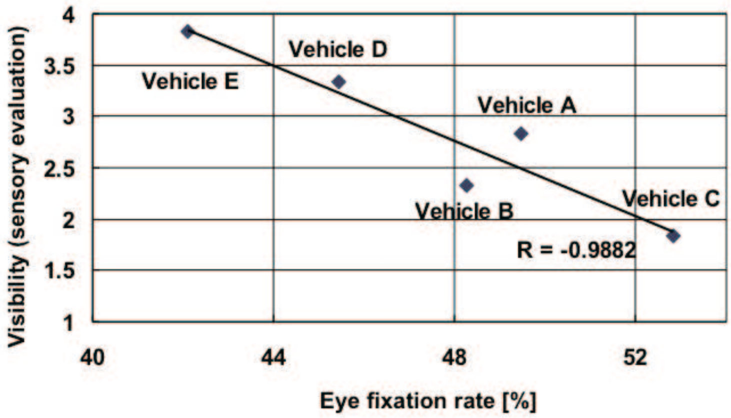

FIGURE 4. Correlation between experimental eye-fixation rate and sensory evaluation

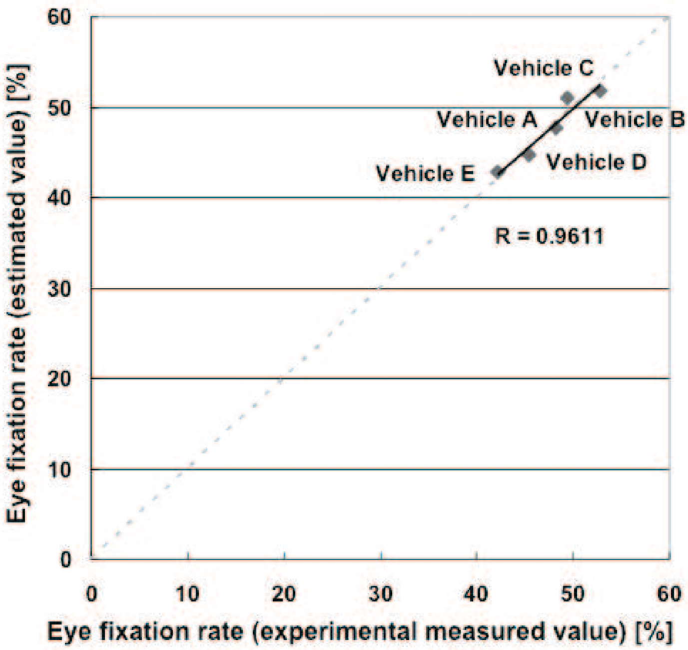

FIGURE 5. Correlation between experimentally measured value and estimated value

vehicles are classified as "good visibility" or "bad visibility" based on subjective evaluation; however, it is needed to classify automatically and objectively in the case of applying vehicle design. The K-means method was used to classify the commercial vehicles. The algorithm of the K-means method is as follows [9].

Let X $= \{x_1, x_2, x_3, \ldots, x_n\}$ be the set of data points and V $= \{v_1, v_2, \ldots, v_c\}$ be the set of centers.

1) Randomly select "c" cluster centers.

2) Calculate the distance between each data point and cluster center.

3) Assign the data point to the cluster center whose distance from the cluster center is minimum of all the cluster centers.

4) Recalculate the new cluster center using

$$v_i = \frac{1}{c_i}\sum_{j=1}^{c_i} x_i \tag{3}$$

where "c_i" represents the number of data points in the ith cluster.

5) Recalculate the distance between each data point and the newly obtained cluster centers.

6) If no data point was reassigned, then stop; otherwise, repeat from step 3).

Vehicles were classified based on the eye-fixation rate using the K-means method, and the result is shown in Figure 6. Here, bad visibility vehicles are shown as a gray plot and good visibility vehicles are shown as a dark gray plot. From Figure 6, vehicles A-E seem to be "bad visibility vehicles" and vehicles F-J are classified as good visibility vehicles. Vehicles A-E have been described as having bad visibility in the consumer report [10], and this result seems to be appropriate. Vehicles can be classified by the K-means method quickly.

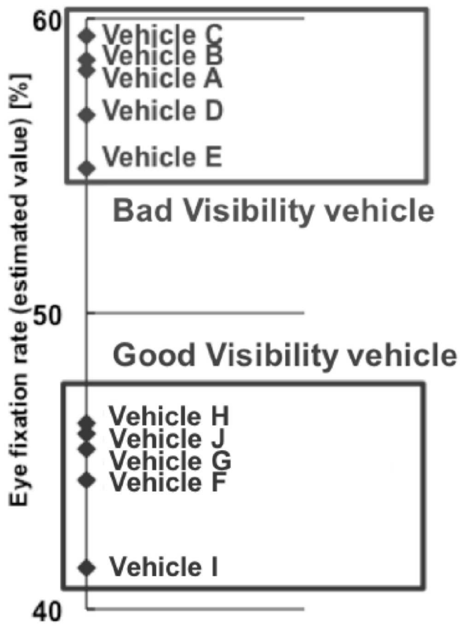

Figure 6. Estimated value of the eye-fixation rate and the result of classification by the K-means method

4. **Conclusions.** In this study, a linear model of obstacle feeling based on the measured eye-fixation rate and parameters such as the angle between the forward-facing direction and the right-A pillar, the dead angle of the right-A pillar, and the angle between the forward-facing direction and meter face was constructed experimentally. The results suggested that the visibility of a vehicle can be quantified and estimated by this linear model and information concerning vehicle dimensions. This quantitative estimate seemed to match with the subjective sensory evaluation of various drivers. In addition, good and bad visibility vehicles could be classified by the K-means method based on the result of modeling.

These results likely contribute to efficient design; however, only C-segment vehicles were evaluated in this paper and the experimental data were only recovered from three evaluators, so it is left to future study to acquire data from more evaluators and to apply this method to other segment vehicles. Furthermore, more commercial vehicle data need to be acquired and the visibility of more commercial vehicles needs to be classified.

Nevertheless, this method can be applied to other vehicles not manufactured in Japan; thus, if designers can acquire interior designs of the body and apply this method, they will be able to design their vehicles to have good visibility.

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