The Evaluation for Visibility of a Back Image on a Transparent Display

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ABSTRACT

Transparent display is useful device for some applications but has a privacy issue that a back image appears on the opposite side to the display image. We investigated the condition human cannot see a back image.

1 INTRODUCTION

Recently, automobiles are remarkably developing. More and more vehicles operated with a lot of systems support human's driving. Autonomous vehicles will appear in the near future. And in such a trend, the opportunities for using a window as a display will increase. Currently, head-up-display (HUD) is one solution for displaying images on wind-shield. When autonomous vehicles appear, passengers seem to require to watch images such as an entertainment or a teleconferencing on wind-shield.

Transparent display is one of the devices to realize displaying images on a window of a car (ex. transparent screen, organic light emitting diode, micro LED etc.). In case of applying a transparent display to the window, there is an issue that the image shown to inside a car is visible from outside a car in some cases (Fig.1). This image appears on the opposite side to the display (back image). The back image might affect privacy. The back image can be seen from outside a car because the light displaying image leaks to the outside a car by reflection of a glass surface or by scattering in display components. Fig.2 (a) is a picture of transparent screen image to simulate to see from inside a car and Fig.2 (b) is a picture from outside a car.

To be unable to see the back image, the luminance of the image leaking to outside a car needs to be much smaller than the luminance by ambient light. As a result, the contrast for back image decreases, and a back image cannot be seen (Fig.2 (c)). Conventionally, the evaluation for the contrast for opaque displays is established [1]. In the case of the transparent display, there are several positions of the object plane of the background (the reflection from the surface of the display, the scattering light from display components and the transmitted light through the transparent display), and back image which cannot be seen for opaque displays generates. We recognize that the evaluation for the back image is not established at the moment.

The purpose for this investigation is to build the evaluation system to find a condition not to see a back image.

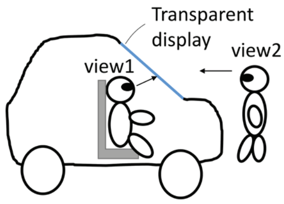

Fig.1 Two positions of observers for transparent screen for a window of a car

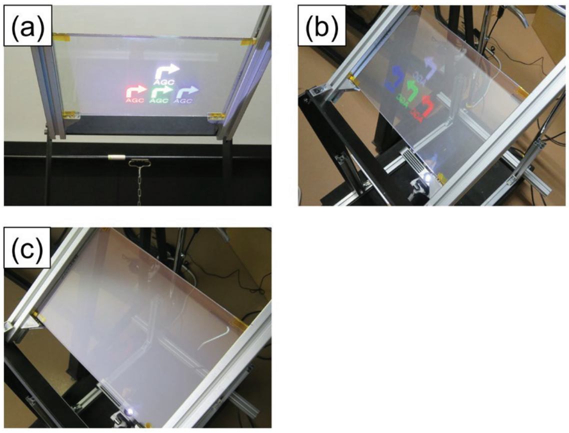

Fig.2 Image of transparent screen to simulate a window of a car
(a) Display image from inside a car (view1)
(b) Back image from outside a car (view2)
(c) Back image invisible

2 EXPERIMENT

2-1 Experiment setup

The setup in this experiment consists of artificial illumination, a transparent display and an observer who sees the back image. Fig.3 shows the positions for each components.

To construct an artificial illumination we installed high power illuminations and white screen on the ceiling and the wall of the test room which intercepts external lights.

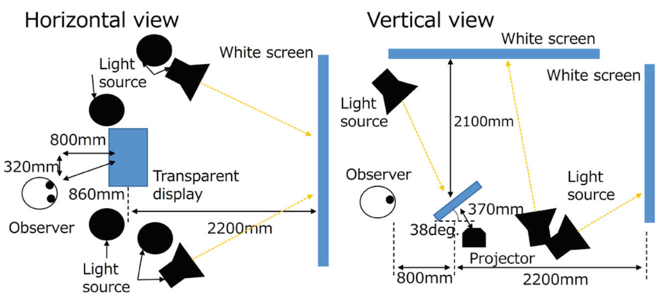

Fig.3 Experiment setup

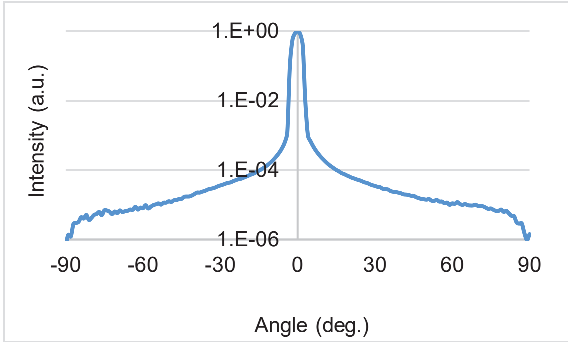

Fig. 4 Intensity distribution of the transmitted light

We can make different conditions (ex. a position of the object plane of the background, the real image or virtual image) by exposing the each background to intense light from the high power illumination.

We used a transparent screen and a projector as a transparent display. The properties of the transparent screen were as follows: transmittance 71%, haze 1.4, screen gain about 0.5. Fig.4 shows the intensity distribution of the transmitted light with respect to angle in measuring at the condition that incident light was vertical to the transparent screen.

The projector's characteristics were as follows: light power 3000lm, focal length 370mm and projected size about 8inch. The viewing distance was set to 860mm. Transparent screen was tilted to 38 degree. The luminance of the back image was controlled by changing the luminance of projected image by using neutral density filters. The projected image was Landolt ring (Fig.5). The color of Landolt ring was four, they were red, green, blue and white.

2-2 Method

We estimated the visibility of back image by taking a questionnaire. The number of observer was ten. The position of the observer was the opposite side to the projector.

In this experiment, we investigated the contrast threshold in terms of the dependence on the luminance of the background and the dependence on the position of the object plane of the background. The contrast threshold can be defined as the minimum contrast that can be resolved. In the investigation for the contrast threshold with the dependence on the luminance of the background, we set a position of the object plane of the background at the ceiling. The conditions were five kinds of luminance of the environmental illumination. In the investigation for the dependency of the contrast threshold on a position of the object plane of the background, we set the luminance of background to 200cd/m^2. The conditions were four kinds of the position of the object plane of the background. The background of the transparent screen is composed of superposition of the three background (Fig.6). The first background is the screen at the ceiling. We recognize the light reflected by the surface of the transparent screen as the background. The second background is the transparent screen. We recognize the light scattered by the components of the transparent screen as the background. The third background is the screen through the transparent screen. We recognize the light transmitted through the transparent screen as background. These object planes of the background are not the same, and the background image is composed of real image and virtual image. In this measurement, we changed four background conditions:①at the ceiling, ②at the transparent screen, ③at the screen through the transparent screen, ④at the superposition of the three backgrounds described above. The background luminance composed of three background was set to about 66cd/m^2, then the total background luminance was about 200cd/m^2. One of the feature for this measurement system is controlling the background luminance independently.

Next, we explain the way to decide whether people can or cannot see the back image. The image of Landolt ring was projected on the transparent screen by a projector for one second with various periods. When the observer can see the image of Landolt ring, the observer answers the color and the open direction of Landolt ring. If the observer answers the correct direction, we regard the back image as visible. Otherwise, we regard the back image as invisible.

Table1 shows the experimental conditions. In this calculation, we took an average of 10 people.

We used the Michelson contrast as the visibility evaluation index. In calculating the Michelson contrast, we considered the luminance including background luminance. When the back image changed invisible to visible under a certain condition, we decided the Michelson contrast as the contrast threshold. The unit of luminance is candela/square meter.

Fig.5 Landolt ring (Test image)

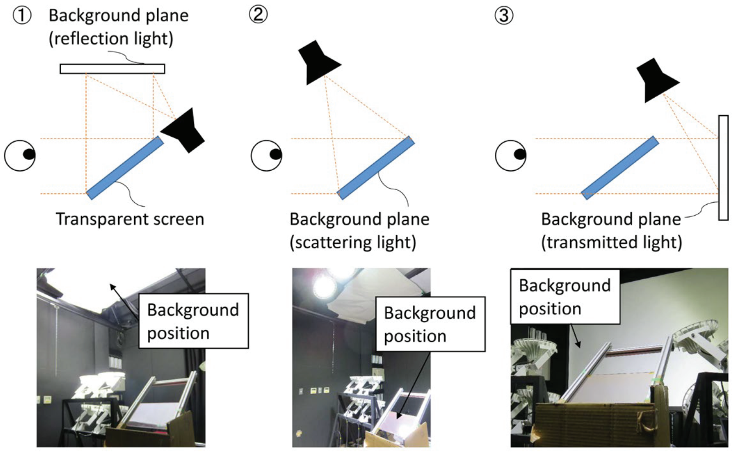

Fig.6 Position of the object plane of the background for transparent screen

Table 1. Experimental Conditions

Background luminance (cd/m²)		400 / 300 / 200 / 100 / 0.2								
Back Image Luminance (cd/m²)	**Red**	6.25	3.1	0.63	0.31	0.06	0.03	0.006	0.003	0.0006
	Green	92.6	46.3	9.3	4.6	0.93	0.46	0.09	0.05	0.01
	Blue	0.96	0.48	0.1	0.05	0.01	0.005	0.001	0.0005	0.0001
	White	110	55	11	5.5	1.1	0.55	0.11	0.06	0.01
Distance between background and back image (mm)	**Ceiling screen**	0								
	Transparent screen	−2100 (minus means the distance between back image and virtual image.)								
	Screen through transparent screen	2400								

3 RESULTS

Fig.7 shows the results of the dependency of the contrast threshold on the luminance of the background. These results show that the contrast threshold of green and white is higher than the contrast threshold of red and blue. Since the sensitivity of green is higher than red and blue, the luminance of green becomes higher than red and blue. So the contrast threshold of green might be higher than red and blue. The contrast threshold in the bright condition keeps constant.

The contrast threshold in the dark condition (~0.2cd/m²) like night becomes higher than the contrast threshold in the bright condition (>100cd/m²). This behavior is caused by the sensitivity different from cone cell and rod cell. The rod cell works mainly under the dark surroundings. On the other hand, the cone cell works mainly under the bright surroundings. So we need to consider two contrast threshold for bright surroundings and dark surroundings.

Fig.8 shows the results of the dependency of the contrast threshold on a position of the object plane of the background. The contrast threshold keeps constant. The contrast threshold is independent on a position of the object plane of the background. The contrast threshold at the multiple background whose luminance is about 66cd/m² shows the same contrast threshold at the one background whose luminance is about 200cd/m². These results indicate that the contrast threshold is independent on a position of the object plane of the background.

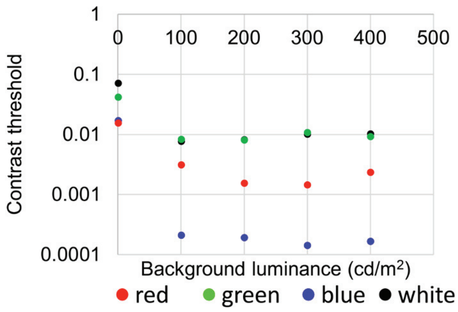

Fig.7 Contrast threshold for background luminance

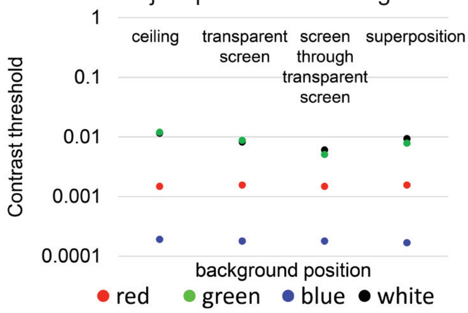

Fig.8 Contrast threshold for background position

4 DISCUSSION

In this section, we discuss the relationship between the indoor evaluation and the outdoor evaluation. Fig.9 shows the picture when the visibility is investigated outside under the sunlight. The outdoor illuminance is about 50,000lux. The back image luminance is 23cd/m^2 for white color and display image luminance is 2280cd/m^2. The luminance of the reflection of clouds is 1310cd/m^2 and the luminance of the reflection of sky without clouds is 934cd/m^2. The contrast at the reflection of sky area is 0.013. The value is higher than 0.009 which is the contrast threshold for white measured in the indoor experiment. In spite of the contrast higher than the contrast threshold, the back image is invisible like Fig.9. Under the bright condition such as outdoor in the daytime, the pupil size becomes smaller than under the indoor condition. The pupil size which is related with the illuminance might affect the contrast threshold. This result suggests that the contrast threshold at the bright conditions such as outdoor in the daytime becomes higher than at the condition such as indoor. So, it is more difficult to see a back image under the high illuminance than under the low illuminance. We also investigated the visibility of a back image at the condition that there are several multiple background images reflected on the glass surface. The background is composed of the reflection of sky and tree branch. Fig.10 shows the picture when the visibility is investigated outside under the shade of sunlight. The outdoor illuminance is about 2,700lux. The luminance of the reflection of sky is 158cd/m^2 and the luminance of the reflection of tree branch is 78.4cd/m^2. When we adjusted the luminance of a back image, the contrast at the reflection of sky area became 0.007 and the contrast at the reflection of tree branch became 0.015. In spite of the contrast higher than the contrast threshold, the back image is invisible like Fig.10. This result suggests that the visibility of a back image depends on the spatial frequency of a background image.

On the other hand there would be an effect of size for Landolt ring. We are investigating a dependency of the contrast sensitivity on the spatial frequency for a transparent screen with the striped pattern (Fig.11). We observed that the contrast sensitivity function has the peak. The contrast sensitivity function of transparent screen behaves similarly to the contrast sensitivity function of the conventional opaque display. The size of Landolt ring might become a parameter for the contrast threshold. We are looking at the effect of the outside illuminance and the size of Landolt ring on the visibility.

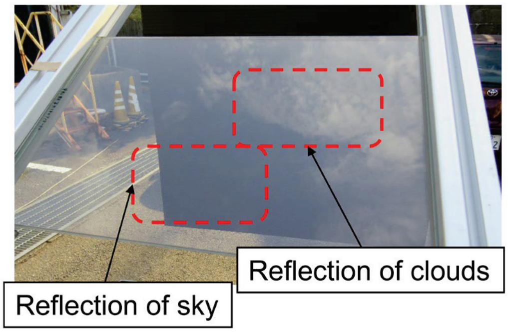

Fig.9 Investigation under the sunlight

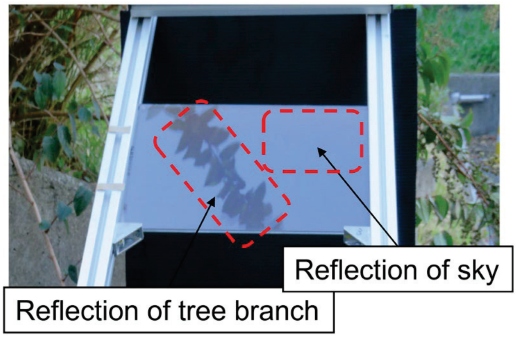

Fig.10 Investigation under the shade of sunlight

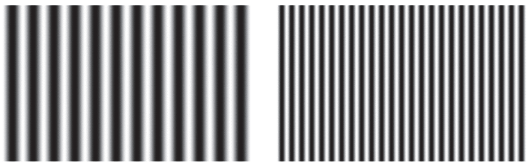

Fig.11 Striped pattern (Test image)

5 CONCLUSIONS

We investigated the contrast threshold not to see a back image from outside a car for transparent screen. We found that the contrast threshold is independent on the position of the background plane and that the contrast threshold in bright surroundings differs from the contrast threshold in dark surroundings. We also found that the contrast threshold becomes higher under high illuminance than the low illuminance.

REFERENCES

[1] Wyszecki G. & Stiles W.S. (1982). Color science: concepts and methods, quantitative data and formulae (2nd edition). New York: Wiley