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Detectability of Nonuniformities in Automotive Exterior Displays: A Study for Model Validation

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1. Abstract

The automotive industry is experiencing significant growth in the use of exterior displays, driven by advances in technology and the increasing demand for innovative ways to enhance vehicle aesthetics and functionality. This trend is benefiting from topics such as digitalization, safety and customization. In particular, the use of autonomous vehicles creates a wide range of potential applications for this technology.

For observers the uniformity of the display is an important indicator for the perceived quality. Therefore, nonuniformities can disturb the observer's perception, which makes reliable detection important.

To evaluate these nonuniformities objectively and reproducibly, the model of Schier et al. offers a promising approach to detect nonuniformities by predicting the visibility of contrasts in luminance distributions [1]. The model's general approach is to simulate human contrast vision perception by taking the environment into account. However, the model has not yet been compared with measurement data from automotive applications.

This paper describes a study to validate the previously mentioned model for the use case of exterior displays. For this purpose, an extensive test person study was conducted to determine the perception threshold of different contour shapes.

For the study setup the adjustment method was chosen to determine the contrast threshold. The study was conducted with 32 test subjects and was carried out with an automotive Mini-LED display, on which specific nonuniformities were displayed. Seven different contour shapes were analyzed during the study. The results show that the shape of the contour plays a crucial role and significantly changes the perception threshold.

The study design presented in the paper is suitable for determining the contrast threshold on automotive exterior displays. The results of the study can be used to verify the model and to evaluate the model performance.

Keywords: visual perception, contrast vision, contrast threshold, contour integration

2. Introduction

Exterior displays have the potential to be a major trend in the automotive sector [2]. There is a great opportunity due to individual vehicle aesthetics, improved safety and communication, branding and advertising, and the integration with vehicle connectivity [3]. The visual impression of a display is particularly important. Differences in the brightness of the display are perceived as particularly disturbing and are referred to as inhomogeneities. This perception is influenced by several factors. In detail, the influence begins with the eye, which functions as a visual apparatus, and continues through to image processing in the visual cortex, involving all the influences of the human brain.

Existing models for assessing homogeneity in this area are based on the perception of one point of the light distribution or image under consideration. The surrounding area is either not considered at all or only to a small extent (black mura) [4]. The same applies to the VDI guideline for the assessment of photometric uniformity. It proposes a calculation scheme for assessing the uniformity of light sources or illuminated scenes. One of the characteristics described is luminance uniformity, which is calculated as the difference between two luminance values [5]. However, it is known from various phenomena that the immediate environment also has a major influence on perception and thus on the observer's perception of contrast [6].

Schier's current research applies a model that simulates perception by taking the environment into regard and can thus simulate relevant effects of the human visual system, that are strongly influenced by the environment [1].

The applicability of the enhanced model to automotive lighting products has not been proven. In this work we conduct a psychophysical study of contrast threshold for stimuli with different contour shapes. The measurement results can be compared to the model to evaluate its performance.

In addition to create a study for validation, the focus is on the evaluation of the impact of contour integration. Contour integration is the ability of the visual system to group spatially distinct elements into coherent contours. This ability enables humans to detect and identify object boundaries, even when they are fragmented or partially obscured [7], [8]. A key feature of contour integration is that smoothly aligned elements are more easily detected than isolated or randomly oriented segments which could been shown in different studies [9].

This suggests that the brain has specialised mechanisms for grouping local orientation signals into global shape representations. These underlying processes are believed to depend on long-range horizontal connections between orientation-selective neurons in early visual areas, such as V1 and V2, that facilitate the integration of linear or circular elements [10]. From an ecological perspective, this ability probably evolved to enable the reliable identification of object boundaries in natural environments, where contours frequently define meaningful shapes but are rarely presented as continuous lines [11].

The aim of the designed study is to investigate if contrasts are recognized better or not due to the influence of contour integration.

3. Methods

Observers

A total of 32 observers participated in the study on a voluntary basis. A maximum age of less than 40 years was considered when selecting the subjects. The upper age limit was set to ensure that the group of test subjects had the best possible visual acuity and were free from any age-related visual impairments. All subjects were tested for visual acuity and contrast sensitivity under photopic conditions using the FrACT test [12]. The test results were evaluated against WHO limits and showed normal results for all observers [13].

Used Equipment

The study was conducted in a laboratory environment at L-LAB in Lippstadt, Germany, to ensure reproducible dark conditions without glare or disturbing light sources.

An automotive Mini-LED display with 5920 LEDs (40 columns x 148 rows) was chosen to display different contrasts and different contours to the observer.
The chosen display shows some non-uniformity due to the manufacturing process. To ensure that the viewer sees a uniform image, a calibration process was developed for the display.

The calibration process was done by a mapping between LEDs and measured luminance to generate a correction matrix for each individual LED to ensure a uniform display. The

calibration results were checked by the Sampled Uniformity process in the Information Display Measurements Standard [14] with the following result:

$$N = 100\,\%\,(1 - \frac{L_{min}}{L_{max}})$$

$$N_{Initial} = 15{,}6\,\% \qquad N_{Calibrated} = 1{,}2\,\%$$

A high value indicates an inhomogeneous surface, while a low value indicates a homogeneous one. An analysis of the luminance images clearly demonstrates the difference between the initial situation and the correction. It is evident that there has been a significant enhancement of the uniformity. Hotspots were removed and the darker edge area was adapted to the central area (figure *1*).

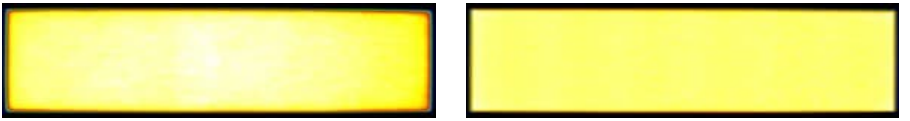

Figure 1: result of displaycalibration

Furthermore, several tests were started to characterize the display. This includes, among other things, the consideration of the degradation behaviour and the consideration of the linear relationship between the controlled gray levels and the measured luminance. The investigations showed that there is no significant deviation on the determined contrast threshold within the study.
The luminance measured to determine the contrast in the test images shown were measured using an LMK 5-5 luminance camera from TechnoTeam GmbH.

All the used equipment was controlled by a Python script that was self-developed. This script was used to control the upcoming pictures on the display and to capture the luminance images from the luminance camera.

Test images

The impact of contour integration on the contrast threshold of the test subjects was evaluated using seven different contours. To investigate the influence of contour integration on the contrast threshold, the test images show contours that are closed to different levels in order to compare them with each other.

The following images are the central section of the test images created and shown on the display:

Test

Figure 2: test images
1) filled square 2) contour square 3) contour square (II)
4) contour square (III) 5) contour square (IV) 6) vertical line

images 3 and 4 show the contour of a square where only every second pixel in test image 3 and every third pixel in test image 4 is darker. Test image 5 (IV) shows only dimmed corner points and central support points. All test images were created in different contrasts with as little increments as possible to determine the contrast threshold as precisely as possible within the study. When creating test images 6 and 7, care was taken to ensure that the area where the contrast changed remained identical and that no changes occurred as a result of this.

Procedure

The vision test mentioned above was performed immediately before the study. Directly after the vision test, the participating test subjects were shown a demonstration to clarify the task. The elapsed time including the demonstration and the visual acuity tests was used as an adaptation period and was a total of 15 minutes before the start of the contrast threshold test. An adaptation luminance of approximately 1,000 cd/m² was implemented to ensure a homogeneous adaptation luminance when viewing the display, which was set to a brightness of 1,000 cd/m². This avoids any influence of glare.

The adaptation method was used to determine contrast thresholds. This is a psychophysical procedure in which the subject independently adjusts a stimulus until a certain criterion is met [15]. Subjects were randomly shown one of the seven test images generated and had to either reduce the contrast until the difference in contrast was unnoticeable or increase the contrast until the observer could see a contour. To prevent a learning effect, the order of the test images was randomised, as well as the order between increasing and decreasing contrast. Each test image was tested in five iterations for both directions. In total 10 threshold values per test subject were determined for each test image.

To determine the contrasts shown, all test images were first measured in all increments using the luminance camera. Out of this data the Michelson contrast was determined for each individual gradation. Depending on the test image, this resulted in an adjustable contrast resolution of 0.001 that could be shown on the display.

4. Results

In order to evaluate the performance of the contrast vision model on an automotive application, a study was conducted to detect the contrast perception threshold. The influence of contour integration was measured with the help of the differently closed contours in the form of the previous mentioned test images.

The study was successfully conducted on all 32 participants. For each test image, 320 threshold values were detected and documented.

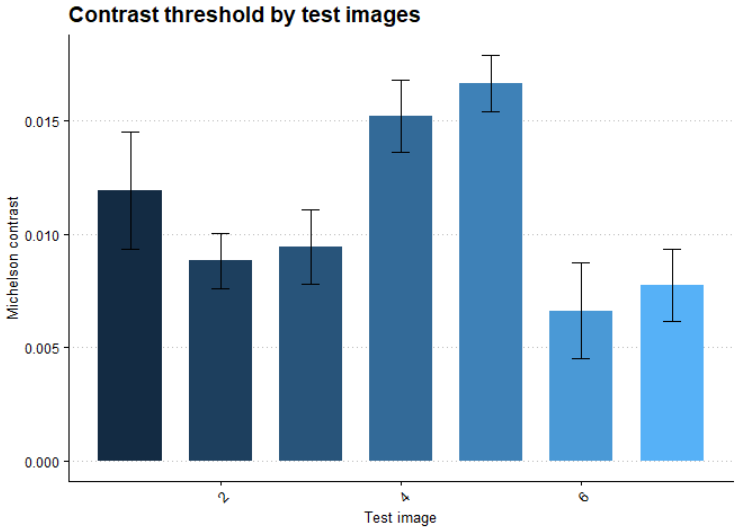

Figure 3: Contrast Threshold by test image

The following contrasts were determined for the test images

test image	description	mean contrast	std. deviation
1	filled square	0.0119	0.0026
2	contour square	0.0088	0.0012
3	contour square (II)	0.0094	0.0017
4	contour square (III)	0.0152	0.0016
5	contour square (IV)	0.0167	0.0012
6	vertical line	0.0066	0.0021
7	vertical line interrupted	0.0078	0.0016

Table 1: contrast threshold by test image

The averaged contrast thresholds of all subjects shown in figure 3 and table 1 varied significantly between the individual test images. A contrast threshold value of 0.0066 was determined for the detection of the vertical line, while a contrast threshold value of 0.0167 was determined for the detection of the square contour. formed by the corner points and the centre support points (contour square IV).

We can also see from the data that there is a significant increase in the contrast required to detect the contours as the support points decrease for the contour of the square as well as for the vertical line [16]. To assess the magnitude of the differences observed between the test images presented, generalized eta squared was calculated. This statistic quantifies the proportion of total variance explained by the effect, while accounting for other sources of variance in the design [17]. The resulting value of 0.774 indicate a large effect size [18].

This finding serves to confirm the influence of contour integration on the recognition threshold in contrast vision. As the results from table 1 show, the detection of continuous and closed contours in the study conducted here is easier than the detection of individual areas. This confirms previous literature findings that environmental factors and contrasts are highly relevant to contrast sensitivity.

test image	mean contrast increase	mean contrast decrease
1	0.0138	0.0101
2	0.0093	0.0083
3	0.0094	0.0095
4	0.0156	0.0148
5	0.0176	0.0158
6	0.0071	0.0062
7	0.0082	0.0074

Table 2: Contrast threshold increase / decrease

Table 2 shows a comparison of the contrast thresholds determined between the gradual increase in contrast until a test image became visible and the gradual decrease until a test image was no longer visible. A higher contrast threshold is detected when the contrast is increased to the point of visibility. This can be explained by the fact that the pattern that appears when the contrast is increased is initially unknown. Only when the pattern is clearly visible it can be recognized.

The study results fulfil the expectations regarding the influence of contour integration and are suitable for validating Schier's model on an automotive application.

5. Summary and Conclusions

A study was designed to validate the contrast vision model on an automotive exterior display. This involved conducting a study with 32 test subjects. By using visual tests, it was possible to ensure the visual ability of the test subjects. The method chosen for the study was the adjustment method, in which a stimulus was gradually brought closer to the recognition threshold. To ensure that the test subjects only perceived the contrast differences shown, the display used was calibrated in advance using a self-developed process and the improvement in homogeneity was measured according to the SID standard.

To take contour integration into account, seven different test images were created that showed contours with varying degrees of fragmentation. The subjects' recognition threshold was determined for each of these test images, and the average contrast at which the contour was still recognized was then calculated. As a result of the study, well-connected lines and shapes are more recognizable than non-connected ones. The determined contrast threshold varies significantly between the individual test images. The generalized eta squared, a statistic quantifier, was calculated for the test images and showed a large effect size of 0.774.

With the help of the results obtained within the study, Schier's contrast threshold prediction model can be validated on the use case of an automotive application. This validation is intended to evaluate the performance of the model as well as to check the model's suitability for a real application.

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