Optical Performance of Exterior Displays

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Autonomous cars will populate roads soon and inform e.g. pedestrians by exterior displays, which raises acceptance. They raise traffic safety as well for manual driving. We build a full-scale movable mock-up with RGB LEDs matrix and e-paper displays. Optical measurements and evaluations were performed. A 35” RGB LED display (128 x 64, 6 mm pixel pitch) and animated icons showed best results.

1 Introduction

Future cars will drive autonomously and share traffic with manually controlled cars and others road users, e.g. pedestrians. Authorities will demand to visualize the status of an autonomously driving car. Most importantly, exterior displays support acceptance in mixed traffic scenarios as well as manual driving.

Many prototypes and research vehicles have been presented and evaluated. Most approaches use text-based messages or tiny symbols in combination with relatively low resolution and/or small displays (Fig. 1). An important use case is a crosswalk (left). In addition, following traffic can be warned via a rear display (Fig. 1 right) which raises safety.

Fig. 1 *Examples of front and rear display demonstrators.*

A good basis for the systems design of exterior displays are electronic road signs e.g. acc. EN 12966 [1] which is proven and accepted. Further details and evaluations of our project can be found in [2].

2 Mock-Up for Exterior Displays

We have designed and built a movable battery-powered full-scale mock-up (Fig. 2) for front and rear displays with a width of 80 cm and a height of 40 cm. This covers relevant “classes” of EN 12966 [1].

The selected RGB LED matrix has a pixel pitch of 6 mm, which results in a resolution of 128 x 64 (h x v). The demonstrator enables all relevant tests such as readability vs. icon size, text height and distance, benefits of blinking. Other displays such as RGB LEDs tiles with 3 and 4 mm pixel pitch and monochrome and color e-paper displays were evaluated as well for optical and subject evaluation.

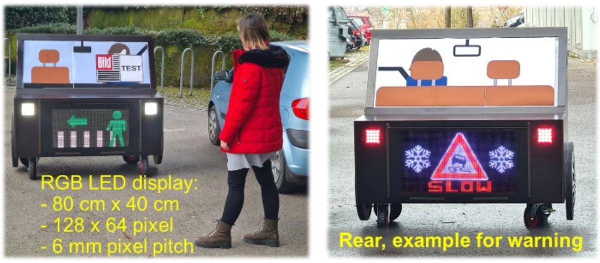

Fig. 2 *Our demonstrator for measurements and evaluation for bright light performance and size vs. distance.*

We investigated three typical use cases:

1) A “pedestrian” waits at a crosswalk and has the right to pass. It is easy to imagine that the person might feel uncomfortable when an (autonomous) car is approaching without visual communication with the “driver” (Fig. 2 left).
2) “Oncoming vehicle”: This is the most challenging use case for front displays as the speed of two cars decreases the duration of observation. An example is a rural road at 72 km/h (20 m/s) which results in 1 s for 40 m distance.
3) A “following vehicle” (Fig. 2 right) is the “easiest” use case in terms of readability as the relative speed of the two cars driving in the same direction usually does not differ much. It is used for warnings such as “slippery road”, “I will stop” and information (front display @ parking).

3 Optical Performance at Bright Light

Fig. 3 shows the ambient light performance measurements set-ups used: The left side visualizes the EN 12966 approach, which defines only a non-specular (diffuse) geometry; we used an angle of 5°. For the LED displays, we measured additionally with this set-up the specular reflection by moving the measurements device by 5° to the right.

A sampling (integrating) sphere (Fig. 3 right) was used for the color filter array (CFA) e-paper display to evaluate the influence of the two measurements procedures “specular included” (SCI, white diffuse) and “specular excluded” (SCE, black light trap).

DGaO Proceedings 2022 – *http://www.dgao-proceedings.de* – ISSN: 1614-8436 – urn:nbn:de:0287-2022-B006-6

submitted: 13.07.2022 published: 05.09.2022

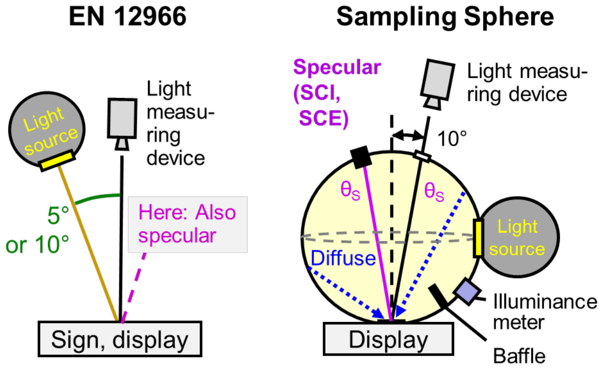

***Fig. 3** Set-ups used for bright light measurements: Modified traffic standard (left) and sampling sphere (right).*

The results of those measurements are listed in Tab. 1: The two e-paper displays show good results for readability with a reflectance of about 50% and a contrast ratio being 10:1. The RGB LEDs matrix displays are “CE” types and not optimized for bright light use. The diffuse reflectance is in the range of a few percent; 16 % to 29 % is reached for specular geometry. This results in a relatively low contrast ratio in the range of 4:1 (limit of EN 12966) for 15,000 lx for a normalized luminance of 1,000 cd/m².

Display	Reflectance of White		Ambient Contrast Ratio	
Monochrome e-paper	55 %		10 : 1 (diffuse)	
Color e-paper (CFA)	43 %		9 : 1 (diffuse)	
LED RGB matrix (reference for 1,000 cd/m²)	**Diffuse** (LED off)	**Specular** (LED off)	**Diffuse** @ 15 klx	**Specular** @ 15 klx
3 mm	1.5 %	24 %	60 : 1	3.9 : 1
4 mm	1.6 %	16 %	44 : 1	4.3 : 1
6 mm	3.3 %	29 %	31 : 1	3.5 : 1

***Tab. 1** Comparison of bright light performance.*

Color performance is as well important for exterior displays as they should grab attention and most traffic signs consist of colored symbols. The CIE 1976 UCS color chart on the left of Fig. 4 shows the relatively small color gamut of the e-paper display incl. a photo of the RGBCMYWK. The performance was as well evaluated by subjects and rated as poor and insufficient. The RGB LED gamut is large, exceeds most TV standards, and fulfills traffic standards.

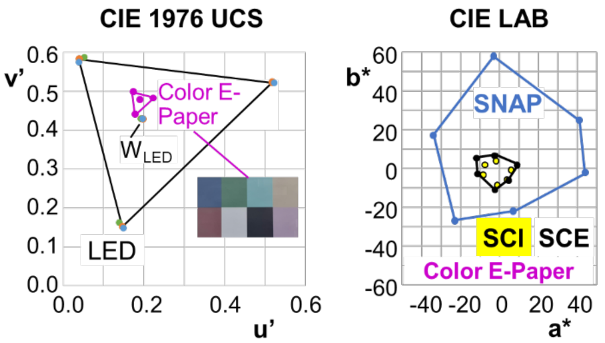

***Fig. 4** CIE color measurements for RGB LEDs and color filter array (CFA) e-paper (right: comparison to SNAP).*

The CIE LAB chart on the right side of Fig. 4 provides a further comparison of the color performance of the CFA e-paper. This color space is used in the printing industry; SNAP is the reference for newspapers. The gamut of the CFA display is just about 10% of SNAP for SCE and even smaller for SCI. Our findings prove that CFA e-paper displays are hardly suitable for exterior displays.

4 Summary

Exterior displays will raise traffic safety and acceptance (autonomous cars). We built a full-size prototype with a large RGB LED display for front and rear content evaluation and measurements:

- The display height of 40 cm and a width of 80 cm represents a reasonable compromise between design, integration, and readability. It was used for displaying signs, icons and text.
- RGB LED matrix displays are superior to reflective technologies because of their wide color gamut and attention-grabbing flashing capability. The luminance should be at least 3,000 cd/m² (similar to EN 12966 at 40,000 lx). A pixel pitch of 6 mm is perceived as somewhat pixelated at distances of less than 6 m.
- Ambient light measurements were performed for three emissive LED and two reflective e-paper displays. All displays proved their sunlight performance by high reflectance of e-paper and low reflectance (and high luminance for white) for the LED displays. The color gamut is large for RGB LEDs but too small for e-paper (only ~10% of newspaper printing standard SNAP).
- Subjects preferred LED displays instead e-paper displays. The color rendering of the latter was judged as being poor; a white background was preferred also for monochrome. A suitable application for e-paper is license plates.
- Studies with subjects showed that they could read the RGB LED display for typical content from 30 to 60+m maximum distance, which covers the three use cases.

Our findings help to design and implement exterior displays with optimized user information for different types of vehicles from cars to commercial versions. This increases the acceptance of autonomous cars for pedestrians and raises safety when mounted on vehicles by providing information and warnings.

References

[1] European Standard EN 12966-1 “Vertical road signs” http://www.sinaldetransito.com.br/normas/pmv_en_12966_1.pdf (accessed May 23, 2022).

[2] N. Nowak, K. Blankenbach: “Design, Measurements, and Evaluation of Exterior Displays for Autonomous Cars,” in *SID International Symposium 2022, Digest of Technical Papers* **53**:669-672 (2022)