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Automotive Exterior Displays: System Parameters and Technologies to Improve Traffic Safety

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ABSTRACT

Autonomous driving will change traffic behavior: Visual communication with a "driver" is not feasible, especially for pedestrians. Exterior displays can fill this gap and raise traffic safety incl. manual driving. We report on use cases, ambient light measurements, display size and technologies and evaluations with subjects for symbols and readability.

1 Introduction

The automotive industry sees a huge trend to autonomous driving. However, many traffic situations relay on the visual communication with other road users such as a hand wave gesture. Visual information is as well established since long time by e.g., traffic lights and break lights. Displays can support autonomous driving [1] by signaling of this driving mode or warnings. Examples of exterior displays (see Fig. 1) of various sizes and resolutions have been presented for front and rear.

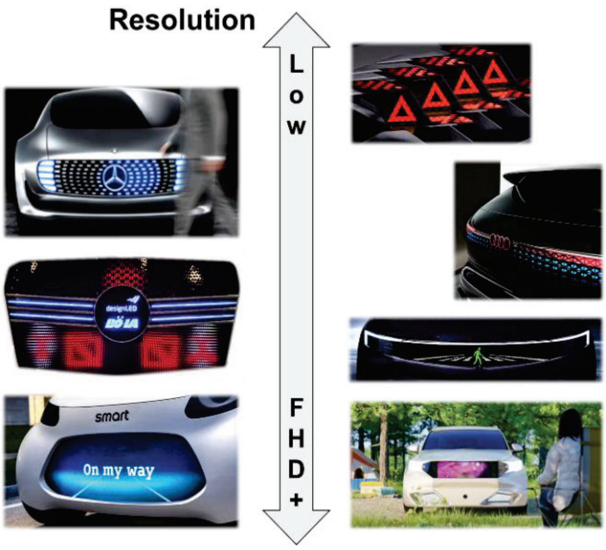

Fig. 1 Examples of exterior car displays vs. resolution by Mercedes, OLED Works, Audi, Forvia, Stellantis, Hyundai.

Fig. 2 shows applications of exterior displays for public transportation (left and center) and information (right) of important traffic messages beside advertisements (financing these systems). The bus destination display including the related standards provide as well proven recommendations for the character height of exterior displays for "reasonable" readability. Beside the graphics examples in Fig. 1, numerous demonstrators with text-only visualizations (Fig. 3) have been presented. All those activities were the motivation for our work on size, pixel pitch, display technologies and readability of exterior displays.

Fig. 2 Examples of public exterior displays with low to high resolution; sources: Toyota, RoadAds.

Fig. 3 Examples of exterior displays for text; sources: Toyota, Matsunaga et al. [2].

2 Use Cases for Exterior Displays

We started with the definition of use cases in Table 1 incl. the typical maximum values for the effective speed for an observer and its longest distance to the display.

Table 1 Selected use cases for exterior displays

Use Case	Description	Speed	Distance
Pedestrian	"Safe to cross"	< 50 km/h	< 50 m
Following car	Warnings, e.g., slippery road	< 20 km/h	< 50 m
Oncoming car	Warnings, e.g., jam or icy road	< 200 km/h	< 100 m
Shared ride*	"Available", "reserved" …	0 km/h	< 10 m
Operational data*	State-of-charge …	< 10 km/h	< 10 m
Entertainment*	Video, beat …	0 km/h	< 10 m
License plate*	Identification …	< 10 km/h	< 20 m

* Not discussed here

However, exterior display systems are more than just mounting those devices to a car as Fig. 4 visualizes: Such display systems are determined by use cases and must be readable at all lighting conditions incl. good color reproduction (traffic signs). Their GUI content must be easily understandable for everybody and grab attention by e.g., flashing. So, evaluations with subject on symbols etc. must be performed (see below). Other topics are the integration into cars incl. stylish design and crash-safe integration. Furthermore, reasonable use cases must be defined and derive display parameters according to the observer parameters.

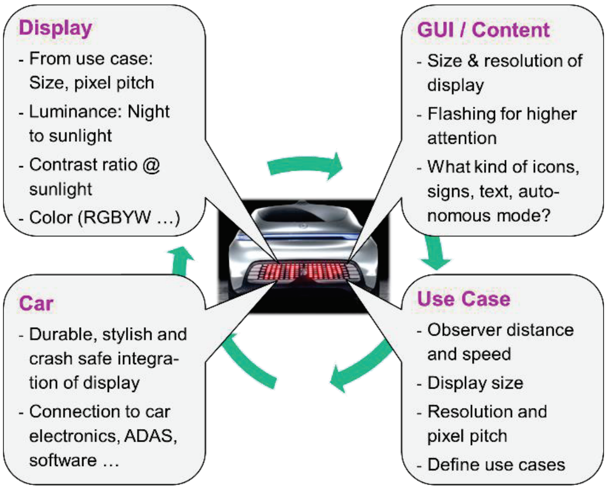

Fig. 4 System aspects of exterior displays.

There are many uses cases for exterior displays possible from safety-relevant topics over operational data (e.g., state-of-charge) to fun (beat mode, watching a video). We investigated three important uses cases of Table 1 for our work (see Fig. 5):

(1) Pedestrian crosswalk: Today's visual communication with the driver of an approaching car has to be replaced by a display for autonomous vehicles (Fig. 10 left). The typical distance to read the display range from 60 m down to 2 m with a duration of typically more than 10 s.

(2) "Following vehicle": This is the "easiest" use case in terms of readability because the relative speed of the two cars driving in the same direction does not differ much. A rear display can be used for the information of the autonomous driving mode or for warnings such as "slippery road" (Fig. 10 right) and information (e.g., "break down").

(3) "Oncoming vehicle": As the relative speed of approaching cars is high, the duration for reading the content of an exterior displays is the lowest of all three uses cases. An example is a rural road at 72 km/h (20 m/s) which results in 1 s for 40 m distance. Therefore, the height should be as large as possible (40 cm can be read at ~150 m distance).

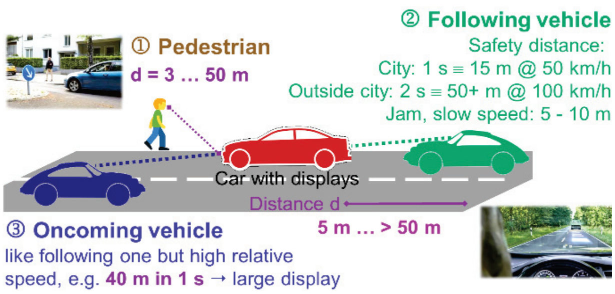

Fig. 5 Three important use cases for exterior displays which were examined more in detail in this paper.

3 Optical Measurements and Display Evaluation

Beside the common automotive requirements, exterior displays have to deal with sunlight. Therefore, projection is not an option as those systems are limited to night drive. We compared RGB LEDs and reflective e-paper. LCDs do not make much sense as the resolution in unnecessarily high for typical viewing distances (see Table 1) and high luminance is hard to achieve. RGB LEDs are easiest to customize and many show cars (Fig. 1, Fig. 2) relay on that. Furthermore, they are very widespread in "Variable (Traffic) Message Signs" (VMS) and well defined (e.g., EN12966 [3]) for e.g., size and symbol height depending on speed and type of the road.

The pixel pitch of LED-based VMS is 10 mm to 50 mm depending on the road type and speed. The use case ① "pedestrian crossing" has a minimum distance of 2 m to 3 m. To evaluate a reasonable pixel pitch, we conducted a survey with 14 participants which had to judge on the perceived pixelation and readability of three RGB LED tiles with pixel pitches of 3 mm, 4 mm, and 6 mm (Fig. 6 left). The right side of Fig. 6 show the typical rendering of color signs for VMS.

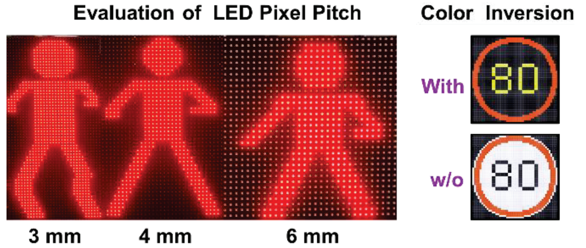

Fig. 6 RGB LED displays for evaluation of pixel pitch and optical measurements (left, higher reflectance of the 6 mm display) and reproduction methods of traffic signs (right).

The subjects had to judge on the perceived pixilation with a rating scale of 1 to 5 (1: disturbing, 5: pixelation is hardly perceived) for observer distances of 3, 6 and 12 m. Longer distances were not investigated as the visual acuity distance for 3 mm pixel spacing is 10 m [4]. All content on the displays (Fig. 6 left) were set to the same height (minor differences in horizontal width). The displays were placed side by side to allow judgments on differences to be perceived at a glance.

The results are plotted in Fig. 7 as mean values: The pixelation of the display with 6 mm pixel pitch is comparatively perceived as more disturbing at all distances. However, the readability of symbols and text is barely affected by the 6 mm pixel pitch display. We conducted all further tests with 6 mm since most of the use cases involve long distances.

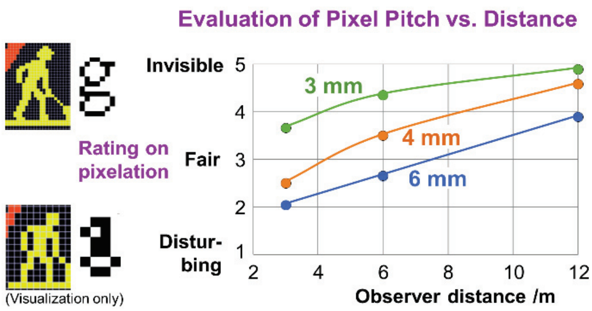

Fig. 7 Evaluation of the perception of symbol depending on pixel pitch (Fig. 6) and distance.

In the next step we measured the reflectance and ambient contrast ratio of our three RGB LEDs displays with a modified EN 12966 set-up (specular geometry added, more details see [5]). The results are listed in Table 2: The specular reflectance is about one order larger than the diffuse value. That is mostly due to the glossy paint and the white diffuse reflector cup of the LEDs. The ambient light contrast ratio (ACR) is normalized here for 1,000 cd/m² and a typical road illuminated by 15,000 lx [3]. All three CE LED displays are in the range of the threshold “4:1” of EN12966 for these conditions. However, this standard refers only to diffuse measurements and the luminance of any display at 15,000 lx should be at least 2,000 cd/m². In consequence this verifies the use of these displays for visual assessment outdoors.

Table 2 Measurement results for RGB LEDs for reflectance and ambient contrast ratio acc. EN12966.

Pixel Pitch of RGB LEDs	Reflectance of Black (LED off)		Ambient Contrast Ratio (ACR)	
ACR normalized to 1,000 cd/m²	Diffuse	Specu-lar	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

The 3D chart in Fig. 8 shows the visibility (≡ legibility and readability) for distances from 10 to 60 m and the display’s contrast ratio. The chart is based on the formula provided in [6], which was parametrized to our displays. A contrast ratio of 5:1 results then in a reasonable visibility level of 5 for up to 60 m.

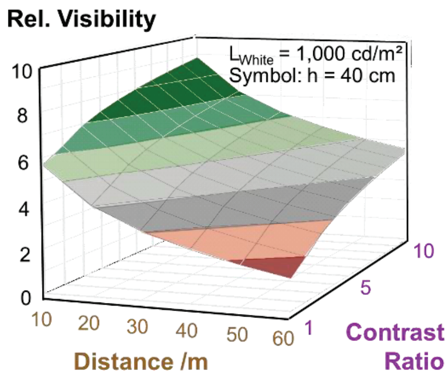

Fig. 8 Visibility (readability, >4 is acceptable) vs. observer distance and ambient contrast ratio acc. [6].

E-paper is basically suitable for outdoor applications. We made an additional evaluation with subjects regarding color reproduction (Fig. 9) of color e-paper and color mode. The participants preferred symbols on a white background (without color inversion, Fig. 6 right) more than on a black background (no color inversion). Due to the poor color reproduction of the color filter array (CFA) e-paper, participants ranked black and white icons over the colored ones. However, monochrome e-paper is not suitable as no warning color (red) is possible.

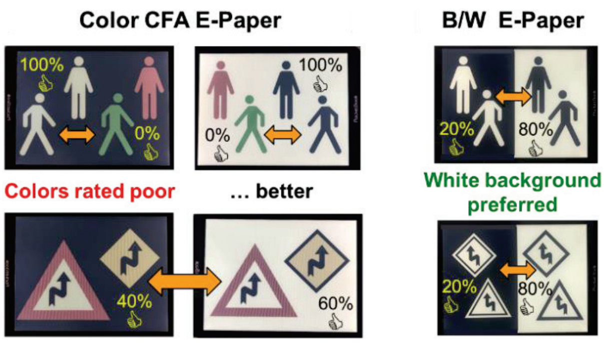

Fig. 9 Evaluation of symbol reproduction depending on background for color and monochrome e-paper. The numbers refer to the mean values of the subjects.

4 Mock-Up and Evaluations with Subjects

We built a battery powered moveable (up to pedestrian speed) mock-up (Fig. 10) for the evaluation of the LED display and its content in a close-to-real scenario. As height is a main factor for readability vs. distance here, 40 cm is a reasonable compromise for the use cases of Table 1 and well evaluated standards of traffic signs (e.g., [3]). An aspect ratio of 2:1 (80 cm x 40 cm) is good for the preferred visualizations acc. to Fig. 11. The pixel pitch of 6 mm (see Fig. 7) is also sufficient for a font height of 10 cm (like license plates) as resulting in 16 pixels for this height. We could easily change between front (left) and rear (right) display by just replacing the poster in “windshield” and putting a red color filter in front of the lamps.

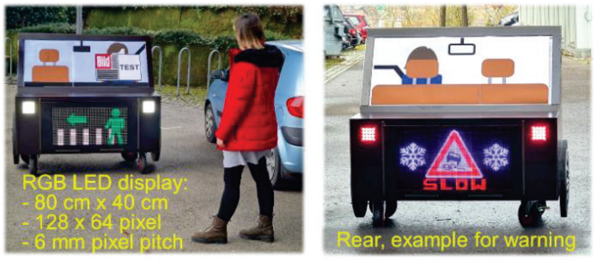

Fig. 10 Full-scale moveable mock-up with RGB LED matrix display used for evaluation with subjects. Front (left) and rear (right) simulation is performed by the poster in the “windshield” and filters for lights.

In parallel we started with an online survey involving 117 participants to evaluate the best design of symbols and text (Fig. 11) for an 80 cm x 40 cm display. Traffic signs are a good approach for exterior displays as being well known.

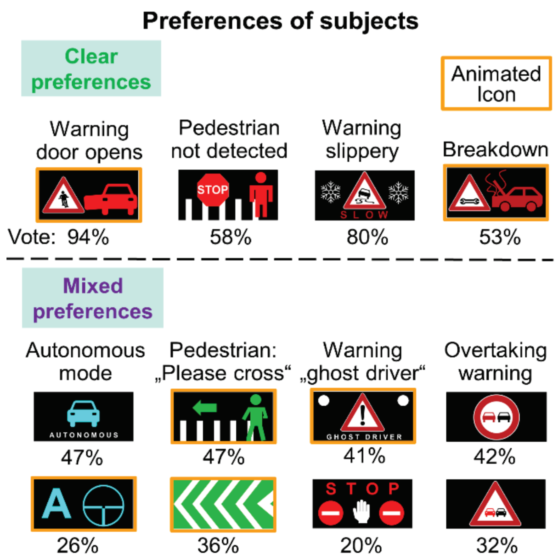

Fig. 11 Preferences of the survey for eight visualizations with three choices each. Orange frame: Animated.

The participants had eight scenarios with typically three different visualizations e.g., "you are driving in a narrow street, and a vehicle door opens in front of you” to rank. Animated icons (visualized by orange frame) were preferred for warnings.

The top of Fig. 11 shows uses cases with a clear preference (> 30% to the second one) by the participants over the other proposals (not shown). The bottom visualizes designs with less clear ratings but text helps definitively for non-standard symbols.

The evaluation using the mock-up started with a readability test (Fig. 12) for 27 subjects. The distance for the two heights of text (10 and 20 cm, left) and the symbol (20 cm) when it becomes “clearly readable” was measured. All participants were easily able to read the text from a distance of 65 m, 10 cm height was rated slightly difficult here. The “safe” distance for reading was 35 m. Rain and night reduce the distance by about 30%. For subjects being older than 60 years the readability distances are reduced by about 15% compared to young people (20-30 years) The warning symbol was identified from 40+ m distance but the meaning “need repair” resulted in only 30 m due to the rendering by only a few pixels in height (pixel pitch of 6 mm).

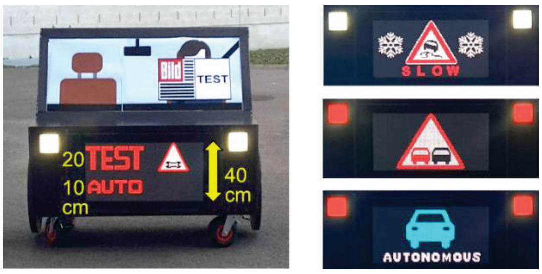

Fig. 12 Test images for distance-dependent readability tests for text and symbols for front and rear use cases.

The “pedestrian” use case (Fig. 14) lead to mixed results due to the less realistic approaching speed of the mock-up (text see [2]). We asked as well for the intuitiveness of the content shown. All symbols except for the “orange person” (“what should I do now?”) were rated as “very clear in its meaning”. All participants stated that they want to have such a front display.

5 E/E Integration of Exterior Displays in Cars

There are various methods how to integrate exterior displays into the electrical and electronics (E/E) system of cars such as display domain controllers, head units and “smart displays” (for distant displays). System design requirements as “easy to integrate” into manual and autonomous cars, low update rate of the content etc. and discussions with the automotive industry results in the “smart display” proposal which is shown in Fig. 13.

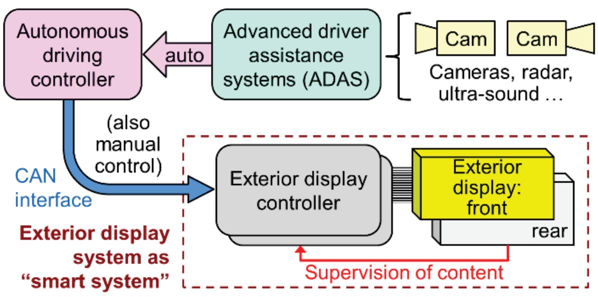

Fig. 13 Car integration concept for exterior displays.

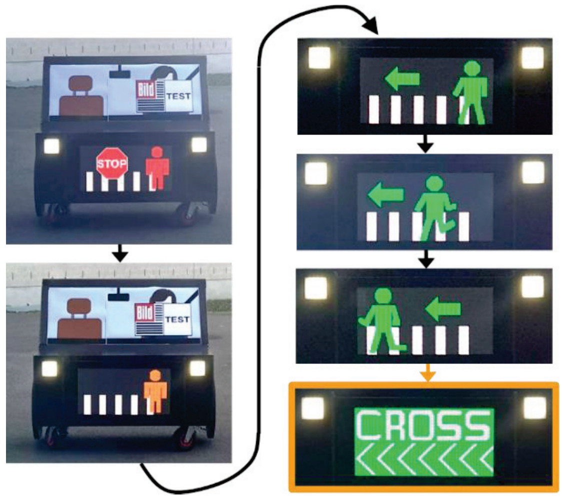

Fig. 14 Symbols used to evaluate “pedestrian crossing” from “do not cross” (top left) over “attention” (orange, bottom left) to animated stimulation to cross (top right). The animated “cross” with chevrons (bottom right) is a prompt to start crossing if the pedestrian is hesitating.

6 Summary

Exterior displays raise traffic safety for both manual driven and autonomous cars. Much effort has to be made for standardization, see e.g., [1] incl. “Japan's View on External Signaling” by MLIT, Japan. We have built an automotive exterior display mock-up and evaluated displays and content:

- The size of an exterior display of 80 cm by 40 cm is a reasonable compromise regarding readability up to 60 m.
- RGB LED matrix displays are superior to color e-paper due to their larger color gamut and ability to animations. A pixel pitch of 6 mm provides a good legibility.
- Content should base on familiar traffic symbols incl. text; animated icons help to grab attention for warnings.
- Evaluations resulted in a height of 10 cm for text and 30 cm for symbols except for oncoming cars (use case ③).

Our findings help to design and implement exterior displays with optimized user information for various use cases of autonomous cars. This raises acceptance by pedestrians and improves traffic safety for oncoming or following cars.

References

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