

Exterior Displays and HMIs for autonomous Cars: Challenges and Solutions to Raise Traffic Safety



Source: Hyundai MOBIS

Karlheinz Blankenbach

Pforzheim University | www.displaylab.org | kb@displaylabor.de

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 **CAR.HMI**
EUROPE

Karlheinz Blankenbach

- Full professor @ Pforzheim University
- Info: www.displaylab.org
- Society for Information Display (www.sid.org)
 - "Automotive Displays & HMI"
 - Display metrology (ICDM)



- Honorary president DFF (www.displayforum.de)



- Chairman  **electronicdisplays** Conference

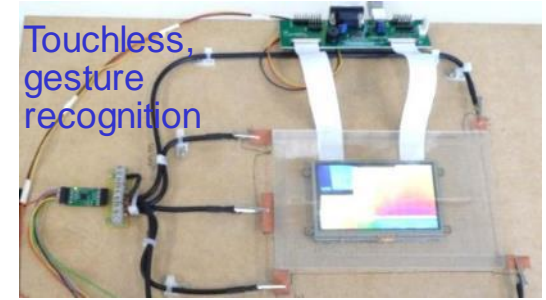
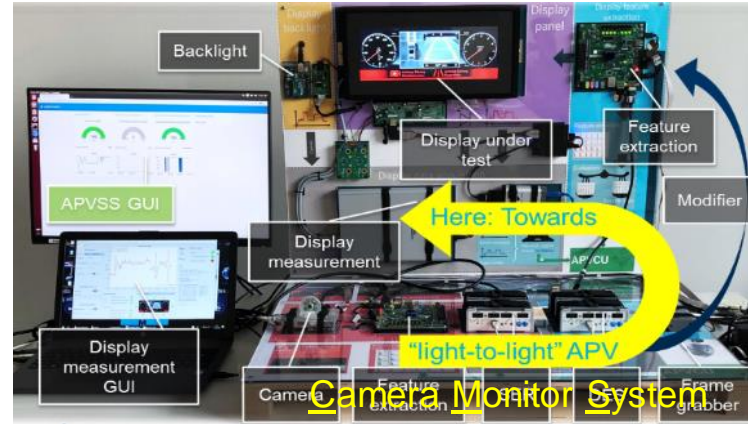
- Member of  **ELED** automotive interior lighting

Activities @ Display Lab

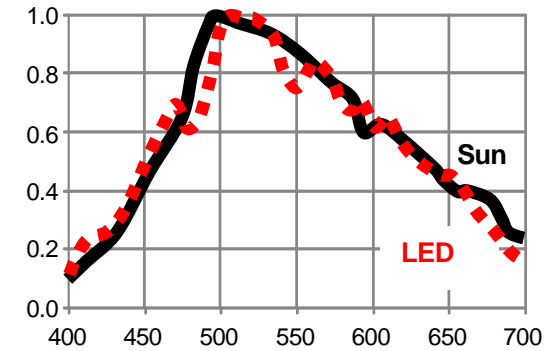
- Applied R&D 'around' displays, LEDs ...
- Funded by BMBF, BW, industry ...
- Many references
- Consultancy
- Workshops ...

We prototype and/or evaluate your display, HMI or idea!

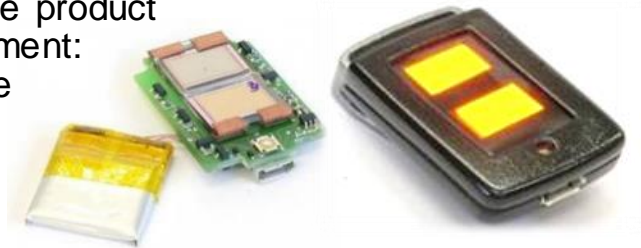
Examples of Projects



Touchless, gesture recognition



Complete product development: wearable OLED signs



Uniformity



Evaluation



Overview

Introduction

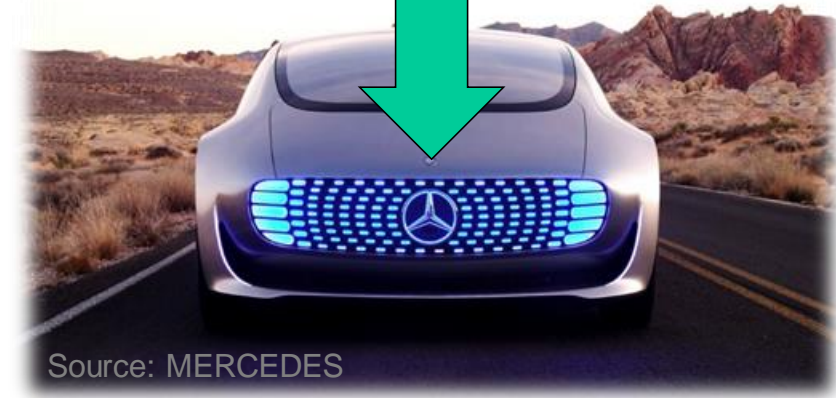
Use Cases & Mock-Up

Evaluation by Subjects

Summary



- Visual communication in traffic has a long history
- Examples: Direction indicators (incl. animated), brake lights, hazard lights, headlight flasher, traffic lights ...
- Why not evolving from a few to many pixels (display)?



Source: MERCEDES

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- Exterior displays create acceptance for autonomous driving
- From show cars to mock-up

• Autonomous cars are slower than manual driven ones!

• Pedestrian crossing: Will the car stop?



Source: Toyota, Pforzheim University

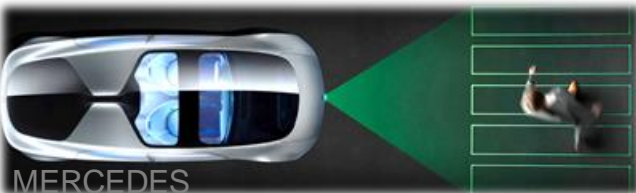
Exterior Displays: Information, Notifications, Safety ...

Exterior displays raise traffic safety!

and comfort ...



Front Displays



- Mostly low resolution
- Projection limited to night

Rear Displays



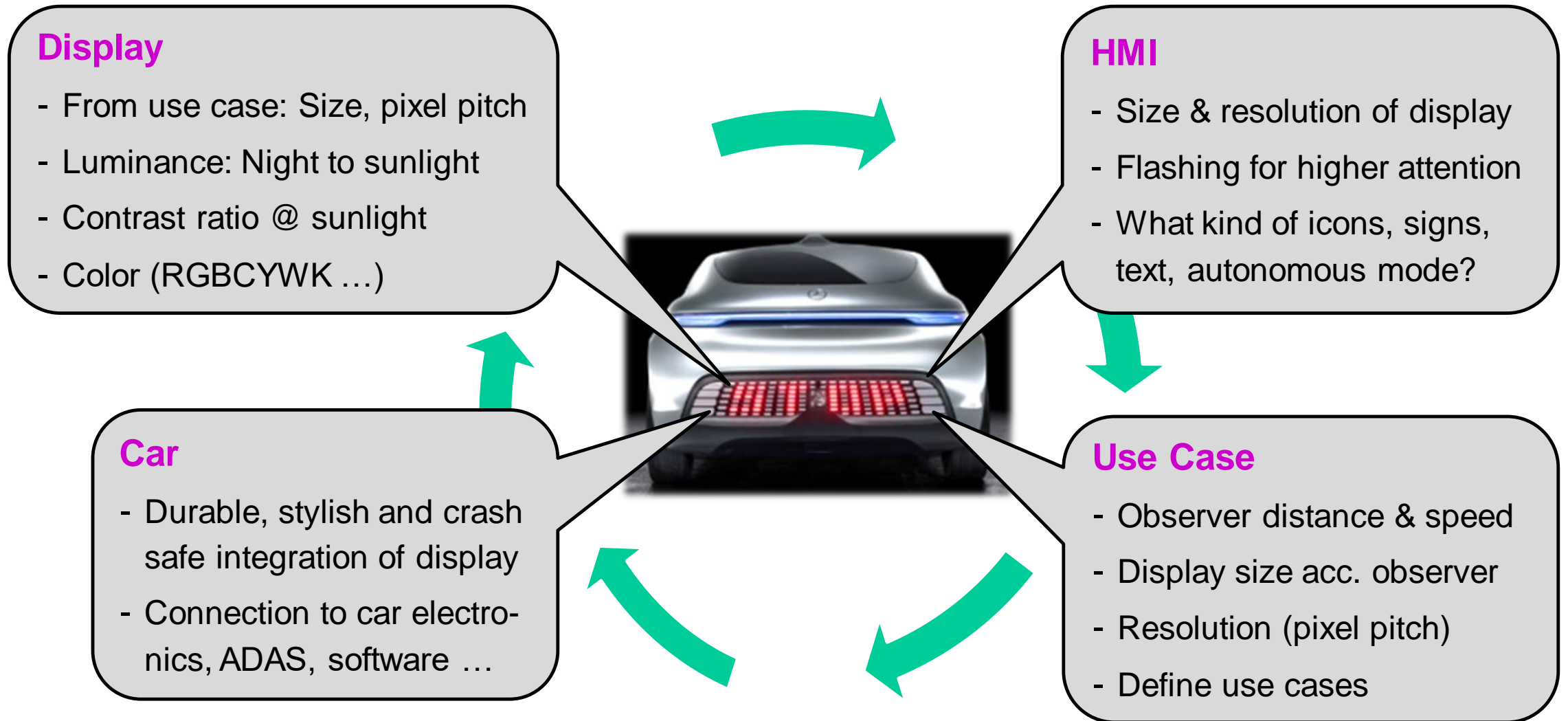
- Easier to integrate than front
- Low resolution, "tiny"

"Public" Displays



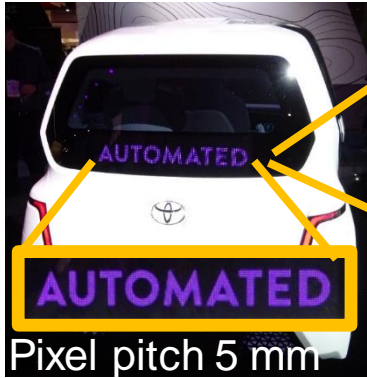
- Well known for public transportation
- Text size of busses as basis for exterior car displays

Exterior Display Systems



From Prototypes, Busses & Road Signs to Mock-Up Design

R&D Cars with Small Displays



WATCH OUT!

Black Panel effect

HAPPY BIRTHDAY!

RGB LED for text:
Height ~ 8 cm
Width ~50 cm
100 x 16 pixel



$h = 20 \text{ cm}, w = 35 \text{ cm}$

<https://doi.org/10.36463/idw.2019.1125>

“Best Practice”



“Vertical road signs” EN 12966

- Box size: 45 - 125 cm
- Font size: 10 - 40 cm
- Luminance > 3 kcd/m²
- Color (R, G, B, W ...)
- Beam width (angle)
- Type of road (speed)
- Color inversion ...

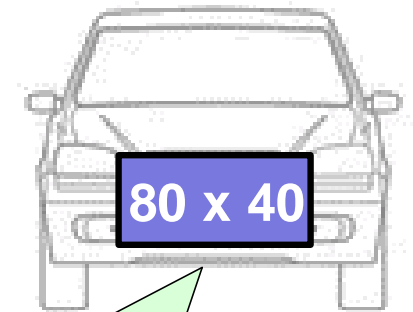
Size range	Character height h
A	100
B	160
C	240
D	320
E	400

Best practice for our display



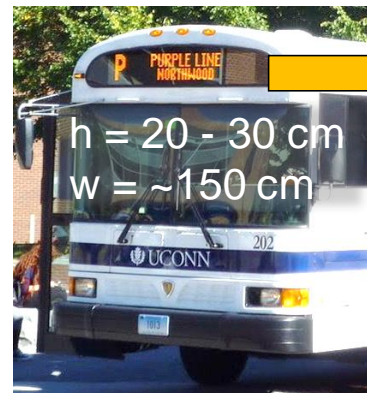
64 x 64

Size range	height a
A	450



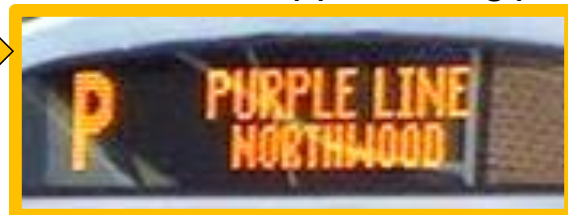
→ 80 cm x 40 cm is “reasonable” for test display

Bus Destination Displays



$h = 20 - 30 \text{ cm}$
 $w = \sim 150 \text{ cm}$

Approaching pedestrians



Character height:
Line #: 20 - 30 cm (Line “P”)
Text : 10 - 15 cm (“PURPLE LINE”)



Source: Toyota, Pforzheim University

Overview

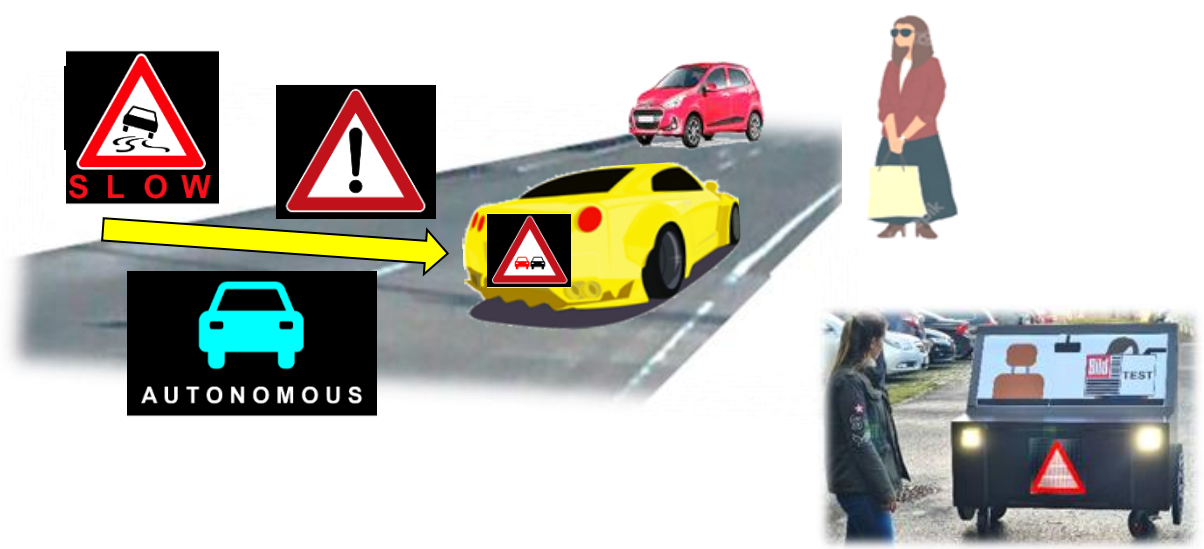
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Summary

- Geometric conditions for three use cases
- Design of mock-up



Use Cases and Distances for Exterior Displays

- Observer distance & relative speed to display for front and rear display
- This is relevant for display size, pixel pitch, resolution, angles, ...

Observer distance:
3 m ... > 50 m



① Pedestrian

$d = 3 \dots 50 \text{ m}$



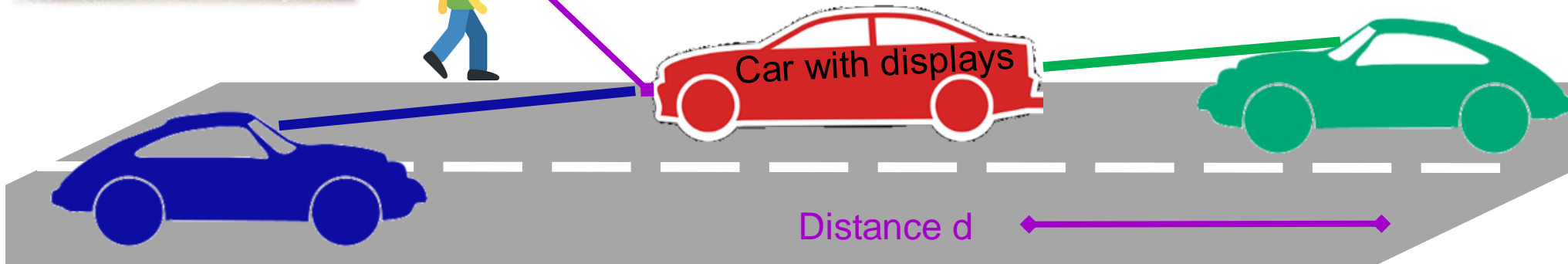
② Following vehicle

Safety distance:

City: 1 s \equiv 15 m @ 50 km/h

Outside city: 2 s \equiv 50+ m @ 100 km/h

Jam, slow speed: 5 - 10 m



$5 \text{ m} \dots > 50 \text{ m}$

③ Oncoming vehicle

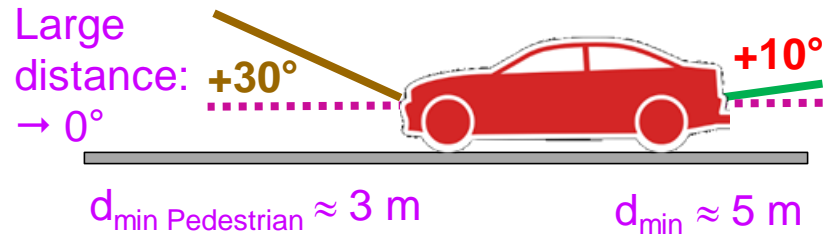
like following one but high relative speed, e.g. 40 m in 1 s \rightarrow large display

Exterior displays should be “large” like traffic signs

Geometric Conditions & LED Optimization by Secondary Optics

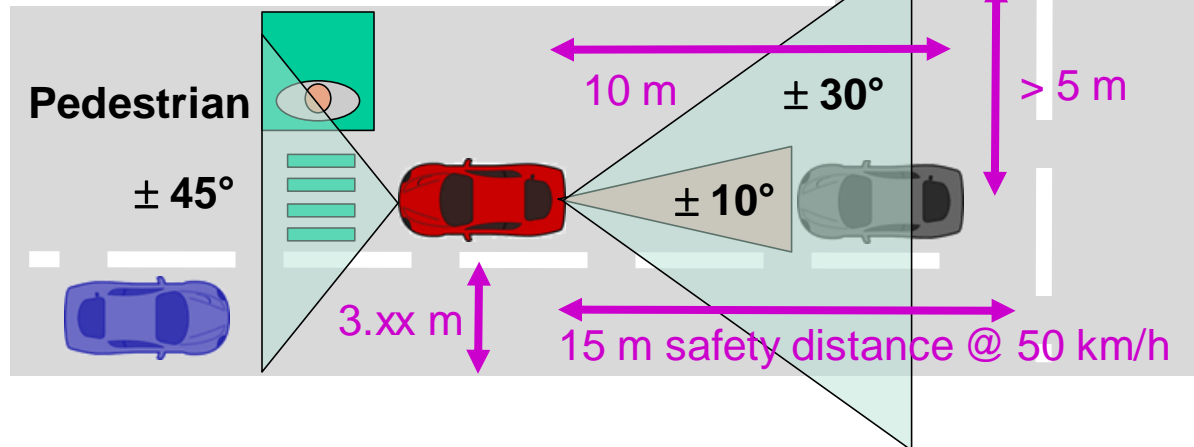
Angles & Distances for Front & Rear Display

Vertical Angles



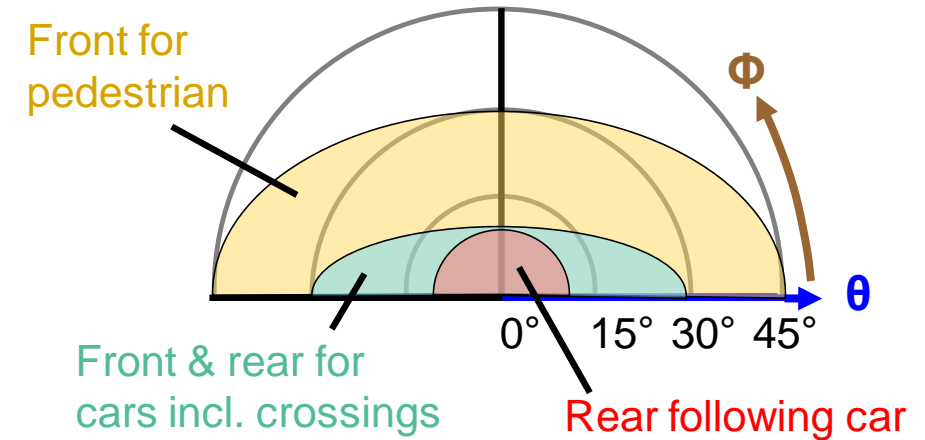
(not to scale)

Horizontal Angles



LEDs & Emission Angle Optimization

Angles are different from EN 12966 Beam Width Classes

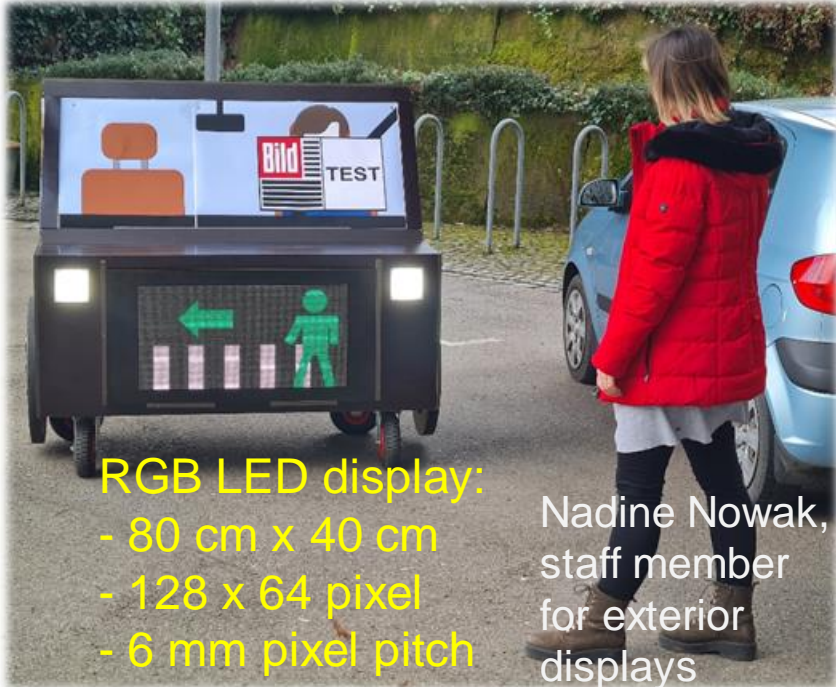


Raise of luminance by light shaping (secondary optics) compared to “standard” LED display:

- **Front** ($\pm 45^\circ$ & $0^\circ/+30^\circ$): $L \approx 5 \times L_{\text{LED Display}}$
- **Rear** ($\pm 30^\circ$ & $0^\circ/+10^\circ$): $L \approx 25 \times L_{\text{LED Display}}$
- **Following car** ($\pm 10^\circ$ & $0^\circ/+10^\circ$): $L \approx 70 \times L_{\text{LED Display}}$

Full - Scale Moveable Battery - Powered Mock - Up

Use Case ①: Pedestrian



Use case ②: Following Car



Block Diagram

Displays:
LED, e-paper

Pushbuttons,
sensors

Micro-controller

Battery
(12 V 100 Ah)

Data

- Evaluation of use cases regarding distance & symbols
- Evaluation of readability vs. distance & symbol size

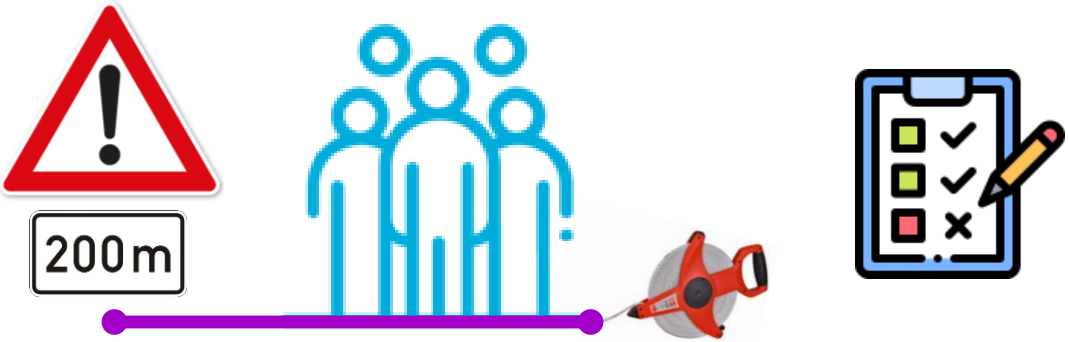
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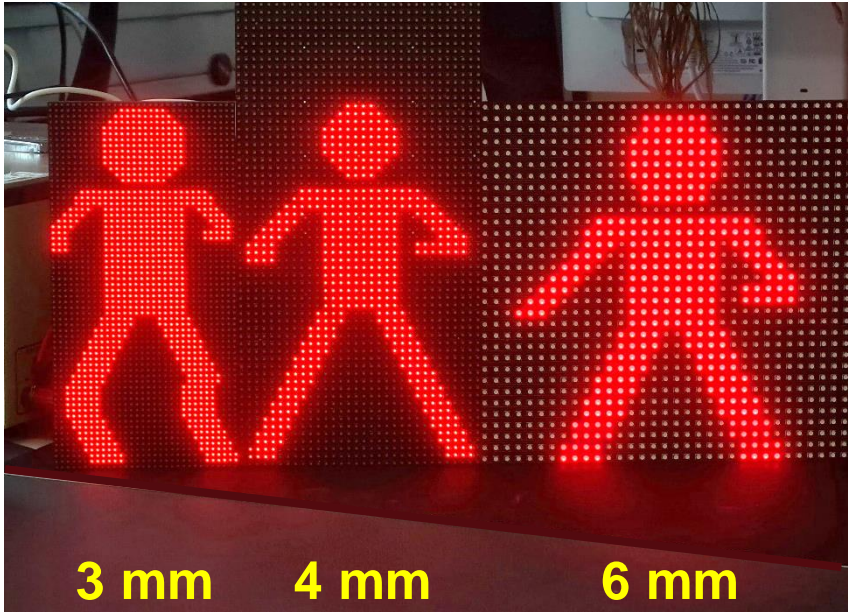
Evaluation by Subjects

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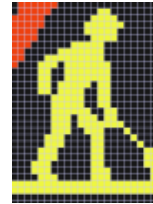


1st Step: Evaluation of LED Pixel Pitch vs. Distance

Pixel Pitch Examples



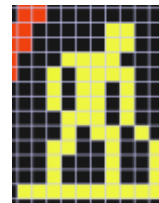
Evaluation of Pixel Pitch vs. Distance



Invisible

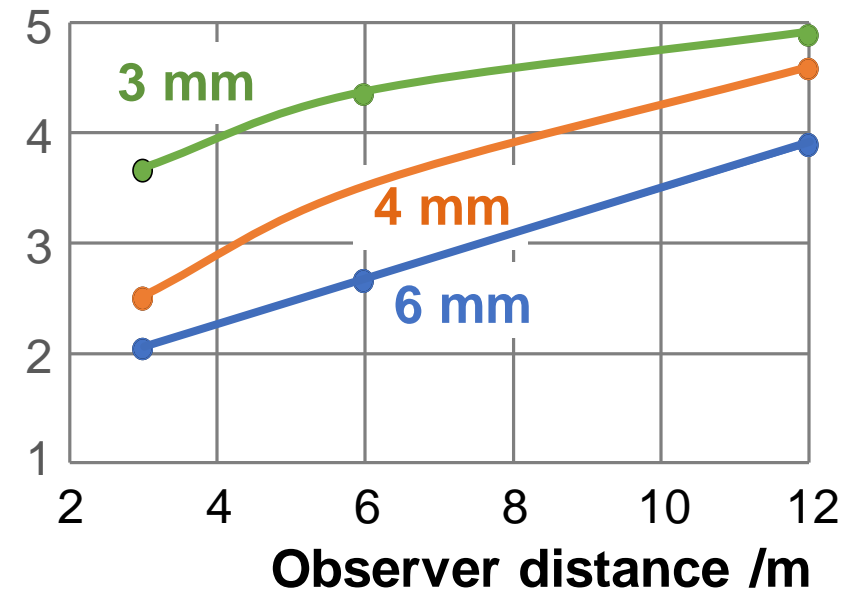
Rating on pixelation

Fair



Dis-
turbing

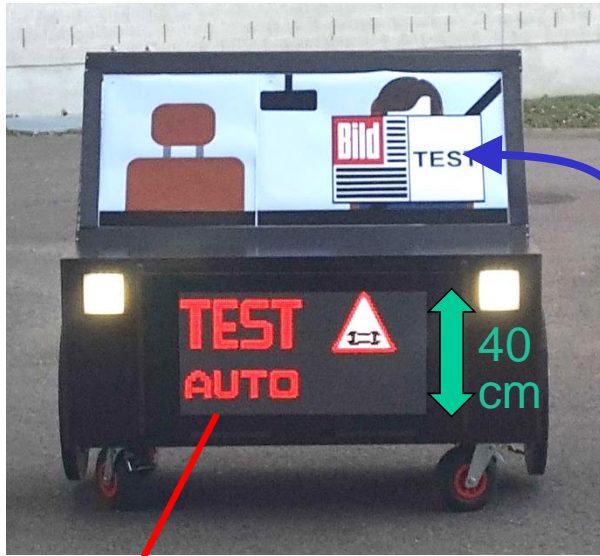
Examples, not used



- Observer distance & pixel pitch: “10x Rule”: 10 x pixel pitch (mm) = distance (feet)
- Minimum distance for pedestrians ~ 3 m → 1 mm pixel pitch for eye matching
- Exterior displays mostly large viewing distance (see above)
- Evaluation: 6 mm (EN 12966: > 10 mm) is reasonable for exterior displays

2nd Step: Evaluation with Mock - Up: Readability, Interpretation ...

Test for readability & symbols ① ② ③



Readability of text

- $h = 8.5 \text{ cm} \rightarrow (65 \pm 4) \text{ m}$
~30% less @ rain & night
- $h = 6 \text{ cm} \rightarrow (38 \pm 5) \text{ m}$
20-30 y: 50 m, 60+ y: 42 m

Recognition of "Slippery"

- Symbol: $(65 \pm 12) \text{ m}$
- "SLOW": $(48 \pm 13) \text{ m}$

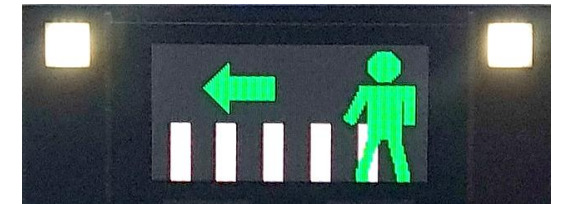
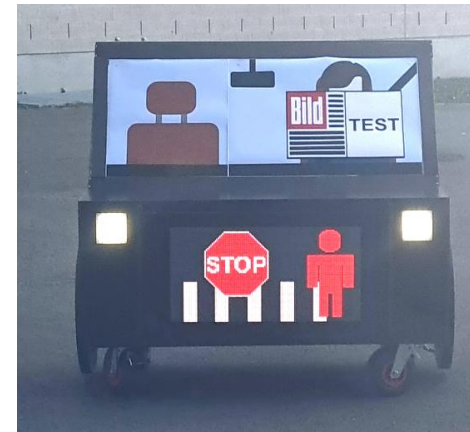
Needed for traffic monitoring by authorities

- No significant difference by gender
- All traffic signs: with $h = 40 \text{ cm}$: $d = 40+ \text{ m}$

Height of 40 cm 👍

27 participants

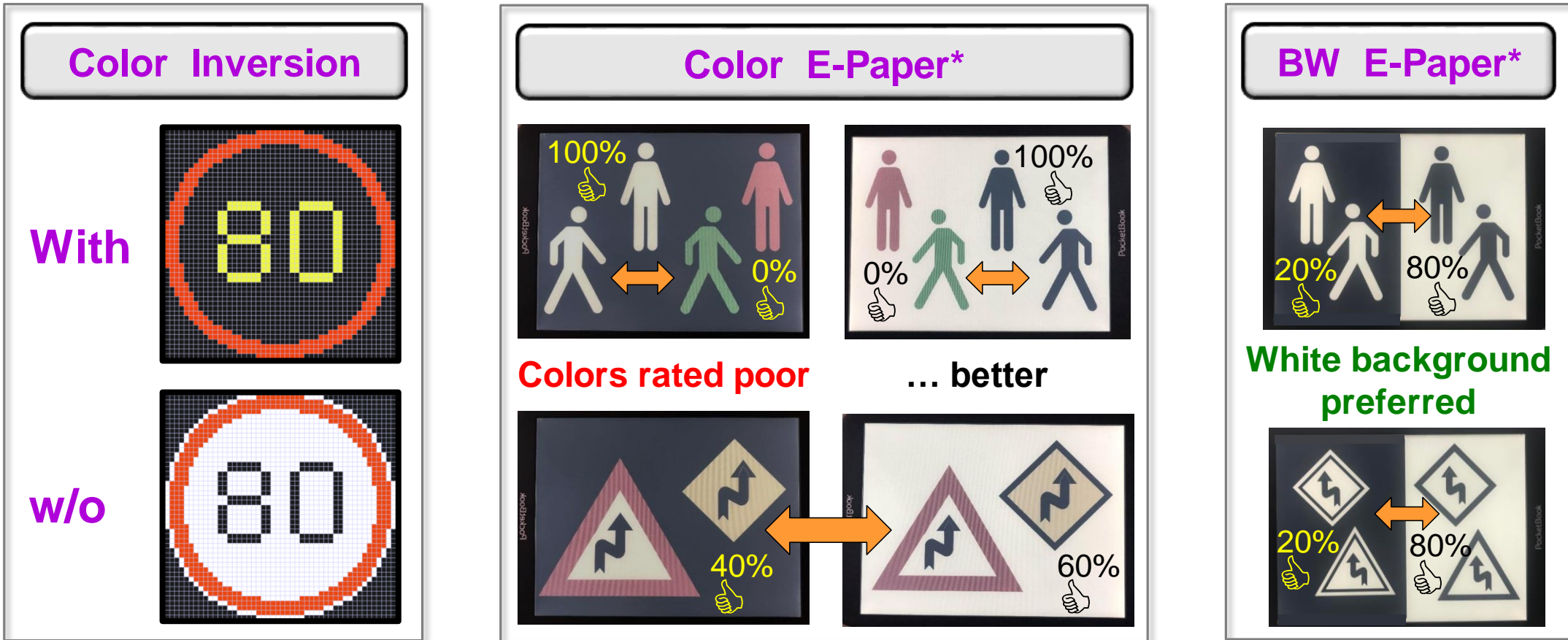
Use case ①: Pedestrian crossing



"Great", "Feel safer", "Orange ?", "I walk when car shows green person and slows down" ...

Effects of slowing down see <https://doi.org/10.36463/idw.2019.1125>

Evaluation of Inversion Mode and Color for E-Paper



- Color e-paper: Black and white icons are preferred over colored ones (“too dark for black bg”)
- Monochrome e-paper: Slightly better results due to higher reflectance
- E-paper: “No color inversion” mode preferred but challenging for car design
- RGB LEDs: With inversion (black background) judged best (simultaneous brightness contrast)





* Real photos

Exterior Displays & HMI


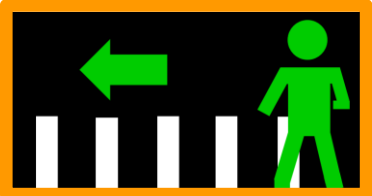






Preferences of subjects (117 participants, online, Pforzheim University Display Lab)

Animated Icon

Clear preferences

<p>Warning „door will open“</p>  <p>Vote: 94%</p>	<p>Pedestrian not detected: „please do not cross the road“</p>  <p>58%</p>	<p>Warning slippery</p>  <p>80%</p>	<p>Breakdown</p>  <p>53%</p>
--	---	--	---

Mixed preferences

<p>Autonomous mode</p>  <p>47%</p>	<p>Pedestrian detected: „please cross the road“</p>  <p>47%</p>	<p>Warning „ghost driver“</p>  <p>41%</p>	<p>Overtaking warning</p>  <p>42%</p>
 <p>26%</p>	 <p>36%</p>	 <p>20%</p>	 <p>32%</p>

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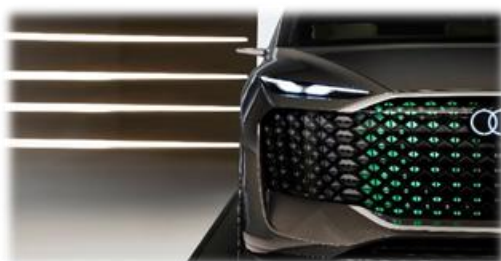
Further Use Cases & Show Cars

Hyundai MOBIS: LCD



Source: Hyundai MOBIS, <https://youtu.be/iDXowH4DuQM>

AUDI & BMW



FORVIA & designLED



Other ideas:

- State-of-charge (SoC) for electrical vehicles
- Car rental, shared ride: „Welcome Sue, this is your car“, „I’m available book me now!“ ...
- Commercials, advertisements ...

Raise traffic safety!



Raise comfort

Standards & Studies for Exterior Displays

SAE J3134:2019

Automated Driving System (ADS) Marker Lamp: Guidelines for the use, performance, installation, activation, and switching of marking lamps on ADS vehicles.

Example:

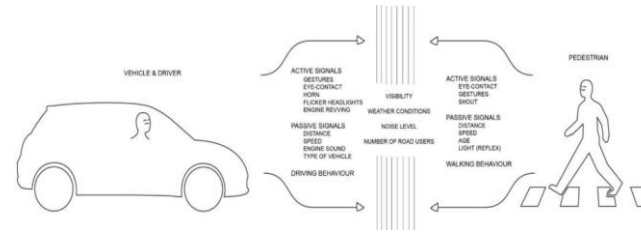
CityMobil2

1. Whether it is stopping
2. Whether it is turning
3. How fast it is going
4. Whether it is going to start moving
5. Whether it has detected me

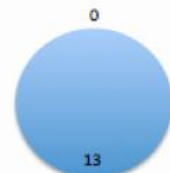
Usage of Pictorials or Symbols:

Pictorials, symbols, text, and other forms of communication are not addressed

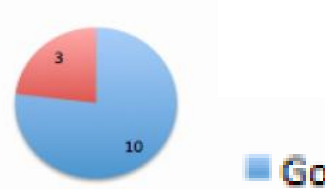
Chalmers 2015



Eyecontact



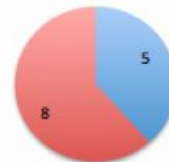
Phone



Newspaper



No Driver



AVIP - Autonomous vehicles' interaction with pedestrians;
<https://publications.lib.chalmers.se/records/fulltext/238401/238401.pdf>

BMW 2019



Results in the first round	Low beam	Low beam + guiding light
Average velocity	45.11 km/h	59.78 km/h
Summed up steering motion	6.37°	2.02°
Average steering velocity	0.39°/s	0.30°/s

M. Budanow, C. Neumann: "Road projections as a new and intuitively understandable human-machine interface," Advanced Optical Technologies, doi.org/10.1515/aot-2018-0055

UNECE GRE Task Force Autonomous Vehicle Signalling Requirements (AVSR),
 "Taskforce Autonomous Vehicle Signalling Requirements," <http://www.unece.org>

Summary

Exterior Displays

- Benefits

- Increase traffic safety!
- Pedestrians feel safer
- Many other applications such as SoC, QR, joy ...

- Challenges

- Legibility and recognition of “new” icons (standards)
- Sunlight readability
- Integration into cars

Full-Scale Mock-Up

- RGB LED Display: 80 x 40 cm², 128 x 64, 6 mm pixel pitch
- Front- & rear possible
- Sunlight readable
- Battery powered

Measurements & Evaluation

- RGB LED display is best, e-paper: License plates ↓
- Use of traffic signs
- “Pedestrians want display”
- Readability for 50+ m: Text > 10 cm, sign > 30 cm



Exterior Displays provide outstanding benefits for traffic safety!



Thank you
for your
kind attention!

HOHMANN & BRAND | HELLA DESIGN TEAM

Contact: kb@displaylabor.de

Info: www.displaylab.org

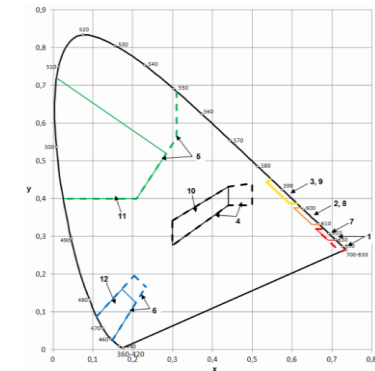
Appendix

Optical Measurements

- Ambient contrast ratio
- Color gamut



Sign illuminance (lx)	L3, L3(*)	
	$L_a(\min)$	$L_a(\max)$
40 000	3 100	9 300



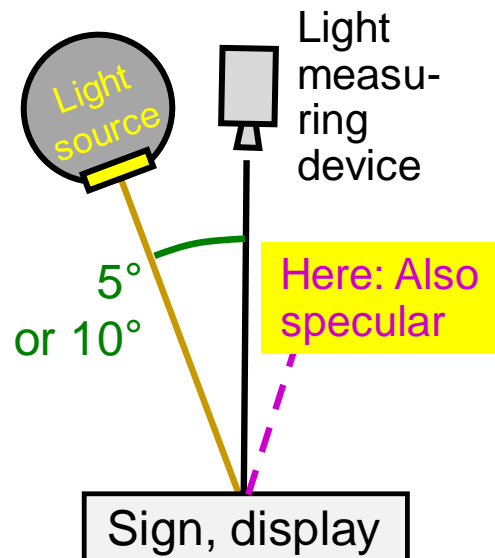
$$LR_{10} = \frac{L(0 \text{ lx})_{\text{sign on}}}{L(40 \text{ klx})_{\text{sign off}}} \geq 3 \text{ (white)}$$

EN12966

Display Reflection Measurements

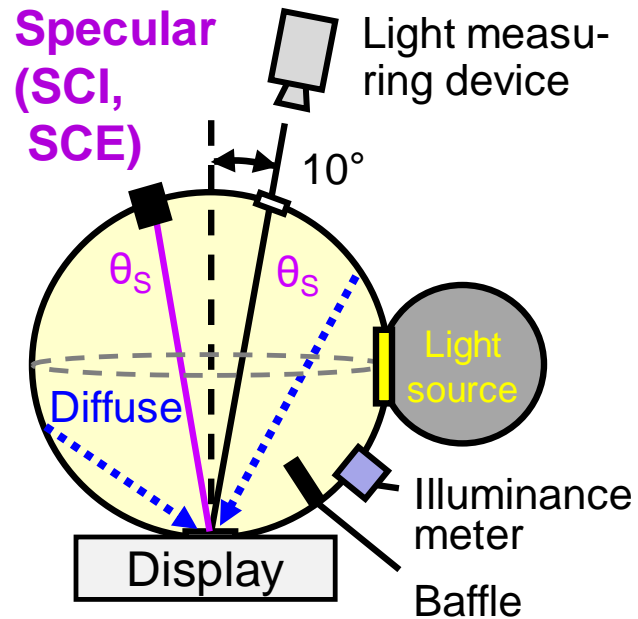
EN 12966

Standard for traffic signs



- Diffuse geometry
- Standardized for traffic signs
- Limited impact for displays

Sampling Sphere



- Standardized for displays
- Best method for evaluation of ambient light performance
- Specular in- & excluded leads to different results ↗

Effects on Contrast Ratio of Surfaces Characteristics

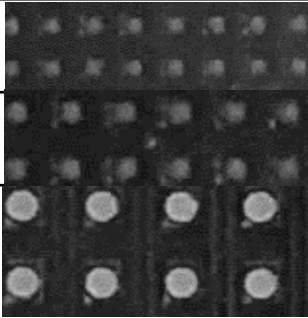
	Glossy	Matte	Rem.
Specular Included (SCI)			Reflec. higher & CR lower
Specular Excluded (SCE)			Reflec. Lower & CR higher

Cut-out

Measurement spot

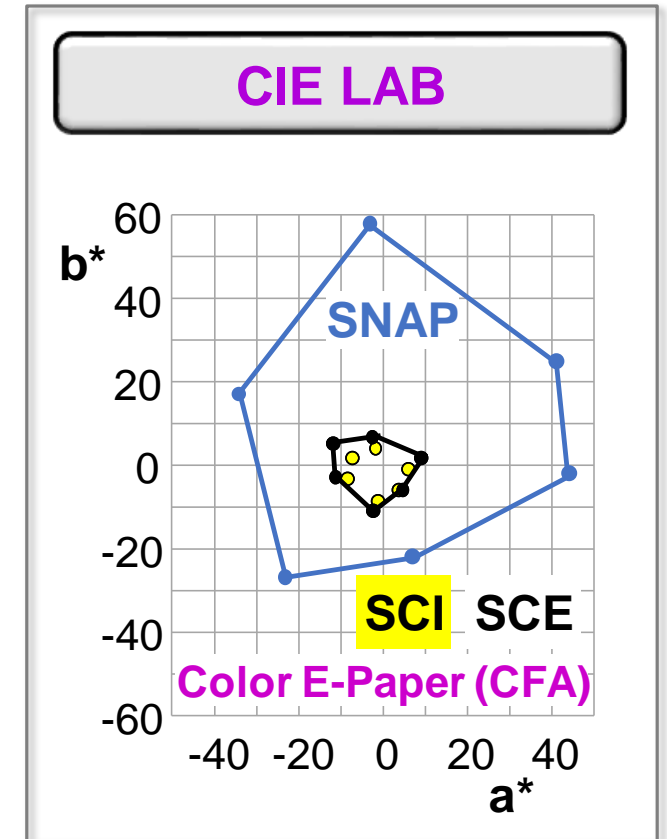
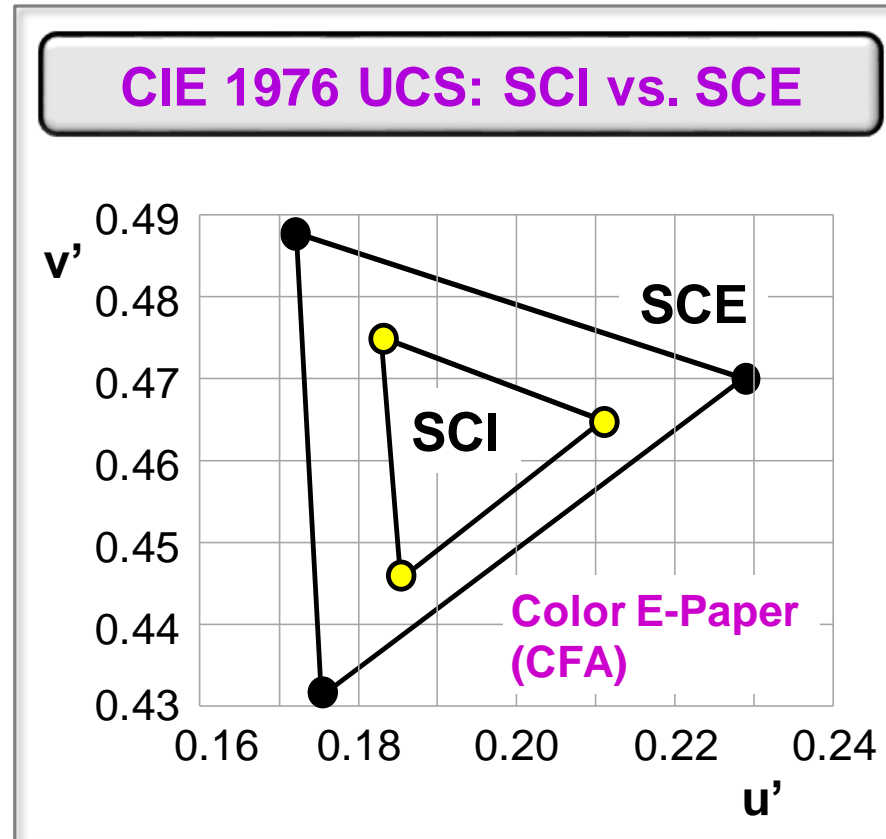
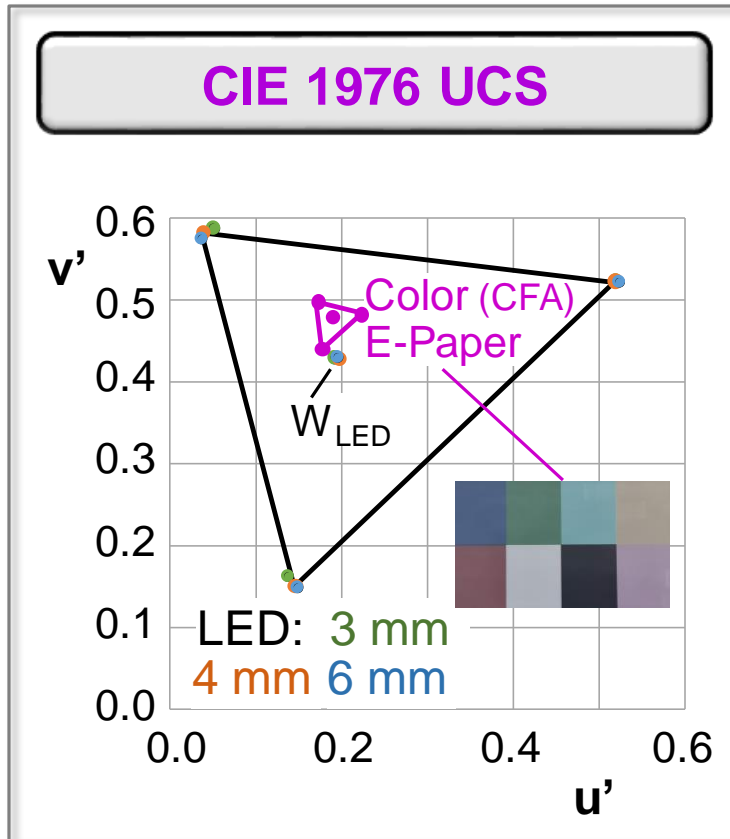
- We used both methods for evaluation
- Matte surface best for exterior displays

Measurement Results of E-Paper and LED Displays

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/m ²)		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

- **Reflectance** (of white state) is THE measure for displays @ ambient light:
 - E-Paper: 40 % - 50 % is acceptable
 - LEDs and others: The less the better, 1% is standard for automotive LCDs
- **Contrast ratio** is THE measure for readability/legibility @ ambient light:
 - 2:1 is lower limit for sunlight (ISO 15008), mostly specular reflections towards road

Measurement Results of E-Paper and LED Displays



Color gamut is THE measure for the perception of displays and colored traffic signs:

- CFA e-paper: Color gamut very small, only 10% of newspaper (SNAP, right)
- RGB LEDs: Huge gamut, perfect for rendering saturated colors of traffic signs