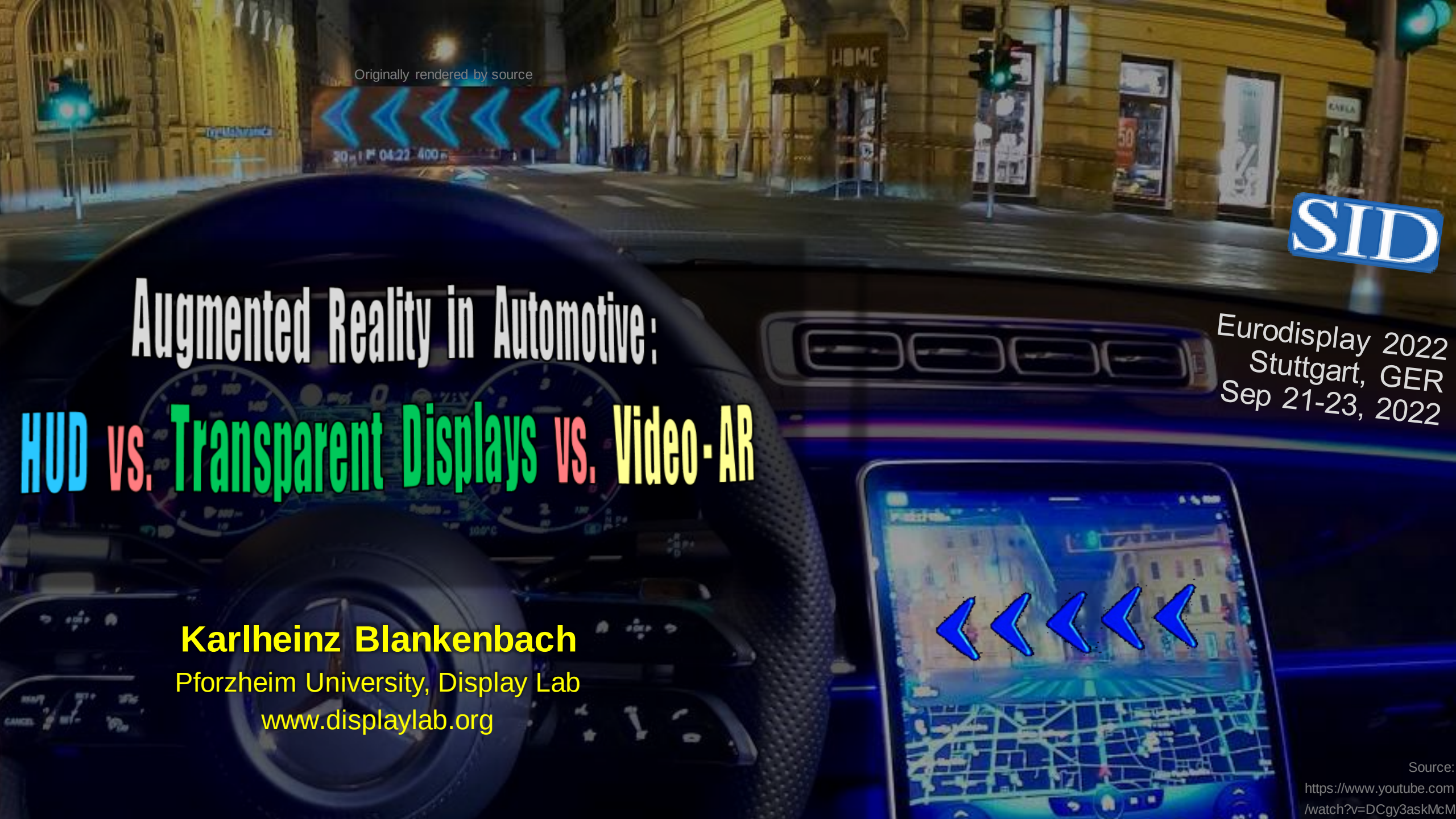


Augmented Reality in Automotive:

HUD vs. Transparent Displays vs. Video-AR

Eurodisplay 2022
Stuttgart, GER
Sep 21-23, 2022

Karlheinz Blankenbach
Pforzheim University, Display Lab
www.displaylab.org

Source:
https://www.youtube.com
/watch?v=DCgy3askMcM

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

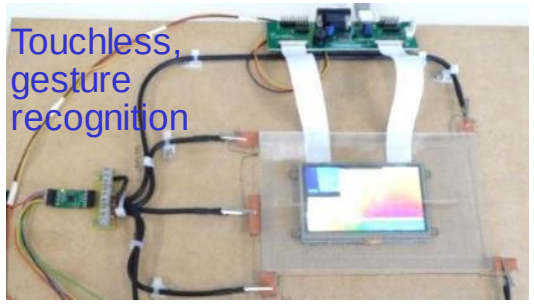
Activities @ Display Lab

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

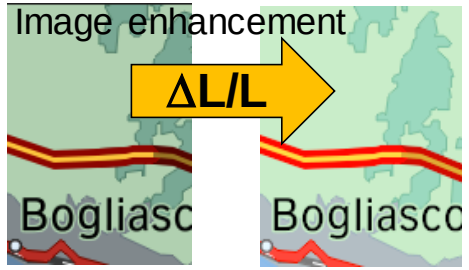
We prototype and/or evaluate your display, HMI or idea!

Examples of Projects

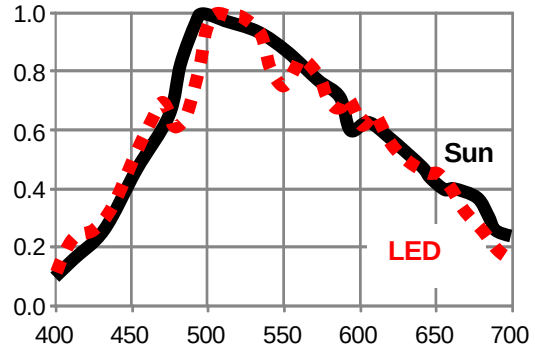
Camera Monitor System


Touchless, gesture recognition


LED displays & lighting



Measurements & simulations




Avionic OLED

Complete product development: wearable OLED signs


Uniformity


Evaluation

Overview

- Introduction
- AR - HUD
- Transparent Displays
- Video-AR on Display
- Light Guide Display
- Summary

Augmented Reality raise safety & comfort – and builds trust in ADAS

Only public, no private (NDA) information is shown.

Source:https://plat4m.com

Overview

- Introduction
- AR - HUD
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- Augmentation in cars
- AR system overview

Approaches to Present AR Content to Car Drivers

Source: BMW, HELLA, Mercedes, SAINT-GOBIN

In-Car Augmentation

by displays

- **HUDs**
- **Transparent displays**
- **Video-AR on large displays**

Augmentation by Glasses

- May benefit from transparent AR
- Also suitable for passengers
- Chances for aftermarket

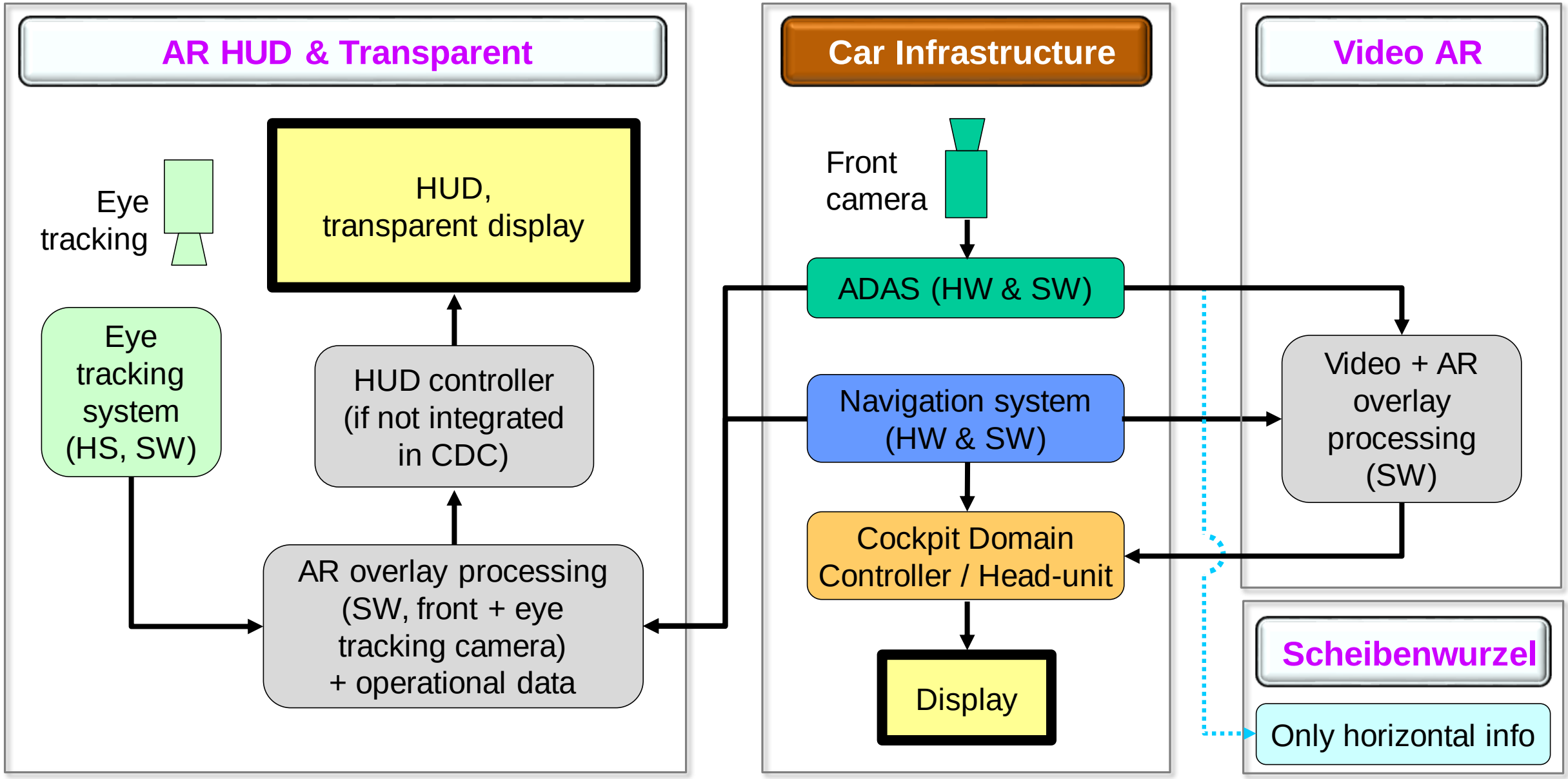
Driver worn **glasses**

External Augmentation

by **head lamps**

- Good for night drive
- Limited at daylight conditions

Augmented Reality vs. System Design



Overview

- Introduction
- AR - HUD
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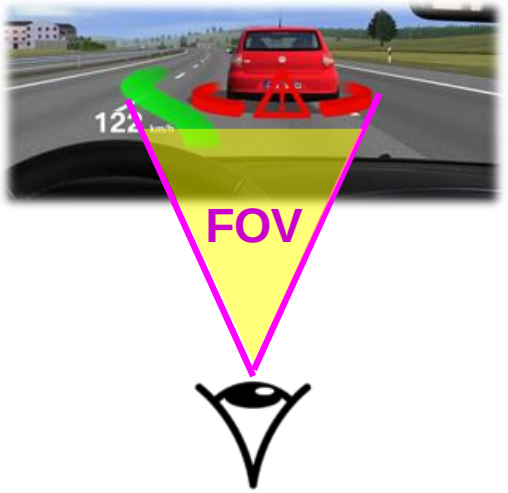
- FOV vs. augmentation
- Wide FOV technologies



Main objectives of AR-HUDs:

- Manual driving: Improve situational awareness!
- Autonomous driving: Monitoring of maneuvers → Building trust in ADAS
- But: Only visible for driver

AR - HUD Fundamentals

Basic requirement for AR effect:

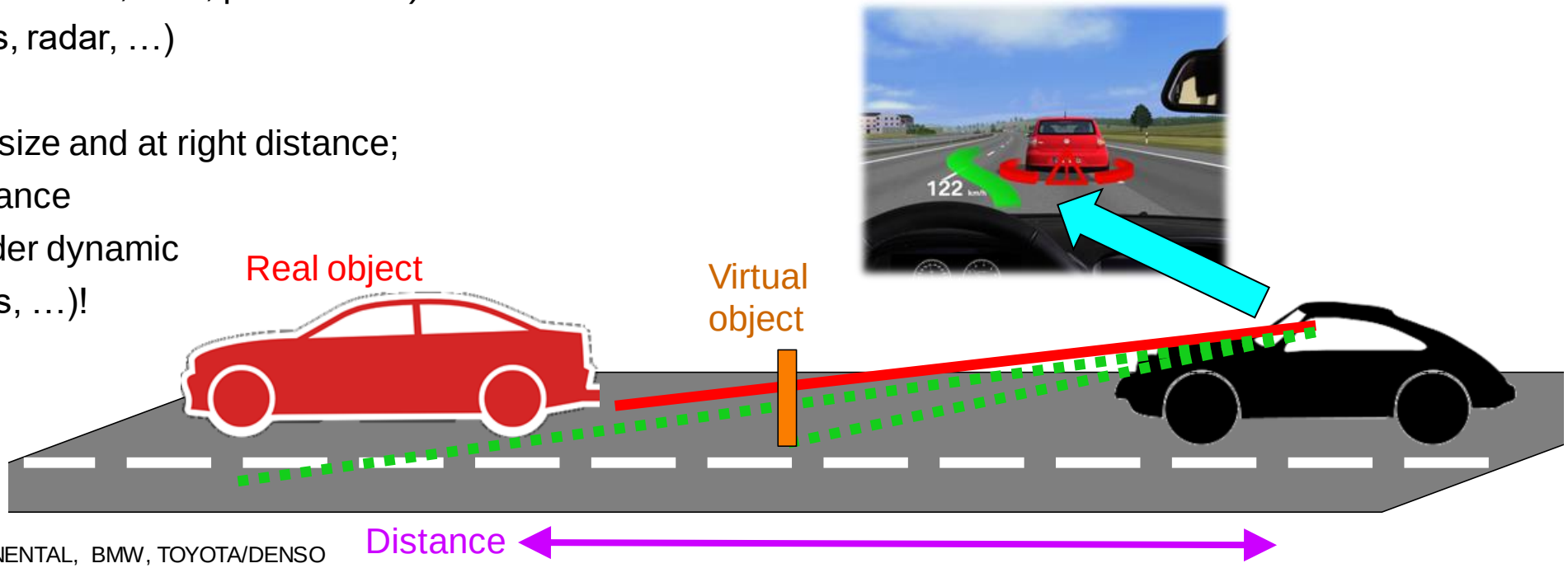
Real and virtual object are object are aligned and at the same distance (no difference detectable)

→ FOV must be adequate!

„Virtual object/image“ paints the road“

System aspects for AR effect:

- Absolute position and orientation of car
- Track relative (to car) position of head and eyes
- Identify and track objects (like lanes, cars, pedestrians)
- ADAS functionality (cameras, radar, …)
- (3D) AR content generation
- Display AR image with right size and at right distance;
  Distance > 6 m as fixed distance
- Perform all above topics under dynamic conditions (latency ↙, bumps, …)!



Source: CONTINENTAL, BMW, TOYOTA/DENSO

AR - HUD: Field of View (FOV) vs. Augmentation

Augmentation at right place (eye) and lag-free (bumps, moving objects …)

α_V

40°

20°

10°

5°

Judged as "great AR"

Huge space for 10° x 5° for mirror-HUD ➞ HOE

α_H 20° 10° 40° 60°

Huge challenges toward large FOV AR - HUDs & great UX!

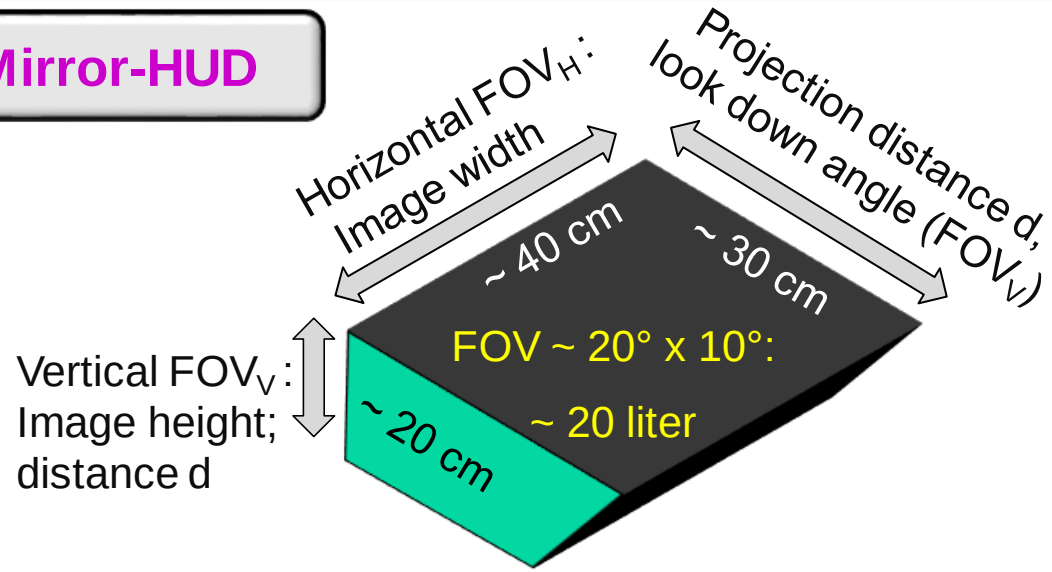
Source: BMW, CONTINENTAL, HYUNDAI, MERCEDES, PANASONIC, TOYOTA

Wide FOV AR - HUD Optical Systems

Challenges:

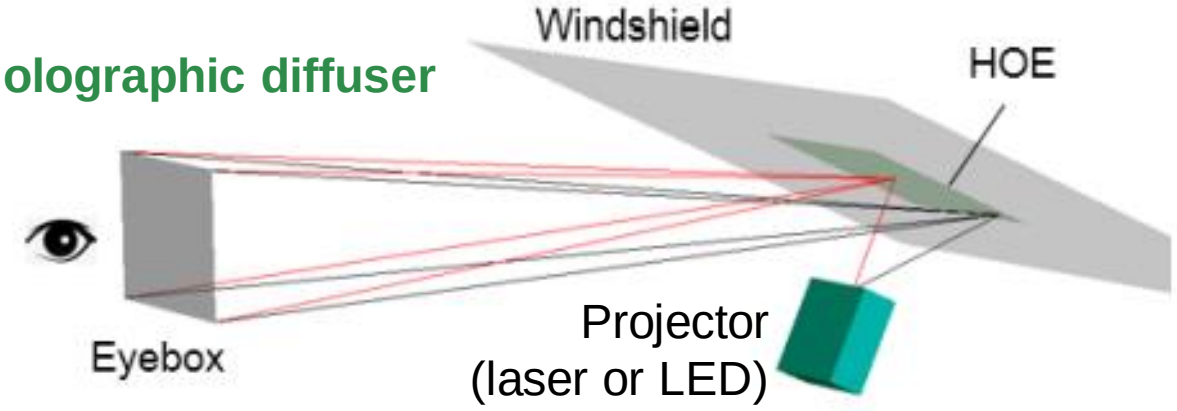
- Optical system design for large FOV
- New PGUs like MEMS, laser-based
- Today's mirror-based HUDs reach practical limit
  e.g. volume/space, sun load, reflections …
- But: Low volume/space for AR-HUD required
  ➞ Holographic methods

Mirror-HUD

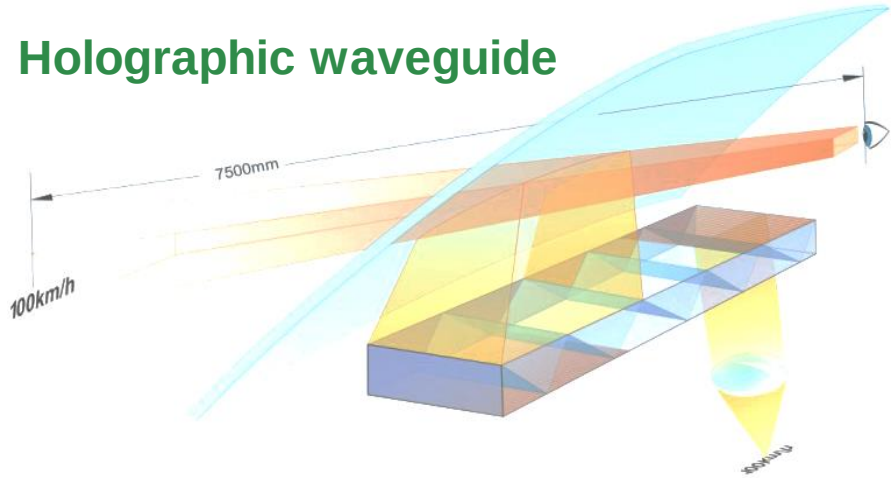


Holographic HUD

Holographic diffuser



Holographic waveguide



Source: CERES HOLOGRAPHICS, CONTINENTAL DIGILENS

Challenges for AR - HUDs

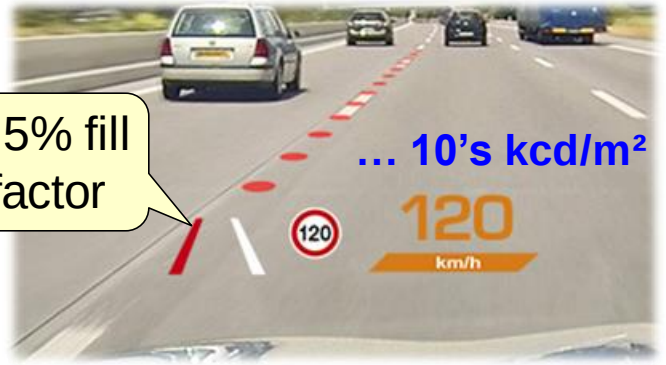
Resolution

Eye matching: 120 ppd (incl. warping):

- 20° x 10° ≡ 3 MP
- 40° x 20° ≡ 12 MP
- 60° x 40° ≡ 35 MP
- Windshield size ≡ 100 MP

Massive computing power and interface speed required:
40° x 20° ≡ 20 GBit/s

Readability



$$C_R \approx \frac{L_{HUD}}{L_{Road,\,sky}} + 1 \geq 2:1 \quad \text{(ISO 15008)}$$

$L_{Background}$ @ day: …10's kcd/m²

$L_{HUD} \geq L_{Background}$

➡ L_{HUD} @ day > 20 kcd/m²

Occlusion

Adjust HMI

Many images of (AR-) HUDs are artist rende-rings!

Safety for manual driving!

Source: CONTI, DENSO, U Linz

AR - HUD Examples: Real Photos

Animation vs. Real World

Nice looking with some zoom

AR-HUD by MER-CEDES

FOV: 10° x 5° ≡ 77” @ 10 m

https://www.youtube.com/watch?v=DCgy3askMcM

Animation vs. Real World

Nice looking with zoom

Good idea to increase arrows?

AR-HUD by VW ≡ 70” @ 10 m

https://www.driving.co.uk/news/volkswagen-id-3-id-4-get-augmented-reality-head-displays/
https://www.youtube.com/watch?v=uQT5pRs0yCQ

Readability of HUD

https://www.youtube.com/watch?v=uQT5pRs0yCQ
https://www.youtube.com/watch?v=DCgy3askMcM

Overview

- Introduction
- AR - HUD
- **Transparent Displays**
- Video-AR on Display
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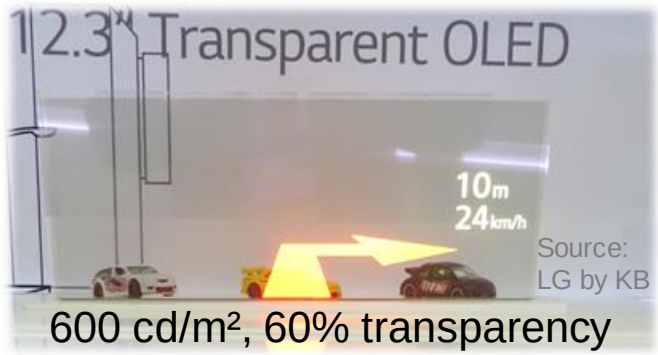
- Display technologies
- System aspects of transparent displays



600 cd/m², 60% transparency

- Large size achievable
- Visible for all passengers
- Challenges: Luminance, transparency, refocusing

Display Approaches for Windshield & Windows

Visible for all

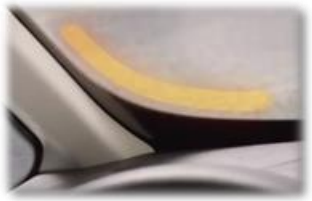
Touch possible

Integration & replacement?

Refocusing to 1 m for AR

Privacy? Content visible from both sides!

Display 5E6



Principle:

Fixed objects with different color

- Simpler and cheaper than matrix
- Easier to integrated & to drive
- Limited content, hardly any AR

Display MATRIX

Touch-like UX

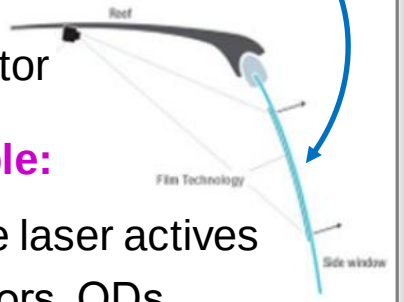
Principle:

Any object at any location

- AR for safety (position tracking), joy of use (e.g. autonomous)
- Great UX incl. gesture and touch-like control
- Integration, data rate, complex …

Projection

Projector



Principle:

Invisible laser actives phosphors, QDs …

- No electronics in glass
- Luminance yet not high enough, 10+ y R&D

Source: SAINT-GOBAIN "Driving tomorrow" video, LG, LUMINEQ, SUN Innovations

Transparent Display Technologies

OLED

- Automotive ready
- 1,000 cd/m² & car LT achievable
- Transp. 45% … 70%

Electro-Luminescent

- Automotive ready
- Transparency > 80 %
- 1,500 cd/m² achievable
- Only yellow & segmented

Micro-LED (µ-LED)

- High transparency (> 70%)
- Long lifetime
- High luminance (> 2,000 cd/m²)
- Early stage technology
- Production of large displays

Requirements: L > 10 kcd/m², dimming, (area) color, transparency > 70%, invisible structures

Sources: LG, LUMINEQ, PLAYNITRIDE, SAMSUNG, TIANMA, photos by KB

Overview

- Introduction
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- AR on existing display is easy to implement at lowest cost

Camera Monitor Systems (CMS)

AUDI

Sources: HONDA, LEXUS

Augmented Reality on Infotainment Display

- Easy to implement
- Visible for all passengers
- AR-”video” can be magnified (zoom)
- Lowest cost, now integration issues
- Sunlight & snow performance

- Eyes off the road (less safety, combine with “Scheibenwurzel Display”, s.b.)
- Refocusing

Sources: MERCEDES, YOUTUBE

Overview

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- Summary

- "Pixelated" RGB LEDs for directional guidance

“Scheibenwurzel - Display”

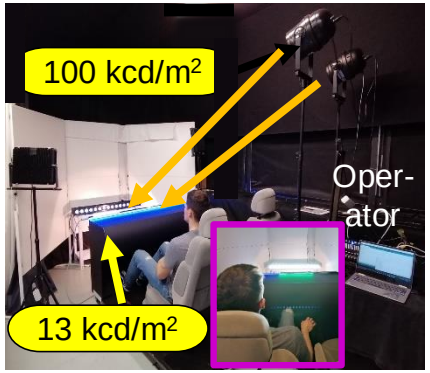
“Scheibenwurzel” - Display

Pixelated RGB LED light guide located at bottom of windshield (Volkswagen ID.Light)

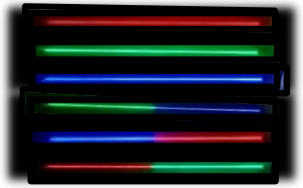
- Directional warning @ low cost & multi-purpose (incl. driving mode)
- Can be added to low FOV HUDs, transparent and video-AR displays
- Easy to integrate, ergonomic for many use cases
- Already in MP (VOLVO used 10 red LEDs in the past for warnings)

Topics @ Display Lab

- Luminance vs. illuminance from night to sunlight + blinding
- RGB luminance ratio for equal perceived brightness of colors
- Variances due to age, gender etc.



Tests: Threshold & same brightness



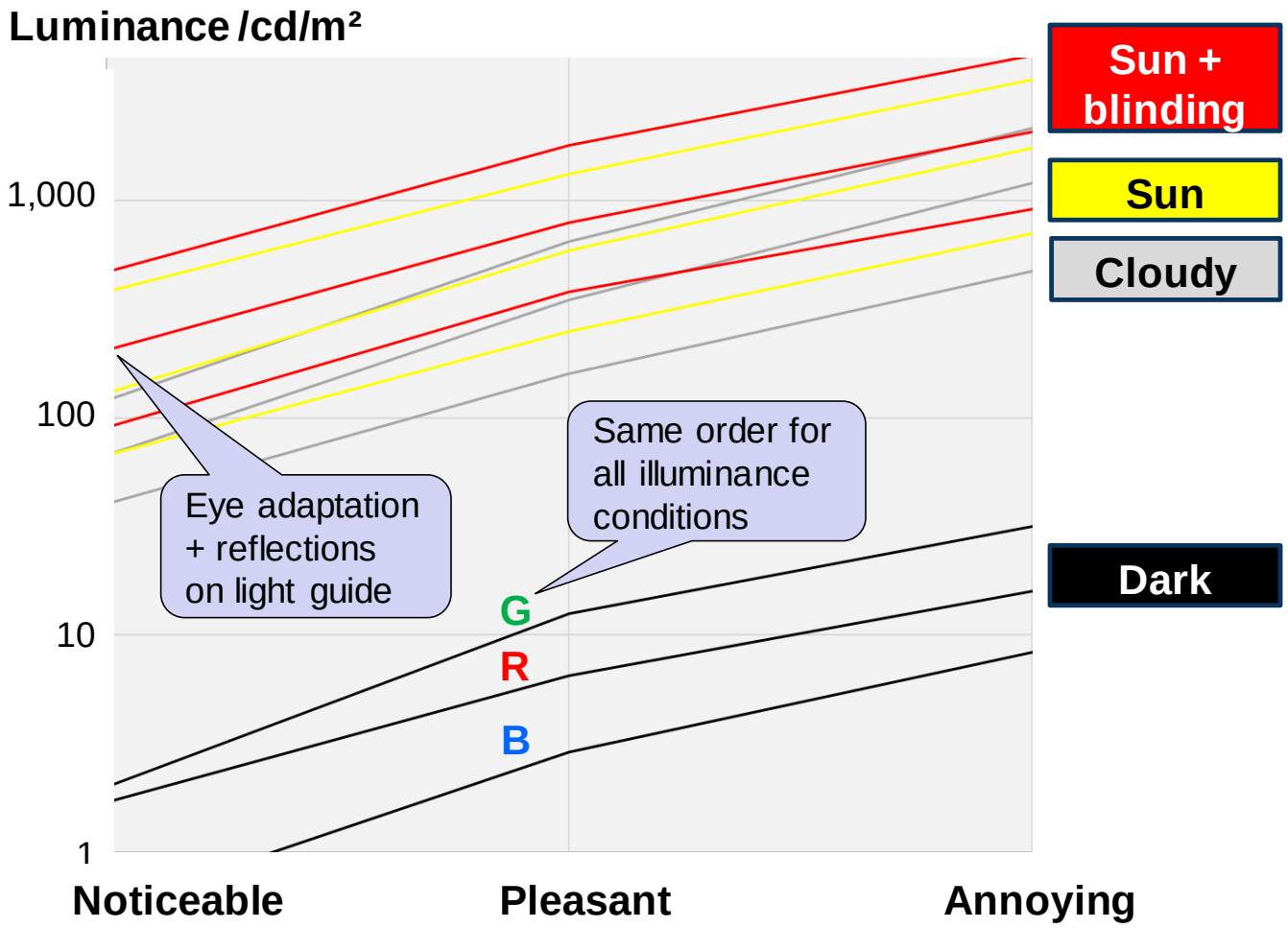
Results:

- L_{White} > 3,300 cd/m² @ blinding sunlight
- RGB luminance ratio 35 : 50 : 15
- Realtive large variance among subjects

Sources: ISELED INOVA, VW

“Scheibenwurzel - Display”: Luminance & Low Res Graphics

Luminance vs. Illuminance



Examples of 8 Line Display

Speed with color for smaller (orange) and larger (red) speed as allowed

Navigation with animated arrow and remaining distance to turn

Warning for slippery road, animated example incl. manual drive

Trajectory for recommended (manual) or intended (autonomous) path

Overview

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Augmented Reality (AR): HUD vs. Displays

Augmentation raise safety for manual driving & builds trust in ADAS and autonomous!

Best way to realize?

AR-HUD

- No eyes off the road
- No refocusing
- "Driver only" (ADAS trust)
- High effort & cost
- Sunlight & snow

Transparent Display

- No eyes off the road
- Large image
- "For all" (ADAS trust)
- Refocusing
- High effort & cost
- Sunlight & snow, cracks …

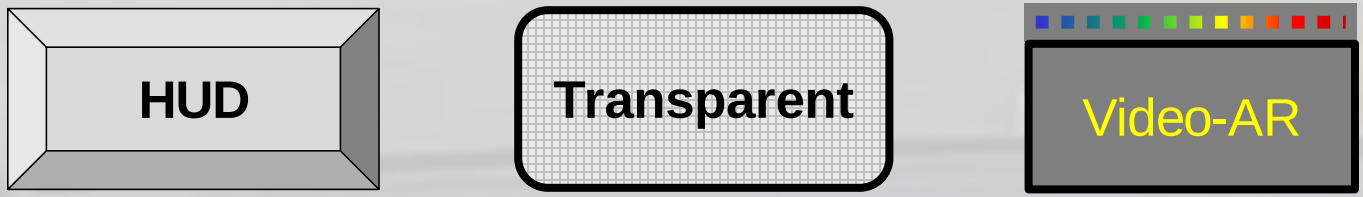
Video-AR

- AR-"video" can be magnified (zoom)
- "For all" (ADAS trust)
- Low effort & cost
- Eyes off the road
- Refocusing

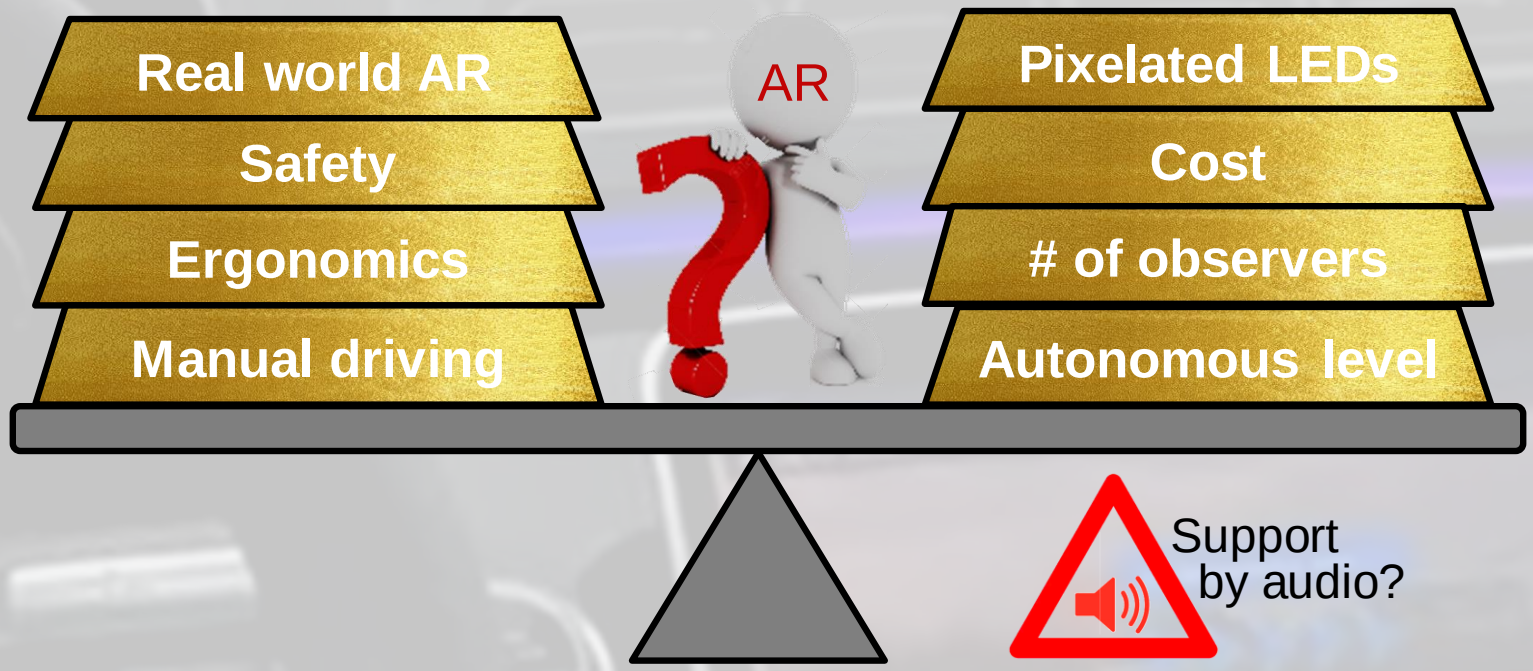
LED Light Guide

- Low effort & cost
- Add-on for low FOV HUDs and displays incl. transparent
- Low level of augmentation

Approaches



Criteria



“Cost vs. class” & “AR ergonomics” vs. “autonomous level + 1” may decide!

Contact: kb@displaylabor.de

Info: www.displaylab.org

Source: AUDI

Overview

Spare slides for Q&A

Towards AR - HUDs

Conventional HUD

- FOV typically up to 6° x 3°
- Projection distance 2 - 3 m
- Only “operational data”

Trend for AR-HUD

- FOV > 20° x 10° incl. “conventional”
- Projection distance: 2 m … 30 m

  → New HUD techniques required

HUD: Operational data

AR-HUD: Operational & AR data

Challenges for AR-HUD

- New PGUs like MEMS, laser-based, holographic
- Low volume for AR-HUD (Volume ~ FOV)
- AR GUI/HMI design and evaluation!
- No latency of AR content rendering and positioning incl. bumps, driver movements, …

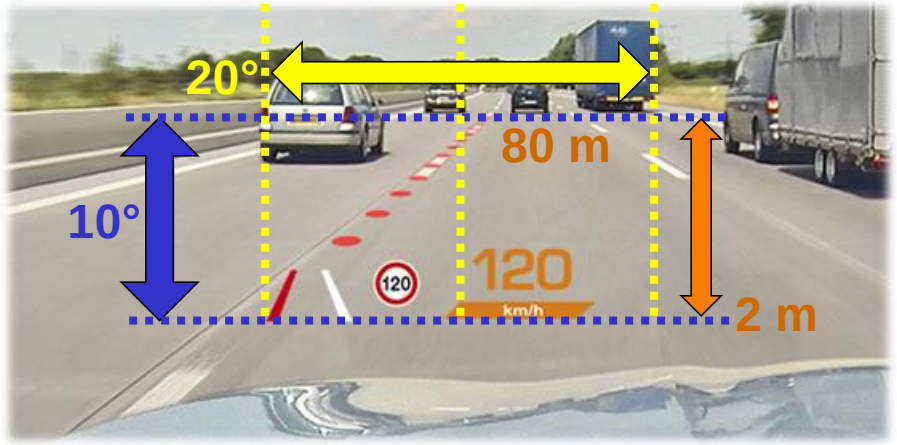
Source: CONTINENTAL, BMW, PANASONIC, HYUNDAI

Significantly less
- Time for capturing display data (less blind driving)
- Refocusing (~ 2s for aged; 1 s ≅ 33 m @ 120 km/h)
- Vergence (“redirecting” eye balls)

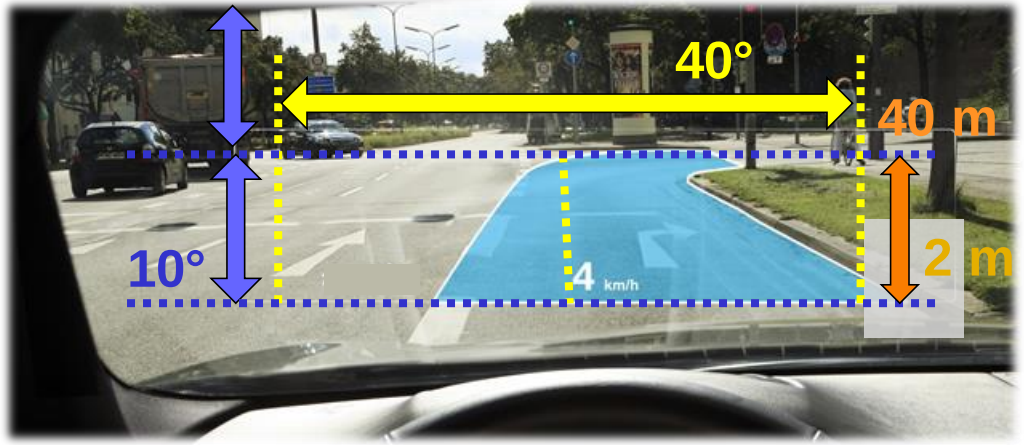
compared to instrument cluster or infotainment display

“Reasonable” FOVs for AR - HUDs

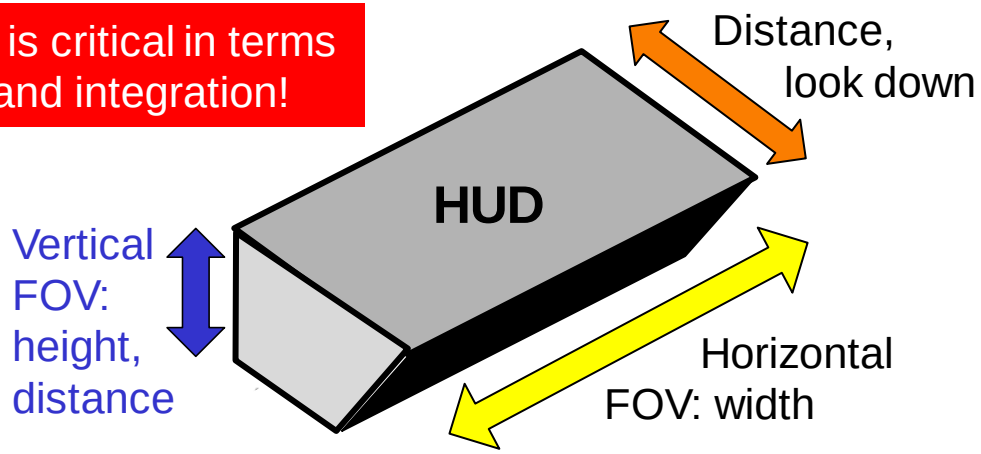
Highway ADAS



Urban Wayfinding



Volume is critical in terms of cost and integration!



- **Distance**:
  - **2 m** for operational information
  - AR ideal @ object position, **10+ m** as compromise
- **Vertical FOV: 10° - 20+°**
  (10°: 3° look down angle, > 20°: traffic signs …)
- **Horizontal FOV: 20° … 40°** with some AR limitations

Source: BMW, CONTINENTAL

AR - HUDs Enhance Active Safety Systems

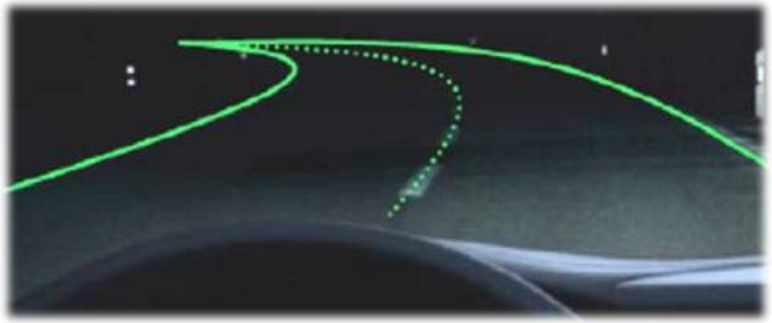
Braking distance indicators for forward collision warning and lane markings for lane departure warning

AR HUDs increase safety!

Less AR content is better!

X-ray vision to increase situational awareness at urban intersections

Lane markings @ night drive



Low visibility support by icons for other vehicles and lane markings

Sensor-driven world-fixed graphics can also be used to cue drivers' attention to relevant hazards quickly and accurately, especially for low-visibility or near-invisible objects by super imposing virtual representations of pedestrians, occluded vehicles, and driving lanes. In addition, AR can be used to assist elderly drivers' with visual and cognitive impairments in driving environments associated with increased crash risks.

Source: Gabbard, Kim., Fitch, IEEE Vol. 102, No. 2, 2014

AR - HUDs

AR-HUD Benefits

- Rise safety
- Higher comfort
- Better acceptance of autonomous driving
- Supports manual driving incl. safety

AR-HUD Challenges

- Volume, dashboard
- Readability (luminance)
- HMI & evaluation
- CE expectations of video-/photo- AR
- No benefit for Level 5 and traffic jams

Source: BMW, BYTON

Windshield vs. Head - Up Display (HUD)

Less distraction as presenting driving- relevant information within the field of driving scene!

Transparent Displays in Windshield

- Transparent display (70%, e.g. OLED) integrated in windshield (→ wind “screen”)
- Segmented or matrix display (pixel)
- Benefits: No head-down, integration, information for passengers, AR possible, …
- Drawbacks: Luminance, transparency, refocusing, parallax, driver vs. passenger, rainbow effects, sun reflections, …

Less distraction = more safety!

Source: SAINT-GOBAIN ”Driving tomorrow” video, BMW, CONTINENTAL

HUD

Screen-fixed content

AR: World-fixed content

- Projection with LCD or DMD as imager with bright light source or laser
- Mostly matrix display (pixel)
- Benefits: No head down, faster focusing (direct view ~ 2 sec for the aged), AR, supports manual driving (when used to autonomous driving), …
- Challenges: Luminance, integration, large FOV for AR, driver only, value for fully automated driving, …