Augmented reality head-up displays: from requirements to solutions

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Abstract

The benefits of head-up displays (HUD) are proven for various applications. Today's automotive HUDs show mostly operational data. This paper discusses requirements of augmented reality (AR) HUDs.

1. Introduction

Many modern cars are equipped with HUDs visualizing mostly speed and directions (Fig. 1 left). Those HUDs have typically a field of view (FOV) of about 8° by 3° (h x v). They base on a projection system using small displays, curved mirrors and a combiner in the windshield [1]. AR-HUDs (Fig. 1 right) will provide more benefits for manual (wayfinding) and autonomous driving (building trust). They require new techniques due to large FOV.

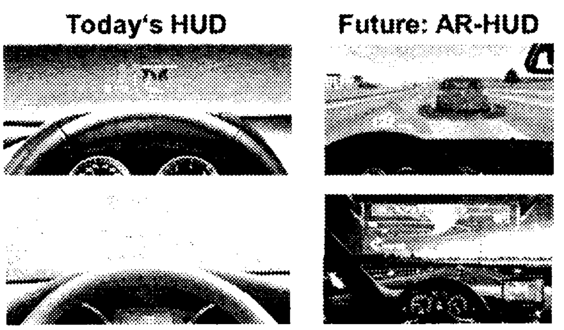

Figure 1: From today's HUD with small field of view (FOV, left) towards AR-HUDs (right) with large FOV. Sources: BMW, MERCEDES, PIONEER

2. Considerations on AR-HUD Field of View

The useful AR distance and FOV depends on the "amount" of augmentation and the traffic scenario. The basic parameters for the vertical FOV_V and the distance d are visualized in Fig. 2 top:

- Calculation of angles by $\tan(\alpha) = h/d$, where h is the height of the eye, distance d as object to eye
- Minimum distance for urban traffic: $d_{min} \sim 5$ m
- Maximum distance for highways: $d_{max} \sim 80$ m

With these assumptions, we can calculate the vertical FOV_V values from α_V according to Fig. 2 top:

- FOV_V for look-down from $\alpha_{Vmin} - \alpha_{Vmax} \approx 15°$
- 1° to 2° have to be added system performance.
- Framing cars and annotated information require a look-up angle α_{VIu} of at least 5°. This results in a total FOV_V of about 20° for highway use cases.
- AR augmentation of close objects like shops and traffic signs require at first approach 20° for look-up angle α_{VIu}. This results in 40° for vertical FOV.

Corresponding considerations are made for the horizontal FOV_H for different scenarios, Fig. 2 bottom:

- Passing a car on highway: $\alpha_H \approx 20°$, Fig. 1 right
- Urban wayfinding: $\alpha_H \approx 40°$
- Annotated information in cities: $\alpha_H \approx 60°$

This raises the FOV (h x v) by more than one order of magnitude compared to present HUDs in series production. So new technologies are required.

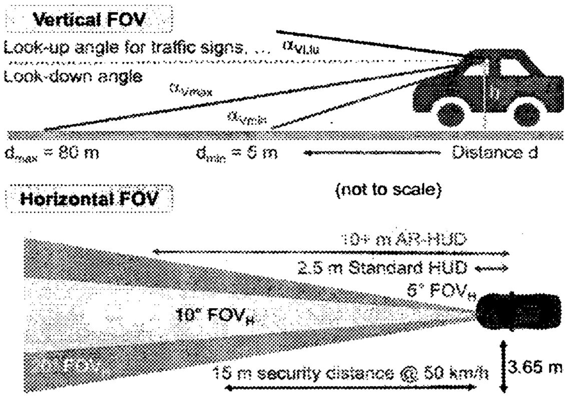

Figure 2: Visualization of geometrical conditions for AR-HUDs: Vertical (top) and horizontal (bottom) FOV and real object distance d

3. Requirements and Solutions

The optical power output rises with the FOV in approximately linear relation. Expanding from 8° to 60° (h) and 3° to 40° (v) results in 100x. The luminance of the HUD's is calculated by

$$L_{Lightsource} = \frac{L_{HUD}}{T_X \cdot R_X} \quad (1)$$

T_X represents transmission in the optical path and R_X for reflectance. The reflectance of holographic combiners is significantly higher (about 85%) thus enabling AR-HUDs, holographic waveguides [2] reduce their volume. The contrast ratio must exceed on bright roads:

$$CR = \frac{L_{HUD}}{L_{Road}} + 1 \quad 3{:}1 \quad (2)$$

4. Summary

AR-HUDs with a FOV larger than 40° by 10° require holographic methods and highest light output for readability for augmented data on bright background.

5. References

[1] Sako, Ketal, "Development of New Head-Up Display System Utilizing RGBW LCD and Local Dimming Backlight," SID Symposium Digest of Technical Papers, Vol. 47, p. 680-683 (2016).

[2] Richter, Petal, "Volume Optimized and Mirror-less Holographic Waveguide Augmented Reality Head-up Display, " SID Symposium Digest of Technical Papers, Vol. 49, p. 725-728 (2018).