## 4.3. AUTOMOBILE HEAD UP DISPLAY AND AUGMENTED REALITY

While Head Up Display (HUD) systems have been used in commercial jet transport since the early 1970s,[259] their adoption in smaller passenger aircrafts is still recent.[260] As early as 1988, a limited number of Oldsmobile convertibles were already equipped with an HUD that projected a digital speedometer and turn-signal indicators onto the windshield.[261] Nevertheless, large-scale, built-in HUD deployment is recent in the automotive industry, reserved for premium models, and mostly limited to a small area on the windshield or on a standalone fold-up glass screen on the dashboard, displaying only speed, navigation, and a limited number of driver aid instructions. Add-on HUD equipment, adjusted on the dashboard, has also been proposed by various providers, mostly for displaying navigation or speed information, as the display unit may not be connected to the vehicle.

An HUD is a transparent display system that presents data without requiring users to look away from the windshield; thus, the driver can obtain information on relevant vehicle and road data while keeping their head in an upright position (hence the name "head-up display") and maneuvering the vehicle with a low reaction time. An additional advantage of HUDs due to their optics is that the image is projected at a given distance, generally to infinity (with parallel rays hitting the retina) in case of aircraft, and to approximately 3–20 m in the case of automobile systems. This allows the driver to view both real and AR images without additional eye focusing strain.[262]


**Fig. 4.2.** A head-up display for passenger vehicles developed at Cambridge, the first to incorporate holographic techniques, has been incorporated into Jaguar Land Rover vehicles.

An early development was made by Cambridge University's Centre for Advanced Photonics and Electronics (CAPE), namely Two Trees Photonics and Alps for Jaguar Land Rover (JLR), with the HUD becoming an

[259] Naish, J. Michael. "Application of the Head-Up Display (HUD) to a Commercial Jet Transport." Journal of Aircraft 9.8 (1972): 530–536.

[260] https://www.ainonline.com/aviation-news/general-aviation/2021-06-23/faa-approves-first-general-aviation-head-display

[261] Weihrauch, M., G. G. Meloeny, and T. C. Goesch. The first head-up display introduced by General Motors. No. 890288. SAE Technical Paper (1989).

[262] https://www.fic.com.tw/automotive/ar-hud/

available option on JLR vehicles in 2014[263] (see Fig. 4.2). Two Trees Photonics, which took over the development of an HUD product for the automotive industry, was later acquired by Daqri, an AR helmet and AR glasses producer, which had raised up to US$275 million before ceasing its activities in 2019.[264] This illustrates the technical challenges of viable HUD devices. However, in 2021, Mercedes introduced an AR-HUD that used a digital mirror device from Texas Instruments, with 1.2 Mpixels projected in a 10° (horizontal) × 5° (vertical) FOV image, which appears 10 m away.[265]

HUDs may also be a part of an ADAS, allowing the driver to visualize and understand, for example, the time headway to the preceding vehicle or the necessary maneuvers to change lanes or avoid another vehicle under the optimal safety observation conditions. These scenarios represent traffic hazards with eyes on the road. An HUD can also be a crucial device for presenting the traffic environment to the driver when they take back control of an automated vehicle if the self-driving system is unable to handle the traffic situation, lacks essential road information (e.g., road lane marking), or lacks any other data necessary to operate correctly.

Here, the following question arises: What characteristics are required for an HUD to provide all necessary information to the driver in the most critical situations, in terms of visual comfort, distance, contrast, visibility, FOV, and accuracy? While sufficient feedback has not yet been acquired in all driving conditions, some early virtual simulated experiments offered some indications of the robustness and optimal virtual display distance for AR-HUD images. Experiments conducted in a CAVE-like driving simulator revealed that driver preference and task efficiency in maintaining intervehicle distances were for 10 m, compared with 6 m when using motion parallax information.[266] Motion parallax is indeed a crucial visual depth cue that requires driver head movements to be considered for correct distance perception (see Chapter 2).

As an example, Volkswagen's AR HUD system provides active and dynamic navigation instructions that are reflected onto the windscreen. They appear to be 10 m in front of the vehicle and are displayed with the correct perspective. The LCD display is mounted inside the dash panel with high-precision mirrors reflecting the generated ray bundles onto the windscreen with separate lenses for close- and far-range display levels. A device called the AR creator positions the symbols in the display window, using data from the front camera, radar sensor, and navigation map. The displays are stabilized with respect to the vehicle's movements and adapted to the geometry of the optical projection system.[267]

Again, startup companies with capital investment and cooperation with OEMs or large automotive suppliers have developed and proposed AR-based HUD systems. One example is EyeLights, which is a French company that formed in 2016 and sells HUD devices to be integrated in motorcycle riders' helmets; now, it is proposing automotive HUD systems and is already working with Renault and Toyota. At the 2022 CES, AGC announced a large cooperation with EyeLights,[268] which also raised approximately €20 million later in 2023 with BPI, the

[263] http://www.eng.cam.ac.uk/news/heads-cambridge-holographic-technology-adopted-jaguar-land-rover

[264] https://techcrunch.com/2019/09/12/another-high-flying-heavily-funded-ar-headset-startup-is-shutting-down/

[265] https://arstechnica.com/cars/2020/07/augmented-reality-heads-up-displays-for-cars-are-finally-a-real-thing/

[266] Halit, Lynda, et al. "Head Motion parallax effect on driving performances when using an AR-HUD: Simulation Study on Renault's CARDs Simulator." Proceedings of the DSC Europe (2015): 71–77.

[267] https://www.volkswagen-newsroom.com/en/the-new-id3-valuable-likeable-digital-15490/controls-connectivity-and-assist-systems-15492

[268] AGC and EyeLights have joined forces to bring the Augmented Reality windshield to CES 2022 | AGC Glass Europe (agc-glass.eu). Since 2020, the Consumer Electronics Show (CES) has become the major automotive trade event, showcasing innovations in infotainment, telematics, and connected and autonomous vehicles. At CES 2014, Oculus presented its affordable Rift HMD. This was noticed by Facebook, which led to its acquisition of Oculus

French public investment bank, a European Innovation Council (EIC) fund equity investment with other founding structures.[269] Envisics, a UK-based company, has recently raised a US$50 to $500 million value with Hyundai Mobis, InMotion Ventures (the investment arm of JLR), and Stellantis,[270] while WayRay (see Section 2.2) is now estimated at US$500 million.[271] Both companies claim to develop high-quality AR HUD systems with multiple image plans for several virtual object distances.

for ~US$2 billion 2 months later: The First Look at the New Oculus VR Prototype | WIRED, Facebook Buys Oculus, Virtual Reality Gaming Startup, For $2 Billion (forbes.com).

[269] EyeLights secured €20m from investors including Bpifrance, EIC Fund and Techstars | Nordic 9

[270] https://techcrunch.com/2023/03/08/envisics-raises-50m-at-a-500m-valuation-for-its-in-car-holographic-tech/

[271] https://techcrunch.com/2018/09/18/wayray-raises-80m-at-a-500m-valuation-led-by-porsche-for-its-holographic-ar-display-tech/