4.4. WINDSHIELD AR AND AR GLASSES FOR SELF-DRIVING

The history of electric visual display technologies is relatively old, starting with the commercial deployment of cathode-ray tubes (CRTs) in the 1930 for television sets,[272] but the original CRT technology is very rarely used today. Over the past few decades, liquid-crystal display (LCD) technology – flat-panel displays using the light-modulating properties of liquid crystals combined with polarizers to block or let light pass from a backlight – has been largely deployed for many uses, including in the automobile industry.[273] LCD screens are largely deployed in VR, AR HMDs, and optical systems for HUDs, though recently some high-end OEMs have started to integrate organic light-emitting diode (OLED) technology-based display units for high-level color rendering.[274] LCD screens with low power consumption and no geometric distortion are made in almost any size and resolution up to 8K (7680 × 4320 pixels), while OLED screens are composed of an LED matrix, allowing enhanced contrast and virtually infinite black color, which are inherent in their design.

OLED (or active-matrix OLED [AMOLED]) screens are progressively replacing LCD screens in smartphones, laptops, TVs, and VR helmets (e.g., Oculus Meta Quest), although with a lower resolution than those based on single fast-switch LCD (1832 × 1920 pixel per eye for Guest 2)[275] and the HTC Vive Focus, although with a lower resolution than the 120° FOV Focus3, which has a 5K combined resolution.[276] For VR headsets as well as automotive display systems, weight gain is crucial (for an HMD user's comfort and ecological behavior, and for the automotive OEMs for the available space under the dashboard). In the future, new headsets may use (micro) OLED display systems, which can have a 4K resolution or better for each eye, such as the Apple Vision Pro, announced in 2023 with delivery planned for early 2024.[277]

Furthermore, windshield AR and AR glasses are both constrained by the available space and optical performance requirements for efficient driver comfort and high-level image quality. The former is on the way to being progressively introduced on the automotive market this decade with a large-scale industrial deployment (see Section 4.3). Though windshield HUD development is intensive for high-quality immersive systems,[278] it also has some additional inherent constraints compared with AR glasses, with the latter not requiring a costly and bulky integration in a limited driver cockpit space under the dashboard.

As seen earlier, one of the problems with AR HMDs or glasses is the difficulty in correctly managing sharp variations between low- and high-luminosity visibility conditions (see Section 4.2), such as those between in-room and outside sunny observations. In the case of in-cabin conditions, the driver's head is less likely to be exposed to intense lighting, as opposed to the windshield of the vehicle. As previous vehicle safety analyses have demonstrated, strong luminosity changes may represent a traffic hazard that strongly affects drivers' visual performance.[279] However, similar to how drivers frequently prefer smartphone-based navigation systems to the

[272] http://www.earlytelevision.org/telefunken_rfb_t2.html

[273] Castellano, Joseph A. Liquid gold: The story of liquid crystal displays and the creation of an industry. World Scientific, 2005.

[274] https://group.mercedes-benz.com/company/magazine/technology-innovation/hyperscreen.html

[275] https://developer.oculus.com/resources/oculus-device-specs/

[276] https://business.vive.com/us/product/vive-focus/

[277] Apple Vision Pro - Apple

[278] A US patent was published at the end of 2021 for Apple for a lenticular lens ray–based light-field HUD. See: patent US-11163157-B1 Myhre; Graham B. et al. "Light field head-up display" (2021): 1–18.

[279] Schumann, J., et al. "Daytime veiling glare and driver visual performance: Influence of windshield rake angle and dashboard reflectance." Journal of Safety Research 28.3 (1997): 133–146.

less recent versions integrated in the dashboard, drivers may also prefer to use removable AR glasses if they are connected to vehicle data.

We have also seen that the alignment of displayed information with the surrounding road environment and traffic is crucial for correct and precise information as well as driver and traffic safety, as correct visual information must be provided to the eye's motion parallax mechanism. To allow an HUD to consider eye position, a head- and eye-tracking device should be installed, which requires additional in-cabin equipment. While using AR glasses, there is no need to track head movements; however, to provide all necessary vehicle data, AR glasses must be connected to the vehicle through wireless communication. It is only a matter of time before connected AR glasses will have the necessary optical and rendering capabilities to represent a viable alternative to HUD systems. Connected AR helmets without standalone rendering capabilities but with live streaming options also represent a sufficient and cost-efficient AR solution for providing the driver with all necessary information during driving and/or while taking back control from a self-driving vehicle.

AR information projected onto an AR-HUD system, on the vehicle's windshield, or on a semitransparent screen above the dashboard in front of the windshield can be crucial as a visual aid for navigation, speed, road, and traffic safety information for the driver. However, several display parameters must be considered to guarantee the correct perception of the displayed information and the driving environment simultaneously. Visual perception is highly involved during driving, and an HUD is a well-adapted tool for conveying information to the driver because it does so without disturbing or distracting them from the road. This is because information is directly displayed in his or her FOV. Among the various parameters, which include luminosity conditions, resolution, contrast, and image rendering characteristics (see Section 4.2), transport delay and motion parallax are two essential technological characteristics that condition the correct and safe use of rendered information.

Indeed, motion parallax is a strong depth cue used by drivers to estimate the distance of near and far environmental objects. This is achieved through the differential motion on the retina, generated by either the objects or the observer's movements. During driver displacement, images of nearby objects move faster on the retina than those of distant objects but also the ones generated through the driver's lateral head movements. The impact of head motion parallax and the influence of the projection distance were evaluated subjectively in a study conducted in 2015[280] The study demonstrated that when AR information is displayed, it is necessary to have an acceptable alignment of AR highlights and the real marking of vehicles or infrastructure elements to avoid drivers becoming confused over the objects and experiencing discomfort (e.g., eyestrain and focusing difficulties). Furthermore, the majority of subjects reported a preference for the headtracking system (70% at 6 m and 90% at 10 m), while all subjects (100%) highly preferred 10 m as a projection distance whether their head was tracked or not.

There has been heavy investment in high-quality AR glasses technologies, which should allow users to see as with eyeglasses or sunglasses while simultaneously displaying CGI with a sufficient FOV, using six-DOF tracking for its integration in the real world. Yet, there are still no commercially available AR glasses with such capabilities on the market. However, DigiLens' Argo (see also Section 2.3) claims to provide such a technology with 30° FOV waveguides, 85% see-through capabilities, and over 2,500 nits to the user's eye using LCOS and an LED light engine with an HD display. The device has IP65 certification and an integrated Snapdragon XR2 chipset.[281]

Interestingly, DigiLens is also working on automobile AR-HUD and AR helmet products using the same type of technology. Putting commercially available AR glasses on the market that are comparable to high-end AR helmets is challenging. Apple proposing an AR helmet instead of AR glasses is a significant development, although it is looking for a dramatically new AR device to seamlessly integrate all Apple devices in the everyday real world

[280] 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 Driving Simulation Conference (2015): 71–77.

[281] https://www.forbes.com/sites/moorinsights/2023/01/10/digilens-makes-waves-in-the-ar-market-with-its-argo-headset/

with intuitive navigation using eyes, hands, and voice (see also Chapter 6). In the next decade, we will see whether the rapid development of new technologies will allow full-purpose AR glasses to be used by all as well as provide an alternative to automotive HUDs.

The use of AR systems is increasingly useful for drivers and may be even more crucial for self-driving. In L3 autonomous vehicles, the driver may be in hand-over and eyes-off driving for an extended duration, and thus, in a passive monitoring mode relative to incoming traffic or infrastructure-related events. Nonetheless, drivers' reaction times depend on their level of engagement in driving and the awareness of all available information concerning the vehicle's situation in traffic and the road environment. When the driver takes back control of the vehicle, initiated either by the self-driving system when it meets a situation that it cannot handle or by the driver who wishes to exit autonomous mode, he or she will take longer to resume control from automation when engaged in a secondary task prior to transition.[282]

All information on the road environment and traffic is therefore greatly helpful, and immediate AR provides visual information that is easily accessible and enhances driver and road traffic safety. AR information provided by HUD or AR glasses may substantially reduce the takeover time as well as boost the situational awareness of the driver, helping them to anticipate hazards.[283] Showing the rapid development of micro-display technology for AR glasses, Microoled, a French display technology company has raised in July 2023 €23 million to further develop their proprietary AMOLED technology for near-eye displays with optimal picture resolution, image brightness, and power consumption efficiency and build a new display production plant.[284] Indeed, micro-display market is expected to reach $4.4 billion by 2027, representing a fourfold increase since 2020 and 15 million AR smart glasses sold in 2025 among the 70 million virtual and augmented reality devices, with a market value of $21 billion..[285]

The rapid development of 3D display technology for AR headsets, glasses and other in-car systems (see also Chapter 6) is part of the rapid development of display systems everywhere in everyday life, from home cinemas to the interior of self-driving vehicles. Unfortunately, in automated vehicles use of in-cabin display systems may induce self-driving car sickness effects, because of the perceived incoherences between the vehicle's motion and virtual optical flows the occupant may see. The following chapter will briefly present the underlying perceptual mechanisms and some of the techniques that are increasingly being proposed to avoid them.

[282] Eriksson, A., et al "Takeover time in highly automated vehicles: noncritical transitions to and from manual control." Human Factors 59.4 (2017): 689–705.

[283] Dogan, Ebru, et al. "Transition of control in a partially automated vehicle: Effects of anticipation and non-driving-related task involvement." Transportation Research Part F: Traffic Psychology and Behavior 46 (2017): 205–215.

[284] https://microoled.net/e21-million-fundraising-for-microoled-led-by-jolt-capital/

[285] https://www.kbvresearch.com/microdisplays-market/, https://www.ccsinsight.com/company-news/extended-reality-is-on-the-path-to-growth/