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Augmented Reality in Automotive Glass: A Technological and Industry Perspective

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Abstract

Augmented Reality (AR) technology enables real-time visual overlays projected directly onto the windshield, enhancing occupants' perception and situational awareness. These informative graphics elevate the windshield’s critical safety role by alerting drivers to hazards and providing essential data, all while keeping their focus on the road. This paper will examine practical use cases of AR-integrated laminated glass for automotive windshields, offering an outline of current technologies as well as a look at emerging innovations. It highlights the synergy between an ancient material and modern cutting-edge technology, whereby making the invisible, visible.

Keywords

Augmented Reality, Automotive Glass, Smart Glass, AR, Head-Up Display, HUD, Automotive Safety, Autonomous Vehicles, Windshield, Laminated Glass

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1. Introduction

Augmented reality (AR) is reshaping the function of automotive glass from a passive safety barrier and transparent visibility component into an active interface that displays pertinent real-time data to drivers, all while keeping their eyes focused on the road.

In the United States alone, nearly 300,000 annual injuries are attributed to distracted driving-related accidents (National Highway Traffic Safety Administration [NHTSA], 2023). One key to reducing the risk of vehicular accidents is keeping drivers' eyes directed toward the road, rather than downward into the vehicle's cabin.

Head-Up Display (HUD) modules currently play a leading role in creating an augmented reality experience for drivers by projecting or displaying pertinent information onto a vehicle's windshield within the driver's ideal visual field, the area in which visual data is most accurately and efficiently processed by the human eye (Gish & Staplin, 1995).

Automotive AR overlays digital information, such as navigation cues or hazard alerts, directly onto the reality seen through a vehicle's windshield or other transparent display medium, enhancing user awareness and interaction (Billinghurst, Clark, & Lee, 2015). Its uses in automotive applications include:

- Real-time vehicle data, such as speed
- GPS navigation information, including real-time directional cues for turns
- Current speed limits, upcoming speed changes, and road signs such as stop signs
- Road hazard alerts and driver alerts

Automotive AR, which is created by combining HUD and a vehicle's windshield, provides a more cohesive, integrated driving experience with increased safety benefits by keeping a driver's eyes focused on the road.

The objective of this paper is to provide a comprehensive and in-depth compilation of the current state of AR integration in automotive glass applications, specifically windshields, to determine existing limitations and explore solutions. The scope of the paper includes:

- Industry Trends & Market Adoption
- Technical Foundations of AR in Automotive Glass
- Challenges & Barriers to Adoption
- Comparison of AR Windshield Technologies
- Future Trends & Research Directions
- Industry Recommendations

2. Industry Trends & Market Adoption

AR was initially suggested for fighter pilots in the 1940s, and the first aircraft with a non-gunsight HUD was flown in 1960 (Weintraub & Ensing, 1992). Automotive manufacturers brought it to production vehicles in 1988 (HUDWAY, 2023).

- 1988: Nissan was the first manufacturer to offer a HUD in the Japanese domestic market (JDM) with the 1988 Nissan Silvia S13.
- 1988: General Motors began using head-up displays. Their first HUD units were installed on Oldsmobile Cutlass Supreme Indy Pace Cars and replicas. Optional HUD units were subsequently offered on the Cutlass Supreme and Pontiac Grand Prix before becoming more widely available.

Today, more than 33 manufacturers offer HUDs in their vehicles. Many manufacturers offer HUD as an option on upper trim levels or special packages. Nearly all manufacturers make the technology available, but only to specific models (Cars.com, 2024). HUD is not yet considered a common option and is typically reserved for higher-end vehicles. However, as technologies progress and costs decrease, it is estimated that more vehicles will be equipped with HUD (Continental, 2022).

Advanced Driver Assistance Systems (ADAS) are becoming standard on many vehicles, and this technology integrates readily with HUD. As more drivers demand ADAS features, such as lane keep assist, adaptive cruise control, and other autonomous driving features, it is theorized that HUD demand will increase as well (Mordor Intelligence Research & Advisory, 2024).

3. Technical Foundations of AR in Automotive Glass

Head-Up Display (HUD) technology was first used by fighter pilots as early as 1942 (Pen & Sword, 2007). Functionality was rudimentary and limited to gunsights. By 1975, pertinent data for take-off, landing, and in-air flight, such as altitude, could be overlaid against the backdrop of the sky (CRC Press, 2001). HUD technology keeps the viewer’s “head up” rather than looking downward at gauges and controls. This not only decreased the time it took for pilots to look down at their gauges but also eliminated the need for their eyes to adjust to lighting and distance changes caused by looking inside the cockpit. (Wolffsohn et al., 1998)

The first fighter pilot HUDs evolved from reflector sights, using optics, a high-brightness cathode ray tube (CRT), and programmable waveform generation to project information onto a transparent screen in the pilot's line of sight (Fred H. Previc; William R. Ercoline 2004).

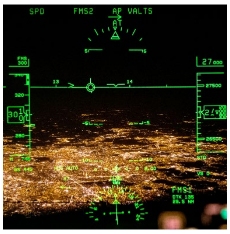

Fig. 1: Aviation HUD from a pilot’s view. Stock photo licensed from Canva Pro.

Today, automotive glass—specifically windshields—and HUD units play a critical role in AR technology. HUD systems use displays, such as LED, and a series of glass mirrors and lenses to project visuals onto a windshield. From the driver’s seat, this projected visual appears to float on the windshield, overlaying the real-world backdrop outside the vehicle. The HUD unit and the windshield are essentially the devices used to create AR, a viewer's perception of combining virtual and real-world assets into a single visual (Continental, 2022).

The introduction of AR use in automotive glass began with a simple HUD displaying only the driver’s ground speed (HUDWAY, 2023). Later iterations in the early 2000s included additional information such as engine RPM, fuel level, and other simple gauges in a single-color LED display. Adjustments for brightness and vertical positioning were possible through dashboard-mounted controls.

Fig. 2: Early simplistic HUD. Stock photo licensed from Canva Pro.

Today's HUD units are far superior, providing multicolor displays with data such as speed limits, GPS navigation directions, hazard warnings, active ADAS statuses, and many other beneficial safety advancements.

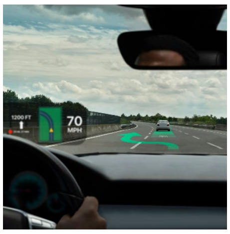

Fig. 3: Example of modern HUD capabilities. Stock photo licensed from Canva Pro.

4. Comparison of AR Windshield Technologies

Today's production vehicles primarily use a contained projected HUD unit inserted into the vehicle's dashboard, projecting an image onto the windshield in the driver's field of view. Common types of HUD include projected, holographic, and emissive.

4.1. Projected HUD

Projected HUDs project an image onto a treated section of the windshield in the driver's field of view (Gabbard, Fitch, & Kim, 2014).

As stated by Lumineq, projected HUD units are comprised of:

1. Data processing electronics
2. An LED display
3. A mirror reflecting the LED display onto a rotating mirror
4. A rotating mirror reflecting the image onto the windshield, adjustable for optimal positioning
5. A lens or filter to clarify the image
6. A special coating on the display area of the windshield (LUMINEQ, 2022)

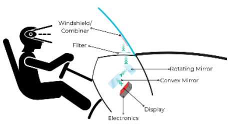

Fig. 4: Projected HUD diagram. Created by the author with Canva.

4.2. Holographic HUD

Holographic HUDs are more advanced than LED displays in that they emit a three-dimensional image as opposed to a two-dimensional image (Skirnewskaja & Wilkinson, 2022). The components and setup are similar to projected HUD but use lasers rather than LEDs. Holographic HUDs, due to their three-dimensional viewing, have the potential for a more holistic AR experience. This could be established by the driver interacting with floating objects using gestures.

4.3. Emissive HUD

Emissive HUDs sandwich an LED screen inside laminated glass. Emissive HUD units have fewer components and are generally more compact than projected HUDs (LUMINEQ, 2022). Emissive HUDs. They are comprised of:

1. Data processing electronics
2. A data transfer cable
3. A digital display
4. Emissive HUD types include:
5. Mini/micro light emitting diode (LED)

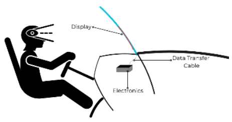

Fig. 5: Emissive HUD diagram. Created by the author with Canva.

5. Challenges & Barriers to Adoption

Despite the excitement, the road to widespread AR windshield adoption is not without obstacles.

5.1. Hardware Limitations

Projected HUD

The size limitations of projected HUD units are currently the primary barrier to a more immersive AR experience (Pablo Richter, 2019). The main way to achieve a larger display size with a projected HUD unit is by increasing the unit's size. However, due to dashboard size constraints and other dashboard components, enlarging projected HUDs is not practical.

Emissive HUD

Unlike projected HUD, which can account for windshield curvature using a concave mirror, emissive HUD units are embedded within windshield lamination. They must precisely account for windshield curvature to ensure practical implementation (WayRay, 2023).

Laminated Auto Glass (Windshield)

Windshields themselves present limitations for HUD systems. Projected HUDs require a specially coated windshield area to display images clearly. Uncoated windshields cause internal refractions, creating a "ghost" image that appears blurry or out of focus. For emissive HUDs, windshield curvature can skew the image, requiring precise calibration (Pablo Richter, 2019).

Software Limitations

Creating a cohesive AR experience requires aligning real-world inputs with timely virtual inputs. HUD information, such as turn-by-turn navigation, must occur exactly at the right moment without delay. Safety-related data, such as hazards, must be displayed with sufficient lead time (Gabbard, Fitch, & Kim, 2014).

User Adoption

Users must trust AR technology to adopt it effectively. If AR proves distracting rather than helpful, it may not gain widespread adoption. Currently, only the driver can view the HUD due to viewing angle limitations caused by the curvature of the windshield and its effect of reflecting the image.

Regulatory Compliance

Regulatory bodies play a critical role, especially concerning the driver's field of view. There is a delicate balance between providing useful data to enhance safety and minimizing distractions (NHTSA, 2023).

Economic Barriers

Adding technology options like HUD increases vehicle production costs. Projected HUDs have moderate costs due to existing production methods, but emissive HUD technology remains costly due to ongoing development (Gabbard, Fitch, & Kim, 2014).

6. Future Trends & Research Directions

The automotive HUD market is predicted to grow from $1.57B in 2025 to $4.62B by 2030, proving its place in the market (Mordor Intelligence Research & Advisory, 2024). HUD technology continues to lose exclusivity amongst only high-end vehicles and trim levels, gaining more adoption amongst economy automakers as regulatory bodies demand increased safety features for drivers.

Trends also show more data being displayed by HUD units, expanding deeper into multimedia usage, as well as providing earlier alerts for road hazards.

The shift into a true immersive experience, more closely aligned with the definition of AR, will begin once displays grow larger to can display information in relevant areas within the driver's field of view, as well as allow passengers to interact with objects on the screen using gestures. This development may also extend AR visibility to passengers, giving them insights into key data as well.

Future uses could include adaptations for other types of auto glass. Practically, this could mean entertainment for passengers through side windows or displaying messages on rear windows to alert those outside the vehicle to safety issues.

Fig. 6: Illustration of possible future HUD capabilities. Stock photo licensed from Canva Pro.

7. Conclusions & Industry Recommendations

Augmented reality is no longer a futuristic concept in automotive glass—it is an emerging reality already being implemented by the majority of automakers. While this technology was previously only available for high-end vehicles, it is now being implemented in economy brands, too. AR has been shown to increase safety by displaying timely and relevant information to drivers while keeping their eyes up and on the road, rather than downward and inside the vehicle (Gabbard, Fitch, & Kim, 2014).

Practically, the advancement of AR in the automotive market must overcome the issue regarding display size as the foremost hurdle. Holographic HUD provides the most promising technology by creating three-dimensional images that most closely match an immersive AR experience, but the size and position of the units may limit display size. This could be resolved through the use of multiple projectors, but costs must be considered (Skirnewskaja & Wilkinson, 2022). If holographic HUD does not prove promising, emissive HUD display technology must evolve to account for the curvature of windshields. Alternatively, carmakers could adopt flat windshields. Although nearly all manufacturers use curved windshields for safety and aerodynamic purposes, Tesla's Cybertruck windshield is an example of a mostly flat windshield. Integration will require partnerships between windshield manufacturers and automakers to determine viability. Achievement of this has the potential to significantly decrease injuries and deaths caused by distracted driving and poor visibility (NHTSA, 2023).

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