

Advance HMI for AI-Enabled Hardware and Applications

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Abstract

The evolution of Human-Machine Interfaces (HMIs) is critical to the success of AI-driven hardware applications. These interfaces must seamlessly integrate into devices, enabling intuitive interactions while supporting real-time data visualization and multi-sensing capabilities. MicroLED displays and micro sensor technologies offer solutions through their unique features, such as high brightness, low power consumption, transparency, and ease of integration.

1. Introduction

The rapid advancement of artificial intelligence (AI) has ushered in a new era of hardware applications, where intuitive and adaptive Human-Machine Interfaces (HMIs) play a pivotal role. These AI-enabled devices demand HMIs that go beyond traditional input-output functionalities to deliver seamless, context-aware, and non-intrusive user experiences. This paper explores the evolving requirements for HMIs in AI-driven systems, focusing on key design considerations such as transparent and non-intrusive displays, multi-sensing capabilities, and integration with advanced algorithms for real-time adaptability.

To achieve such a goal there is a need for non-intrusive displays that harmonize with the user environment while delivering high-resolution, low-power visual interfaces. Additionally, the integration of multi-sensing capabilities, such as environmental awareness, gesture recognition, and biometric sensing, is the cornerstone for enabling hardware to anticipate and respond to user needs dynamically.

MicroLED and microSensor transfer technology is a promising solution to achieve the major requirements for such advanced HMI. However, there are challenges associated with microLED such as scalability, yield, throughput, performance and cost.

By addressing these requirements, VueReal microSolid printing outlines a turnkey platform for designing, developing and manufacturing HMIs that not only enhance usability but also unlock the full potential of AI-enabled hardware in diverse applications, including consumer electronics, automotive systems, and industrial automation.

2. Autonomy

As self-driving vehicles rely on autonomy to navigate complex environments, the need for sophisticated Human-Machine Interfaces (HMIs) becomes more critical. Autonomous systems must continuously capture and process vast amounts of data from their surroundings to make real-time decisions. Equally important, these systems must effectively communicate this information not only to the vehicle's passengers but also to external parties, such as pedestrians, cyclists, and other vehicles (Figure 1).

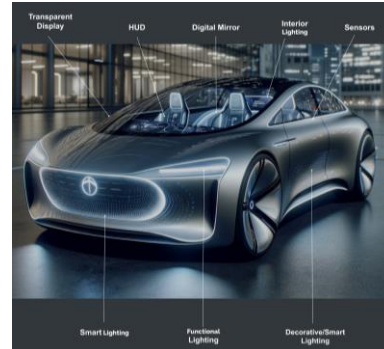


Figure 1: different interfaces in modern automotive applications.

Advanced HMIs play a pivotal role in bridging this communication gap through multi-modal interactions. For example, visual displays on the vehicle's exterior can provide real-time signals to pedestrians, indicating the car's next move, such as stopping at a crosswalk or yielding. Similarly, interior HMIs can ensure that passengers remain informed and confident about the system's decisions, enhancing trust and safety.

These HMIs must be designed to handle the unique demands of autonomous systems, including:

- **High-Resolution, High Brightness and High Transparency Displays:** For clear, non-intrusive communication with the surrounding environment.
- **Dynamic Adaptability:** Capable of adjusting content and modality based on environmental conditions and context.
- **Integration with Sensors:** Seamless integration with cameras, LiDAR, and other sensors to capture and relay real-time data.
- **Energy Efficiency:** Ensuring sustainable operation without compromising performance.

By enabling intuitive and effective communication between autonomous systems and their environment, HMIs are essential for ensuring safety, usability, and widespread adoption of autonomy across industries.

3. Enhancing Surrounding Awareness

In an increasingly interconnected world, the integration of Artificial Intelligence (AI) and Augmented Reality (AR) is transforming how we perceive and interact with our surroundings. These technologies will be playing a crucial role in enabling systems and individuals to achieve enhanced situational awareness (Figure 2).



Figure 2: Surrounding awareness is essential for fully immersive augmented reality.

AI acts as the brain of surrounding awareness systems, processing vast amounts of data from cameras, sensors, and other inputs in real time. It identifies, interprets, and predicts the behavior of objects and entities within the environment, ensuring that the system can make intelligent, data-driven decisions.

AR, on the other hand, acts as the visual layer of surrounding awareness. It overlays critical information onto the user's field of view, creating a seamless blend of the physical and digital worlds. By visualizing data processed by AI in a way that is intuitive and context-aware, AR empowers users to make faster, more informed decisions. For instance:

The synergy between AI and AR is particularly powerful in dynamic environments where real-time data analysis and intuitive visualization are critical. Together, these technologies enable systems to be highly aware of their surroundings, enhance human decision-making, and promote safety and efficiency across a wide range of applications.

These levels of integration and interaction is doable if compact systems are developed for both capturing multi-modal data from the surrounding areas and visualizing the extracted and generated data for the users seamlessly. The multi-modal data extraction can enable different HMIs and adaptable HMIs for different scenarios.

4. Enabling Advance Functional Designs

The evolution of display, sensor and lighting technologies is increasingly driven by the need to meet the stringent demands of modern applications, including automotive, consumer electronics, health, and fitness. Key attributes such as form factor, ease of lamination onto different materials and curvatures, reliability, and transparency play a pivotal role in unlocking advanced functionalities while enhancing design flexibility and user experiences.

4.1. Advanced Form Factors for Enhanced Design Flexibility

Modern applications demand displays, sensors and lighting solutions that break free from traditional rectangular, rigid formats. Flexible, thin, and lightweight form factors allow these technologies to be seamlessly incorporated into unconventional designs, such as curved surfaces, and foldable consumer electronics. For example:

- A) Automotive: Reliable and Flexible displays enable integration into curved interiors or exteriors, creating sleek, ergonomic interior or aerodynamic exterior designs while maximizing screen real estate. Furthermore, removing the bulky packaging enables more useful space in the compact interior space.
- B) Consumer Electronics: Foldable or rollable displays in smartphones and tablets offer greater portability without compromising screen size.
- C) Wearables: Ultra-thin, flexible sensors and displays conform to the human body, providing comfort and

functionality in devices such as fitness trackers and health monitors.

4.2. Ease of Lamination on Diverse Materials and Curvatures



Figure 3: future of health and fitness tracking using microSensor.

The ability to laminate displays and lighting components onto various materials, including glass, plastics, and metals, as well as conform to curved or irregular surfaces, is essential for next-generation designs. Laminating directly onto substrates with complex geometries ensures seamless integration while reducing assembly steps. Key benefits include:

- A) Automotive: Displays and lighting can be laminated onto curved windshields, instrument panels, or even exterior surfaces, enabling smart HUDs, ambient lighting, and dynamic vehicle exteriors.
- B) Health and Fitness: Displays and light strips laminated onto flexible polymer substrates can conform to wearable devices, ensuring comfort and durability during physical activities.
- C) Consumer Electronics: Lamination onto unconventional surfaces allows for edge-to-edge designs and infinity displays, enhancing the aesthetic appeal of devices like smartphones and smart home products.

4.3. Reliability for Diverse Operating Environments

Reliability is critical for displays and lighting systems that must operate under varying environmental conditions. Applications in automotive, healthcare, and wearables often expose these components to extreme temperatures, humidity, mechanical stress, and UV radiation. Reliable systems must maintain performance and durability under these conditions. For example:

- A) Automotive: Displays and lighting systems must withstand vibration, thermal cycling, and outdoor exposure, ensuring consistent performance over a vehicle's lifespan.
- B) Wearables: Devices in fitness and healthcare require materials that resist sweat, impact, and frequent bending or stretching.
- C) Consumer Electronics: High-reliability solutions ensure robust performance in portable devices subjected to everyday wear and tear.

4.4. Transparency for Multi-Functional Integration

Transparency is increasingly valued in applications where displays and lighting must coexist with other functional or aesthetic requirements. Transparent displays and lighting systems offer the advantage of creating non-intrusive interfaces while preserving visibility and design integrity. Applications include:

- A) Automotive: Transparent displays embedded in windshields or side windows enable HUDs and augmented reality overlays, enhancing safety and usability without obstructing the driver's view.

- B) Consumer Electronics: Transparent lighting in smart home devices creates ambient effects while maintaining a sleek and minimalist design.
- C) Healthcare and Fitness: Transparent light sources in wearable health monitors ensure unobtrusive integration with skin-mounted devices or transparent medical displays.

Materials such as transparent conductive films, microLEDs, and advanced polymers enable high levels of optical clarity while maintaining functionality.

5. MicroLED and MicroSensors

Integration of 100s to millions of micrometer size microLEDs and microSensors enable a new paradigm in hardware manufacturing. This technology has the potential to revolutionize several industries and accelerate adoption of new features in automotives, consumer electronics, AR/VR, health, fitness, autonomy, automation and more.

MicroLED and microsensor technologies bring a host of unique features that make them ideal for enabling the next generation of Human-Machine Interfaces (HMIs) required by AI-driven hardware. Their scalability, versatility, and performance allow for seamless integration into various applications, empowering devices to interact with users and their surroundings more effectively and efficiently.

5.1. Key Features of MicroLED and MicroSensors:

- A) High Brightness: MicroLEDs provide unparalleled brightness, ensuring visibility even in direct sunlight. This is critical for outdoor applications such as automotive displays, AR devices, and wearables.
- B) Low Power Consumption: Both microLEDs and micro sensors are highly energy-efficient, which is essential for portable devices, wearables, and systems with limited power sources.



Figure 4: display and lighting blend in the car structure.

- C) Transparency: MicroLED arrays can achieve a high degree of transparency, allowing for seamless integration into smart glass, heads-up displays (HUDs), and other non-intrusive display solutions.
- D) Ease of Integration and Lamination: These technologies are designed for straightforward integration into various substrates, making them compatible with curved, flexible, or rigid surfaces. This enables new design possibilities across industries.
- E) Thin and Lightweight: MicroLED and micro sensor solutions have a minimal footprint, ensuring that devices remain compact and lightweight while still delivering advanced functionality.
- F) Reliability: Built with robust materials and advanced manufacturing processes, these technologies offer long lifespans and consistent performance, even in demanding environments.

- G) Multi-Functionality: By combining display and sensing capabilities, microLEDs and micro sensors can enable interactive displays that also gather environmental data, perform biometric scans, or respond to user gestures.
- H) Customization: These technologies are highly adaptable, allowing for tailored designs to meet specific application requirements, from high-resolution displays to multi-sensor arrays.

5.2. Enhanced Transparency

The unique features of microLED and micro sensor technologies directly address the demands of advanced HMIs required by AI-driven hardware. These interfaces need to seamlessly blend into devices while delivering powerful performance, multi-modal interaction, and real-time adaptability.

Non-Intrusive Interfaces: With transparency and minimal design impact, microLEDs can create non-obtrusive displays, ideal for AR glasses, HUDs, and smart windows, which enhance situational awareness without disrupting the user's view.

To achieve high transparency, both backplane and frontplane need to be optimized.

Layer Optimization for Transparency: A key aspect of enhancing transparency in microLED displays is optimizing the material layers used in both the backplane and frontplane. Here, we removed the unnecessary layers from the opening areas, thereby reducing optical interference and maximizing transparency. Additionally, by positioning layers with potential optical distortions under opaque regions of the pixel, we reduce the haze effects. As demonstrated in Figure 5, the optimized backplane has significantly higher clarity.

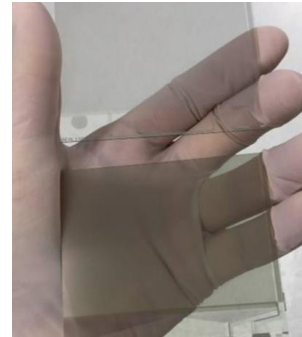


Figure 5. Original backplane (bottom) vs optimized backplane (top)

Sharing Pixel Circuits Between MicroLED Sub-Pixels: we used a microLED pixel architecture with shared pixel circuit approach to enhance display transparency. These switches selectively activate during each sub-frame, allowing the intended microLEDs to connect to the driving circuit in a precise sequence. To eliminate color breakout, each adjacent pixel has a different sub-pixel activated during each sub-frame. This structure is demonstrated in Figure 6.

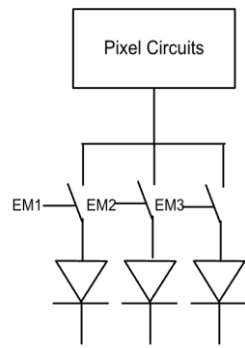


Figure 6. Shared pixel circuits between subpixels.

Figure 7 demonstrates 10" MicroLED display with transparency over 85% laminated to the side window of car. This display can be used as external communication in a robo-taxi applications.

To further enhance transparency and functionality, we have developed a new driving system based on micro-driver. Figure 8 shows the transparency of different resolutions based on micro-driver architectures. As it is demonstrated, even at very high resolutions, the display can achieve over 50% transparency.

7. Conclusion

MicroLED and micro sensor technologies are driving a new paradigm in Human-Machine Interfaces, enabling smarter, more intuitive interactions for AI-driven hardware. Their unique combination of high brightness, low power consumption, transparency, and multi-functionality positions them as foundational tools for next-generation devices.



Figure 7: high brightness laminated MicroLED display for robo taxi.

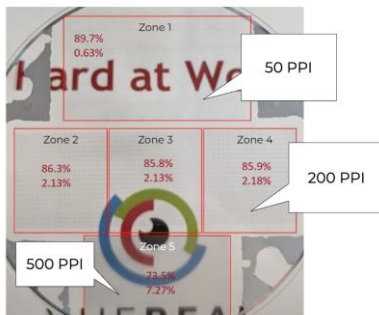


Figure 8: Microdriver display transparency as function pixel density.

VueReal's innovations, such as scalable manufacturing and customizable solutions, provide the framework for meeting the diverse requirements of industries like automotive, healthcare, consumer electronics, and AR/VR. By leveraging these technologies, we can build a more connected, adaptive, and efficient future for AI-enabled systems.

Acknowledgement

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References

- [1] R. Chaji, E. Fathi, H. Zamani, "Low-cost micro-LED displays for all applications," SID Digest, v. 48, pp. 264-267, San Jose, USA, June 2017.
- [2] R. Chaji, E. Fathi, H. Zamani, "Essential of MicroLED Production," SID Digest, v. 51, 323-327, online, June 2020
- [3] A. Paranjpe, et al., "MicroLED: key manufacturing challenges and solutions," v. 49, 579-600, San Jose, USA, May 2018.
- [4] F. Templier et al., "GaN-based emissive microdisplays: a very promising technology for compact, ultra-high brightness display systems," SID Digest of Technical Papers, 1013-1016, 2016.