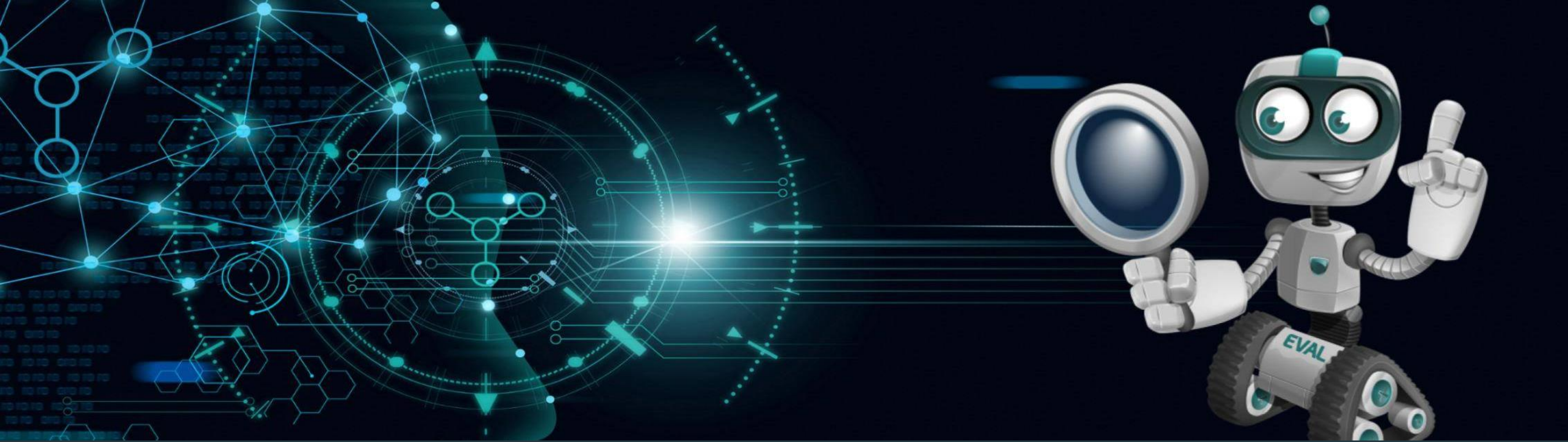
Optical See-through HMDs in Augmented Reality

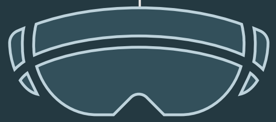
GROUP 6 (2021UCS1555-65)

CSE-1



Introduction to AR

Augmented Reality (AR) is a technology that enhances the real-world environment by overlaying digital information, such as images, videos, or 3D models, onto the user's real-world view in real-time. AR works by using devices like smartphones, tablets, or head-mounted displays (HMDs) to blend virtual elements with the physical world.



Examples of AR Applications

GAMING: Games like Pokémon GO overlay virtual creatures onto real-world locations for users to find and interact with.

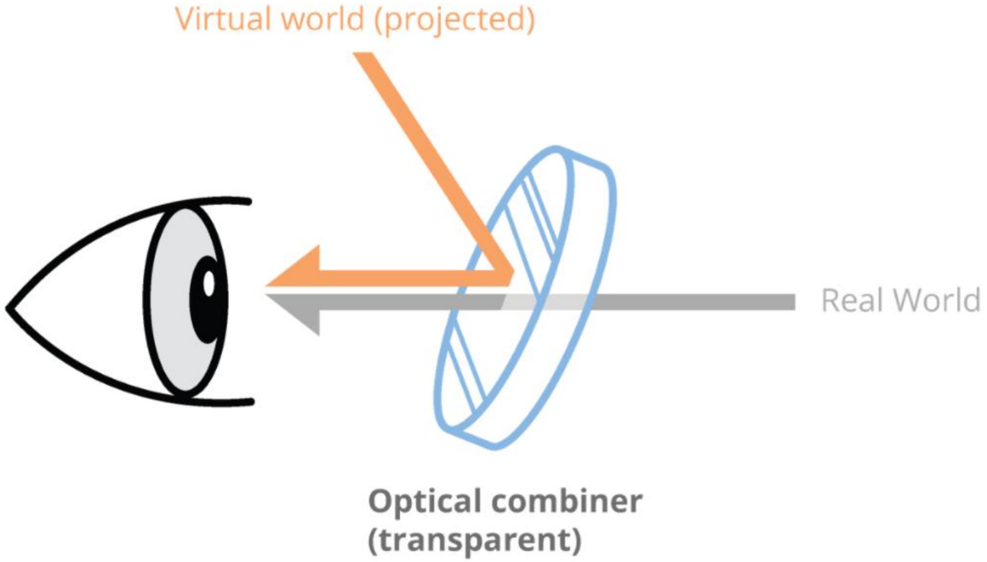
EDUCATION: AR enhances learning experiences by allowing students to view and interact with 3D models of concepts such as the solar system or human anatomy.

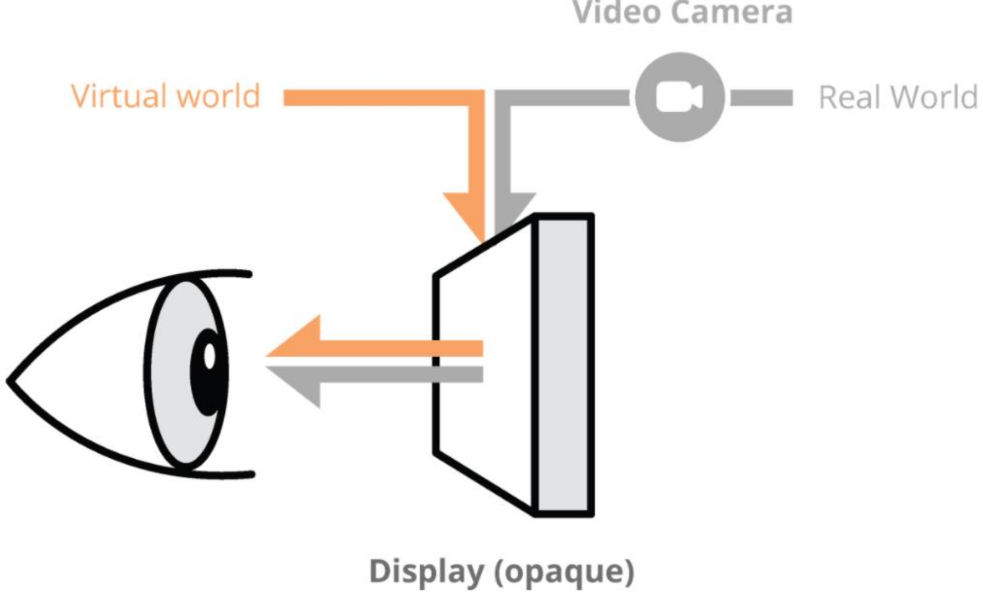
NAVIGATION: AR provides users with real-time navigation instructions, overlaying arrows or paths directly onto the view of the real world.

HEALTHCARE: Surgeons use AR to project real-time patient data or medical images during operations.

Introduction to HMDs

Head-Mounted Displays (HMDs) are wearable devices that position a screen or optical system directly in front of a user's eyes, providing virtual or augmented reality experiences. These displays either fully immerse users in a computer-generated world or seamlessly blend digital elements with the real environment, depending on the type of HMD.





Types of HMDs

1. **Optical See-Through HMDs (transparent display):** These HMDs allow users to see the real world through transparent optics, with digital information projected onto their field of view. The transparency enables a natural interaction with the real environment while displaying virtual elements on top.

- **Examples:** Google Glass, Microsoft HoloLens.

2. **Video See-Through HMDs (camera captures and processes the real-world view):** These HMDs capture the real-world view through external cameras and display it on internal screens. The real-time video feed is digitally combined with virtual elements, offering higher precision for visual manipulation. However, the real world is viewed indirectly through the video display.

- **Examples:** ZED Mini 3, Samsung Gear VR.

1. Real-World View:

- Optical See-Through HMDs (OST-HMDs): Allow users to view the real world directly through transparent optics, with digital content projected on top. This creates a natural blend of physical and virtual environments, but the alignment and occlusion of virtual objects can sometimes be less precise.
- Video See-Through HMDs (VST-HMDs): Capture the real-world view using cameras and display it on internal screens with digital elements integrated into the video feed. This provides higher control over the virtual-physical alignment, but the user's view of the real world is indirect, seen only through the screen.

2. Occlusion Handling:

- OST-HMDs: Struggle with occlusion, as it's difficult to fully block or obscure virtual objects behind real-world elements.
- VST-HMDs: Handle occlusion better since the real-world view is captured and digitally manipulated, making it easier to render virtual objects behind or around real-world items.

What is Optical See-Through HMD and how does it work?

Optical see-through HMDs allow users to see both real-world surroundings and virtual objects superimposed on them. This is achieved using transparent optics, which reflect light from digital displays while letting real-world light pass through. The virtual objects appear to float in the user's environment, allowing them to interact with both real and virtual elements simultaneously.

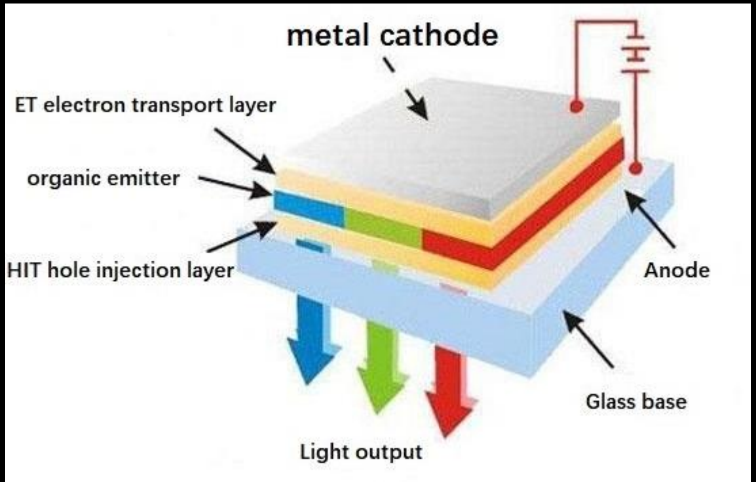
Key Components:

- **Optics:** Transparent or semi-transparent mirrors that reflect digital images while allowing users to see the real world.
- **Sensors:** Track the user's head position, eye movements, and the environment to adjust the virtual content accordingly.
- **Display:** Typically located on the sides, projecting virtual content onto the optics that blend it with the real world.

Display Technologies in Optical See-Through HMDs

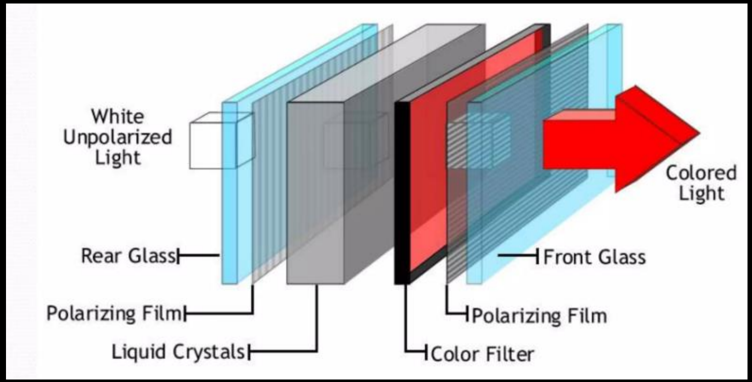
- **LCD (Liquid Crystal Display)**: Widely used for their affordability but can suffer from slower refresh rates and limited contrast in bright environments.
- **OLED (Organic Light-Emitting Diode)**: Offers better contrast, deeper blacks, and faster refresh rates. However, OLEDs can have a shorter lifespan and are more expensive.
- **Micro-LED**: Emerging technology that promises high brightness, excellent contrast, and low power consumption, making it ideal for AR applications.

LCD



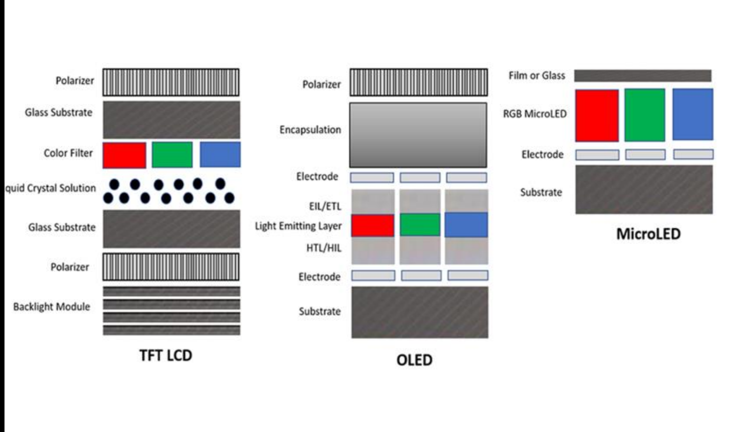
Cost-effective but may struggle in bright environments.

OLED



Excellent contrast but can be more power-hungry and expensive.

Micro-LED



Best suited for AR due to brightness and energy efficiency but still under development and expensive.

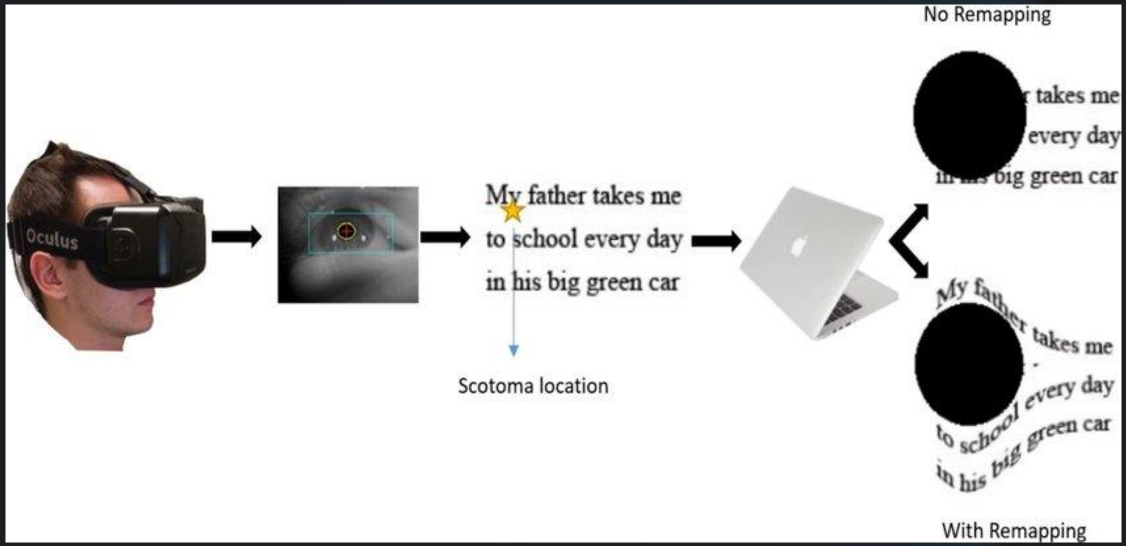
Tracking and Sensors in Optical HMDs

Accurate tracking is essential to ensure that virtual objects are properly anchored in the real world. Without precise tracking, the virtual elements can appear jittery or misaligned, breaking immersion and reducing the overall user experience.

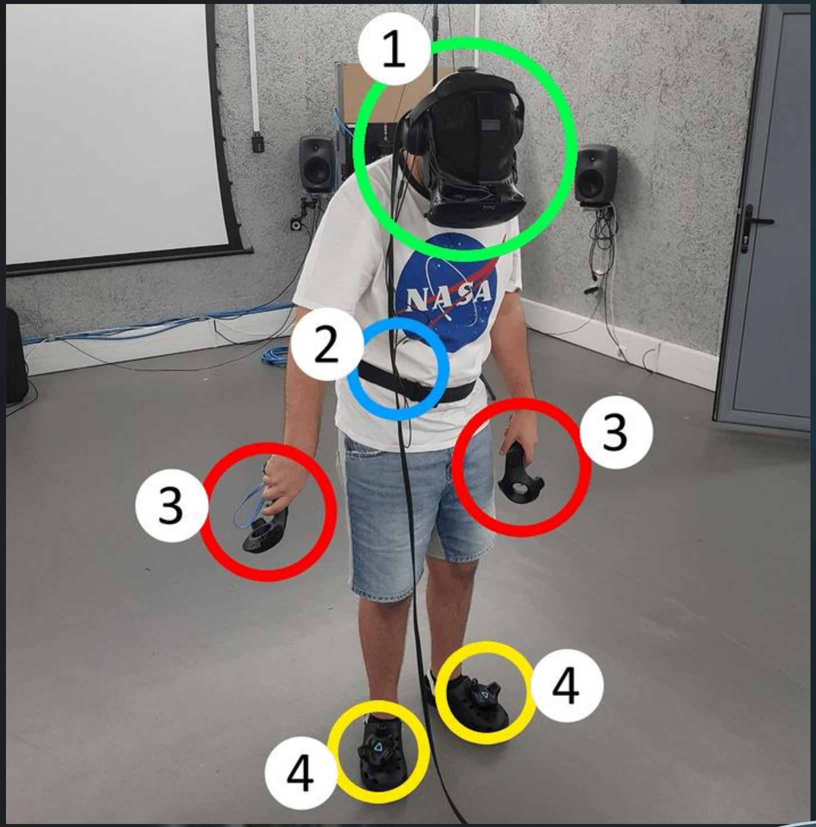
Types of Tracking

- **Head Tracking**: Tracks the orientation and position of the user's head to update the virtual content according to their viewpoint.
- **Eye Tracking**: Detects where the user is looking, allowing the system to adjust focus or interact with virtual objects based on gaze.
- **Hand Tracking**: Detects hand movements for gesture-based interactions with virtual elements.

Eye Tracking



Hand Tracking



Field of View (FoV) in Optical See-Through HMDs

- Field of View (FoV) refers to the observable area or the range of the user's vision that can be seen through the display at any given time., FoV is critical because it determines how much of the augmented content is visible relative to the real world.
- A **wider FoV** allows users to see virtual objects more naturally integrated into their environment, mimicking how they perceive the real world. Wider FoV allows a more immersive and realistic experience.

Current Limitations of FoV in Optical See-Through HMDs

1. Narrow Field of View: Currently, most Optical See-Through HMDs, such as the Microsoft HoloLens or Magic Leap, offer a FoV in the range of **30-50 degrees**. This is significantly smaller than the natural human FoV, which can span around 135 degrees horizontally and 180 degrees vertically which can feel restrictive and reduce the overall immersiveness.

2. Technical Challenge: One of the main challenges in increasing FoV in Optical See-Through HMDs is balancing **optical clarity, size, and weight**. Wider FoV requires more complex optics, which can increase the bulk and weight of the device, affecting user comfort and portability.

- Additionally, a wider FoV can be challenging due to **lens distortion** and **light transmission issues**.

3. How FoV is Being Improved in Optical See-Through HMDs:

- **Advanced Optical Systems**: New optics like **waveguides** and **freeform lenses** improve FoV by efficiently directing light, minimizing distortion, and keeping headsets lightweight and compact.
- **Lightweight Designs**: Manufacturers are using **lighter materials** and **holographic lenses** to expand FoV while reducing weight and maintaining user comfort.
- **Adaptive Rendering**: **Foveated rendering** focuses on high resolution in central vision, while **eye-tracking** dynamically adjusts visuals, optimizing FoV without overwhelming the hardware.

Applications of Optical See-Through HMDs

- **Healthcare:** Surgeons can use optical see-through HMDs to overlay crucial patient data, such as MRI or CT scans, directly onto the patient's body during surgery, improving precision and enhancing decision-making in real-time. It also assists in training medical professionals by enabling interactive simulations.
- **Military:** Optical HMDs provide soldiers with real-time data overlays, including maps, enemy positions, and navigation aids, directly in their field of view without blocking situational awareness. This technology improves battlefield coordination, decision-making, and safety.
- **Education:** In classrooms and training environments, optical HMDs enhance learning by projecting 3D models, simulations, and interactive lessons into the real world. Students can interact with digital content in an immersive way, making complex subjects like anatomy, engineering, or architecture more accessible and engaging.

Real-World Example: Microsoft HoloLens

One of the most notable optical see-through HMDs, the HoloLens is widely used in industries like architecture, healthcare, and manufacturing. It allows users to interact with augmented reality overlays without obstructing their view of the real world, enabling tasks like collaborative design, remote maintenance, and surgical planning. The device seamlessly blends digital and physical worlds, making it a powerful tool for professionals across various fields.

Challenges in Optical See-Through HMDs

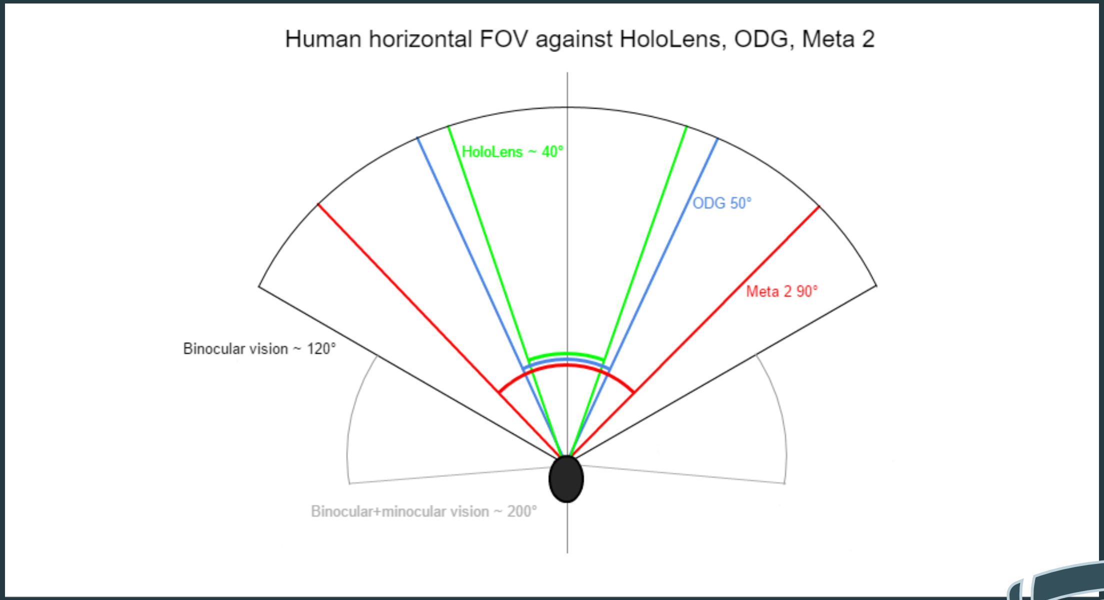
Field of View: Still narrow in most devices, limiting immersion.

Resolution: Maintaining high resolution while ensuring the optics are lightweight and transparent is a challenge.

Latency: Delays between real-world actions and virtual updates can cause disorientation.

Power Consumption: Balancing performance with battery life is critical for portable HMDs.

Current Solutions and Research Areas



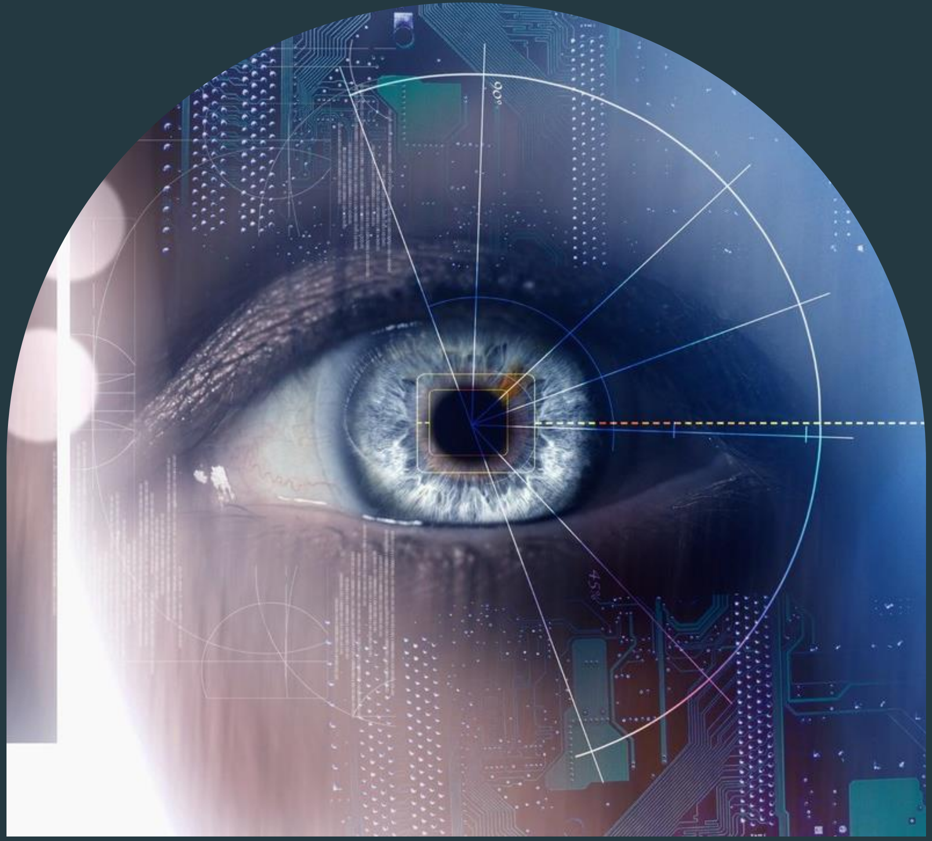
- **Expanded FoV**: Research is ongoing into new optical systems that can increase FoV without adding bulk.
- **Higher Resolution Displays**: Micro-LED and advanced OLED technologies aim to improve clarity and reduce power consumption.
- **Low-Latency Tracking Systems**: Development of faster sensors and algorithms to reduce tracking latency and improve real-time interaction.

Comfort and Ergonomics

- **Weight Distribution**: Ensuring the HMD's weight is evenly distributed to avoid discomfort during prolonged use.
- **Fit and Adjustability**: Head straps, padding, and customization options for various head sizes to enhance user comfort.
- **Visual Comfort**: High-quality optics to minimize eye strain, motion sickness, or fatigue during extended sessions.

User Experiences

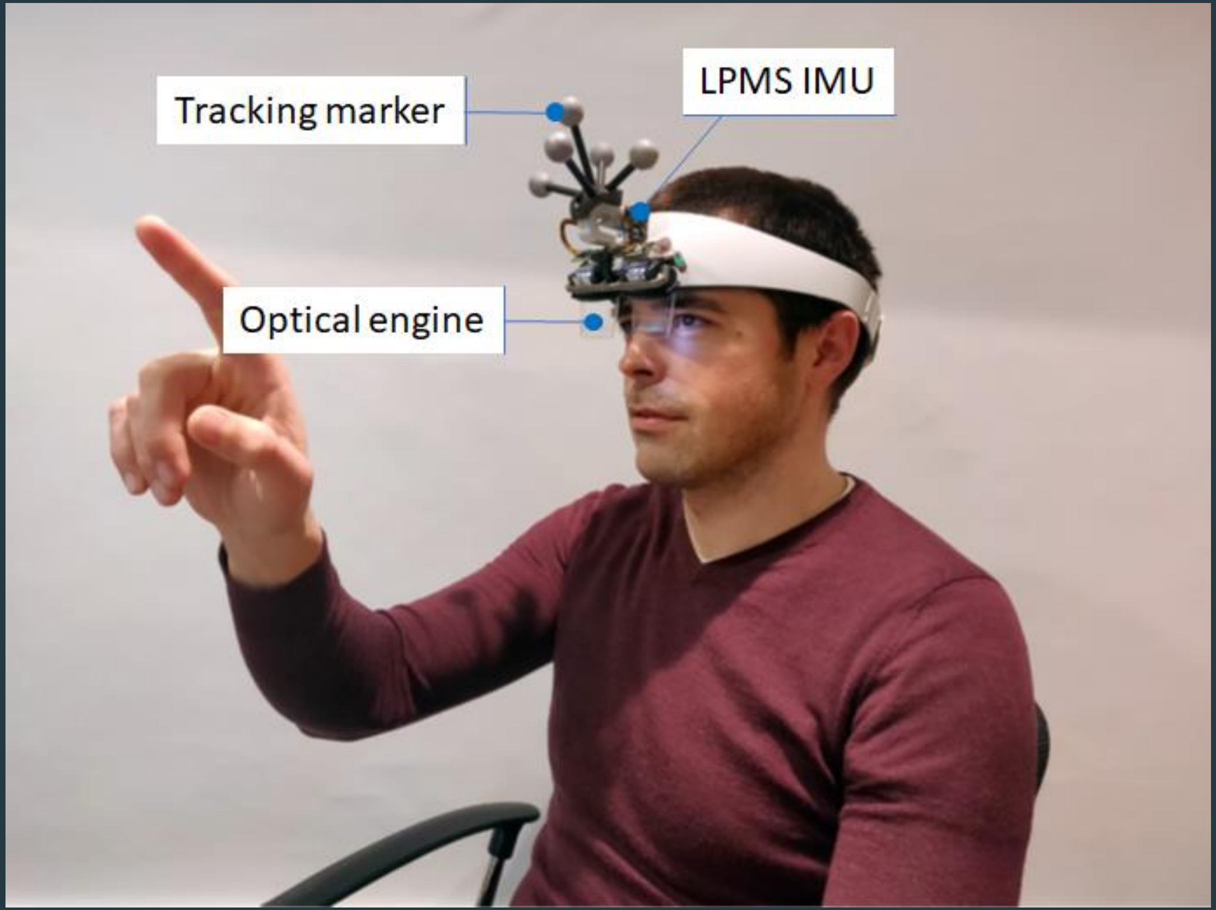
- **Ease of Navigation**: Designing intuitive menus and controls that are easy to navigate, especially when using gestures or voice commands.
- **Minimal Cognitive Load**: Simple and clear visual elements to reduce the user's cognitive burden and avoid overwhelming them.
- **Customizable Interfaces**: Allowing users to personalize their experience, such as changing display settings or interface layout.



User Experience and Interaction with Optical HMDs

Interaction Methods (Gesture-Based, Voice Commands, Controllers)

- **Gesture-Based**: Users can interact with virtual objects using hand movements, such as pinching, grabbing, or swiping in the air.
- **Voice Commands**: Users can control the system or interact with content using voice commands, often powered by AI assistants.
- **Controllers**: Physical controllers can be used for more precise interactions in complex applications.



Future Work

- **Enhanced Optical Systems**: Develop advanced waveguides and freeform optics to improve clarity, light transmission, and field of view.
- **Higher Display Resolutions**: Focus on micro-LED and OLED technologies for better brightness and resolution and explore retinal projection displays.
- **Improved Tracking Technologies**: Integrate AI for enhanced tracking accuracy and combine multiple tracking methods (head, eye, hand) for natural interactions.
- **User Comfort and Ergonomics**: Utilize lightweight materials and customizable designs to enhance comfort during prolonged use.
- **Broader Applications**: Investigate industry-specific solutions in fields like healthcare and education and integrate HMDs with IoT devices for real-time information.

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