Visual Displays (Part 1)

Reading: Understanding Virtual Reality (2nd Edition), Ch. 5, 259-300
Reality vs. Virtual Reality

In a virtual reality system, input and output devices exist in the loop between human perception and action.
Immersive Display Types

**Head-Mounted Displays (HMDs)**
- Oculus Rift
- Oculus Quest
- HTC Vive (Pro)
- Valve Index
- Windows Mixed Reality

**Head-tracked Displays (HTDs)**
- Single screen displays
- Surround-screen and multiscreen displays
- Workbenches and tabletop displays
- Arbitrary surface displays
- Autostereoscopic displays
General Display Properties

- Emitting Technology
- Spatial Resolution
- Temporal Resolution
- Color, Contrast, Brightness
Display technologies include liquid crystals, light-emitting diodes, digital light processing, and organic light-emitting diodes.
Spatial Resolution

Spatial resolution is a measure of visual quality.

This depends on both the number of pixels and size of the screen.

Commonly measured in dots per square inch (dpi) or cycles per degree.
Cycles per Degree

cycles per degree = number of pixels / (2 * FoV in degrees)

(1024 pixels per line) / (2 * 40 degrees) = 12.8 cycles per degree

Snellen acuity is (20/x), where x = 600 / cycles per degree

600 / 12.8 cycles per degree = 47
Snellen acuity = 20/47
Temporal Resolution

**Refresh rate** is the speed at which a visual display device refreshes the displayed image (Hertz).

Commonly confused with **frame rate**, which is the speed images are generated and placed in the graphics buffer.
Immersive Display Properties

- Grounding
- Display Channels
- Screen Geometry
- Field-of-view (FOV)

- Field-of-regard (FOR)
- Optics
- Focal Distance
- Latency
Grounding

Head-Grounded

Grounding is the point of contact between display screen and the world and/or the participant.
Grounding

World-Grounded

Grounding is the point of contact between display screen and the world and/or the participant.
Two simultaneous visual display channels with separate views are required for **stereopsis**.
Display Channels

- **Spatial** multiplexing consists of positioning separate images for each eye.

- **Temporal** multiplexing, or time interlacing, presents different images for each eye using active shutter glasses.

- **Polarization** multiplexing provides two separate image sources filtered through oppositely polarized filters.

- **Spectral** multiplexing, or anaglyphic stereo, displays the view for each eye in a different color.
Screen Geometry

- Screens come in a variety of different shapes including rectangular, circular, L-shaped, hemispherical, and hybrids.
- Projection mapping supports display on any surface.
Field-of-view (FOV) is the maximum number of degrees of visual angle that can be seen instantaneously on a display.
Field-of-Regard (FOR) is the amount of the physical space surrounding the user in which visual images are displayed.
Optics

- Optics allows images in a display worn close to the eyes to appear to be a further distance away.

- Optics are essential for virtual reality headsets.
  Even the cheapest cardboard display has a basic convex lens for each eye.

- Lenses have different optical features that can influence the displayed images.
Lens Features

- **Spherical aberration** distorts the shape of the image.
- Lines that are rendered as straight will appear curved.
- The graphics system must pre-distort the images.
Lens Features

- Chromatic aberration warps different color hues by different angles.

- Edges appear to have a ghost-like effect where one color continues on past the edge of the object.

- Greatest at the edges and perhaps imperceptible in the center of the view.
Chromatic Aberration
Focal Distance

The focal distance of a display is the apparent optical distance of the images from the viewer’s eyes.

With most current technology, all images are on the same focal plane regardless of their virtual distance from the viewer.
Latency is the delay (lag time) between user movements and display updates. All VR systems have some amount of “motion to photon” delay.

This can be stressful for the viewer’s perceptual system, which may manifest as nausea or headaches.
Logistic Display Properties

- Ergonomics
- Mobility
- Tracker Integration
- Light Pollution
- Environment Requirements
- Portability
- Throughput
- Safety
Ergonomics

Immersive displays should be:
Comfortable
Unobtrusive
Lightweight
Mobility can affect the immersion and usefulness of the VR experience. Tethered VR systems often require cable management.
Tracker Integration

The type of visual display can also influence integrated motion tracking. Tracking systems with a limited operating range or those that require cables will restrict the user’s movement.
Light pollution refers to excess visible light from external or internal source. This can interfere with visual presentation of the virtual world.

Most consumer headsets are attached tightly to the face, so interference from outside light is minimal.
Environment Requirements

The physical environment often determines which types of visual displays are appropriate.

Projection-based displays generally require a means of limiting the external light to maintain good contrast.

Background lighting is less important for headsets, but the size of the physical space is a major factor.
Portability
Throughput

Head-mounted displays are single user.

Projection-based systems can support multiple users.
Only one user can be the driver and receive the correct perspective.
Other users receive a distorted view.
Safety

There are safety issues involved with visual displays.

The most obvious problem with headsets is the risk of tripping or colliding with real-world objects.

Eye fatigue or nausea can also be a problem.
(don’t drive a car immediately afterwards)
# Immersive Display Types

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HMDs are *wearable displays* in which the device is attached (coupled) to the user’s head. Sophisticated device that requires the complex integration of electronic, optical, mechanical, and even audio components.

There have been numerous designs over the years.
HMD Ocularity

- **Monocular**
  Image goes to only one eye.

- **Biocular**
  Identical image to both eyes.

- **Binocular**
  Different but matched images to each eye (stereoscopic).
Interpupillary Distance (IPD)

- Horizontal distance between a user's eyes
- Display with too high IPD = eye strain, fusibility problems
- Display with too low IPD = reduced stereoscopic volume

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You should always remember to adjust the IPD when putting on a VR headset!
Simple Magnifier HMD Design

- Display images directly in front of the user’s eyes using one or two small screens
- Combination of refractive lenses and/or mirrors used to magnify the images
Thin Lens Equation

\[
\frac{1}{p} + \frac{1}{q} = \frac{1}{f}
\]

\(p\) = object distance  
(distance from image source to eyepiece)

\(q\) = image distance  
(distance of image from the lens)

\(f\) = focal length of the lens
Fresnel Lens

- A **Fresnel lens** consists of a concentric series of simple lens sections

- Thin lens with short focal length and large diameter
  
  Results in more even resolution distribution and less distortion.
LEEP Optics

Large Expanse Extra Perspective
Very wide FOV for stereoscopic images
Higher resolution in the center
Lower resolution on the periphery
Introduces pincushion distortion
FOV Distortions

Distance along z-axis
Collimated Displays

\[ \frac{1}{p} + \frac{1}{q} = \frac{1}{f} \]

What happens if \( p = f \)?

If the image source is placed at the focal point of the lens, then the virtual image appears at optical infinity.

This is useful for flight simulators.
Other HMD Terminology

**Exit Pupil**
The area in back of the optics from which the entire image can be seen. A large exit pupil is important if the IPD is not adjustable or the mount is not secure.

**Vignetting**
The blocking or redirecting of light rays as they pass through an optical system.

**Eye Relief Distance**
Distance from the last optical surface in the HMD to the front surface of the eye.
Head-Mounted Displays

Advantages
Complete visual immersion (360 FOR)
Each user can have their own HMD
No need for temporal multiplexing
More portable and less expensive than other immersive displays

Disadvantages
Accommodation-convergence mismatch
Must deal with weight and ergonomic issues
Cannot see the real world
Physical objects need graphical representations
Augmented Reality HMDs

**Optical see-through** displays place optical combiners in front of the user’s eyes.

Combiners are partially transparent and partially reflective, so user can see the real world and virtual images reflected on the head-mounted screens.

Provide direct view of real world with full resolution and no time delay.

Registration problems between the real and virtual world are highly visible.
Augmented Reality HMDs

**Video see-through** stream real-time video from head-mounted cameras to the graphics subsystem.

Can be achieved by mounting cameras to a regular virtual reality HMD.

Easier to support a wider field-of-view.

Real world typically has lower visual quality and introduces latency.
Participation Exercise

The participation exercise has been posted on Canvas.
Image Credits

- 3D User Interfaces: Theory and Practice (2nd Edition)
- Understanding Virtual Reality: Interface, Application, and Design (2nd Edition)
- Sabarish Babu, Virtual Reality Systems Course, Clemson University