PA198
Augmented Reality Interfaces

Lecture 3

Augmented Reality Displays

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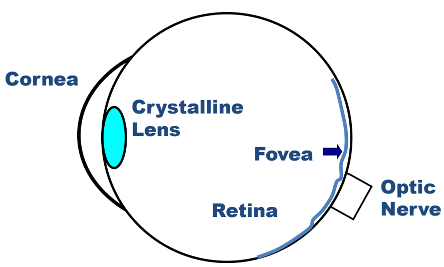
The Eye

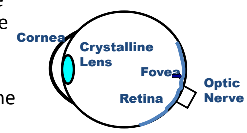
Basic Eye



Sherman & Craig, pp. 151-159

The Eye

- Accommodation describes the altering of the curvature of the crystalline lens by means of the ciliary muscles
  - Expressed in diopters
- Retina is the sensory membrane that lines the back of the eye and receives the image formed by the lens of the eye
- Fovea is the part of the human retina that possesses the best spatial resolution or visual acuity



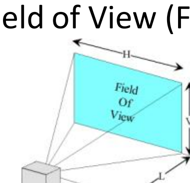
Sherman & Craig, pp. 151-159

Properties of the Eye

- Approximate Field of View
  - 120 degrees vertical
  - 150 degrees horizontal (one eye)
  - 200 degrees horizontal (both eyes)
- Acuity
  - 30 cycles per degree (20/20 Snellen acuity)

Sherman & Craig, pp. 151-159

Field of View (FOV)



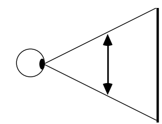
- The FOV the user can achieve at a given eye location limited by vignetting of off axis field angles
  - Vignet: reduction of an image's brightness or saturation at the periphery compared to the image center
- This will be limited by the eye relief and the FOV of the system

FOV limitations

- Eye must rotate to view off axis field angles
  - Eye point of rotation located 10mm behind pupil
  - Will cause translation of pupil
    - As the eye translates out of Eye Box the user will move eye closer to the system
      - Effectively decreasing the Eye Relief

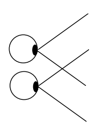
Monocular Field-of-View

- FOV may be measured horizontally, vertically or diagonally
- Monocular FOV is the angular substance of the displayed image as measured from the pupil of one eye
  - Usually expressed in degrees



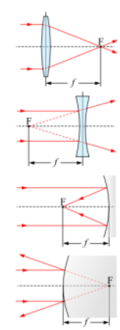
Binocular Field-of-View

- Total FOV is the total angular size of the displayed image visible to both eyes
- Binocular FOV refers to the part of the displayed image visible to both eyes
  - Also known as stereoscopic FOV



Focal Length

- The focal length of an optical system is a measure of how strongly the system converges or diverges light
- Represents the distance from the surface of a lens (or mirror) at which rays of light converge



The focal point F and focal length f of a positive (convex) lens, a negative (concave) lens, a concave mirror, and a convex mirror

https://en.wikipedia.org/wiki/Focal_length

Optics Characteristics

Diopter

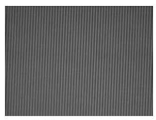
- The power of a lens is measured in diopters
  - Where the number of diopters is equal to:
    - 1/(focal length of the lens measured in meters)
- The main benefits over focal length
  - The lensmaker's equation has the object distance, image distance, and focal length all as reciprocals
  - When relatively thin lenses are placed close together their powers approximately add

https://en.wikipedia.org/wiki/Dioptre

Contrast Transfer Function (CTF)

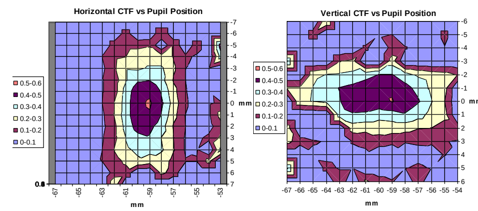
- CTF: measurement of contrast for a given spatial frequency square wave pattern

$$\text{Contrast(frequency)} = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}}$$



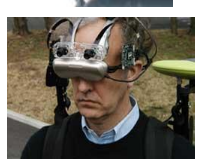
Example of square wave pattern displayed by HMD

CTF Depends on Pupil Position



- Horizontal and Vertical CTF both measured as function of pupil position
- Cutoff at 50% of CTF at ideal pupil position

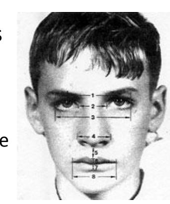
Ocularity



- Ocularity is another criterion for categorising HMDs:
  - Monocular
    - HMD image goes to only one eye
  - Biocular
    - Same HMD image to both eyes
  - Binocular (stereoscopic)
    - Different but matched images to each eye

Interpupillary Distance (IPD)

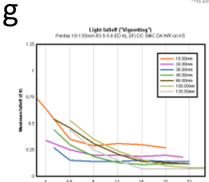
- IPD is the distance between the center of the pupils of the two eyes
- It is critical for the design of binocular viewing systems
  - Because both eye pupils need to be positioned within the exit pupils of the viewing system
- Viewing systems include
  - Binocular microscopes, night vision devices or goggles (NVGs), and head-mounted displays (HMDs)



https://en.wikipedia.org/wiki/Interpupillary_distance

Vignetting

- In optics, vignetting is a reduction of an image's brightness or saturation at the periphery compared to the image center
- An unintended and undesired effect caused by camera settings or lens limitations

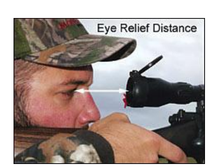


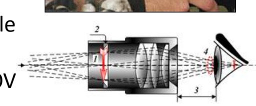
Example of vignetting characteristics dependent on focal length

https://en.wikipedia.org/wiki/Vignetting

Eye Relief

- The eye relief of an optical instrument (i.e. telescope, microscope, binoculars) is the distance from the last surface of an eyepiece at which the user's eye can obtain the full viewing angle
- If a viewer's eye is outside this distance, a reduced FOV will be obtained
- The calculation is complex

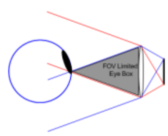




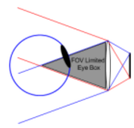
Optics showing eye relief and exit pupil.
(1) Real image, (2) Field diaphragm
(3) Eye relief, (4) Exit pupil

https://en.wikipedia.org/wiki/Eye_relief

Eye Relief Effect on Viewable FOV



Pupil placed at ER resulting in vignetting of off axis field angles (lose FOV at edges)



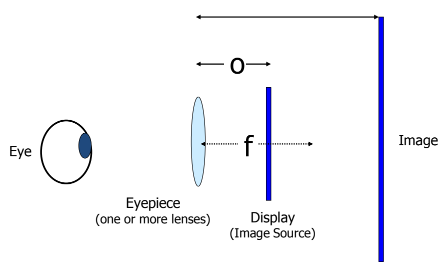
Eye point of rotation placed at ER resulting in reduced clearance between user's eye and the HMD, but vignetting minimized

Image-Forming Optical System

- An image-forming optical system is a system capable of being used for imaging
- The diameter of the aperture is a common criteria for comparison among optical systems
  - i.e. Large telescopes
- The traditional systems are:
  - Mirror-systems (catoptrics) - has a focal point
  - Lens-systems (dioptrics) - has a focal point
  - Optical fiber - transfers an image from one plane to another without an optical focus

https://en.wikipedia.org/wiki/Image-forming_optical_system

Simple Magnifier HMD Design



Sherman & Craig, pp. 151-159

Thin Lens Equation

- 1/p + 1/q = 1/f

  where

- p = object distance
  - Distance from image source to eyepiece
- q = image distance
  - Distance of image from the lens
- f = focal length of the lens

Thin Lens Equation Conventions

- If the incident light comes from the object, we say it is a real object, and define the distance from the lens to it as positive
  - Otherwise, it is virtual and the distance is negative
- If the emergent light goes toward the image, we say it is a real image, and define the distance from the lens to it as positive
  - f = positive for a converging lens
- A light ray through the center of the lens is un-deflected

Formulas

- Visual Resolution in Cycles per degree
  - (Vres) = Number of pixels /2(FoV in degrees)
- Example
  - (1024 pixels per line)/(2*40 degrees) = Horizontal resolution of 12.8 cycles per degree
- To convert to Snellen acuity (as in 20/xx)
  - Vres = 600/xx
  - So: Vres = 600/12.8 (20/47)

Sherman & Craig, pp. 151-159

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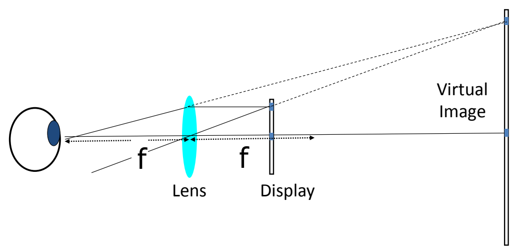
Virtual Image



Sherman & Craig, pp. 151-159

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Large Expanse Extra Perspective (LEEP)

- LEEP provides extreme wide-angle stereoscopic optics used in photographic and virtual reality systems
- Higher resolution (more pixels) in the middle of the field of view, lower resolution on the periphery
- Pincushion distortion

Photo courtesy of Leep Systems, Inc.
Figure 1. LEEP Optical Viewer

https://en.wikipedia.org/wiki/Eric_Howlett

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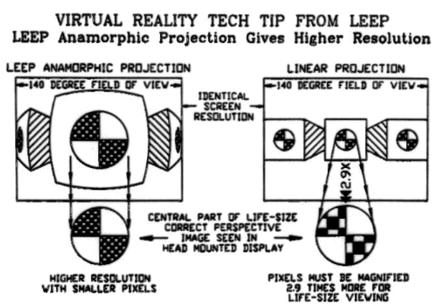
LEEP Standard



http://www.leepvr.com/sid1992.php

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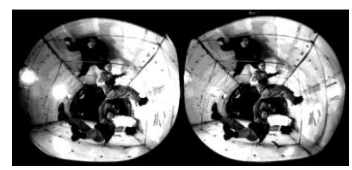
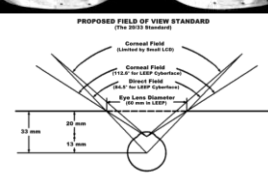
LEEP Standard





http://www.leepvr.com/sid1992.php

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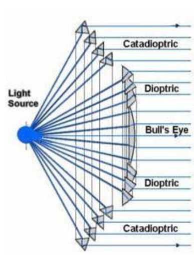
Fresnel Lens

- Lenses of large aperture and short focal length without the mass and volume of material
  - That would be required by a lens of conventional design
- Can be made much thinner than a comparable conventional lens
  - i.e. Using a flat sheet
- A Fresnel lens can capture more oblique light from a light source
  - Thus allowing the light to be visible over greater distances
- More even resolution distribution
- Less distortion



https://en.wikipedia.org/wiki/Fresnel_lens

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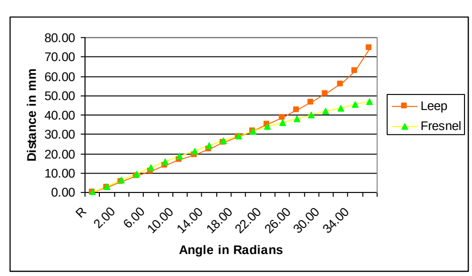
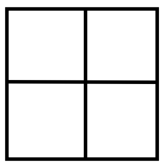
Relationship Between Angle and Screen distance

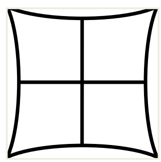


Sherman & Craig, pp. 151-159

Distortion in LEEP Optics

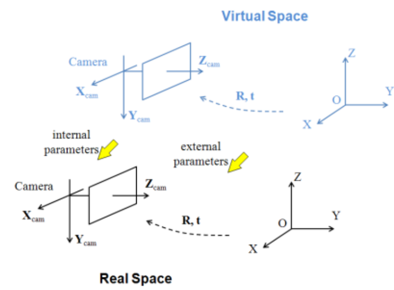


A rectangle



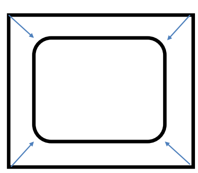
Maps to this

Camera Calibration



To Correct Distortion

- Must pre-distort image
- This is a pixel-based distortion
- Graphics rendering uses linear interpolation
- Too slow on most systems



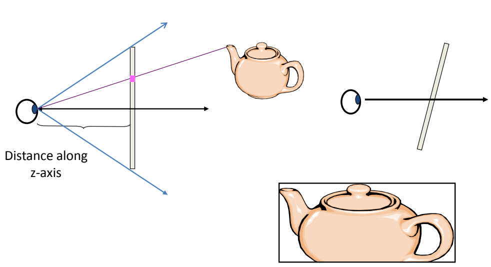
Sherman & Craig, pp. 151-159

Distorted Field of View

- Your computer graphics model assumes some field of view
- Scan converter may overscan or underscan
  - Not all of your graphics image may appear on the screen
- Problem
  - Are the display screens aligned perpendicular to your optical axis?

Sherman & Craig, pp. 151-159

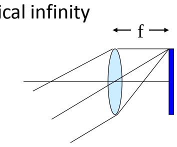
Distorted Field of View Example



Sherman & Craig, pp. 151-159

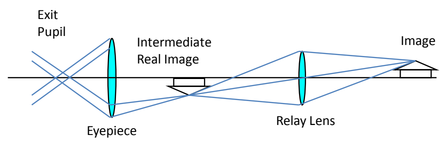
Collimated (o=f)

- Optical collimators can be used to:
  - Calibrate other optical devices
  - Check if all elements are aligned on the optical axis
  - Set elements at proper focus
  - Align two or more devices such as binoculars or gun barrels and gunsights
- If the image source is placed at the focal point of the lens, then the virtual image appears at optical infinity
  - $1/p + 1/q = 1/f \quad q = \infty$, if p=f



https://en.wikipedia.org/wiki/Collimator

Compound Microscope HMD Design



- Relay lens produces a real image of the display image source (screen) at some intermediate location in the optical train
- The eyepiece is then used to produce an observable virtual image of this intermediate image

Sherman & Craig, pp. 151-159

Exit Pupil

- The area in back of the optics from which the entire image can be seen
  - Important if IPD not adjustable, mount not secure
- Compound microscope optical systems have a real exit pupil
- Simple magnifier optical systems do not have an exit pupil

Sherman & Craig, pp. 151-159

Displays

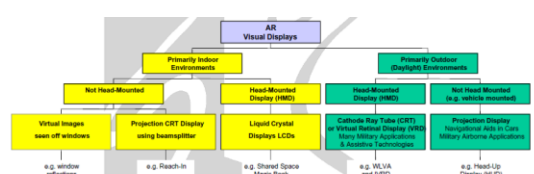
Visually Coupled Systems

- Integration of the natural visual and motor skills of a user into the system that is controlling
- Basic components include:
  - An immersive visual display
    - HMD, large screen projection (CAVE), dome projection, etc
  - A means of tracking head and/or eye motion
  - A source of visual information that is dependent on the user's head/eye motion

AR Displays Classification

- The most popular classification of display technologies can be categorized into:
  - Head mounted devices
    - Head up display (HUD)
    - Head mounted display (HMD)
    - Head Mounted Projector (HMP)
  - Non-head mounted devices
- Another one is split into (see next slide):
  - Indoors
  - Outdoors

Another AR Displays Classification



Heads-Up Displays

Heads-Up Displays (HUD)

- HUD is any transparent display that presents data without requiring users to look away from their usual viewpoints
- Origins on military where the pilot's eyes do not need to refocus to view the outside after looking at the optically nearer instruments
- Applications
  - Military aviation, commercial aircraft, automobiles, etc

https://en.wikipedia.org/wiki/Head-up_display

HUD Generations

- First Generation
  - Use a CRT to generate an image on a phosphor screen, having the disadvantage of the phosphor screen coating degrading over time
  - The majority of HUDs in operation today are of this type
- Second Generation
  - Use a solid state light source, for example LED, which is modulated by an LCD screen to display an image
  - These systems do not fade or require the high voltages of first generation systems
  - These systems are on commercial aircraft

https://en.wikipedia.org/wiki/Head-up_display

HUD Generations .

- Third Generation
  - Use optical waveguides to produce images directly in the combiner rather than use a projection system
- Fourth Generation
  - Use a scanning laser to display images and even video imagery on a clear transparent medium

https://en.wikipedia.org/wiki/Head-up_display

HUD for Car Video

https://www.youtube.com/watch?v=EQmd-3dBRXo

Head-Mounted Displays

Head Mounted Displays

- Optical System
- Image Source
  - CRT or Flat Panel (LCD)
- See-through or non see-through
- Mounting Apparatus
- Earphones
- Position Tracker

Characteristics of HMDs

- Immersive
  - You are inside the computer world
  - Can interact with real world (mouse, keyboard, people)
- Ergonomics
- Resolution and field of view
- Tethered

Modern HMDs

Video Head-Mounted Display

- Video head-mounted displays accept video from a camera and mix it electronically with computer graphics
  - Easier to perform registration and calibration
  - Watch a digital representation of the world
- Most popular method until now for AR

TriVisio

- Stereo video input
  - PAL resolution cameras
- 2 x SVGA displays
  - 30 degree FOV
  - User adjustable convergence
- $6,000 USD

http://www.trivisio.com/

Vuzix Display - Wrap 1200DXAR

- 4th generation
- 3 DOF head tracker
- Stereoscopic 3D video
- 16:9 or 4:3 aspect ratio
- 1920 x 1080 resolution
- Weighs less than three ounces

https://www.vuzix.com/

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Video See Through Example

https://www.youtube.com/watch?v=nEGtha40PUo

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Optical Head-Mounted Display

- Nowadays, see-through displays are lightweight with high-resolution optical devices
- However, certain inefficiencies remain such as sufficient:
  - Brightness
  - Resolution
  - Field of view
  - Contrast

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Optical Head-Mounted Display

- Various techniques have existed for see-through HMDs and can be summarized into two main families:
  - “Curved Mirror” (or Curved Combiner) based
  - “Waveguide” or "Light-guide" based
- The curved mirror technique has been used by Vuzix in their Star 1200 product, by Olympus, and by Laster Technologies
- Various waveguide techniques have existed for some time
  - These techniques include diffraction optics, holographic optics, polarized optics, and reflective optics

https://en.wikipedia.org/wiki/Optical_head-mounted_display

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Waveguide Techniques

- Diffractive waveguide
  - Slanted diffraction grating elements (nanometric 10E-9)
    - Nokia technique now licensed to Vuzix
- Holographic waveguide
  - 3 holographic optical elements (HOE) sandwiched together (RGB)
    - Used by Sony and Konica Minolta
- Polarized waveguide
  - 6 multilayer coated (25–35) polarized reflectors in glass sandwich
    - Developed by Lumus

https://en.wikipedia.org/wiki/Optical_head-mounted_display

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Waveguide Techniques .

- Reflective waveguide
  - Thick light guide with single semi reflective mirror
    - This technique is used by Epson in their Moverio product
- "Clear-Vu" reflective waveguide
  - Thin monolithic molded plastic w/ surface reflectors and conventional coatings
    - Developed by Optinvent and used in their ORA product
- Switchable waveguide
  - Developed by SBG Labs

https://en.wikipedia.org/wiki/Optical_head-mounted_display

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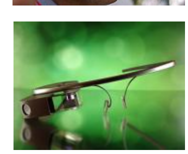
Google Glass

- Google Glass is based on OHMD technology
  - Displays information in a smartphone-like hands-free format
  - Wearers communicate with the Internet via natural language voice commands
- Available to the public on May 15 2014 for $1,500
  - Stopped on January 15 2015



https://en.wikipedia.org/wiki/Google_Glass

Innovega iOptik System

- It comprises a pair of contact lens which refocus polarized light to the pupil
- Allows the wearer to focus on an image that is as near as 1.25 cm to the eye
- Prototype features a field of view of 60 degrees or more
  - Aiming at 120 degrees FOV
- Designed for military use
  - A consumer version coming soon

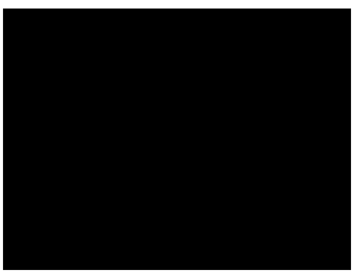
http://www.innovega-inc.com/index.php

Microsoft HoloLens

- First fully self-contained, holographic computer
  - Uses spatial audio
  - Limited FOV
- Features
  - Inertial measurement unit (IMU)
    - Includes an accelerometer, gyroscope, and a magnetometer)
  - Four "environment understanding" sensors (two on each side)
  - Energy-efficient depth camera with a 120°×120° angle of view
  - 2.4-megapixel photographic video camera
  - Four-microphone array
  - Ambient light sensor

https://www.microsoft.com/microsoft-hololens/en-us

Innovega iOptik System Video



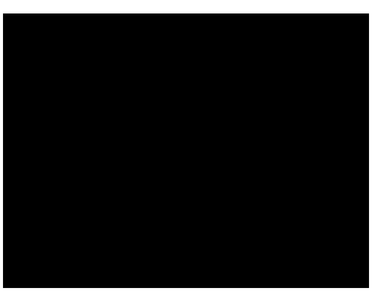
http://www.innovega-inc.com/videos.php

Pinlight Displays

- Wide Field of View Augmented Reality Eyeglasses using Defocused Point Light Sources
- Instead of conventional optics
  - LCD panel
  - An array of point light sources
- Coding allows for miniature see-through projectors

http://pinlights.info/

Pinlight Displays Video



http://pinlights.info/

Comparison of OHMDs Technologies

Combiner technology	Size	Eye box	FOV	Other	Example
Flat combiner 45 degrees	Thick	Medium	Medium	Traditional design	Vuzix, Google Glass
Curved combiner	Thick	Large	Large	Classical bug-eye design	Many products (see through and occlusion)
Phase conjugate material	Thick	Medium	Medium	Very bulky	OdaLab
Buried Fresnel combiner	Thin	Large	Medium	Parasitic diffraction effects	The Technology Partnership (TTP)
Cascaded prism/mirror combiner	Variable	Medium to Large	Medium	Louver effects	Lumus, Optinvent
Free form TIR combiner	Medium	Large	Medium	Bulky glass combiner	Canon, Verizon & Kopin (see through and occlusion)
Diffractive combiner with EPE	Very thin	Very large	Medium	Haze effects, parasitic effects, difficult to replicate	Nokia / Vuzix
Holographic waveguide combiner	Very thin	Medium to Large in H	Medium	Requires volume holographic materials	Sony
Holographic light guide combiner	Medium	Small in V	Medium	Requires volume holographic materials	Konica Minolta
Combo diffuser/contact lens	Thin (glasses)	Very large	Very large	Requires contact lens + glasses	Innovega & EPFL
Tapered opaque light guide	Medium	Small	Small	Image can be relocated	Olympus

https://en.wikipedia.org/wiki/Optical_head-mounted_display

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Bionic Contact Lenses

https://en.wikipedia.org/wiki/Optical_head-mounted_display

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Head Mounted Projector

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Head Mounted Projector

- Retro-reflective Material
- Potentially portable
- NVIS P-50 HMPD
  - 1280x1024/eye
  - Stereoscopic
  - 50 degree FOV

http://www.nvis.com/

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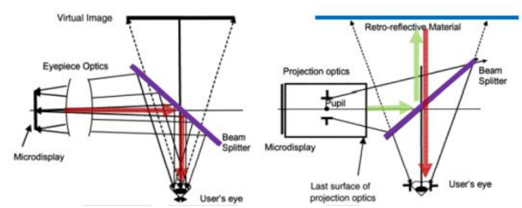
HMD vs HMP



Head Mounted Display

Head Mounted Projector

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Non-Heads Mounted Displays

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Non-Head Mounted Devices

- The most common non-head mounted displays can be categorised as:
  - Small Area Displays
  - Large Area Displays
  - Spatial Displays

Small Area Displays

- Small area displays are portable and thus be suitable for many VR applications
- The major disadvantages of these displays are the limited working area and resolution
  - Getting better!
- Small area displays have also illumination problems

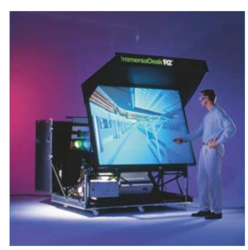
Small Area Displays .



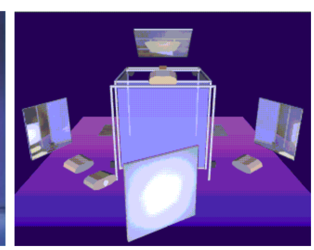

Large Area Displays

- Three basic configurations:
  - Front projection
  - Back projection
  - Conventional monitors
    - CRTs, LCDs TouchScreens and Plasma
- Users must use 3D glasses or HMDs
- The most significant disadvantage of large screen displays is the limited area of operation
  - i.e. Limitted movement

Large Area Displays

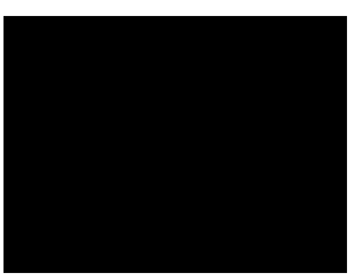


ImmersaDesk



CAVE System

AR for Large Screens Video



https://www.youtube.com/watch?v=EtYEtHHHJkc

Spatial Displays

Spatial Displays

- In contrast to small area displays spatial displays isolate most of the technology from the user and integrate it into the environment

- Large screens and spatially immersive displays extend the idea of ImmersaDesk using multiple projection screens and can be used to create a very effective and immersive experience

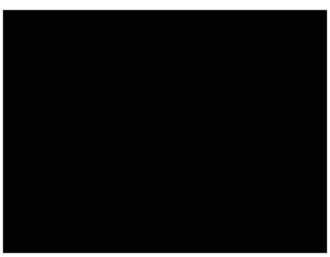
Spatial Displays .

- Nothing to wear and/or carry
- Uses digital projectors to display information
- Marker-based and markerless devices


AR Phone Keypad


AR Keyboard

Spatial AR Video



https://www.youtube.com/watch?v=Df7fZAYVAIE

Pico Projectors

- Extra small projectors
  - Microvision, 3M, Samsung, Philips

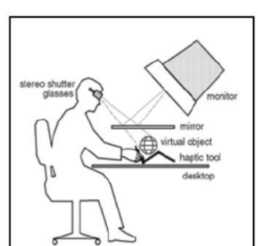
http://www.mvis.com/

MIT Sixth Sense

- Comprised of a pocket projector, a mirror and a camera
- $350 to build

http://www.pranavmistry.com/projects/sixthsense/

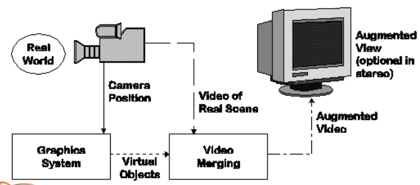
AR Haptic Workbench



AR Types

Monitor-based AR

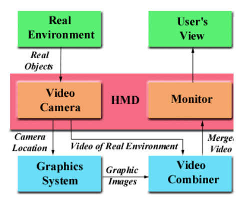
- Simplest available
- Treat laptop/PDA/cell phone as a window through which you can see AR world

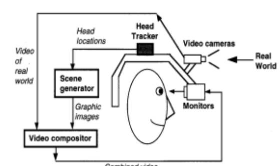


Advantages of Monitor-based AR

- Consumer-level equipment
- Most practical
- A lot of current research aimed here
- Other current active area is a flip-down optical display

Video See-Through AR





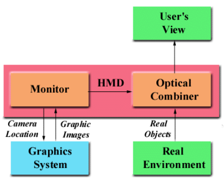
Advantages of Video See-Through AR

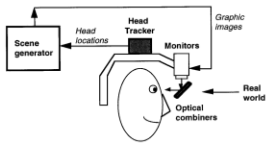
- Flexibility in composition strategies
- Real and virtual view delays can be matched
- True occlusion
- Wide FOV is easier to support

Disadvantages of Video See-Through AR

- Not easy to make ‘good’ quality photorealistic graphic scenes
- Can be more expensive

Optical See-Through AR





Advantages of Optical See-Through AR

- Safety
- Light weight
- Simplicity (cheaper)
- Resolution
- No eye offset

Disadvantages of Optical See-Through AR

- Prone to lighting conditions
- Registration much harder!
- Optics are not yet there

Other AR Types

Eye Multiplexed AR Approach

- Let users combine the views of the two worlds mentally in their minds
  - The virtual scene is registered to the physical environment
  - The rendered image shows the same view of the physical scene that the user is looking at
- However, the rendered image is not composited with the real world view
  - Up to the user to mentally combine the two images in their minds

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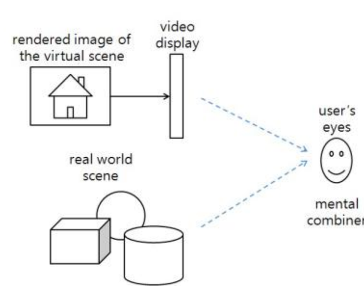
Eye Multiplexed AR Architecture



Billinghurst, M., Clark, A. Lee, G. A Survey of Augmented Reality, Foundations and Trends in Human-Computer Interaction, Vol. 8, No. 2-3 2014

Other Sensory Displays

Billinghurst, M., Clark, A. Lee, G. A Survey of Augmented Reality, Foundations and Trends in Human-Computer Interaction, Vol. 8, No. 2-3 2014

Alternate Displays

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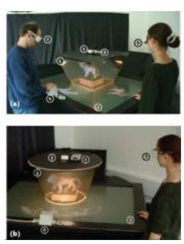
Virtual Showcase

- Mirrors on a projection table
  - Head tracked stereo
  - Up to 4 users
  - Merges graphic and real objects
  - Exhibit/museum applications
- Fraunhofer Institute (2001)



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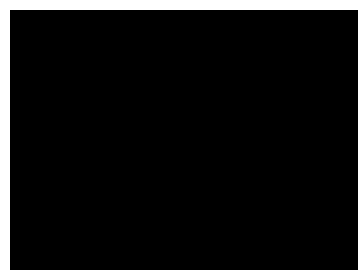
Augmented Paleontology



Questions

Acknowledgements

- Special Thanks to Prof. Mark Billinghurst