Outline of today’s lecture

• Display technologies
• Ways to accomplish stereoscopic and other 3D
• Implications when integrating 3D display systems
• Virtual Reality and Augmented Reality
Physiological Aspects

Visual Acuities (see next slide) (depends on visual task and luminance)

Visual Field: approx. 200°, with 120° binocular overlap

Limits of depth perception from lateral disparity

Temporal Resolution: approx. 50 Hz, increasing with luminance

Physiological Aspects - Visual Acuities

Point acuity: 1 minute of arc
Grating acuity: 1-2 minutes of arc
Letter acuity: 5 minutes of arc (5.8 mm at 4 meters distance)
**Stereo acuity: 10 seconds of arc**
**Vernier acuity: 10 seconds of arc**

Acuity fall-off across visual field: Compare figure 2.18
Several receptors interconnected -> superacuity
Acuity depends on brightness/contrast
Acuity depends on color (e.g. weak blue)
Physiological Aspects

Spectral sensitivity of photoreceptors

Three types of receptors
- Blue receptors: 450 nm +/- 30 nm
- Green receptors: 550 nm +/- 40 nm
- Red receptors: 600 nm +/- 35 nm

Visual Displays - Basic Technologies

- Cathode Ray Tubes (fast forward)
- Flat Panel Displays
  - ELD (Electroluminescence Displays)
  - LCD (Liquid Crystal Displays)
  - TFT (Thin Film Transistor LCD)
  - OLED (Organic Light Emitting Diodes)
  - SED (Surface-Conduction Electron-Emitter Display)
- Micro Mirror Devices
Basic Technologies - Cathode Ray Tubes (CRT)

Components:
1. Cathode (electron gun)
2. Electron beam
3. Focusing coils
4. Deflection coils
5. Anode connection
6. Mask for beam collimation
7. Phosphor layer composed of different sub-pixels
8. Closeup of (7.)

Advantages:
- high resolutions
- easy to control
- reliable technology
- low cost
- fast

The role of the phosphor coating:
- **Fluorescence** (glowing when hit by electron beam)
- **Phosphorescence** (after glowing while being activated)
- **Persistency** (time until glowing phosphorescence decreases below 10%) typically 5-60 milliseconds.

- Persistency is important. Short persistency requires high update rates otherwise flicker. Long persistency causes stable but smeary images.

- **Granularity** of the phosphor -> spot size, image resolution

- **Type of phosphor** defines color:
  - p1 : green, average persistency
  - p4 : white, short persistency
  - p12 : orange, average persistency
  - p31 : green, short persistency

Picture source: Wikimedia Commons
How is color accomplished in displays?

Most usually, colors are mixed by additive composition of base colors

1. Spatially modulated color composition

2. Temporally modulated color composition (see next slide)

Color shutter technology.

- Sequential display of color fields on monochromatic CRT
- Synchronization of the fields with color filters

- Filters can be:
  a) LCD filters (electronically controlled)
  b) Optical filters (mechanically coupled)

- Advantages: No color convergence errors
- Disadvantages: High frequent oscillations in the visual field decompose colors
Liquid Crystal Displays

No electric field = light passes through

Pixel Addressing:

Deposit an electronic charge on intersections between horizontal and vertical electrodes sequentially row by row.

Limited speed, since certain minimum time is required to is deposited (depending on the capacity of the intersections)

When last row has been addressed, first rows have already lost their electric charge

Poor contrast image
Basic Technologies - Flat Panel Display

Thin Film Transistor Matrix (TFT):

An array of transparent transistors is deposited on the LCD.

Pixels can be switched on and off.

Pixels can keep their electric voltage levels and hence their optical properties.

=> Significant contrast and intensity enhancements.

Basic Technologies - Flat Panel Display

Color reproduction / Optical Efficiency:

Groups of adjacent pixels are forming one effective color pixel.

Sub-pixels are covered with color filters.

Common sub-pixels configuration are RGB stripes, triads or quads.

Efficient resolution is reduced.

Light intensity is diminished significantly when passing through polarizes, liquid crystals, and color filters (poor optical efficiency).

(see also page 96)
Basic Technologies - Flat Panel Display

Electro Luminescence Displays (plasma panel displays):

Gas is encapsulated between electrodes

When a certain amount of voltage is applied (striking voltage) the plasma discharges and glows until the potential drops below the discharge voltage.

Plasma cell keeps “glowing” for a while without being refreshed.

Active luminance, high intensity display

Sandwich Technique

vertical transparent electrodes

glass substrate with plasma cells (Neon, Argon)

horizontal transparent electrodes

glass
Basic Technologies - Micromirror Devices (MMD)

- Matrix of micro mirrors
- Addressable and electronically controllable
- Used for Light Reflection and Projection Display Systems
- Very high optical efficiency

Basic Technologies - Micro Mirror Devices (MMD)

MMD System Working Principle

Light intensity controlled by pulse code modulation (PCM)
Basic Technologies – OLED (Organic Light Emitting Diodes)

Specific organic materials (polymer chains) emit light when a current is applied

Matrix Display same as in TFT Displays – Transistor Arrays

Thin organic layers serve these displays as a source of light.
No backlight illumination required

Benefits:
• Brighter and more brilliant picture
• Unlimited viewing angle
• Low power consumption
• Economic production (can be “printed”)
• Fast "response time"
• Large and flexible (thin film technology) -> “Video Wallpaper”

http://www.oled-display.info/
Basic Technologies – SED (surface-conduction electron-emitter display)

- Same working principle as in CRT displays
- Light emission based on phosphorescence
- An array of “electron guns” tightly packed nearby pixels

http://www.oled-display.info/SED-TV-technology.pdf
3D Display Categories

Stereographic Displays
(2 projected planar views)

- Dual Display
  - Immediate Mode
- Single Display Plane
  - Multiplexed

True Volumetric Displays

- Temporal MUX
- Spatial MUX
- Chromatic MUX
- Polarization MUX
- Spectral MUX

Dual Display Immediate Mode

Dual Channel Head Mounted Display (HMD) (© nVision)
Temporal Multiplexing and “Ghosting”

Time Multiplexed Stereo Image Pair

V-Sync at 60 Hz

Additional V-Sync at 120 Hz
(enforced with sync. doubler)

V-Sync at 60 Hz

Active Shutter Glasses
(LCD-Shutters)

Temporal Multiplexing and “Ghosting”

Two Pixels are Drawn On-Screen:
Purple Pixel for the Right Eye
Green Pixel for the Left Eye
120Hz screen refresh rate

Pixel Intensity (Phosphor)

Shutter Opacity Left Eye

Shutter Opacity Right Eye

0% 100% 0% 100%

Open Right Close Left
Close Right Open Left
Open Right Close Left
Open Right Close Left

Left eye sees purple pixel due to after-glowing
Right eye sees green pixel due to shutter response
Spatial Multiplexing

The stereo image pair is presented on alternating pixels, pixel columns, or scan-lines.

Optical arrangements are used to block-out the wrong image for the corresponding eye.

Effective resolution is reduced.

Chromatic Multiplexing – Anaglyph Technique

Complementary Colour Mixing
Chromatic Multiplexing - Anaglyph Technique

**Encoding:**
A stereo image pair is combined into one so-called anaglyph.

The left eye view is encoded with the red colour component.

The right eye view is encoded with the complementary colour, i.e. green and blue colour components.

**Decoding:**

The left eye uses a red colour filter that passes through the dominant red components.

The right eye uses a cyan colour filter that passes through dominant blue and green components.

Images courtesy: [http://axon.physik.uni-bremen.de/research/stereo/color_anaglyph/index.html#ana](http://axon.physik.uni-bremen.de/research/stereo/color_anaglyph/index.html#ana)

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Chromatic Multiplexing - Anaglyph Technique

Conventional filter materials are used to separate the color spectra of a stereogram.

Image splitting by chromatic separation.

- Spectrum of the cyan filter
- Spectrum of the red filter
Light Polarization Multiplexing

Whiteboard

Practical example
Spectral Filtering – Infitec Teknology

Narrow band spectral filters allow different select sub-bands of the tri-stimulus spectra.

Advantage: Filter-based optical multiplexing
Which allows for "natural color" stereo image separation.

Combined Temporal and Filter Multiplexing

The stereo image pair is displayed on-screen using a time multiplexing scheme.

The Z-Screen is an active optical polarizer, that alternates the direction of the transmitted light.

The user wears passive glasses that do not need synchronization.

Observe: Loss of luminance
3D Displays and Optical Systems - Projection Systems

3D Projection Display Systems require:

Very high intensity image source
- Transmission LCD/TFT Panel + Light Source
- Reflection LCD/TFT Panel + Light Source
- Projection CRT (specialized high intensity CRT tube)
- MMD
- Light Valve
- (Laser)

Focusing optics/color splitter
- Wide / narrow angle optics, fixed or variable

Projection screen
- Transparency / Diffusion / Specular Properties

Means of splitting left/right channel
- Time Multiplexing / Chromatic Separation / Light Polarization

3D Displays and Optical Systems - Projection Systems

3D Front Projection Systems:
Image source and observer are located on the same side of the projection surface
(- user may interfere with projection beam)

Stereo 3D with active shutter glasses
- requires very fast image source (>120 Hz)
- high speed DLP projectors
- single graphics pipeline
- screen with good diffuser properties

Stereo 3D with passive polarizing glasses
- requires two image sources
- image alignment problems
- dual graphics pipeline required
- requires special silver screen which preserves polarization

Stereo 3D with spectral separation (Infitec)
- dual projector setup
- image alignment problems
- screen with good diffuser properties
3D Displays and Optical Systems - Projection Systems

3D Rear / Retro Projection Systems:

- Image source is positioned behind the projection screen
- No interference between user and image source
- Requires transparent screen material
- Polarization 3D stereo is problematic since polarization is affected in transmission

Stereo 3D with active shutter glasses
- requires very fast image source
- High Speed DLPs
- Relatively expensive for large projection sizes
- Single graphics pipeline

3D Displays and Optical Systems - Projection Systems

3D Rear / Retro Projection Systems: Examples

- Caves
- Virtual Planes
- Viewing wands
3D Displays / Optical Systems - Autostereoscopic Displays

Autostereoscopy - stereoscopic perception with the “naked” eye

**Image Splitter (e.g., Sanyo)**
*(Light Barrier Mask)*

- Display divided in vertical stripes
- Alternate stripes display left and right image
- Slit-mask is blocking out the view of the left eye onto the right picture and vice versa
- Only a single user
- Dedicated observer position
- Horizontal resolution decreased

![Image Splitter Diagram](image)

3D Displays / Optical Systems - Autostereoscopic Displays

**(Double) Lenticular Lens Arrays**

- Display divided in vertical stripes
- Alternate stripes display left and right image
- Half-Cylinder shaped lenses project the stripes to the corresponding eye
- Several viewing zones
- Dedicated observer distance
- Horizontal resolution decreased

![Lenticular Lens Arrays Diagram](image)
3D Displays / Optical Systems - Autostereoscopic Displays

Examples (Heinrich-Hertz Institute, Berlin)

- Allows for user movements
- Uses head-tracking
- Screen is automatically positioned correctly with a robot arm
- Allows for user movements
- Uses head-tracking
- Lenticular array is shifted

3D Displays / Optical Systems - Volumetric Displays

The display creates a real volumetric representation which is perceived as a 3D structure without the need for glasses or other aids.

The idea is to project dynamic images onto oscillating or rotating surfaces in order to create the sensation of a volumetric object.

Prototypes have been built using:
- rotating LED matrices
- rotating helical projection surfaces with laser projection laser
- lasers projecting into fog
- experiments are underway to bring a solid crystal to illumination on addressable positions

All these systems can only show transparent/monochrome objects

Mechanical problems and limits, dead viewing areas

Commercial systems are far ahead
3D Displays / Optical Systems - Volumetric Displays

Visions in 1993

Image © Actuality Systems
http://www.actuality-systems.com/
Siggraph 2001

LightSpace Technologies®: Depth Cube

http://www.lightspacetech.com/

• Display with 20 different depth layers
• Depth resolution limited to
• Time sequential projection of depth layers
• Limited observer position

http://www.lightspacetech.com/
Choice of VR Displays - Evaluation of Requirements

How many observers are watching at the same time?

What resolution and color fidelity requirements are there? -> basic display technology

Is wide field of view desirable?

Is immersion an important issue for the application?

Is stereoscopic 3D rendering required?

If yes, decide which type
  • one screen polarized -> take care for optical properties of the system
  • one screen time multiplexed -> display must tolerate high refresh rates
  • dual screen (HMD) -> check for resolution
  • autostereoscopic?

Does the application require interaction with haptic stimuli?

3D Displays and Optical Systems - Projection Systems

Considerations with regard to stereo image projection

Time-multiplexing with active shutters:
  • both front and retro projection possible
  • active glasses are quite expensive (if many are required)
  • very high speed projector is required (light valve technology, expensive)

Polarized filtered images:
  • projection screen must preserve polarization (aluminized silver screen)
  • retro projection not yet possible (no suitable screen material available)
  • glasses are very cheap
  • two projectors are required (can cause image alignment problems)
Augmented Reality (AR)

Augmented reality aims at mixing pictures of the real world with computer generated image. A footage of the real world is overlaid (blended) with synthetic images in real-time.

Different flavors of AR systems:
- Optical see-through AR
- Video-see through AR
- Spatial augmented reality (SAR)

AR makes use of / requires
- motion capture and spatial registration
- computer vision

Augmented Reality (AR), continued

Optical see-through AR systems:

The real world is viewed directly and by means of some optical components computed images are blended into the field of view of the observer (half-mirrors, lenses ...).

BMW's vision of AR in automotive industry:
http://www.youtube.com/watch?v=P9KP2ASyds&feature=related
Augmented Reality (AR), continued

Optical see-through AR at BMW

BMW’s vision of AR in automotive industry:
http://www.youtube.com/watch?v=P9KPJlA5yds&feature=related

Augmented Reality (AR), continued

Video-see through AR systems:

The real world is perceived upon a display showing a live video stream of the real world. The video of the real world is augmented with computed imagery.

http://www.youtube.com/watch?v=z-aBUyrhcj0
Augmented Reality (AR), continued

Video-see through AR example

Spatial augmented reality (SAR):

Most recent development. The presentation of synthetic images occurs immediately in the same physical space where the user and real objects are situated. No handheld nor head-mounted displays. SAR is typically based on projection displays.


For definition of SAR see also: Raskar, Welch and Fuchs (1998) “Spatially Augmented Reality”
Upcoming Display Techniques

Current trends
"Video-wallpapers"

Novel polymer based thin-film displays are going to revolutionize the way in which we will access visual information:
High light output, flexible, energy efficient, cheap.

Current developments towards production of large displays in roll-to-roll printing machines.
Upcoming Display Techniques

Current trends
"Video-wallpapers"

Swedish companies in the lead. Acreo AB, printed electronics develops printed displays - "Paper Display".
Source: www.paperdisplay.se

Upcoming Display Techniques

Current trends
"Holographic Displays"

Image: Johnny Grattafono, KTH
Upcoming Display Techniques

Current trends
"Holographic Displays"

Image: Johnny Gustafsson, KTH

Upcoming Display Techniques

Current trends
"Pico-Projectors"

Picoprojectors based on DLP/LED available on market.
Upcoming Display Techniques

Coming next:
"Pico-Projectors"
based on laser scanners