Display Technologies

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Outline of today’s lecture

• Physiological limitations of the human visual system
• Display technologies
• Ways to accomplish stereoscopic and other 3D
• Implications when integrating 3D display systems
Displays

Additional Reading

Roy S. Kalawsky: The Science of Virtual Reality and Virtual Environments

Perception: pages 50-59
Displays techniques: pages 98-107

Physiological Aspects

Retinal Resolution: 0.3 to 0.7 arc minutes
(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

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
- Flat Panel Displays
  - Electroluminescence Displays
  - LCD Displays
  - Active Matrix TFT
- Light Valves
- Micro Mirror Devices
Next five slides will go quick!

Say ”stop” if there is anything you have not heard before!

Basic Technologies - Cathode Ray Tubes (CRT)

Advantages:
- high resolution
- easy to control
- reliable technology
- low cost
Basic Technologies - Cathode Ray Tubes (CRT)

Operation modes of CRTs:

- Random scan mode
  - no aliasing, smooth lines
  - transformation in hardware possible
  - little memory required
  - only line drawing possible
  - complex control hardware for the beam
  - flickers if scene becomes complex

- Raster scan mode

Basic Technologies - Random Scan CRT

How it works:

Display primitives are stored in a display list
(ellipses, circles, lines...)

Electron beam is controlled continuously between
vertex -> analog line drawing

+ no aliasing, smooth lines
+ transformation in hardware possible
+ little memory required

- only line drawing possible
- complex control hardware for the beam
- flickers if scene becomes complex
Basic Technologies - Raster Scan CRT

How it works:

Display is rasterized into pixels which are stored in a two-dimensional memory array (raster memory).

Electron beam is traversing the screen line by line in a regular time frame and scheme.

Content of the raster memory controls beam intensity:

+ uses old TV technology (simple approach)
+ filled and shaded surfaces are possible
+ guaranteed screen refresh rate

- aliasing problems “staircase effect”
- electronics required for raster memory readout
- drawing algorithms more complex

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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

How is color accomplished in displays?

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

1. Spatially modulated color composition
   
   see also page 99, in Kalawsky

2. Temporally modulated color composition
   
   see next slide
Basic Technologies - Cathode Ray Tubes (CRT)

How is color accomplished?

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

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Basic Technologies - Flat Panel Display - LCD

Liquid Crystal Displays

No electric field = light passes through

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Basic Technologies - Flat Panel Display - LCD

Addressing of Pixels:

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 keep their electrical state and 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)

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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

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Basic Technologies - Flat Panel Display

Electro Luminescence Displays (plasma panel displays):

*Sandwich-Technique*

- vertical transparent electrodes
- glass substrate with plasma cells (Neon, Argon)
- horizontal transparent electrodes
- glass

Basic Technologies - Light Valves

Application: Projection Displays

- High resolution light modulation (>1600 x 1200)
- High refresh rates possible (>130 Hz)
- Usable for high light output projection displays
- The **first choice** for stereo projection systems
- Tricky problems: Ghost images with slow phosphor

see page 103 in Kalawsky
Basic Technologies - Micromirror Devices (MMD)

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

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Basic Technologies - Micro Mirror Devices (MMD)

**MMD System Working Principle**

Light intensity controlled by pulse code modulation (PCM)
3D Display Categories

- Stereographic Displays (2 projected planar views)
  - Dual Display
  - Immediate Mode
- True Volumetric Displays
  - Single Display Plane
  - Multiplexed

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

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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

Shutter Opacity Left Eye

Shutter Opacity Right Eye

Pixel Intensity (Phosphor)

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

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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

**Encoding:**

A stereo image pair is combined into one so called anaglyph.

The left eyes 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 dominant red components.

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

Images curtsey: http://axon.physik.uni-bremen.de/research/stereo/color_anaglyph/index.html#ana

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

Image splitting by chromatic separation.

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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: Filterbased 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.

Monitor ZScreen 2000i with integrated electronics:

- Light Transmission: 32%
- Field Rate: 40Hz to 200Hz
- Height: 17.25"
- Width: 20.125"
- Depth: 3.25"
- Viewing Area: 15.5" x 11.75"
- Weight: 4.2 lbs. (without cables)
- Frame Material: Extruded Box Section Aluminum in plastic bezel
- Operating Temperature: 0°C to +70°C
- Storage Temperature: -50°C to +125°C
- Power Supply: 18 VAC, 2VA

Observe: Loss of luminance

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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)
- light valve / projection CRT
- extremely expensive
- 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 color field separation (red/green)
- one color capable projector (cheap)
- poor image result
- screen with good diffuser properties

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3D Rear / Retro Projection Systems:

Image source is positioned behind the projection screen

No interference between user and image source

Requires transparent screen material

No polarized 3D stereo possible since polarization is disturbed in transmission

Stereo 3D with active shutter glasses
  • requires very fast image source
  • light valve / projection CRT or latest state of the art 3D DLPs
  • relatively expensive
  • single graphics pipeline

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

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
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

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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 build 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

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3D Displays / Optical Systems - Volumetric Displays

Visions in 1993

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

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LightSpace Technologies’ : Depth Cube

http://www.lightspacetch.com/

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

http://www.lightspacetch.com/

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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)