Overview

Introduction

Display Measurements

Displays (LCD, OLED, E-Paper)

3D, Touch, Systems & Interfaces

Summary & Outlook

- Principles
- Merits
- Shortcomings

Some pictures etc. are courtesy of the companies named on the picture, others from, e.g., SID, …
Best Image Reproduction by 3D
3D - an Old Story: Brewster Stereoscope

- Introduced in 19th century
- Stereo pair observed through 2 convex lenses
3D Display Market by Technology

Units / 1,000

Update Oct. 2011 for 2014: >90M 3DTV

Source: DS, July 2010
3D Display Evolution
Why (not) use 3D Displays?

- It’s the natural progression for display evolution:
  - Monochrome $\Rightarrow$ Color $\Rightarrow$ 3D

- 3D viewing potentially provides a way to extract information from complex data faster and more accurately
  - Potentially save time and improve efficiency

- Current 2D image processing and enhancement is good enough

- The real ROI for 3D is unproven for most applications except some professional ones (see next slide)

- 3D displays can create headache and eye strain

- 3D is a must for mid and high-end TVs but no killer app for a new TV
  - cheapest 3D approach may win despite 3D quality (this is polarization)
Professional Applications for 3D

• Molecular Modelling

• Geospatial

• Microscopy

• Engineering

• Data Visualization

• Oil & Gas Exploration

• Medical
Applications for 3D: Movies

- Main driver for 3D
- Introduced in the 1950’s
- Mainly animation
- AVATAR is all-time #1 blockbuster

From anaglyph to polarization
Approaches for 3D Content for Movies etc.

- **2D to 3D Conversion**
  - Real-time 2D to 3D Conversion
  - Low Quality
    - Automatic
      - Chip
    - Manual
      - Frame by Frame

- **3D intended Content**
  - High Quality
    - 3D Animation
    - Shooting real image
4 requirements for 3D perception

- **Stereopsis**: Left and right eye see slightly different image
- **Accomodation**: Eye focusing on an object which is
  - infinite: relaxed pupil
  - close: strong curvature of pupil
- **Realistic 3D Impression**: 
- **Vergence**: Eye position when looking at
  - object in infinite: parallel
  - close objects: converging
- **Motion Parallax**
Fundamentals of 3D perception: Stereopsis

Each eye sees an object as a 2D image but from different perspective

- Brain creates 3D impression
Stereoscopic Vision

- Human eye & brain in combination integrates multiple cues (‘Hilfestellungen zu Tiefenwahrnehmung’) to perceive depth

- **Primary Cues**
  are provided by slightly different views of each eye.
  The eye must be therefore of highest resolution (fovea).
  Practically, these differences are effective up to 30 m.
  Only these cues need a 3D display.

- **Secondary Cues**
  Many cues are seen by a person with one eye and can be therefore displayed on a 2D (standard) screen.
Primary Cues (Stereopsis)

Depth perception by stereopsis: with two slightly different images of our eyes (parallax): Disparity.

... difference is relative small:

→ large eye resolution necessary!
Secondary Cues (Monoscopic Cues)

3D is perceived by the human visual system in various ways. There are monoscopic cues (secondary cues) that do not exploit the fact we have two eyes \( \Rightarrow \) 2D screen could be OK!

Some of these cues are:

- Occlusion (Verdeckung)
- Linear perspective
- Size (constancy)
- Aerial perspective
- Motion parallax (s.a.)
- Shadows & shading
3D Displays Overview

3D Displays

Volumetric

Stereoscopic

3D quality, price

- Provide real depth cues due to presentation (usually projection) of the image onto a 3D surface
- The 3D image changes with the viewer’s position relative to the display
- Bulky with limited size

- Caters to our binocular vision by presenting a left eye image that is segregated from the right eye image using an optical, physical or temporal modulation (or some combination)
- The 3D image does not change with the viewer’s position relative to the display (for a given image)
Stereoscopic 3D Displays Overview

3D (non volumetric)

Stereoscopic

Auto-stereoscopic

Near-The-Eye Helmet Mounted Displays

Present two views, one for each eye

Glasses technologies:
- Polarisation
- Time-sequential
- Spectral

Displays:
Direct View & projection

Multi-view displays
Limits:
- Resolution
- Size of viewing zone

Systems:
- Fixed position
- Head-tracking displays
- Multi-view displays

Individual displays dedicated to each eye
often regarded as separate approach because
stereoscopic (2 views)
& auto-stereoscopic
(no glasses)
**Fundamental Issues of 3D Displays: Accommodation**

- Physiological issue: Accommodation (Fokus) vs. vergence (Augenstellung)

![Diagram showing accommodation-vergence conflict in 3D displays]

Accommodation - vergence conflicts in 3D displays cause fatigue & discomfort
Fundamental Issues of 3D Displays: Depth Perception

- Due to limited resolution of 3D displays, the display can show infinite depth.

![Graph showing depth perception](image)

3D content on 3D displays “looks compressed” in depth.
Fundamental Issues of 3D Displays: Cross Talk

- 3D Cross talk - if eye specific information is not well separated
- Information for left eye is visible with right eye and vice versa

3D cross talk creates a ghost image which may cause discomfort (discussed later)
**Autostereoscopic 3D**

**Definition:** No glasses etc. are needed for 3D but limited ‘sweet spot’

- Autostereoscopic displays became feasible with FPDs
- Various autostereoscopic technologies exist
- They differ in advantages & disadvantages

**Autostereoscopic displays**

- Uses AMLCDs with an added optical element to create a dual view (left eye/right eye) presentation of the image on the screen (PDP: too large pixel size)
- An optimum viewing space is created (sweet spot)
Autostereoscopic Mask Principles

Parallax Barrier

Screen
Parallax barrier
Left eye
Right eye

Lenticular Lens

Screen
Lenticular lens
Left eye
Right eye

Source: WIKIPEDIA
Autostereoscopic Displays

Essential for mobile devices

Source: Fujifilm

Source: Nintendo

TV sets and monitors
(issue: 2+ viewers)

Source: Tridelity
Multimedia Displays

Autostereoscopic AMLCDs

• **Merits**
  - No eyewear required
  - Good chromaticity
  - Some designs allow easy conversion between 2D and 3D
  - Based on mainstream technology (AMLCDs)

• **Issues**
  - Horizontal display resolution is reduced by the number of domains
  - Very narrow viewing angle in two domain design, there are transition zones with higher domain count
  - Some designs are 3D only
Head Tracked: Principle of Operation

Moving mask controlled by head tracking
Head Tracking Single User

SeeReal Head Tracked Display

This is a version of the fixed viewing zone display. The prism mask is moved laterally in accordance with the tracker output.
Multi - View : Philips Lenticular

PHILIPS 42” WOW DISPLAY (9-VIEW)
MERCEDES Split View - Auto-stereoscopic the other Way
Anaglyph

- Uses familiar red and green/cyan glasses for image separation
- Generally monoscopic but good color can be obtained
Polarisation Separation

• Left and right image is displayed at the same time

• Only half of resolution of display for 3D image but this might be acceptable for 4k TVs.

• Cheaper than time sequential both in terms of display and glasses

• Either diagonally or circularly polarised for each view, with appropriate polarisation in the glasses (cheap)

• Usually based on LCD technology.
Polarisation Separation
Polarisation Separation

TV set

LCD pixel

Polarisation separation by patterned retarder

Passive Glasses

Imaging

Separation/Encoding by polarization

Decoding
Projection with Polarisation Glasses

- L and R images presented at the same time
- Passive low cost system – no need for data transfer to glasses
- Multi viewer hassle free
Time - Sequential

- Left and right image is displayed sequentially
- Uses synchronized (usually IR) shutter glasses (expensive)
- Left and right image with full display resolution (better than polarization but more expensive)
- Requires fast display as minimum for $\geq 200$ Hz frame rate
- Direct view & projection
  - Direct view: LCD, PDP, CRT (gone)
  - Projection: mostly DLP
Time - Sequential Visualisation
Time - Sequential: AMLCD needs quad frame frequency

- New content is written to display from top to bottom
- Hold type display causes “double images” (old and new frame)
- Therefore 1 full 3D frame consists of four subframes (R, L, 2 for updating)
- Response time of LCD shall be below 2ms for cross-talk free 3D
Time – Sequential Direct View

Samsung 55-inch 240Hz 3D LCD Display
Time – Sequential Projection

- Active glasses alternate between left eye and right eye views
- Glasses are synchronized to the projector with a wireless signal
- Expensive glasses
- No special screen is needed
- No alignment issue
### Summary for 3D Displays

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<th>Shutter</th>
<th>Polarization</th>
<th>Auto-stereoscopic</th>
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<td><strong>Merits</strong></td>
<td>• Full resolution of panel</td>
<td>• Cheap glasses</td>
<td>• No glasses</td>
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<td></td>
<td>• Multi viewer</td>
<td>• Multi viewer</td>
<td>• Best approach for many applications</td>
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<tr>
<td></td>
<td></td>
<td>• Standard panel upgraded by foil</td>
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<td></td>
<td></td>
<td>(&lt;50 @ 40”)</td>
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<td><strong>Short-comings</strong></td>
<td>• ≥ 240 Hz panel</td>
<td>• Resolution half of panel</td>
<td>• Tiny sweet spot</td>
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<td></td>
<td>• Loss of luminance</td>
<td>• Glasses needed</td>
<td>• Single viewer</td>
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<tr>
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<td>• Expensive glasses</td>
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<td>• Resolution at least half of panel</td>
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Head / Helmet Mounted Displays (HMD)

1990: 3D HMD for stereo-endoscope (BMBF: AESCULAP, SEL, AEG {Blankenbach})

- 2 monochrome white CRTs
- 3 images (11 x 8 mm²) on each CRT
- Superposition with RGB filters

Research project:
Commercial price would have been too high.

~2005: DaVinci 3D surgery
Near To Eye Displays (NTE) → Augmented Reality

GOOGLE Glass

Fraunhofer

- Use case for professional
- CE user: Acceptance with camera (digital ethics)?
Head / Helmet Mounted Displays (HMD)

Merits
- Good 3D effect possible
- Full resolution to each eye
- High contrast
- Immersive experience

Issues
- Potential discomfort: Some devices are bulky and have high weight
- User blocked from environment
- HMD isolates user
- Cost
- Resolution often too poor for superb 3D

Would you accept that?
Even for video on the go?
### 3D Measurements Basics

- **Different geometries**
- **Measurement devices “standard”**
- **Take care of**
  - Polarisation sensitivity
  - Flicker sensitivity of measurement devices
- **Issue: L and R crosstalk**

**Sources:** IDMS
3D Luminance, Contrast Ratio, Grey Scale, Color

- All measurements: Measure through glasses (if apply)
- Absolute measurements: “Standard”, compare left and right “eye”
- Crosstalk measurements: Different images for left and right “eye”
- All differences between L and R should be small
- Polarisations glasses: Measure head tilt as well

\[ \sum L_R + L_L \]

Luminance or color meter

Left and right image shown on one screen

\[ L_{White}^{Left} \]

\[ L_{Black}^{Right} \]
Autostereoscopic 3D

- Parallax barrier layer or lenticular lenses provide separation for left and right eye.
- Therefore every display has a "sweet spot" for 3D vision (incl. head tracking)
- Measurements like for glasses with addition of movement (sweet spot dependency)
- Additionally incident viewing angle characteritics
Switchable Quad Full HD Auto Stereoscopic 3D Display
Key Questions for Stereo Displays

• Technology is ready, but how much is the user willing to pay for 3D?

• What application will make stereo displays widely used?

• Will PC gamers really pay to play in stereo?

• Are glasses a real barrier?

• What is about image quality?

• What is about human factors like discomfort, eye fatigue, headache?

• What is about 3D TV? (Shifted in Europe to 2020+)

• Is professional market large enough for companies to survive?
Why the Time Might be Right for More Widespread Use of 3D Displays

• Inexpensive compute power
  - Microprocessors
  - High performance graphics cards

• New interest

• Suitable, affordable display technology
  - e.g. high resolution Active Matrix LCDs and PDPs

• Widely available content
  - Professional applications increase over years but relative low in total
  - Consumer apps might get a kick by 3D apps for smart 3D TVs