Special Topics in Virtual Reality

Display Devices

https://tinyurl.com/STVR2018
Display Devices

Stereoscopic Output

- Desktop Screens
- Head-Mounted Displays
- Parallax Screen Displays

„Exotic Displays“

- Volumetric Displays
Classification of stereoscopic displays

- Goggle Bound Displays
  - Head-Mounted Displays
    - Boom-like Displays
    - Retinal Displays
    - Head-Mounted Projectors
  - Spatial Displays
    - Projection Displays
      - Surround Screen Displays
        - CAVEs
        - Domes
      - Embedded Screen Displays
        - Workbenches
        - Walls
        - Oblique Screens
    - Desktop Configurations
      - Transparent Projection Screens
  - Desktop Monitors
  - Reach-In Systems

- Autostereoscopic Displays
  - Re-Imaging Displays
    - Pepper's Ghost Configurations
    - Real Image Displays
  - Volumetric Displays
    - Solid-State Displays
    - Multi-planar Displays
  - Parallax Displays
    - Parallax Barrier Displays
  - Holographic Displays
    - Electrophotographic Displays
    - Lenticular Displays
Classification of AR displays
Human Field of View

[Bimber2005]
Head-Mounted Display (HMD)

- head-mounted (!) helmet, goggles, clips, ...
- one or two displays directly in front of eyes
- two displays $\rightarrow$ perfect stereo channel separation!
- display technology:
  - CRT
  - LCD
  - laser (retinal displays)
  - projector
- type: immersive, see-through, video see-through
Head-Mounted Display History

- 1960 Heilig
- 1963 Hall, Miller
Head-Mounted Display History

- 1969 Sutherland
  - vector display: “3000 lines at 30 frames per second”
  - ultrasound & mechanical tracking
  - CRT see-through display
Head-Mounted Display (HMD)

- **optical see-through**
  - semi-transparent mirror
  - overlay over real world
  - brightness problem
  - occlusion problem

- **video see-through**
  - real world via camera composited
  - occlusion solvable
  - only video resolution of real world (~HD)
optical see-through HMD

[Haller2007]
optical see-through HMD

display via half-silvered mirror as overlay (“add”) over reality

Advantage: undistorted view of reality in realtime an wide FoV

Disadvantage: no complete occlusion, only visible against darker background
optical see-through HMD

<table>
<thead>
<tr>
<th>Picture</th>
<th>Specification</th>
<th>Lens Form</th>
<th>Specification</th>
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<td>Off-axis Design</td>
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(3D VIS Lab, University of Arizona - "Head-Mounted Display Systems" by Jannick Rolland and Hong Hua)
pinlight see-through HMD

defocused pinlights act as “projectors”, projecting a virtual image through an LCD on the retina

Advantage: wide FoV

Disadvantage: preprocessing dependent on eye position, eye positions has to be measured

Figure 2: Pinlight Projection. A defocused point light source, or pinlight, placed near the eye is coded with a spatial light modulator to create a narrow field of view image that appears in focus without the use of refractive or diffractive optics.

pinlight see-through HMD

http://doi.acm.org/10.1145/2601097.2601141.
diffractive see-through HMD

Vuzix / Nokia Waveguide
diffractive combiner (with
laser pico projector)

Figure 5. Surface relief slanted sub-wavelength gratings as
optical combiners and exit pupil expanders.
video see-through HMD

[Haller2007]
video see-through HMD

camera delivers image to display
→ no direct view of reality

Advantage: real image can be manipulated, too!

Disadvantage: time lag, parallax between eye and camera view point

But parallax-free design possible! →
parallax-free video see-through HMD

optics are designed so that the (reflected) camera viewpoint is in the users pupil

video:
parallax-free video see-through HMD

free – form prisms allow for an extremely compact construction

[Inoguchi2008]
Older Commercial HMDs

- datavisor (nvision)
- ST40 (Kaiser)
- Addvisor (SAAB)
- i-glasses
- glasstron (Sony)
Commercial HMDs

- HTC Vive Pro
- Oculus Rift
- Pimax 8k
- Meta2
- Sony HMZ-T2
Commercial HMDs: Panoramic HMD

www.Sensics.com

claims:

- Panoramic field of view: from 82° to 180° diagonal
- A modular, upgradeable design
- High resolution: Up to 4200x2400 pixels per eye (2400x1720 effective)
- Ease of use: weighing less than 1 kg (2 lbs.), open-frame design: comfortable and stays cool
Commercial HMDs: Panoramic HMD

the field of view is considerable larger than other HMDs’:

delivering a better sense of immersion
Commercial HMDs: Panoramic HMD

The wide field of view is made possible by using not one LCD but several, which in combination with special optics tile seamlessly:
Retinal HMD

image exists on display surface, is viewed by eye

image exists **only** on retina
Retinal HMD

since the laser beam is extremely thin, even tiny particles throw shadows on the retina

“eye floaters”:
Retinal HMD (NOMAD, Microvision)

uses laser to directly project on users retina

Advantages: bright, always focussed, see-through

Disadvantages: monochrome (red) 32 shades

very sensitive to impurities in the eye!
Google Glass

Preliminary specs:

Display
High resolution display is the equivalent of a 25 inch (64cm) high definition screen from 8 feet (2.4m) away (~15° diagonal)

Camera
Photos - 5 MP
Videos - 720p

Audio
Bone Conduction Transducer

Connectivity
Wifi - 802.11b/g
Bluetooth
Oculus Rift
Oculus Rift

shader corrects geometric & chromatic distortions:
Light Fields HMD

Micro lenses in front of segmented views:

Bare Microdisplay

Near-Eye Light Field Display

"Perceived" Image (Close-Up Photo)
Light Fields HMD

Flat (~10mm) optical element:
Light Fields HMD

Depth of Field:

Simulated Retinal Images of the Prototype

- near focus ($d_a = 25$ cm)
- far focus ($d_a = 100$ cm)

Photographs of the Prototype

- near focus ($d_a = 25$ cm)
- far focus ($d_a = 100$ cm)
Light Fields HMD (video)

Near-Eye Light Field Displays

Douglas Lanman    David Luebke
NVIDIA Research

NVIDIA®
Light Fields HMD

Advantages:
• depth-of-field
• thin optics

Disadvantages:
• reduced resolution

"Near-Eye Light Field Displays"
Douglas Lanman (NVIDIA), David Luebke (NVIDIA), in ACM Transactions on Graphics (TOG), Volume 32 Issue 6, November 2013 (Proceedings of SIGGRAPH Asia), November 2013
Head-Mounted Projectors

uses projector to display from users viewpoint on (retro-reflective) environment

Advantages: „correct“ occlusion

Disadvantages: heavy, varying focus distance, stereo separation depends on retro-reflection quality
Head-Mounted Projectors

simplified head-mounted projector set-up

eexample prototypes (note „glowing eyes“)

[Furht2011]
head attached display: VR telescope

Consists of a video camera and monitor

Very rugged, immediately usable by untrained users

→ *mechanical tracking* in the joint allows easy video augmentation (precise & fast rotation sensor)

[Link to AR Telescope](https://www.igd.fraunhofer.de/en/Institut/Abteilungen/VRAR/Projekte/AR-Telescope)
head attached display: zacturn 2.0

comparable to “VR telescope”:

Austrian development: www.zkoor.at
head attached display: zacturn 2.0
head attached display: Boom

Fakespace boom
Hand-held Displays

Tablet PCs
smartphones
essentially the same as video
HMDs

contain enough sensors for
many AR applications:
GPS
compass
acceleration
camera(s)
Projection Displays
Classification of Projection Technology

- Cathod Ray Tubes (CRT)
- Liquid crystal (LCD)
- Micro-Mirrors (DLP)
- Reflective LCD (LCOS, D-ILA)
- exotic and little-used devices (Laser, Eidophor)
CRT Projector

„Cathode Ray Tube“ („Kathodenstrahlröhre“)

- Same technology as classic TV-set
- Three different tubes (RGB)
- Analog technology
- Fast (120Hz-180Hz frame-rate → active stereo)
- Low luminance (typically 1000 ANSI lm)
- Good color reproduction
- Black is really black!
- Expensive, but extremely good images
CRT Projector
Calibrating them is a lengthy and tedious procedure:

STEP ONE: VERIFY THE CORRECT SCREEN/PROJECTOR DIMENSIONS
STEP TWO: VERIFY THE CORRECT SCANNING POLARITY
STEP THREE: CENTER THE GREEN IMAGE IN THE PICTURE TUBE
STEP FOUR: CENTER THE GREEN IMAGE ON THE SCREEN
STEP FIVE: ADJUST THE OPTICAL FOCUS
STEP SIX: ADJUST THE TUBE “FLAPPING”
STEP SEVEN: ADJUST THE GREEN REFERENCE IMAGE
STEP EIGHT: ADJUST THE GREEN REFERENCE IMAGE OVERSCAN
STEP NINE: MATCH THE RED IMAGE TO THE GREEN REFERENCE
STEP TEN: MATCH THE BLUE IMAGE TO THE GREEN REFERENCE
STEP ELEVEN: CENTERING THE USER POSITION CONTROLS

(from a manual)

and then: do it all again for the second projector!
LCD Projector

„Liquid Crystal Display“ („Flüssigkristall“)

- Transmissive LCD panel(s) with lamp
- Slight color-dependent polarization → troubles with polarized stereo!
- Mediocre color reproduction (no gamma curve)
- Higher luminance (>1000 ANSI lm)
- only about 50% of panel surface active
DLP (Micro-Mirror) Projector

„DLP™“ Digital Light Processing
Micro-Mechanical Chips by Texas Instruments

- about 89% of panel surface active
- but visible pixel structure
- inexpensive, but variable color reproduction
DLP Projector

micro-mechanic:
tiltable mirrors
two positions, switched by electrostatic force
DLP Projector

tiltable mirrors, electron microscopic view
DLP Projector

mirrors produce on/off pattern only
modulate on-to-off ratio to generate grayscale
DLP Projector

inexpensive single-chip projectors need color filter wheel to generate colors:

in many cases, these wheels contain „white“ as additional color, thereby significantly enhancing black/white contrast, but impairing color reproduction
DLP Projector

Only expensive three-chip projectors support faithful color reproduction:

Since micro-mirrors are extremely fast, some of these expensive projectors support output frame rates of >100Hz and thereby active stereo

Examples:
- BARCO Galaxy
- Christie Mirage
DLP LED/Laser Projector

Use combined LED/Laser light source instead of mercury lamp

Advantage:
Higher efficiency
Longer lamp life (~20,000h)
No color wheel, since LED/Laser can be pulsed

Disadvantage:
Still not very bright (~3500 lm)
reflective LCD Projector

„LCoS“ Liquid Crystal on Silicon
„D-ILA“ Direct Drive Image Light Amplifier

- high resolutions (up to QXGA, 2048 x 1536)
- almost no pixel structure (93% area usable)
- good colour reproduction
- medium luminance
reflective LCD Projector

The switching elements are placed behind the liquid crystal, so almost no active display area is lost (only 7%)
reflective LCD Projector

The light from the lamp is reflected from the surface of the display element:
reflective LCD Projector

Using three elements and some prisms, we get color output:
reflective LCD Projector

prism
Classification of Stereo Technology

Separation of Left/Right image by

- Space (two displays, parallax display)
- Color (red/green, etc.)
- Time (left after right image, „active“ stereo)
- Plane of Polarization (linear polarized)
- Rotation of Polarization (circular polarized)
- Spectrum (Infitec™)
Parallax Stereo with Lenticulars

Lenticular lenses (cylinders) send different images in different directions.

Similar to “3D” postcards and stickers.
Parallax Stereo with Lenticulars

A raster of cylindrical lenses in front of an LCD shows different rows/columns to the users eyes:
A simple parallax barrier works like this:

A parallax barrier shields a display screen. The distance between screen and barrier, as well as the resolutions of both are calculated to correctly display left pixels (green) only to the left eye and vice versa.
Slanted Parallax Barrier

A simple approach extremely reduces the horizontal resolution.

Better: treat each LCD-triade as three independent pixels ⇒ “triples” horizontal resolution

use slanted barrier, otherwise one view-slice gets only one primary color!

http://csc.lsu.edu/~kooima/pdfs/Kooima-VR07.pdf
Slanted Parallax Barrier

Image calculated for SPB:

original view detail

parallax view detail
Advantages vs. simple approach or lenticular lenses:

- “higher” resolution (distributed over vertical resolution too)
- less view-dependent artifacts than lenticulars
- less expensive to manufacture than lenticulars

Disadvantages vs. lenticular lenses:

- lower contrast, since all light not coming through a slot in the barrier is absorbed
Adaptive Parallax Barrier

Ken Perlin built the prototype of a display with adjustable parallax barrier (essentially another vertically striped LCD in front of the display:

http://mrl.nyu.edu/~perlin/courses/fall98/projects/autostereo.html
Parallax Stereo

Advantages:
- no glasses
- multi-user, when more than 2 viewing zones

Disadvantages:
- lenticular system exhibits color artifacts
- works in praxis only horizontally
- reduces spatial resolution of display
- mediocre separation
Active Stereo

Means stereo de-multiplexed by „active“ glasses, with electronics:

- time-multiplex: left/right/left/right...
- needs fast display (CRT, DLP)
- needs “active” glasses with shutters, which hide the wrong images → synchronization with source needed!
- works good for back-projection
Active Stereo Devices

- infrared emitter
- pulsed infrared light sync signal
- LCD-shutter glasses
- fast display (monitor or projector) >100 frames/s
- Barco “BARON” virtual table (backprojection with CRT projector)
Active Stereo Devices

Ultra short throw distance:
DELL s500 / NEC NP-U300x

1 DLP projector
resolution: 1280x800
Brightness (Lumens): 3200 ANSI lm
Full On/Off: 2300:1
Weight: 7 kg

Price: ≈ 900€!

200cm diagonal @50cm distance
Ultra Short Throw Projection

Main advantages is that front projection for surround display possible:
(Almost) no shadowing by user compared to “classical” front projection
Better luminance distribution than rear projection (low vignetting)
Ultra Short Throw Projection

Main principle: free-form (not spherical!) mirror in beam path:
Passive Stereo

Means stereo de-multiplexed by „passive“ glasses, without electronics:

- Color (red/green, etc.)
- Plane of Polarization (linear polarized)
- Rotation of Polarization (circular polarized)
- Spectrum (Infitec™)
Anaglyph Stereo

Multiplexing by using one color for the left eye image and another for the right:

left

right
Anaglyph Stereo

Combine color images by replacing the red channel of the right-eye image with the red channel of the left-eye image.
Anaglyph Stereo
Anaglyph Stereo

Advantages:

- fast
- inexpensive
- works on all color media (print, TV, etc.)
- works good on back-projection

Disadvantages:

- mediocre color reproduction
ColorCode 3-D

Multiplexing by „splitting depth and color“ between left & right eye:

left

right
ColorCode 3-D

Advantages:
- fast (use a shader)
- inexpensive
- works on all color media
- works good on back-projection
- displays full color (sort of)

Disadvantages:
- your brain melts (eyestrain, blue filter very dark)
Polarization Stereo

Multiplexing by manipulating the direction of oscillation of the projected light.

Using filters in front of the projector(s) and users eyes, and a special screen:

- Polarizing filter
Polarization Stereo

Quality depends on:

filters:

- how much “correct” light is transmitted \((R \rightarrow R, L \rightarrow L)\)
- how much “incorrect” light is transmitted \((L \rightarrow R, R \rightarrow L)\)

screen:

- how much polarization is destroyed?
  (back-projection screens are worse, except for specially designed, hard screens)
Polarization Types

Normal light oscillates in many directions

Linear polarized light oscillates only in one plane

Circular polarized light oscillates only in one rotating direction
Polarization Types

Normal light oscillates in many directions

Linear polarized light oscillates only in one plane
Polarization Types

Circularly polarized light consists of two perpendicular electromagnetic plane waves of equal amplitude and 90° difference in phase.

The oscillation direction of circular polarized light rotates...
A quarter-wave plate divides linearly polarized light into two components polarized normally to each other and 90° out of phase. This produces circularly polarized light.

Polarization Types

linear polarization:
- orientation dependent
- works with all colors

circular polarization
- works in any orientation of the users head
- color dependent (phase shift filter)
- costs more
Infinitec™ Stereo

Spectrum Multiplex:

Advantages:
- orientation independent
- screen independent
- high(er) contrast even in daylight

Disadvantages:
- color distortion
- crosstalk
Infitec™ Stereo

uncalibrated

calibrated
Holographic Projection

Holographic Backprojection by Holografika Ltd. (www.holografika.com)

- No glasses needed, the 3D image can be seen with unassisted naked eye
- Viewers can walk around the screen in a wide field of view seeing the objects and shadows moving continuously as in the normal perspective. It is even possible to look behind the objects, hidden details appear, while others disappear (motion parallax)
- Unlimited number of viewers can see simultaneously the same 3D scene on the screen, with the possibility of seeing different details
- Objects appear behind or even in front of the screen like on holograms
- No positioning or head tracking applied
- Spatial points are addressed individually
Holographic Projection

pixels on screen send different light in different direction, thereby simulating light emanating from points in space:
Holographic Projection

pixels on screen send different light in different direction, thereby simulating light emanating from points in space:
Advanced Topics in Virtual Reality

Tracking Devices

http://www.cg.tuwien.ac.at/courses/SpecialTopicsVR/handouts/

http://tinyurl.com/6vhv2tz
Tracking

VR needs tracking for

- user (head, eyes, body)
- input devices (bat, wand, glove, PIP, …)
- environment (occlusion, interaction, ambient intelligence, …)

to deliver

- position & orientation data (6DoF)
- object identification
- geometric information
Tracking Methods

- mechanical
- magnetical
- optical
- inertial
- ultra-sound
- radio
Mechanical Tracking

Mechanical mount for input device, output device, users head, etc ...

delivers information using angle and/or translation sensors (e.g. on optical basis)
Mechanical Tracking Examples

Fakespace boom     Dextrous Master glove
Mechanical Tracking Examples

phantom tracking & haptic feedback device
Mechanical Tracking

Advantages
- fast (300 – 1000 samples/s)
- short lag (<5ms)
- precise (depending on set-up)

Disadvantages
- tethered (→restriction of movement)
- expensive
Shape Tracking

Principle:

- flexible tape with curvature sensors
- can be used like mechanical tracker
Shape Tracking

Full body motion capture:
Shape Tracking

Advantages

▪ wireless
▪ rugged
▪ delivers skeletal data

Disadvantages

▪ mediocre precision
▪ relative measurements only
Magnetical Tracking

Uses magnetic fields produced by

- geomagnetic field: inexpensive orientation sensor, used in gaming HMDs, cellphones
  2DoF (rotational)

- special transmitter: creates three orthogonal fields
  6DoF (t & r)
Magnetical Tracking: Polhemus

Uses AC magnetic fields, sensitive to ferromagnetic material.
Polhemus LIBERTY™ LATUS™

Wireless version: wireless transmitters; wired receivers:

transmitter

receiver
Magnetical Tracking: Ascension

Uses „DC“ magnetic fields, not sensitive to ferromagnetics
# Magnetical Tracking Comparison

<table>
<thead>
<tr>
<th>SPECIFICATION</th>
<th>FASTRACK</th>
<th>FLOCK OF BIRDS</th>
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<tbody>
<tr>
<td>Operation radius</td>
<td>30” (120”with red. acc.)</td>
<td>36” (96”optional)</td>
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<td>Angular range</td>
<td>all-attitudes</td>
<td>±180° Azimuth&amp;Roll</td>
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<tr>
<td></td>
<td></td>
<td>±90° Elevation</td>
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<tr>
<td>Transl. accuracy</td>
<td>0.03”RMS</td>
<td>0.1”RMS</td>
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<td>Transl. resolution</td>
<td>0.0002”/inch range</td>
<td>0.03”RMS</td>
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<td>Angular accuracy</td>
<td>0.15”RMS</td>
<td>0.5”RMS</td>
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<td>Angular resolution</td>
<td>0.025”RMS</td>
<td>0.1”RMS at 12”</td>
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<td></td>
<td>direction cosines &amp; quaternions;</td>
<td>rotation matrix)</td>
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<td></td>
<td>or IEEE-488</td>
<td>or RS-422/485</td>
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<td>up tp 100 kbaud/sec)</td>
<td>(select. baud rate to 310,000)</td>
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Magnetical Tracking Noise

Polhemus

![Graphs showing position and angles over time](image-url)
Magnetical Tracking: Aurora (NDI)

Used mainly for medical applications, high precision, small working volume (50cm radius), extremely small probes

System Control Unit (SCU)

Aurora 5DOF Sensor, 0.5 mm x 8 mm

transmitters (different versions)
Magnetical Tracking: Aurora (NDI)

Electromagnetic spatial measurement systems determine the location of objects that are embedded with sensor coils. When the object is placed inside controlled, varying magnetic fields, voltages are induced in the sensor coils. These induced voltages are used by the measurement system to calculate the position and orientation of the object. As the magnetic fields are of a low field strength and can safely pass through human tissue, location measurement of an object is possible without the line-of-sight constraints of an optical spatial measurement system.

www.ndigital.com
Aurora Accuracy Performance - Planar Field Generator

The following metrics apply to the Aurora V2 System released in April 2011. The Aurora V2 System achieves 20% higher accuracy performance than previous Aurora Systems.

<table>
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<th>Cube Volume</th>
<th>Dome Volume</th>
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<tr>
<td></td>
<td>RMS</td>
<td>95% Cl</td>
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<tr>
<td><strong>Accuracy - 5DOF Sensors</strong></td>
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<tr>
<td>Position</td>
<td>0.70 mm</td>
<td>1.40 mm</td>
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<tr>
<td>Orientation</td>
<td>0.20°</td>
<td>0.35°</td>
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<tr>
<td><strong>Accuracy - 6DOF Sensors</strong></td>
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<tr>
<td>Position</td>
<td>0.48 mm</td>
<td>0.88 mm</td>
</tr>
<tr>
<td>Orientation</td>
<td>0.30°</td>
<td>0.48°</td>
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*All data collected with the Aurora V2 System in an environment free of electromagnetic disturbances. Accuracy depends on tool design and the presence of metal. Note: Results based on more than 300 random positions and orientations distributed throughout the characterized volume.

www.ndigital.com
Magnetical Tracking: conclusion

Advantages

▪ inexpensive (starting at 2.000€)
▪ no occlusion problems

Disadvantages

▪ tethered → restriction of movement
▪ sensitive to magnetic distortion
▪ noisy
▪ limited range (1-3m)
Optical Tracking

Using a variety of methods:

- active or passive markers
- marker-less
- inside-out
- outside-in
Optical Tracking

Using a variety of sensors:

- 2D: cameras (CCD array)
- 1D: CCD lines
- 0D: photo-diodes
- “2D”: lateral-effect photodiodes
Epipolar Geometry

Epipolar geometry is the geometry of stereo vision. When two cameras view a 3D scene from two distinct positions, there are a number of geometric relations between the 3D points and their projections onto the 2D images that lead to constraints between the image points.

These relations are derived based on the assumption that the cameras can be approximated by the pinhole camera model.

http://en.wikipedia.org/wiki/Epipolar_geometry
Passive Markers, Multiple Cameras (A.R.T.)
camera contains IR-flash and image-processor
targets use retro-reflecting markers in geometric constellations

http://www.ar-tracking.de/
http://www.iotracker.com/
Passive Markers, Multiple Cameras (OptiTrack)

camera contains IR-flash and image-processor

targets use retro-reflecting markers in geometric constellations

http://www.naturalpoint.com/optitrack
Passive Markers, Single Camera (AR-Toolkit)

single camera tracks b/w marker images inside/out
Active Markers, LAPD (HiBall)

- active markers (IR-LEDs) stationary on ceiling
- 6 lateral-effect photodiodes move
Duo Lateral-Effect Photodiode

\[ X = \frac{i_{out2} - i_{out1}}{i_{out2} + i_{out1}} \]

\[ Y = \frac{i_{in2} - i_{in1}}{i_{in2} + i_{in1}} \]

http://hades.mech.northwestern.edu/index.php/Lateral-Effect_Photodiode
Active Markers, 1D sensors (CODA)

- IR-LED targets
- three linear CCDs
Active Markers, „0D“ sensors (ReActor)

- IR-LED targets on suit
- 544 photodiodes on frame
- uses light distribution over frame
MIT „Second Skin“

- IR-sensors targets on suit
- Simple „slide-projectors“ in environment project time multiplexed angle information
- Additionally measures illumination & orientation

Prakash et.al.: “Lighting-Aware Motion Capture Using Photosensing Markers and Multiplexed Illumination”; SIGGRAPH 2007
http://web.media.mit.edu/~raskar/LumiNetra/
Projectors produce binary-coded "fan", which allow a sensor to determine one angle around proj.-center

→ 3 projectors determine position unambiguously
MIT „Second Skin“

Projectors produce time-multiplexed, gray-coded „fan” by projecting different LEDs through a static slide:
MIT „Second Skin“

Advantages

- Inexpensive projectors & sensors
- Perfect identification of sensors
- HF modulated IR light → insensitive to sun etc.
- Coarse orientation from directionality of sensor

Disadvantages

- Time-multiplex → limited # of projectors
- Small working volume (at the moment)
"Lighthouse" Tracking

Developed by Valve

similar to “2nd skin”, uses sweeping laser lines to determine angles to photodiode constellation:

http://www.hizook.com/blog/2015/05/17/valves-lighthouse-tracking-system-may-be-big-news-robotics
"Lighthouse" Tracking

One global sync pulse, followed by two angle-dependent pulses:

https://i.kinja-img.com/gawker-media/image/upload/s--wsP3xmPN--/1259287828241194666.gif
"Lighthouse" Tracking

One global sync pulse:

https://youtu.be/J54doT7k0
"Lighthouse" Tracking
followed by a vertical sweep:

https://youtu.be/J54dotTl7k0
"Lighthouse" Tracking

and by a horizontal sweep:

https://youtu.be/J54dotTl7k0
"Lighthouse" Tracking Video

https://youtu.be/J54dotTt7k0
"Lighthouse" Tracking

Simple time measurement give angles:

http://www.hizook.com/blog/2015/05/17/valves-lighthouse-tracking-system-may-be-big-news-robotics
Optical Tracking: conclusion

Advantages
- precise
- wireless

Disadvantages
- occlusion
- environment lighting sensitive (outdoor!)
- Precise and large range systems still expensive
Ultrasound Tracking

Measures time of flight or phase difference
Ultrasound Tracking

Logitech

Specifications:

- 6 degrees of freedom
- 250 dpi resolution/ 3D mode
- 400 dpi resolution/ 2D mode
- Update Rate: 50 reports/sec
- Tracking Speed: 30 inches/sec
- Tracking Space: 5 ft. long, 100 degree cone
- Host Interface: RS-232 serial, 9 or 25 pin connector
  Power Supply: external 115VAC (230VAC available)
Ultrasound Tracking

Advantages
- inexpensive
- works underwater

Disadvantages
- Measures only distances, needs multiple beacons for 6DoF
- sensitive to air pressure & humidity
- imprecise
Inertial Tracking

measures linear & angular accelerations and integrates position & orientations:

(Old) inertial navigation platform
Inertial Tracking

measures linear & angular accelerations and integrates position & orientations:

(Old) inertial navigation platform
Inertial Tracking

micro-mechanical „tuning fork“:
Inertial Tracking: Xsens

commercial inertial tracking
Inertial Tracking: Intersense

commercial inertial tracking

„Inertiacube“ uses ultrasound for absolute measurement
Inertial Tracking: Perception Neuron

commercial inertial full-body tracking
Inertial Tracking

laser gyro:
Inertial Tracking

MEMS (Microelectromechanical systems)

deliver linear & angular acceleration in compact packages:
  phones
  game controller
Inertial Tracking: conclusion

Advantages

▪ source-less
▪ no occlusion
▪ delivers accelerations! (→prediction)

Disadvantages

▪ drift
▪ relative measurements only
Global Positioning System - GPS

A space-based satellite navigation system that provides location and time information, anywhere on or near the Earth where there is an unobstructed line of sight to at least four Satellites

Maintained by the US government

Alternative systems:

GLONASS (Russia)

Planned for 2014: Galileo (EU)
Global Positioning System - GPS

Principle:
Satellites deliver extremely precise synchronized time
Receiver measures the time differences between different satellites’ signals:

\[
L_1 = c(t - t_1) = \sqrt{\frac{1}{2}(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2}
\]
\[
L_2 = c(t - t_2) = \sqrt{\frac{1}{2}(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2}
\]
\[
L_3 = c(t - t_3) = \sqrt{\frac{1}{2}(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2}
\]
\[
L_4 = c(t - t_4) = \sqrt{\frac{1}{2}(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2}
\]

Solution \((x, y, z, t)\) of the receiver

minimal 4 equations for 4 variables \(\rightarrow\) more satellites higher precision
Global Positioning System - GPS

Advantages:
Works globally
Precise timing information for synchronization purposes (~100ns)
Inexpensive & small receivers
Relative precise: <10m
(enhanced by carrier phase and differential measurement: <10cm)

Advantages:
Works only within line-of-sight of sky
Prone to errors when reflections occur (multipath signals)
Radio Tracking

Principle:


Die 3D-Positionsdaten in x, y, z und der Geschwindigkeitsvektor werden vollautomatisch der Anwendungssoftware übergeben und dargestellt. Zusätzlich können über einen eigenen Telemetriekanal Daten wie z.B. Herzfrequenz, Temperatur usw. mitgesendet werden.”
Radio Tracking

hub  basis station  transponder
Radio Tracking

Advantages

▪ large volume of operation (500m x 500m)
▪ rugged (e.g. inside soccer ball)
▪ up to 16.384 transponders

Disadvantages

▪ 6DoF only with multiple transponders
▪ only ±5cm precision (at best)
“Geometric” Tracking

Instead of tracking only transformations of rigid bodies, the tracker reconstructs scene (and user) geometry in real-time

- Delivers typically a point cloud
- Tracks everything in sight
- Needs post-processing for meaningful data
“Geometric” Tracking

Typically, the devices work like a laser scanner, but with much higher update rates.

Methods include:

▪ Stereo cameras
▪ Phase (“Time-of-Flight”) cameras
▪ Structured light scanners
“Geometric” Tracking: stereo camera

Two (or more) cameras are mounted with a known offset, from the images a depth map is constructed:

Example:
Point Grey “BumbleBee”
1024×768 @20fps
“Geometric” Tracking: stereo camera

Using fast CPUs or GPUs, one can construct a dense depth map from most* stereo images:

Example:
“Stereo Vision on GPU”
R. Yang, 2006

*depends on content: without detectable features, the algorithm does not work
“Geometric” Tracking: ToF camera

Phase cameras measure the phase (~time of flight) of light impulses:

Example:
PMDtec sensor

200×200 @60Hz

~1mm depth resolution

0.3-7m range

60° Field of View

http://www.youtube.com/watch?v=iXZYYuboeSM

http://en.wikipedia.org/wiki/ToF_camera
“Geometric” Tracking: structured light

A pattern is projected on an object and captured from a different angle (→ epipolar geometry):

“Geometric” Tracking: structured light

Example:
Microsoft Kinect
Projects pseudo-random IR point pattern & captures IR @QVGA and visible light @VGA (depth with high latency)
“Geometric” Tracking: structured light
“Geometric” Tracking: segmentation

Depending on which data is needed, costly post-processing routines have to be applied:

- Segmentation in user/background
- Segmentation of user into limbs

e.g. Kinect-SDK: skeleton with 20 nodes
“Geometric” Tracking

Advantages
- No special markers needed
- Delivers scene model (e.g. for occlusion handling)

Disadvantages
- Point data must be post-processed (skeleton-based segmentation, time-consuming)
- Occlusion (when only using one sensor)
- Fine-grained data like finger position or hand- and head-orientation are difficult or impossible to extract
cellphone revisited: tracking

contain enough sensors for many AR applications:
A-GPS
2 DoF compass
3 DoF acceleration camera(s)
Hybrid Tracking

Using a combination of two or more methods two improve:

- precision
- speed
- reliability

e.g.: Intersense: inertial (relative & fast) + ultrasound (absolute & slow)
Hybrid Tracking

inertial tracking has an inherent advantage:

since it directly measures acceleration, it can be used for higher-order extrapolation

→ prediction!
Prediction

To compensate for the system delay, we have to use the predicted future state of our system to generate the virtual environment.

But how to predict?

- linear?
- higher order?
- ?
Prediction: Kalman Filter

The **Kalman** filter is a set of mathematical equations that provides an efficient computational (recursive) means to estimate the state of a process, in a way that minimizes the mean of the squared error. The filter is very powerful in several aspects:

- it supports estimations of past, present, and even future states, and it can do so even when the precise nature of the modeled system is unknown.

Advanced Topics in Virtual Reality

Calibration and Registration
Calibration and Registration

To produce a working 3D viewing and interaction experience, one has to calibrate all devices and register them to reality.

Calibration:
- mapping tracker to real world position
- mapping HMD to real world view

Registration:
- for the set-up to work, all devices have to be „registered“ to each other in the same coordinate system
Calibration

Determine & correct non-linearities and scale factors, e.g.:

- distortions of optics in a HMD:
- distortions of magnetic tracker:
Calibration

mapping of image to projection screen::
Registration

registration parameters for a projection set-up

Correct Stereoscopy

The stereoscopic effect depends heavily on the correct projection of left and right image.

Example: rendering for stereoscopic projection

Wrong: offset or tilt

Correct: off-axis projection
Correct Stereoscopy

A general camera model is necessary, where view plane and eye-point with viewing direction can be defined independently.

This is NOT generally possible in most render packages and OpenGL cameras!
Example: Calibration & Registration for FlyVR

- Virtual world
- 3D model of display surface
- LUT from tex coords to display pixels
- LUT for luminance correction
- Cubemap
- Observer pose $(x,y,z)$
- Geometry texture
- Projector input
- Photograph of display
Advanced Topics in Virtual Reality

Virtual Environments
System Setups
VR setups

Categories:

- Immersive / Augmented (Mixed)
- Single / Multi user
- Local / Distributed
Immersive vs. Augmented setups

Immersive setup
- user sees only simulation
- pro:
  - whole visible world can be manipulated
  - less registration problems
- contra:
  - possible: disorientation & claustrophobia
  - collisions w/reality
  - whole environment must be generated (real objects too → real collisions!)
Augmented (Mixed) setup

- user sees real & virtual environment

  pro:
  - only virtual objects have to be displayed
  - social interaction possible
  - objects outside the simulation are visible (cars, other people, doors, etc.)

  contra:
  - registration between real & virtual world tricky (misregistration very visible)
  - navigation metaphors reduced
The CAVE
(“CAVE Automatic Virtual Environment”)

The “CAVE” consists of 3 to 6 back-projection screens. These screens form (parts of) a cubical room in which the user has a large view of the VE.
A CAVE user

- wears Shutter- or Pol-glasses
- has to be head-tracked
- uses a tracked input device
The CAVE – back projection

- mirrors
- projectors
- screens (semi-transparent)
The CAVE – front projection
The CAVE – front vs. back projection

<table>
<thead>
<tr>
<th></th>
<th>Back</th>
<th>front</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space requirements</td>
<td>Larger than working volume</td>
<td>Working volume</td>
</tr>
<tr>
<td>Screen</td>
<td>Expensive, special corners</td>
<td>White wall</td>
</tr>
<tr>
<td>Vignetting</td>
<td>Extensive</td>
<td>Not noticeable</td>
</tr>
<tr>
<td>Shadows</td>
<td>None</td>
<td>When standing close</td>
</tr>
<tr>
<td>Polarization</td>
<td>Possible, but mediocre</td>
<td>Not really possible</td>
</tr>
<tr>
<td>Top &amp; bottom projection</td>
<td>Possible</td>
<td>Not possible</td>
</tr>
</tbody>
</table>
The CAVE

Images for the CAVE have to be calculated depending on the users and screens position. From the wrong position, the images look like this:
The CAVE
The FLYCAVE
The FLYCAVE - display

projector

mirrors

mirrors

projector
The FLYCAVE - display

mirror  backprojection cylinder  mirror
The FLYCAVE – rendering

Virtual world
- arbitrary scene rendered with OpenSceneGraph (e.g. skybox and foreground objects above)
- drawn via user-created plugin
- defined in lab frame

Cubemap
- six camera views of virtual world
- from viewpoint of observer in lab frame

Geometry texture
- created by projecting cubemap onto 3D model of display surface in lab frame

Display view
- created by lookup table from geometry texture coordinates to display pixels
- physically displayed

3D pose of observer
- defined in lab frame

3D model of display surface
- vertices defined in lab frame
- texture coordinates in arbitrary system
- measured during auto-calibration

LUT from tex coords to display pixels
- measured during auto-calibration
The FLYCAVE – tethered version

Three images are projected via mirrors on a small, translucent ball

Inside the ball, a fly is anchored

The amplitudes of the fly’s wings give its intended direction
The FLYCAVE – tethered version
The FLYCAVE – confinement results
Studierstube

“Studierstube” is a multi-user local VE. It uses see-through HMDs to let users share a common augmented workspace.
Studierstube

The main interface is the “Personal Interaction Panel” a pad and pen combination. The pad is augmented with 2D and 3D widgets, which can be manipulated by the pen.
Using sliders on the PIP to parameterize the AVS network
Studierstube (video)

Two-User Interaction
Select your viewpoint by simply moving your head around....
Spherical Projection Setups

Non-planar screens – mostly spherical – screens used when large FoV is important.

E.g. architectural walkthroughs or car- or flight-simulators:
Motion Simulators

(hemi-)spherical projection in combination with a motion platform delivers an extremely immersive experience:
e.g.: military helicopter simulation
Blue-C

Developed @ ETH Zürich (Markus Gross & Oliver Staadt)
The blue-c system combines the CAVE with real-time image capture and 3D video
Blue-C

http://blue-c.ethz.ch/
The blue-c system includes:

- a fully immersive three-dimensional stereo projection theatre
- real-time acquisition of multiple video streams
- three-dimensional human inlays reconstructed from video images
- voice and spatial sound rendering
- distributed computing architectures for real-time image processing and rendering
- a flexible communication layer adapting to network performance
- a scalable hard- and software architecture for both fixed and mobile installations
Blue-C

Back-projection screens can be switched to transparent → cameras from outside CAVE can grab images → 3D reconstruction of user possible
Blue-C

Capturing the user from a lot of cameras surrounding the system allows to reconstruct a 3D model, which can be rendered from different angles
Blue-C

By using an additional phase, where both shutters of the glasses are opaque, the capturing can be performed invisible to the user:
Blue-C

Background subtraction segments the image into user and background:
Blue-C

Many images & silhouettes from different viewpoint deliver 3D point stream:
Blue-C

3D holographic telephony, system setup:
Blue-C

video:
Motion Simulators

Motion platforms can be used to simulate acceleration. Because humans do not recognize slow changes in acceleration, and because the gravity-vector can be used as substitute for ongoing accelerations (e.g. tilting), a relatively small range of motions is sufficient.
VirtuSphere

- Implements „walking“ in VR
- gigantic „Trackball“
- user inside
- moves in all direction
- ultrasound sensors deliver XY
Virtusphere

Advantages

▪ no physical constraints of (planar) movement

Disadvantages

▪ high inertia → movement difficult
▪ accident prone setup
▪ tracking & display has to be wireless or self-contained (mobile VR)
Virtuix Omni

Low-friction shoes!
Virtuix Omni

Socks!
CyberCarpet

- Implements „walking“ in VR
- omni-directional treadmill
- conveyor belt built from conveyor belts turned 90°
CyberCarpet (movie)
Infinadeck
End of Lecture

Lab-Project:
- 1-2 students per group
- max. 3 months
- work@home or VRVis
- own or given themes

Examn
- this semester (as early as possible)
Thank you for your attention!