Special Topics in Virtual Reality

Display Devices

https://tinyurl.com/STVR2018

Anton L. Fuhrmann
2018

TU WIEN
Technische Universität Wien
Vienna University of Technology

Display Devices

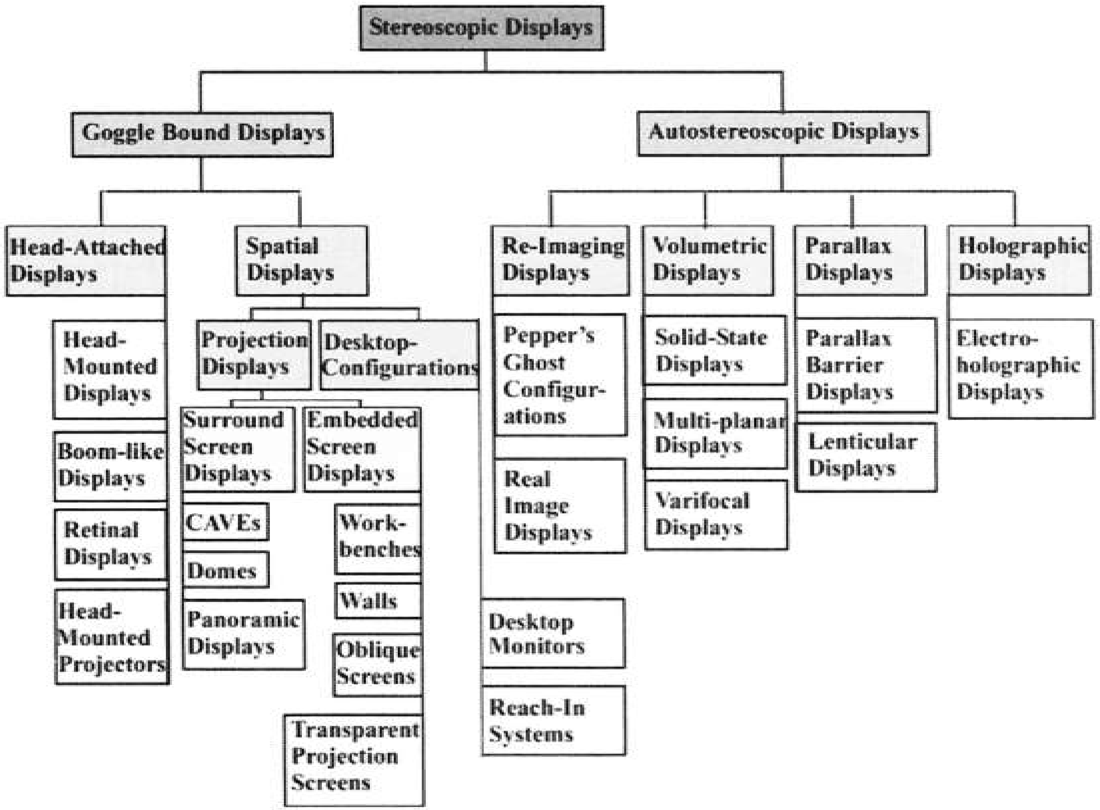
Stereoscopic Output

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

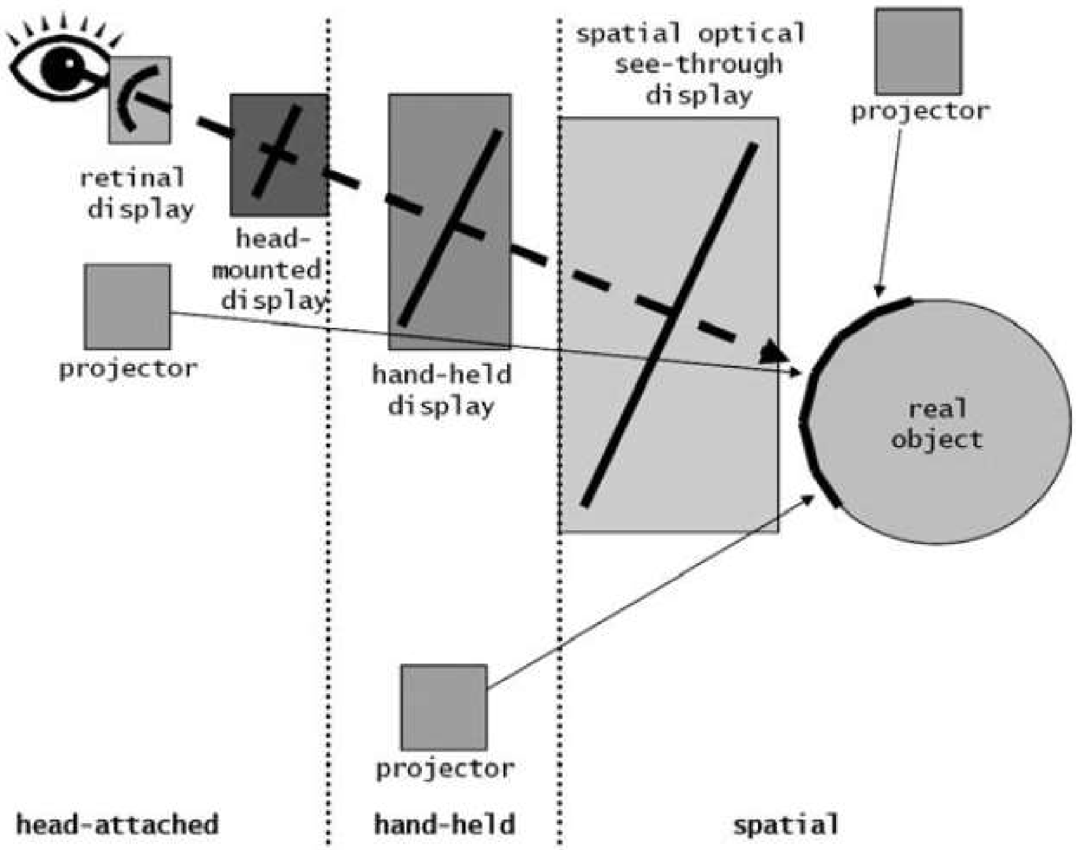
„Exotic Displays“

- Volumetric Displays

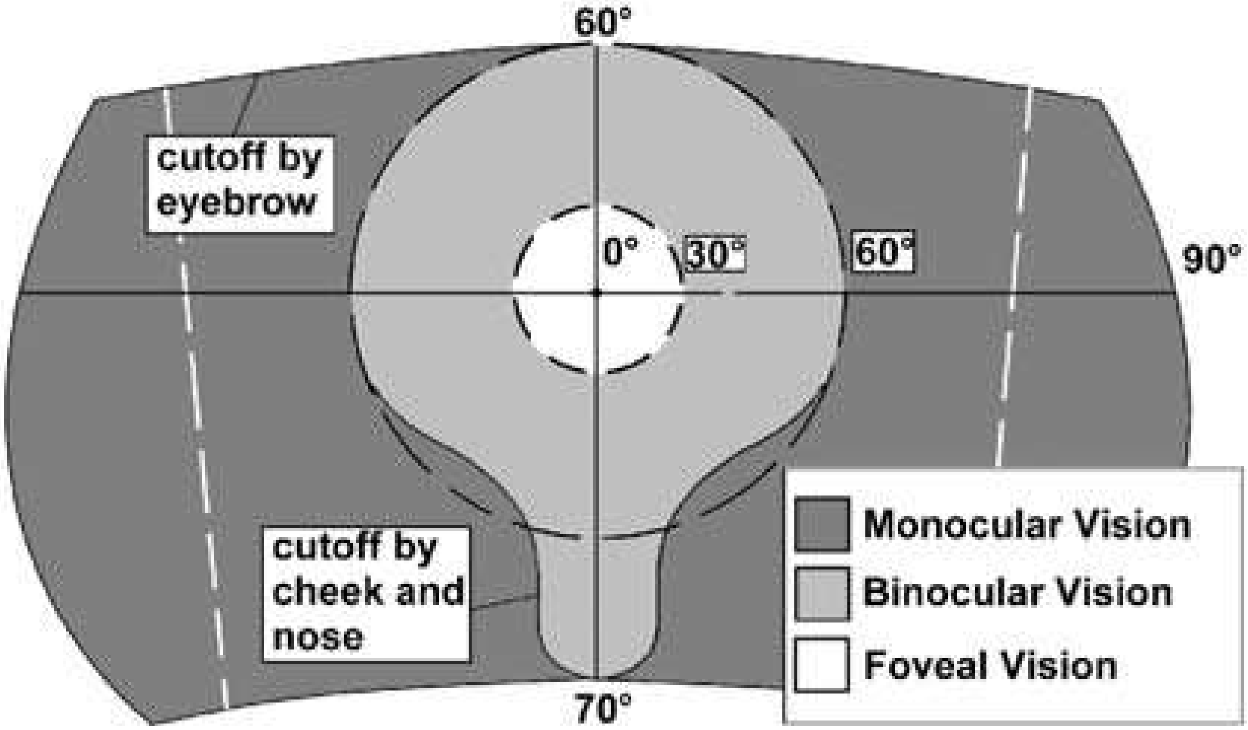
Classification of stereoscopic displays



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 → perfect stereo channel separation!
- display technology:
    - CRT
    - LCD
    - laser (retinal displays)
    - projector
- type: immersive, see-through, video see-through

Head-Mounted Display History

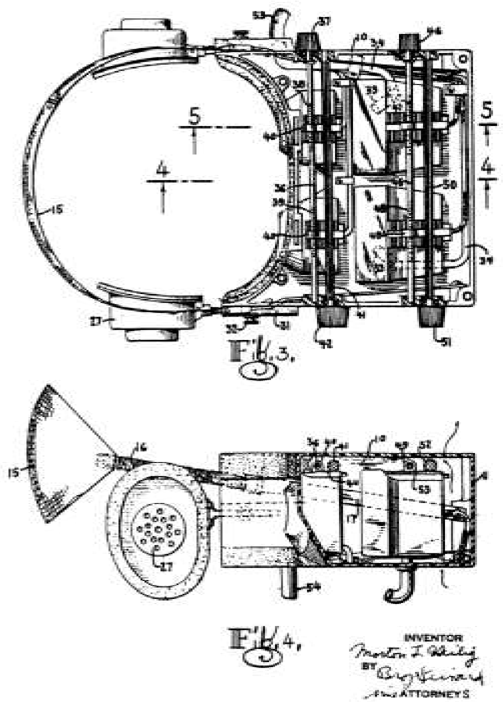


Figure 1.4: *Heilig's early Head-Mounted Display patent [Heilig 1960].*

- 1960 Heilig
- 1963 Hall, Miller

Head-Mounted Display History

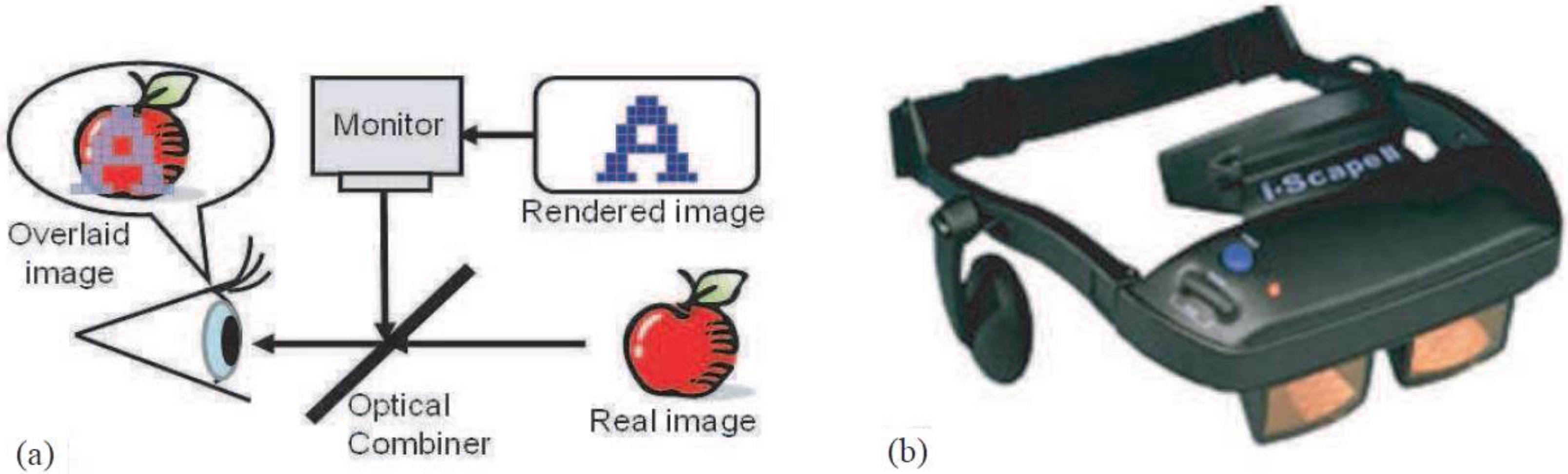
- vector display: "3000 lines at 30 frames per second"
- ultrasound & mechanical tracking
- CRT see-through display

- 1969 Sutherland

Head-Mounted Display (HMD)

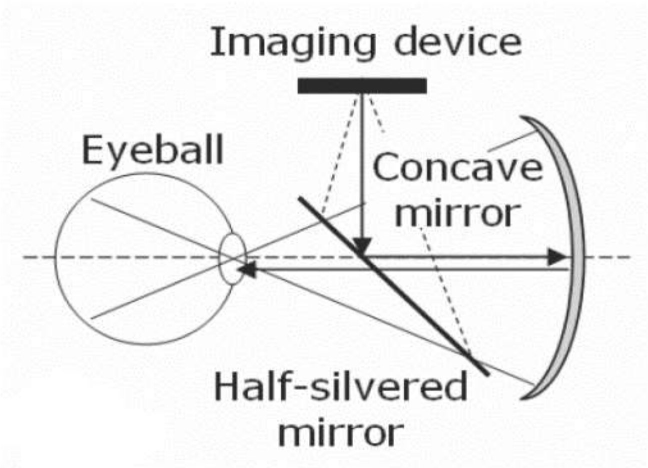
- optical see-through
  - semi-transparent mirror
  - overlay over real world
  - brightness problem
  - occlusion problem
- video see-through
  - real world via camera composited
  - occlusion solvable
  - only video resolution of real world (~HD)

optical see-through HMD



[Haller2007]

optical see-through HMD

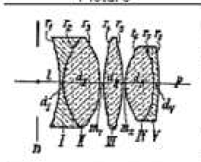
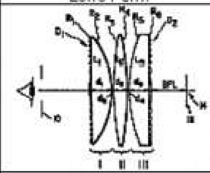
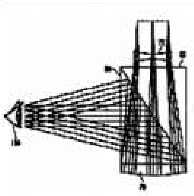
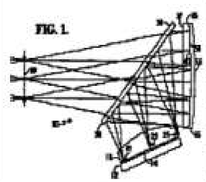
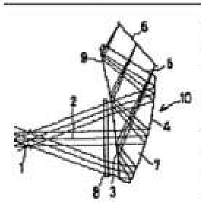
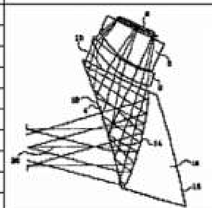
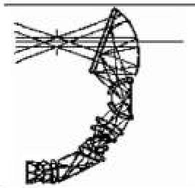
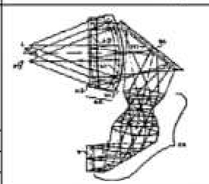
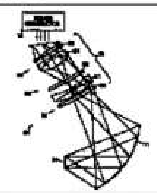
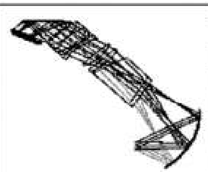


display via half-silvered mirror as overlay ("add") over reality

Advantage: undistorted view of reality in realtime an wide FoV

Disadvantage: no complete occlusion, only visible against darker background

optical see-through HMD

Picture	Specification	Lens Form	Specification
	FOV 70 ELF 100 *H. Erfle* 1478704		FOV 70 EFL 100 *Michael D. Missig* 5446588
	FOV33 EFL 34 *J. D. Robinson* *C. M. Schor* *P.H. Muller* *W.A. Yankee* eyepiece 5696521		*B.S. Fritz* HMD using Mangin Mirror combiner 5838490
	FOV 40-60 EFL 100 Takayoshi Togino Eyepicece with DOE 6181475 5959780		FOV 40 15.2x12.3 MicroDisplay F#/1.7 *J.G. Droessler* Honeywell,Inc Morristown, NJ 6147807
	FOV 50x60 *J.G. Droessler* *D.J. Rotier* Tilted Cat Ocular 1989		FOV 120 *C. Antier* *Jean-Blaise Migozzi* Holographic Binocular Helmet Visor 5124821
	FOV50x60 color Helmet visor display *B. Chen* Off-axis Design 5526183		FOV 60 color 1.3" diagonal CRT *J.P. Rolland* Off-axis Design *IODC94; OE 2000*

other optical configurations

(3D VIS Lab, University of Arizona - "Head-Mounted Display Systems" by Jannick Rolland and Hong Hua)

pinlight see-through HMD

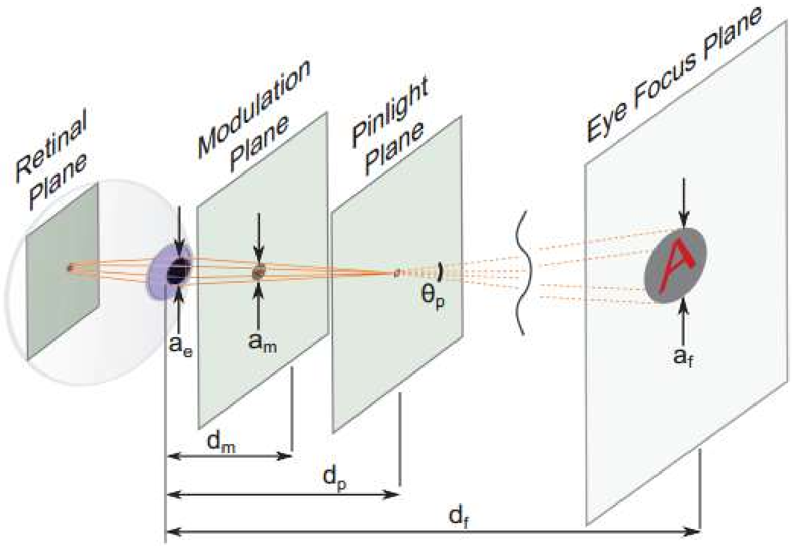


Figure 2: *Pinlight Projection. A defocused point light source, or* pinlight, *placed near the eye is coded with a spatial light modulator to create a narrow field of view image that appears in focus without the use of refractive or diffractive optics.*

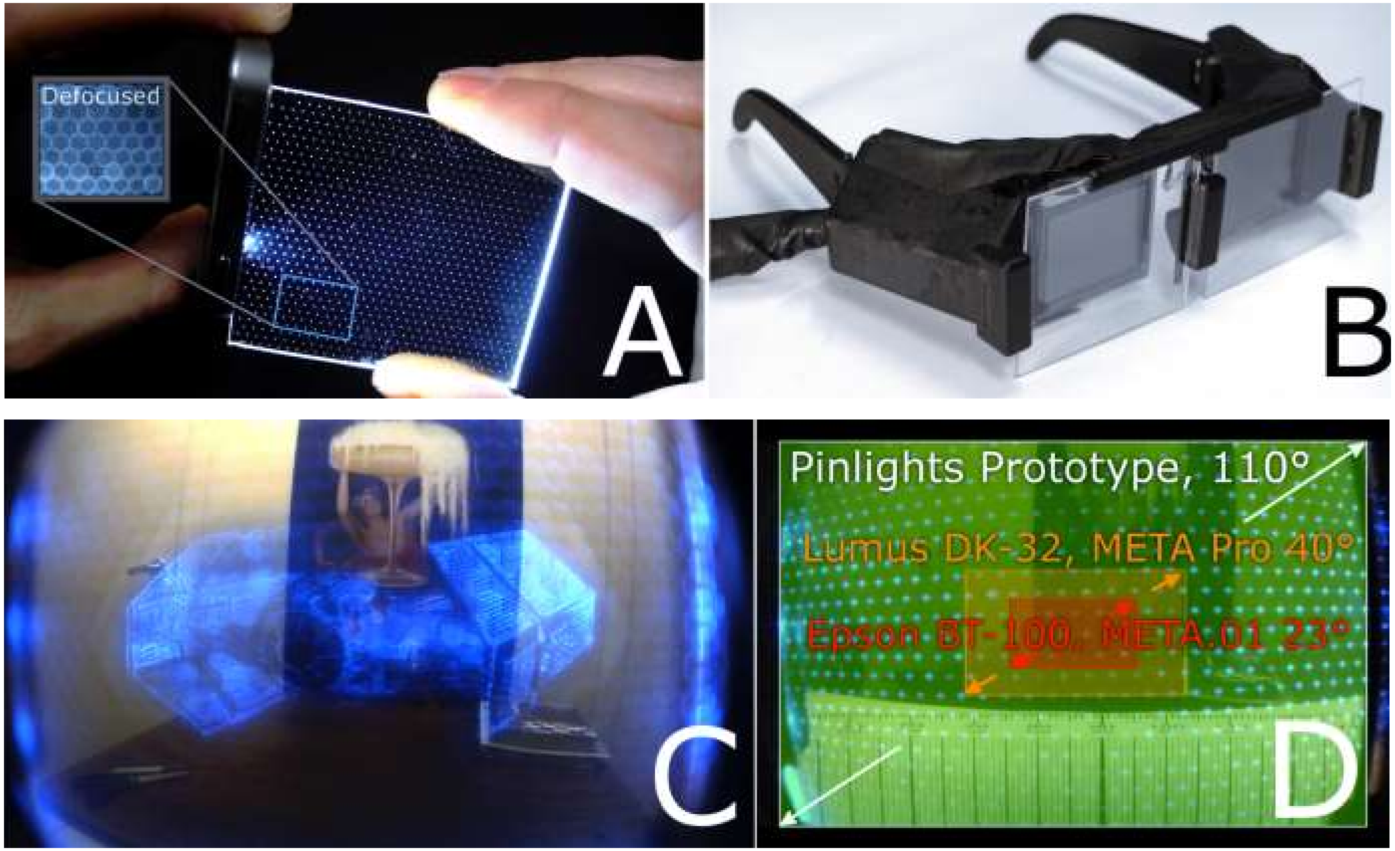
defocused pinlights act as "projectors", projecting a virtual image through an LCD on the retina

Advantage: wide FoV

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

Maimone, A., Lanman, D., Rathinavel, K., Keller, K., Luebke, D., Fuchs, H. 2014. Pinlight Displays: Wide Field of View Augmented Reality Eyeglasses using Defocused Point Light Sources. ACM Trans. Graph. 33, 4, Article 89 (July 2014), 11 pages. DOI = 10.1145/2601097.2601141 http://doi.acm.org/10.1145/2601097.2601141.

pinlight see-through HMD



Maimone, A., Lanman, D., Rathinavel, K., Keller, K., Luebke, D., Fuchs, H. 2014. Pinlight Displays: Wide Field of View Augmented Reality Eyeglasses using Defocused Point Light Sources. ACM Trans. Graph. 33, 4, Article 89 (July 2014), 11 pages. DOI = 10.1145/2601097.2601141 http://doi.acm.org/10.1145/2601097.2601141.

diffractive see-through HMD

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

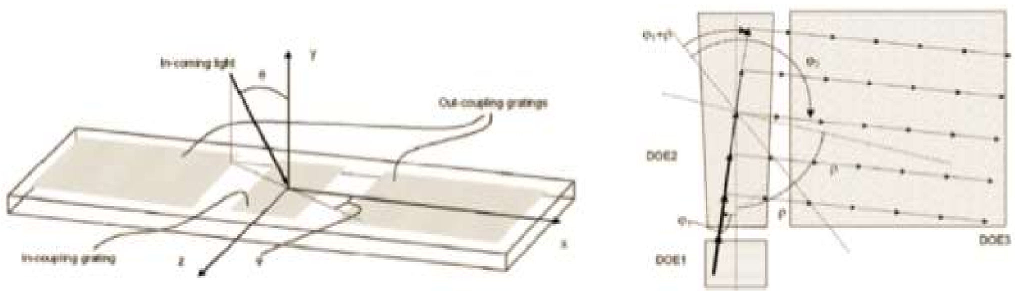
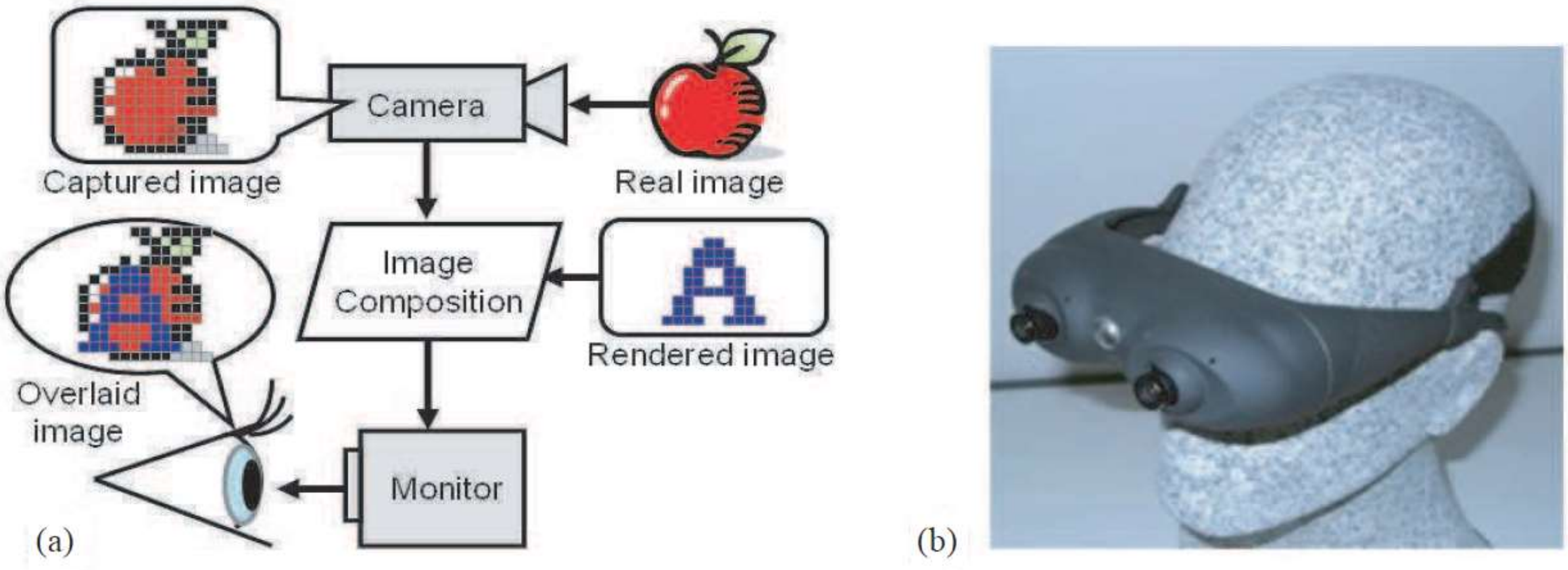


Figure 5. Surface relief slanted sub-wavelength gratings as optical combiners and exit pupil expanders.

[„**Diffractive and Holographic Optics as Optical Combiners in Head Mounted Displays“, Bernard C. Kress**]

video see-through HMD



[Haller2007]

video see-through HMD

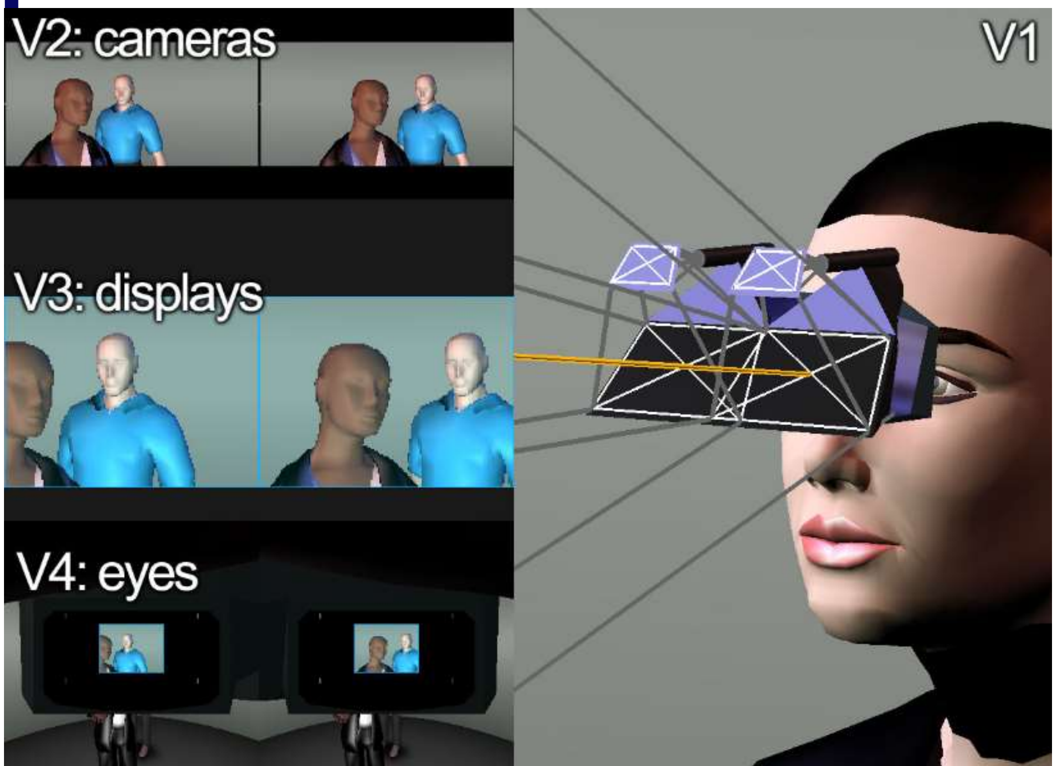
camera delivers image to display
→ no direct view of reality

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

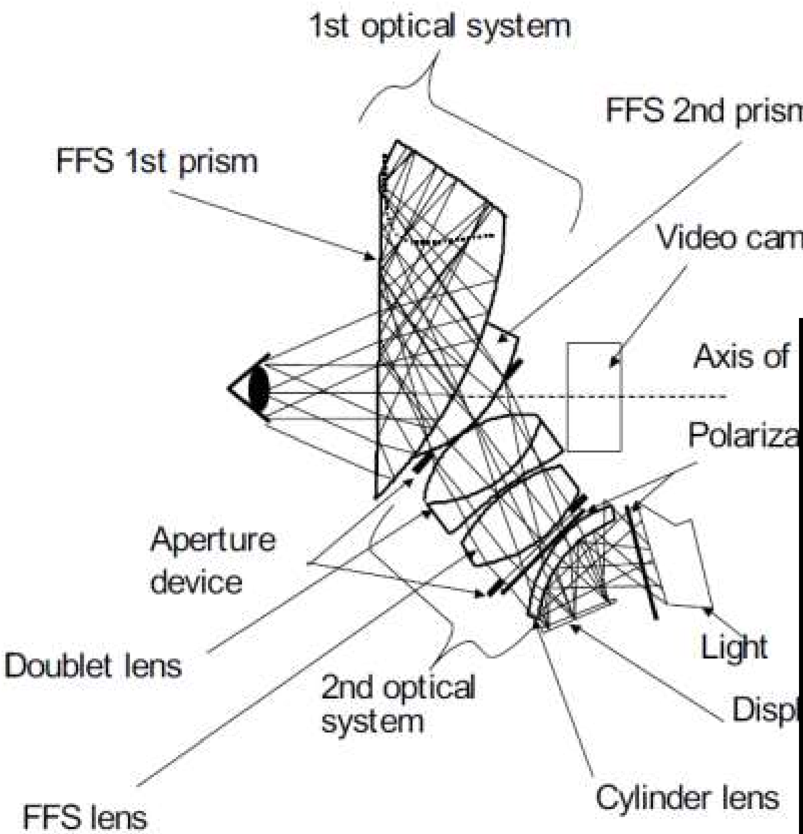


optics are designed so that the (reflected) camera viewpoint is in the users pupil

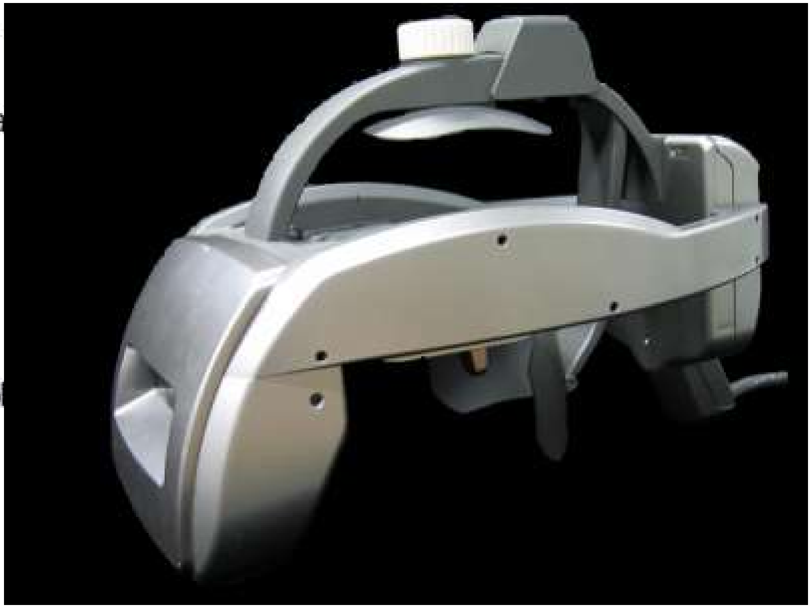
video:

[State2005]

parallax-free video see-through HMD



free – form prisms allow for an extremely compact construction



[Inoguchi2008]

Older Commercial HMDs

datavisor
(nvision)

ST40 (Kaiser)

i-glasses

Addvisor (SAAB)

glasstron (Sony)

Commercial HMDs

HTC Vive Pro

Oculus Rift

Pimax 8k

Meta2

Sony HMZ-T2

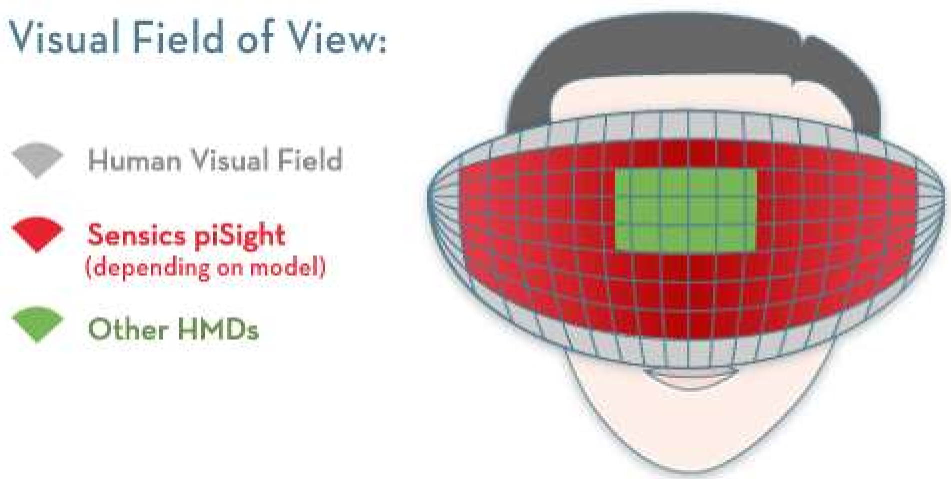
Commercial HMDs: Panoramic HMD

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

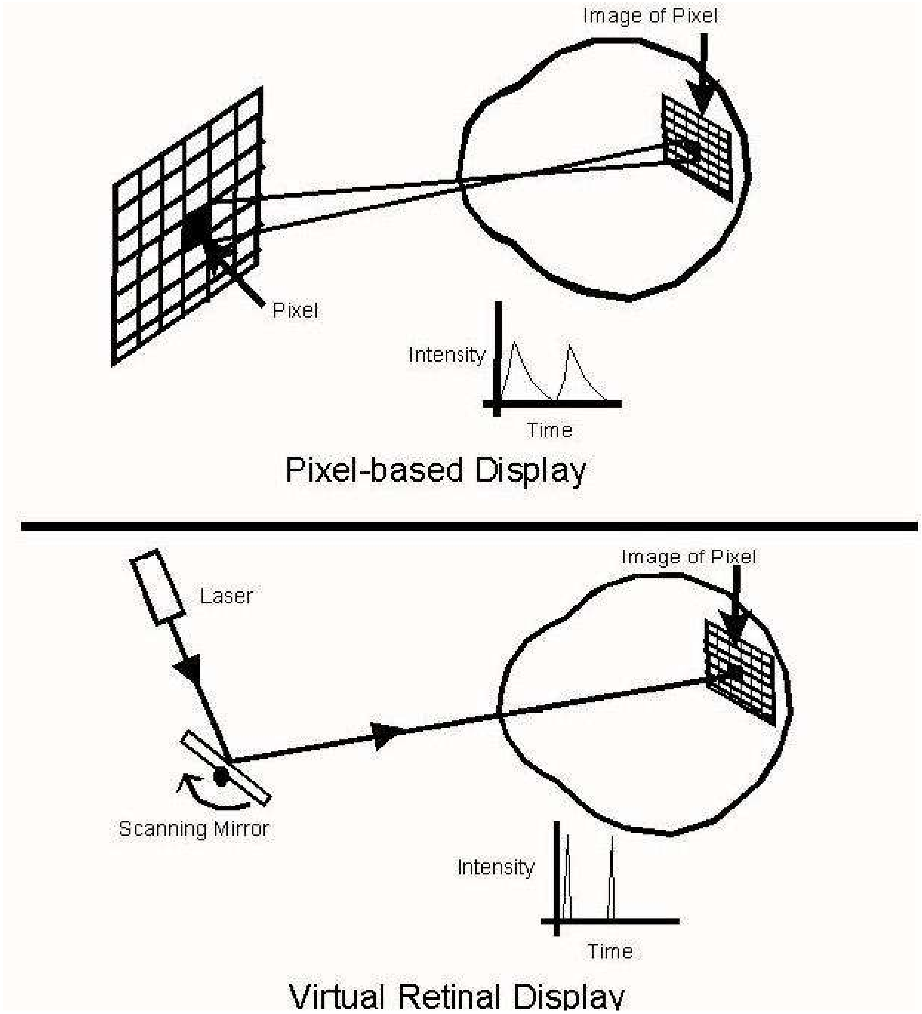
Commercial HMDs: Panoramic HMD

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":

http://en.wikipedia.org/wiki/Floater

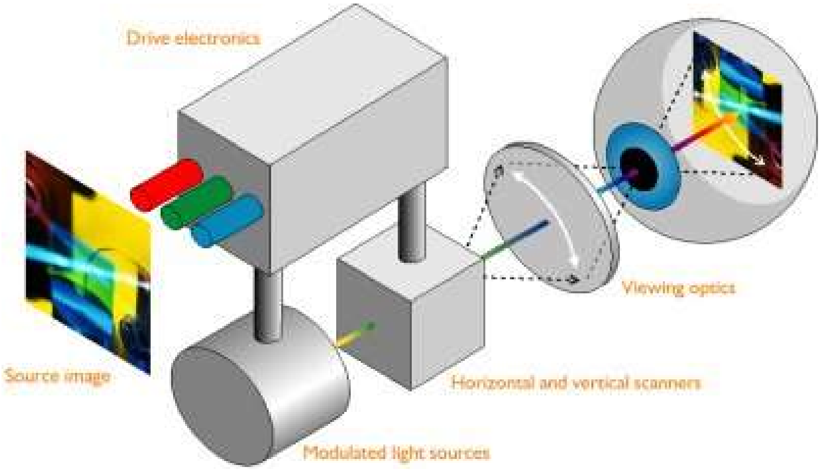
Retinal HMD (NOMAD, Microvision)

uses laser to directly project on users retina

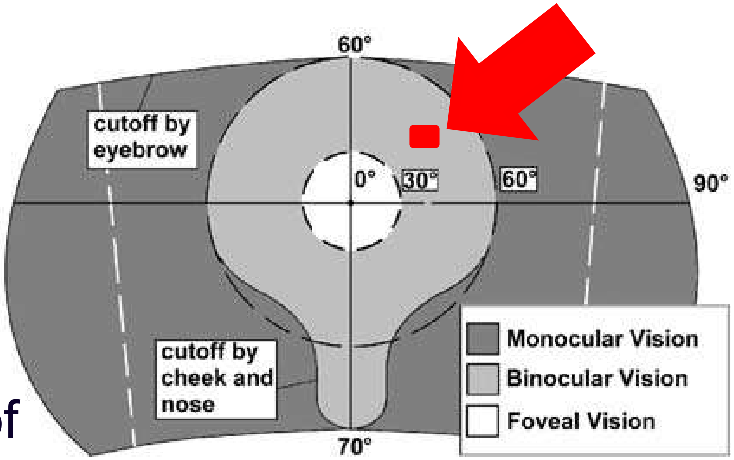
Advantages: bright, always focussed, see-through

Disadvantages: monchrome (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

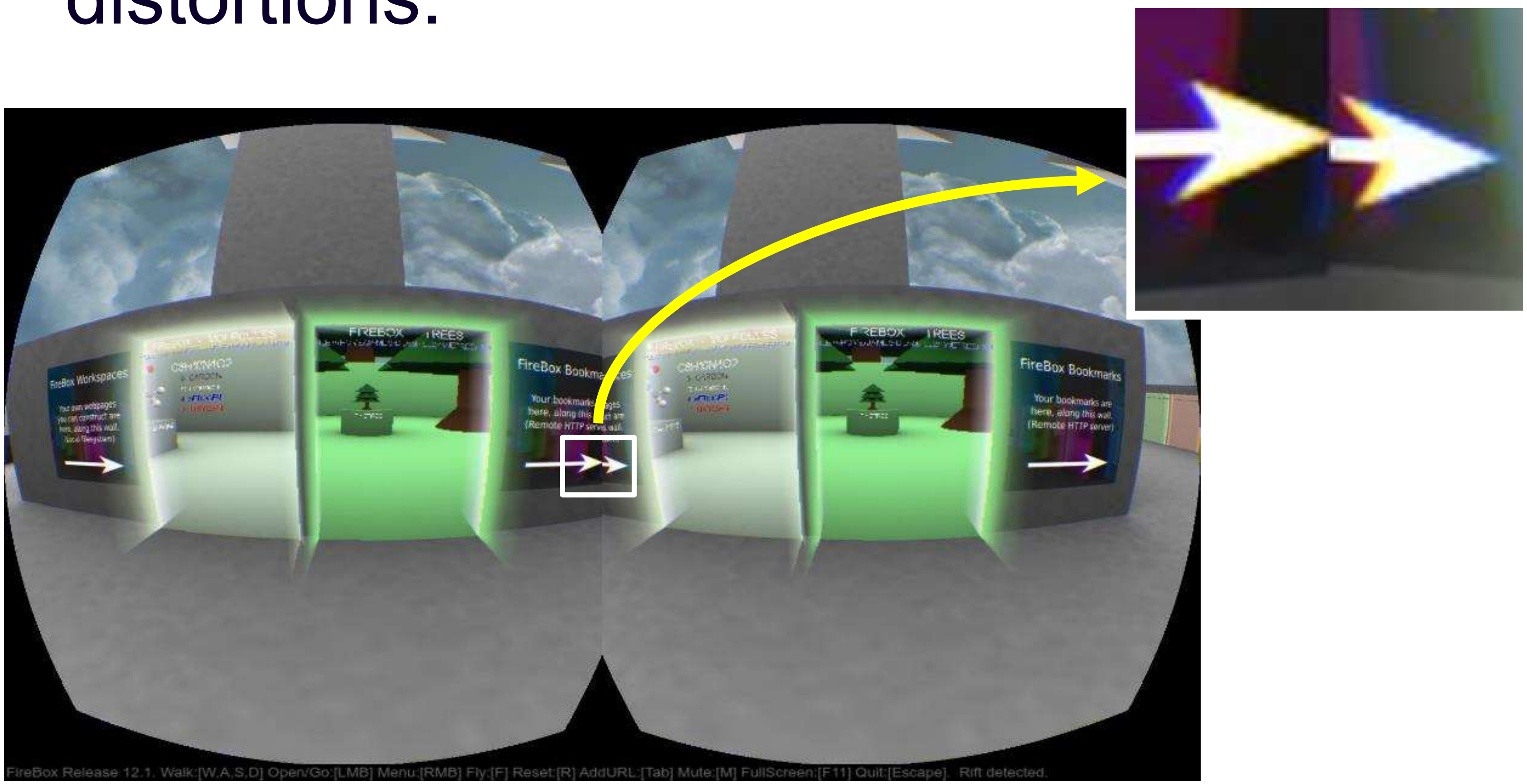
Bluetooth


htc
VIVE

Oculus Rift

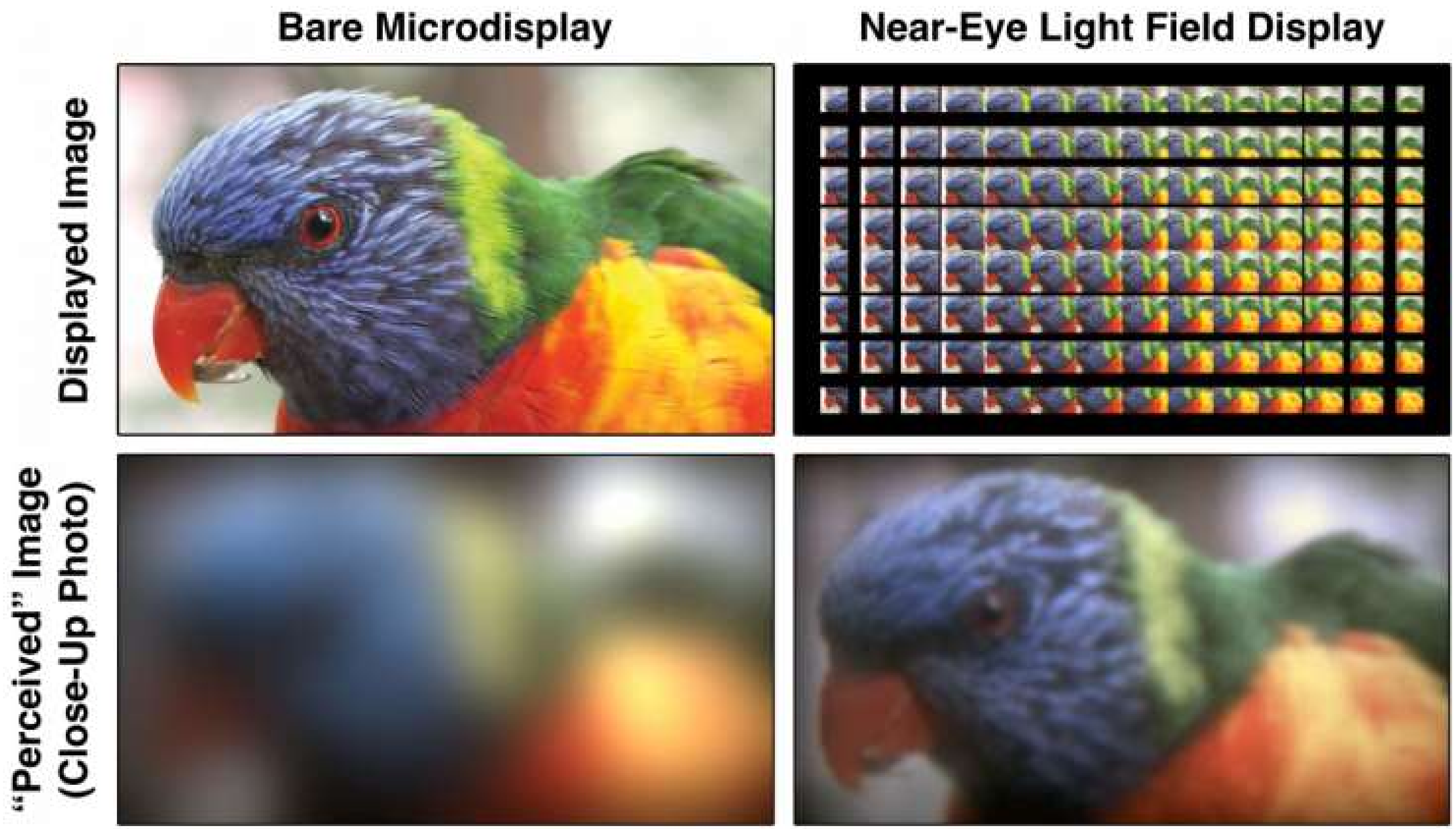
Oculus Rift

shader corrects geometric & chromatic distortions:



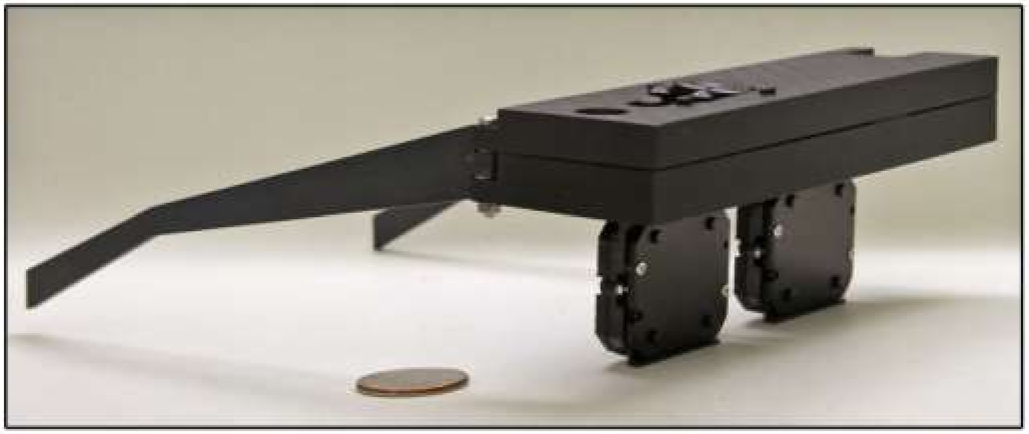
Light Fields HMD

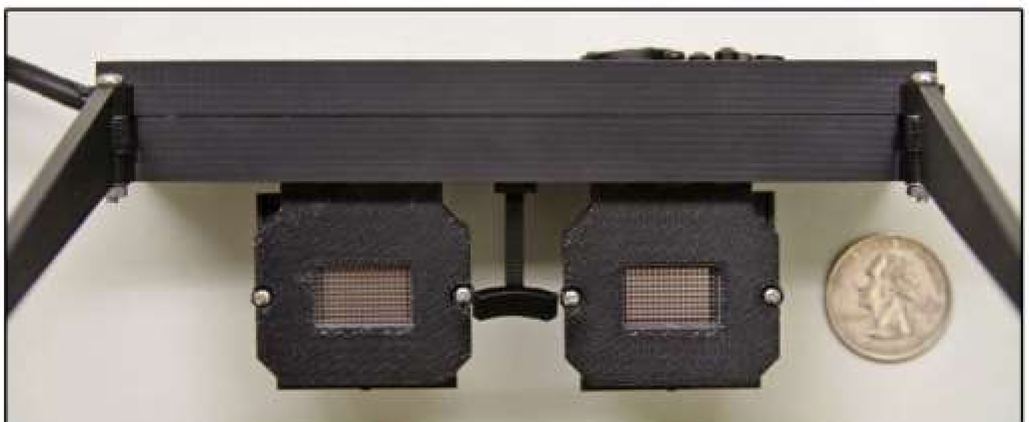
Micro lenses in front of segmented views:

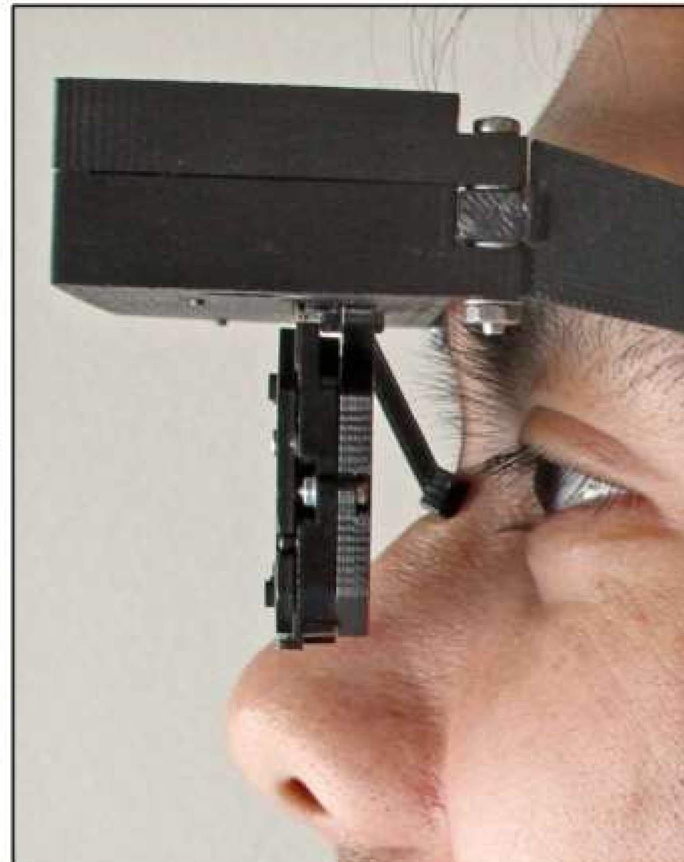


Light Fields HMD

Flat (~10mm) optical element:





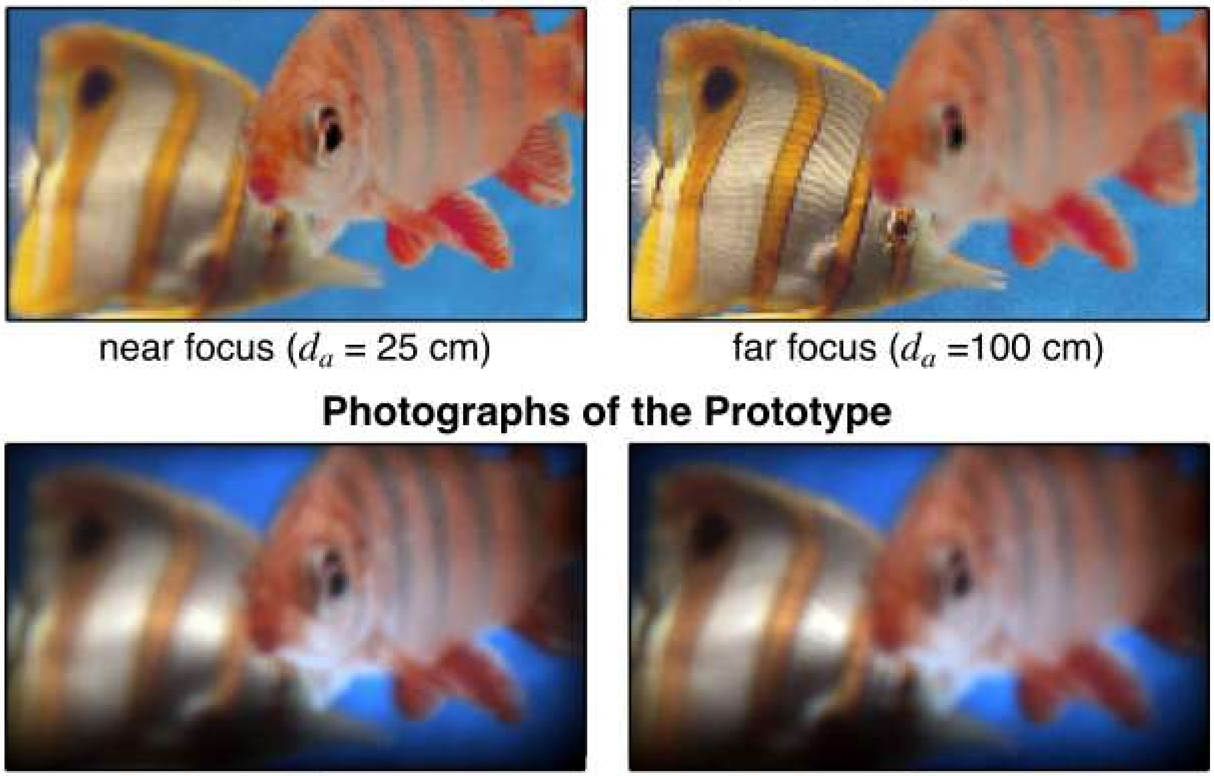


Technische Universität Wien
Vienna University of Technology

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)

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

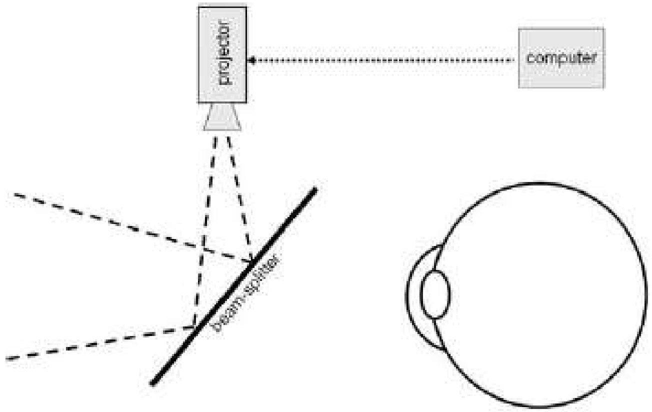
Head-Mounted Projectors

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



(a)

simplified head-mounted projector set-up

(b)

(c)

example 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)

https://www.igd.fraunhofer.de/en/Institut/Abteilungen/VRAR/Projekte/AR-Telescope

head attached display: zacturn 2.0

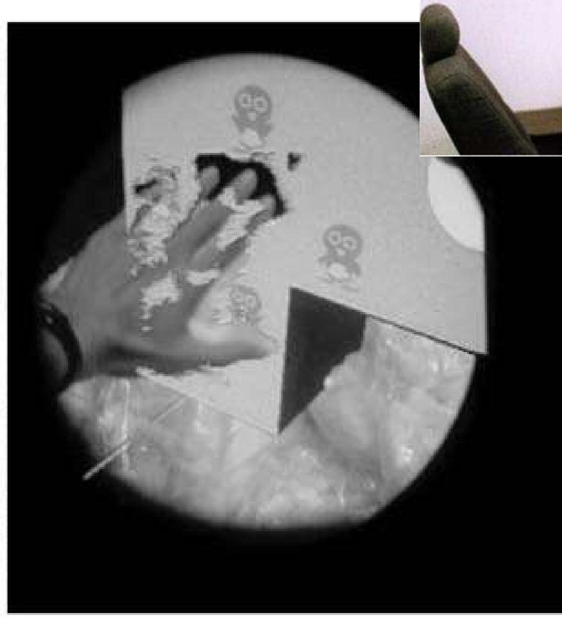
comparable to “VR telescope”:

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

Anton L. Fuhrmann
2018

Technische Universität Wien
Vienna University of Technology

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) } Difficult to adjust
- Analog technology } Difficult to adjust
- 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

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

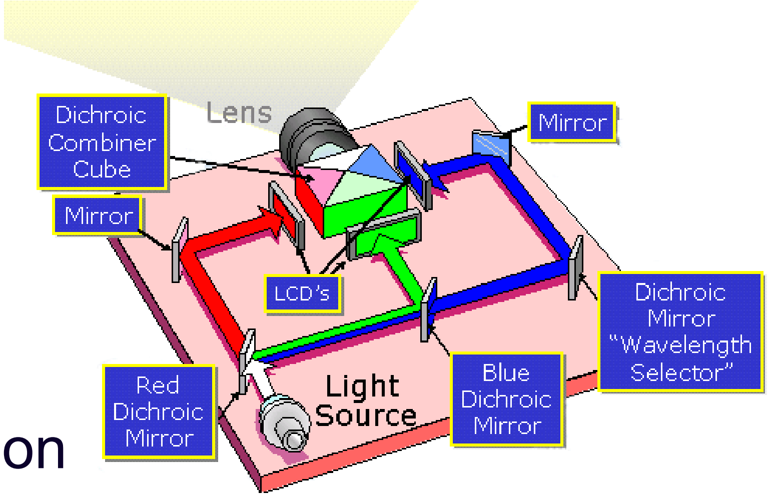
(from a manual)

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

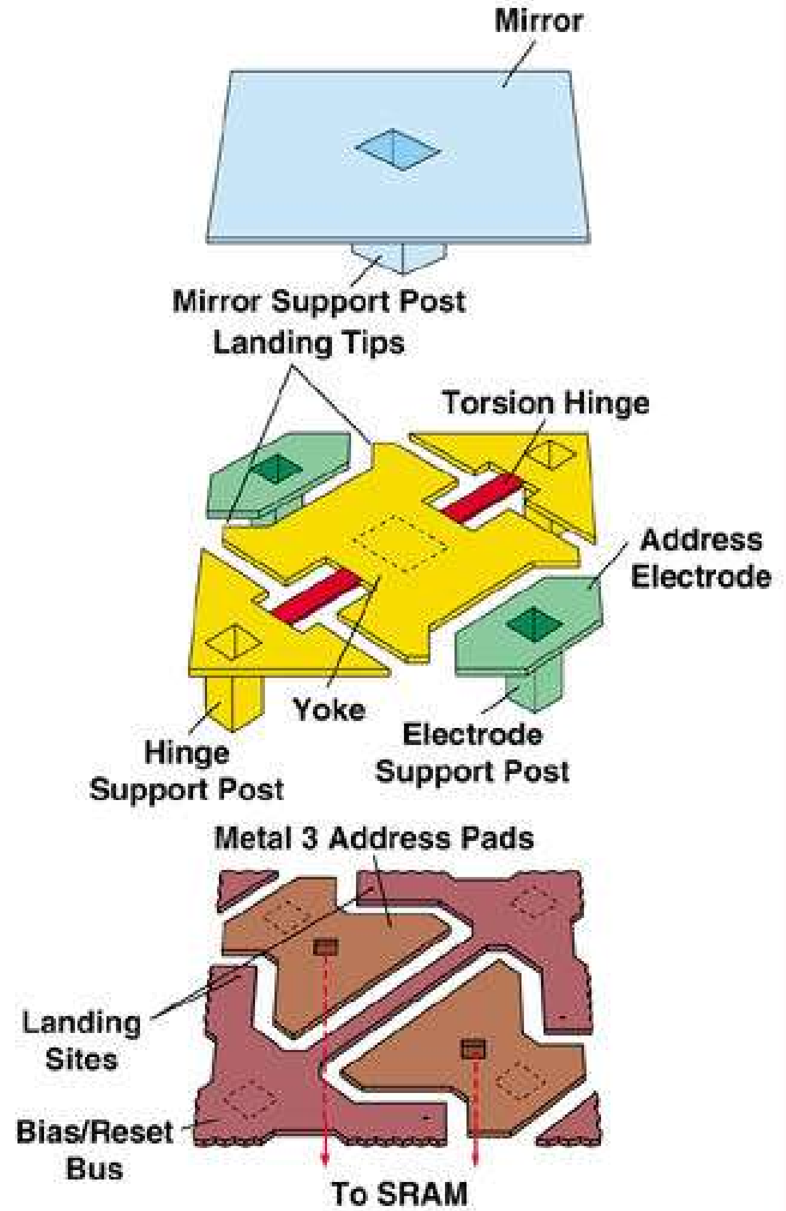
- about 89% of panel surface active
- but visible pixel structure
- inexpensive, but variable color reproduction

DLP Projector

micro-mechanic:

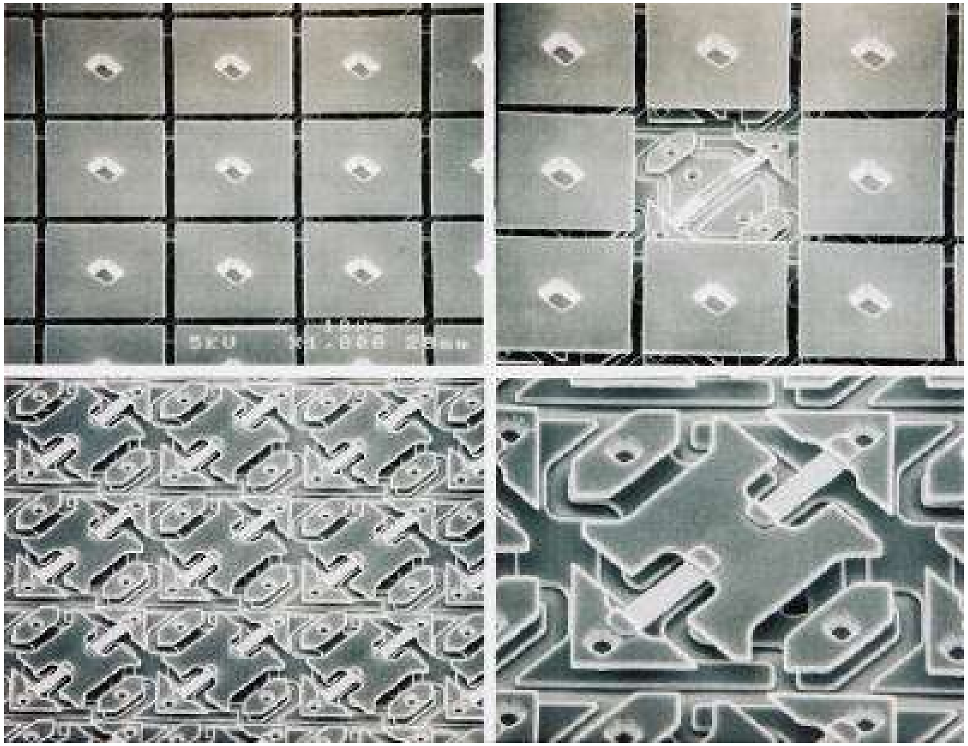
tiltable mirrors

two positions, switched by electrostatic force



DLP Projector

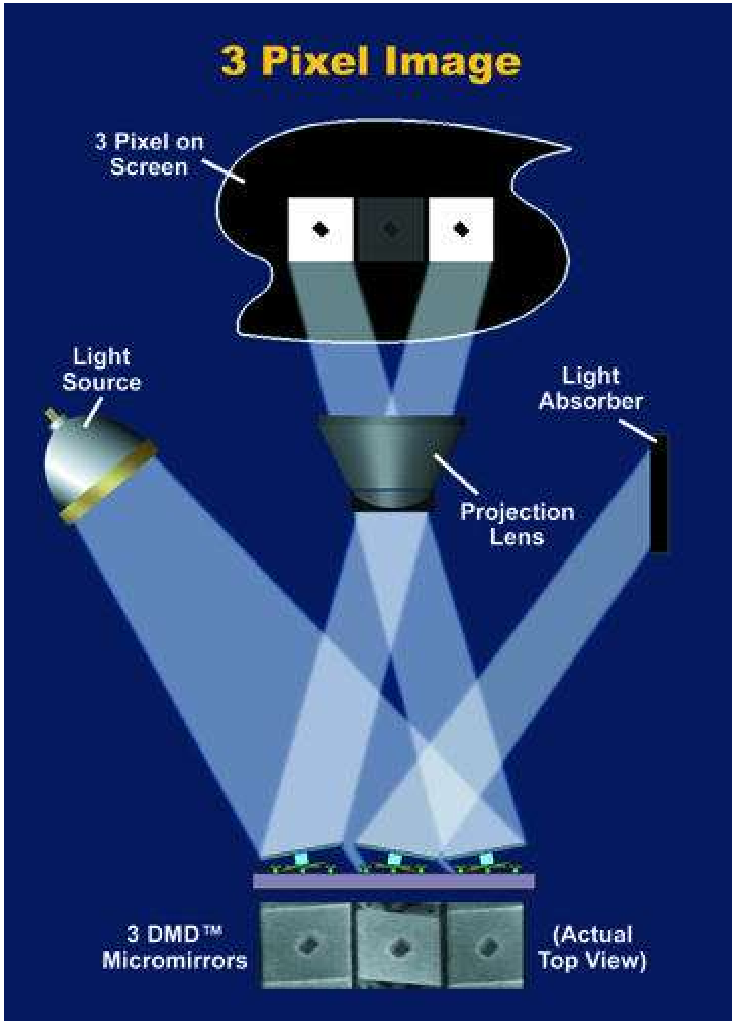
tiltable mirrors, electron microscopic view



DLP Projector

mirrors produce on/off pattern only

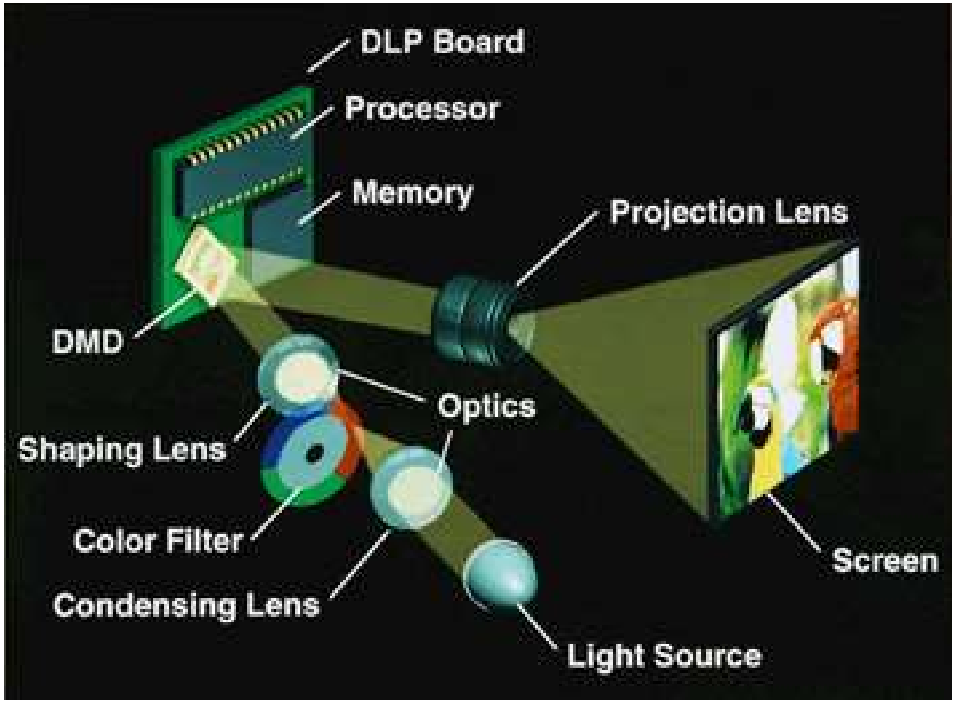
modulate on-to-off ratio to generate grayscale



DLP Projector

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

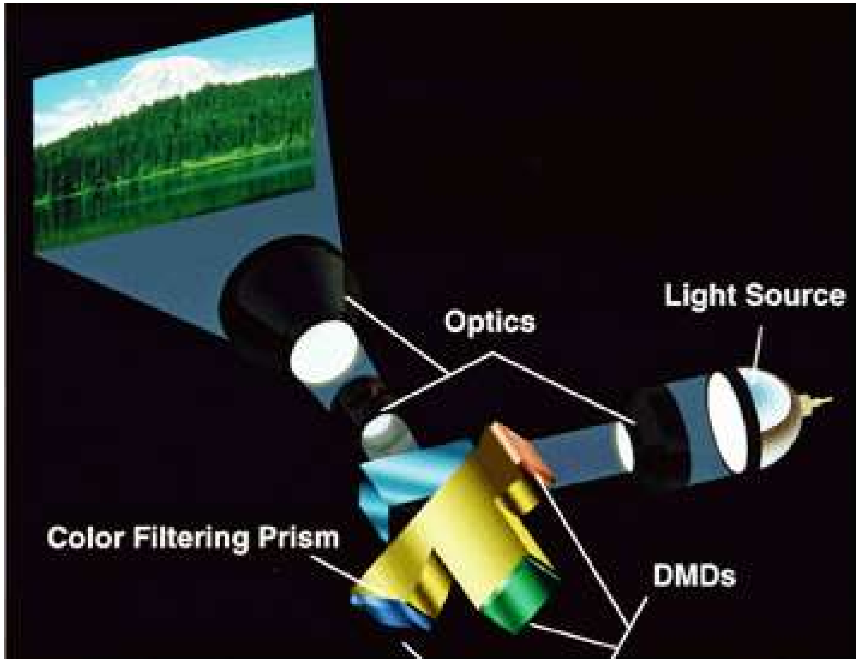
in many cases, these wheels contain „white“ as additional color, thereby significantly enhancing black/white contrast, but impairing color reproduction



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

Technische Universität Wien
Vienna University of Technology

DLP LED/Laser Projector

Use combined LED/Laser light source instead of mercury lamp

Advantage:

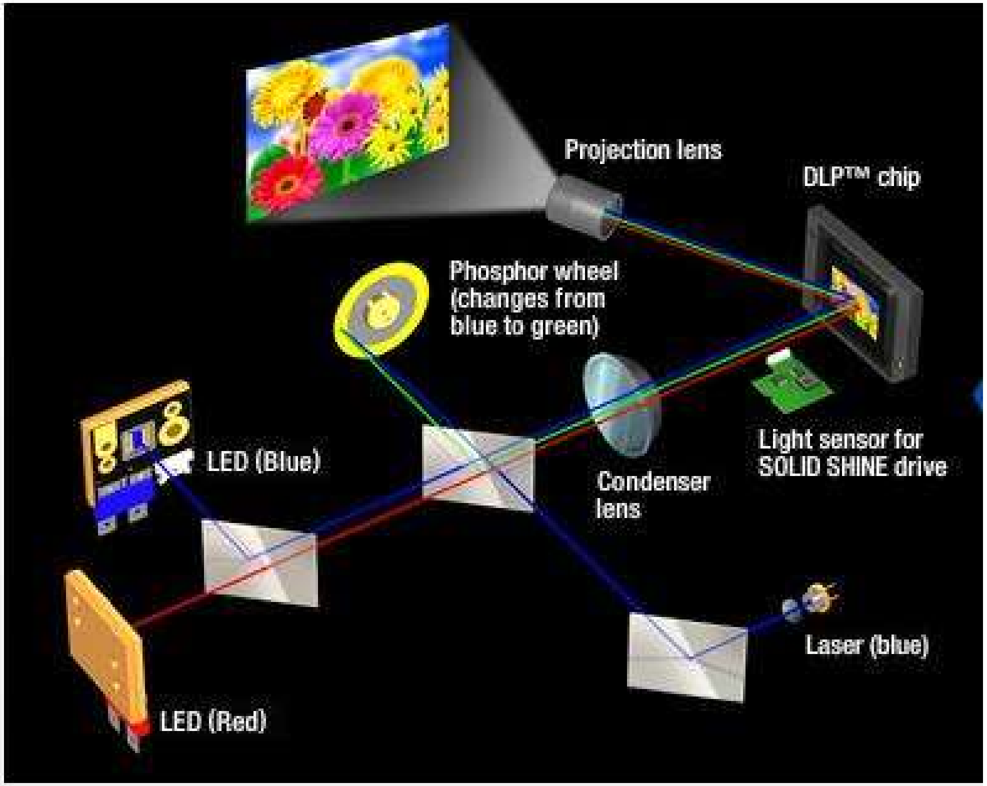
Higher efficiency

Longer lamp life (~20.000h)

No color wheel, since LED/Laser can be pulsed

Disadvantage:

Still not very bright (~3500lm)



reflective LCD Projector

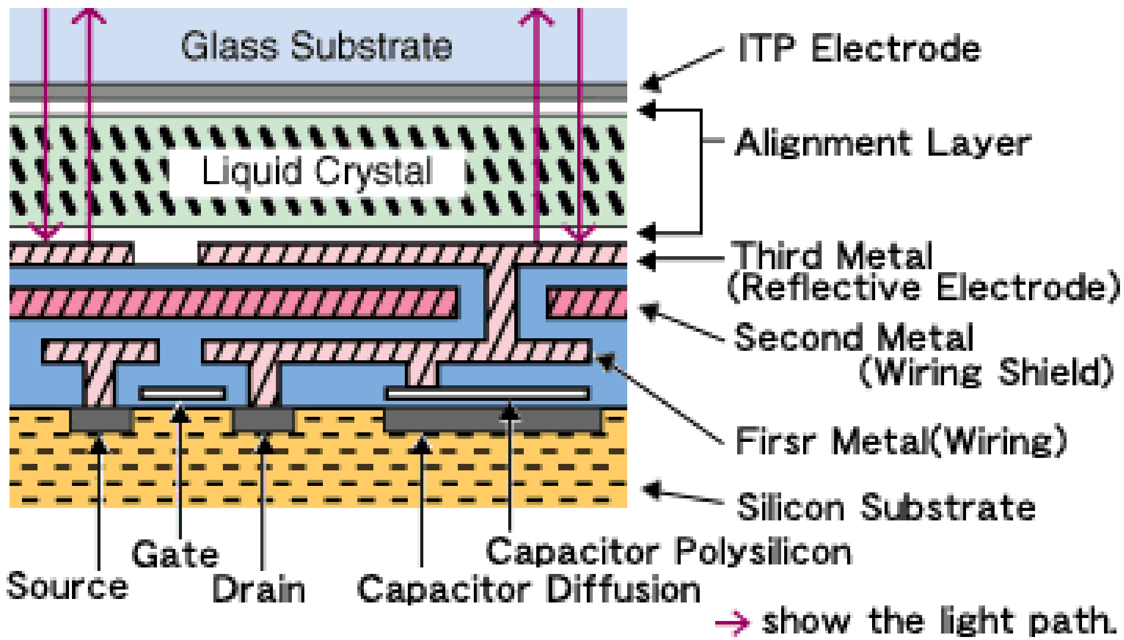
„LCoS" Liquid Crystal on Silicon

„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

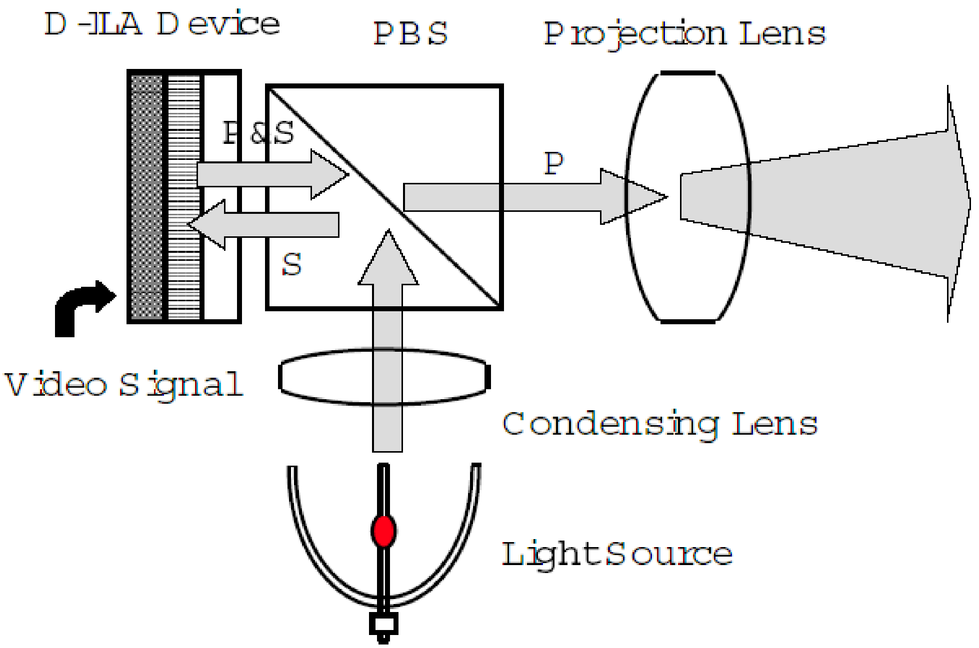
reflective LCD Projector

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



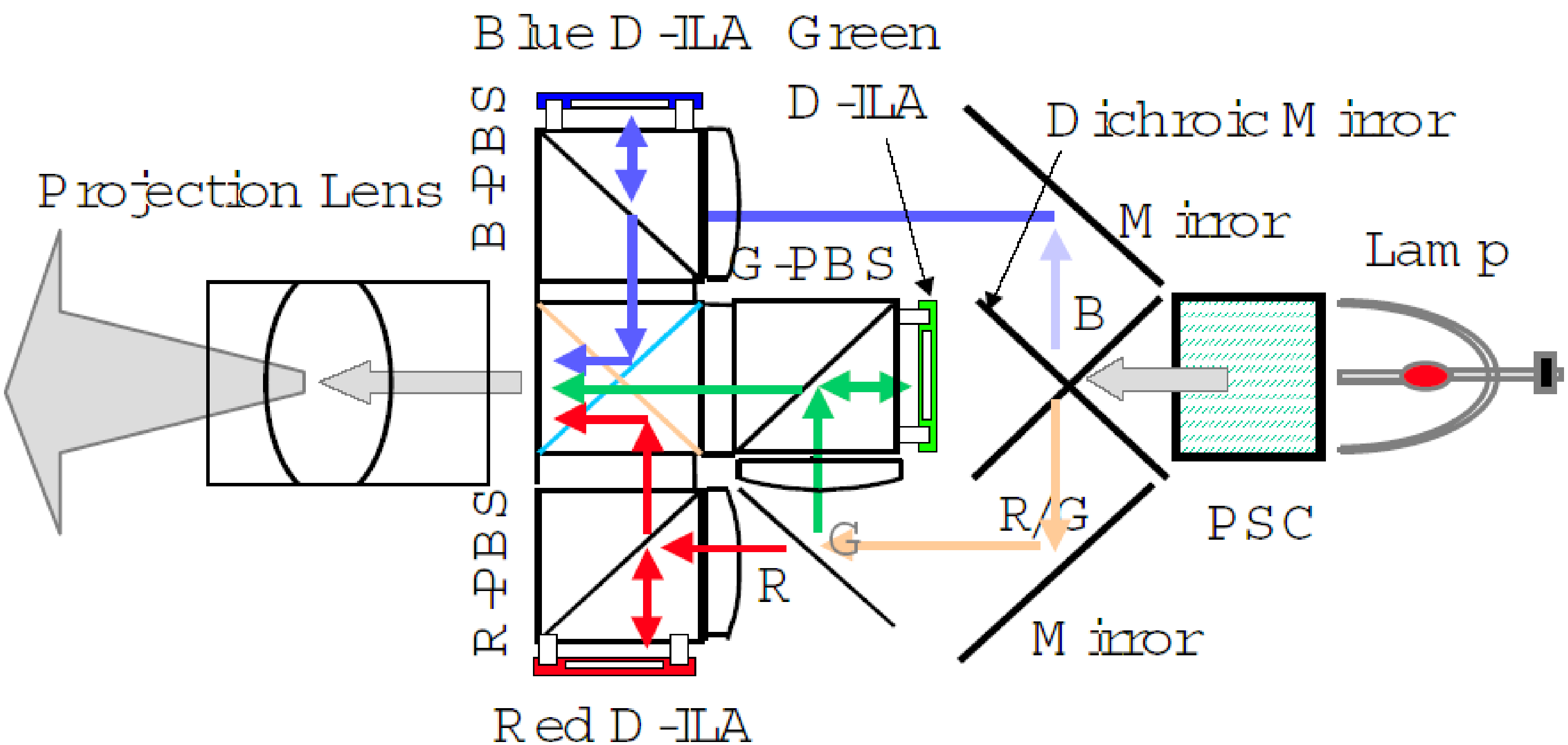
reflective LCD Projector

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

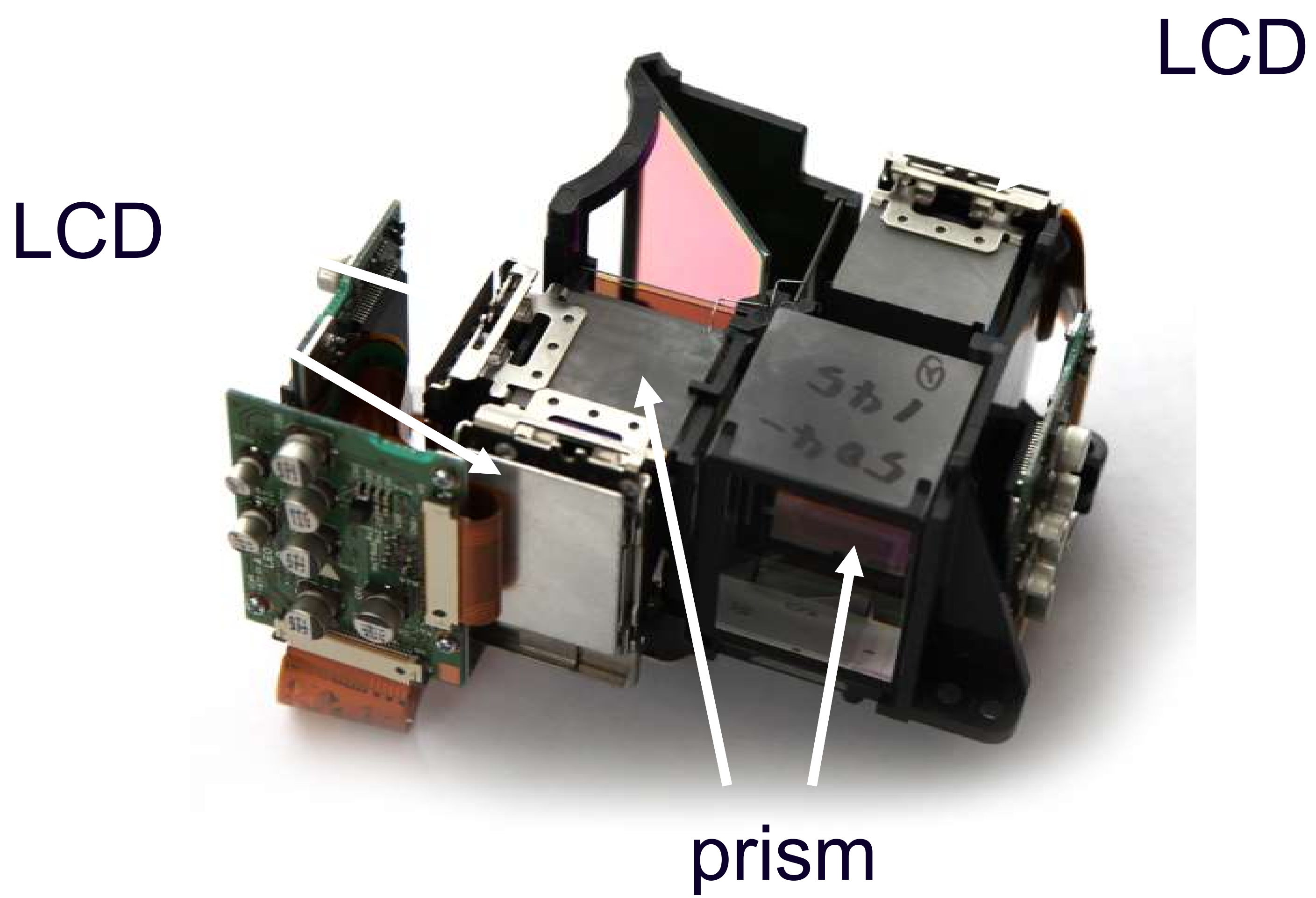


reflective LCD Projector

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



reflective LCD Projector



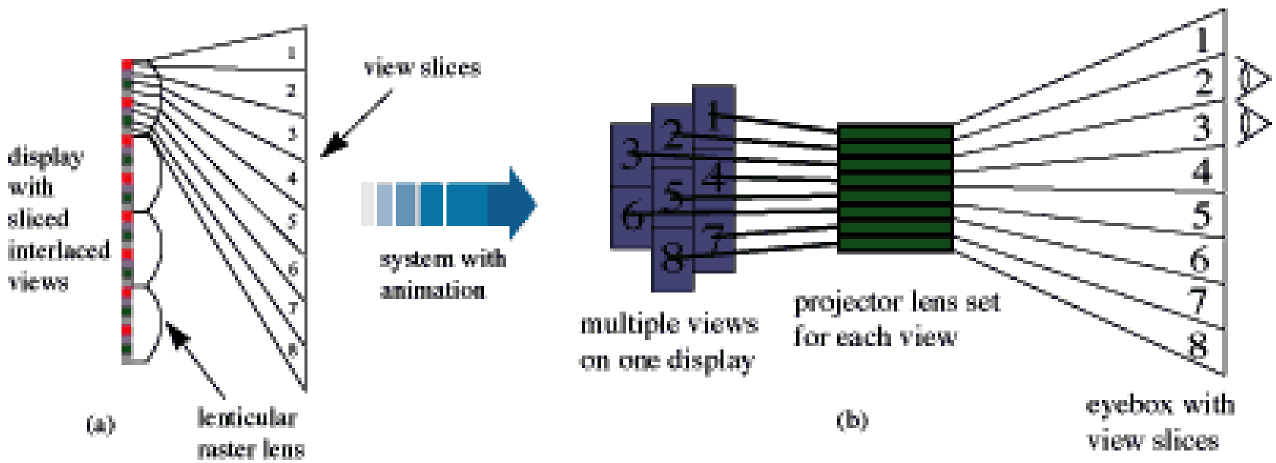
Classification of Stereo Technology

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

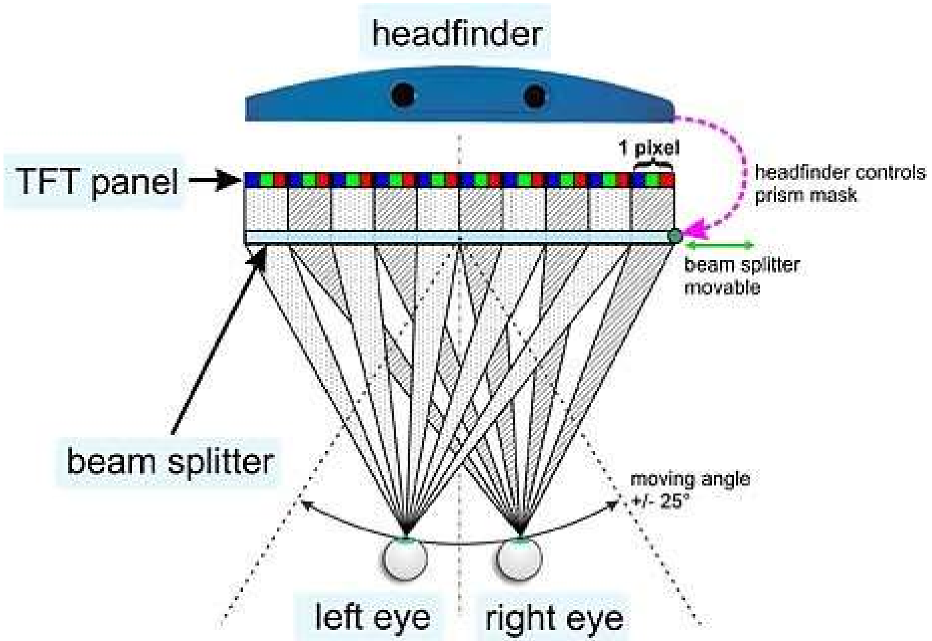
Lenticular lenses (cylinders) send different images in different directions.



Similar to “3D” postcards and stickers.

Parallax Stereo with Lenticulars

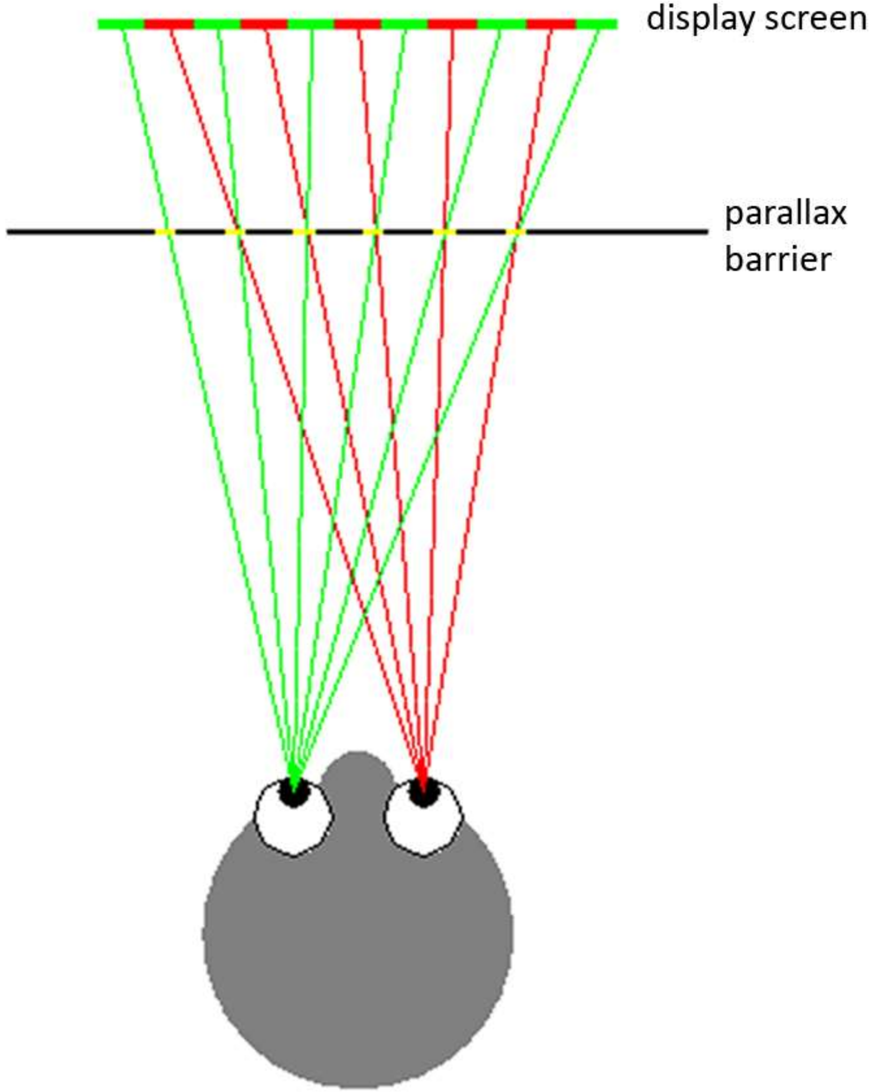
A raster of cylindrical lenses in front of an LCD shows different rows/colums to the users eyes:



Parallax Barrier

A simple parallax barrier works like this:

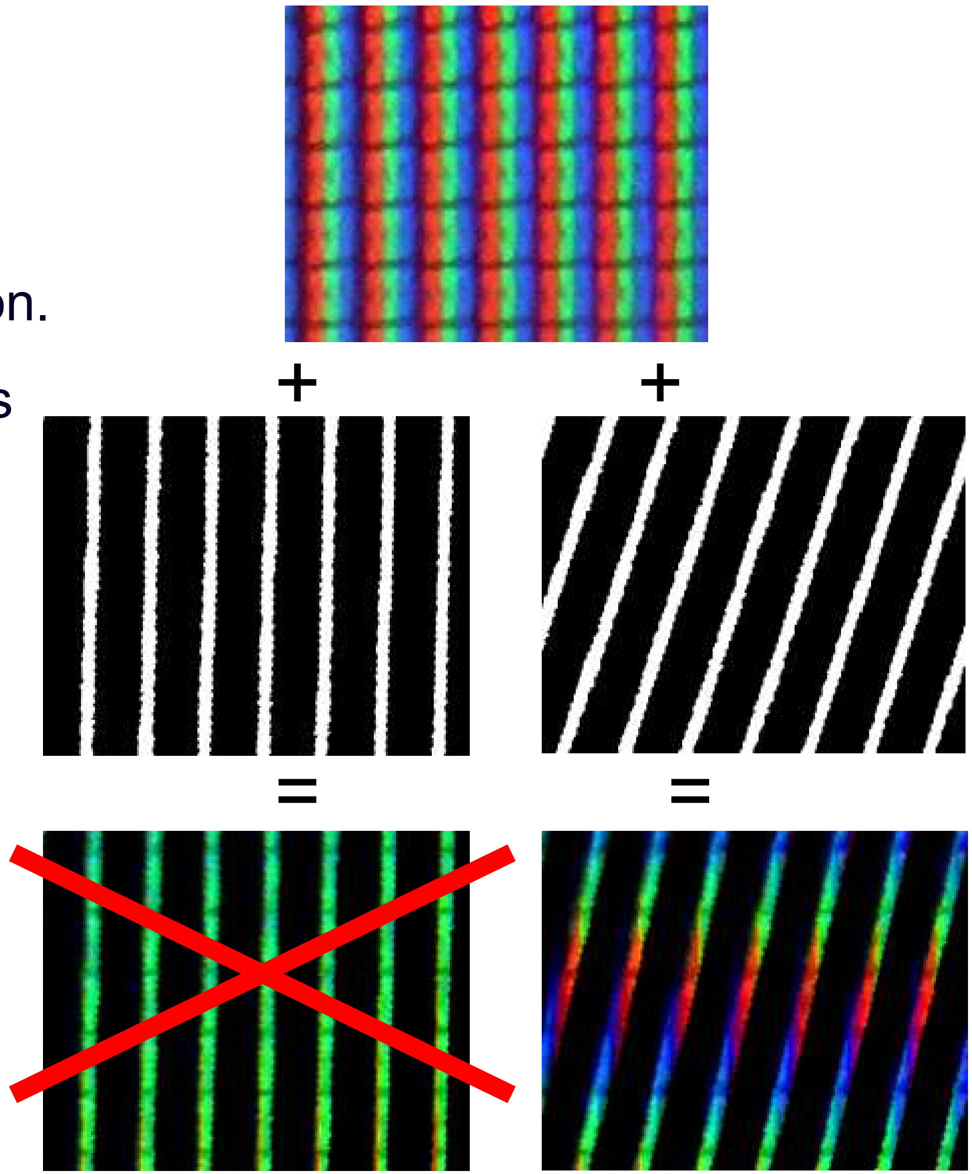
A parallax barrier shields a display screen. The distance between screen and barrier, as well as the resolutions of both are calculated to correctly display left pixels (green) only to the left eye and vice versa.



Slanted Parallax Barrier

A simple approach extremely reduces the horizontal resolution.

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

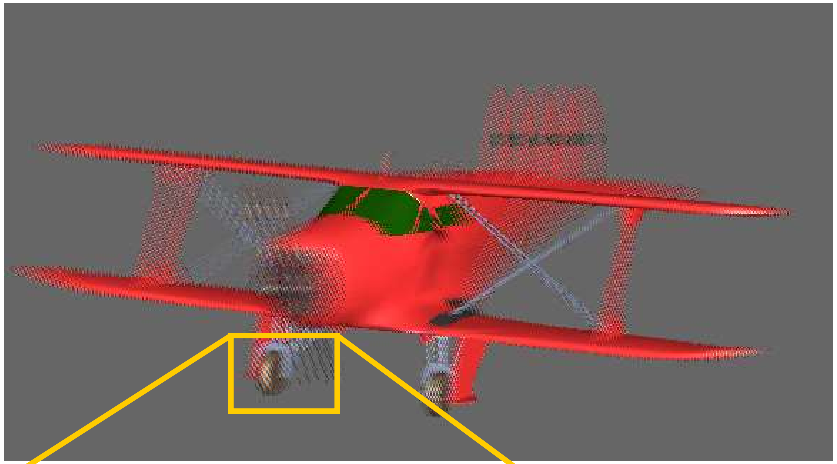


use slanted barrier, otherwise one view-slice gets only one primary color!

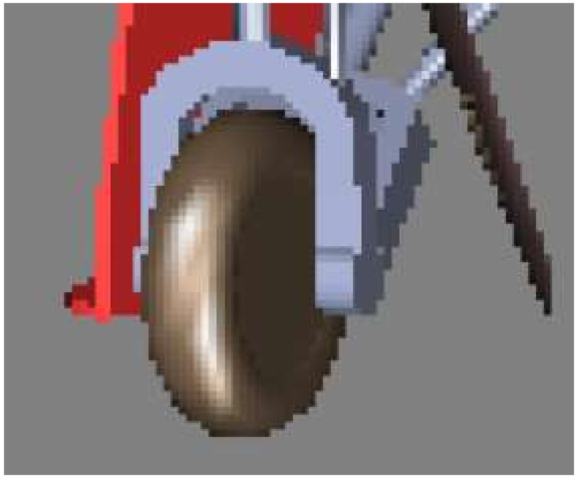
http://csc.lsu.edu/~kooima/pdfs/Kooima-VR07.pdf

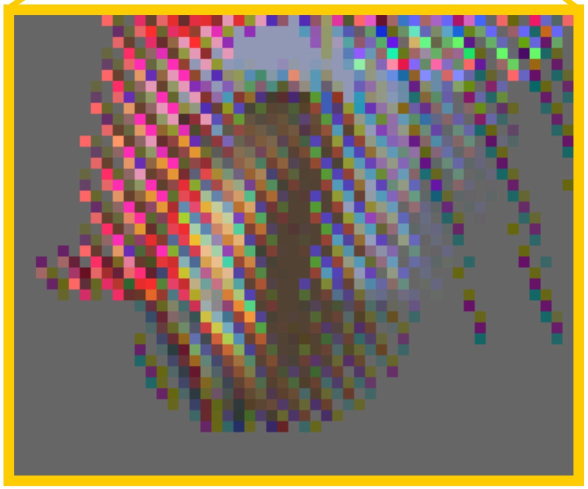
Slanted Parallax Barrier

Image calculated for SPB:



original view detail





parallax view detail

Slanted Parallax Barrier

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

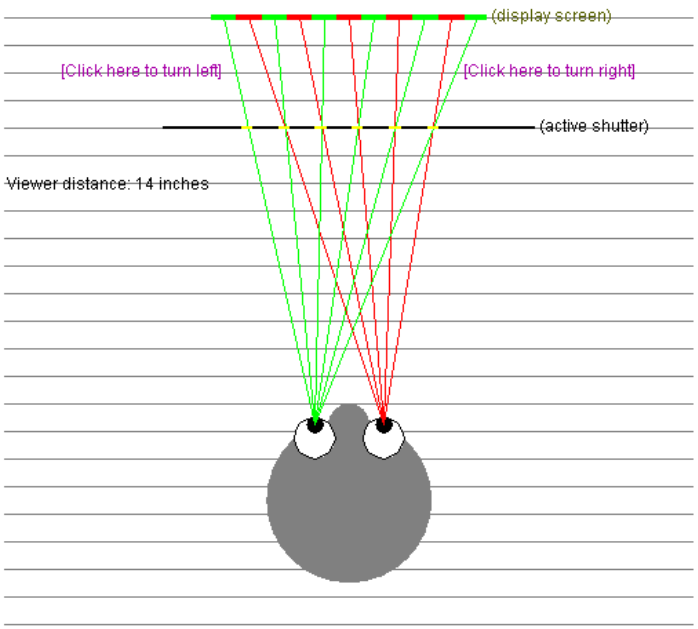
Disdvantages vs. lenticular lenses:

- 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

fast display
(monitor or projector)

>100frames/s

pulsed infrared
light sync signal

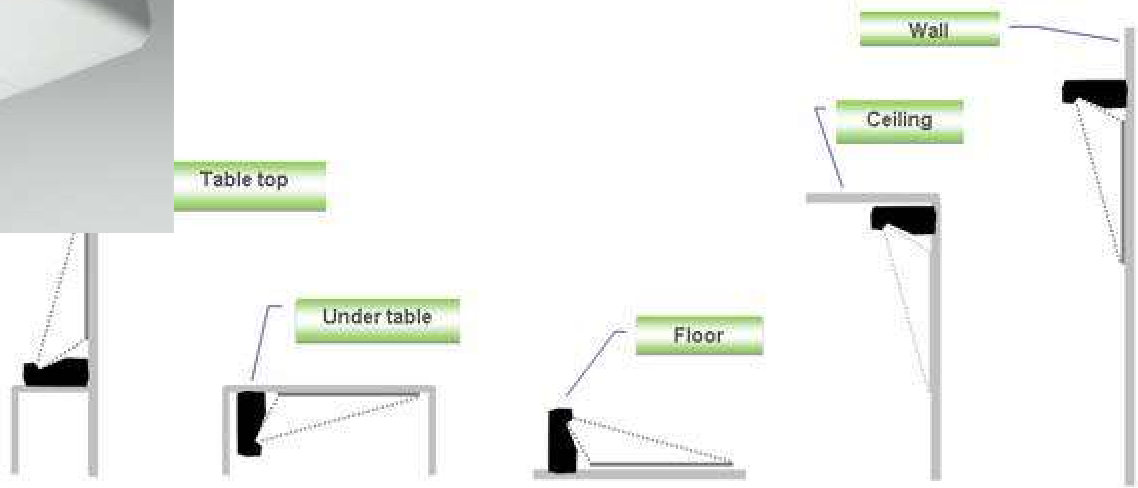
LCD-shutter
glasses

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€ !**



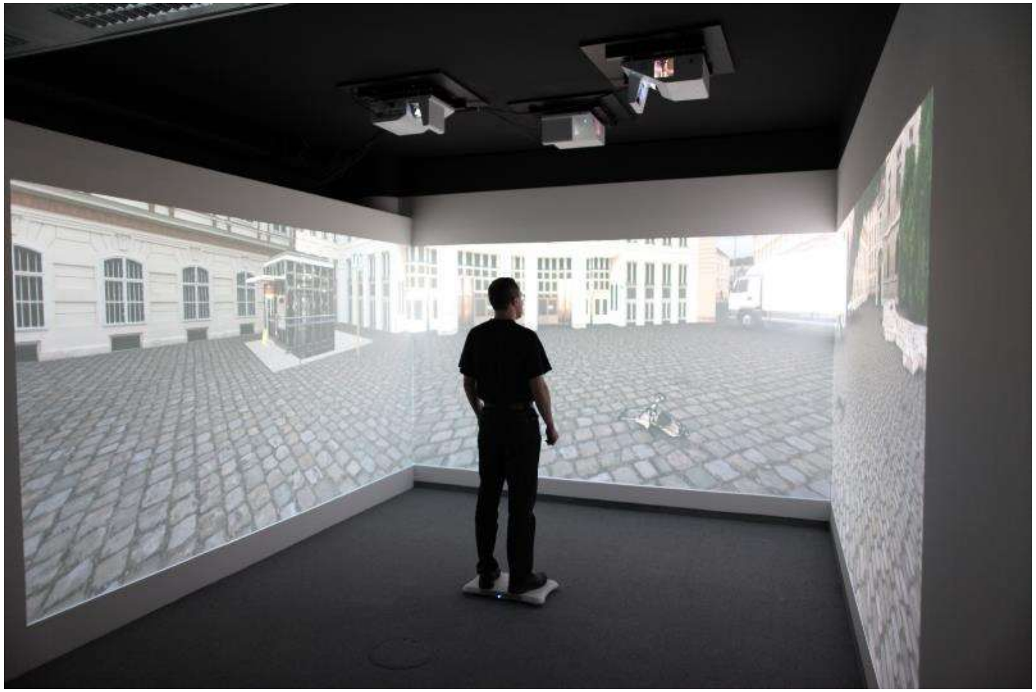
200cm diagonal
@50cm distance

Ultra Short Throw Projection

Main advantages is that front projection for surround display possible:

(Almost) no shadowing by user compared to “classical” front projection

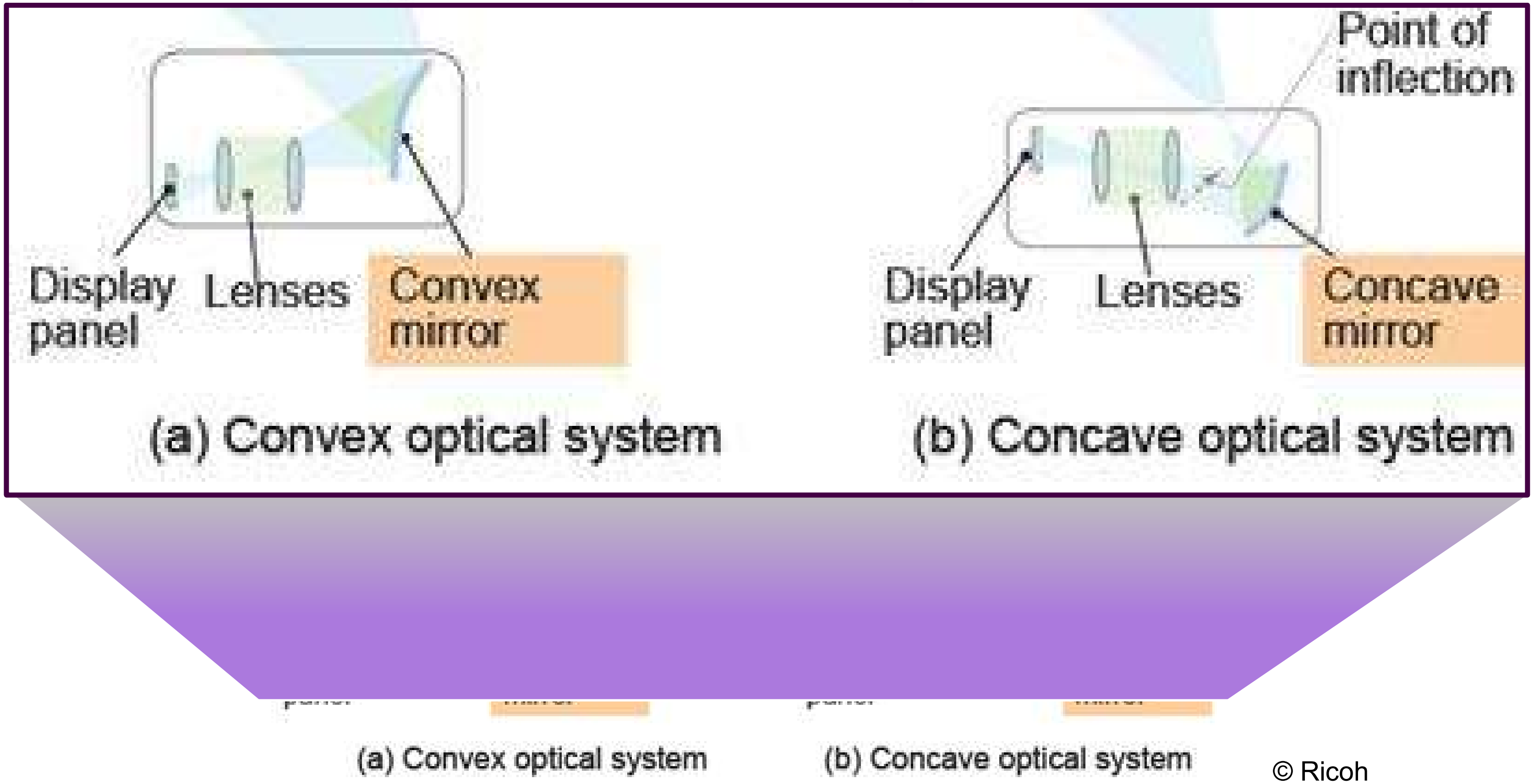
Better luminance distribution than rear projection (low vignetting)



Technische Universität Wien
Vienna University of Technology

Ultra Short Throw Projection

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



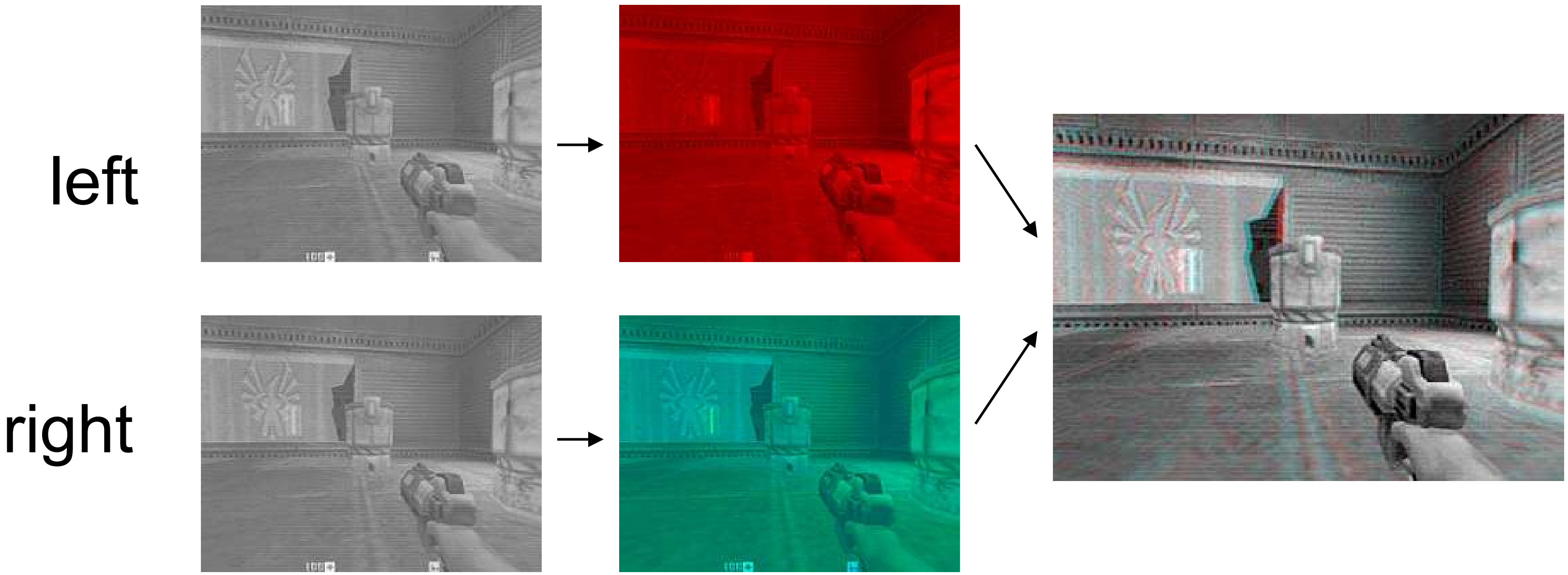
Passive Stereo

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™)

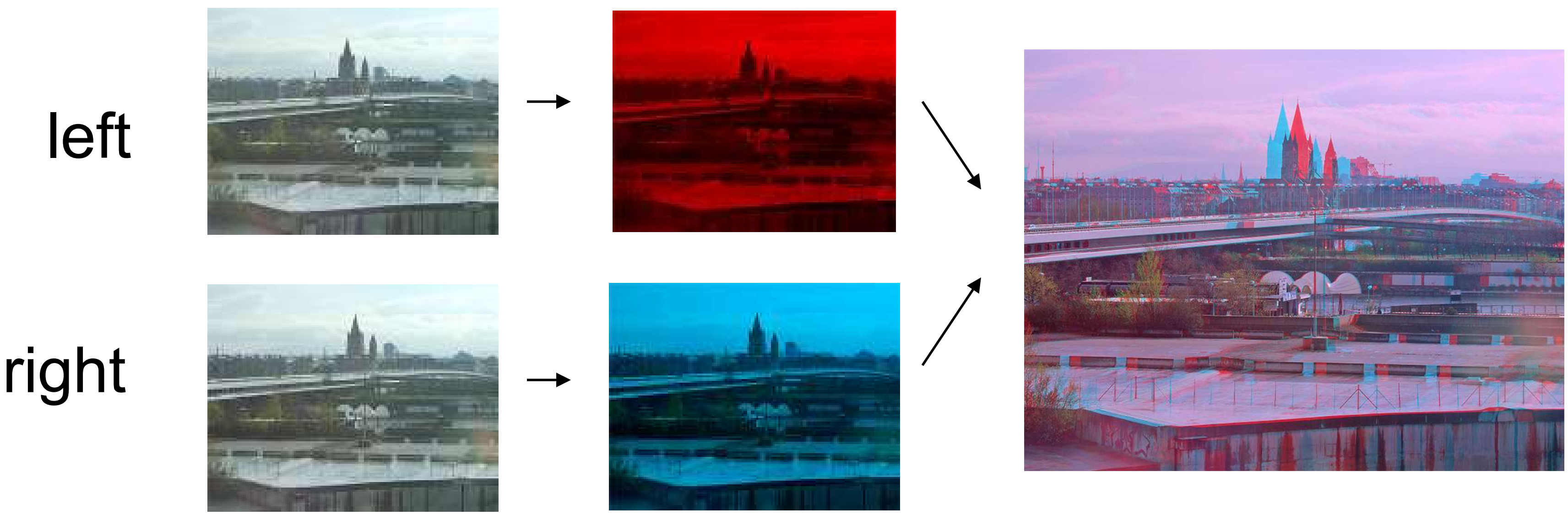
Anaglyph Stereo

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



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:

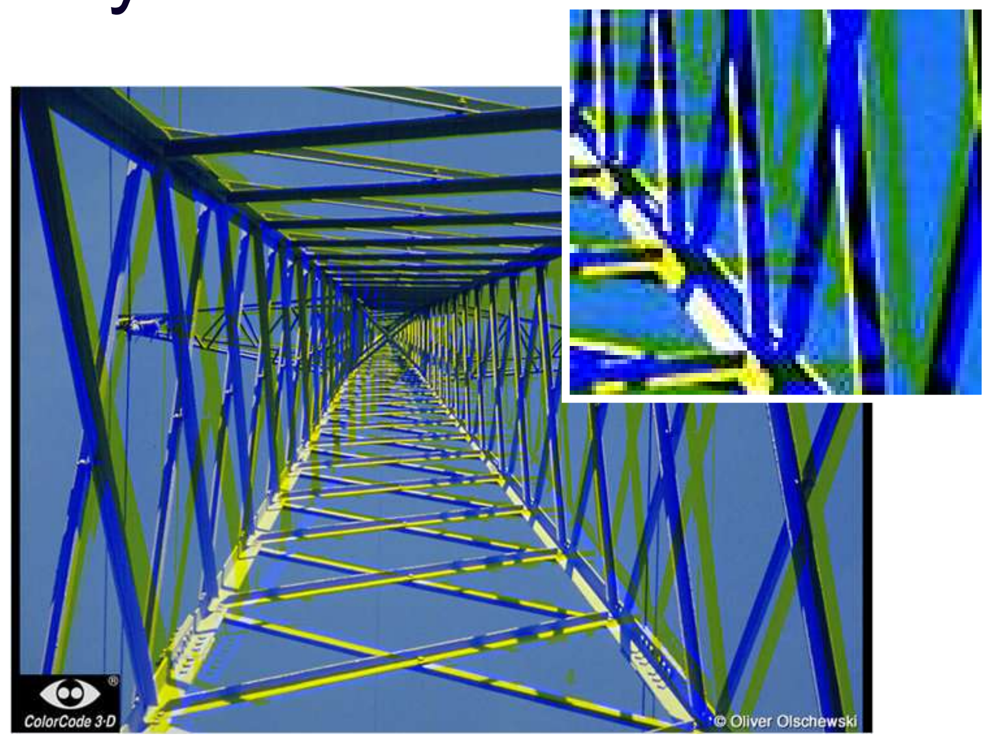
- mediocre color reproduction

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:

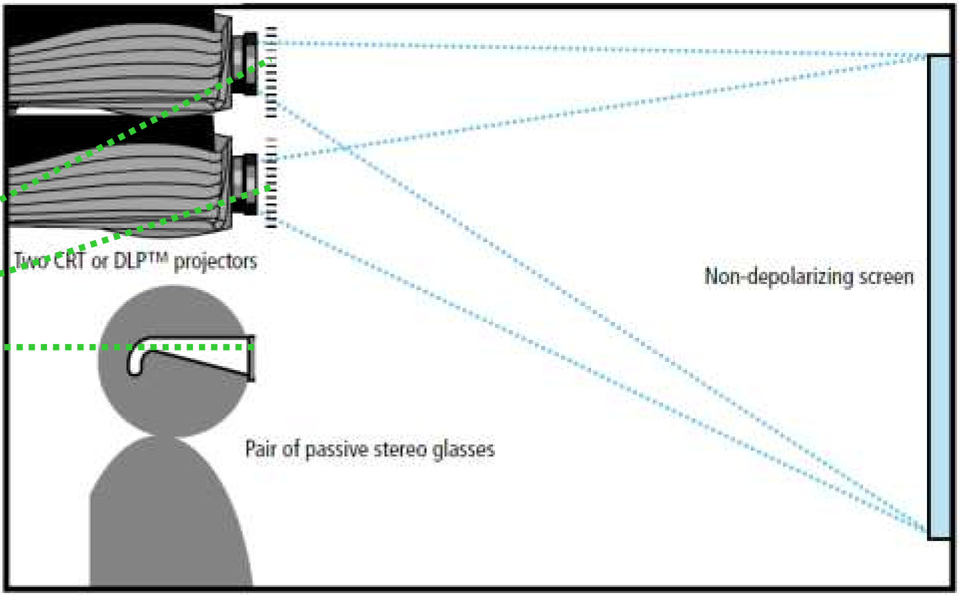
- your brain melts (eyestrain, blue filter very dark)

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→R, L→L)
- how much “incorrect” light is transmitted (L→R, R→L)

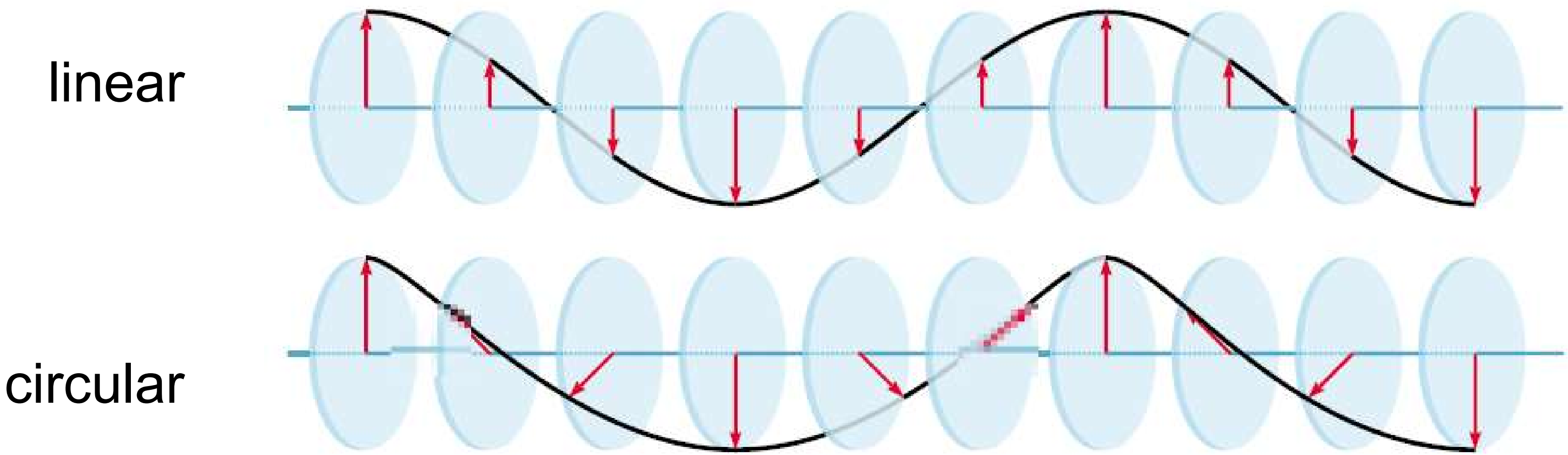
screen:

- 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



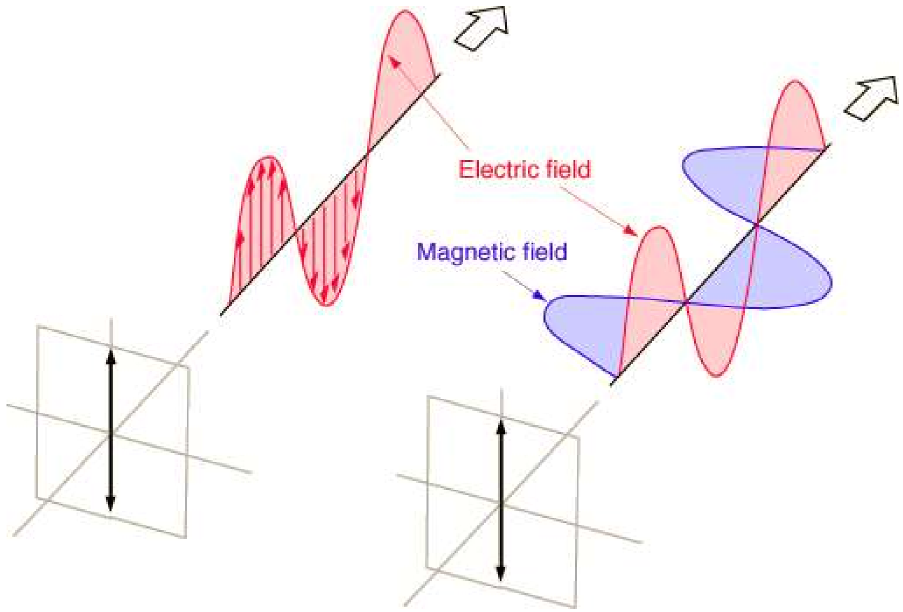
Circular polarized light oscillates only in one rotating direction

TU WIEN
Technische Universität Wien
Vienna University of Technology

Polarization Types

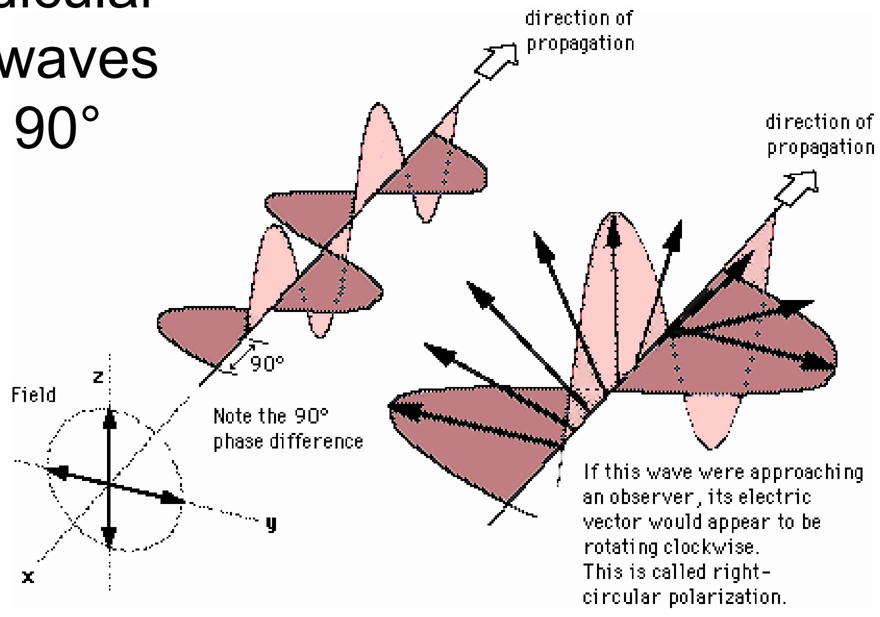
Normal light oscillates in many directions

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.



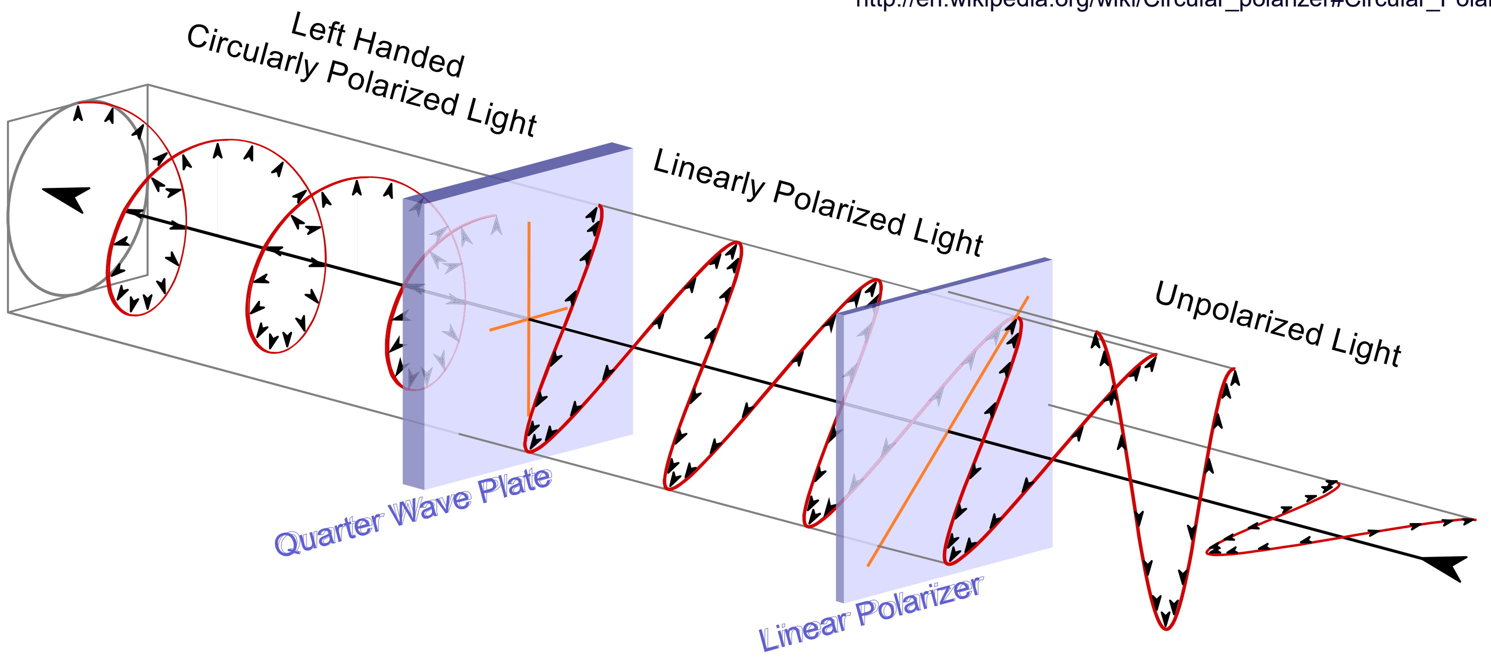
The oszillation direction of circular polarized light rotates

Achieving Circular Polarization

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.

http://en.wikipedia.org/wiki/Circular_polarizer#Circular_Polarizers



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

Infitec™ Stereo

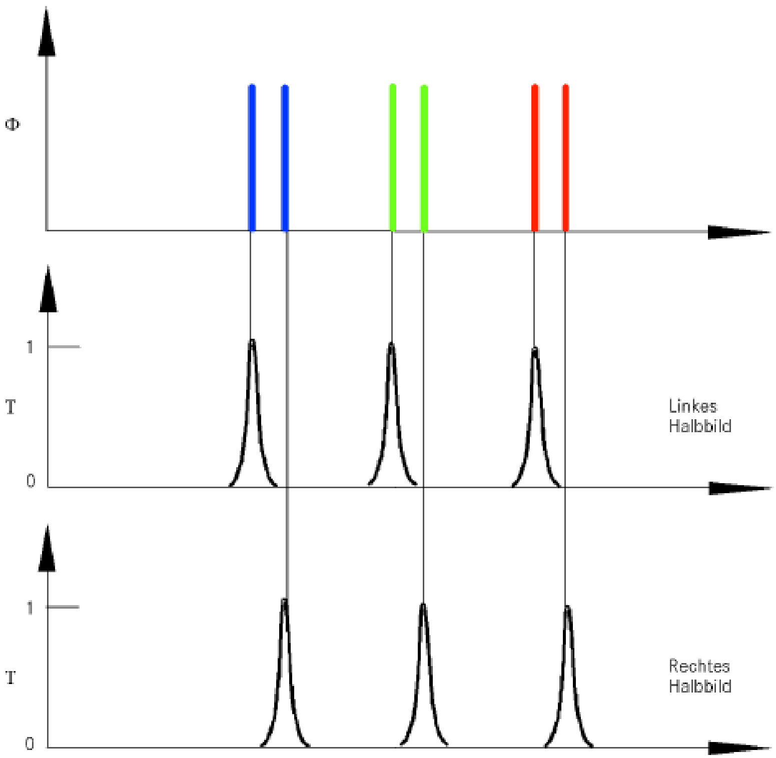
Spectrum Multiplex:

Advantages:

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

Disadvantages:

- color distortion
- crosstalk



Infitec™ Stereo

uncalibrated

calibrated

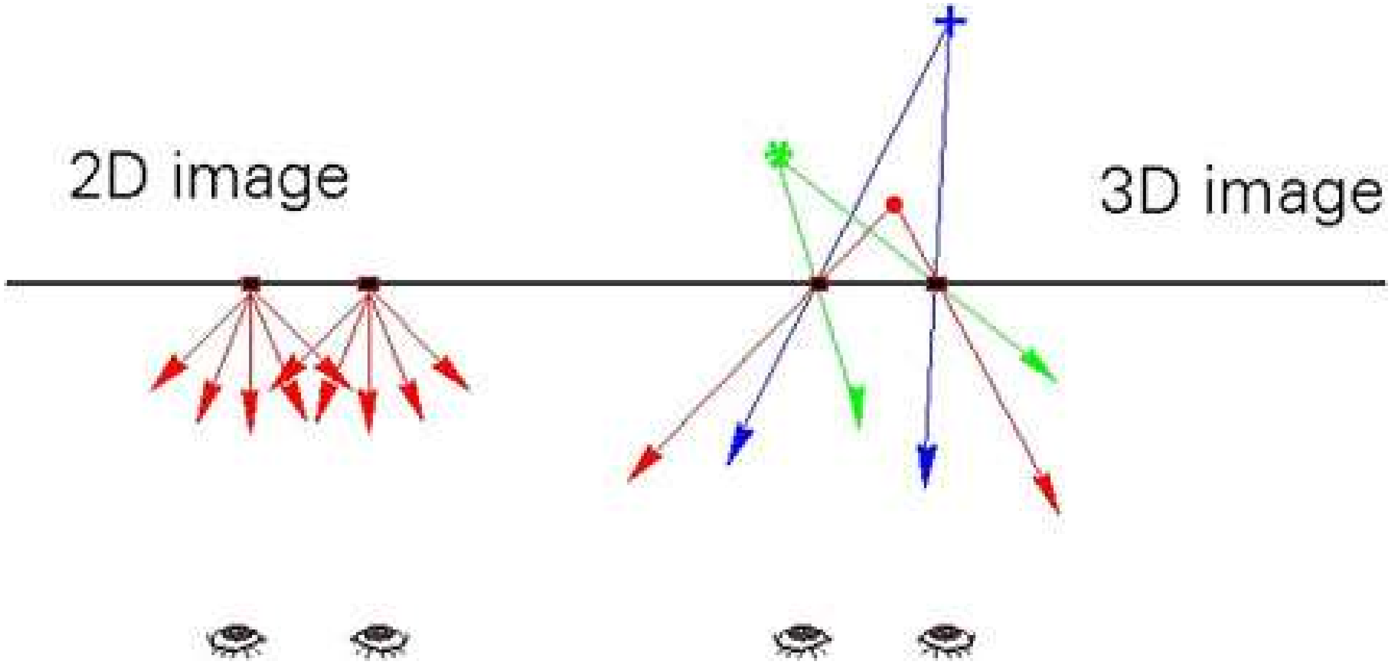
Holographic Projection

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

Anton L. Fuhrmann

2018

TU WIEN

Technische Universität Wien

Vienna University of Technology

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

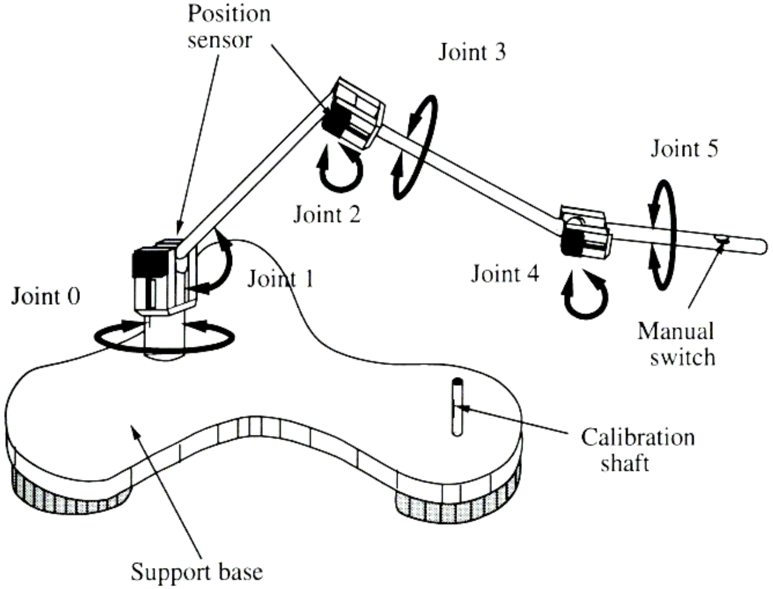
Tracking Methods

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

Mechanical Tracking

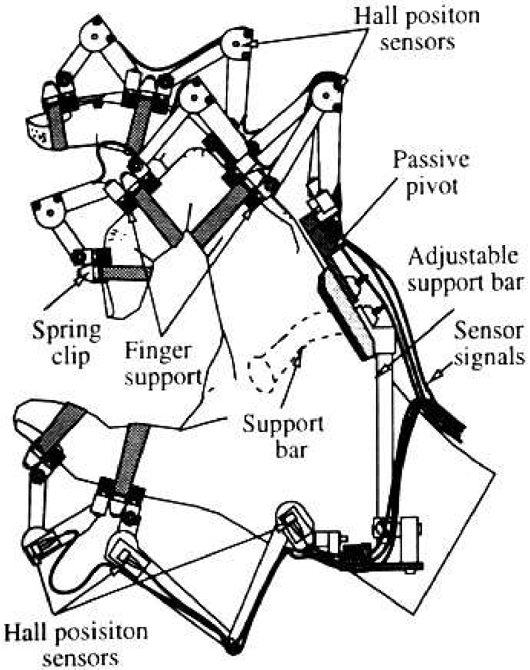
Mechanical mount for input device, output device, users head, etc ...

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



angular sensors:

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)

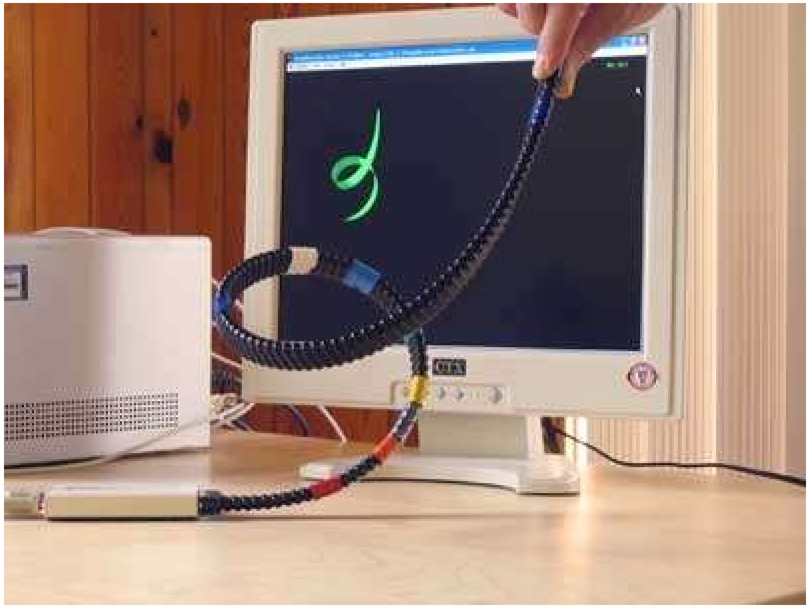
Disadvantages

- 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)

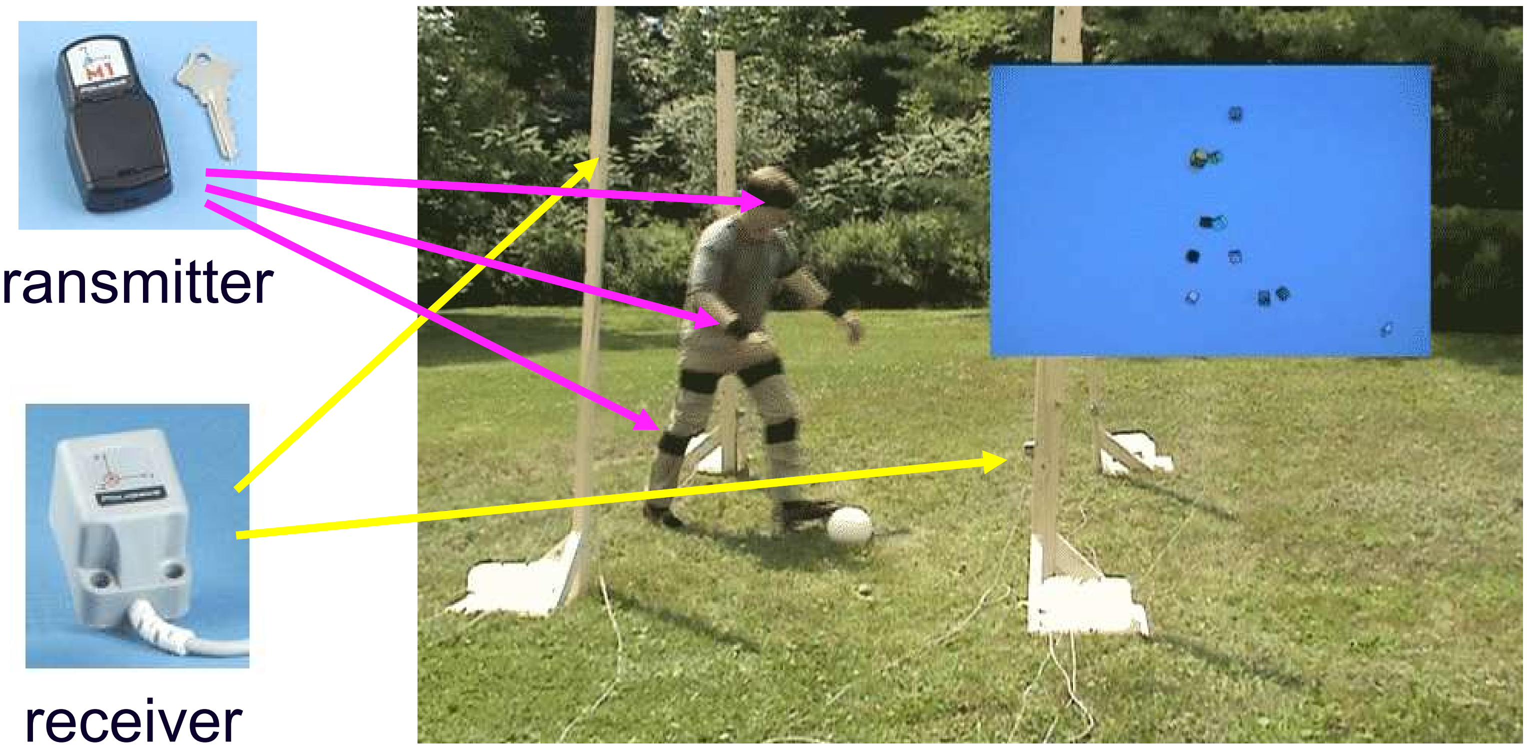
- special transmitter:
  creates three orthogonal fields
  6DoF (t & r)

Magnetical Tracking: Polhemus

Uses AC magnetic fields, sensitive to ferromagnetic material.

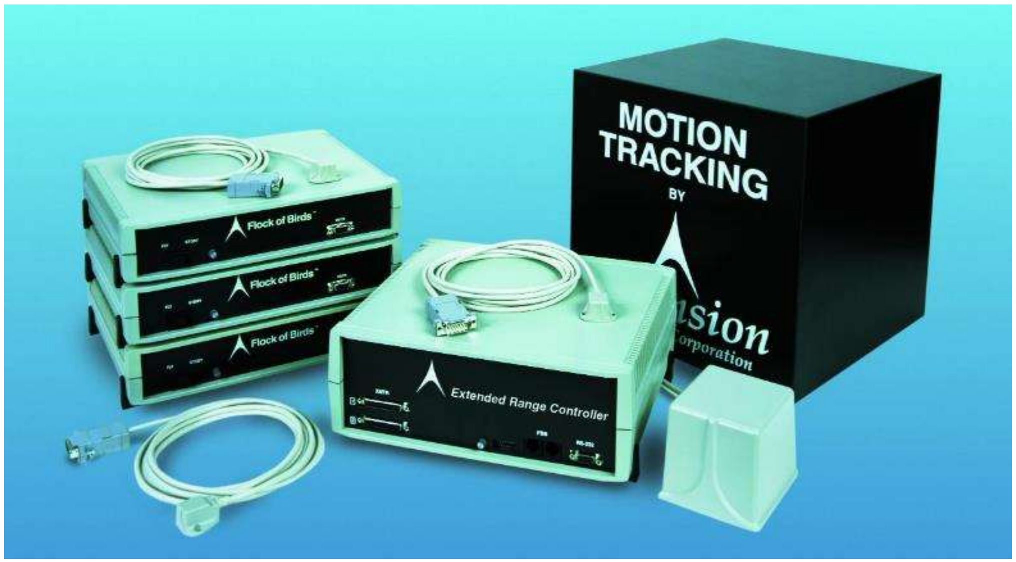
Polhemus LIBERTY™ LATUS™

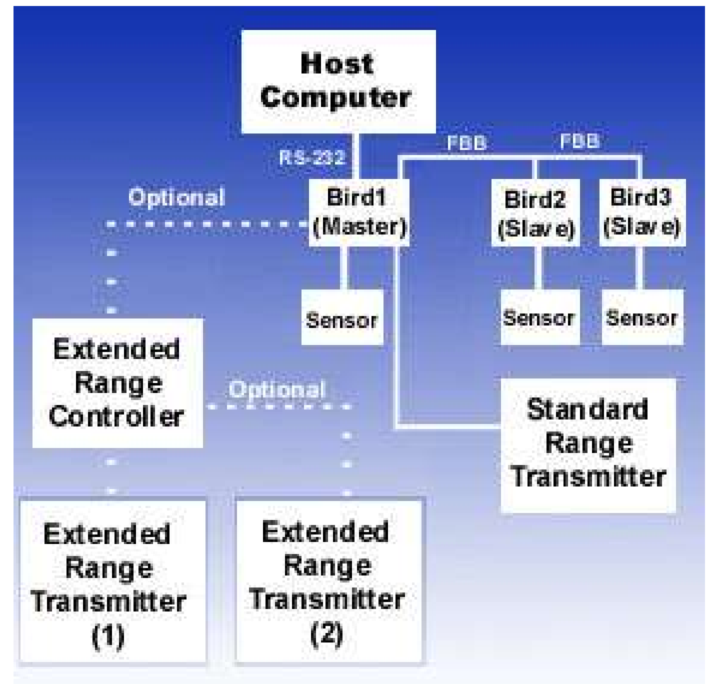
Wireless version: wireless transmitters; wired receivers:



Magnetical Tracking: Ascension

Uses „DC“ magnetic fields, not sensitive to ferromagnetics



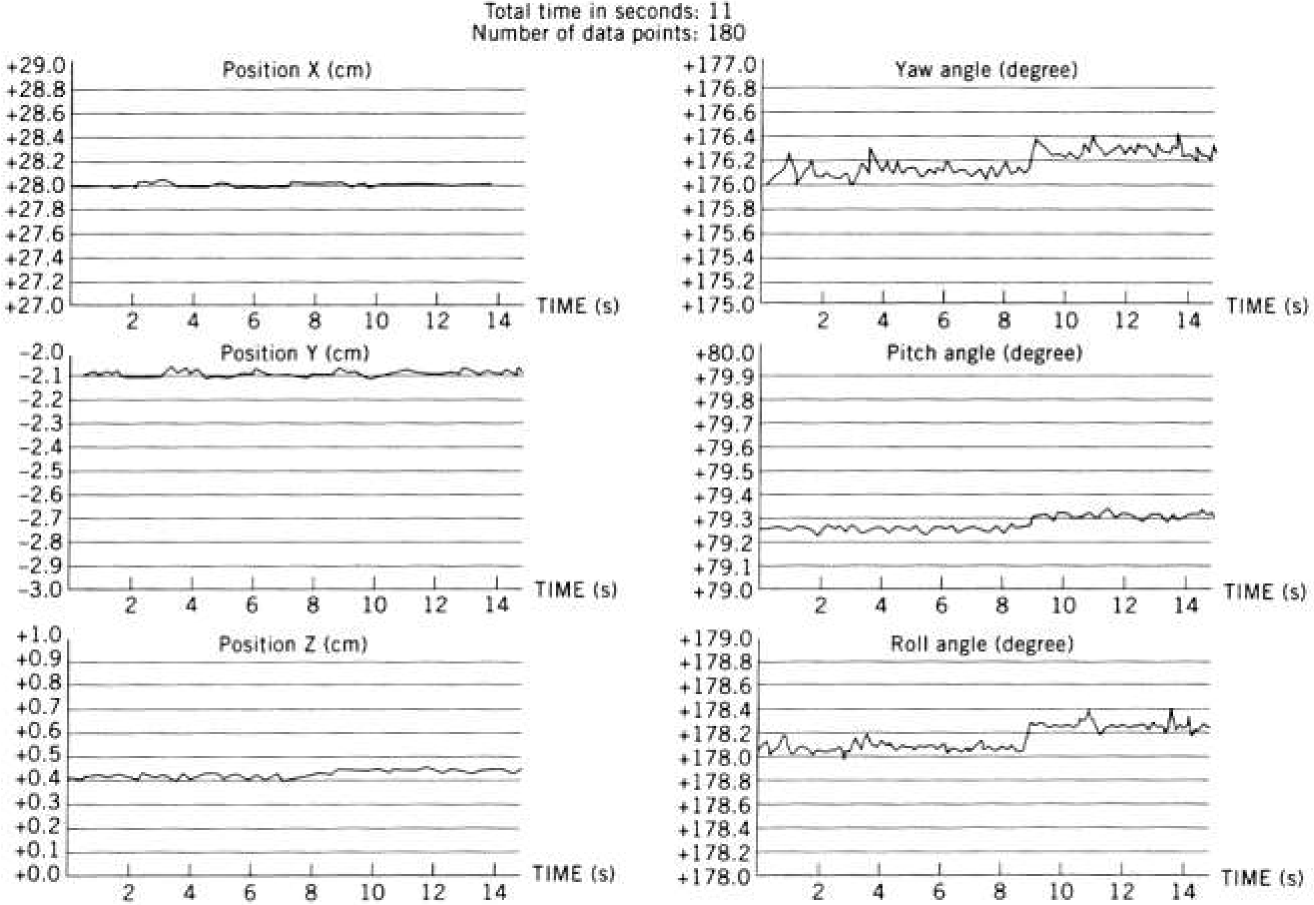


Magnetical Tracking Comparison

SPECIFICATION	FASTRACK	FLOCK OF BIRDS
Operation radius	30" (120" with red. acc.)	36" (96" optional)
Angular range	all-attitudes	$\pm 180^o$ Azimuth&Roll $\pm 90^o$ Elevation
Transl. accuracy	0.03" RMS	0.1" RMS
Transl. resolution	0.0002"/inch range	0.03" RMS
Angular accuracy	0.15^o RMS	0.5^o RMS
Angular resolution	0.025^o RMS	0.1^o RMS at 12"
Update rate (measurements/sec)	120	144
Outputs	Cartesian coord. & orient. angle (selectable direction cosines and quaternions; English/metric units)	Cartesian coord. & orient. angle (selectable rotation matrix)
Interface	RS-232 (selec. baud rates to 115,200 or IEEE-488 up tp 100 kbaud/sec)	RS-232 (selec. baud rates to 115,200) or RS-422/485 (selec. baud rate to 310,000)
Data format	ASCII of Binary	Binary
Modes	Point or stream	Point or stream

Magnetical Tracking Noise

Polhemus



Magnetical Tracking: Aurora (NDI)

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

System Control Unit (SCU)

transmitters
(different versions)

Aurora 5DOF Sensor,
0.5 mm x 8 mm

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

Magnetical Tracking: Aurora (NDI)

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.

	Cube Volume		Dome Volume	
	RMS	**95% Cl**	**RMS**	**95% Cl**
		Accuracy - 5DOF Sensors*		
Position	0.70 mm	1.40 mm	1.10 mm	2.00 mm
Orientation	0.20°	0.35°	0.20°	0.40°
		Accuracy - 6DOF Sensors*		
Position	0.48 mm	0.88 mm	0.70 mm	1.40 mm
Orientation	0.30°	0.48°	0.30°	0.55°

*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

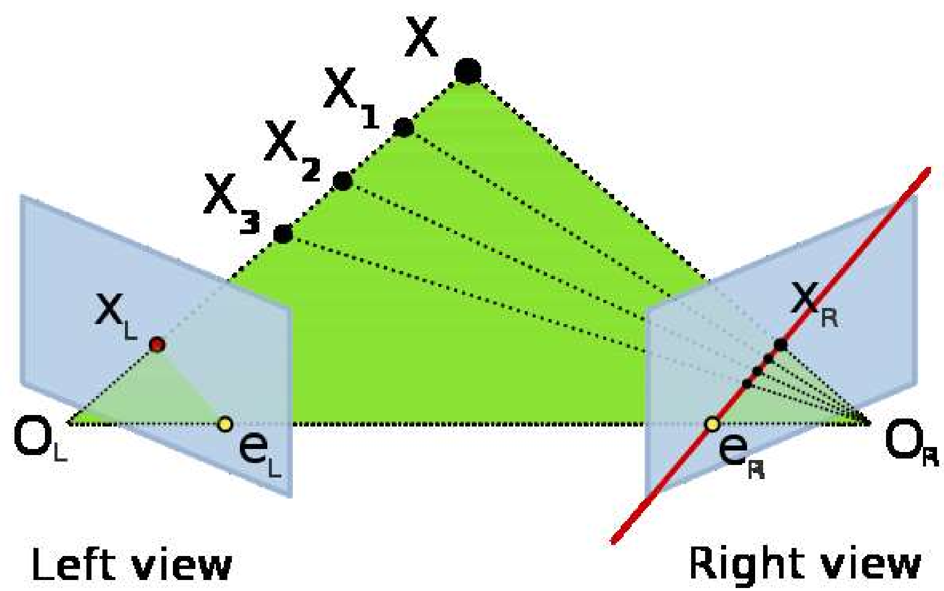
Epipolar Geometry

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)

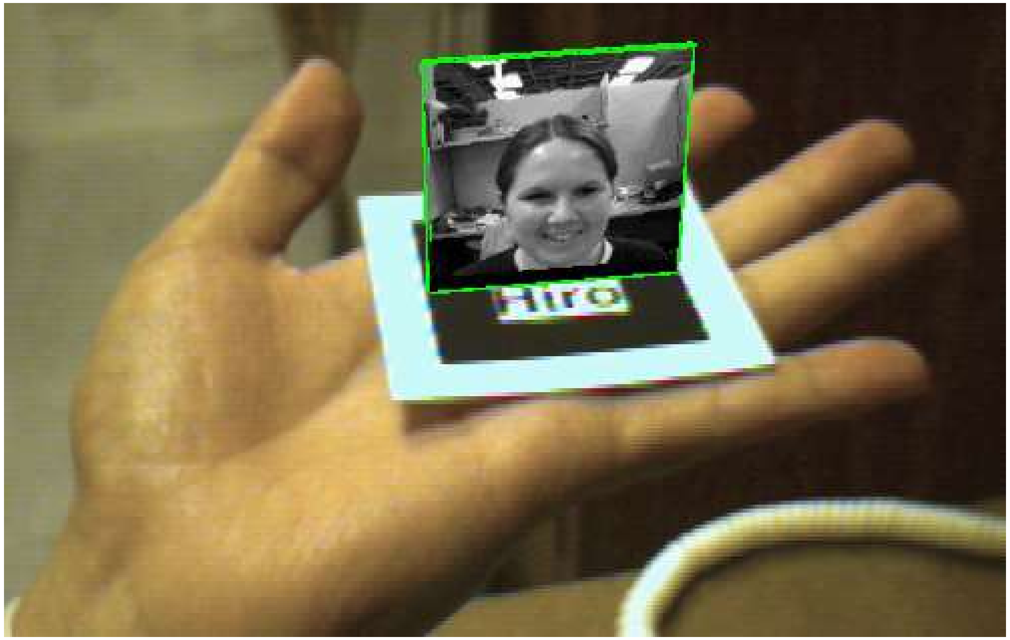
camera contains IR-flash
and image-processor

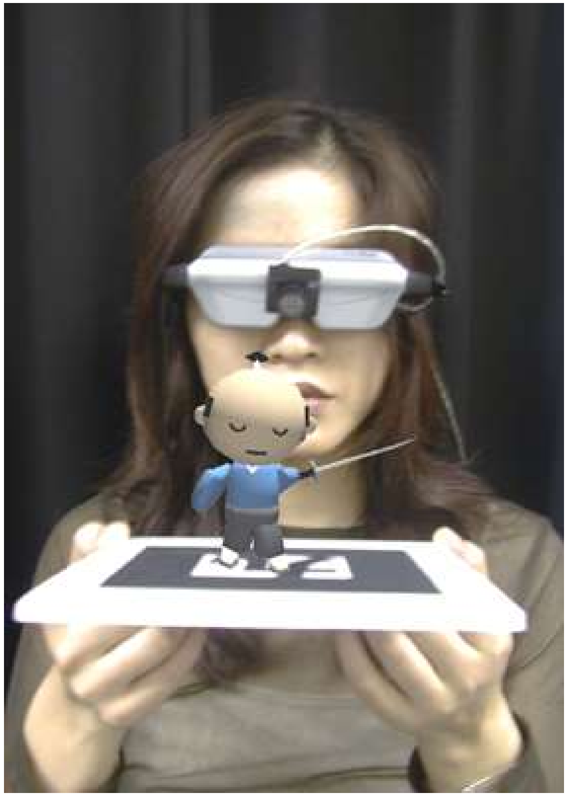
targets use retro-
reflecting markers in
geometric constellations

http://www.naturalpoint.com/optitrack

Passive Markers, Single Camera (AR-Toolkit)

single camera tracks b/w marker images inside/out

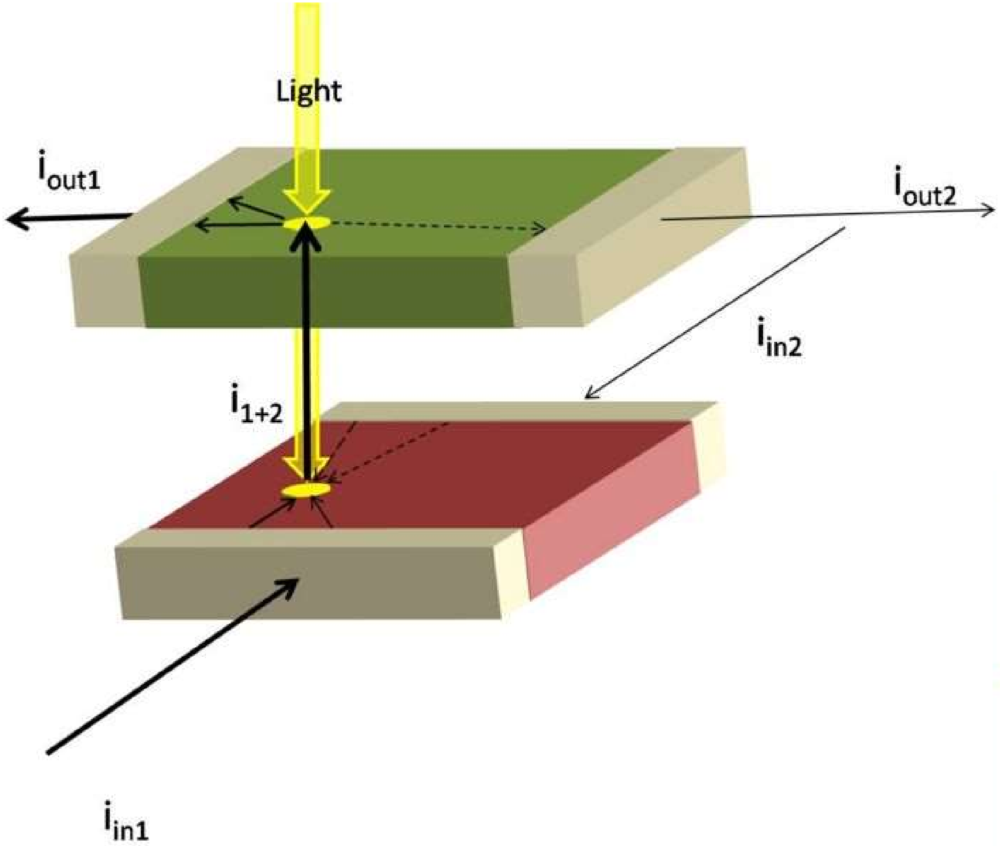




Active Markers, LAPD (HiBall)

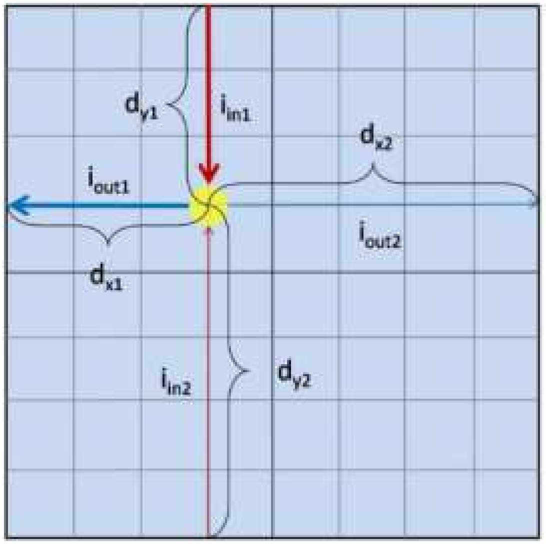
- active markers (IR-LEDs) stationary on ceiling
- 6 lateral-effect photodiodes move

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)

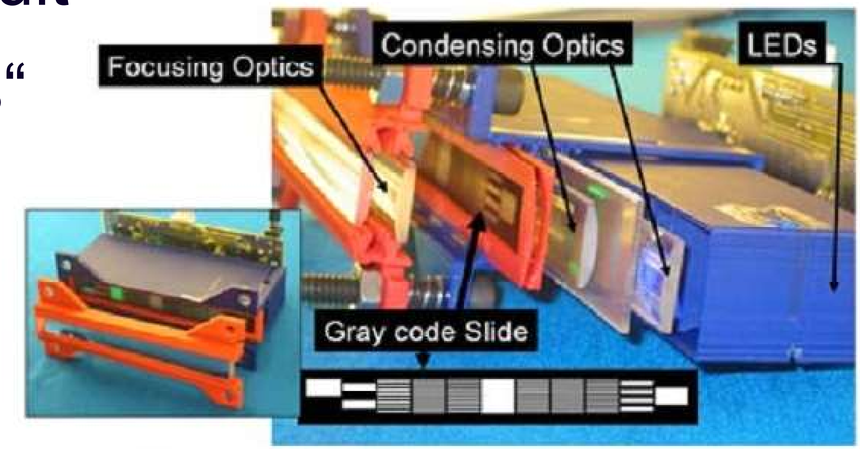
- IR-LED targets
- three linear CCDs

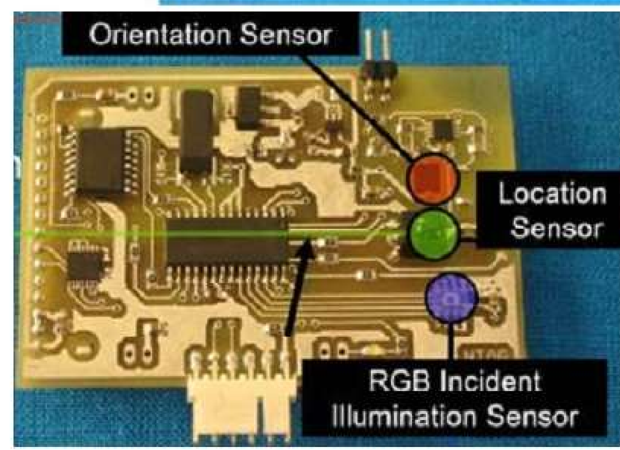
Active Markers, „0D“ sensors (ReActor)

- 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





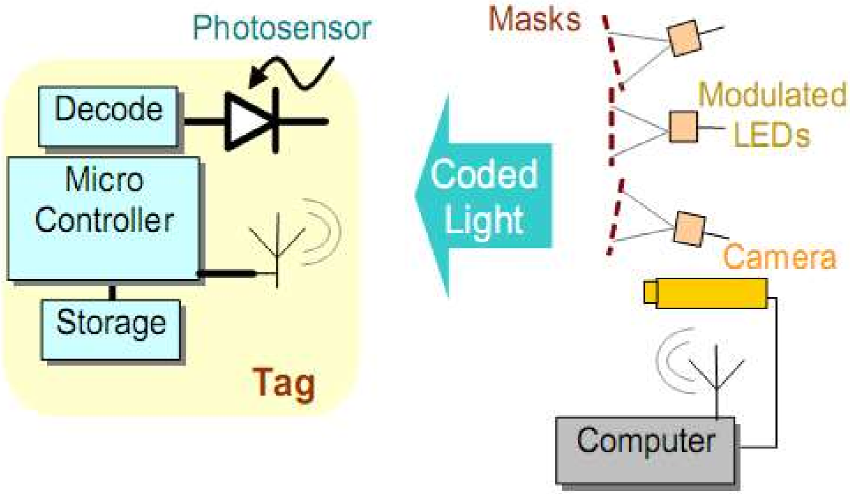
Prakash et.al.: “Lighting-Aware Motion Capture Using Photosensing Markers and Multiplexed Illumination”; SIGGRAPH 2007

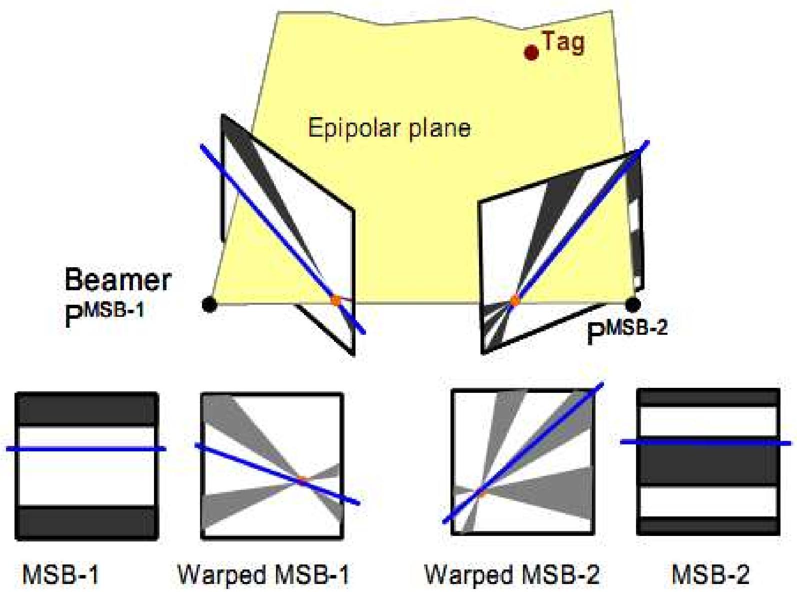
http://web.media.mit.edu/~raskar/LumiNetra/

MIT „Second Skin“

Projectors produce binary-coded „fan“, which allow a sensor to determine one angle around proj.-center

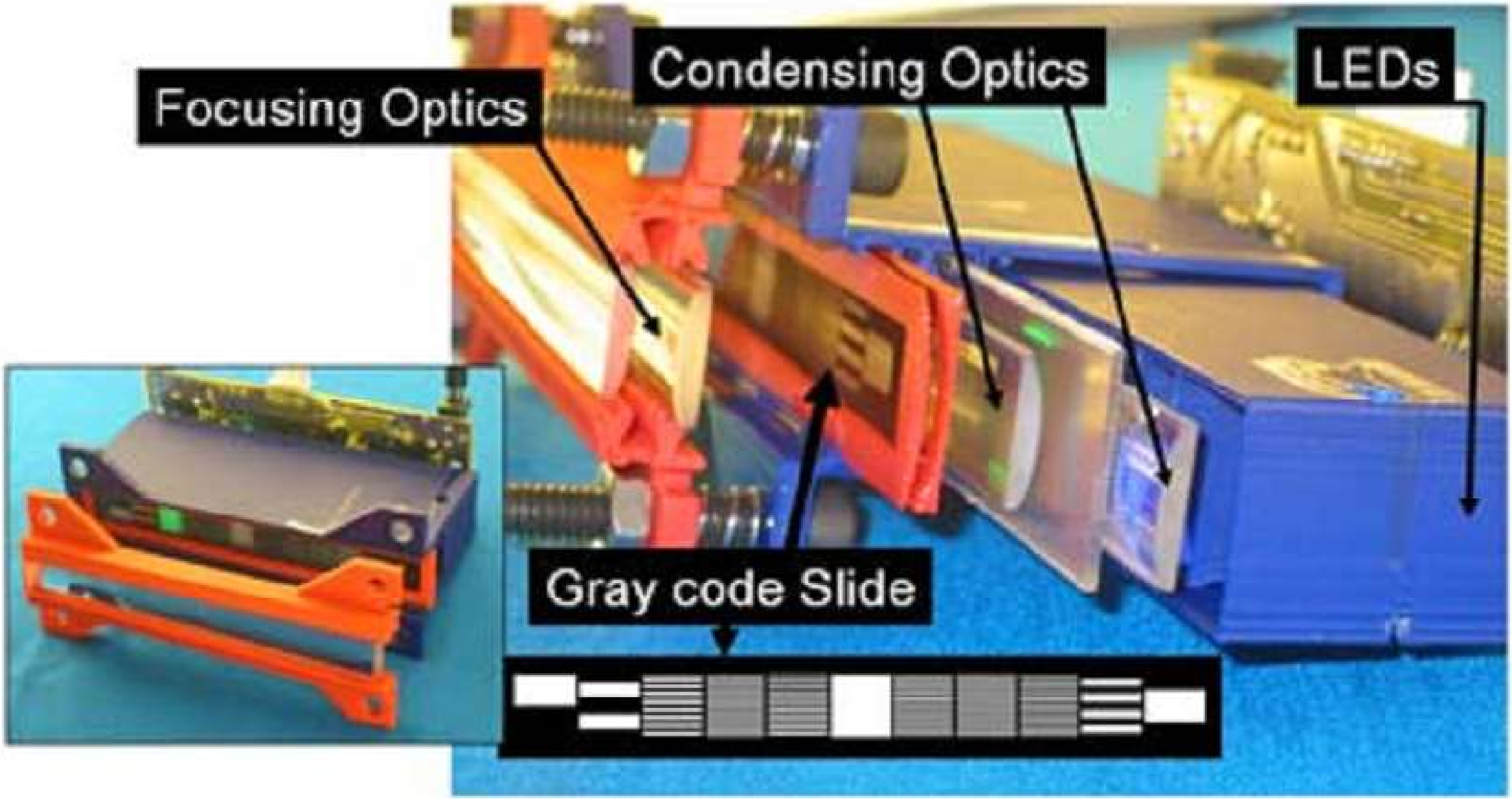
→ 3 projectors determine position unambiguously





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

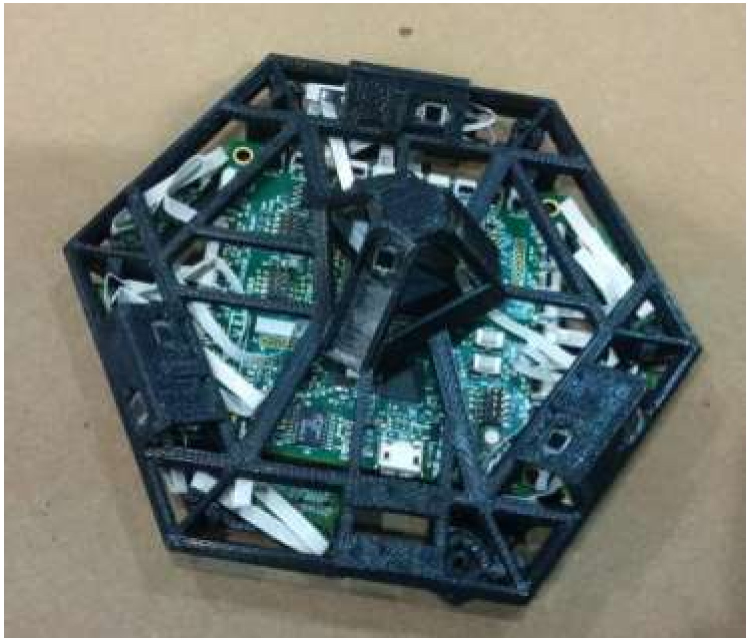
Disadvantages

- 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/J54dotTt7k0

"Lighthouse" Tracking

followed by a vertical sweep:

https://youtu.be/J54dotTt7k0

"Lighthouse" Tracking

and by a horizontal sweep:

https://youtu.be/J54dotTt7k0

"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

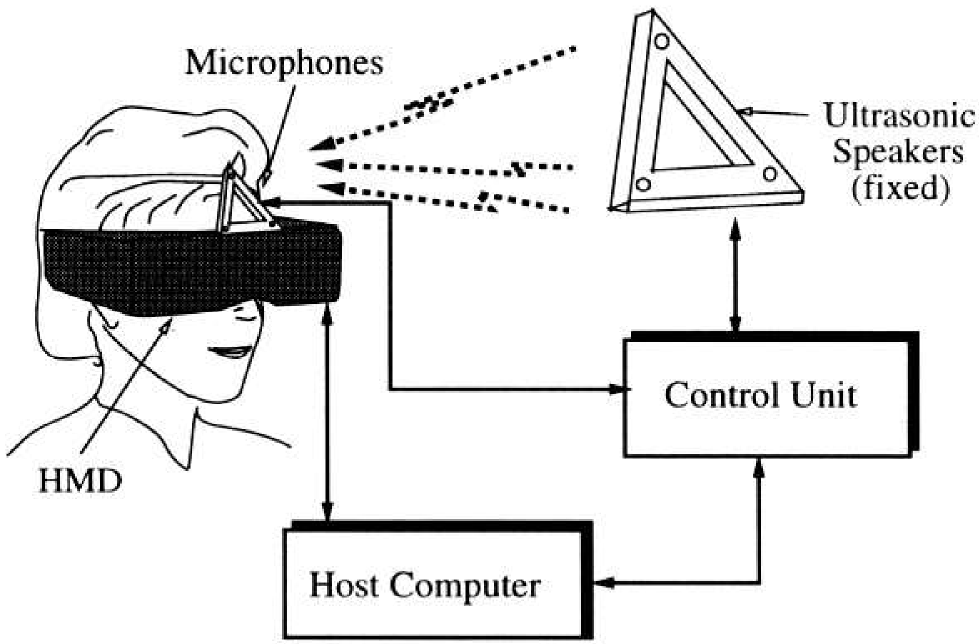
- precise
- wireless

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

Technische Universität Wien
Vienna University of Technology

Inertial Tracking

measures linear & angular accelerations and integrates position & orientations:

(Old) inertial navigation platform

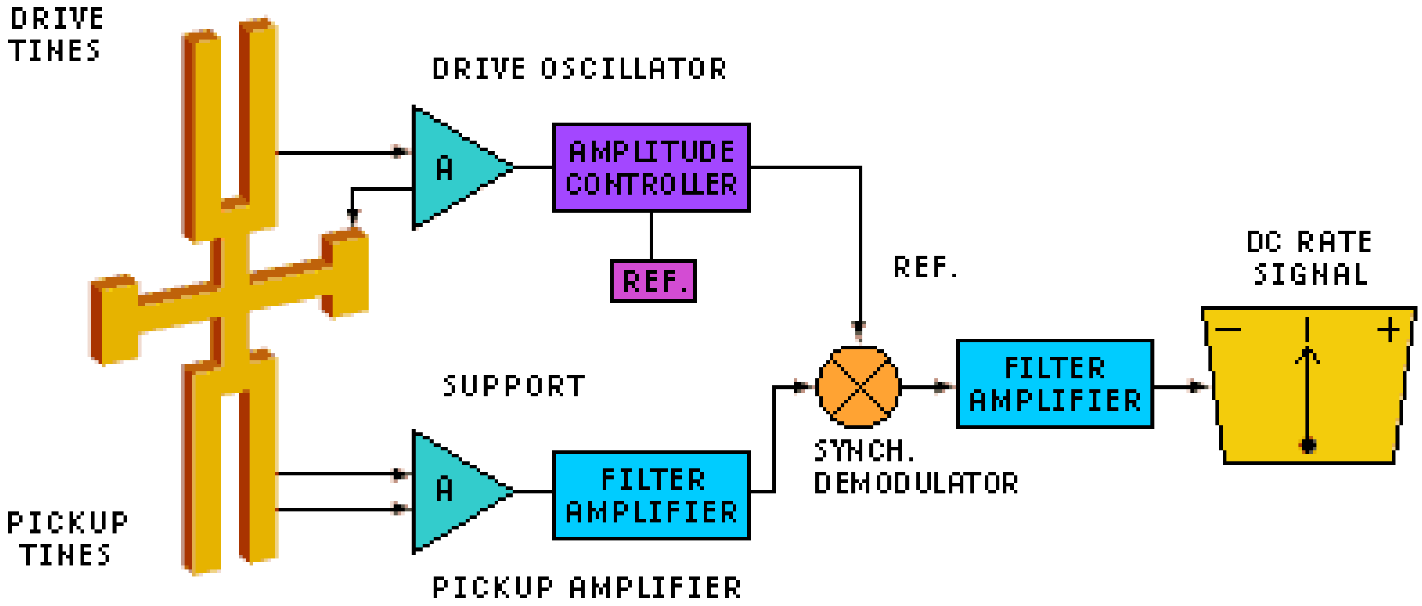
Inertial Tracking

measures linear & angular accelerations and integrates position & orientations:

(Old) inertial navigation platform

Inertial Tracking

micro-mechanical „tuning fork“:



Inertial Tracking: Xsens

commercial inertial tracking

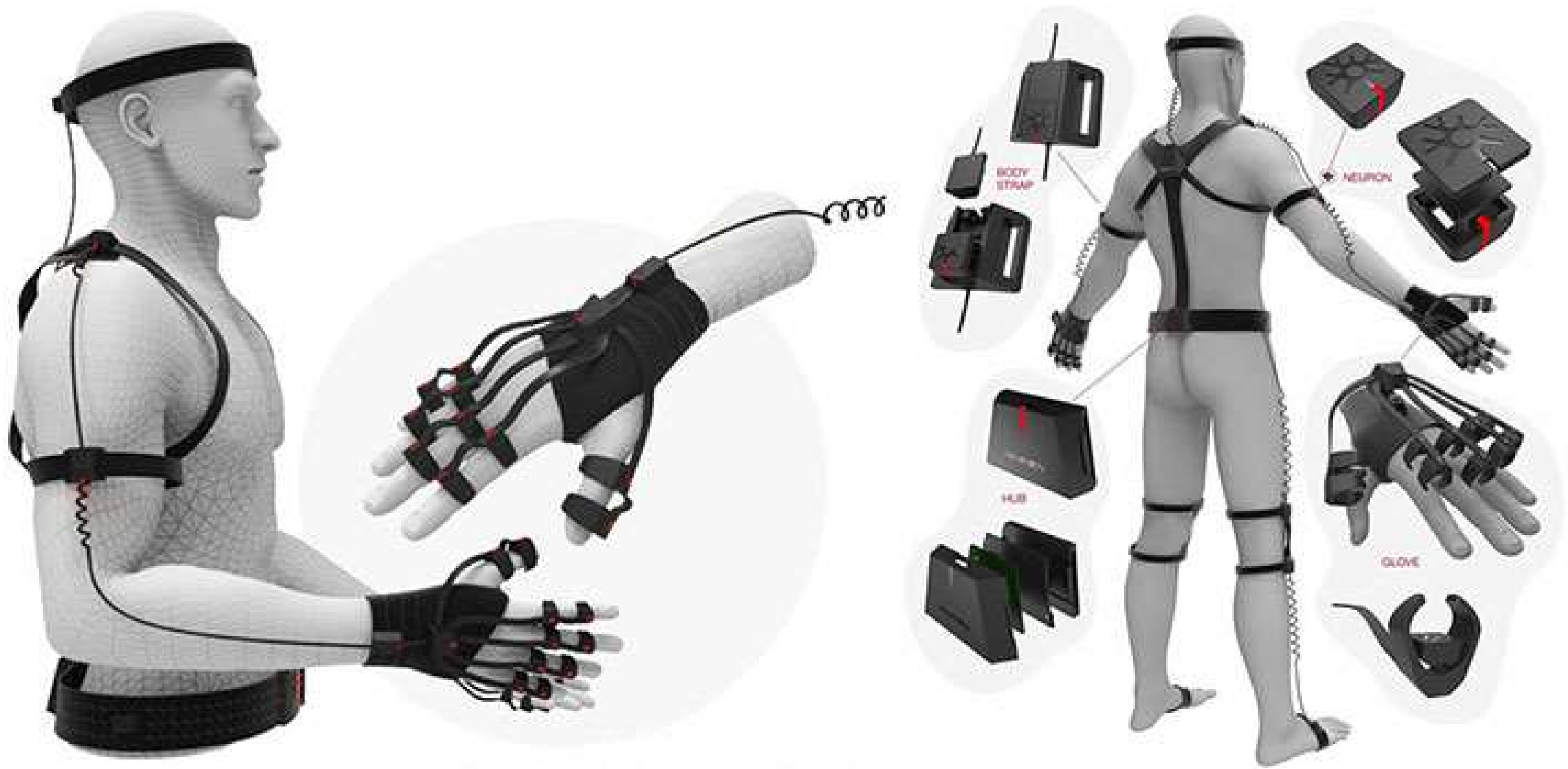
Inertial Tracking: Intersense

commercial inertial tracking

„Inertiacube“ uses ultrasound for absolute measurement

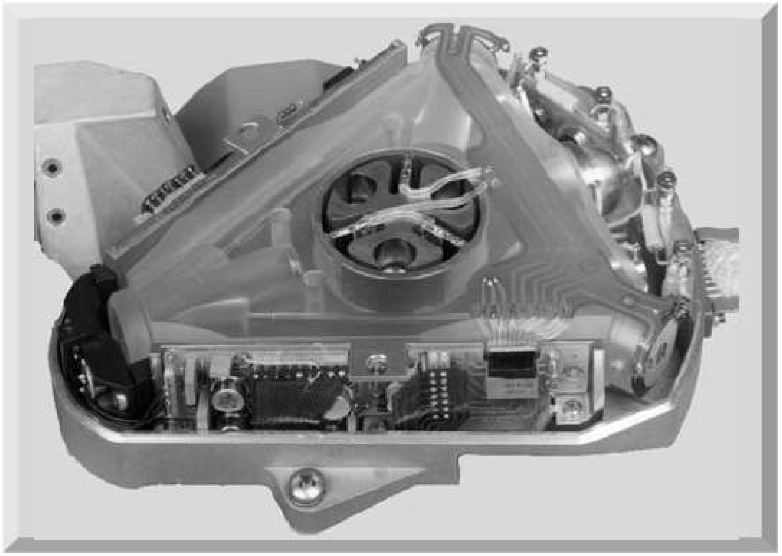
Inertial Tracking: Perception Neuron

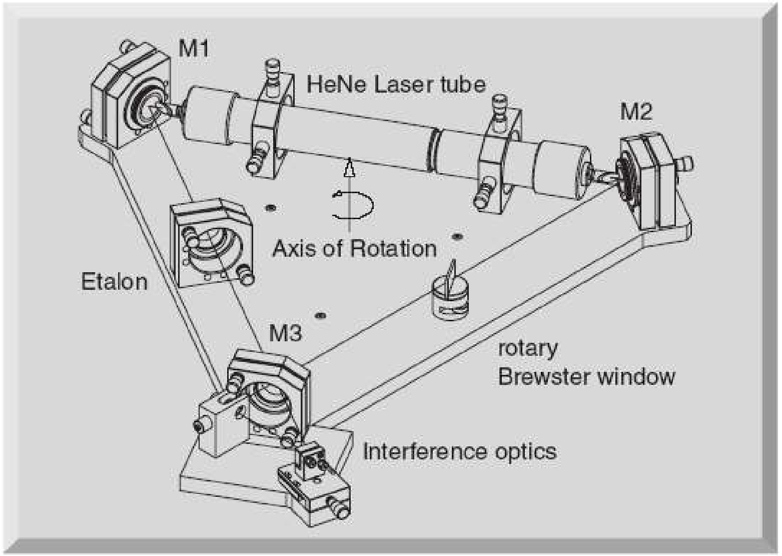
commercial inertial full-body tracking



Inertial Tracking

laser gyro:





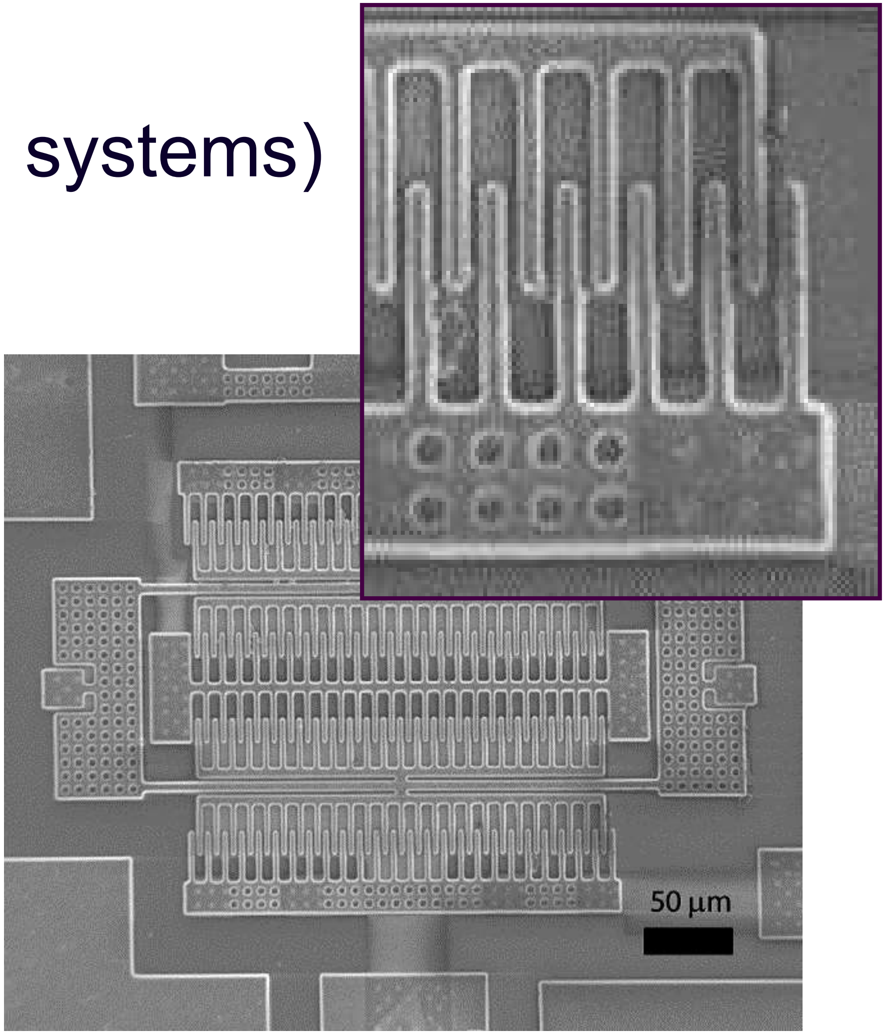
Inertial Tracking

MEMS
(Microelectromechanical systems)

deliver linear & angular acceleration in compact packages:

phones

game controller



Inertial Tracking: conclusion

Advantages

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

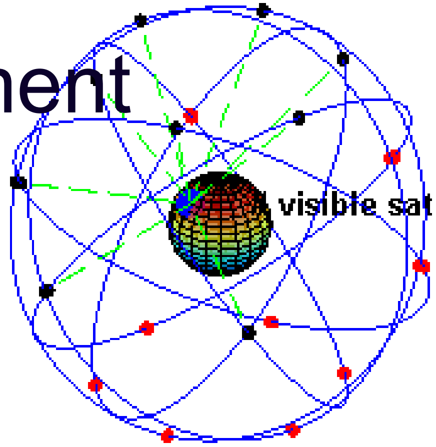
Disadvantages

- 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:

$$L_1 = c(t - t_1) = \sqrt[2]{(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2}$$

$$L_2 = c(t - t_2) = \sqrt[2]{(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2}$$

$$L_3 = c(t - t_3) = \sqrt[2]{(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2}$$

$$L_4 = c(t - t_4) = \sqrt[2]{(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2}$$

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

minimal 4 equations for 4 variables → 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)

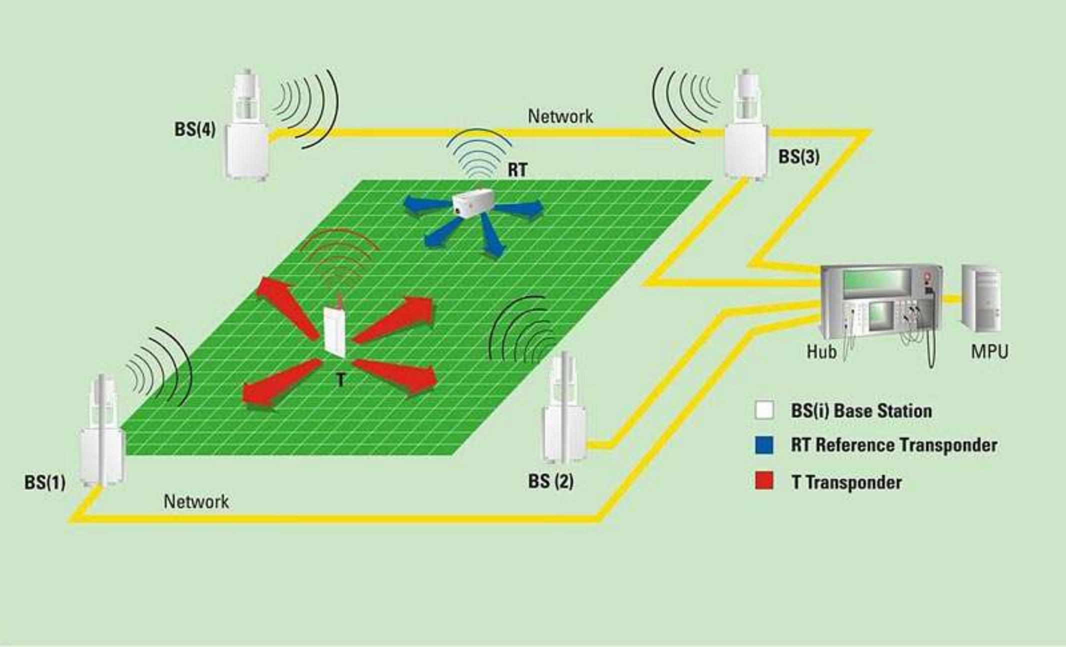
Radio Tracking

Principle:

“Das Echtzeit-Netzwerk ist mit mehreren Basis-Stationen (Mess-Stationen) verbunden. Jedes zu messende Objekt wird über einen Transponder individuell angesprochen und antwortet mit einem bestimmten Signal.

Die Basis-Stationen empfangen die Signale des Transponders und des Referenztransponders und detektieren deren Ankunftszeiten. Die Daten werden dann in Echtzeit über das Netzwerk an den Zentralrechner weitergeleitet, der daraus die aktuellen 3D-Positionsdaten errechnet.

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

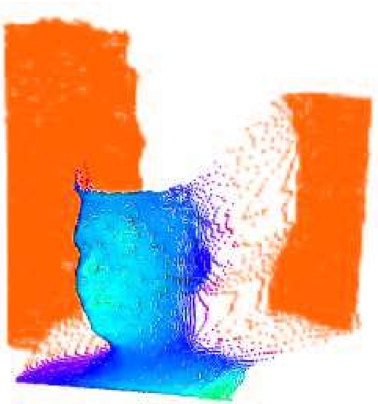
Disadvantages

- 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

http://www.cs.unc.edu/~welch/media/pdf/Yang2006-EDGE-stereovision.pdf

*depends on content: without detectable features, the algorithm does not work

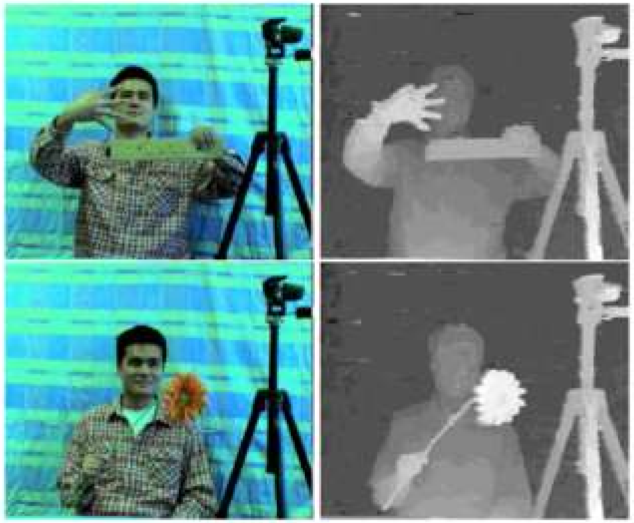


Figure 1: Two sample images and their depth maps from our live system on a 3.0GHz PC with an ATI's Radeon XL1800 graphics card. With this quality, we can achieve 43 fps with 320×240 input images and 16 disparity levels.

“Geometric” Tracking: ToF camera

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

Example:
PMDtec sensor

200×200 @60Hz

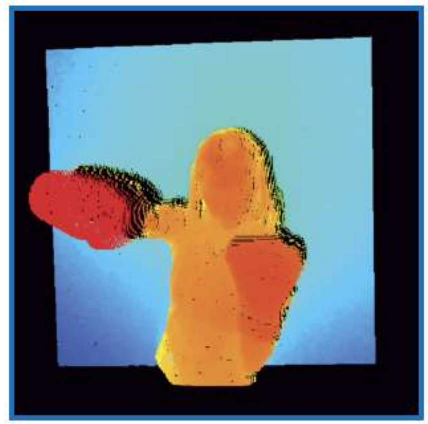
~1mm depth resolution

0.3-7m range

60° Field of View

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

http://en.wikipedia.org/wiki/ToF_camera



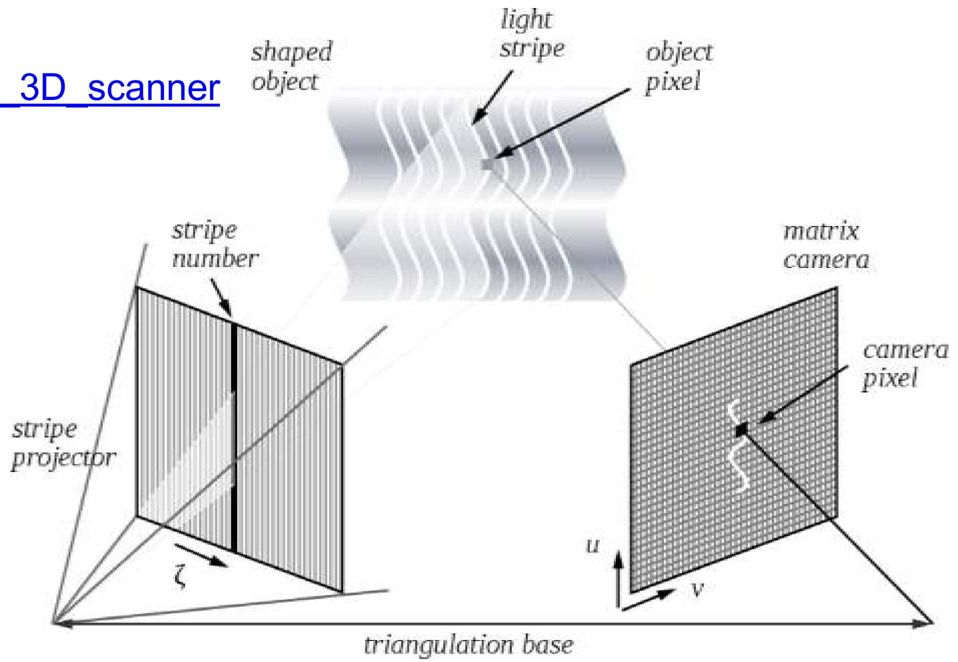
color coded 3D

3D & gray scale

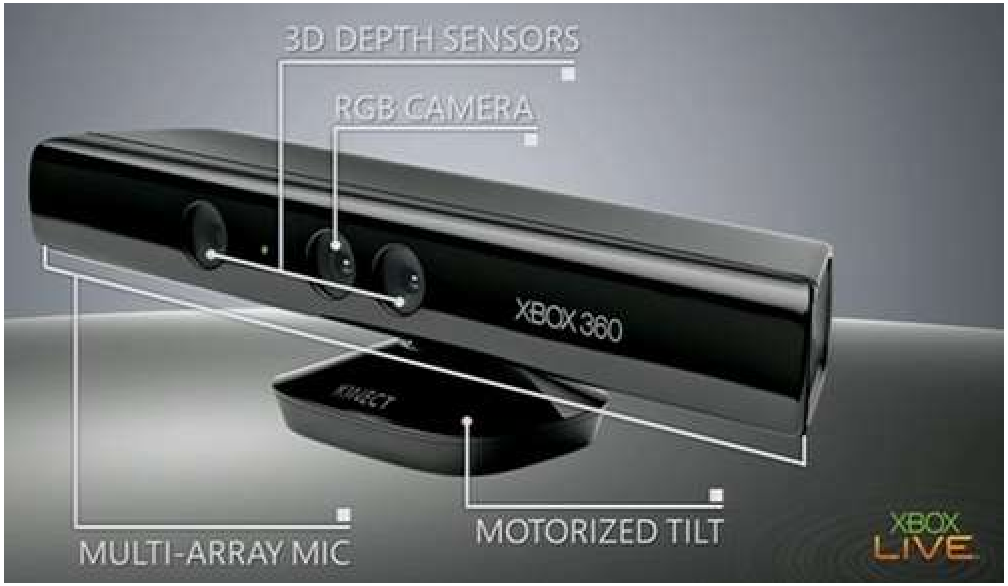
“Geometric” Tracking: structured light

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

http://en.wikipedia.org/wiki/Structured-light_3D_scanner



“Geometric” Tracking: structured light



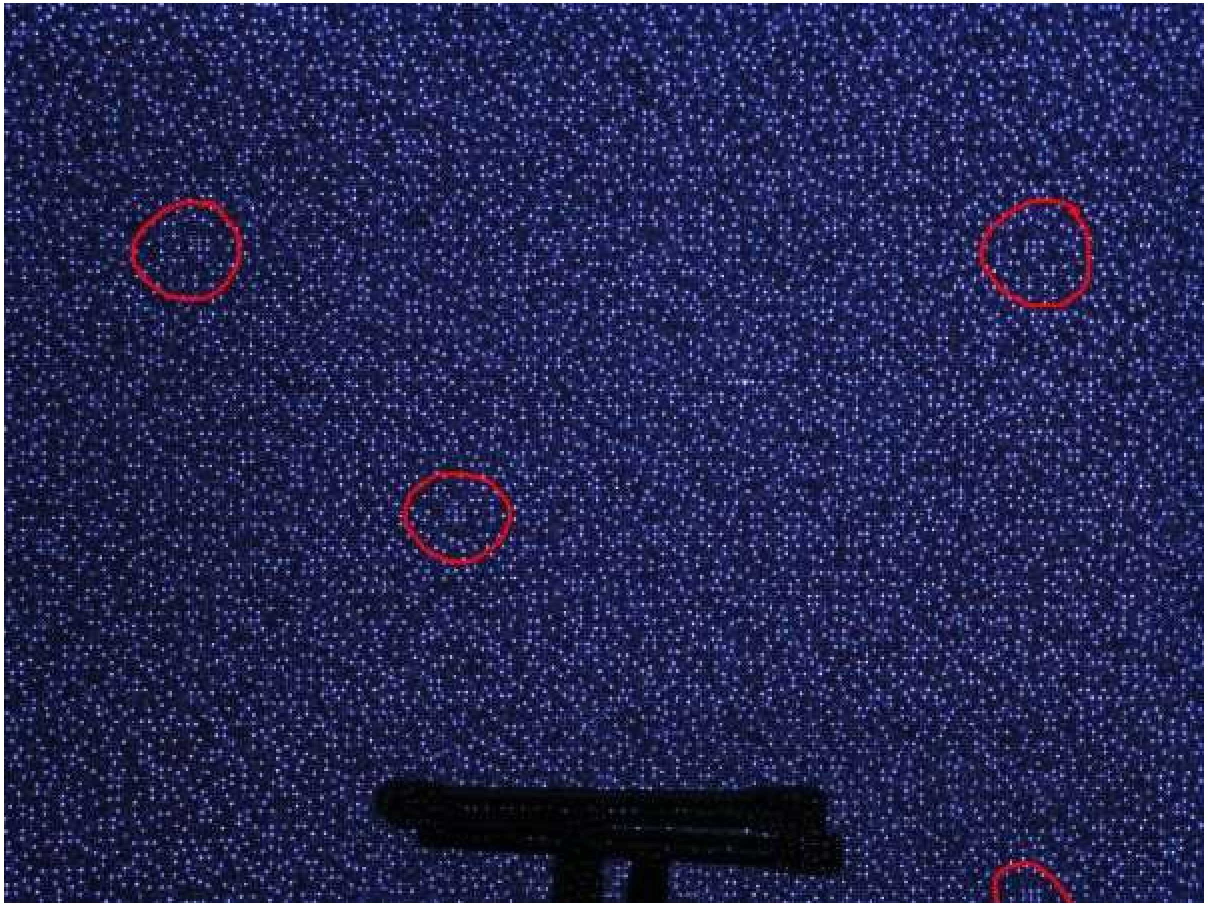
Example:

Microsoft Kinect

Projects pseudo-random IR point pattern & captures IR @QVGA and visible light @VGA (depth with high latency)

Technische Universität Wien
Vienna University of Technology

“Geometric” Tracking: structured light



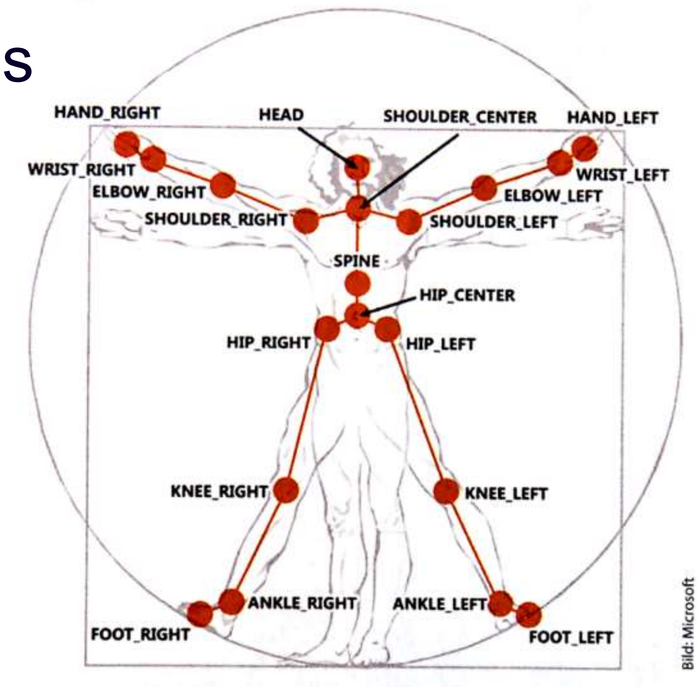
“Geometric” Tracking: segmentation

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:

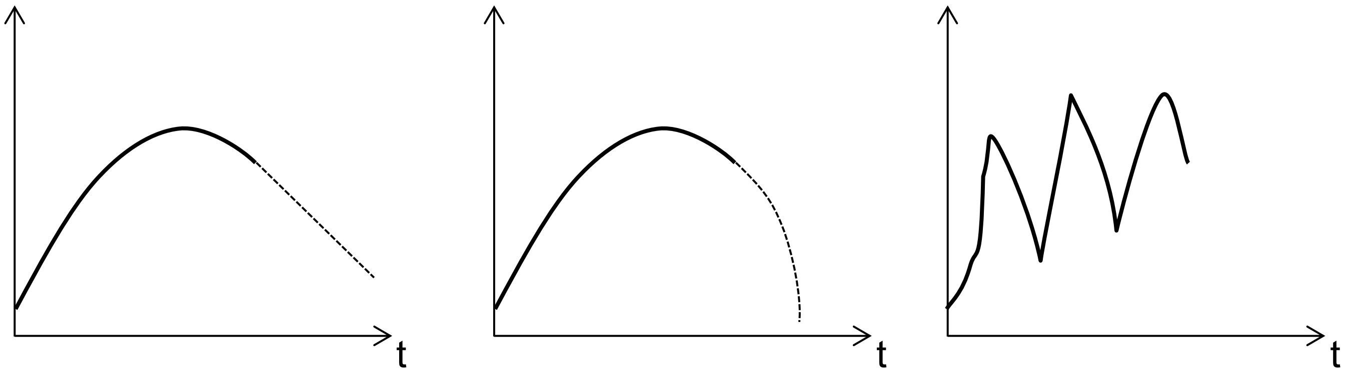
since it directly measures acceleration, it can be used for higher-order extrapolation

→ 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.

Welch, G. et.al., "An introduction to the Kalman Filter", SIGGRAPH 2001, Course Notes

Advanced Topics in Virtual Reality

Calibration and Registration

Anton L. Fuhrmann

2018

TECHNISCHE UNIVERSITÄT WIEN
VIENNA UNIVERSITY OF TECHNOLOGY

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

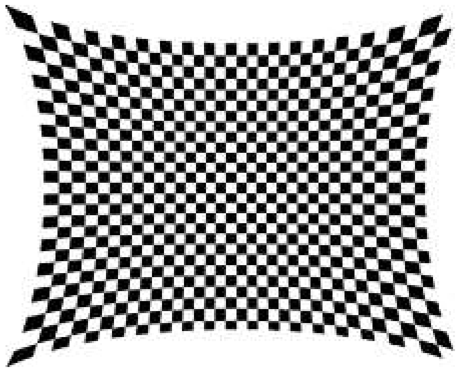
Registration:

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

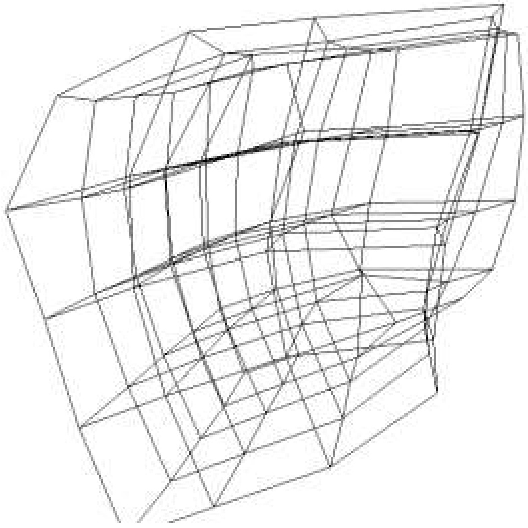
Calibration

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

distortions of optics in a HMD:

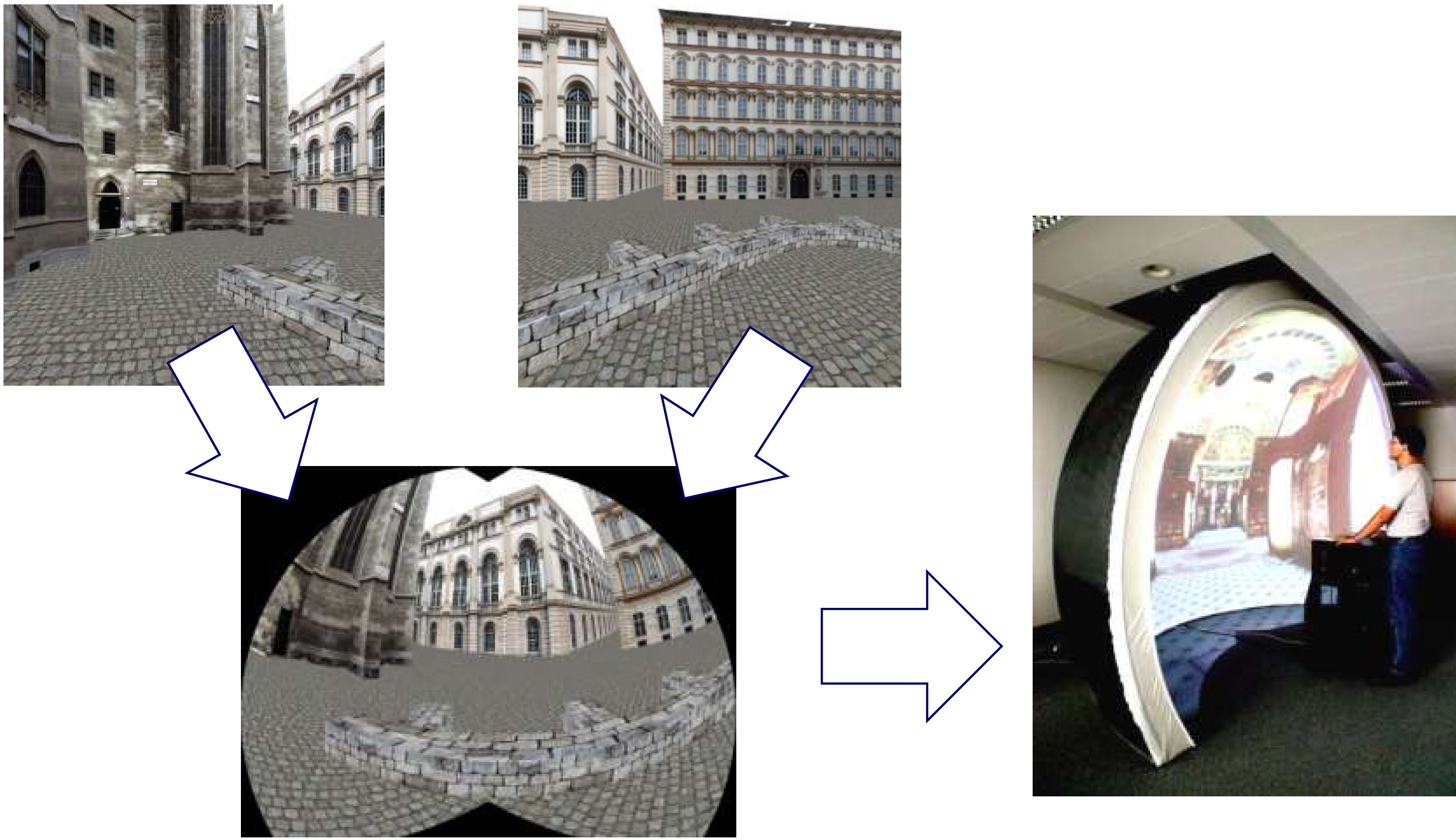


distortions of magnetic tracker:



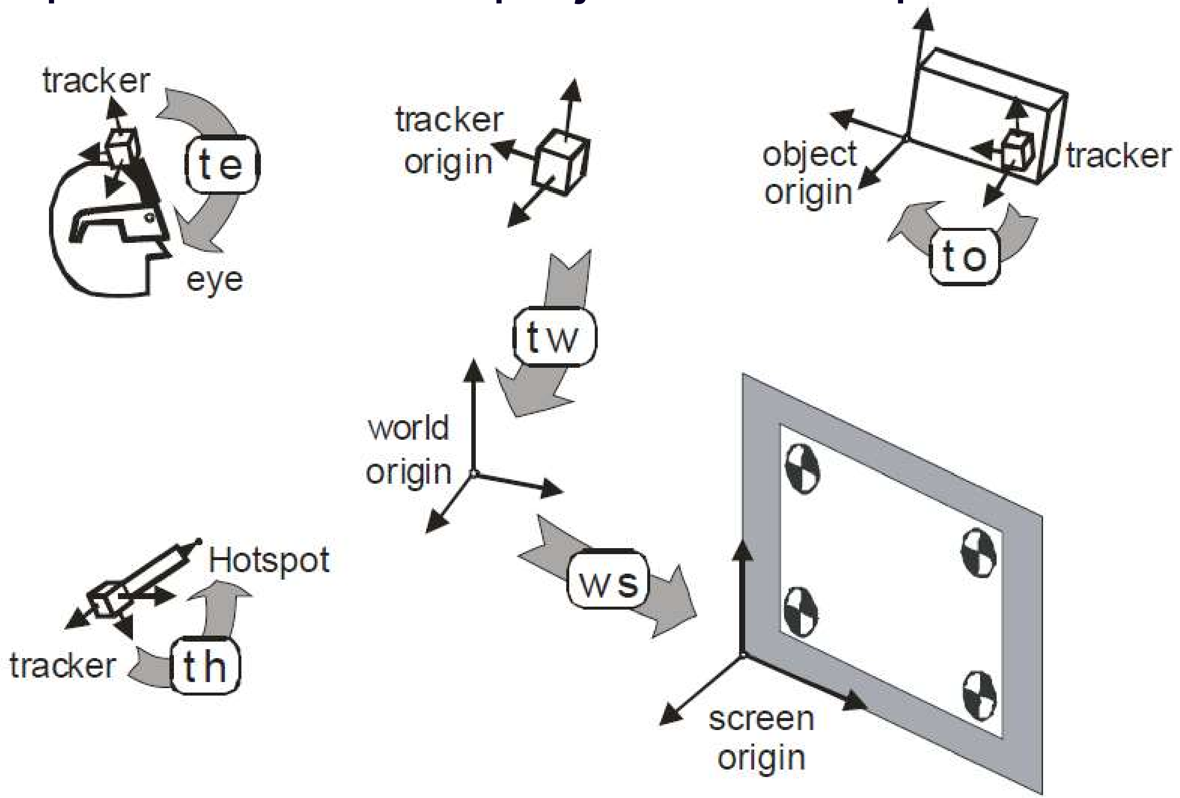
Calibration

mapping of image to projection screen::



Registration

registration parameters for a projection set-up



A. L. Fuhrmann, R. Splechtna, and J. Prikryl. „Comprehensive Calibration and Registration Procedures for Augmented Reality". In *Proceedings Eurographics Workshop on Virtual Environments, pages 219–228, Stuttgart, Germany, May 2001.*

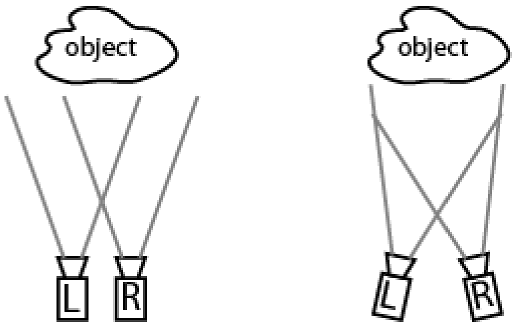
Correct Stereoscopy

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

Example: rendering for stereoscopic projection

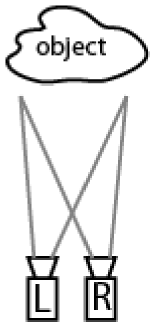
Wrong:

offset or tilt



Correct:

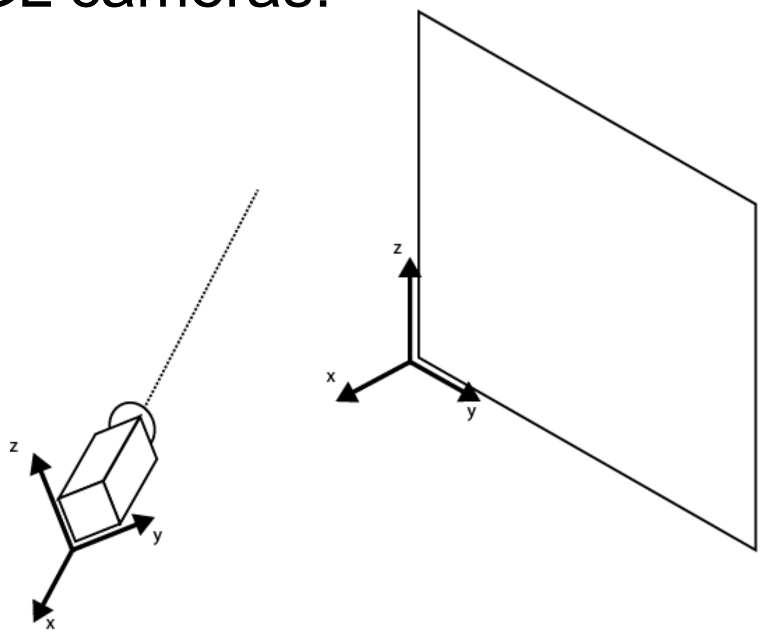
off-axis projection



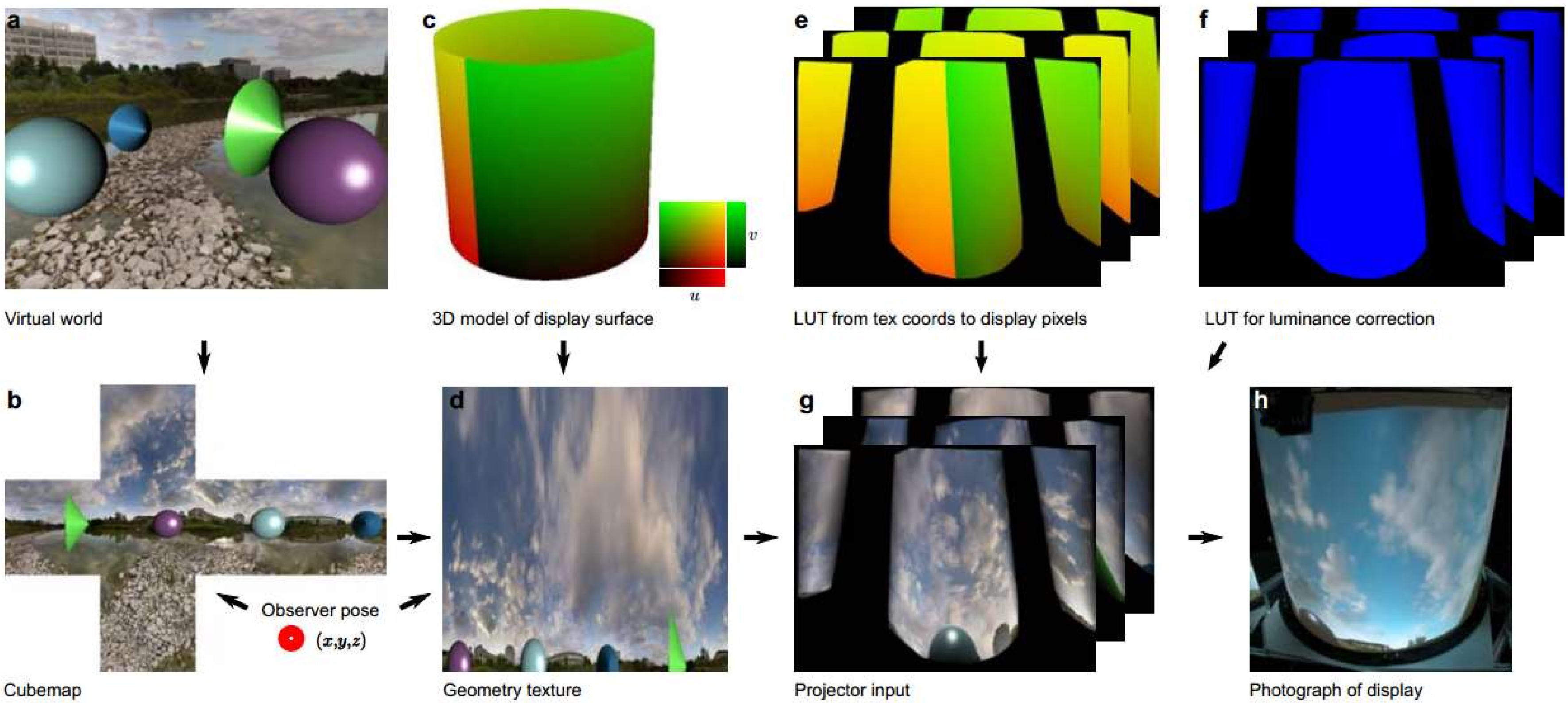
Correct Stereoscopy

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



Advanced Topics in Virtual Reality

Virtual Environments
System Setups

Anton L. Fuhrmann
2018

TECHNISCHE UNIVERSITÄT WIEN
VIENNA UNIVERSITY OF TECHNOLOGY

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!)

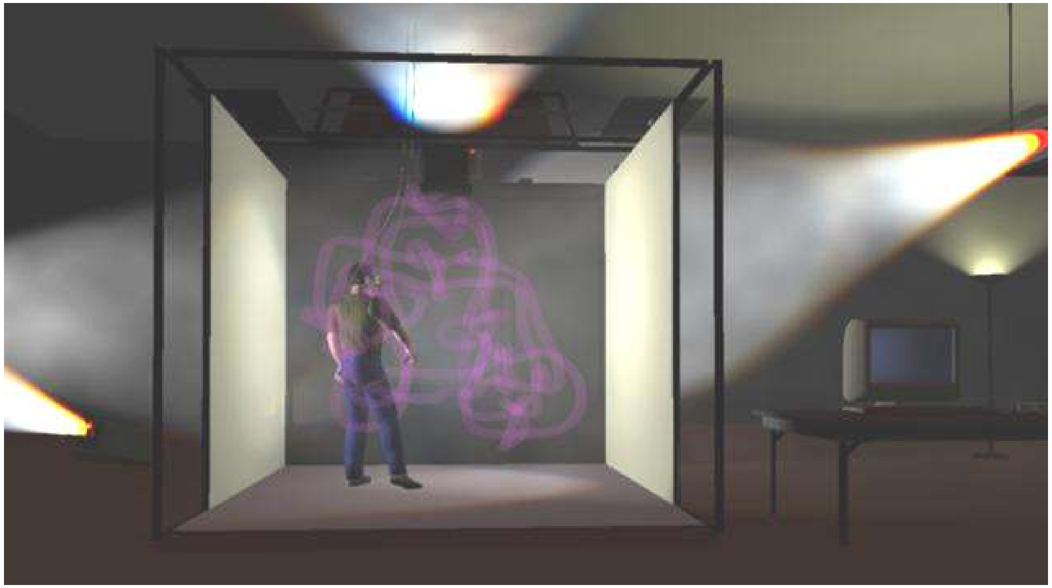
Immersive vs. Augmented setups

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.

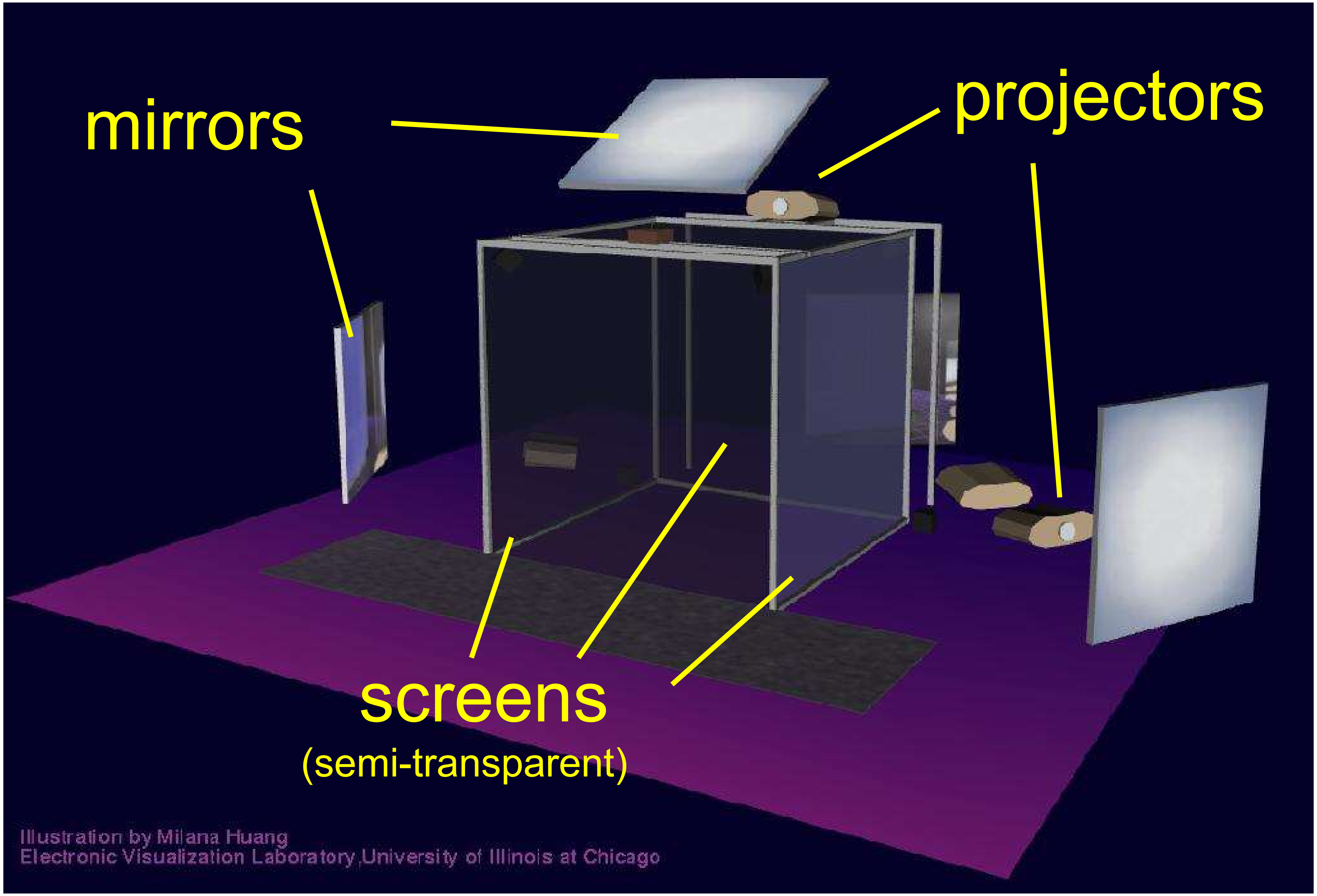


The CAVE

A CAVE user

- wears Shutter- or Pol-glasses
- has to be head-tracked
- uses a tracked input device

The CAVE – back projection



The CAVE – front projection

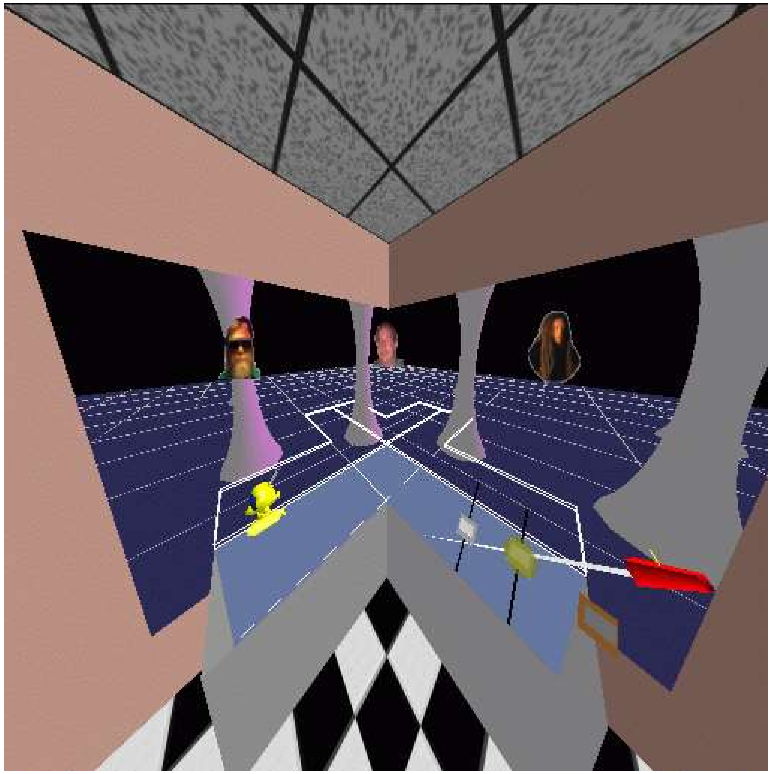
The CAVE – front vs. back projection

	Back	front
Space requirements	Larger than working volume	Working volume
Screen	Expensive, special corners	White wall
Vignetting	Extensive	Not noticeable
Shadows	None	When standing close
Polarization	Possible, but mediocre	Not really possible
Top & bottom projection	Possible	Not possible

The CAVE

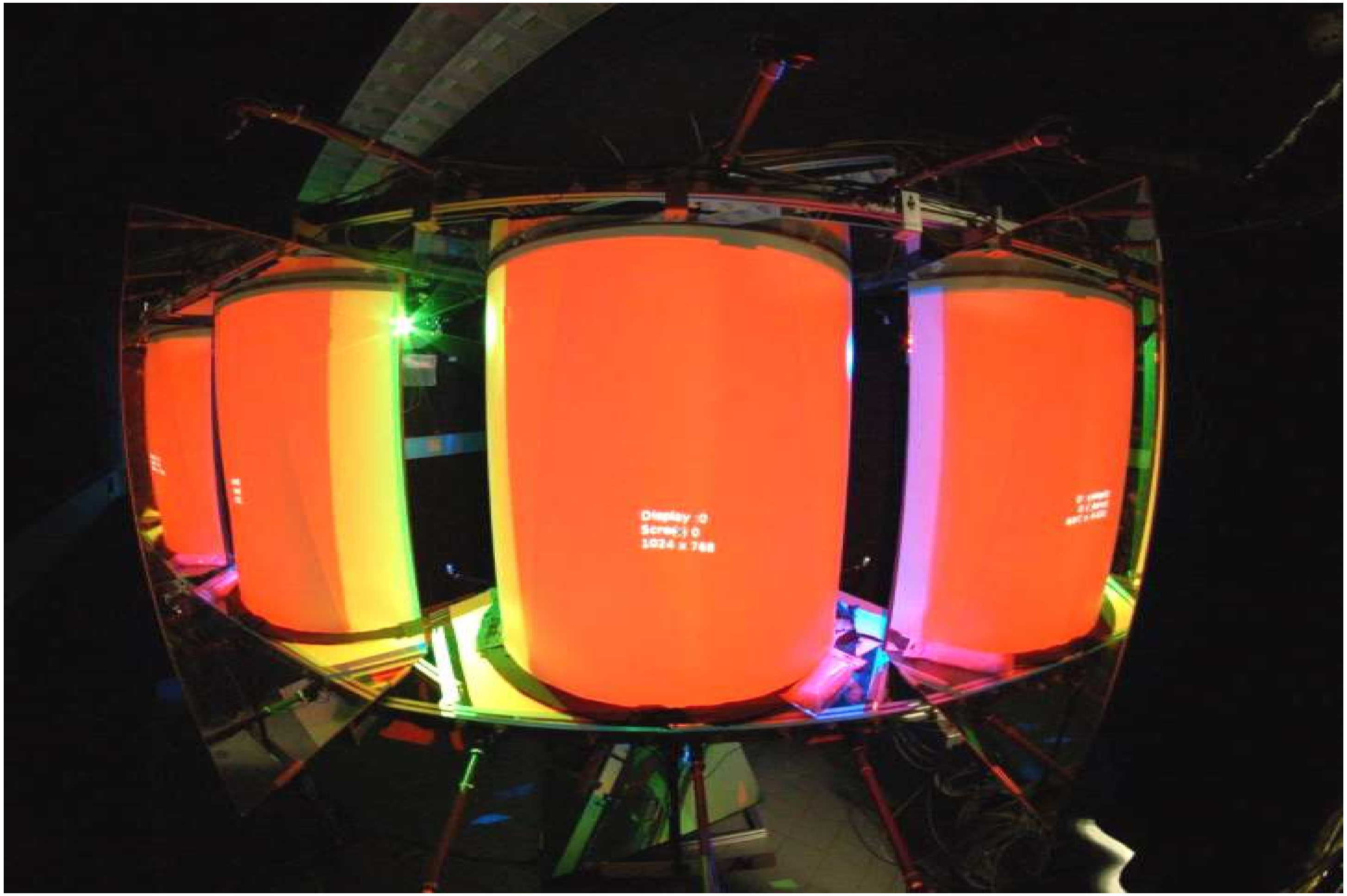
Images for the CAVE have to be calculated depending on the users and screens position.

From the wrong position, the images look like this:

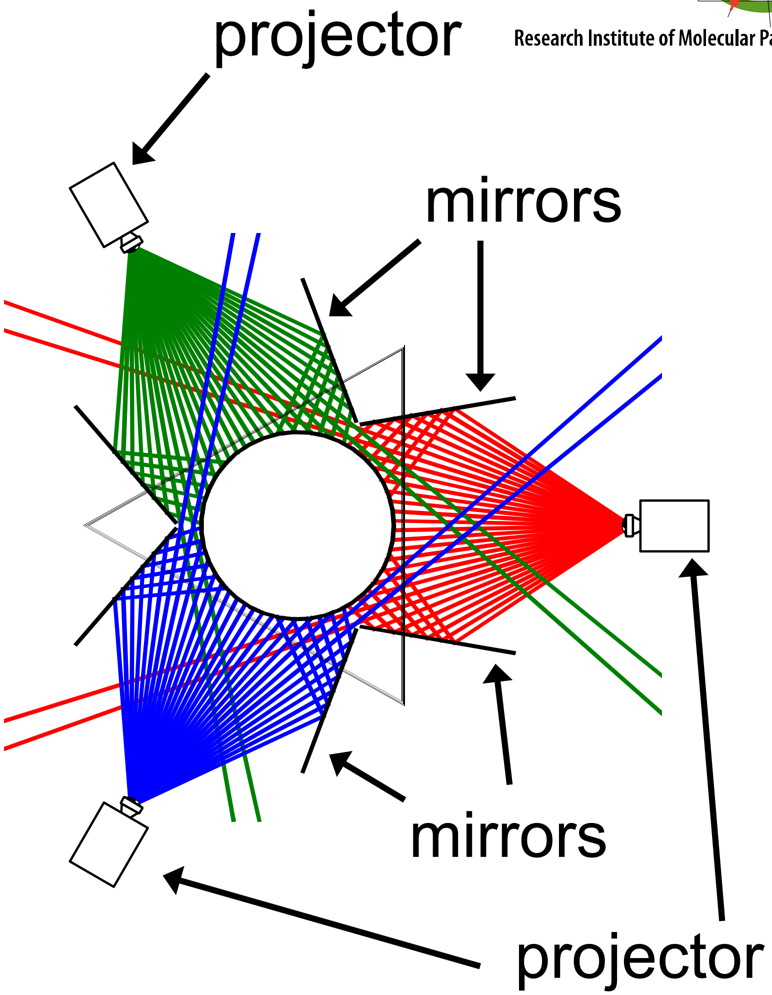


The CAVE

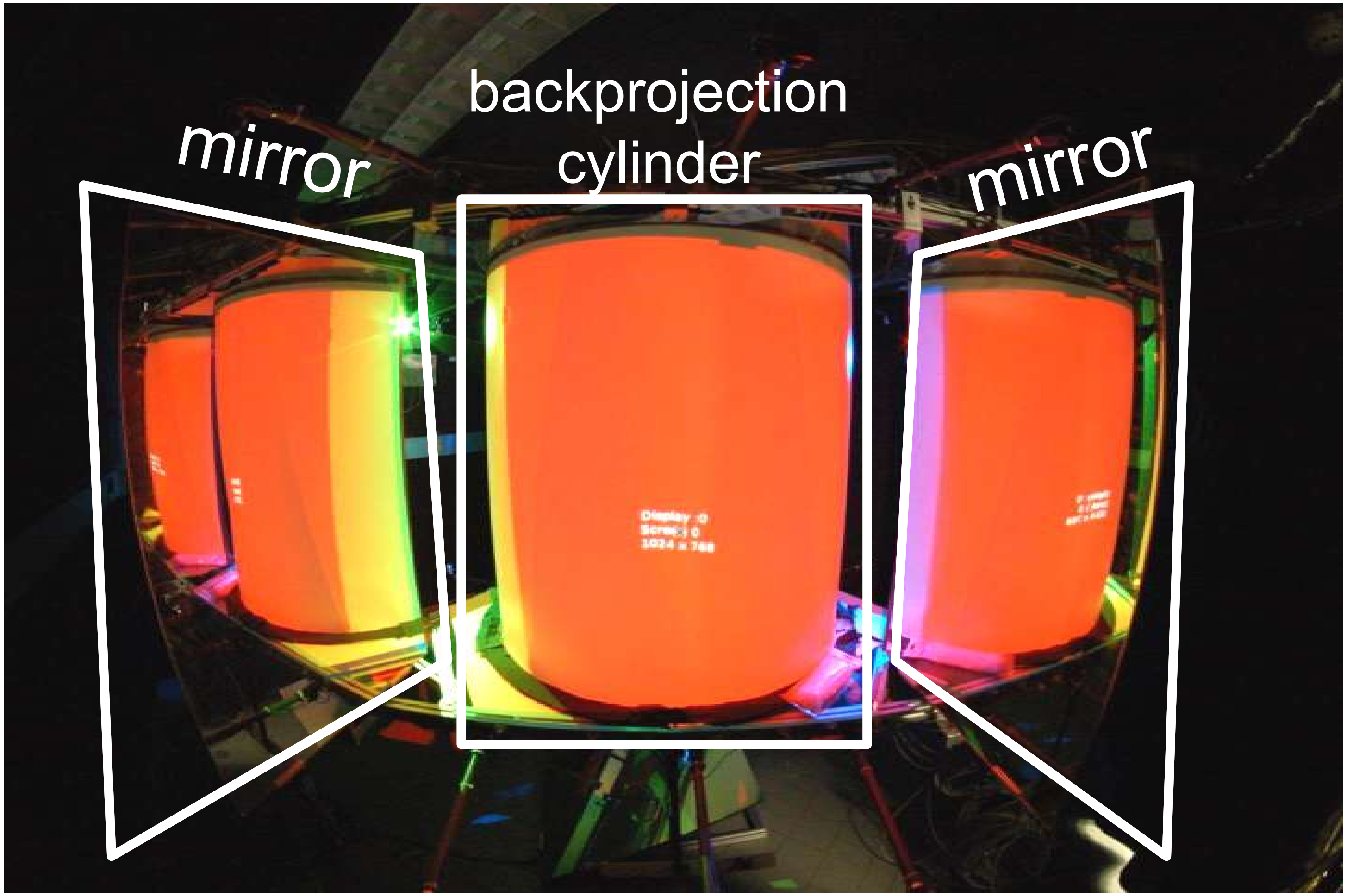
The FLYCAVE



The FLYCAVE - display

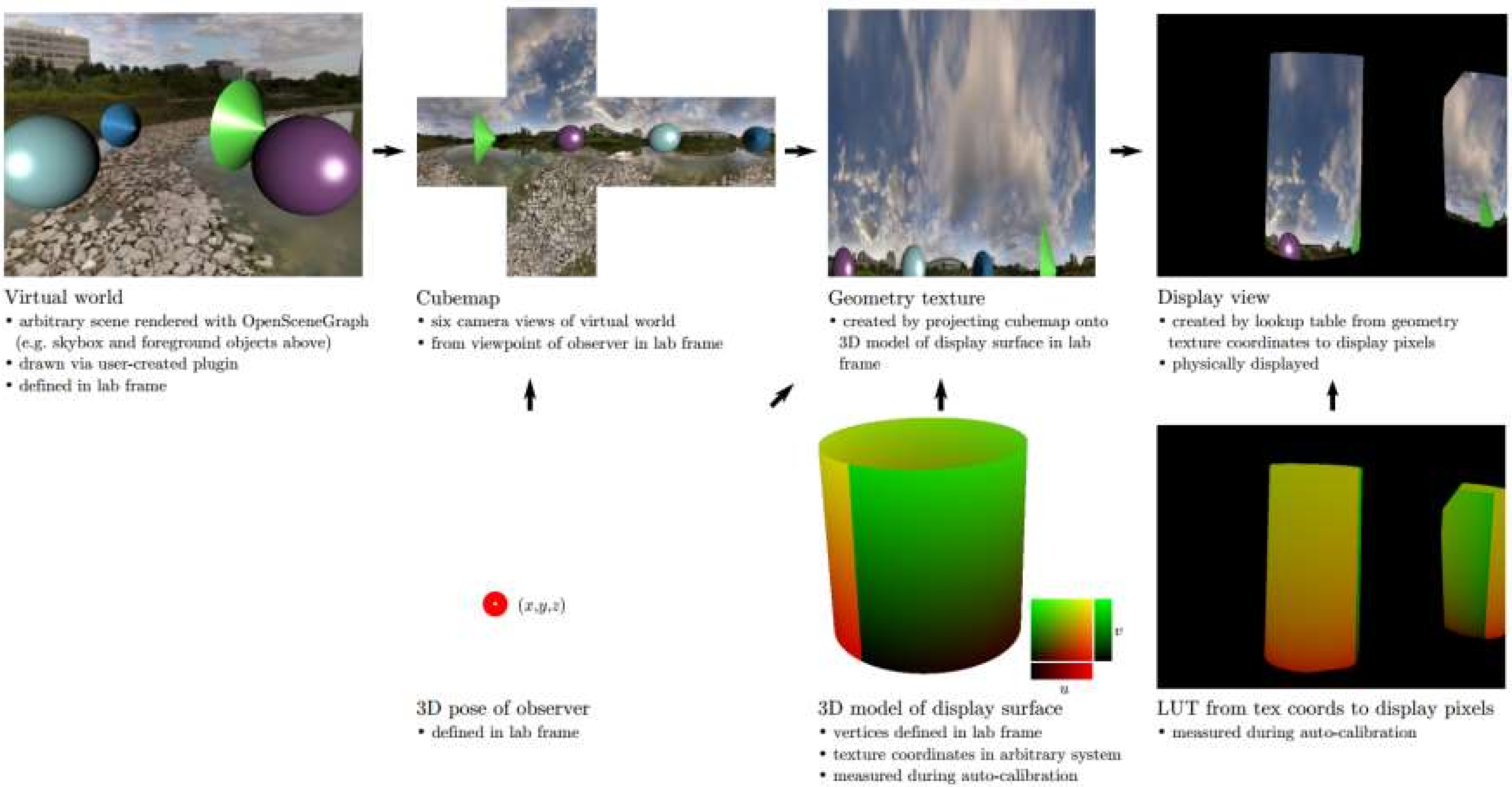


The FLYCAVE - display



The FLYCAVE – rendering

IMP
Research Institute of Molecular Pathology

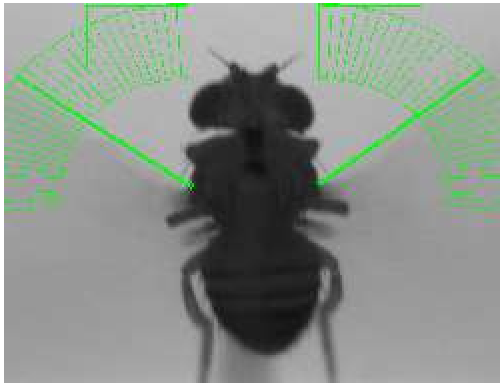


The FLYCAVE – tethered version

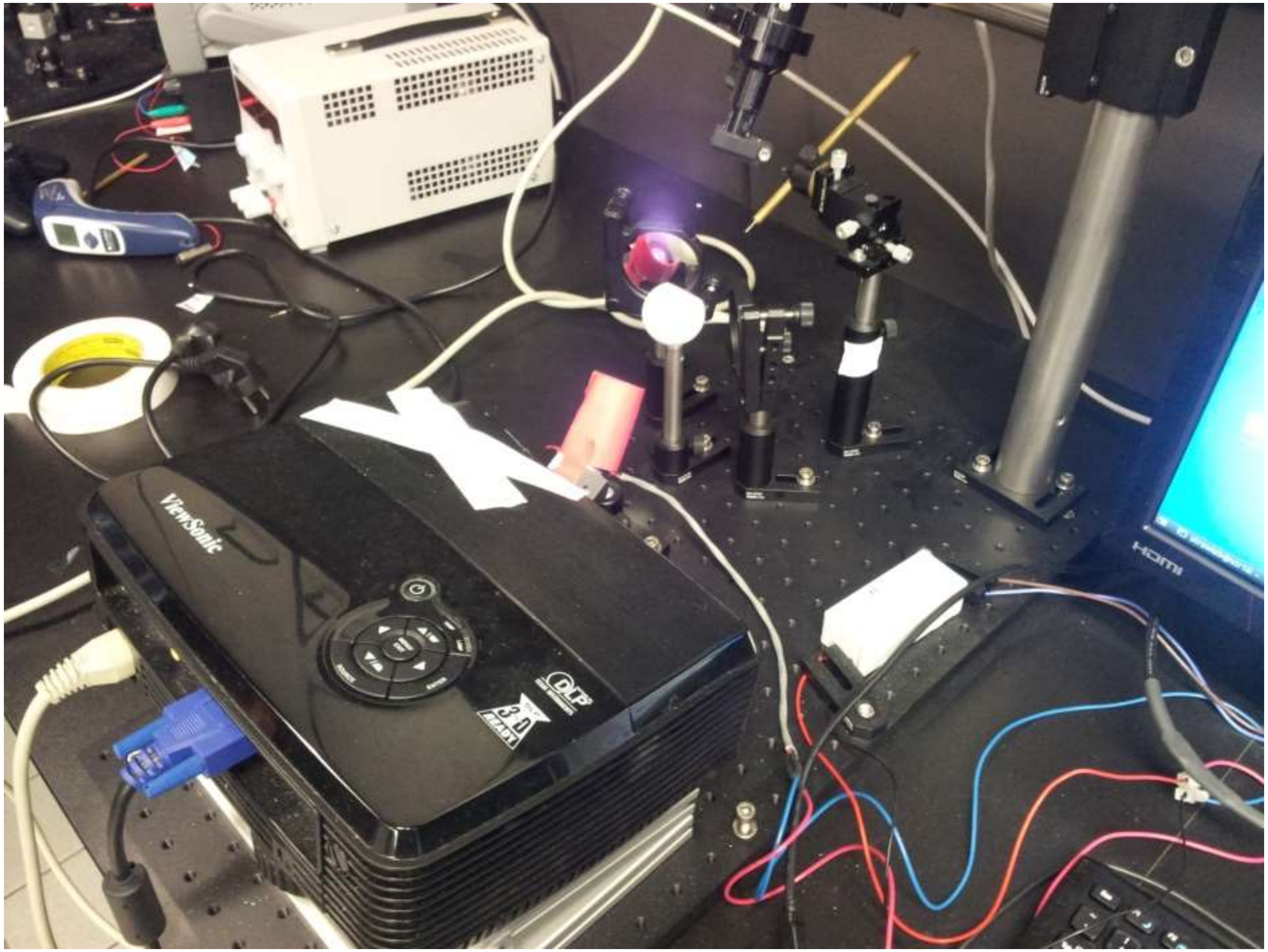
Three images are projected via mirrors on a small, translucent ball

Inside the ball, a fly is anchored

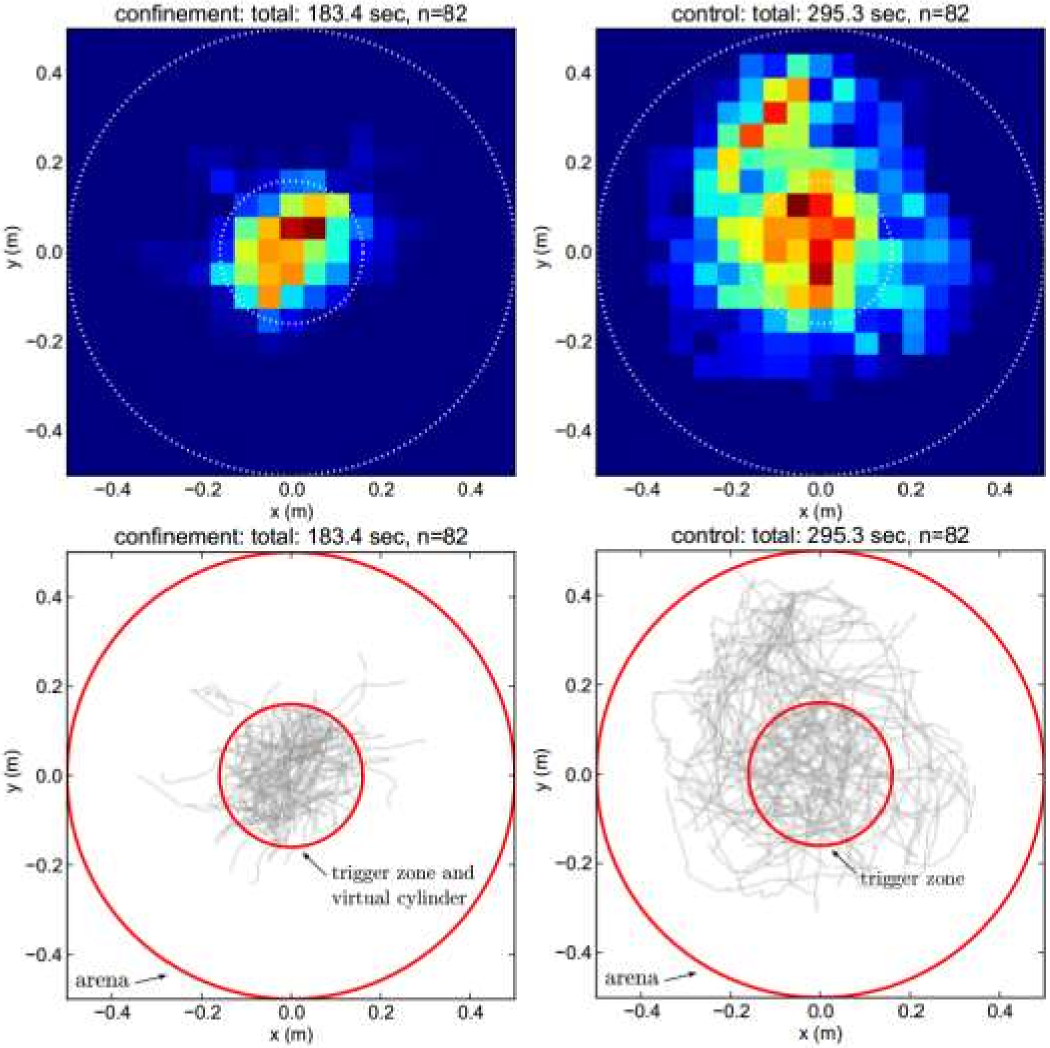
The amplitudes of the fly's wings give its intended direction



The FLYCAVE – tethered version



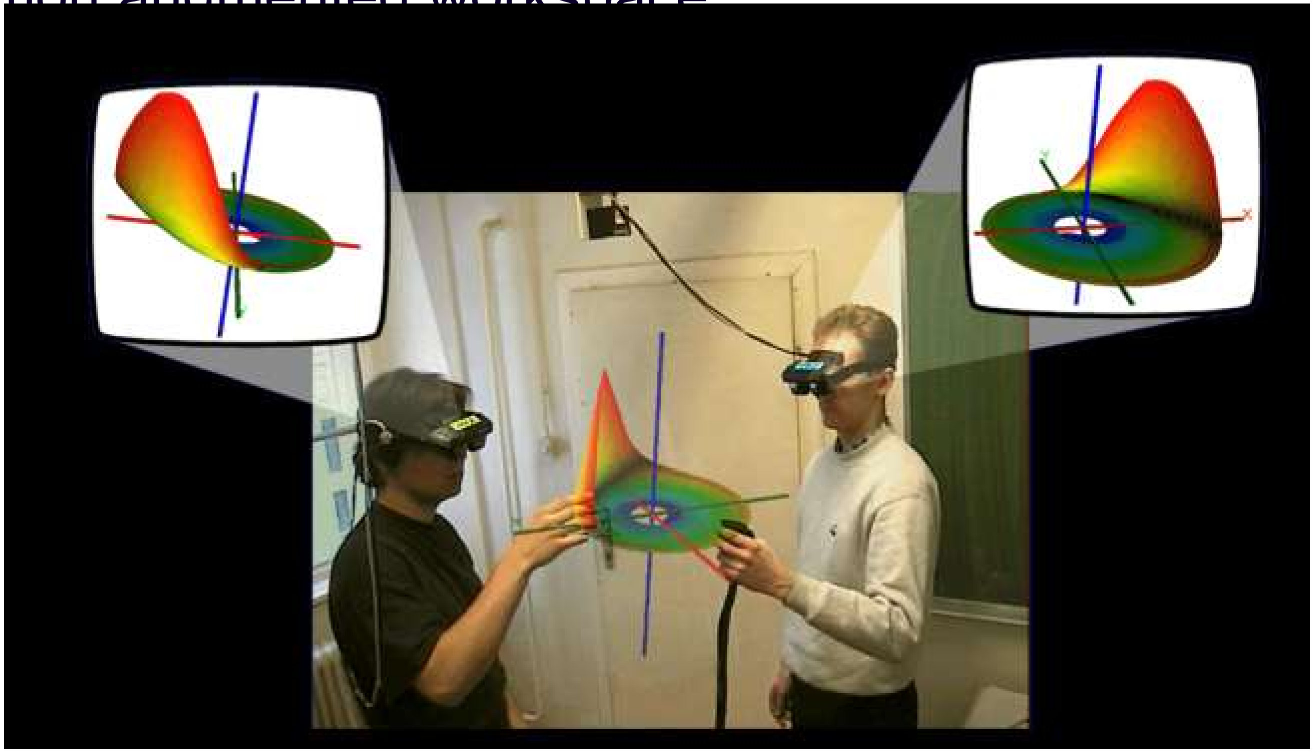
The FLYCAVE – confinement results



Studierstube

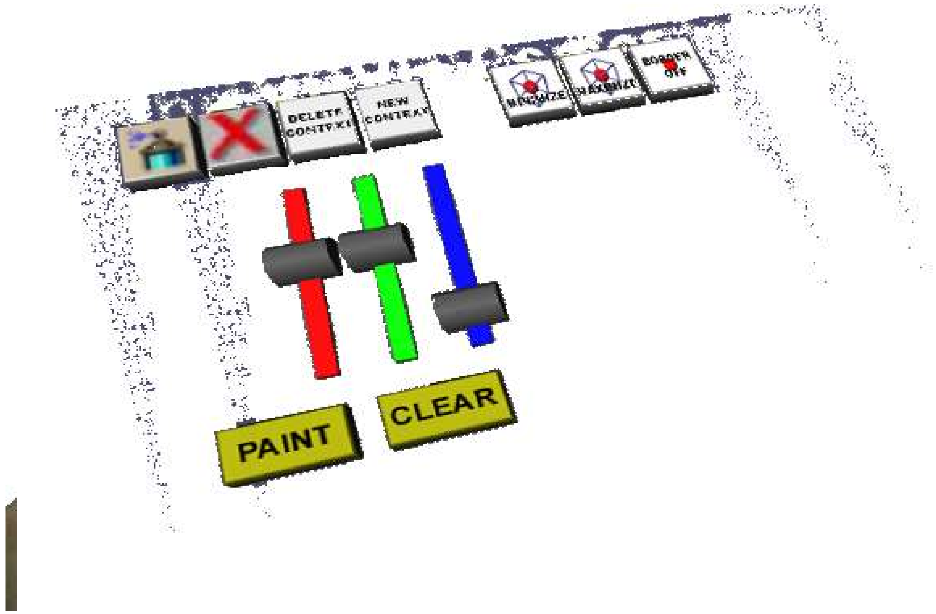
"Studierstube" is a multi-user local VE.

It uses see-through HMDs to let users share a common augmented workspace.



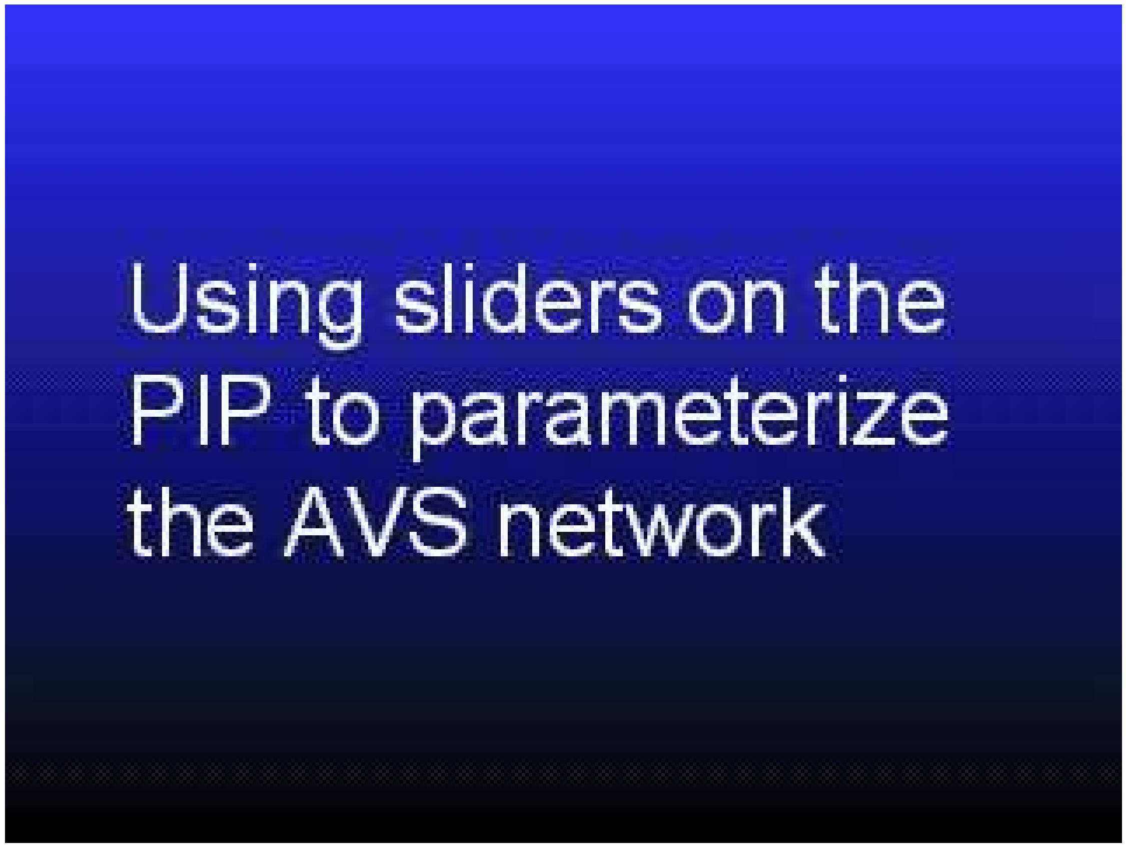
Studierstube

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.



TECHNISCHE UNIVERSITÄT WIEN
VIENNA UNIVERSITY OF TECHNOLOGY

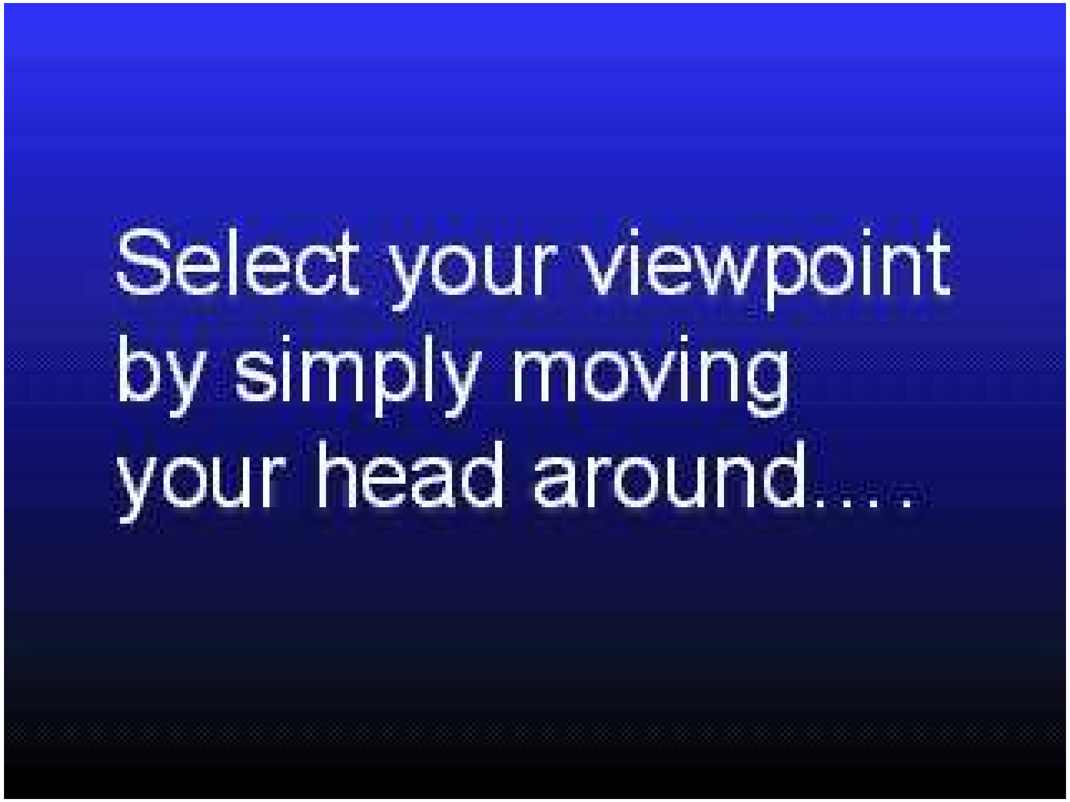
Studierstube (video)



Technische Universität Wien
Vienna University of Technology

Studierstube (video)

Studierstube (video)



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

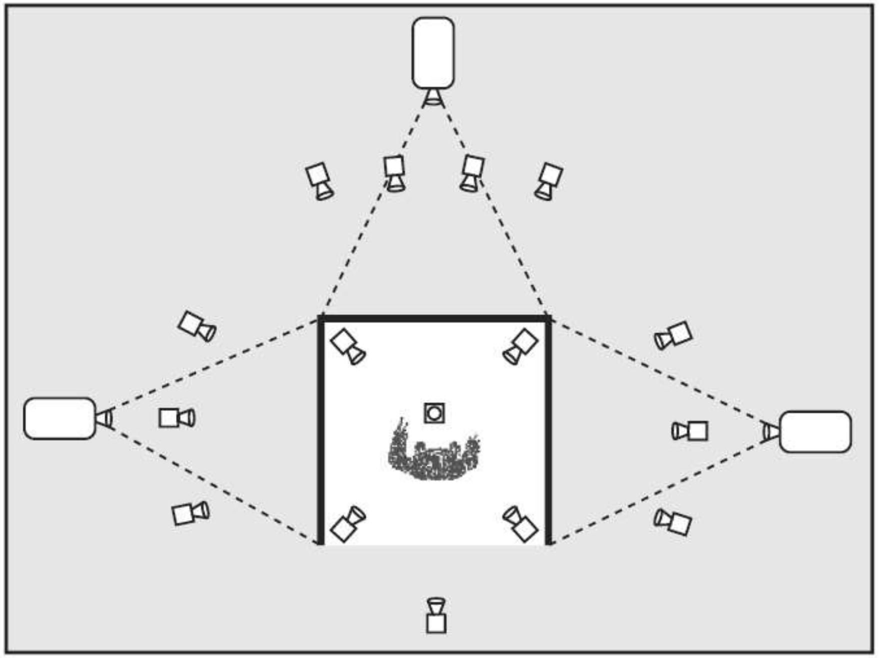
http://blue-c.ethz.ch/

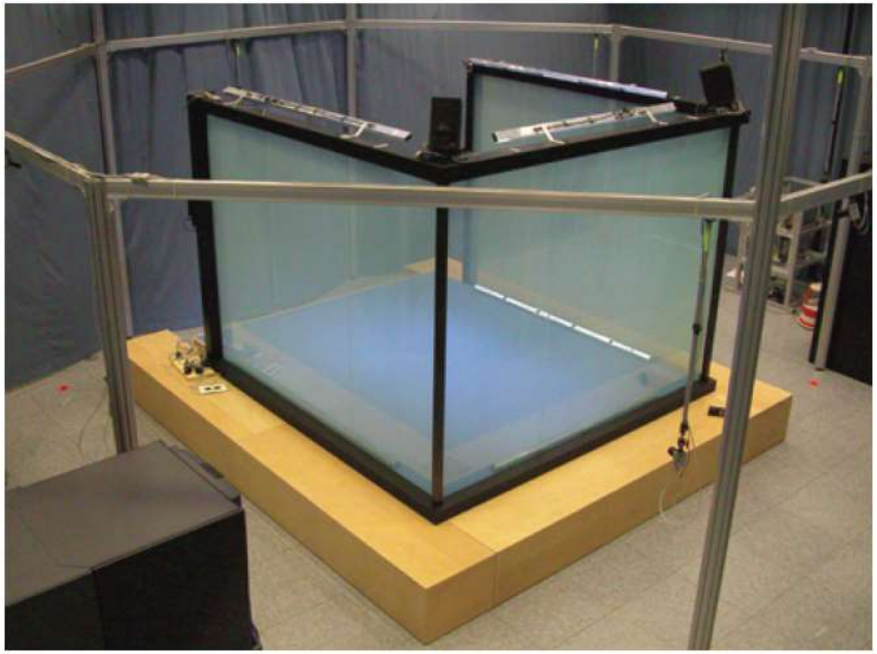
The blue-c system includes:

- 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



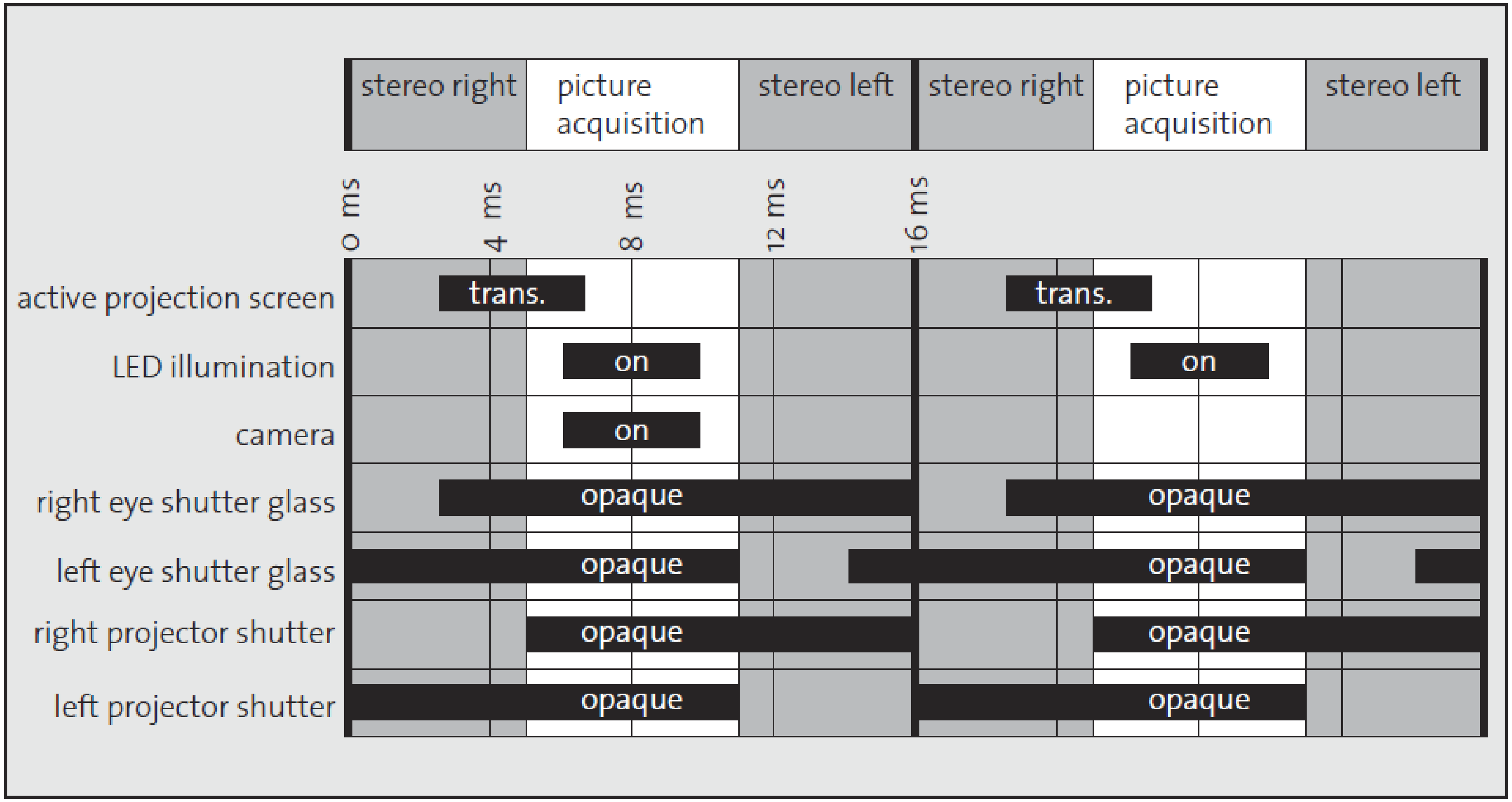


Blue-C

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:

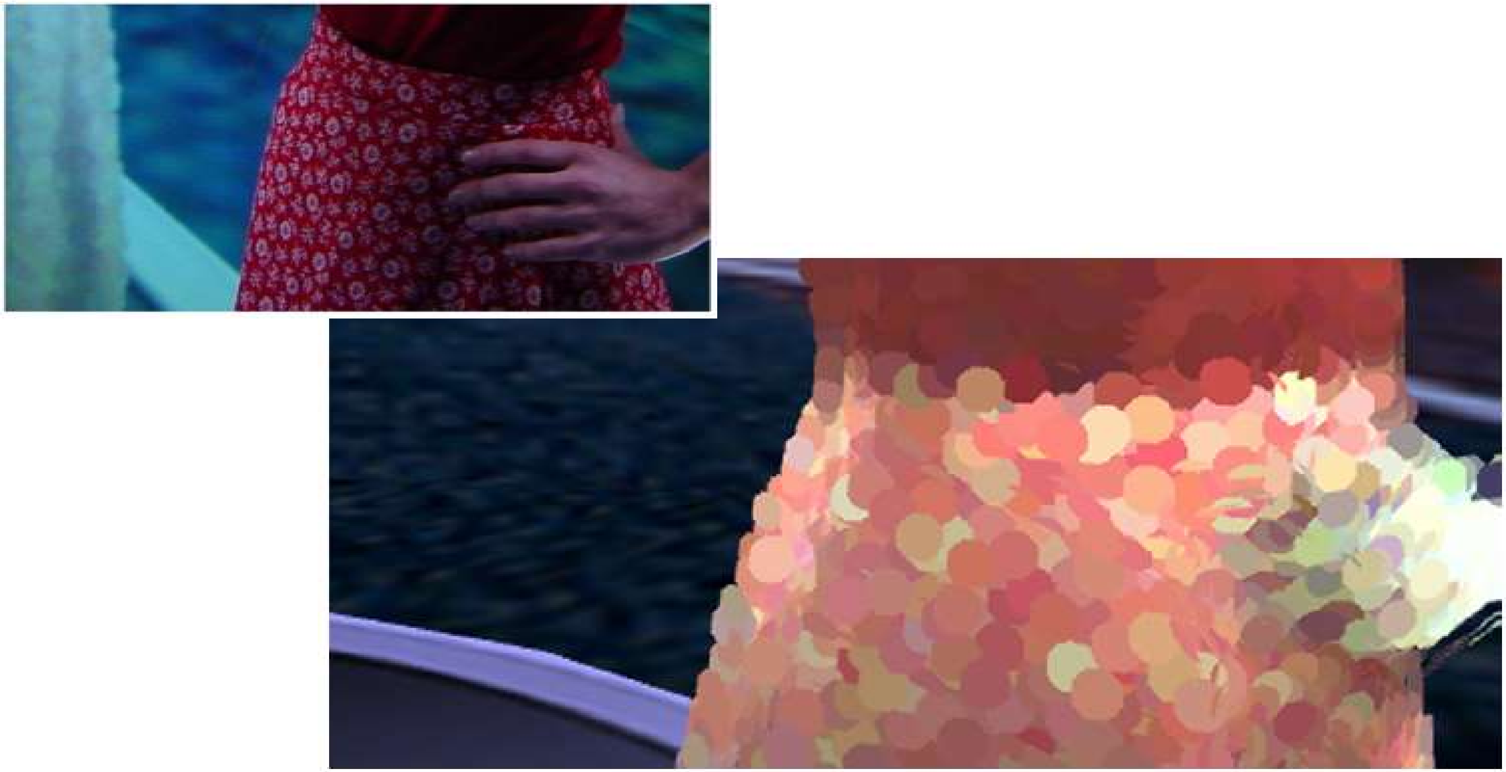


Blue-C

Background subtraction segments the image into user and background:

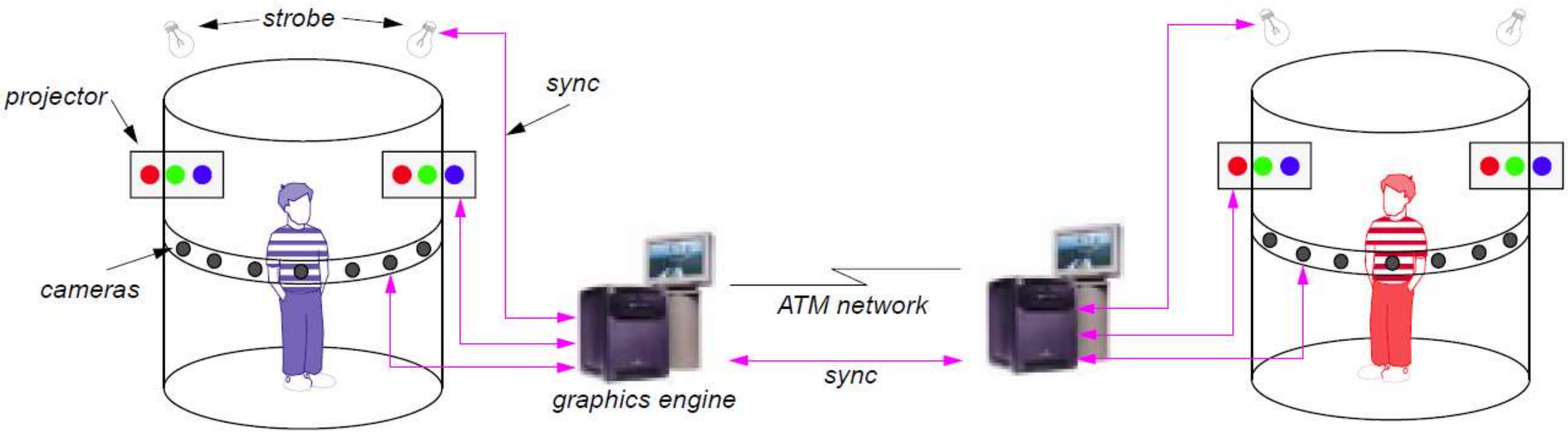
Blue-C

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!