Recent 3D Display Technologies (Excluding Holography [that will be lectured later])

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Contents

- Introduction to 3D display
- Present status of 3D display
  - Hardware system
    - Stereoscopic display
    - Autostereoscopic display
    - Volumetric display
    - Other recent techniques
  - Software
    - 3D information processing: depth extraction, depth plane image reconstruction, view image reconstruction
    - 3D correlator using 2D sub-images
    - 2D to 3D conversion

Outline of presentation

High resolution pickup device

Image pickup

Display device (3D display)

- Stereoscopic display
- Autostereoscopic display

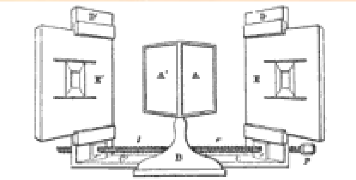
Image pickup

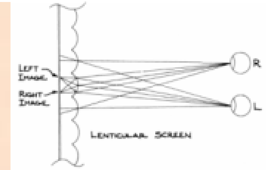
- Image processing (2D : 3D)

Consumer

- Depth perception
- Visual fatigue

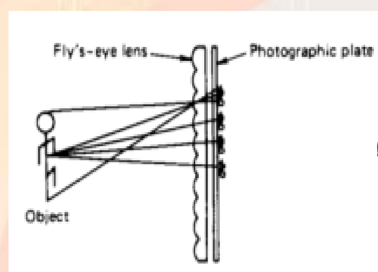
Brief history of 3D display



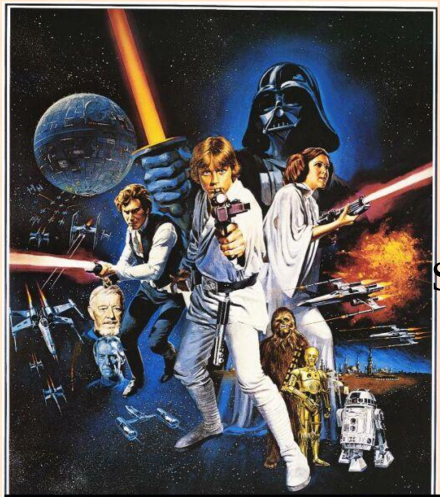


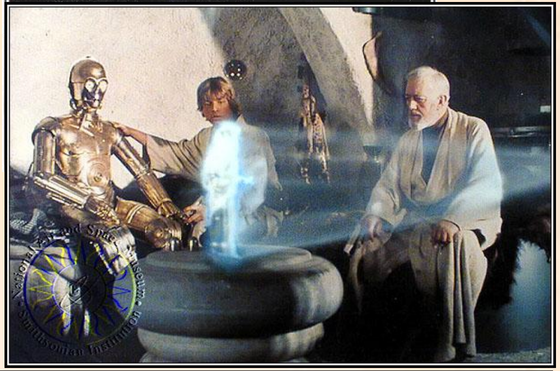
1830 — 1850 — 1900 — 1950 — 2000

- Stereoscope: Wheatstone (1838)
- Lenticular stereoscope (prism): Brewster (1844)
- Autostereoscopic: Maxwell (1868)
- Stereoscopic movie camera: Edison & Dickson (1891)
- Anaglyph: Du Hauron (1891)
- 3D movie: La'arrivee du train (1903)
- Integral photography: Lippmann (1908)
- Lenticular: Hess (1915)
- Parallax barrier: Kanolt (1915)
- Hologram: Gabor (1948)
- Integram: de Montebello (1970)
- Electro-holography: Benton (1989)



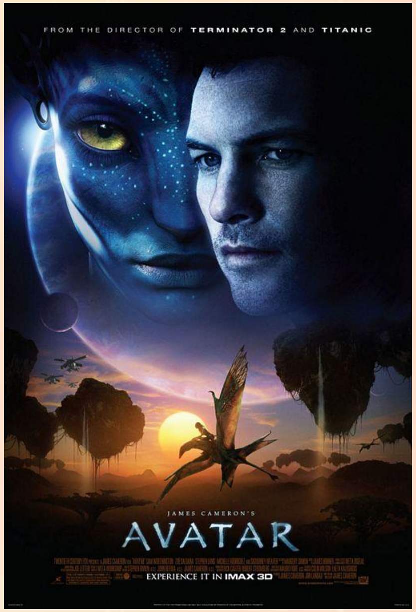
3D movies



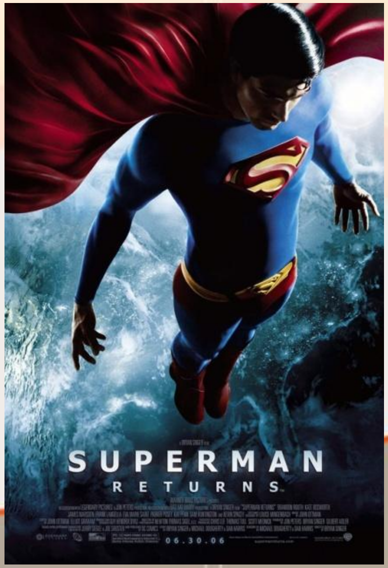


Starwars (1977)

Minority Report (2002)



Avatar (2009)



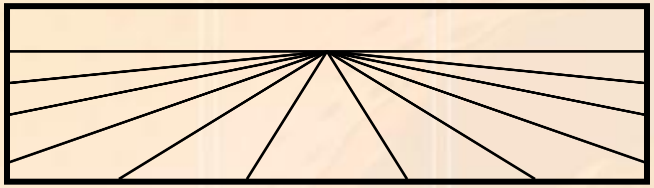
Superman returns (2006)

Cues for depth perception of human (I)

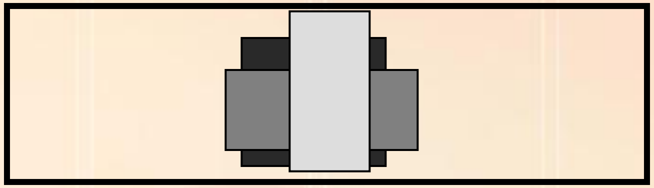
- Physiological cues
  - Accommodation
  - Convergence
  - Binocular parallax
  - Motion parallax

- Psychological cues
  - Linear perspective
  - Overlapping (occlusion)
  - Shading and shadow
  - Texture gradient

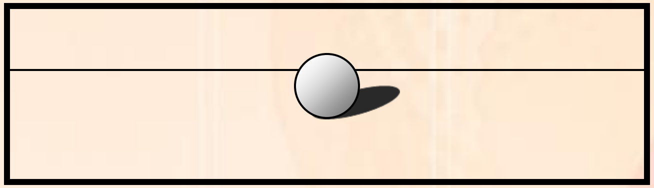
- **Linear perspective**



- **Overlapping**



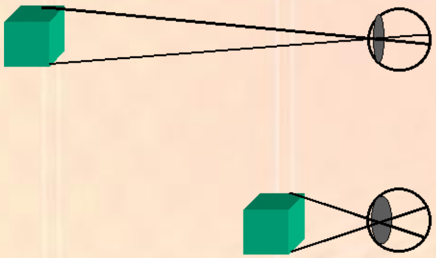
- **Shading and shadow**



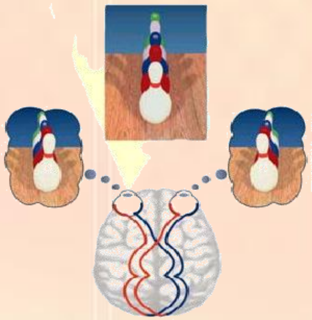
- **Texture gradient**

Cues for depth perception of human (II)

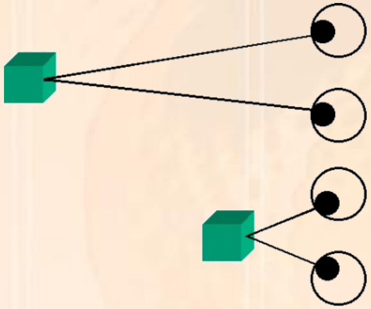
- Physiological cues
  - Accommodation



  - Binocular disparity



  - Convergence



  - Motion parallax

Various methods to display a 3D image

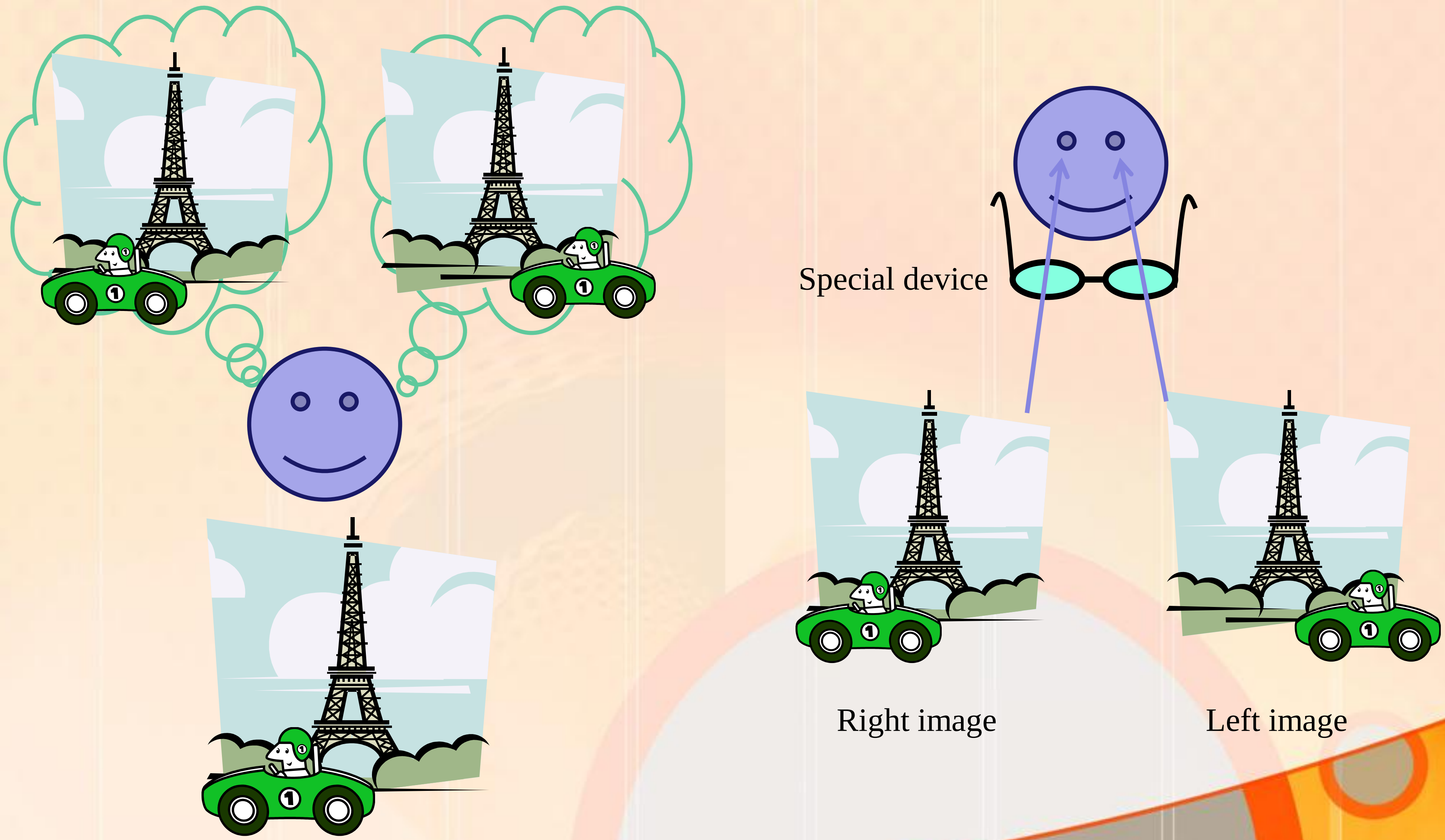
Classification		Depth cues	Key component
Stereoscopy (requires glasses)		Binocular disparity	Polarizing glasses
			LC shutter glasses
			Wavelength selective glasses
Autostereoscopy (does not require glasses)	Two-view or Multi-view display	Binocular disparity, Convergence, Motion parallax (Horizontal only, limited range, discrete)	Parallax barrier
			Lenticular lens
			HOE (Holographic Optical Element)
			Directional BLU
	Super multi-view	Binocular disparity, Convergence, Motion parallax (H only, continuous), Accommodation	Lenticular lens
	High density directional display		Multiple projection
			Laser scanning
	Integral imaging	Binocular disparity, Convergence, Motion parallax (H&V, continuous), Accommodation	Lens array (2D)
	Volumetric display	Binocular disparity, Convergence, Motion parallax, Accommodation	Stacked screens
			Spinning screen/mirror
			Crossed-beam (Two-photon absorption)
	Holographic display	Binocular disparity, Convergence, Motion parallax, Accommodation	Electro-holography (Coherent optics)

Present status of 3D display

Hardware system

- Stereoscopic display
- Autostereoscopic display
- Volumetric display
- Other recent techniques

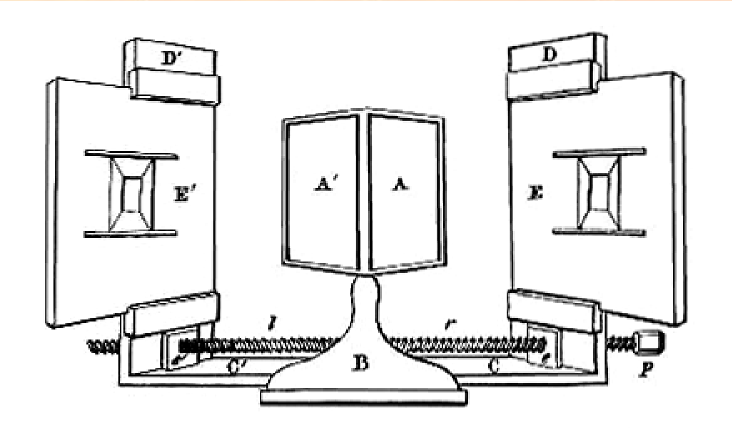
Stereoscopic display



Binocular disparity

Stereoscopic display

Wheatstone



The Wheatstone stereoscope used angled mirrors (A) to reflect the stereoscopic drawings (E) toward the viewer's eyes.

* *Note on a Real-Image Stereoscope.* In ordinary stereoscopes the *virtual* images of two pictures are superposed, and the observer, looking through two lenses, or prisms, or at two mirrors, sees the figure apparently behind the optical apparatus. In a stereoscope which I have had made by Elliott Brothers, the observer looks at a real image of the pictures, which appears in front of the instrument, and he is not conscious of using any optical apparatus.

This stereoscope consists of a frame to support the double picture, which may be a common stereoscopic slide inverted. One foot from this a frame is placed, containing side by side two convex lenses of half a foot focal length, and having their centres distant one and a quarter inches horizontally. One foot beyond these is placed a convex lens of two-thirds of a foot focal length and three inches diameter.

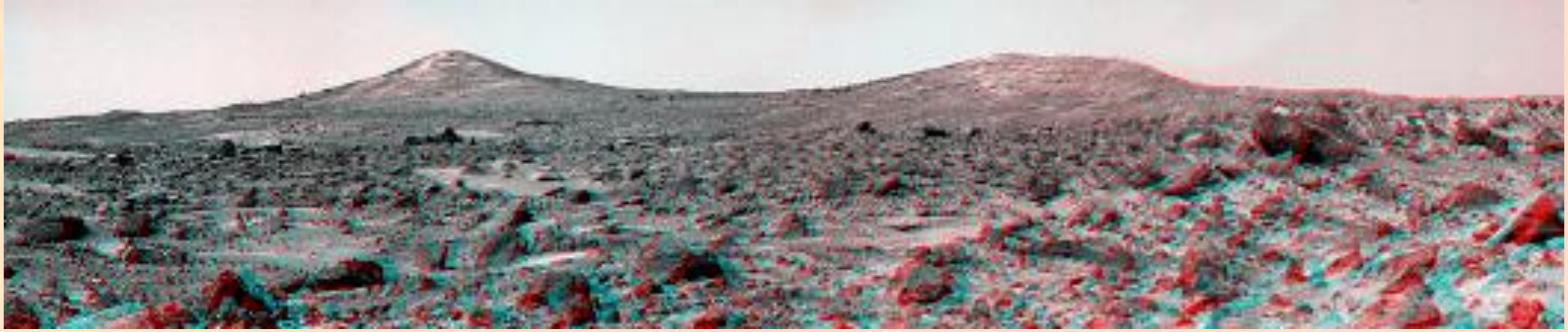
The observer stands about two feet from the large lens, so that with the right eye he sees an image of the left-hand picture, and with the left eye an image of the right-hand picture.

These images are formed by pencils which pass centrically through the two small lenses respectively, so that they are free from distortion, and they appear to be nearly at the same distance as the large lens, so that the observer fixing his eyes on the frame of the large lens sees the combined figures at once.

The figures of the cyclide, though constructed for this stereoscope, may be used with an ordinary stereoscope, or they may be united by squinting, which is a very effective method.

Maxwell's note

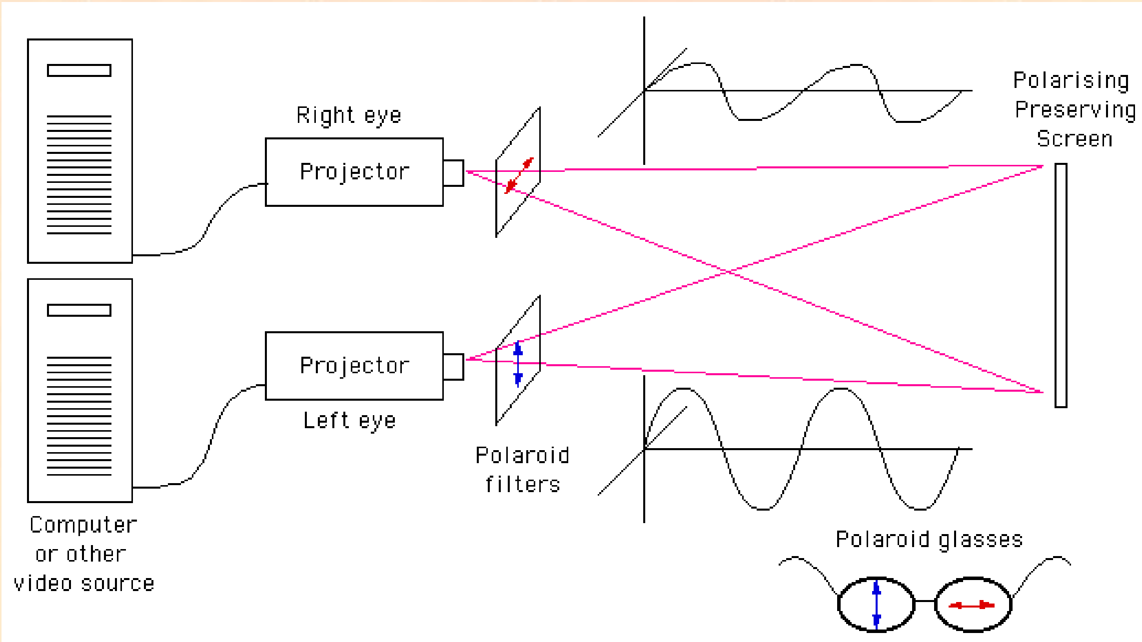
Anaglyph

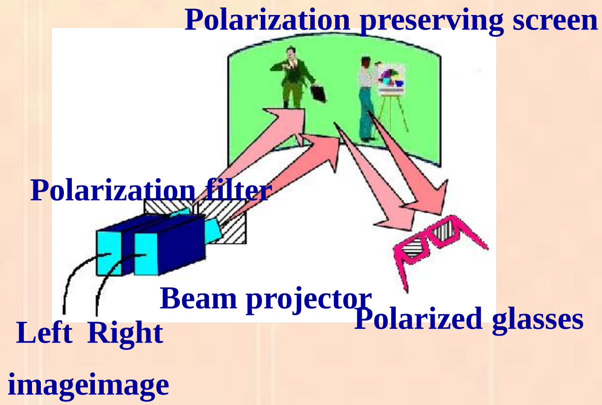


Landscape of Mars

Anaglyph glasses

Polarization multiplexed method

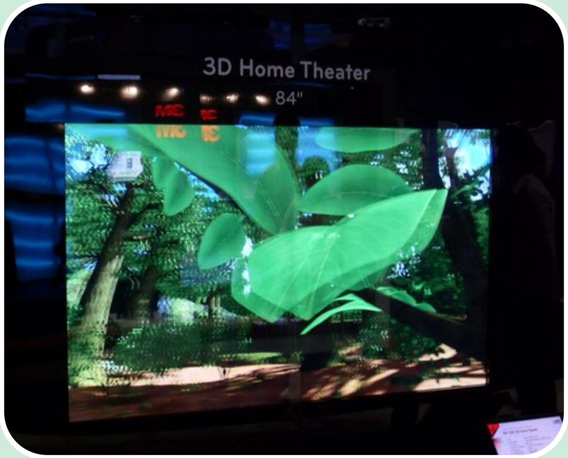




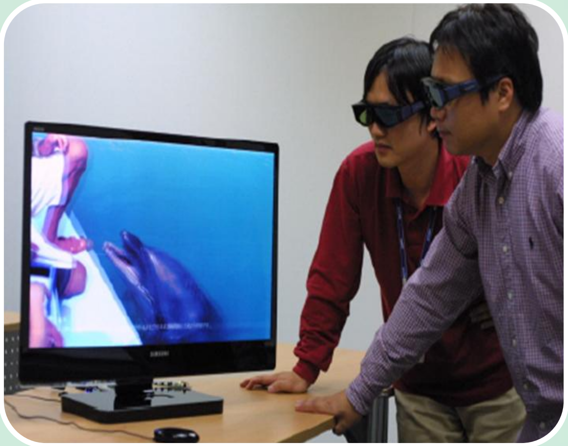
Polarization modulation

→ Luminance decreased

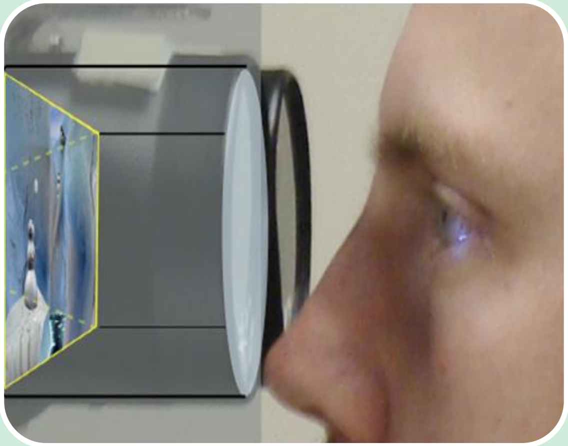
Stereoscopy



Polarization glasses



Shutter glasses

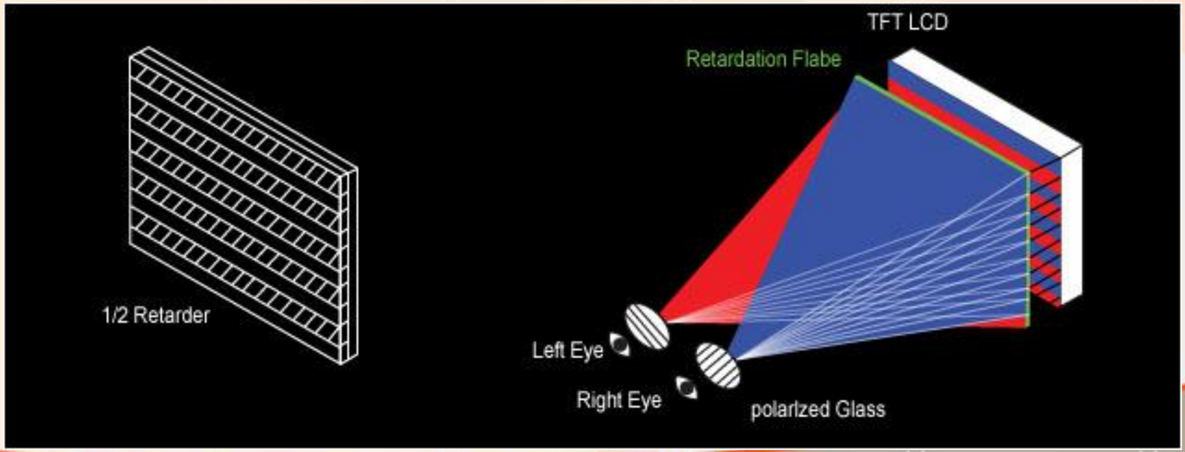


HMD

Uncomfortable, but easy to commercialize

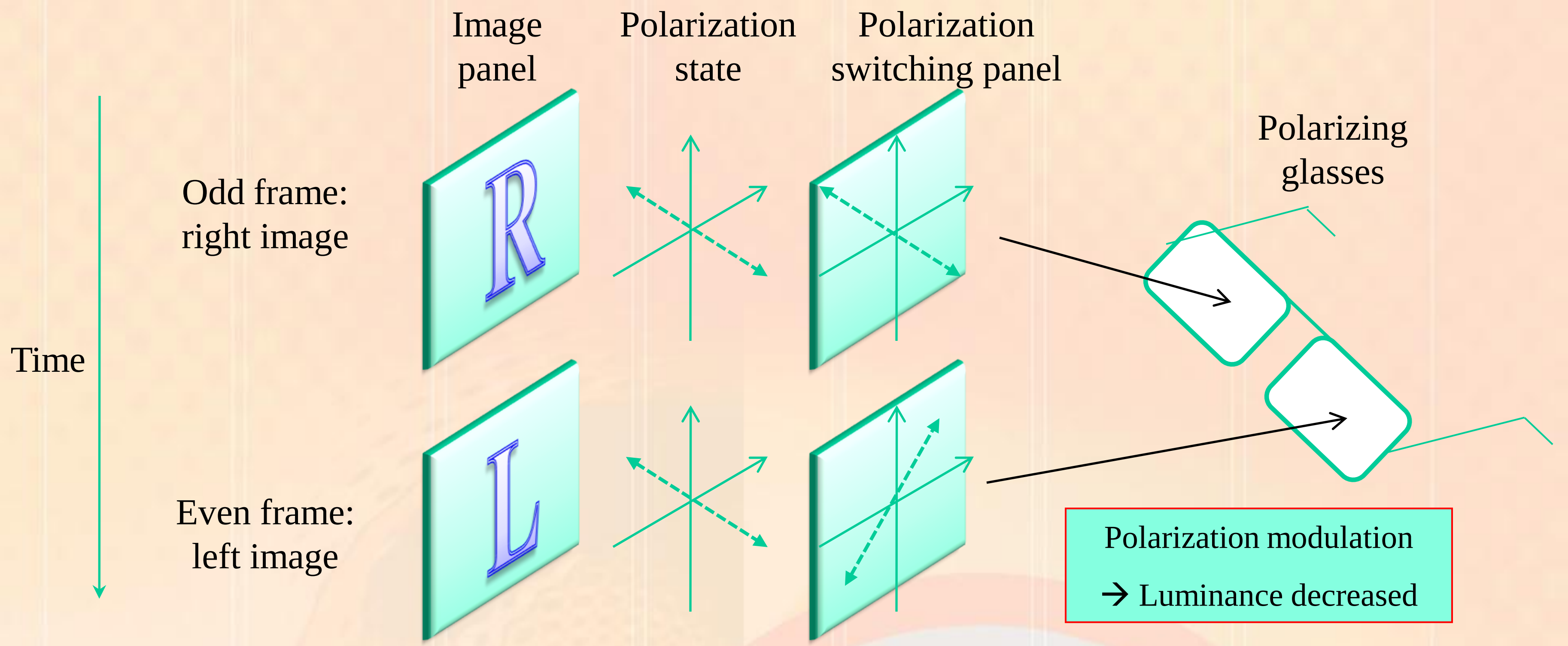
Pavonine (polarization glasses)

Items	2D mode	3D mode
Size [inch]	32	
Resolution	1366 x 768	1366 x 384
Display colors	16.7 M	
2D/3D switching	Possible	
Viewing angle	45 degrees	
Dimension	697 x 393 x 91 mm	
Input signal	VGA, DVI	



http://miracube.net/

Polarization glasses type – active retarder



Polarization modulation
→ Luminance decreased

Display panel

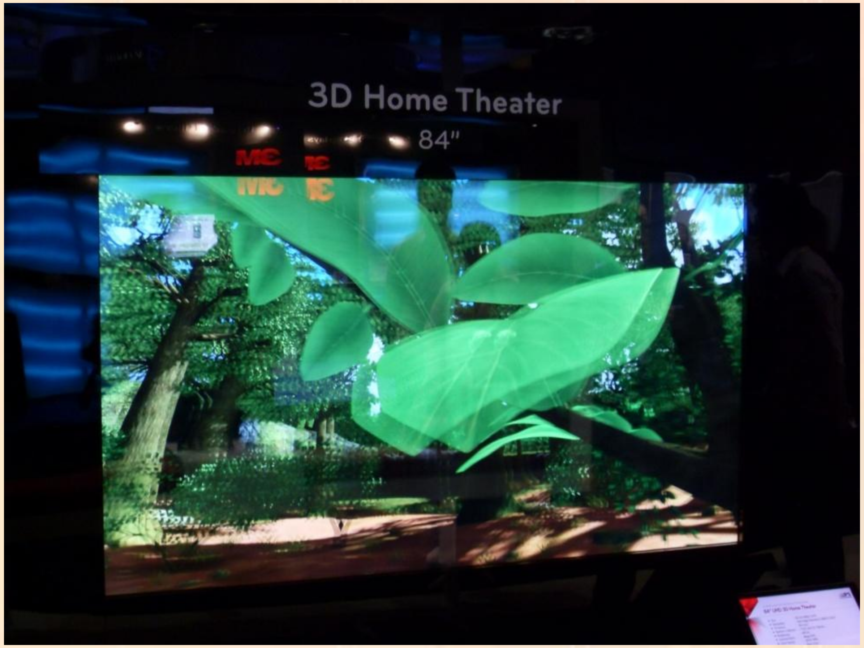
Simple polarizer glasses

Active controlled retarder : Two glasses + one LC layer (TN mode)

LG Display

Jung, S.-M., Park, J.-U., Lee, S.-C., Kim, W.-S., Yang, M.-S., Kang, I.-B., and Chung, I.-J., "A novel polarizer glasses-type 3D display with an active retarder," SID Int. Symp. Digest Tech. Papers 40, 348-351 (2009).

LG Display (3D home theater: polarization glasses)



The world's largest ultra high definition
3D home theater

Items	Feature
Model	84 inch UHD 3D home theater
Size	84 inch Wide [16:9]
Resolution	Ultra high definition [3840 × 2160]
Thickness	28.4 mm
Brightness	600 nit
Contrast ratio	Mega DCR
Color gamut	sRGB 100%
Color depth	Real 10 bit

SID 2010

LG Display (47 inch first mover 3D: polarization glasses)

Items	Feature	
2D	Dimension	1096 × 640 mm
	Pixel pitch	0.5415 × 0.5415 mm
	Resolution	1920 × 1080
	Luminance	400 cd/m^2
3D	3D crosstalk	<1.0%
	Luminance	150 cd/m^2
	Viewing angle	178°(H)/30°(V)

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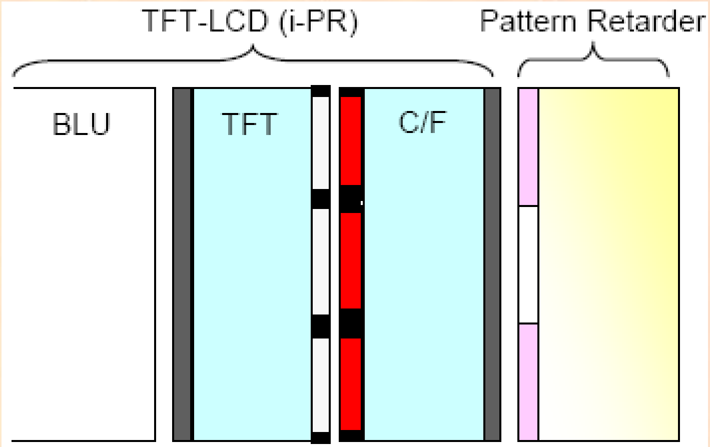
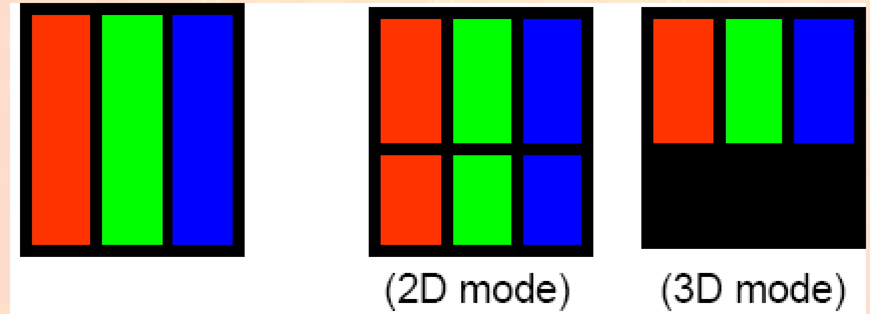
Polarization glasses type (i-PR method)



i-PR configurations with the shape of special pixel in a TFT-LCD



Pixel configurations of conventional and i-PR (in cell patterned retarder)

24 inch WUXGA patterned retarder 3D LCD

2D/3D characteristics			PR	i-PR	Remark
2D	Display mode		IPS	IPS	
	Resolution		1920 × 1200	1920 × 1200	WUXGA
	Luminance (cd/m²)		280	342	
	Contrast ratio (a.u.)		1000:1	1000:1	
	Color gamut (%)		102	102	
3D	3D crosstalk (%)		0.5	0.5	Front
	Viewing angle	Horizontal	160	160	Within 7% of 3D crosstalk
		Vertical	16	32	

SID 2010

Shutter glass method

Shutter glasses type (Samsung Electronics)

55 inches of 240 Hz Full HD 3D LCD

Response time
: 2x faster (liquid crystal)
: 4x faster (signal processing speed)

One frame time for one view is around 3ms
(in order to reduce crosstalk)
Eliminates ghosting in fast moving scenes
with 240 Hz refresh rate.

SID 2009

Comparison

Shutter glasses 3D

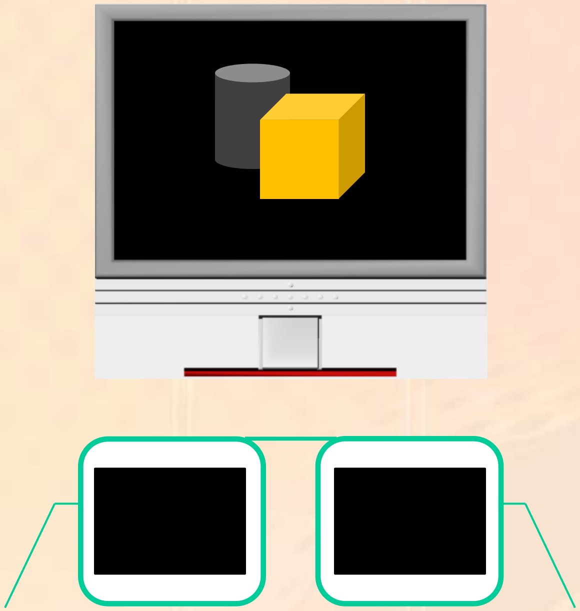


Image through shutter glasses

Active retarder 3D

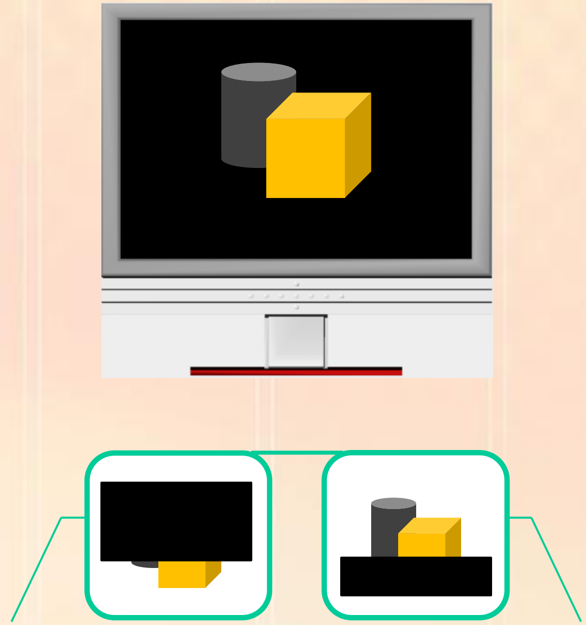


Image through polarizer glasses

The light efficiency for active retarder type can be higher than the shutter glasses 3D display.

Shutter glass type is simple without modification of LCD structure.

Comparison (Polarization vs. shutter glasses)

- Main issues: 3D resolution & crosstalk
  - Polarization glasses: 3D resolution
  - LC shutter glasses: driving speed of LCD and crosstalk (optimized on/off timing generation)

Classification	3D resolution	Crosstalk	Etc.
Polarization glasses	Half of 2D resolution	Low (good extinction ratio of polarizing glasses)	Low light efficiency
LC shutter glasses	Full resolution same as the 2D resolution	High (sequential line-by-line driving architecture of LCDs)	High cost of LC shutter glasses

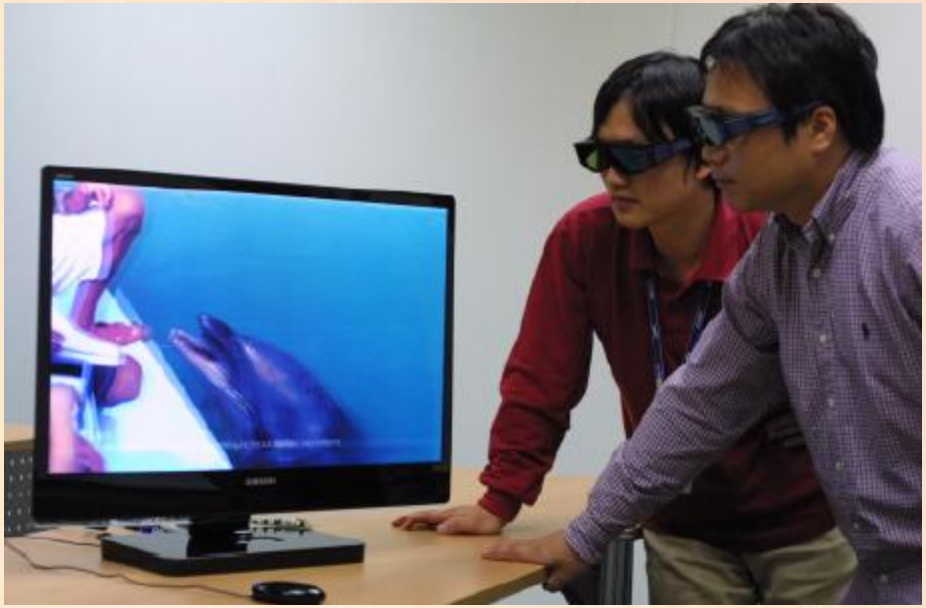
Solution: fast polarization switching (120 Hz) by LG Display

Solution: fast LC switching (240 Hz) by Samsung

- Candidate solution: Fast response time of each optic elements (polarization, LC shutter)

Samsung Electronics (shutter glass)

Novel simultaneous emission driving scheme for crosstalk-free 3D AMOLED TV



- 30 inch Full HD 3D-TV with simultaneous emission with active voltage control driving
- All of the panel's OLEDs are turned on simultaneously, which allows longer time for the active shutter glasses to switch.
- The left and right images are completely separated.
- The proposed method enables a much simpler circuit (6 transistors → 3 transistors)

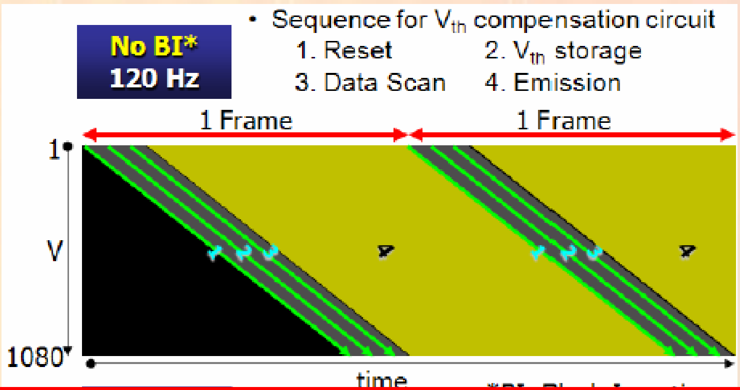
SID 2010

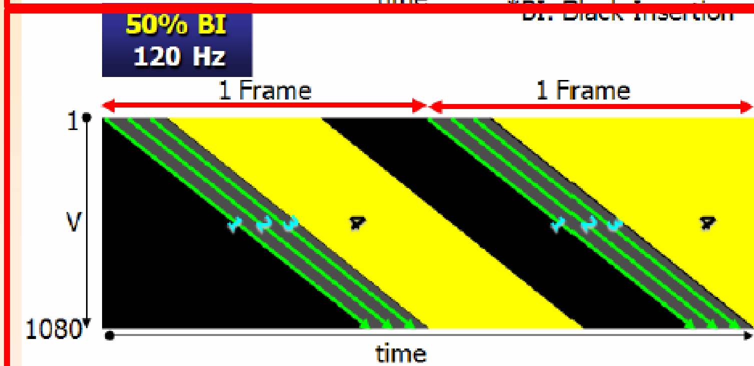
Shutter glasses type (Samsung Electronics)

Novel simultaneous emission driving scheme for crosstalk-free 3D AMOLED TV

For crosstalk-free 3D, the left image and the right image should be presented in such a way that there is no temporal overlap between them.

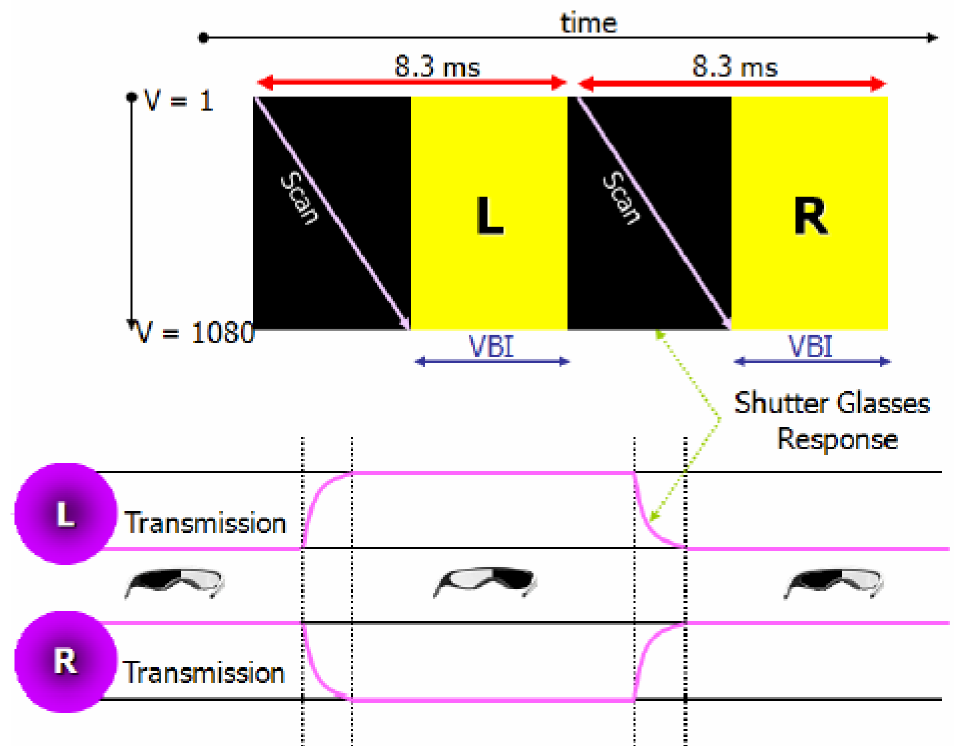
Conventional driving method (No black insertion)





Conventional driving method (50% black insertion)

Proposed simultaneous emission (SE) method



LG 3DTV (shutter glass)

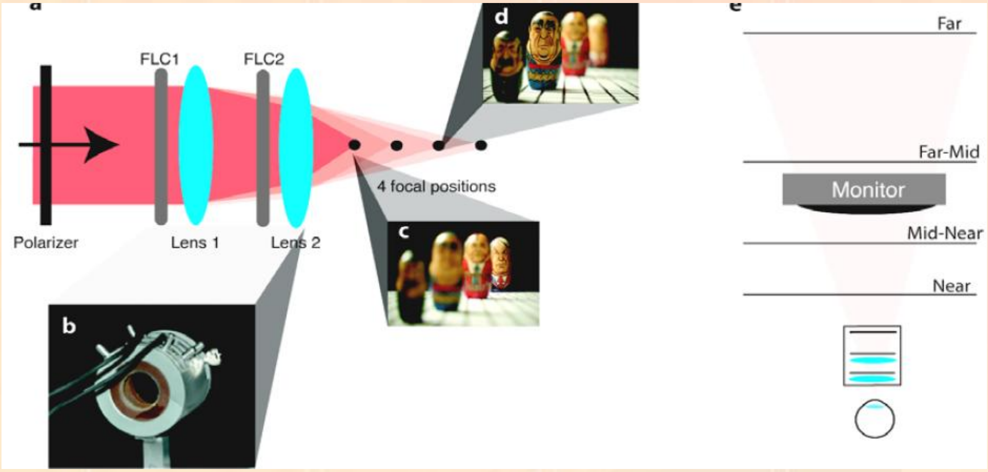
- Full array of LEDs (LEX8)
- Infinite contrast ratio
- 0.88 cm thin, 1.25 cm Bezel
- Nano lighting technology
- Anti-reflection panel
- Truemotion 400 Hz
- Shutter glass type
- 47/55 inch (288 blocks: local dimming)

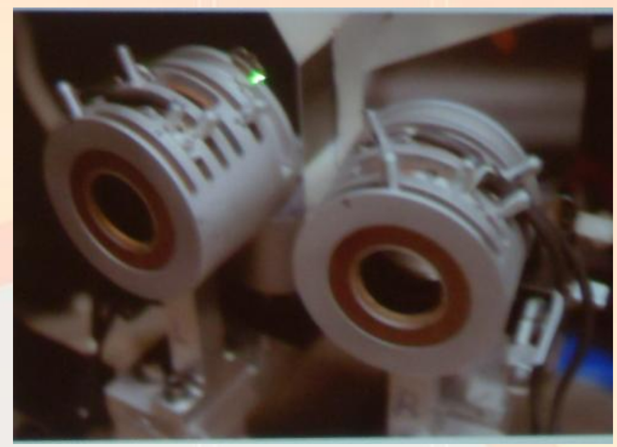
- 31 inch OLED TV
- Full HD 1920 x 1080
- 0.29 cm thin
- 3D ready
- 600 Hz refresh rate

IFA 2010

High-speed switchable lens (UC Berkeley)

3D display system based on high-speed switchable lens





- 4 focal powers separated by 0.6 diopters (5.09, 5.69, 6.29, 6.89 diopters)
- Monitor & lens refresh of 180 Hz, so 45 Hz per eye per lens state
- Field of view: 15°

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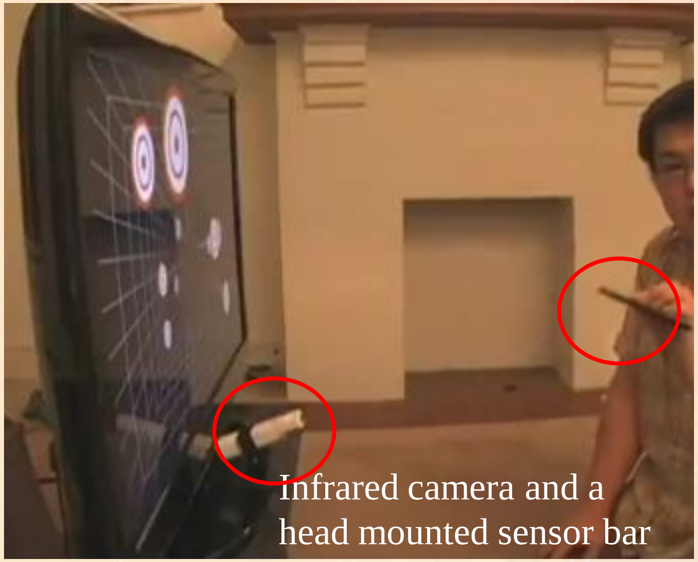
Head tracking for desktop VR display using Wii Remote controller



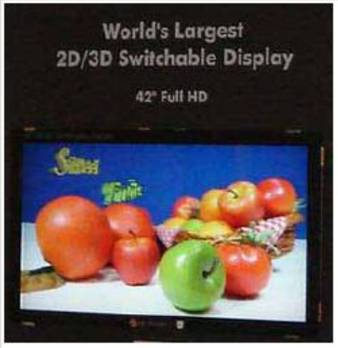
Present status of 3D display

Hardware system

Stereoscopic display
Autostereoscopic display
Volumetric display
Other recent techniques

Autostreoscopic methods

Parallax Barrier



- Advantages
  - Multi-view
  - Easy to fabricate
- Disadvantages
  - Very low 3D luminance

Lenticular

- Advantages
  - High 3D luminance
  - Multi-view
- Disadvantages
  - Special 3D/2D conversion technique
  - Harder to fabricate (high cost)
  - Color dispersion

Integral imaging

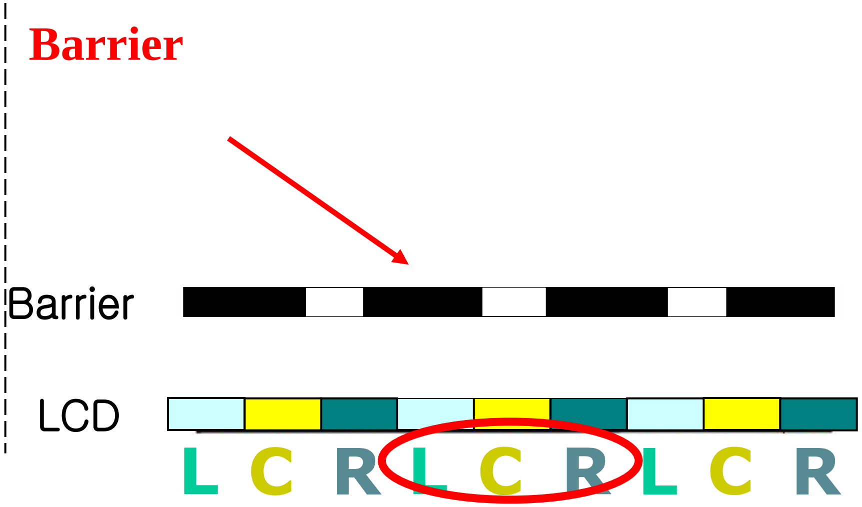
- Advantages
  - Full parallax (both horizontal and vertical)
  - Quasi-continuous view point
- Disadvantages
  - Low resolution
  - Limited viewing angle
  - Limited image depth

Parallax barrier: principle

- *Two view*

Resolution & brightness → 50%

- *Multi view*



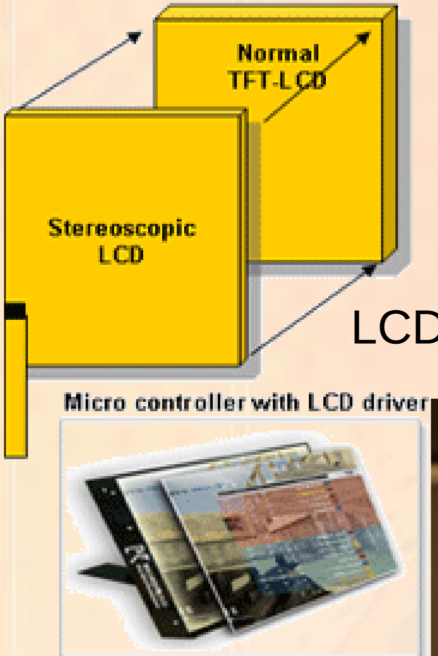
Resolution & brightness → 33%

Parallax barrier

- *Advantages*
  - *2D/3D convertible*
  - *Easy to fabricate (low cost)*

- *Disadvantages*
  - *Low 3D luminance*
  - *Moire pattern*
  - *Color dispersion*

Translucent LC panel for parallax barrier: Samsung 2D/3D switchable mobile phone



LCDs for 3D

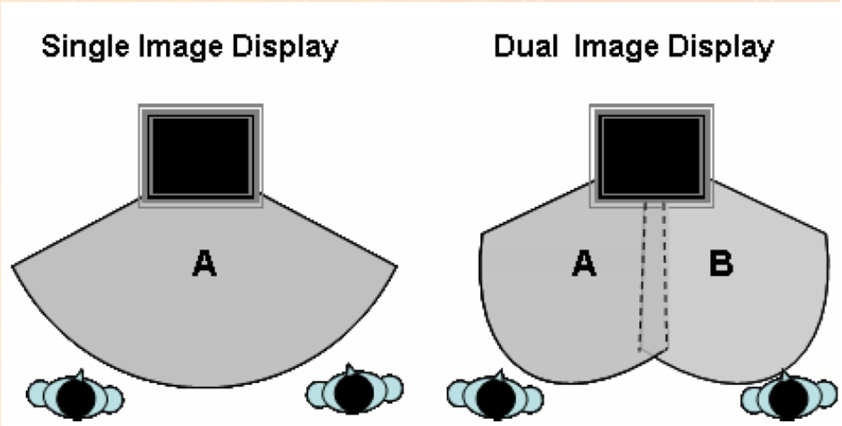
• Samsung dual DMB (2007. 7. 11)

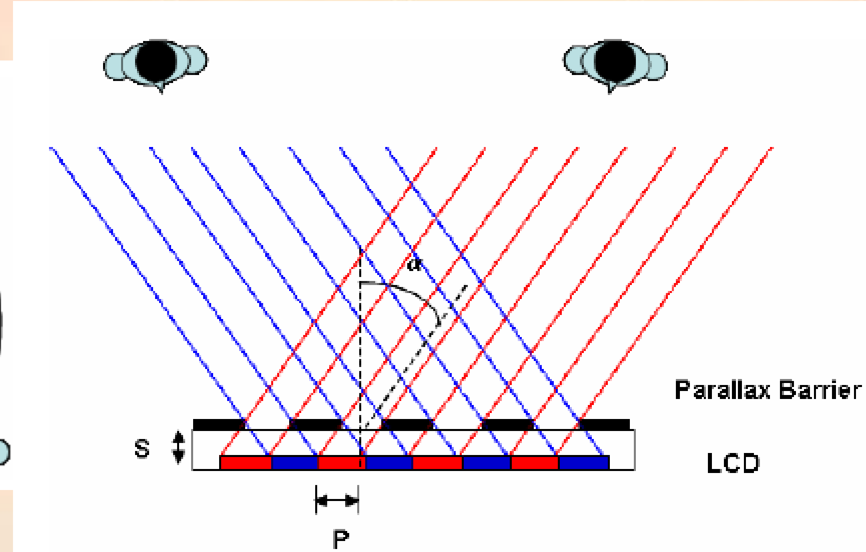
- **Samsung SCH-B710.**
- **The Samsung SCH-B710 is a swivel phone that features mobile TV (DMB) and a 3D QVGA LCD screen.**
- **It also comes with MP3 player, video camera, normal camera, and even Picture In Picture feature, so you can watch TV while watching another channel in an even smaller window on the same screen.**

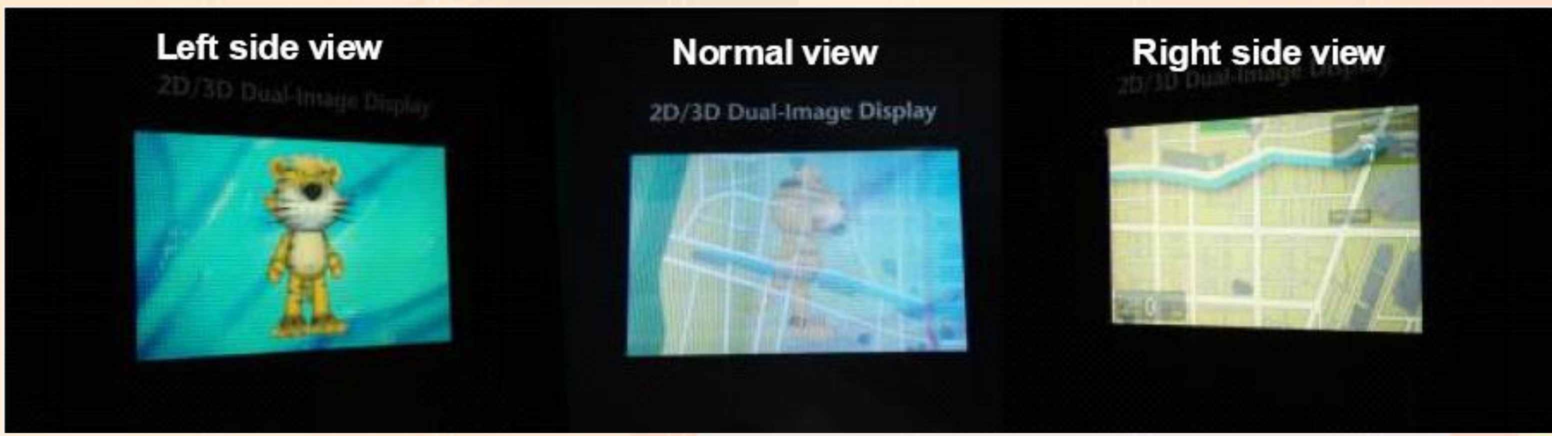
2D resolution: 320 × 240
3D resolution: 160 × 240
Size: 2.2 inch diagonal
Dual camera

Translucent LC panel for parallax barrier: Samsung 2D/3D switchable mobile phone

AUO: 2D/3D dual image switchable display





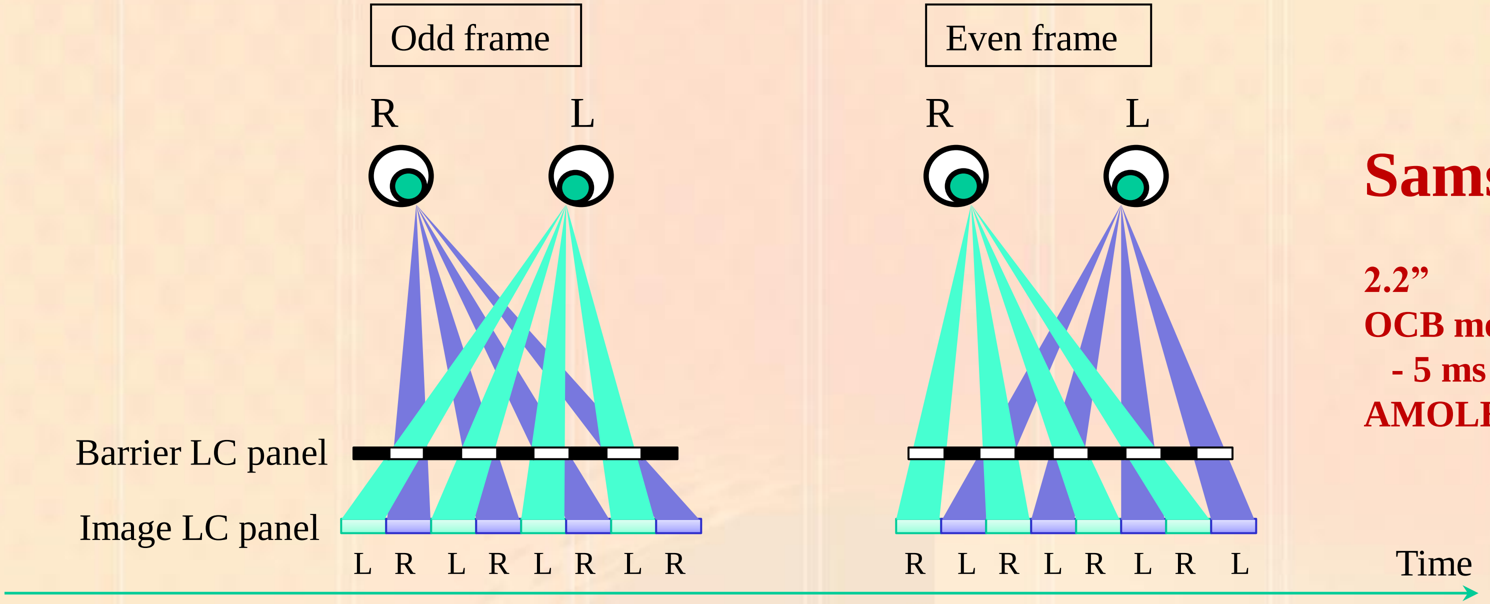


2D/3D dual-image switchable display (AU Optronics Co. Taiwan, SID 2008)

Active parallax barrier method for 2D/3D convertible display

- Basic method: translucent LC panel
  - Cost-effective
  - Easy to implement
  - The addressing does not need to be pixel-wise but only needs to be stripe-wise. Therefore switching time does not need to be fast.
  - 3D resolution is half of the 2D resolution.
- Stripe-wise method: Time-multiplexing active parallax barrier method (for higher 3D resolution)
- Pixel-wise method
  - For local 3D mode
  - Dynamic adjustment control of 3D images for single user application (Seiko Epson)

Time-multiplexing active parallax barrier method



Samsung SDI

2.2”
OCB mode LC barrier
- 5 ms response time
AMOLED

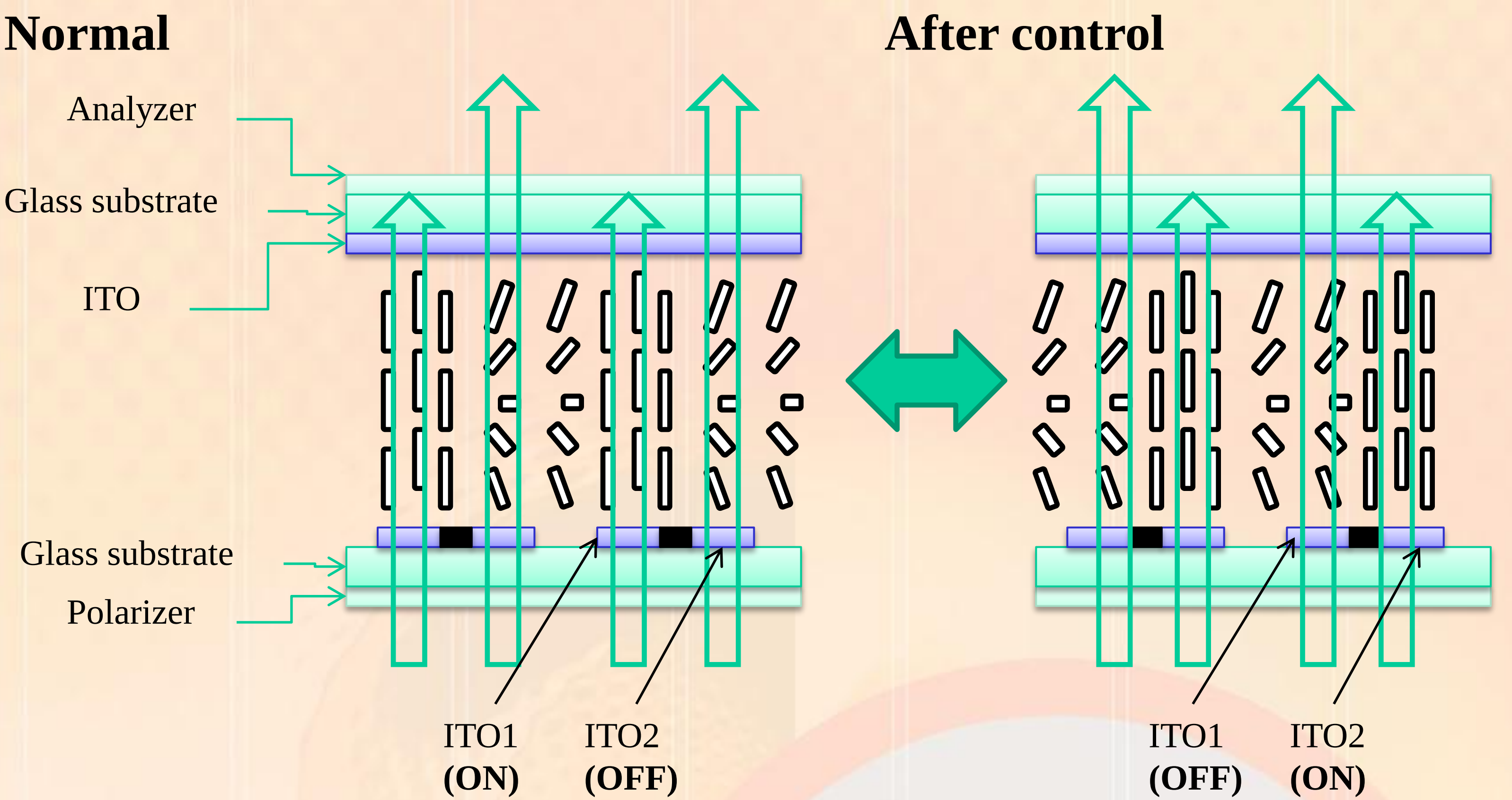
Fabricated 3D display system

Time-multiplexing parallax barrier

Conventional parallax barrier

Lee, H. J., Nam, H., Lee, J. D., Jang, H. W., Song, M. S., Kim, B. S., Gu, J. S., Park, C. Y., and Choi, K. H., “A high resolution autostereoscopic display employing a time division parallax barrier,” SID Int. Symp. Digest Tech. Papers 37, 81-84 (2006).

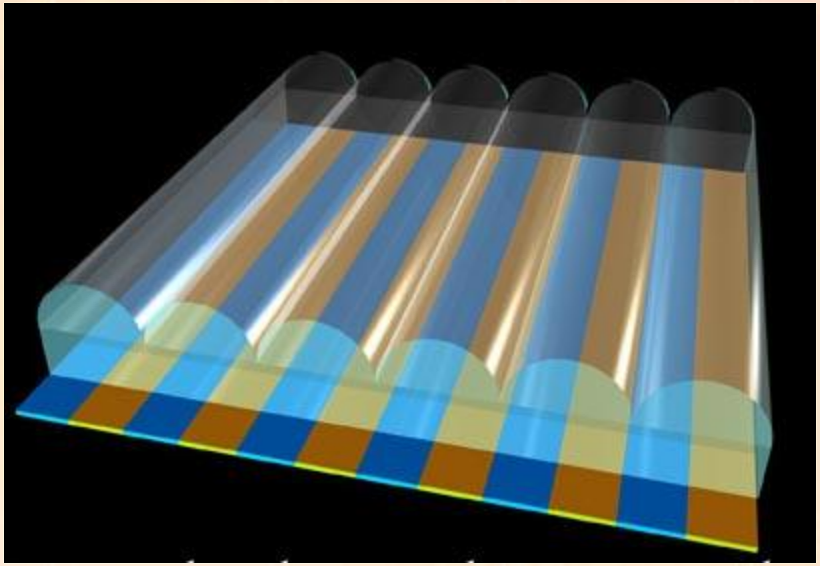
Movable active parallax barrier (Seiko Japan)



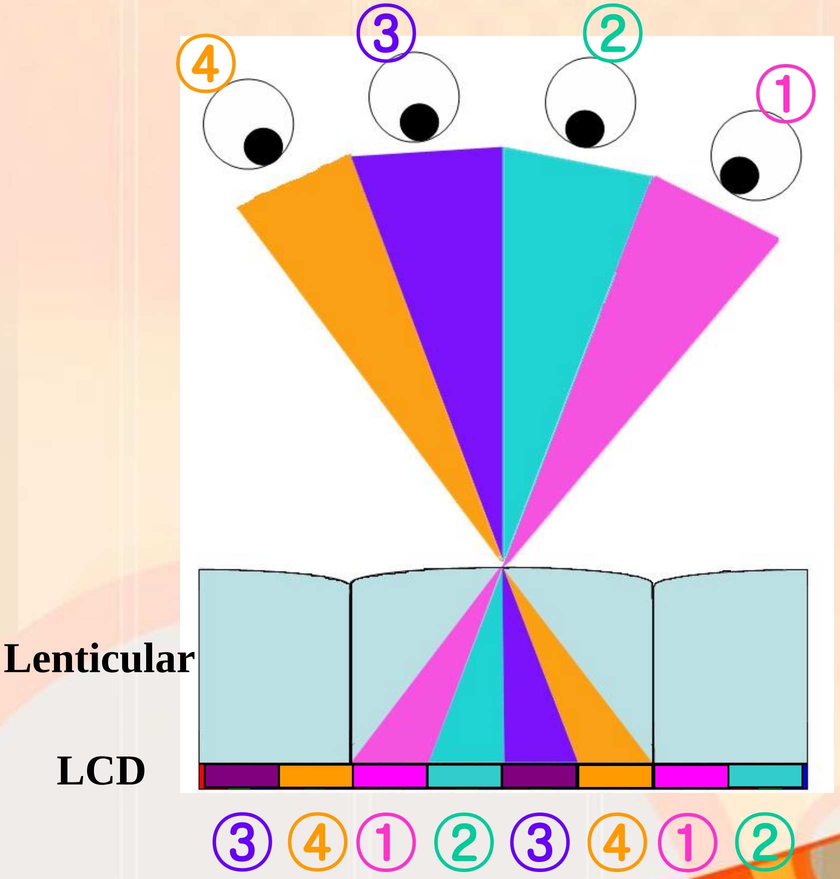
Hamagishi, G., “Analysis and improvement of viewing conditions for two-view and multi-view 3D displays,” SID Int. Symp. Digest Tech. Papers 40, 340-343 (2009).

Lenticular: principle

- **Lenticular lens**



- **Multi-view lenticular**



Lenticular

- *Advantages*
  - *High 3D luminance*
  - *Multi-view*

- *Disadvantages*
  - *Special 3D/2D conversion technique*
  - *Harder to fabricate (high cost)*
  - *Color dispersion*

Active lenticular lens method for 2D/3D convertible display

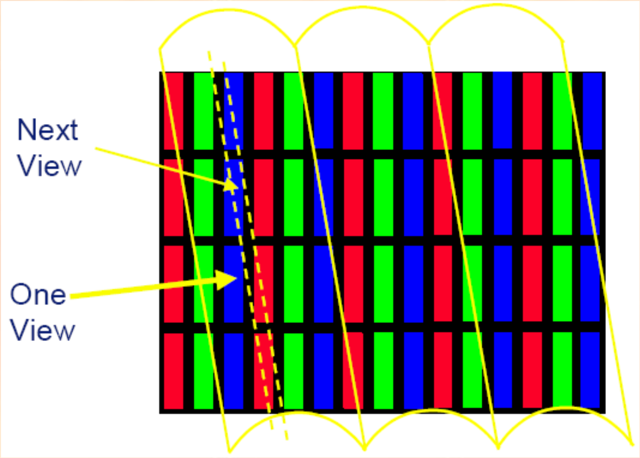
- Better optical efficiency than parallax barrier
- Hard to implement than parallax barrier
- Relatively large thickness which makes it less desirable for the mobile applications

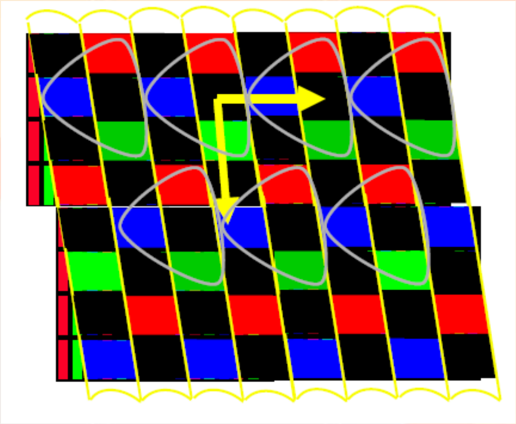
- Three representative methods for achieving LC active lenticular lens method
  - Surface relief method: Complex fabrication, mismatch at the boundary
  - Polarization activated lens method: Complex fabrication
  - Patterned electrode method: High operating voltage, high crosstalk

Philips

Surface relief method

- *Slanted lenticular*
  - *VGA, 9 view 3D display*
    (Recently SVGA)
  - *Increased number of views (slanted lenticular)*
  - *Increasing the number of view (vertical resolution -> horizontal resolution)*
  - *Reducing the black matrix pattern in 3D*
  - *2D/3D compatible display*

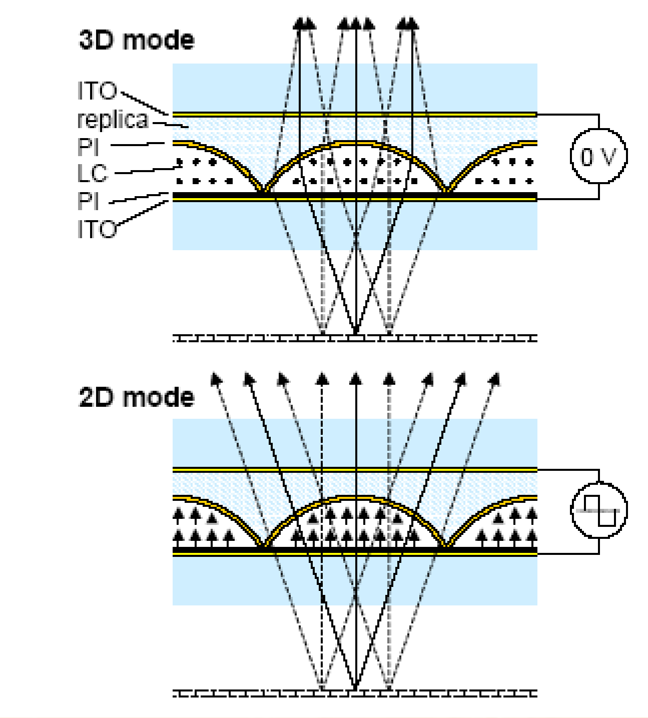




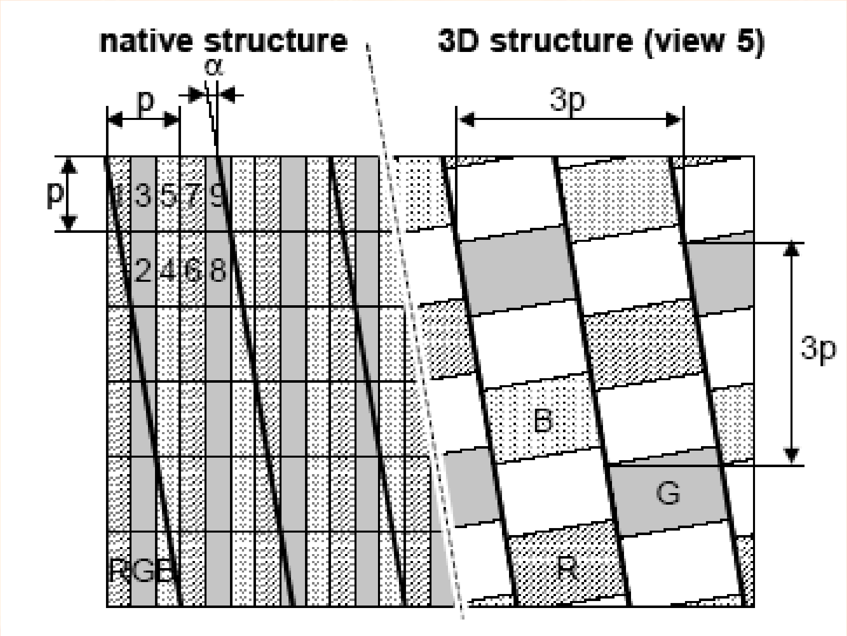
LC active lens - Philips

Surface relief method

- Operation principle



- Pixel & lenticular lens layout

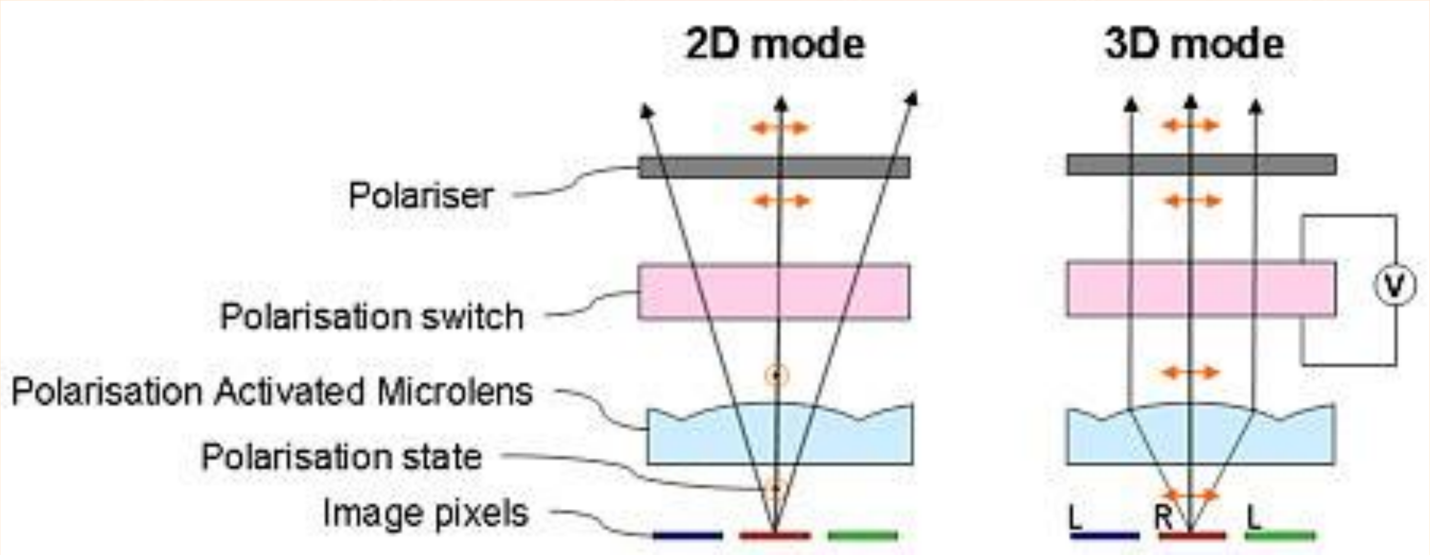


S. T. deZwart, W. L. IJzerman, T. Dekker, and W. A. M. Wolter, "A 20-in. switchable auto-stereoscopic 2D/3D display," Proc. IDW '04, pp. 1459-1460, Niigata, Japan, Dec. 8-10, 2004.

Solid phase LC lens – Ocuity (polarization active lens)

Polarization activated lens method

- Operation principle



J. Harrold, D. J. Wilkes, and G. J. Woodgate, "Switchable 2D/3D display - solid phase liquid crystal microlens array," Proc. IDW '04, pp. 1495-1496, Niigata, Japan, Dec. 8-10, 2004.

2D/3D switchable PDA - Ocuity

Polarization activated lens method

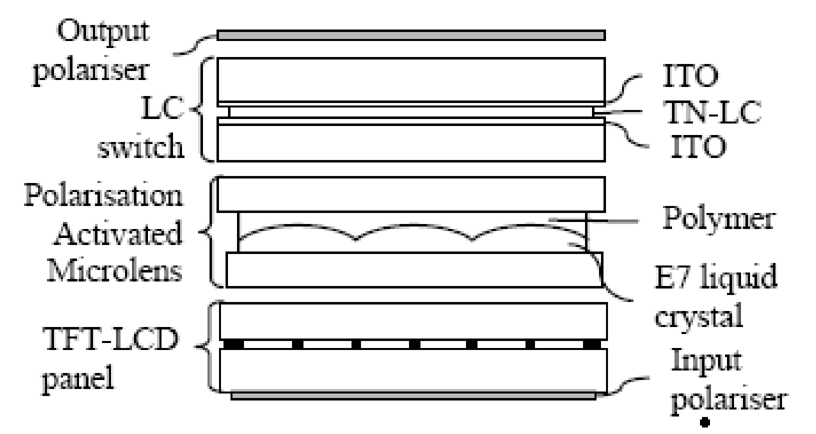


Fig.1 4-substrate Polarisation Activated Microlens reconfigurable 2D/3D display

Switchable 2D/3D PDA

PDA base platform

3.8" Transmissive TFT-LCD

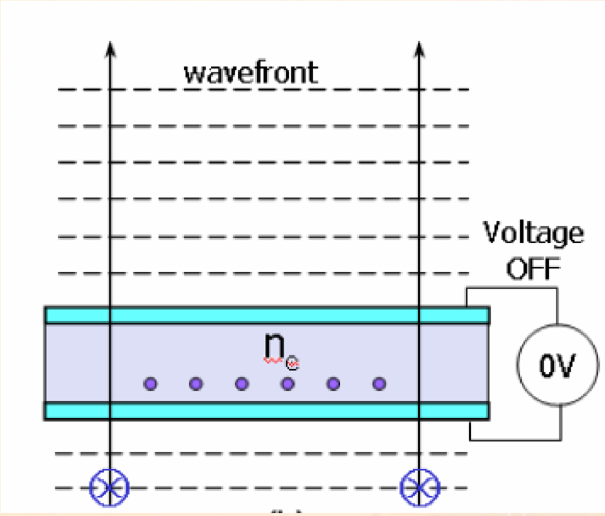
320x**RGB**x240 pixel display

Full brightness in 2D and 3D

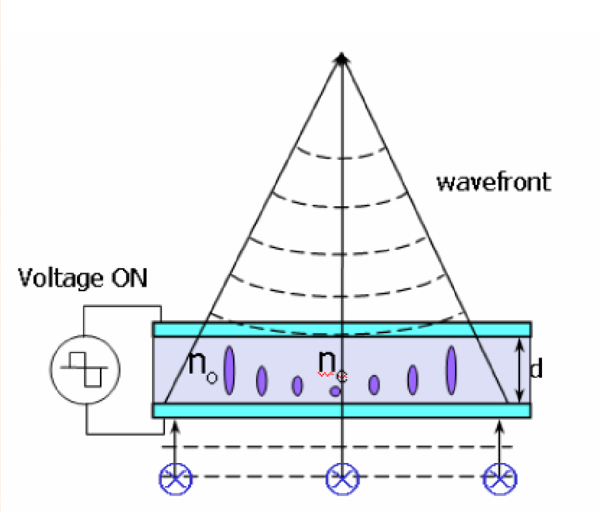
Autostereoscopic 2D/3D switching display using electric-filed-driven LC lens (ELC lens)

Patterned electrode method

LG Display



2D mode



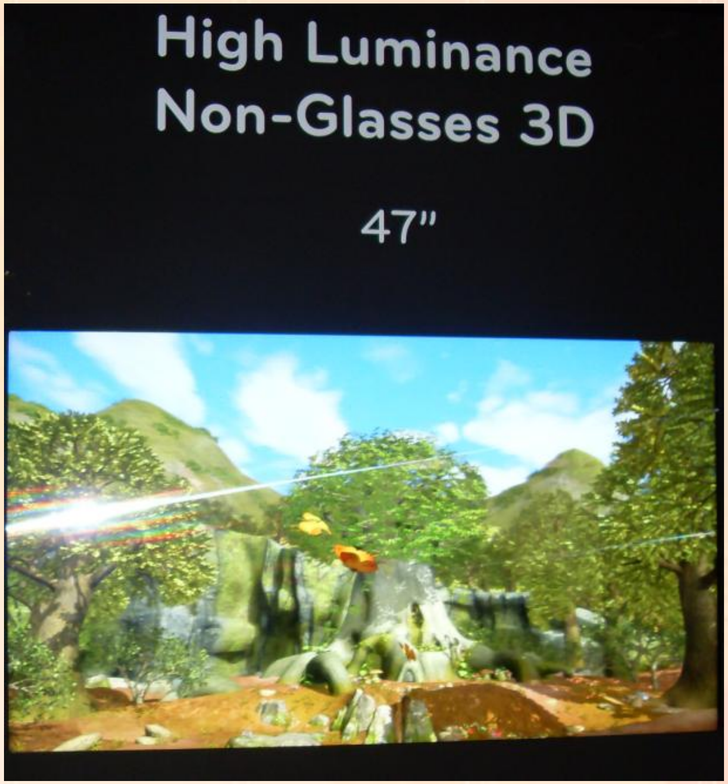
3D mode

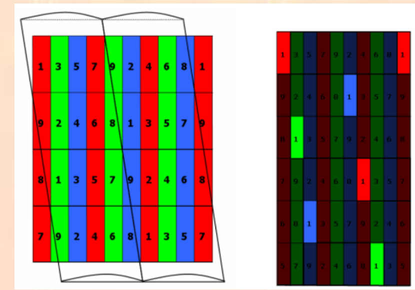
Applied voltage : 7 V below

The electric field at the part of lens edge is much stronger than electric field at center of lens. This non-uniform distribution of electric field causes non-uniform distribution of tilt angle of LC director and the refractive index distribution changes accordingly.

Autostereoscopic 2D/3D switching display using electric-filed-driven LC lens (ELC lens)

Patterned electrode method





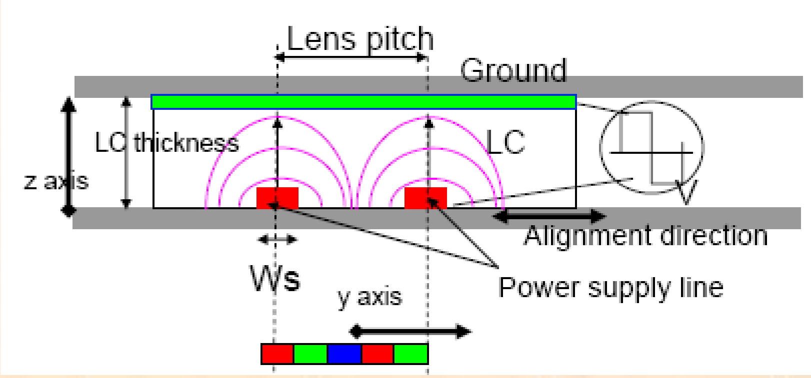
Items	Features
Type	*ELC lens, 2D/3D switching*
Display size	*47 inch*
Resolution (2D)	*1920 x 1080*
Resolution (3D)	*426 x 540*
Brightness	*550 nit*
Viewing distance	*2~3 m*

SID 2010

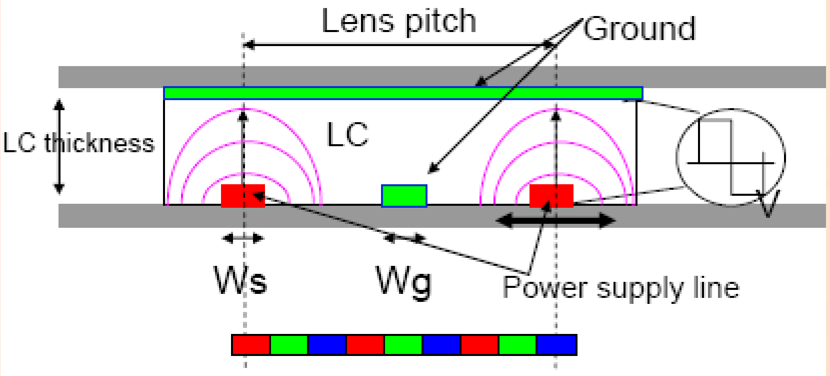
LC gradient index lens (Toshiba)

Autostereoscopic partial 2D/3D switchable display using liquid crystal gradient index lens

Conventional lens



Proposed lens



Lens pitch is larger, horizontal electrical field become insufficient. (Operating power issue in 2D/3D switchable display because most devices are used in portable devices)

Optimization parameter

- Signal width
- Ground width
- Lens aspect ratio
- Material of LC
- Voltage level

1. Three electrodes configuration → Wide viewing angle
2. Driving by two voltage levels → Single layer of ITO electrodes (Low cost, high transparency)

LC gradient index lens (Toshiba)

245 mm

184 mm

Prototype of 2D/3D switchable display

Display size [inch]	12
3D resolution	466 × 350
2D resolution	1400 × 1050
Number of parallax	9
Viewing distance [mm]	500
Viewing angle [degree]	24.5
Lens driving voltage [V]	4.5
Size of lens	500 um
Focal length of lens	1.5 mm

SID 2010

Requirements for LC

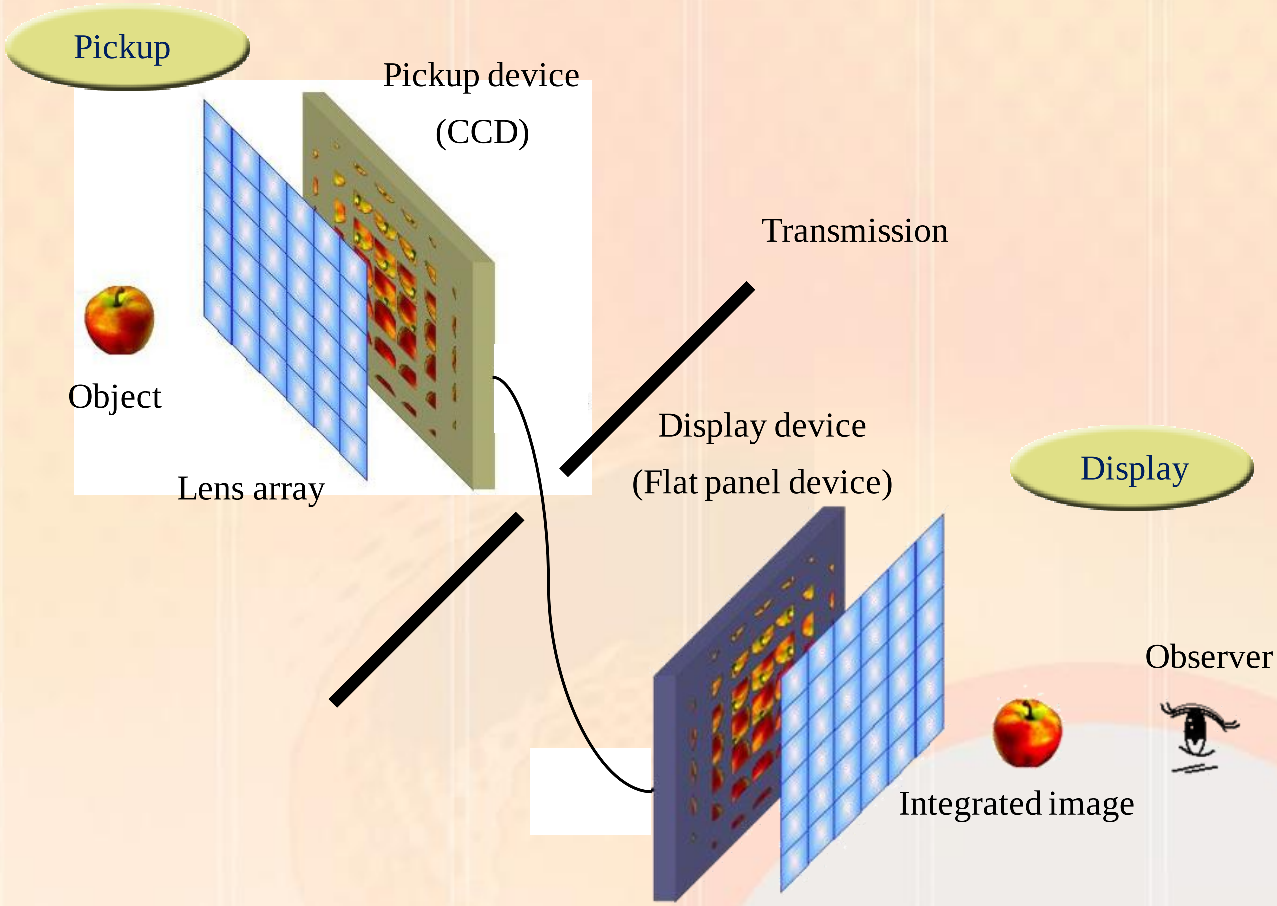
1. High speed driving (Time-sequential, glass type)

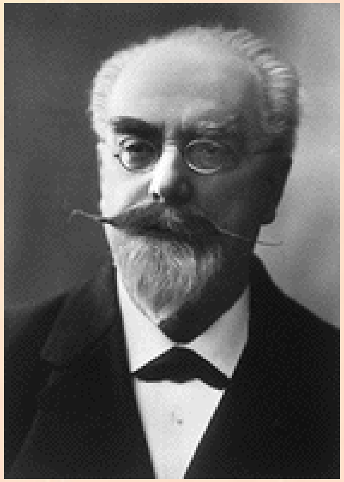
- In 2D display, crosstalk issue is not so severe because it matters only at the image boundaries with large gray scale difference.
- In 3D mode, much faster switching is needed because pixel values are mostly different for left and right images.
- The current 2ms fast LC (mainly TN-LC) does not allow wide viewing angle. So, it can be used for monitors, but is not suitable for TVs.
- To implement faster switching, viscosity of LC needs to be low, but then, restoring force becomes weaker.

2. LC dynamic barrier

- Fast directional beaming devices for multi-view system with full resolution

Integral imaging





- Pickup : Forming integral image composed of many elemental images
- Display : Retracing the original routes and forming 3D image

Features of integral imaging

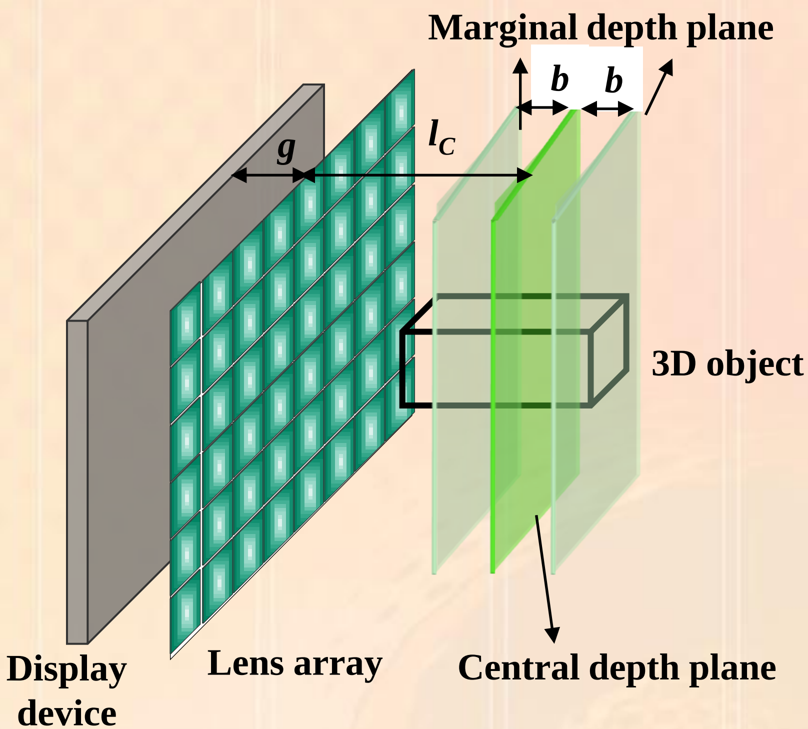
- **Advantages**
  - **No special viewing-aids**
  - **Quasi-continuous viewpoints within viewing angle**
  - **Full parallax (both horizontal and vertical parallax)**
  - **Natural depth perception**
  - **Full-color and real-time 3D animated image**
  - **Multiple observers**
  - **Display devices of 2D technology can be adopted**
- **Issues**
  - **Limited viewing angle**
  - **Limited image resolution**
  - **Limited viewing image depth range**
  - **Difficulty in compatibility with 2D images**

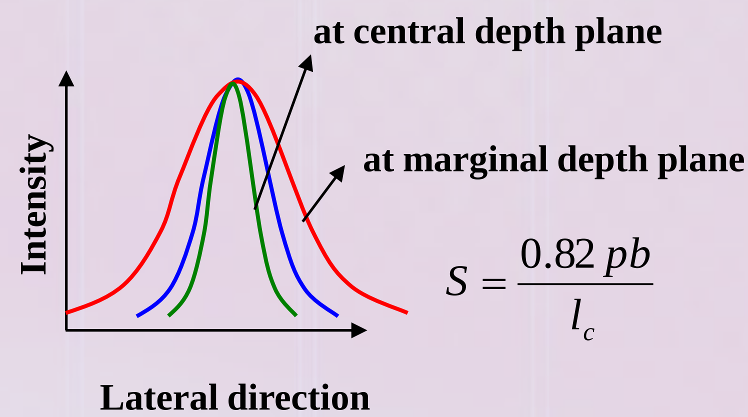
Representative methods for enhancement in integral imaging

- Depth enhancement: Dynamically variable image plane, uniaxial crystal plate, optical path control, polarization devices, layered panel integral imaging,
- Viewing angle enhancement: Polarization-multiplexing method, spatial and time multiplexing using polarization state, dynamic barrier method, embossed screen, curved lens array & screen,
- Resolution enhancement: Moving lens array, spatiotemporally multiplexing, high quality using multiple projector, rotating prism sheets

- 2D/3D convertible integral imaging method
- Integral floating display

Limitation of viewing image depth range





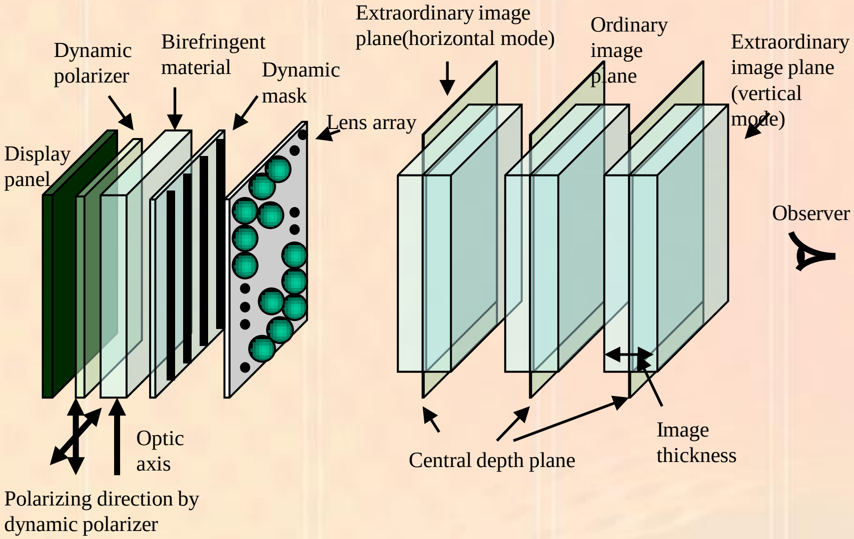
- The gap, g, and the focal length of lens array, f, determine the location of central depth plane, l_c, by lens law.

$$\frac{1}{g} + \frac{1}{l_c} = \frac{1}{f}$$

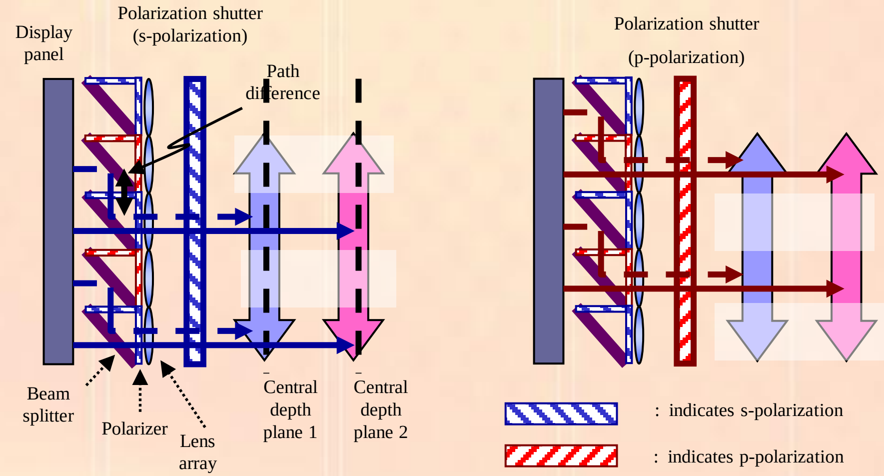
- The quality of 3D image is degraded as the image gets farther from central depth plane.

⇒ Expressible depth is limited.

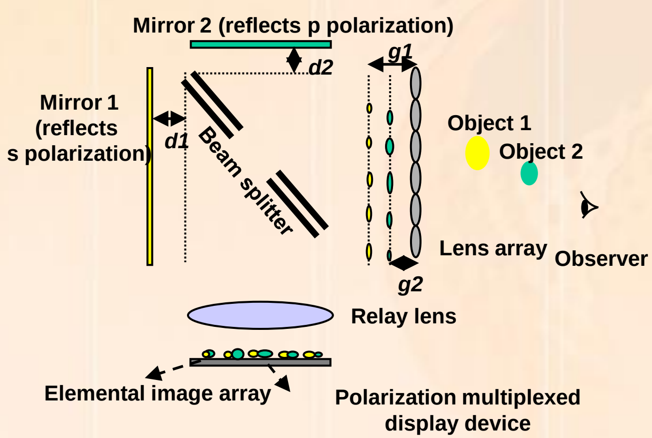
Representative methods for enhanced depth range



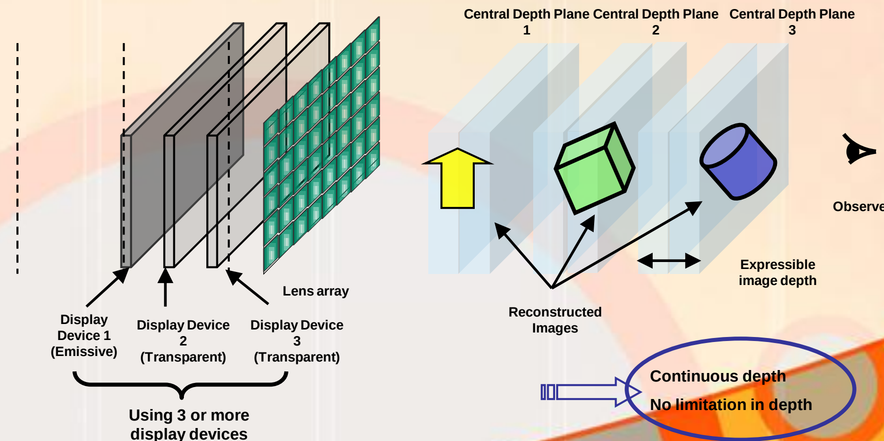
J.-H. Park, S. Jung, H. Choi , and B. Lee, "Integral imaging with multiple image planes using a uniaxial crystal plate," Optics Express, vol. 11, no. 16, pp. 1862-1875, 2003.



J. Hong, J.-H. Park, S. Jung and B. Lee, "A depth-enhanced integral imaging by use of optical path control," Optics Letters, vol. 29, no. 15, pp. 1790-1792, 2004.

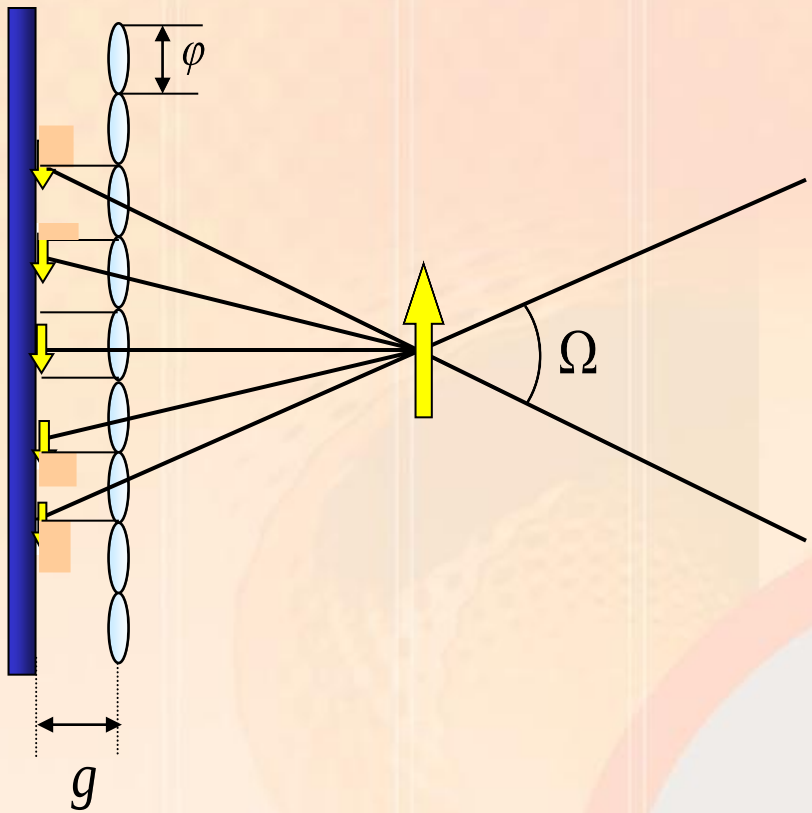


S. Jung, J. Hong, J.-H. Park, Y. Kim, and B. Lee, "Depth-enhanced integral-imaging 3D display using different optical path lengths by polarization devices or mirror barrier array," Journal of the Society for Information Display, vol. 12, no. 4, pp. 461-467, 2004.



Y. Kim, J.-H. Park, H. Choi, J. Kim, S.-W. Cho, and B. Lee, “Depth-enhanced three-dimensional integral imaging by use of multilayered display devices,” Applied Optics, vol. 45, no. 18, pp. 4334-4343, 2006.

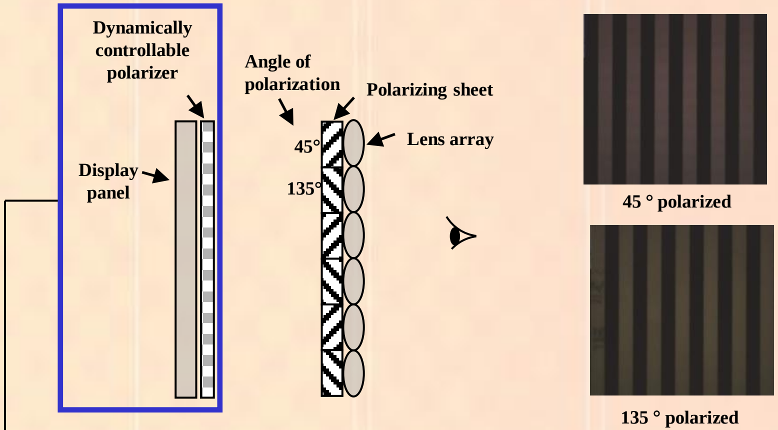
Limitation of viewing angle



- **Viewing angle**

$$\Omega = 2\arctan(\varphi / 2g)$$

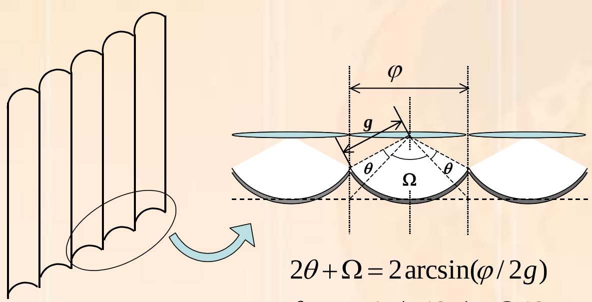
Representative methods for enhanced viewing angle



This part can be replaced with a polarizing shutter screen which is commercially available in the stereoscopy display.

S. Jung, J.-H. Park, H. Choi, and B. Lee, "Wide-viewing integral three-dimensional imaging by use of orthogonal polarization switching," Applied Optics, vol. 42, no. 14, pp. 2513-2520, 2003.

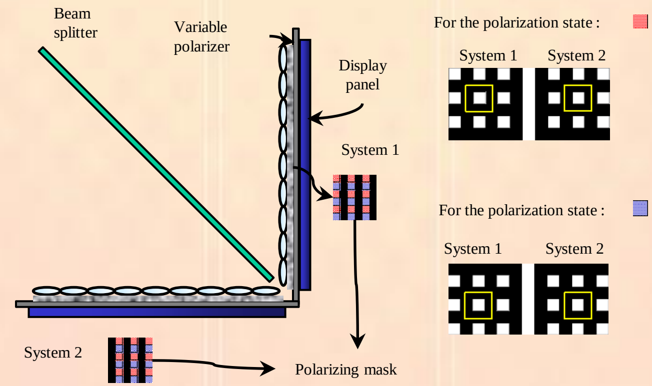
B. Lee, S. Jung, and J.-H. Park, "Viewing-angle-enhanced integral imaging using lens switching," Optics Letters, vol. 27, no. 10, pp. 818-820, 2002.



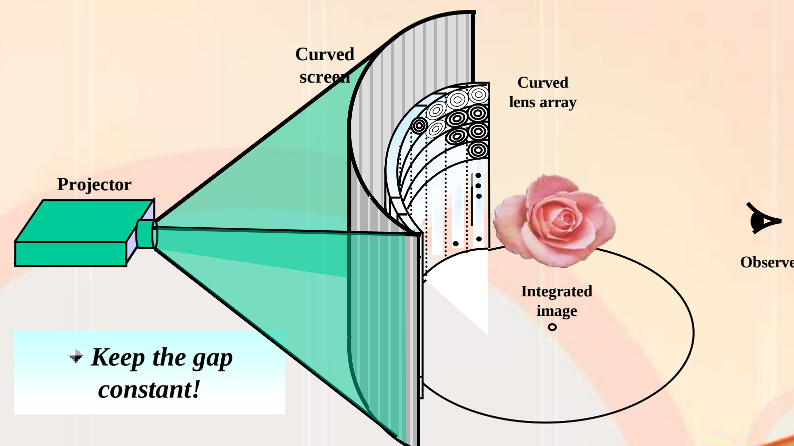
$$2\theta + \Omega = 2\arcsin(\varphi / 2g)$$

$$\theta = \arcsin(\varphi / 2g) - \Omega / 2$$

S.-W. Min, J. Kim, and B. Lee, "Wide-viewing projection-type integral imaging system with an embossed screen," Optics Letters, vol. 29, no. 20, pp. 2420-2422, 2004 .



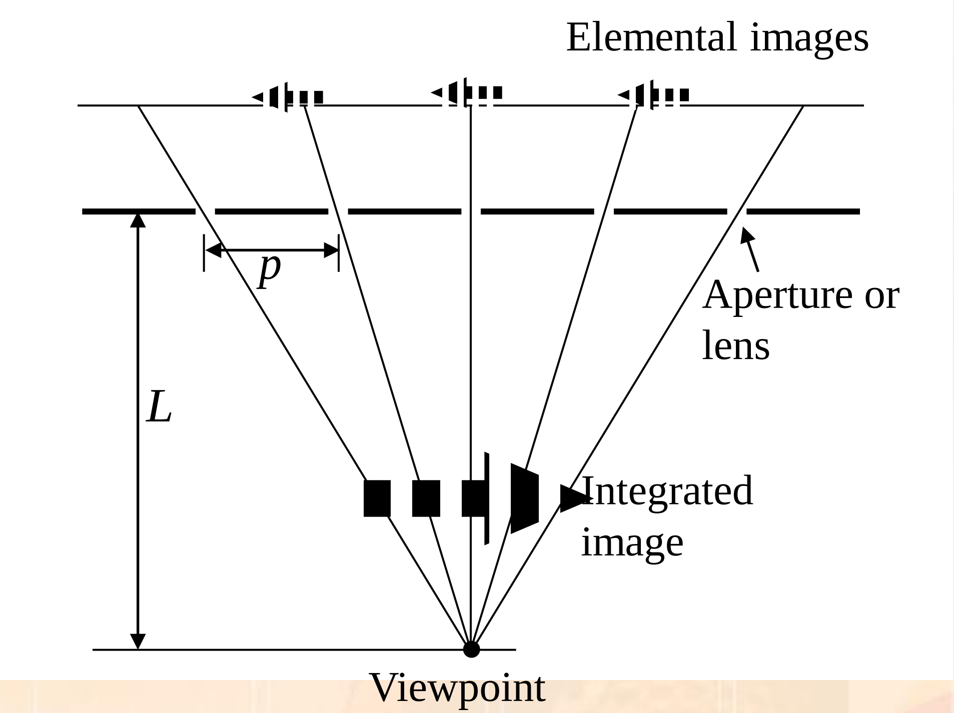
S. Jung, J.-H. Park, H. Choi, and B. Lee, "Viewing-angle-enhanced integral three-dimensional imaging along all directions without mechanical movement," Optics Express, vol. 11, no. 12, pp. 1346-1356, 2003.



Y. Kim, J.-H. Park, S.-W. Min, S. Jung, H. Choi, and B. Lee, "A wide-viewing-angle integral 3D imaging system by curving a screen and a lens array," Applied Optics, vol. 44, no. 4, pp. 546-552, 2005.

Y. Kim, J.-H. Park, H. Choi, S. Jung, S.-W, Min, and B. Lee,"Viewing-angle-enhanced integral imaging system using a curved lens array,"Optics Express, vol. 12, no. 3, pp. 421-429, 2004.

Limitation of viewing resolution



p : pitch of exit pupil

L : viewing distance

From the Nyquist sampling theorem, the upper limit of the viewing resolution

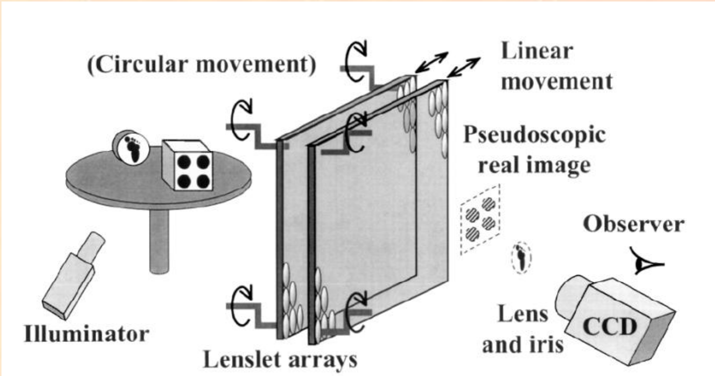
$$\beta_{nyq} \approx \frac{L}{2p}$$

- Sampling of a image by the pitch of the exit pupil

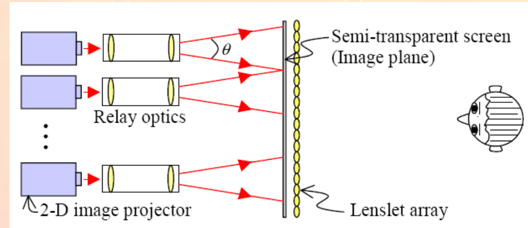
The pitch of the lens or the pitch of exit pupil determines the sampling rate of the elemental image in the spatial dimension.

- C. B. Burckhardt, J. Opt. Soc. Am. 58, 71-76,1967.
- T. Okoshi, Appl. Opt. 10, 2284-2291, 1971.

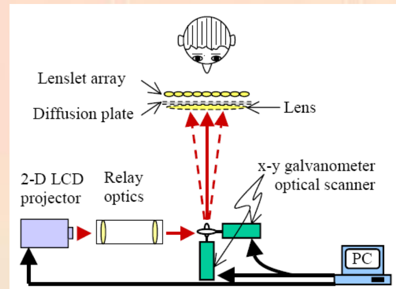
Representative methods for enhanced resolution



J. S. Jang and B. Javidi, "Improved viewing resolution of 3-D integral imaging with nonstationary micro-optics," Opt. Lett. 27, 324–326, 2002.

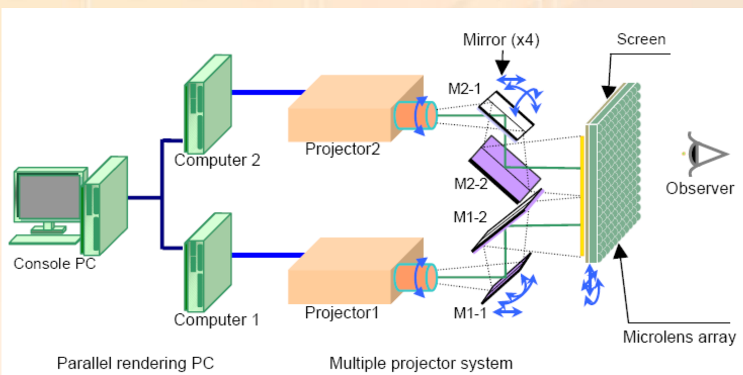


Spatial multiplexing

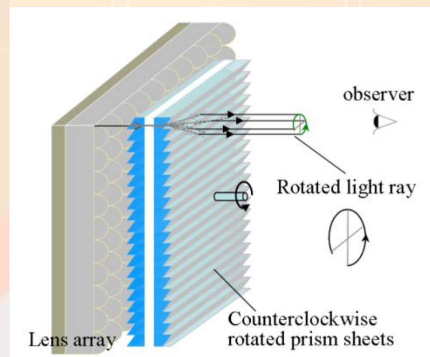


Temporal multiplexing

J. S. Jang, Y. S. Oh, and B. Javidi, "Spatiotemporally multiplexed integral imaging projector for large-scale high-resolution three-dimensional display," Opt. Express 12, 557–563, 2004.

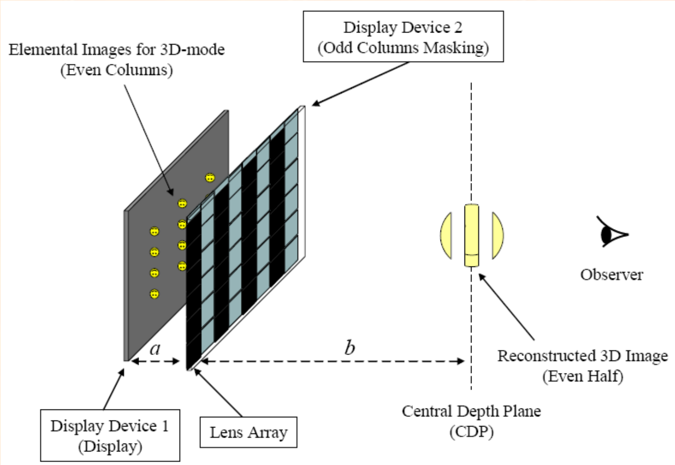


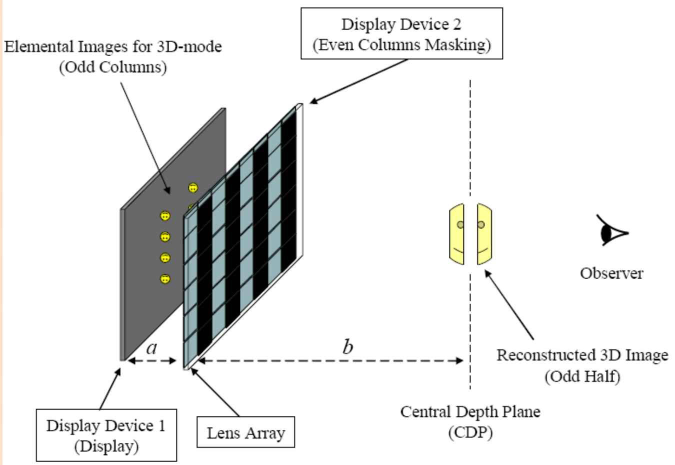
H. Liao, M. Iwahara, N. Hata, and T. Dohi, "High-quality integral videography using a multiprojector," Opt. Express 12, 1067–1076, 2004.

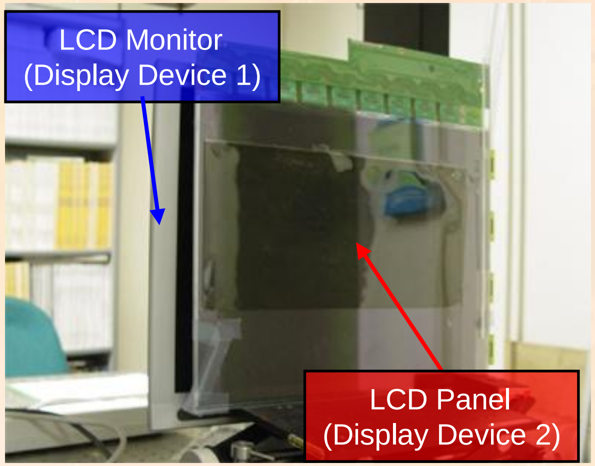


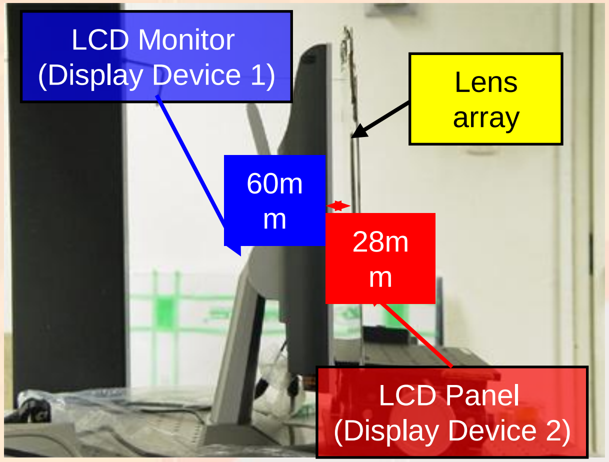
H. Liao, T. Dohi, M. Iwahara, "Improved viewing resolution of integral videography by use of rotated prism sheets," Optics Express, vol. 15, no. 8, 4814-4823, 2007.

Wide viewing angle 2D/3D convertible display



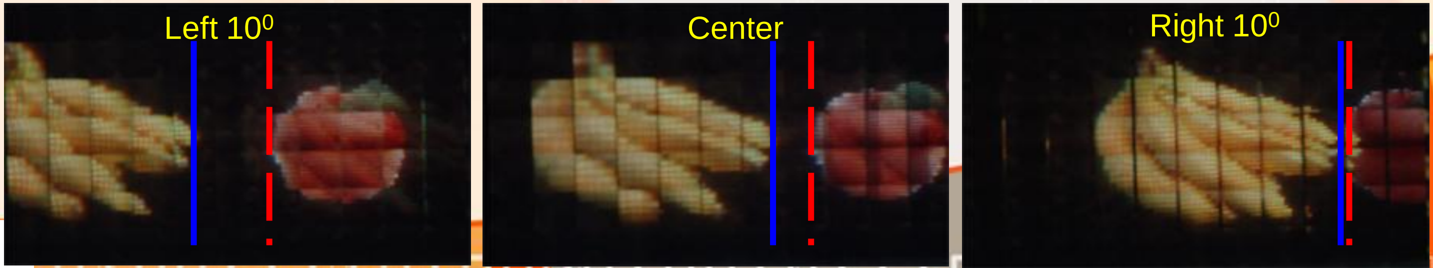






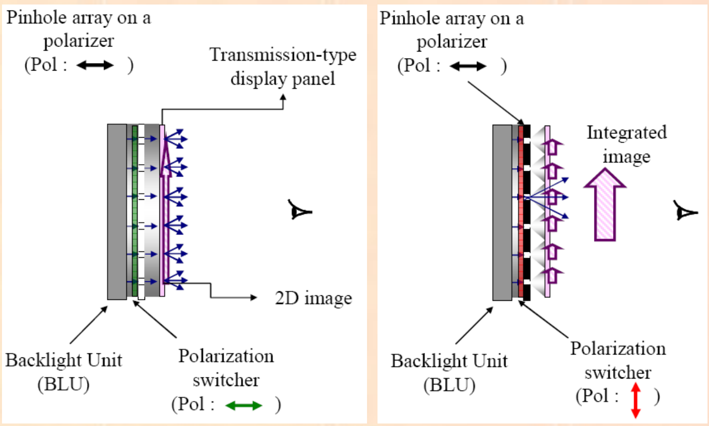
2D image

3D image

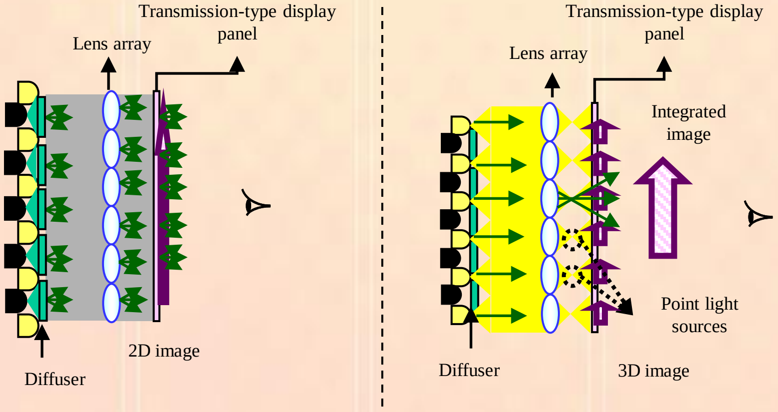


Representative methods of 2D/3D convertible methods

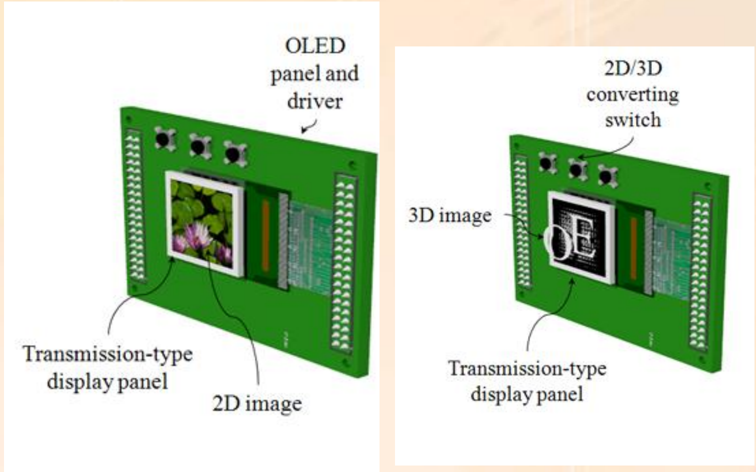
• **2D mode** • **3D mode**



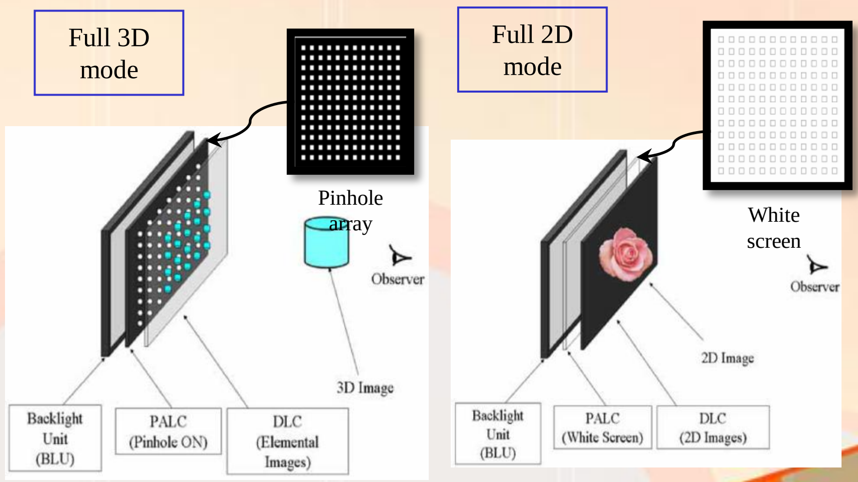
H. Choi, S.-W. Cho, J. Kim, and B. Lee, "A thin 3D-2D convertible integral imaging system using a pinhole array on a polarizer," Optics Express, vol. 14, no. 12, pp. 5183-5190, 2006.



S.-W. Cho, J.-H. Park, Y. Kim, H. Choi, J. Kim, and B. Lee, "Convertible two-dimensional-three-dimensional display using an LED array based on modified integral imaging," Optics Letters, vol. 31, no. 19, pp. 2852-2854, 2006.



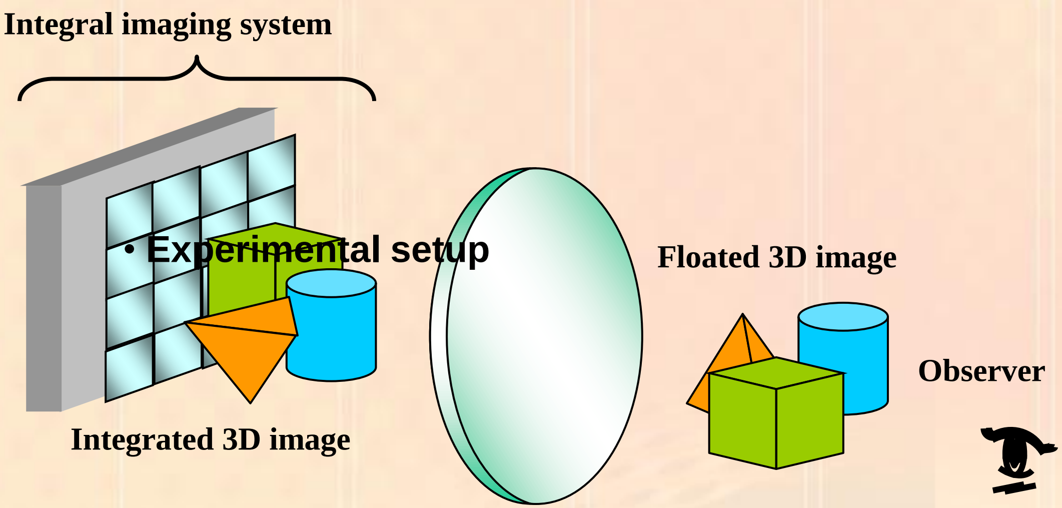
Y. Kim, J. Kim, Y. Kim, H. Choi, J.-H. Jung, and B. Lee, "Thin-type integral imaging method with an organic light emitting diode panel," Applied Optics, vol. 47, no. 27, pp. 4927-4934, 2008.

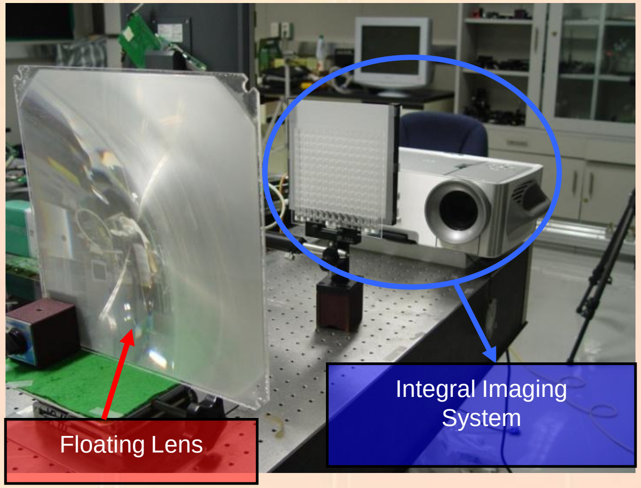


H. Choi, J. Kim, S.-W. Cho, Y. Kim, J. B. Park, and B. Lee, "Three-dimensional-two-dimensional mixed display system using integral imaging with an active pinhole array on a liquid crystal panel," Appl. Opt. vol. 47, no. 13, pp. 2207-2214. 2008.

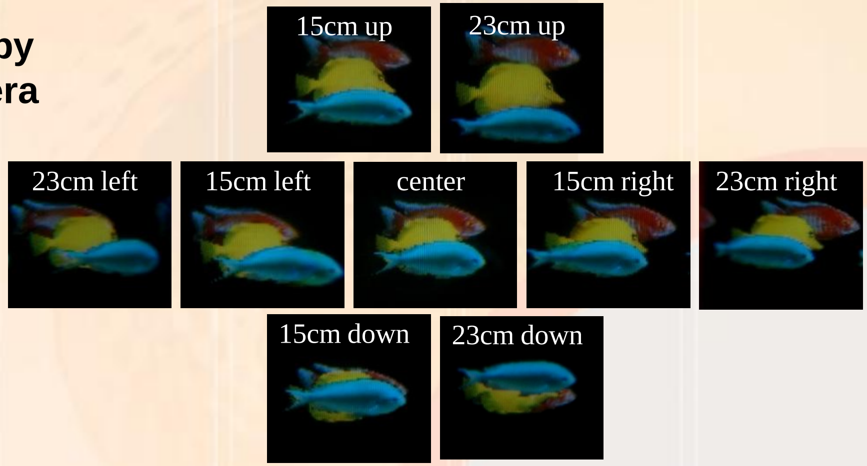
Integral floating display

• Experimental setup



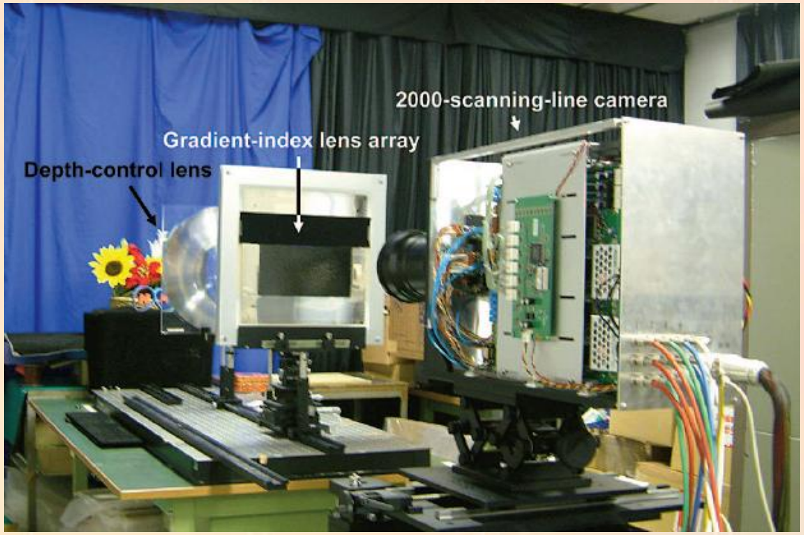


• Image taken by 1m away camera



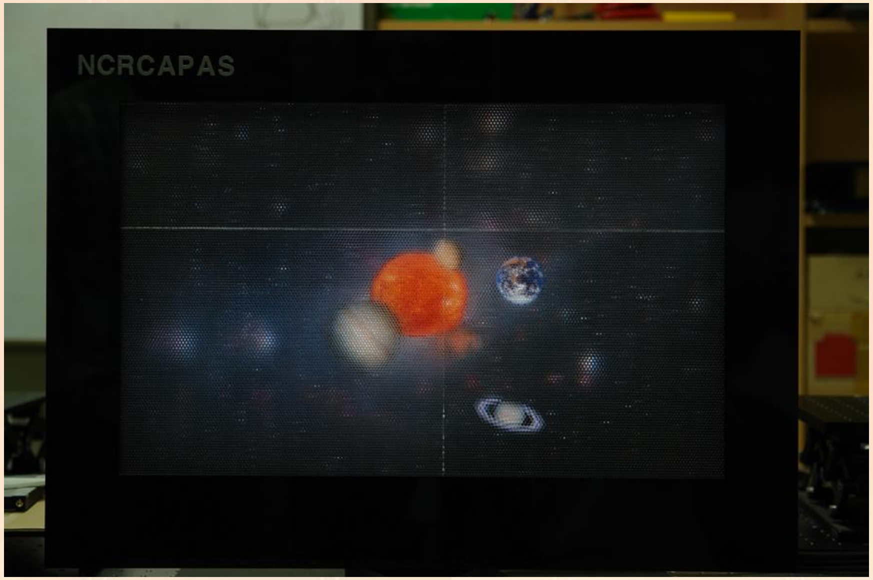
J. Kim, S.-W. Min, and B. Lee, “Viewing region maximization of an integral floating display through location adjustment of viewing window,” Optics Express, vol. 15, no. 20, pp. 13023-13034, 2007.

Gradient-index lens array (NHK)



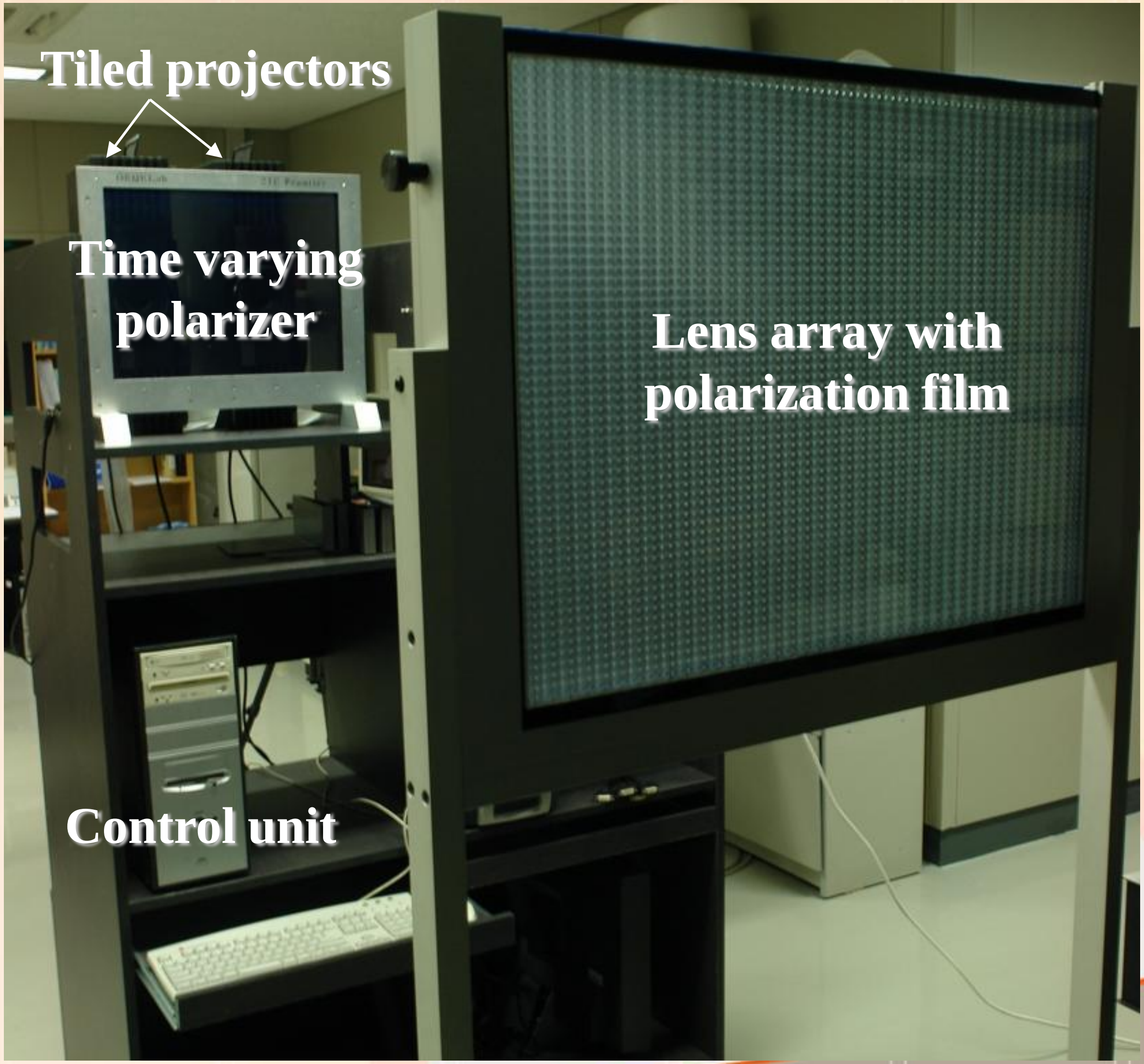
Television camera	Approx. 3200 x 2160
Gradient-index lens array	
Diameter	1.085 mm
Number of lenses	160 x 118
Focal length	-2.65 mm
LCD pixel width	0.1245 mm
Lens array	
Diameter/Pitch	2.64/ 2.64 mm
Number of lenses	160 x 118
Focal length	8.58 mm

High-resolution integral imaging (SNU)

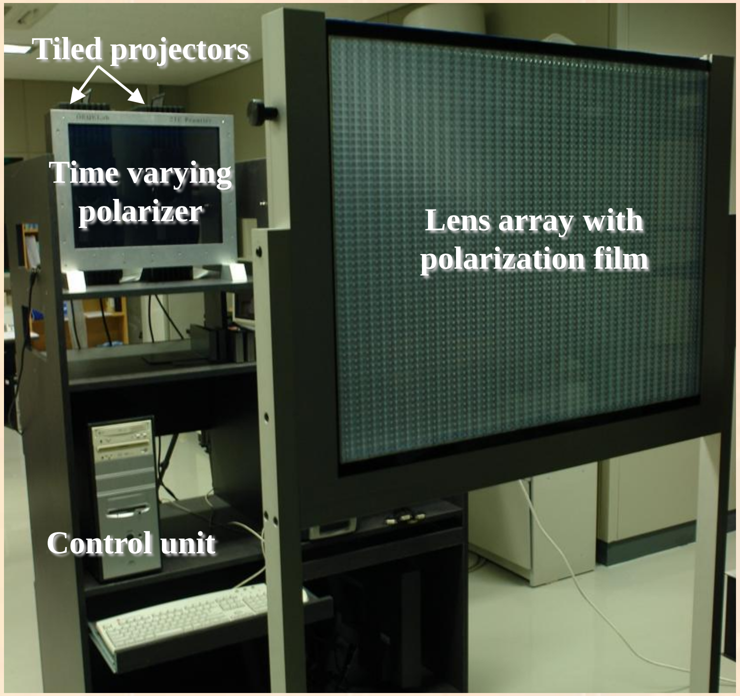


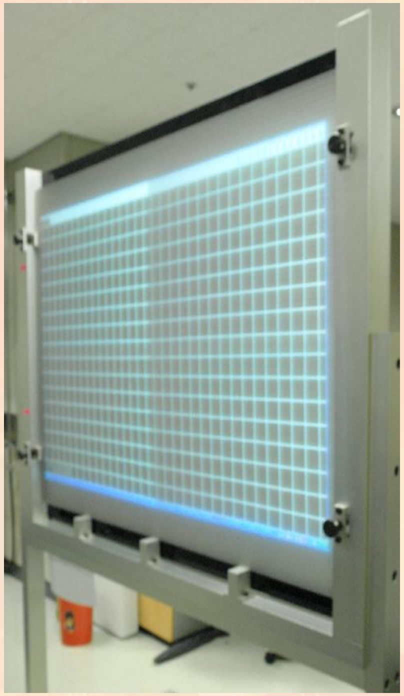
Monitor Type	Flat Panel LCD TFT(Active Matrix)
Size	22.2 inch
Contrast Ratio	400:1
Aspect Ratio	16:9
Maximum Resolution	3840 x 2400
Brightness	235cd/m^2
Response Time	50ms
Pixel Pitch	124.5*um*
Color Depth	24-bit(16.7M Colors)
Viewable Picture Size	22.2 inch

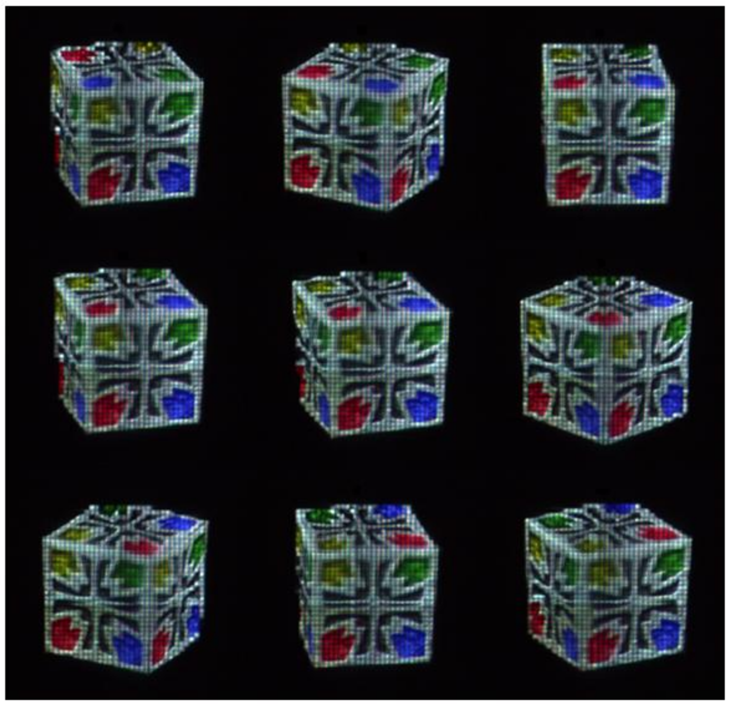
Seoul National University



Projection-type integral imaging (60 inch)



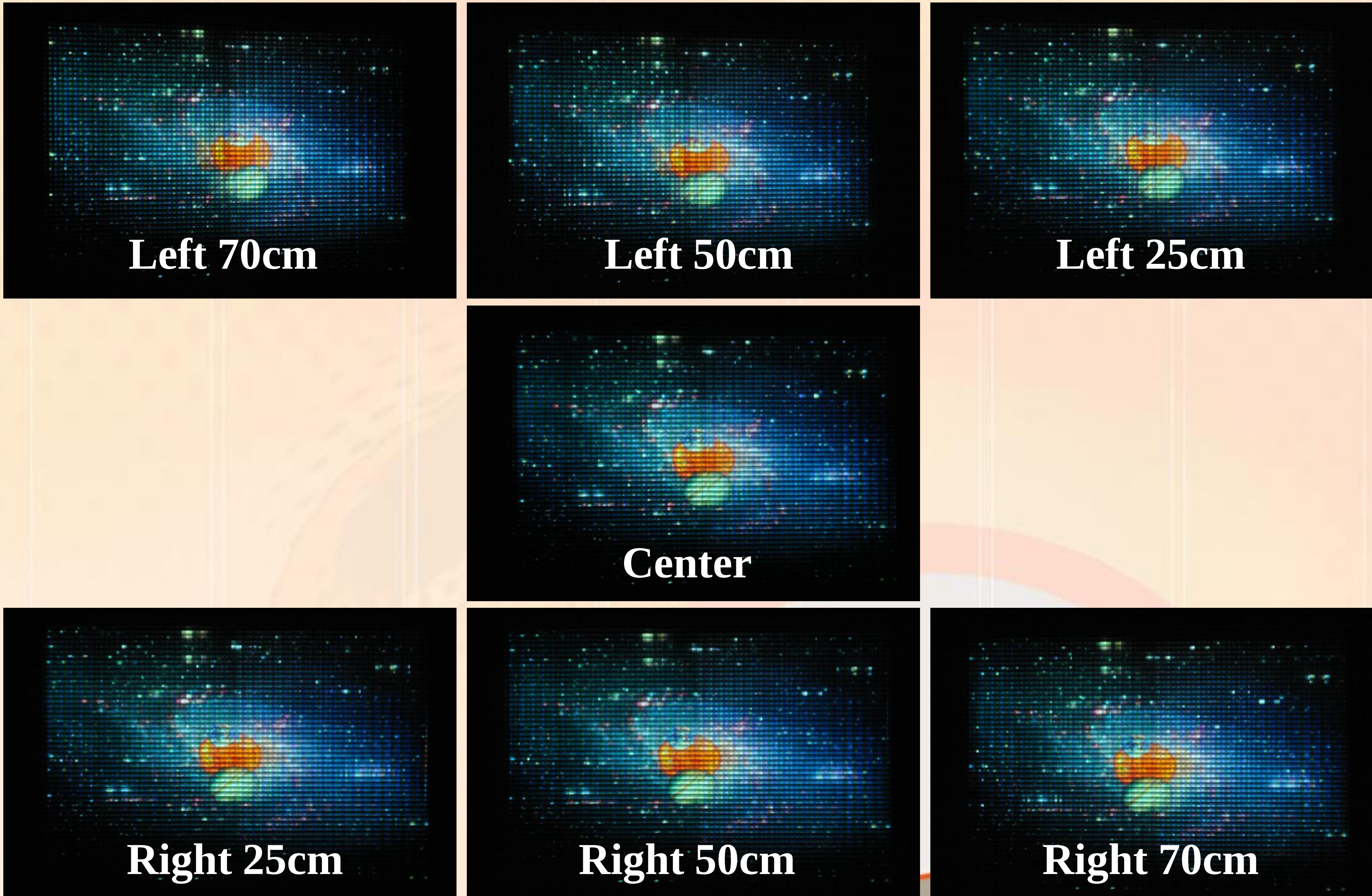




- 4 Full-HD projectors
- 10mm square lens-array
- Display surface size: 1170mm × 910mm

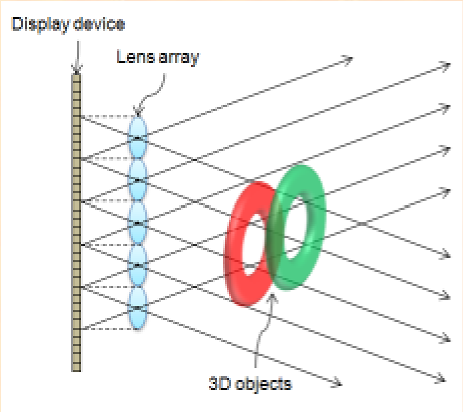
J. Kim, Y. Kim, H. Choi, S.-W. Cho, Y. Kim, J. Park, G. Park, S.-W. Min, and B. Lee, "Implementation of polarization-multiplexed tiled projection integral imaging system," Journal of the Society for Information Display, vol. 17, no. 5, pp. 411-418, 2009.

Projection-type integral imaging (60 inch)

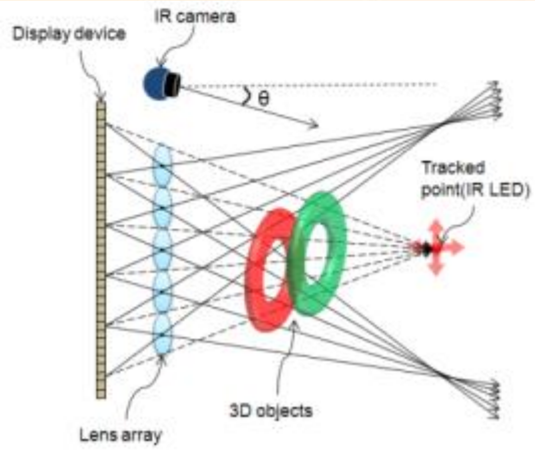


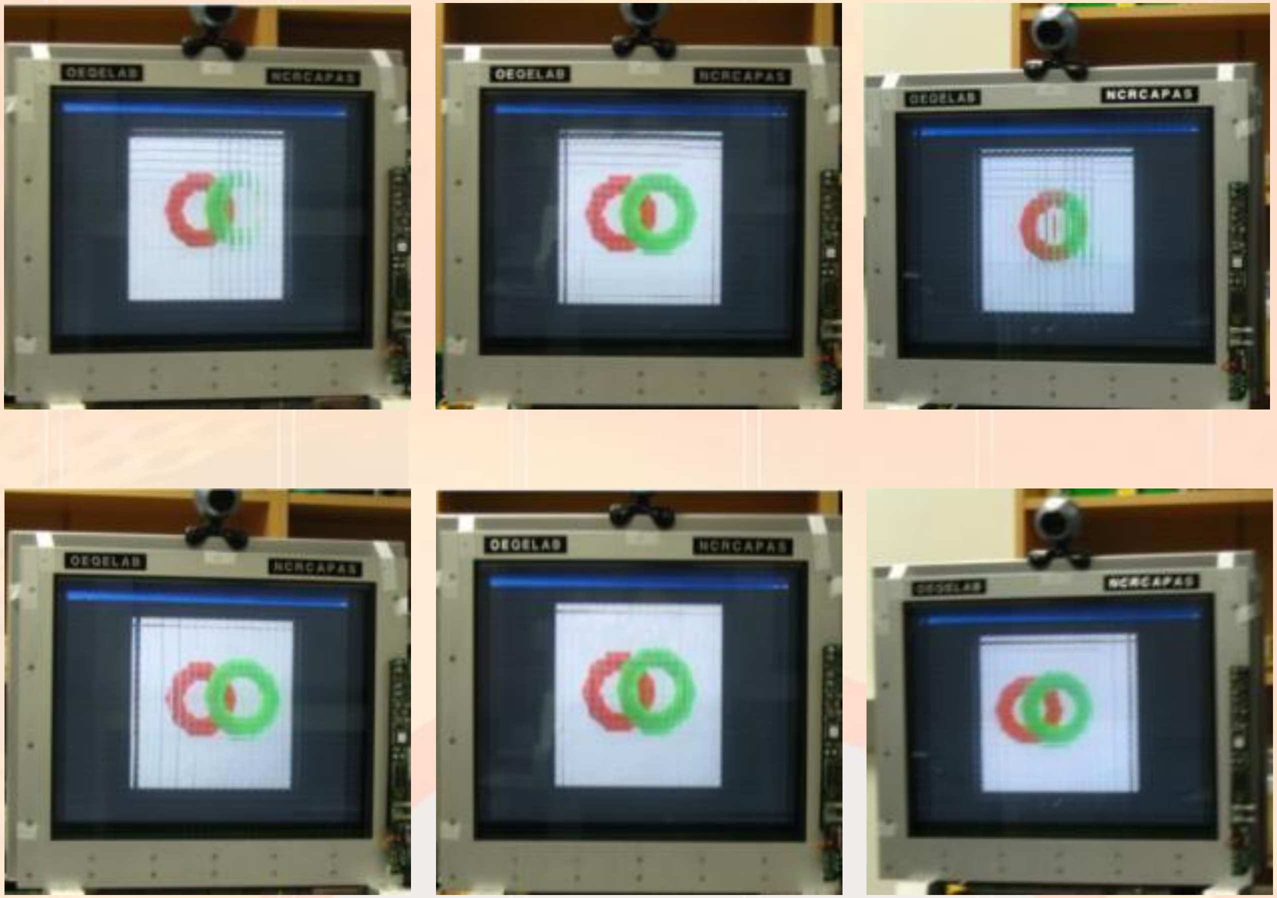
Head tracking integral imaging

without tracking



with tracking

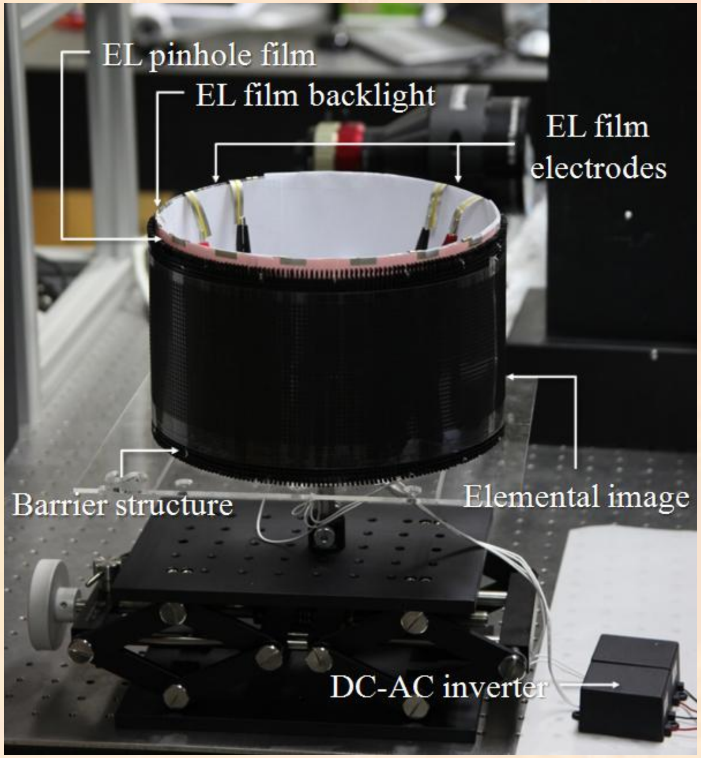




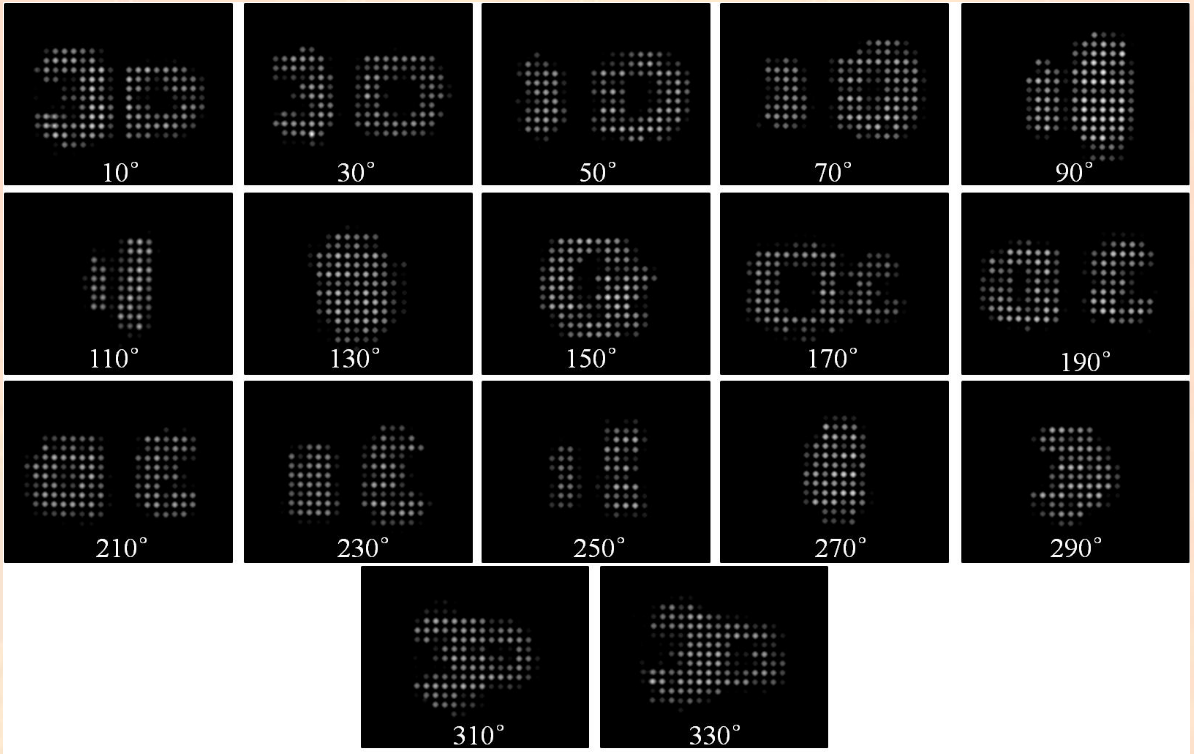
G. Park, J.-H. Jung, K. Hong, Y. Kim, Y.-H. Kim, S.-W. Min, and B. Lee, "Multi-viewer tracking integral imaging system and its viewing zone analysis," Optics Express, vol. 17, no. 20, pp. 17895-17908, 2009.

360-degree viewable cylindrical integral imaging

Cylindrical integral imaging system



Observed 3D images at different view position in 360-degree



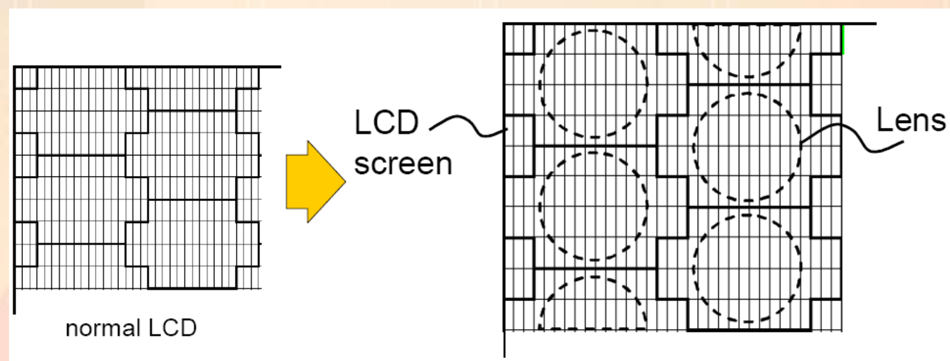
- 360-degree viewable integral imaging system
- Point light source based method using electroluminescent(EL) films
- 2D/3D convertible display

J.-H. Jung, K. Hong, G. Park, I. Chung, and B. Lee, "360-degree viewable cylindrical integral imaging system using three-dimensional/two-dimensional switchable and flexible backlight," Journal of the Society for Information Display, vol. 18, no. 7, pp. 527-534, 2010.

Integral imaging (Hitachi Ltd.)

LCD size	5 inch
LCD resolution	1280 x 768
Number of lenses	256 x 192
Viewing angle	30 degree
Color filter arrangement	Special

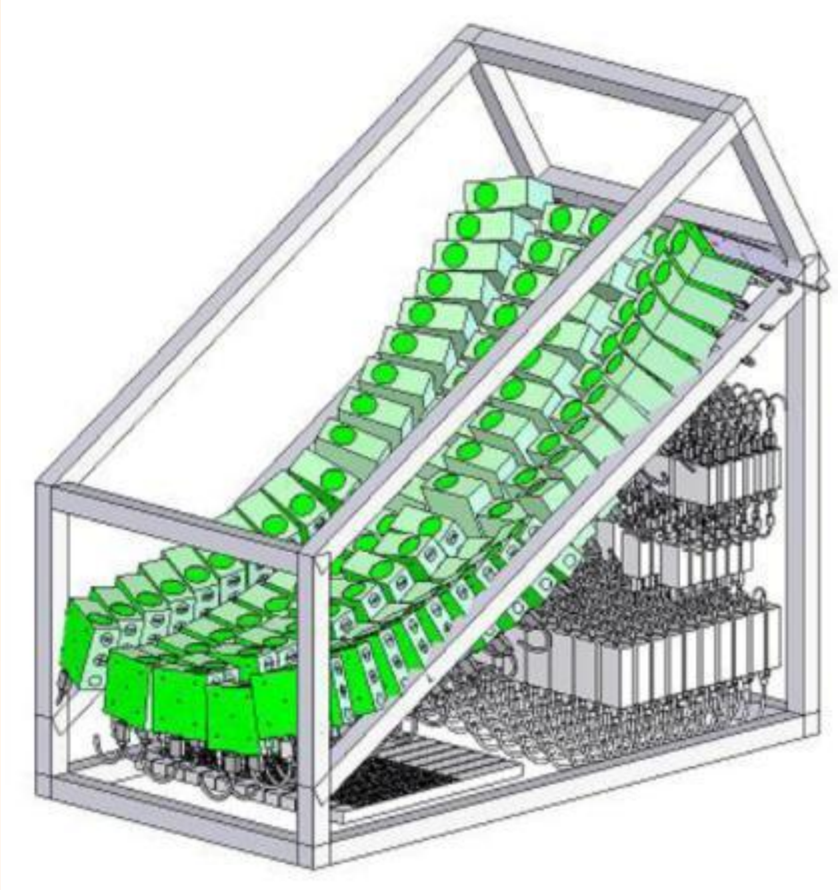
Color filter configuration (reduce moire pattern)

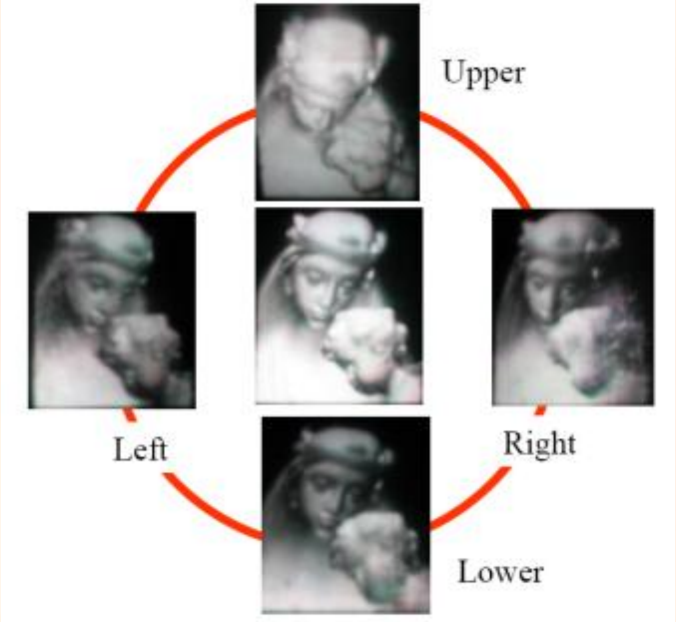


M. Oikawa, M. Kobayashi, T. Koike, K. Utsugi, M. Yamasaki, "Sample applications suitable for features of integral videography," SID2008

Integral imaging (Hitachi Ltd.)

❖ Hitachi : 95 SVGA projectors

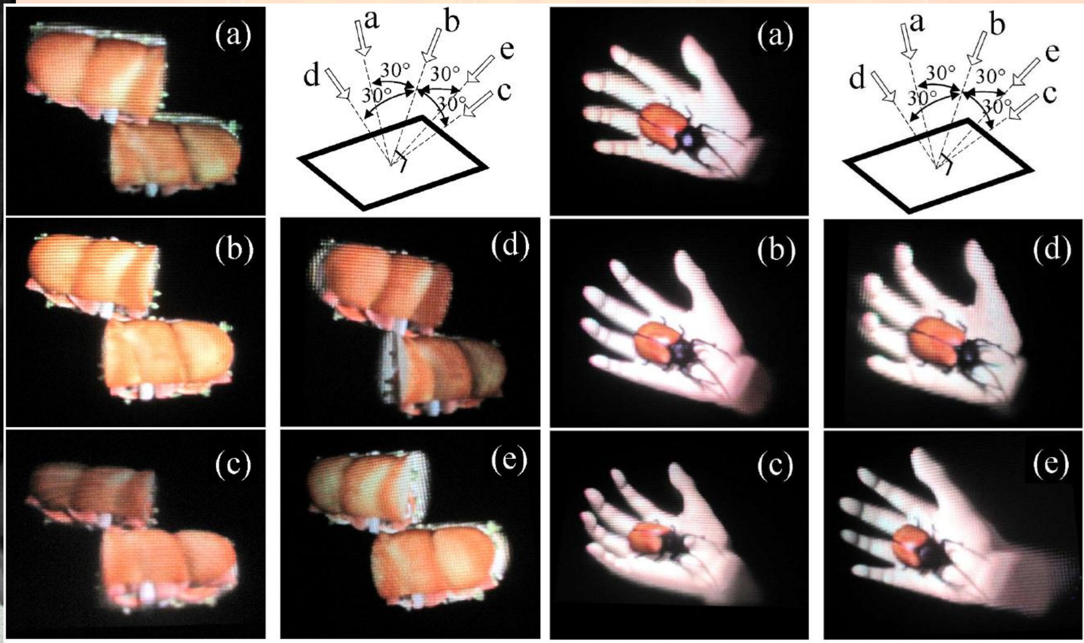




- 95 SVGA projectors
- Two lenticular sheet(7 Lpi)
- Display surface size: 800mm × 400mm

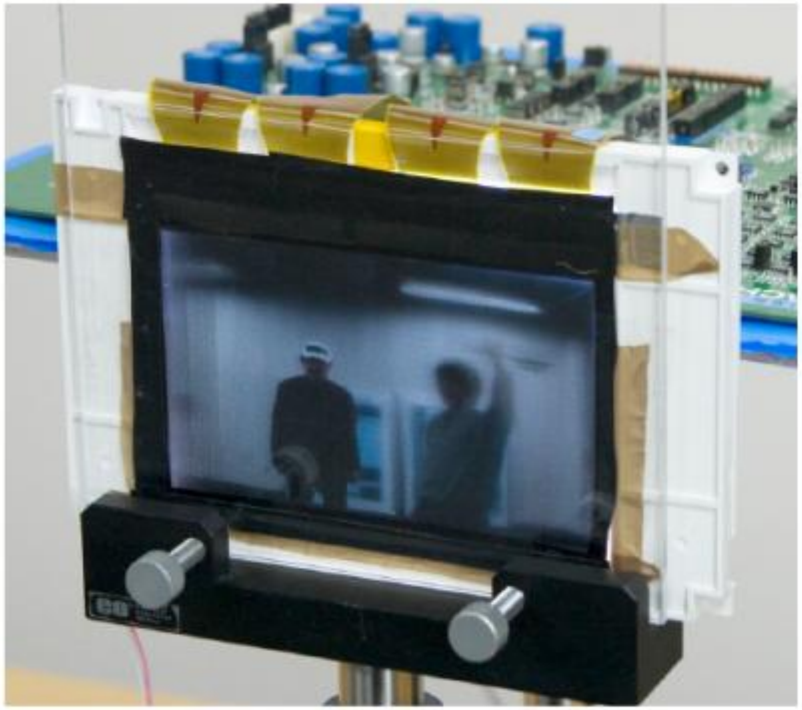
H. Sakai, M. Yamasaki, T. Koike, M. Oikawa, and M. Kobayashi, "Autostereoscopic display based on enhanced integral photography using overlaid multiple projectors," SID, paper 147, 2009.

Integral imaging (Hitachi Ltd.)



M. Yamasaki, H. Sakai, T. Koike, and M. Oikawa, "Full-parallax autostereoscopic display with scalable lateral resolution using overlaid multiple projection," Journal of the SID, vol. 18 (2010).

Real-time pickup from camera array (Tokyo Univ.)



- Real time light field conversion from 64 input views of 320 ×240 pixels by GPU

Y. Taguchi, T. Koike, K. Takahashi and T. Naemura, “TransCAIP: Live Transmission of Light Field from a Camera Array to an Integral Photography Display,“ ACM SIGGRAPH ASIA 2008.

Toshiba

24 inch and 15.4 inch prototype

Resolution: 1920 x 1080

Toshiba's 24-inch 3D display. The can on the bottom right is real.

Interactive integal imaging

SEATAC 2006

21inch Integral imaging (Toshiba)

- Integral imaging with 9 parallax
- 21inch 1280 × 800 3D pixel (wide-XGA)
- 3D viewing zone: +- 15° (horizontal)
- Luminance: 480 cd/m^2 typical

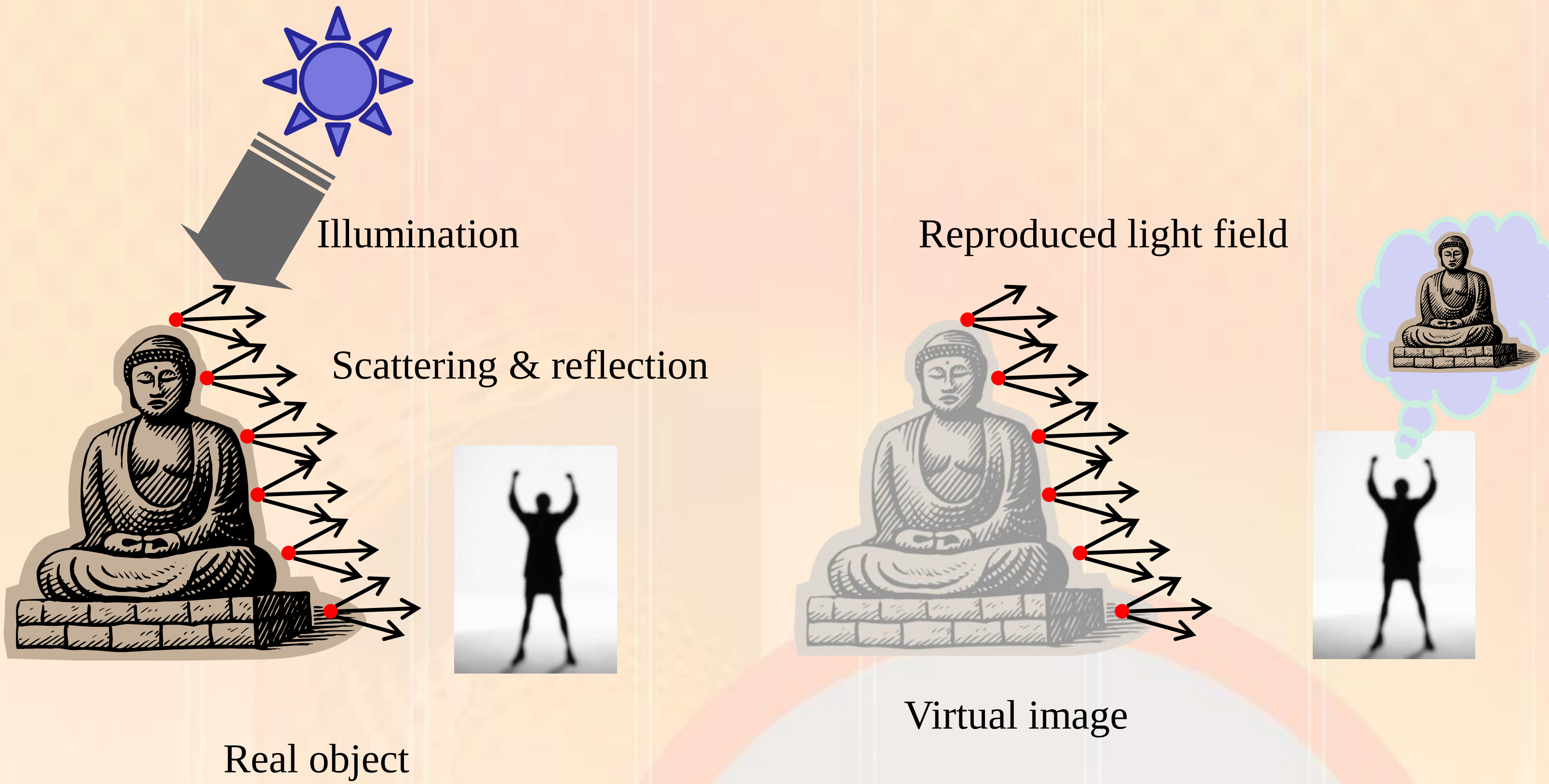
SID 2010

Present status of 3D display

Hardware system

- Stereoscopic display
- Autostereoscopic display
- Volumetric display
- Recent techniques

Volumetric display

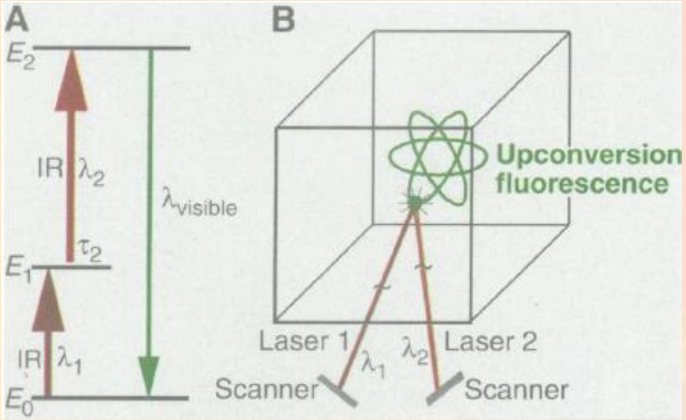


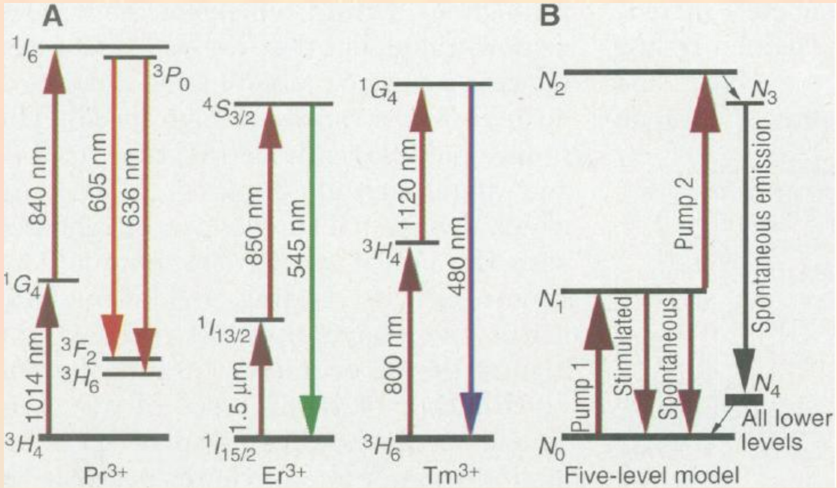
Volumetric display

- Various methods exist.
- Compared to other techniques:
  - Advantages
    - Large viewing region
    - Satisfy almost all depth perception cues
  - Disadvantages
    - Limited space of expression
    - Hard to achieve occlusion
    - Bulky structure
    - Limited contents

Three-color, solid-state 3D display

Two-step, two-frequency (TSTF) upconversion





$$P_v = \xi\left(\frac{P_1P_2}{A^2}\right)\left(\frac{\hbar\omega_{34}}{\hbar\omega_{01}\hbar\omega_{12}}\right)N_T V\sigma_1\sigma_2\tau_1$$

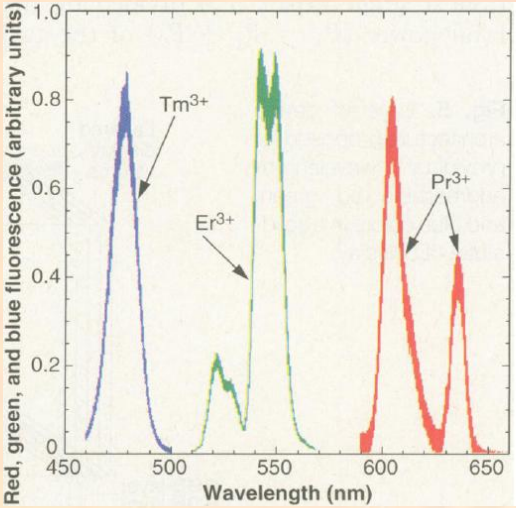
Excitation parameters and material properties of prototype

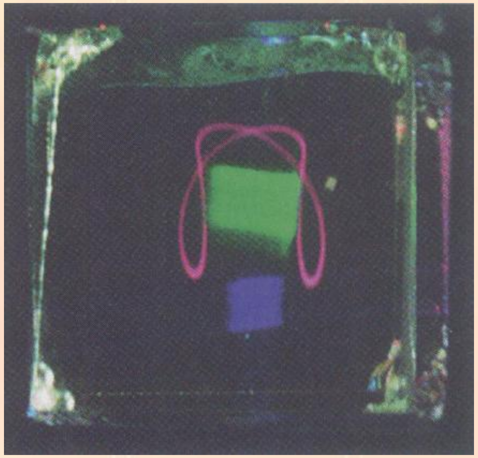
Color	RE ion	Glass composition	λ_1 (nm)	Laser 1	P_1 (W)	λ_2 (nm)	Laser 2	P_2 (W)	σ_1 (cm^2)	τ_1 (ms)
Red	0.1% Pr^{3+}	ZBLNaCl	1014	SDL #5762 MOPA	1	840	SDL #5430	0.2	2.1×10^{-21}	0.18
Green	0.5% Er^{3+}	ZBLAN	1550	SDL #64-SPE-1550	0.1	850	SDL #5430	0.2	4.5×10^{-20}	15
Blue	0.5% Tm^{3+}	ZBLAN	800	$Ti:Al_2O_3$	0.4	1064	Nd:YAG	4	1.5×10^{-20}	1.5
			800	SDL #2350*	0.5	1120	SDL #64-SPE-1120*	0.5		

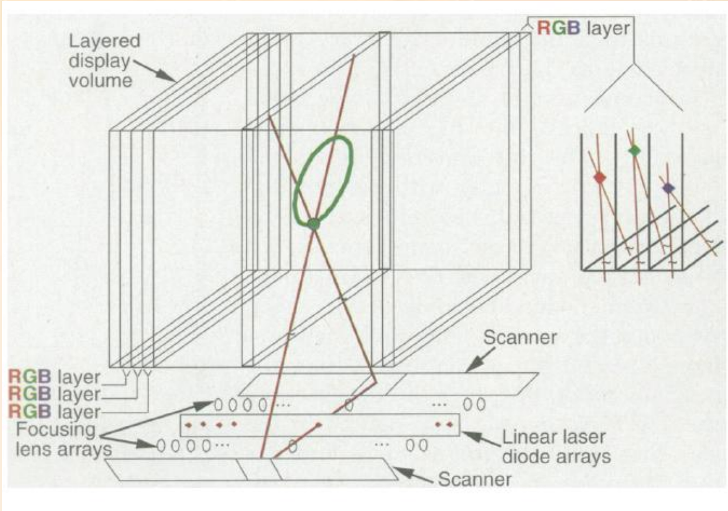
E. Downing, L. Hesselink, J. Ralston and R. Macfarlane, "A three-color, solid-state, three-dimensional display," Science, vol. 273 (1996).

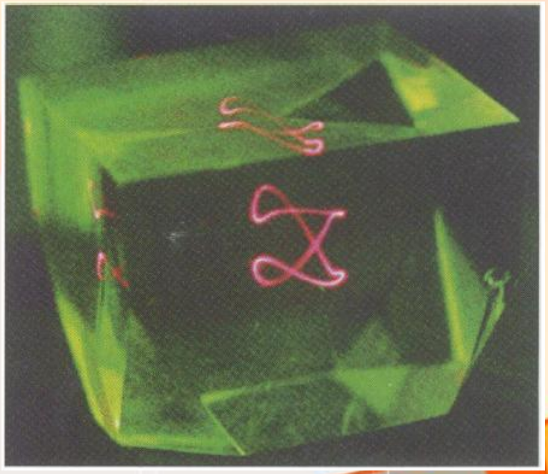
Three-color, solid-state 3D display

Spectral content in Pr^{3+}-, Er^{3+}-, and Tm^{3+}-doped HMFGs

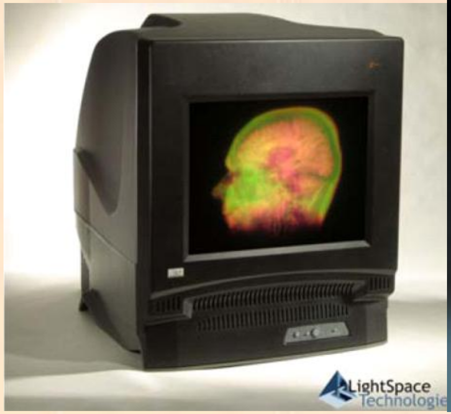


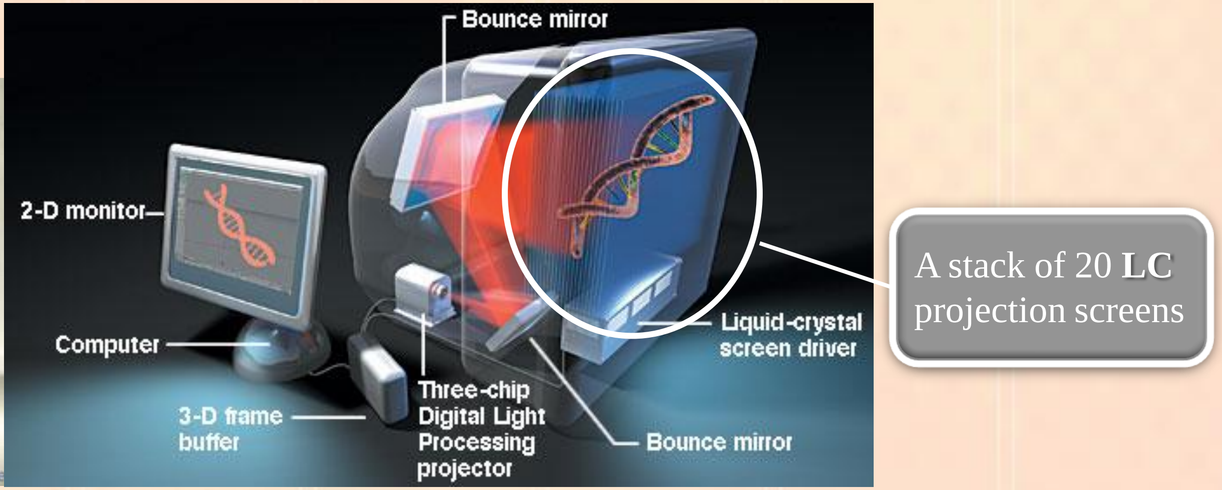






DepthCube





Resolution	**1024×748×20**
Physical voxel count	**15.3 Million**
Perceived voxel count	**465.7 Million**
Color depth	**15 bit**
Refresh rate	**50 Hz**
Update rate	**20 Hz**
Image volume	**15.6”×11.8”×4.1”**

Kent State University
Polymer Stabilized Cholesteric Texture (PSCT) material

- 88% transmittance in the clear state
- 2% transmission in the scattering state (within 10 deg. angle)
- 0.39 ms from clear to scattering
- 0.08 ms from scattering to clear

Holografika

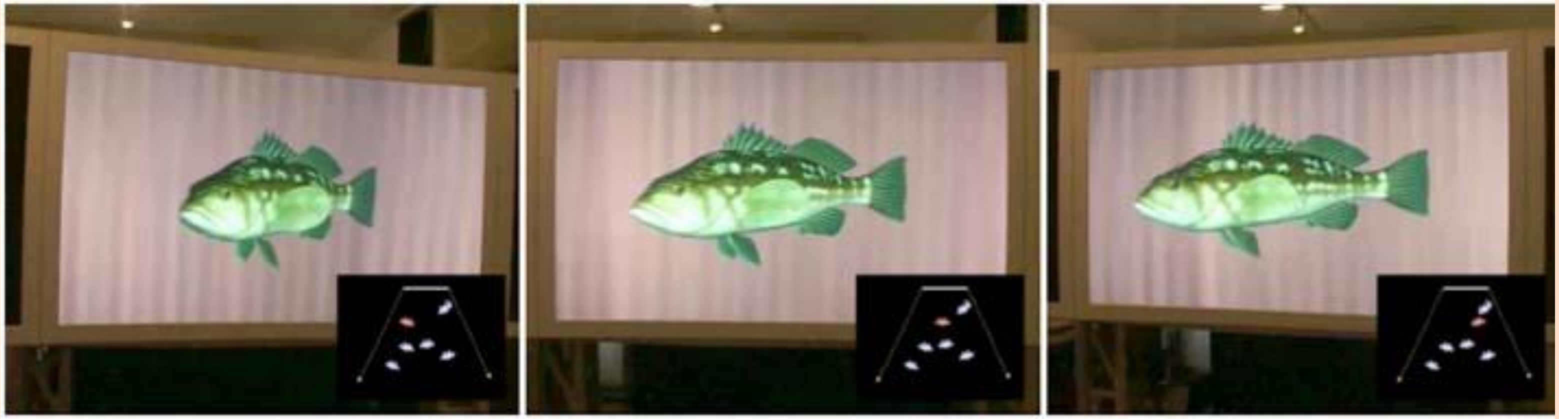
Technical Specification

Specifications	**HoloVizio 640RC**

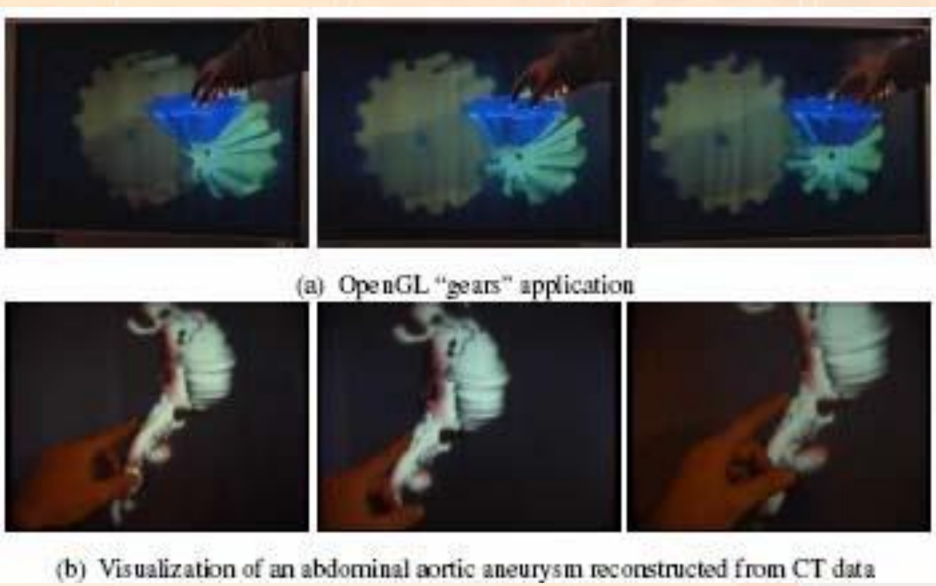
Aspect ratio	**16:9**
Screen size	**72" diagonal, 1600mm x 900mm**
3D resolution	**50.3 Mpixel**
Input signal	**Up to Dual Gigabit Ethernet**
Compatibility	**PC and WorkStation**
Signal cable	**Ethernet (RJ-45)**
Viewing angle	**50-70 degrees**
Color	**16 M (24 bit RGB)**

Dimensions (W x H x D)	**2697mm x 2136mm x 2829mm**
The frequency of the power network	**50 Hz ... 60 Hz**
Nominal voltage level(s)	**230/400 V, 115/200 V**
Power consumption (using projectors with lamps)	**230/400V approx. 3x30A 115/200V approx. 3x60A 5-wire TNS system**
Dissipated heat (using projectors with lamps)	**Approx. 12 kW**
Power consumption (using projectors with LEDs)	**230/400V approx. 3x16A 115/200V approx. 3x32A 5-wire TNS system**
Dissipated heat (using projectors with LEDs)	**Approx. 5 kW**
Temperature	**+5° C...+40° C**
Relative humidity	**Max. 80% / 50%**
Usage	**Indoor**

Holografika



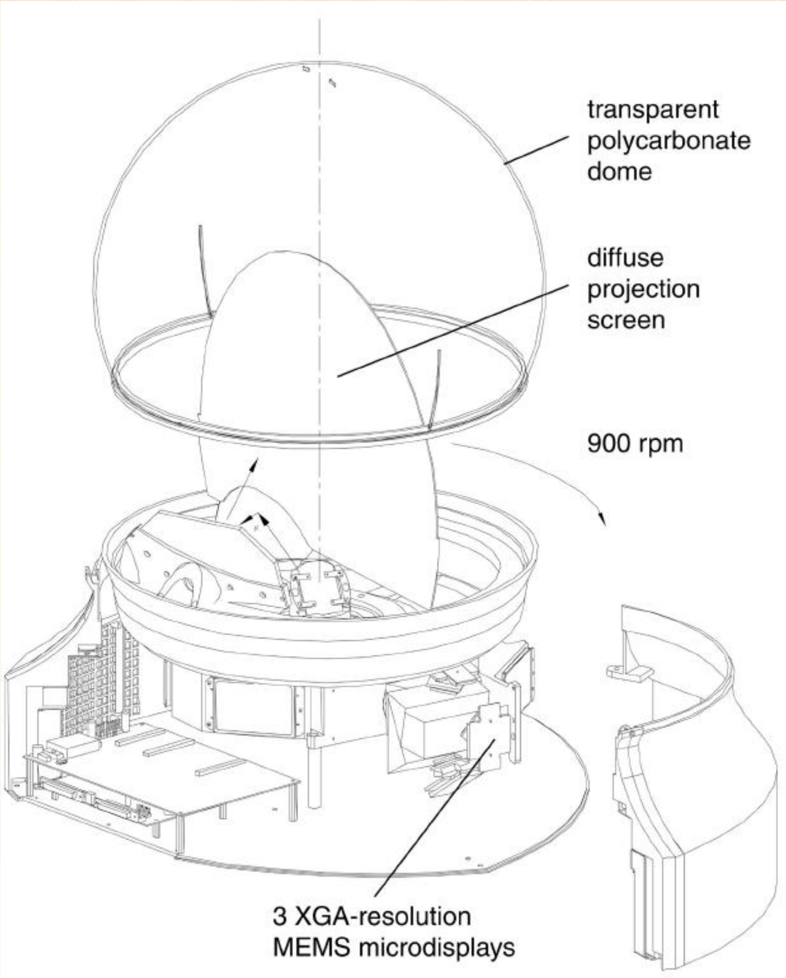
- Images taken from different positions

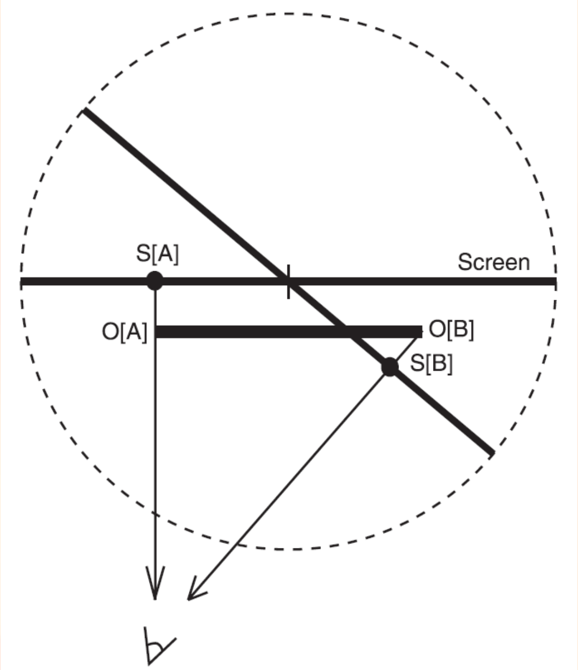


(a) OpenGL "gears" application

(b) Visualization of an abdominal aortic aneurysm reconstructed from CT data

Occlusion-Capable multiview volumetric 3D display - principle



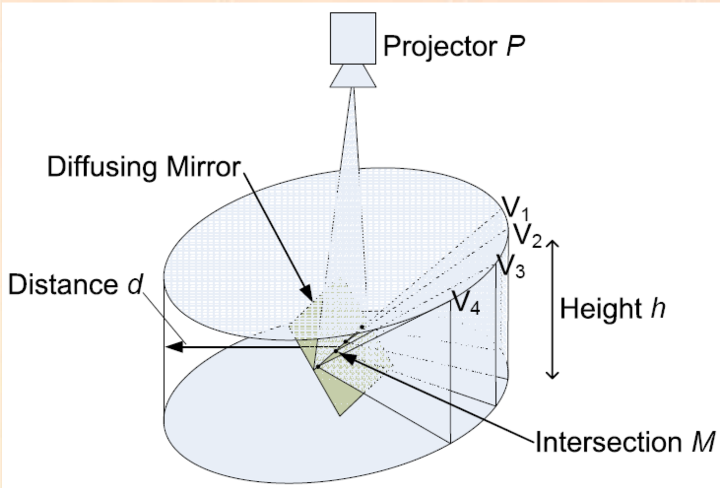


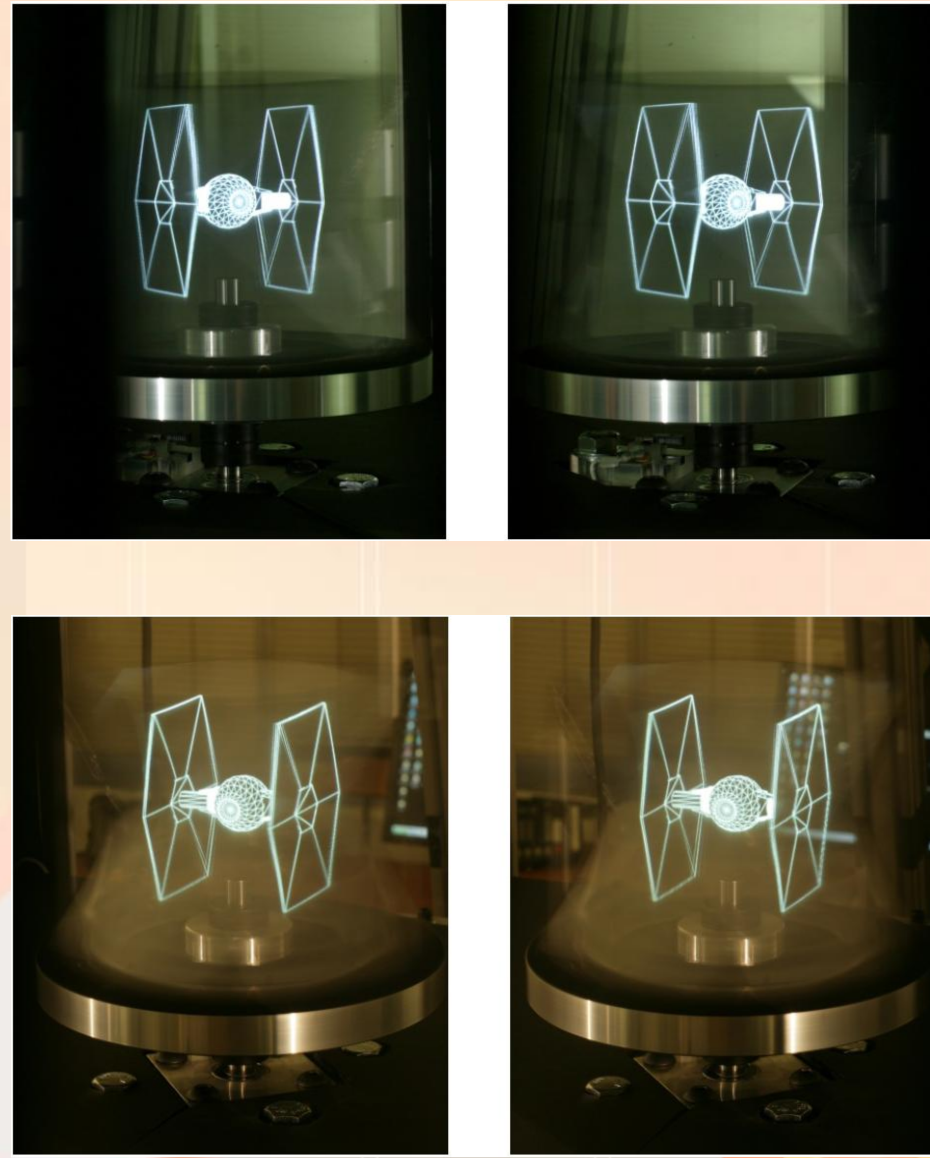
O. S. Cossairt, J. Napoli, S. L. Hill, R. K. Dorval and G. E. Favalora, 2007. Occlusion-capable multiview volumetric three-dimensional display. *Applied Optics 46*, 8 (Mar), 1244-1250.

Occlusion-Capable multiview volumetric 3D display

O. S. Cossairt, J. Napoli, S. L. Hill, R. K. Dorval and G. E. Favalora, 2007. Occlusion-capable multiview volumetric three-dimensional display. *Applied Optics 46*, 8 (Mar), 1244-1250.

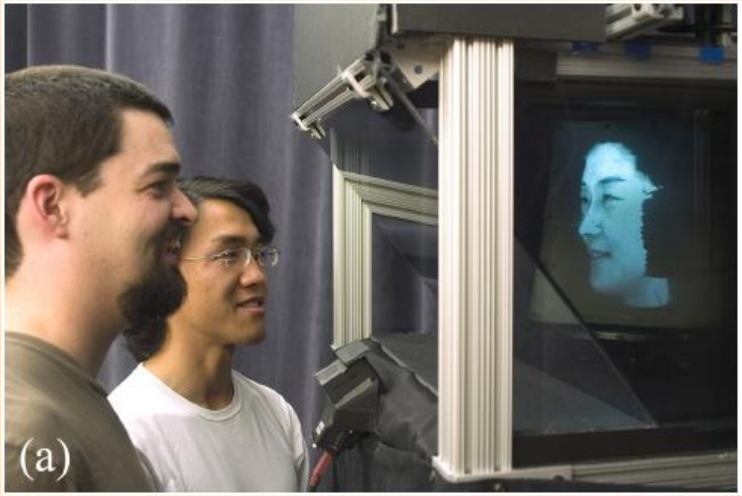
Interactive 360° light field display (1)

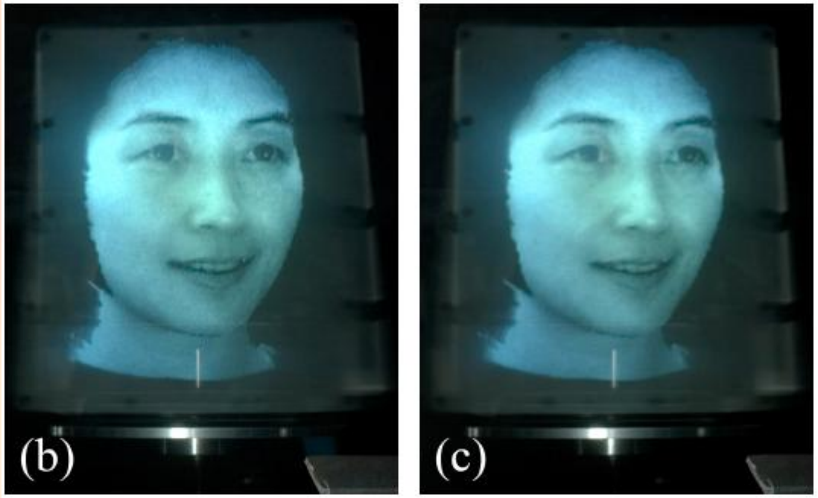




A. Jones, I. McDowall, H. Yamada, M. Bolas and P. Debevec, 2006. Rendering for an interactive 360 Light Field Display. In SIGGRAPH '07, San Diego.

Interactive 360° light field display (2)

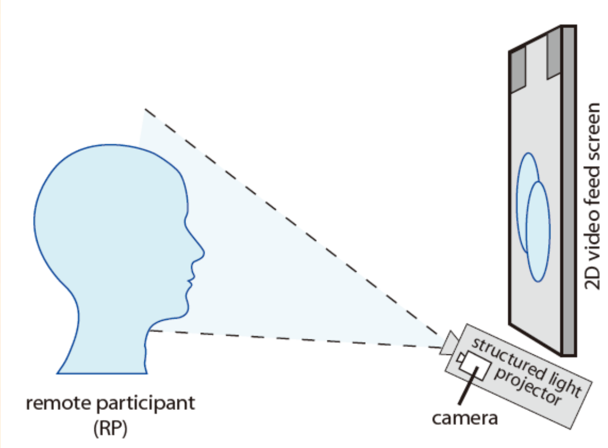




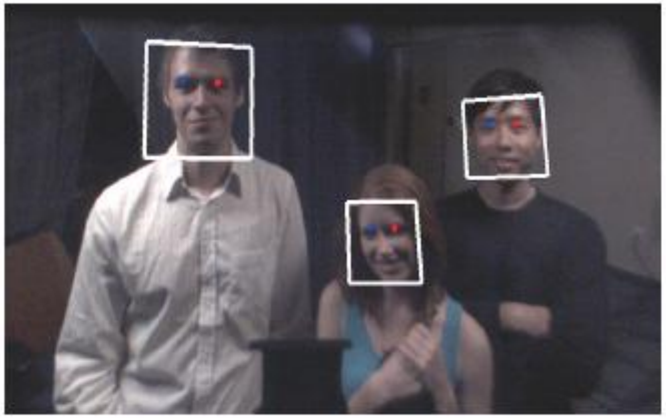
A. Jones, M. Lang, G. Fyffe, X. Yu, J. Busch, I. McDowall, M. Bolas, and P. Debevec, "Achieving eye contact in a one-to-many 3D video teleconferencing system," in SIGGRAPH '09, New Orleans.

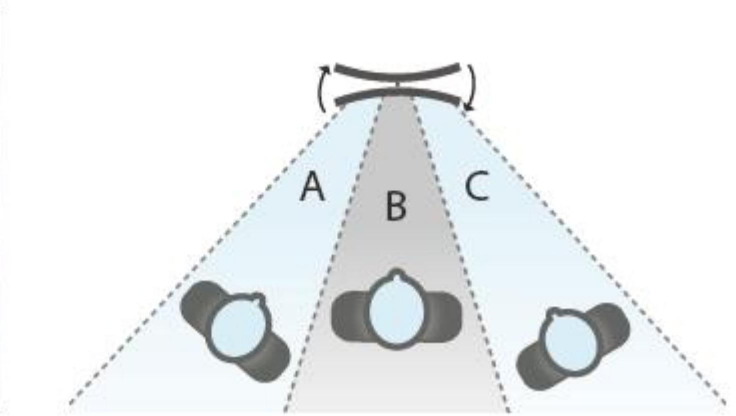
Interactive 360° light field display (2)

3D face scanning using structured light

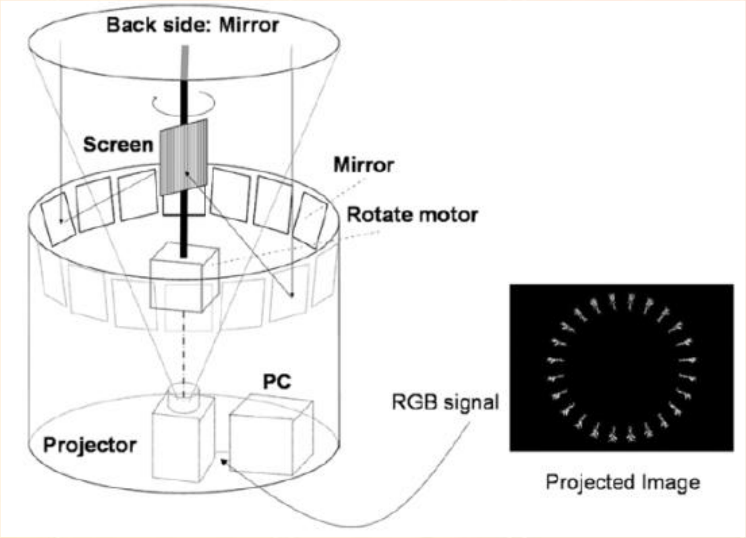


Face tracking of the audiences for correct vertical perspective





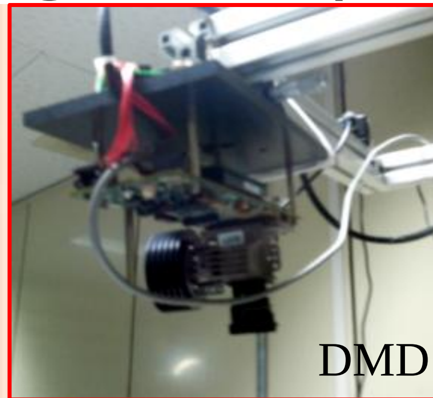
Directional scenes from mirrors (Hitachi)

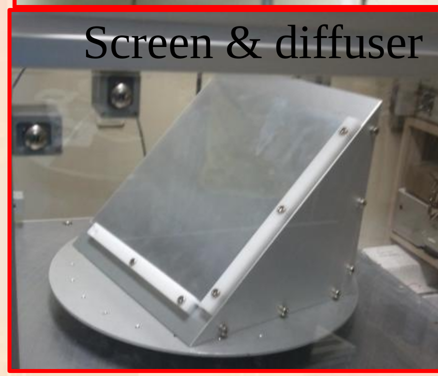


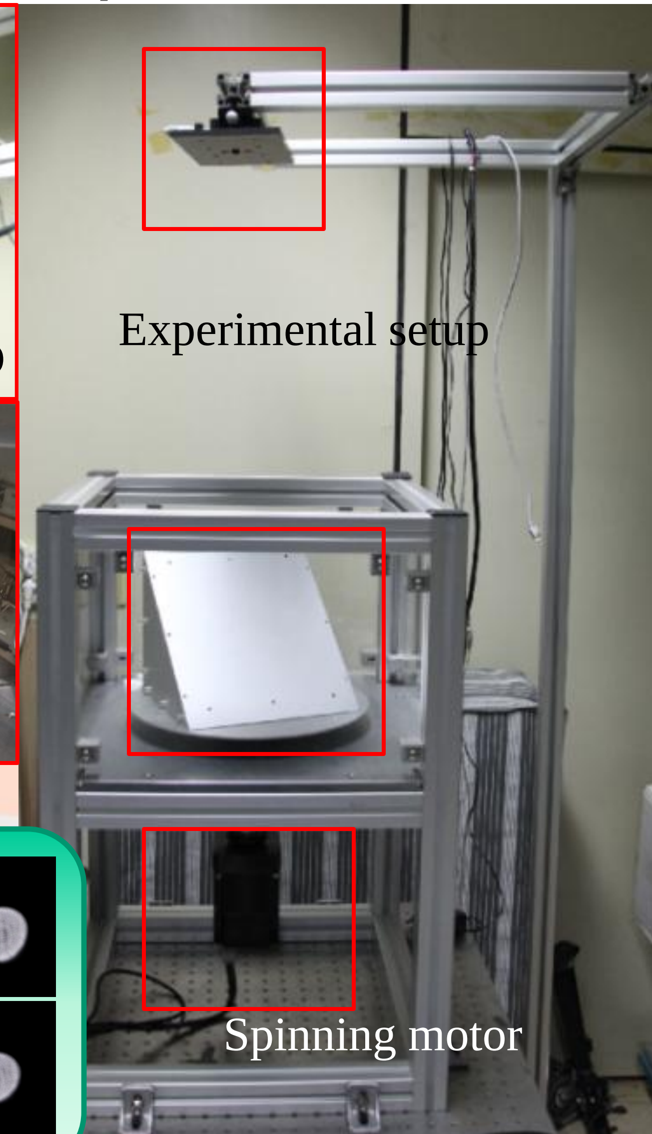
- Directionally reflective screen
- 24 views from 24 mirrors
- Frame rate : 60Hz

R. Otsuka, T. Hoshino and Y. Horry, “Transpost: 360°-Viewable Three dimensional Display System,” Proc. of IEEE, Vol. 94, No. 3, March 2006.

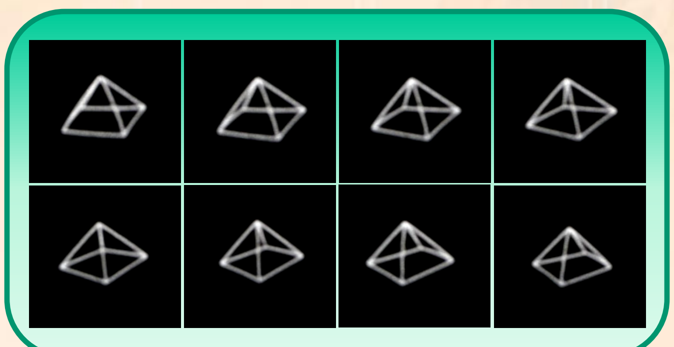
Light field display using DMD (SNU)







- DMD can change its pattern in 12.8Gbs.
- 270 view images and 15 Hz refresh rate
- Holographic diffuser and mirror are needed.
- Spinning motor speed is 300 rpm for safety.

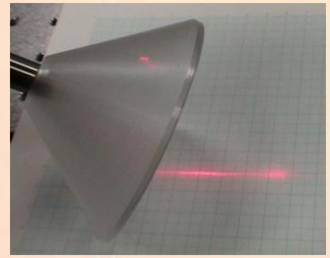


Experimental setup & results

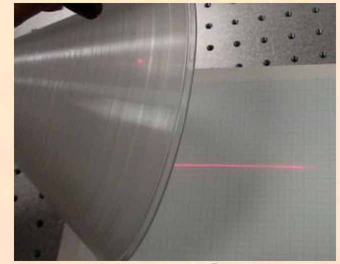
Glass-free table style 3D display (NICT)

Glasses-free table style 3D display for tabletop tasks

Diffusing power

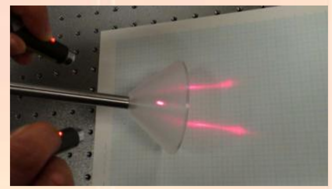


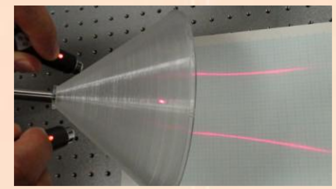
Cutting

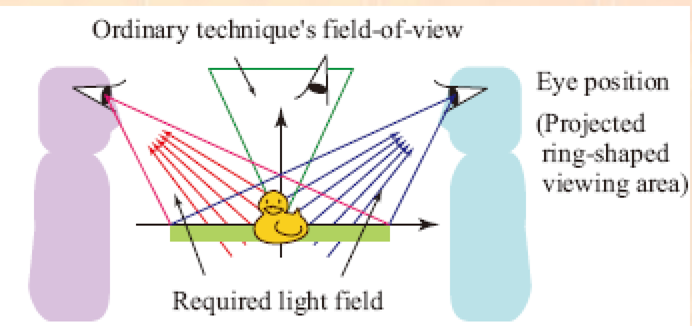


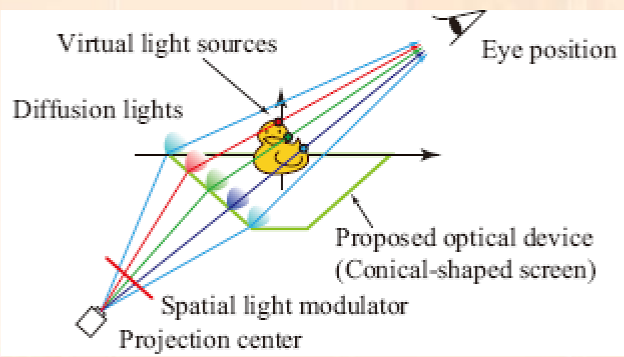
Winding

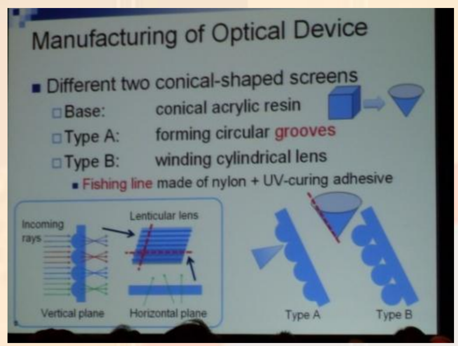
Straightness









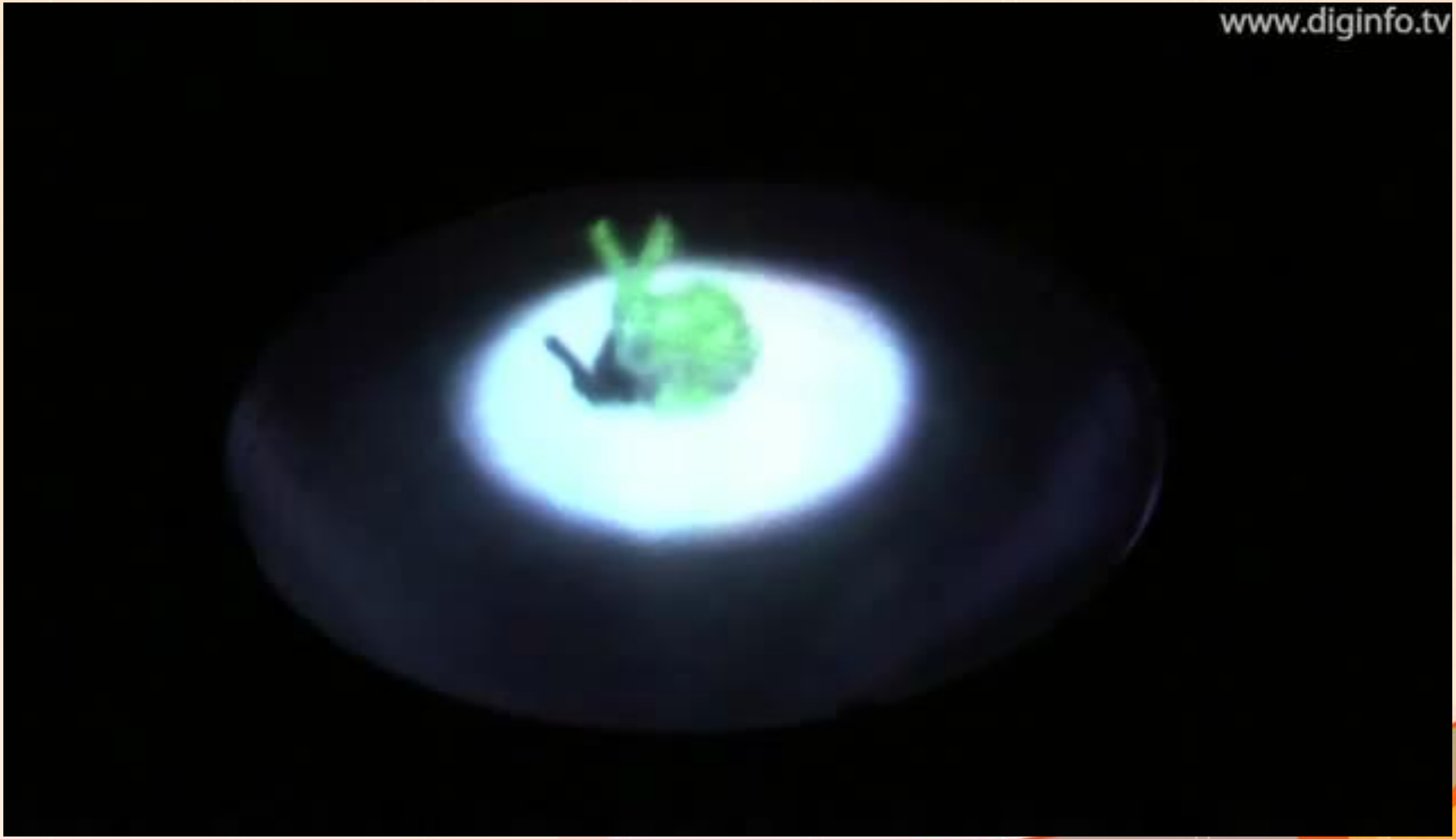


- 31 LCD micro projectors
- Refractive index of acrylic resin: 1.49
- Cutting
  - Diameter: 90 mm(upper), 20 mm(lower)
  - Height: 40 mm
  - Surface thickness: 3 mm
  - Groove pitch : 0.5 mm
  - Groove depth: 0.25 mm
- Winding
  - Diameter: 200 mm(upper), 20 mm(lower)
  - Height: 110 mm
  - Surface thickness: 2mm
  - Diameter of fish line: 0.4 mm
  - Refractive index: 1.58

Glass-free table style 3D display (NICT)

After image distortion compensation/ CG

SID 2010



Rotating LED array(Zhejiang University)

Volumetric display based on rotating LED array

- Large LED screen
  - Resolution: 320 × 256 color LED panel
  - Cylindrical display space: Φ 800 mm × 640 mm
- Color volumetric display: 64 colors per voxel
- High rotating speed: 15 circles per second
- Voxel number: 120 millions voxels
- 360° horizontal viewing field
- 180° vertical viewing angle

SID 2010

Present status of 3D display

Hardware system

Stereoscopic display
Autostereoscopic display
Volumetric display
Other recent techniques

3D optical film (3M) – backlight multiplexing

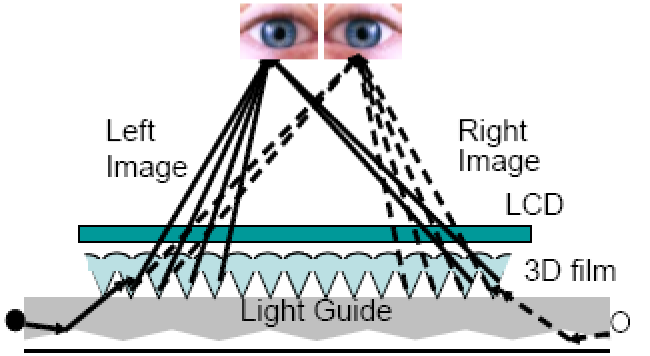
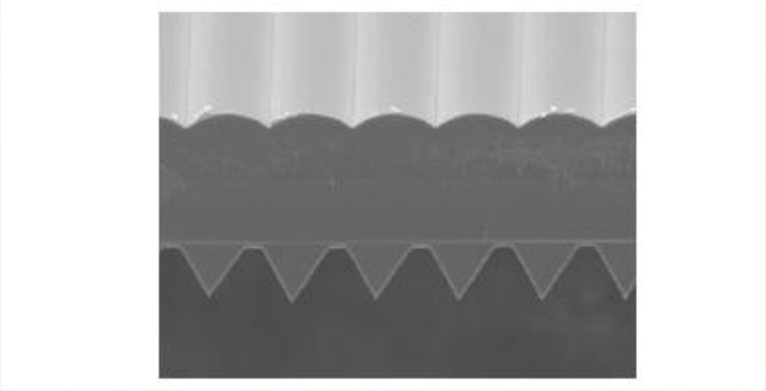


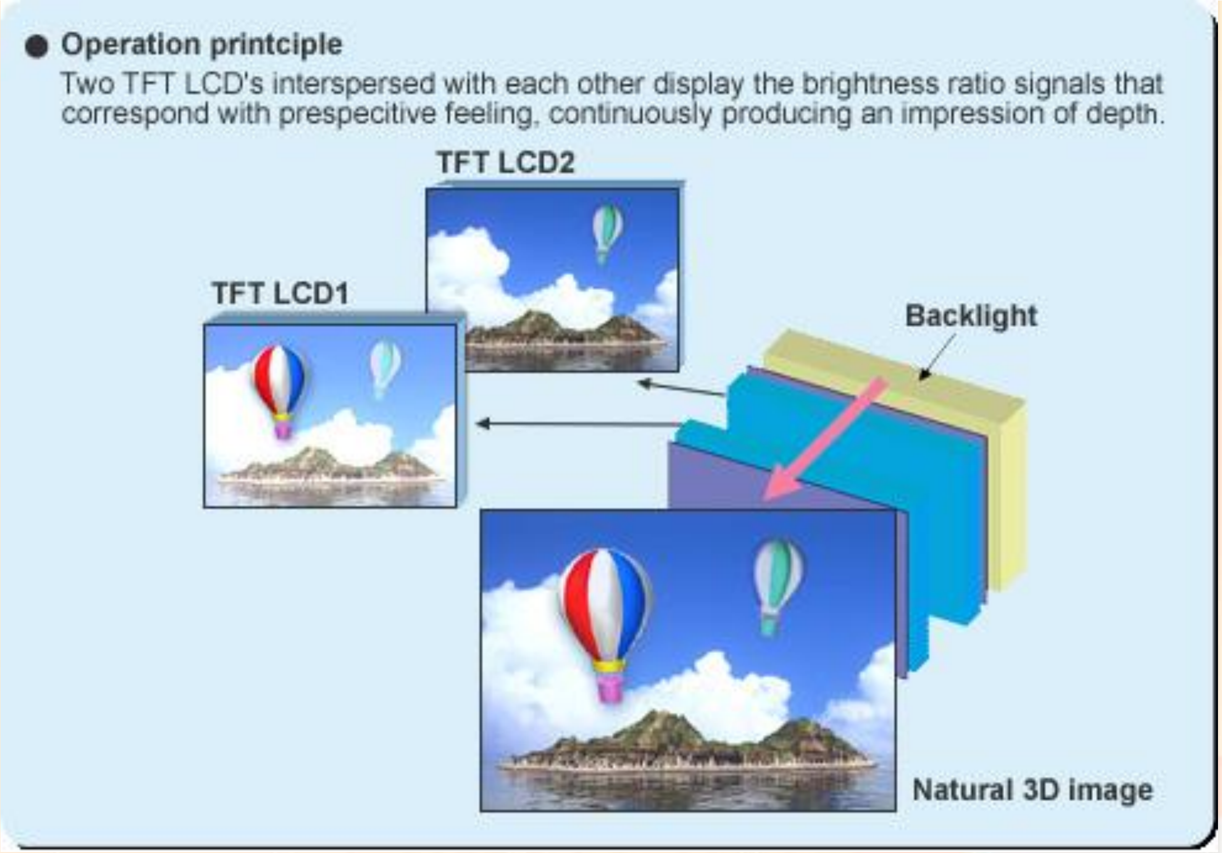
Figure 1: Operational concept of time-sequential autostereoscopic 3D display (not to scale).



1. Directional backlight
2. 3D film
3. 120Hz LCD Panel

Schultz, J.C., Brott, R., Sykora, M., Bryan, W., Fukami, T., Nakao, K., and Takimoto, A., "Full resolution autostereoscopic 3D display for mobile applications," SID Int. Symp. Digest Tech. Papers 40, 127-130 (2009).

Depth-fused 3-D display



Major features/targets

(1) Data amount is only 1.3 times larger than that of traditional 2D version display.
(2) Compact design where two TFT's are just layered.
Target market: Entertainment, on-vehicle applications
Mass production: 2006 (Scheduled)

[Major specification]	**9 inch wide high-definition LCD**
Pixels	**800(horizontal RGB)×480(vertical)**
Brightness	**200 cd/m^2**
Color reproducibility	**45%(Compared with NTSC)**

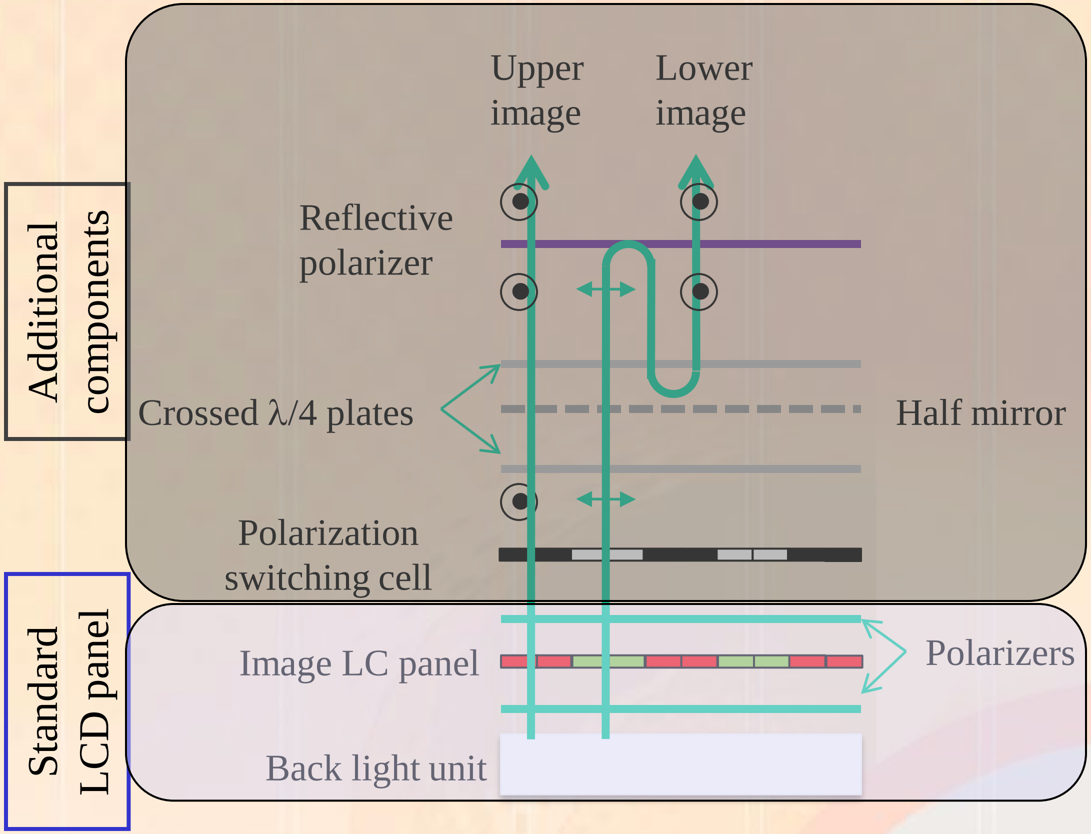
Depth-fused 3D display (two LCD panels)

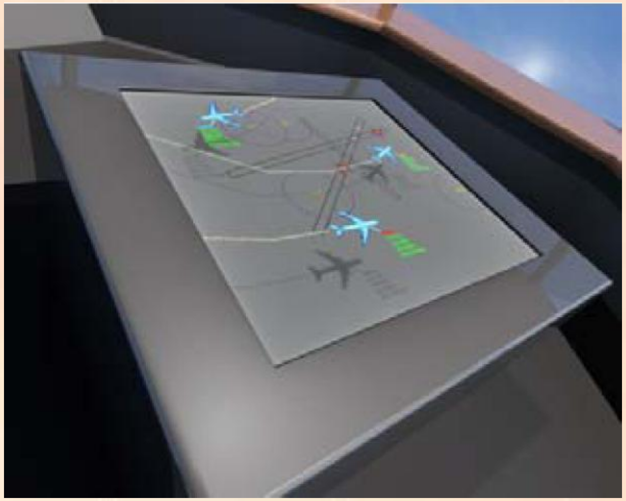
<Samsung>

- 22”
- Viewing angle 170°/160° (H/V)
- Brightness 200 cd/m^2
- Contrast ratio 1000:1

CeBIT 2007

Dual depth display





- Upper image: 50 %
- Lower image: 25 % (from standard LCD panel)

Walton, E., Evans, A., Gay, G., Jacobs, A., Wynne-Powell, T., Bourhill, G., Gass, P., and Walton, H., "Seeing depth from a single LCD," SID Int. Symp. Digest Tech. Papers 40, 1395-1398 (2009).

Super multi-view projection (Takaki group)

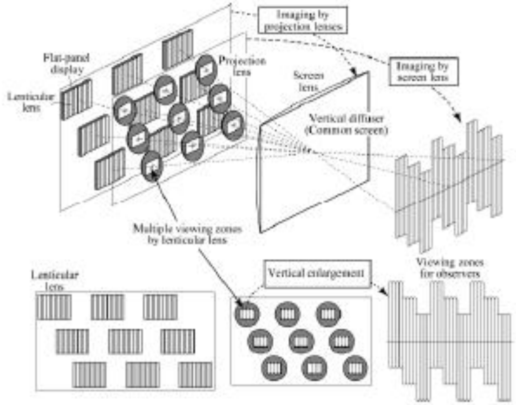


Fig. 1. SMV display system that combines multiple flat-panel systems by a multi-projection system.

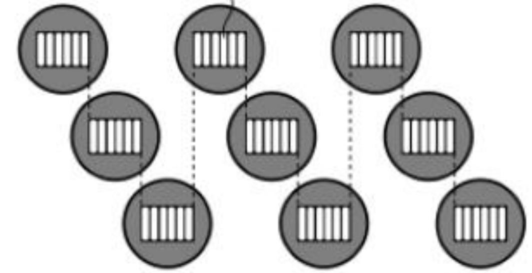
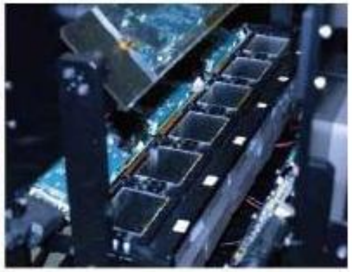


Fig. 4. Arrangement of projection lenses and viewing zones in lens apertures.

(b)



(c)

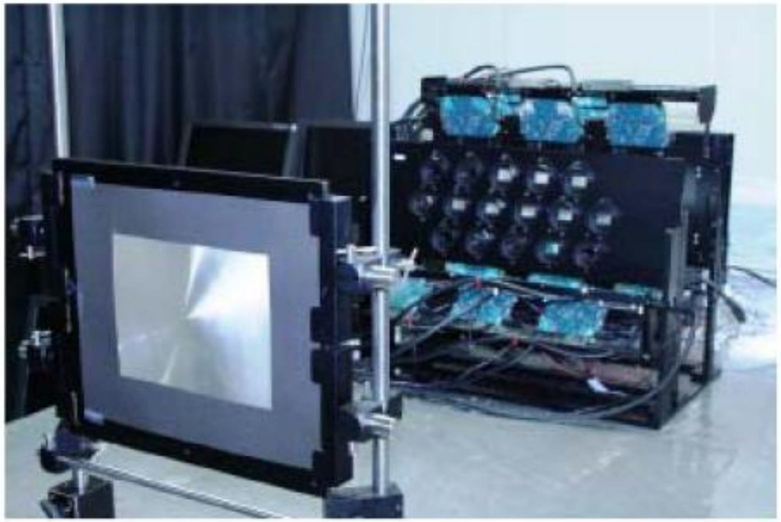


Fig. 9. Photograph of SMV256.

Super multi-view projection (Takaki group)

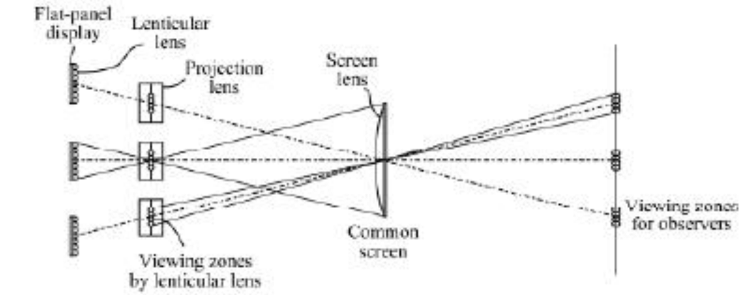


Fig. 2. Horizontal sectional view of the proposed SMV display system.

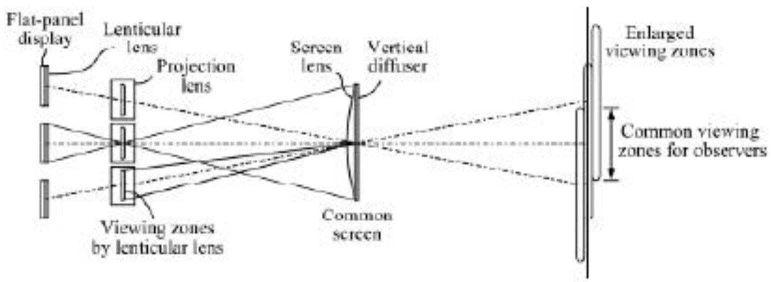
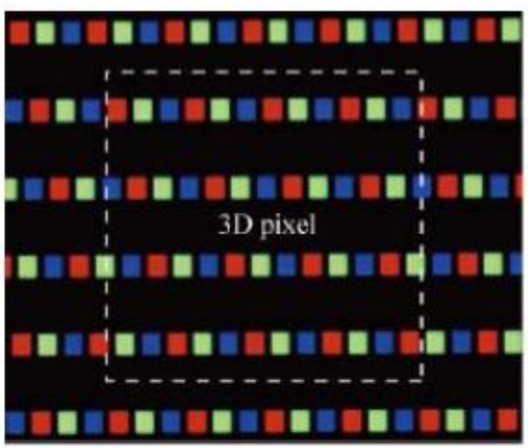


Fig. 3. Vertical sectional view of the proposed SMV display system.



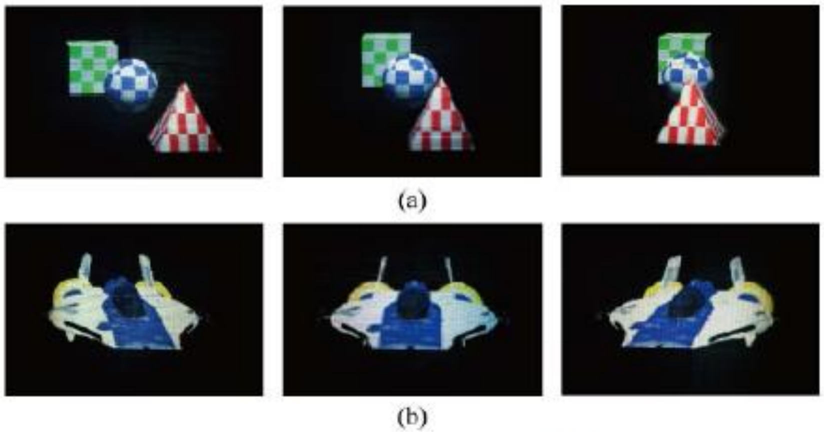


Fig. 11. 3D images produced by SMV256: (a) three objects (Media 1), and (b) spaceship (Media 2).

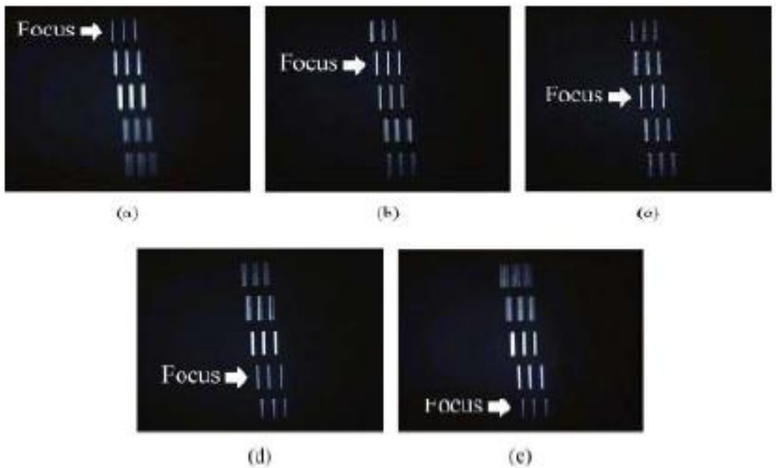


Fig. 12. Focusing on three lines at different depth positions produced by SMV256. The camera focuses on three lines at distances of (a) + 250 mm, (b) + 150 mm, (c) 0 mm, (d) −400 mm, and (e) −800 mm.

Laser plasma display

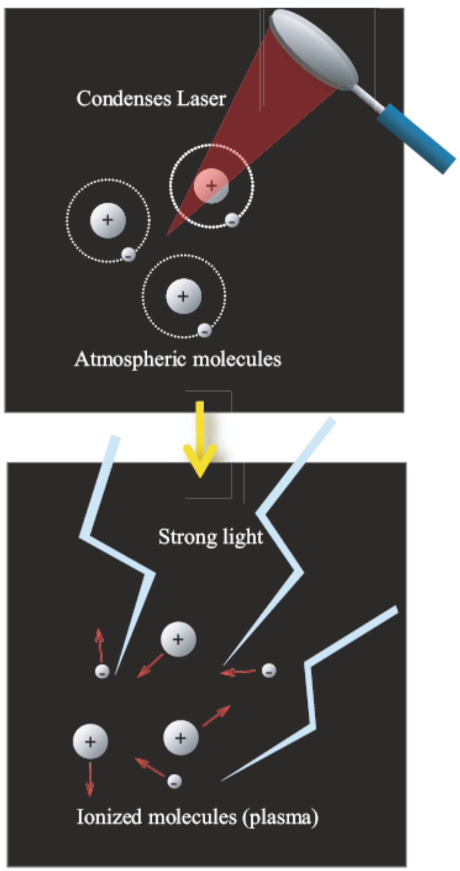


Figure 2. The plasma emission phenomenon. When strong laser beam is focused in midair, molecules are ionized (it is plasma) and strong light is emitted.

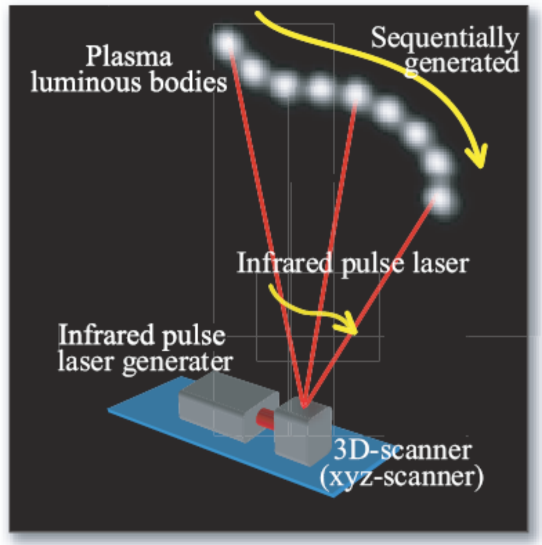
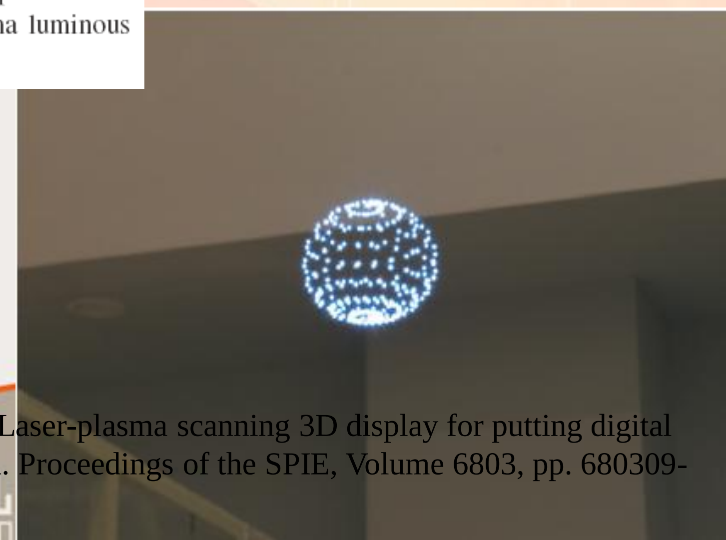


Figure 3. The drawing system mechanism. The 3D display device consists of an infrared one kilohertz pulse laser generator and a 3D-scanner(xyz-scanner). By controlling the laser, plasmas are created at the required position. When many plasma luminous bodies are drawn fast enough (1000 point/sec).



H. Saito, H. Kimura, S. Shimada, T. Naemura, J. Kayahara, et al., "Laser-plasma scanning 3D display for putting digital contents in free pace," Stereoscopic Displays and Applications XIX. Proceedings of the SPIE, Volume 6803, pp. 680309-680309-10 (2008).

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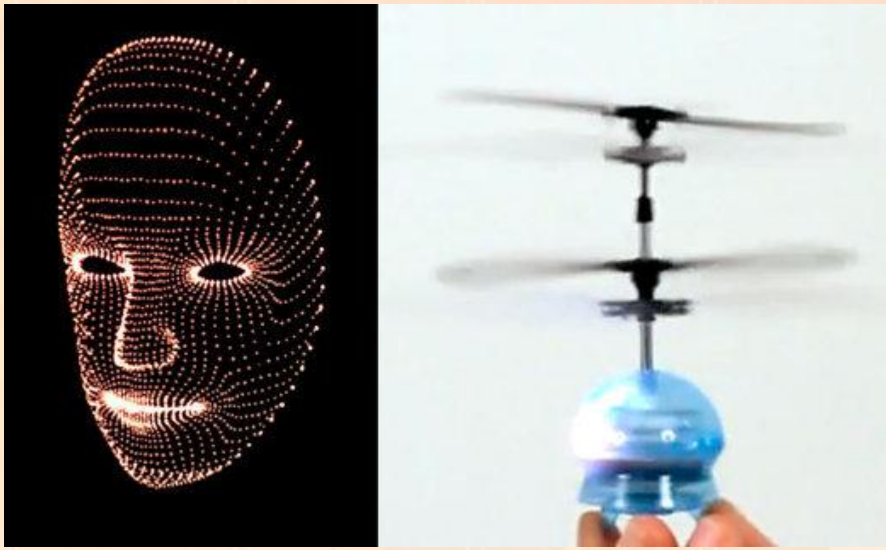
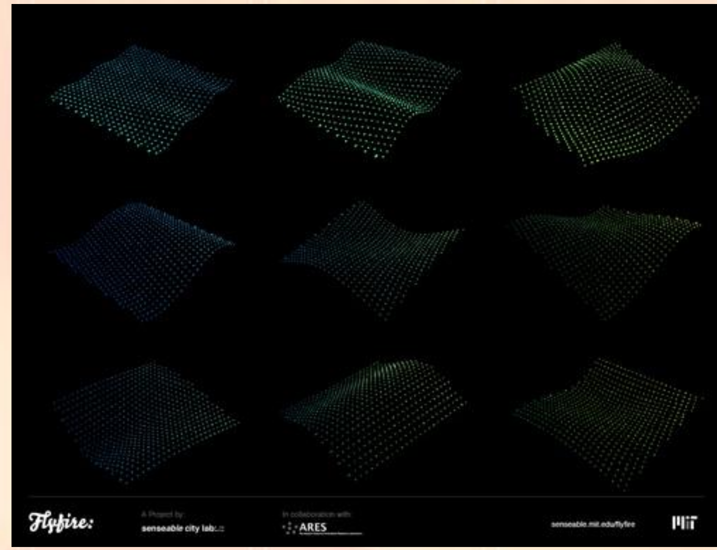
MIT's flyfire project





http://senseable.mit.edu/flyfire/

Present status of 3D display

Software system

3D information processing
3D correlator using 2D sub-images
2D to 3D conversion

3D information processing

- Depth extraction
  - J.-H. Park, Appl. Opt., **43**, 4882-4895, 2004.
  - G. Passalis, Appl. Opt., **46**, 5311-5320, 2007.

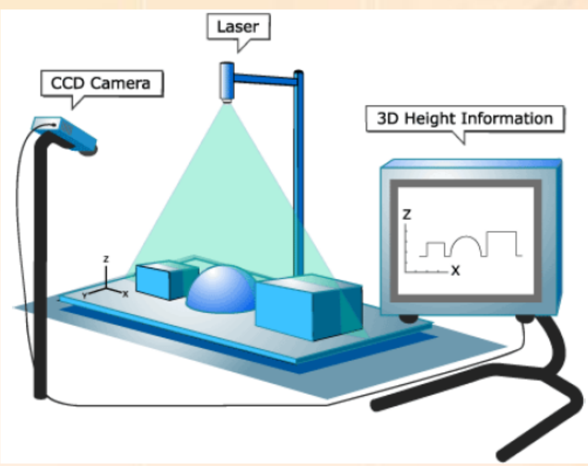
- Depth plane image reconstruction
  - S.-H. Hong, Opt. Express, **12**, 483-491, 2004.
  - S.-H. Hong, Opt. Express, **12**, 4579-4588, 2004.
  - D.-H. Shin, Opt. Express, **15**, 12039-12049, 2007.

- View image reconstruction
  - T. Naemura, Opt. Express, **8**, 255-262, 2001.
  - J.-H. Park, Opt. Express, **16**, 8800-8813, 2008.
  - J.-H. Jung, Opt. Express, **18**, 26373-26387, 2010.

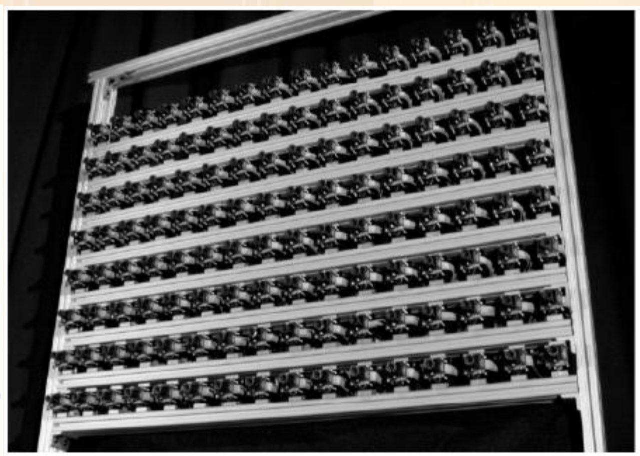
3D view image capture method

- **Active sensor based method**
  - Laser scanner
  - Time-Of-Flight (TOF) sensor (ex. Z-cam)
  - Structured light
- **Passive sensor based method**
  - Multi-camera triangulation, lens array
  - Light field camera
- **Active and passive fusion method**
  - Depth camera + passive camera (single, stereo, multi-view)

< Depth camera (TOF) + stereo camera >



< Structured light system >

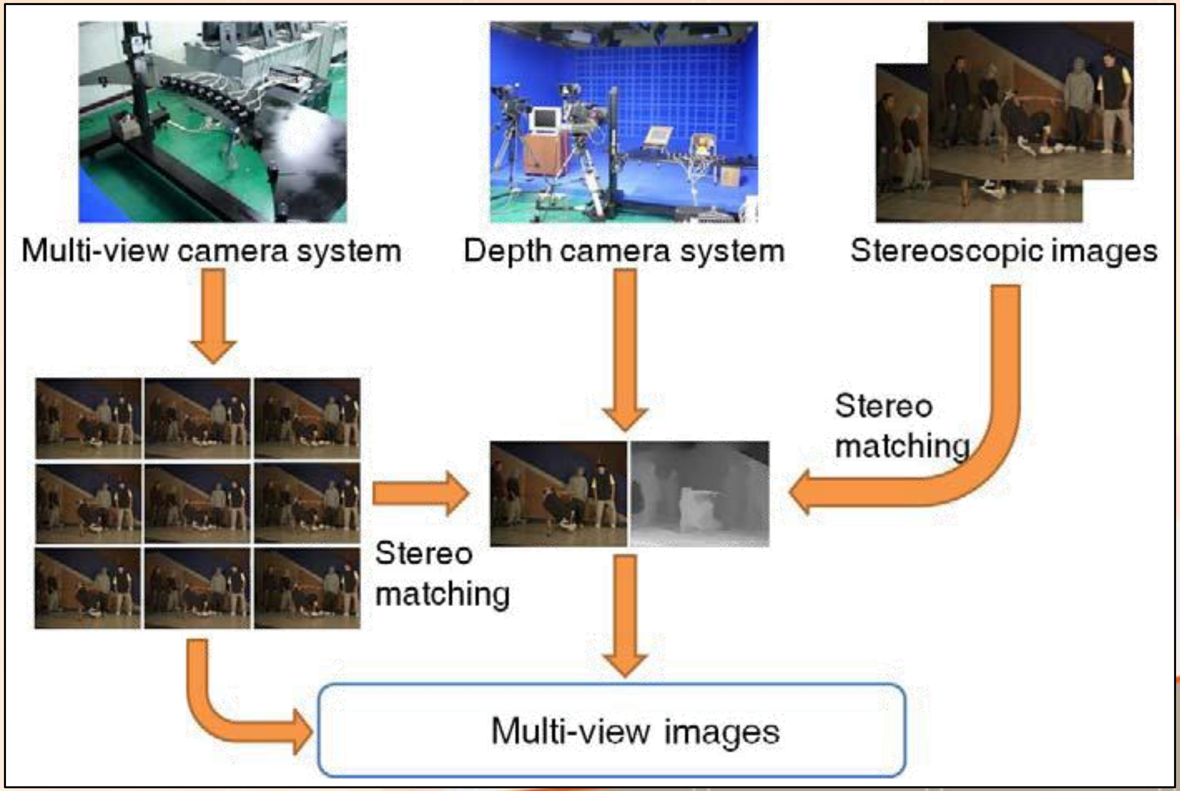


< Multi-view camera array >

< Hexagonal lens array >

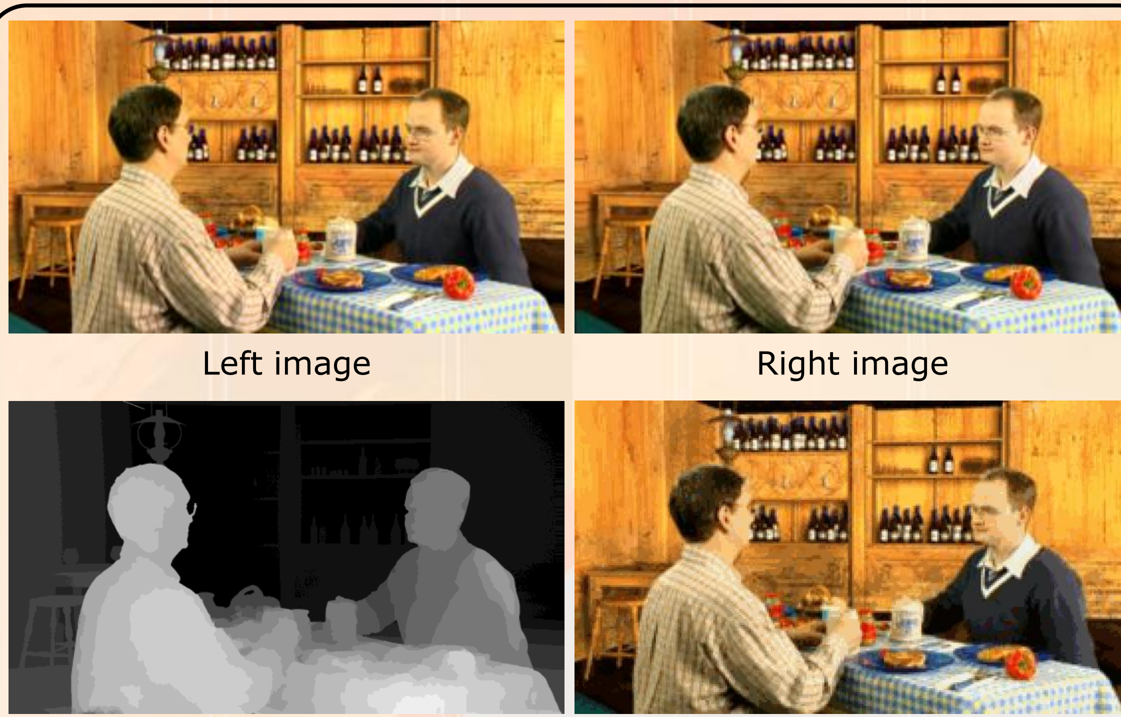
View image generation method

- **View image generation method**
  - Stereo, multi-camera system : Depth extraction using stereo matching
    - Wide viewing angle, direct display (multi-view display)
    - Complex encoding, wideband transmission technique, alignment problem
  - Depth camera system : Depth camera + multi- camera → Depth image-based rendering (DIBR)
    - Texture (single, stereo, multi) and depth map
    - **DIBR**: Arbitrary view point setting, 3D warping, view image synthesis
    - Narrow viewing angle, occlusion problem, depth discontinuity



View image generation method

- **Synthesizing multi-view images based on DIBR**
  - Depth-image-based rendering (DIBR) is the process of synthesizing virtual views of a scene from still- or moving color images and associated per-pixel depth information.
  - The original image points are reprojected into the 3D world, utilizing the respective depth data.
  - 3D warping: 3D space points are projected into the image plane of a virtual camera, which is located at the required viewing position.
  - **The extraction of depth information is an essential issue in view image generation.**



Left image — Right image

Depth map (per-pixel) — Multi-view image (9 views)

C. Fehn, "Depth-Image-Based Rendering (DIBR), Compression and Transmission for a New Approach on 3D-TV," In Proceedings of SPIE Stereoscopic Displays and Virtual Reality Systems XI, pages 93-104, San Jose, CA, USA, January 2004.

Extraction of depth map (Z-cam, TOF principle)

- **Zcam specification**

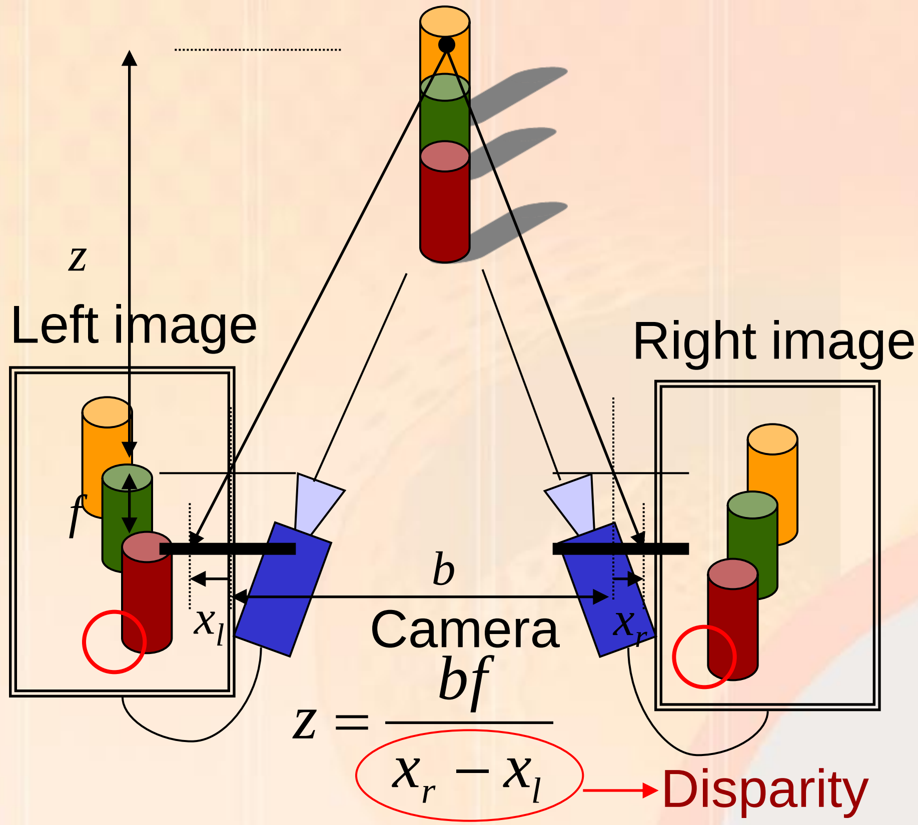
  Depth sensor format : VGA, QVGA, QQVGA
  RGB sensor format : 1.3M pixel, VGA
  Operating range : 0.5~2.5m
  Range resolution : 8bit
  Resolvable depth : 1~2cm
  Field of view : 60 deg(diagonal)
  Frame rate : 60fps
  Dimension : 85(W)×90(H)×62(D) mm

3DV Systems

Microsoft

Depth extraction from planar images

Multi-camera method ⇨ Extract 3D information from two or more perspective images

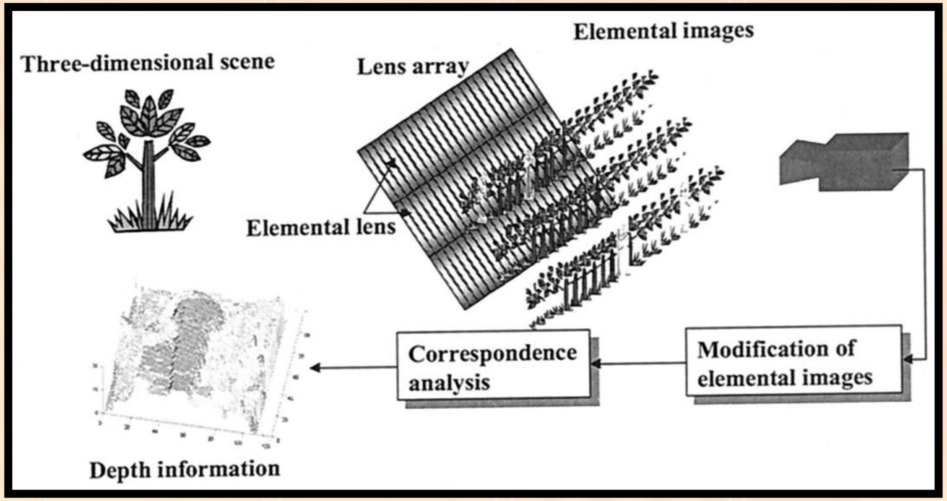


$$z = \frac{bf}{x_r - x_l}$$

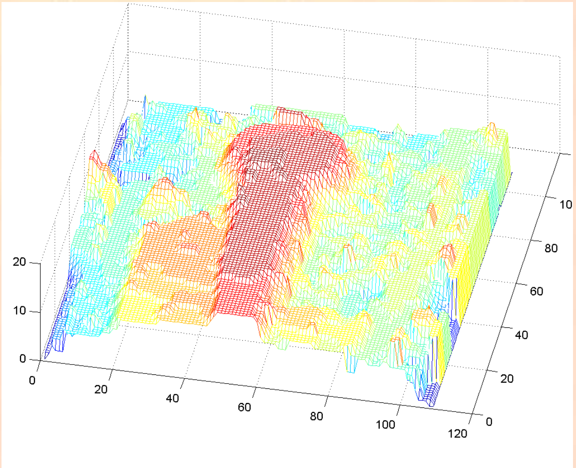
→ Disparity

- **Camera modeling**
- **Image acquisition**
- **Feature extraction**
- **Correspondence analysis**
- **Post-processing**
- **Disparity acquisition**
- **3D depth recovery**

Depth extraction in integral imaging

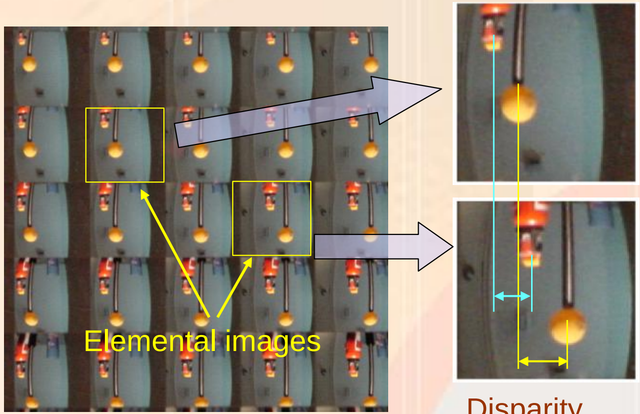


Depth extraction process



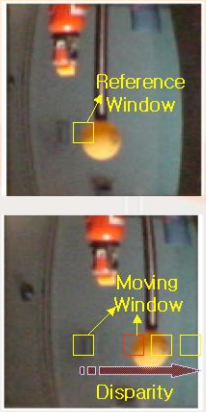
Depth information

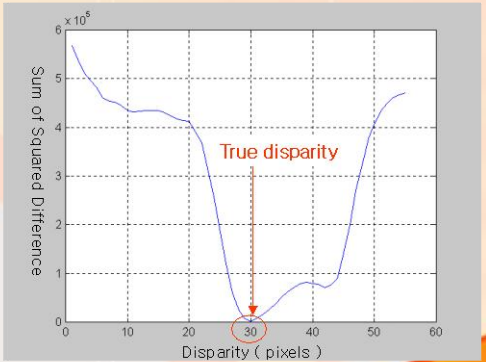
3D scene



Disparity

Elemental image

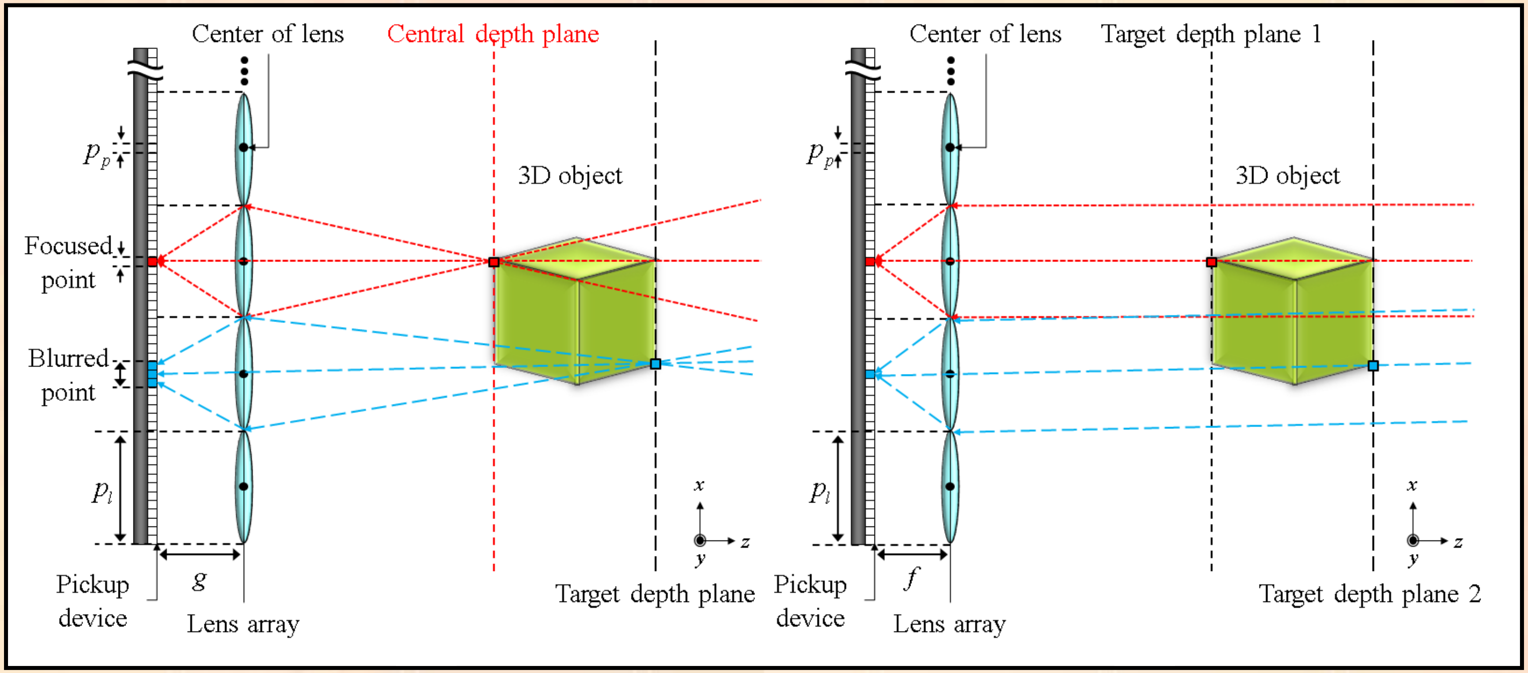




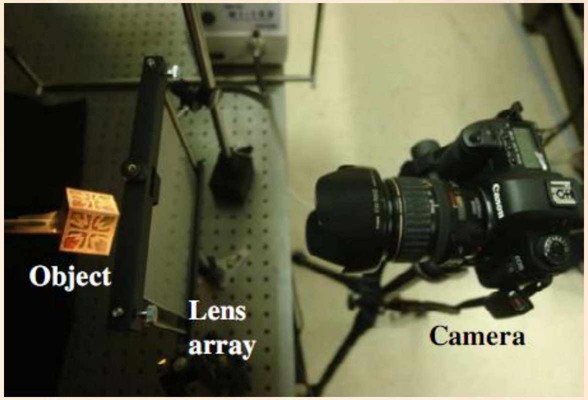
Correspondence analysis

J.-H. Park, S. Jung, H. Choi, Y. Kim, and B. Lee, "Depth extraction by use of a rectangular lens array and one-dimensional elemental image modification," Applied Optics, vol. 43, no. 25, pp. 4882-4895, 2004.

Depth extraction in integral imaging (pickup)



Real mode pickup **Focal mode pickup**



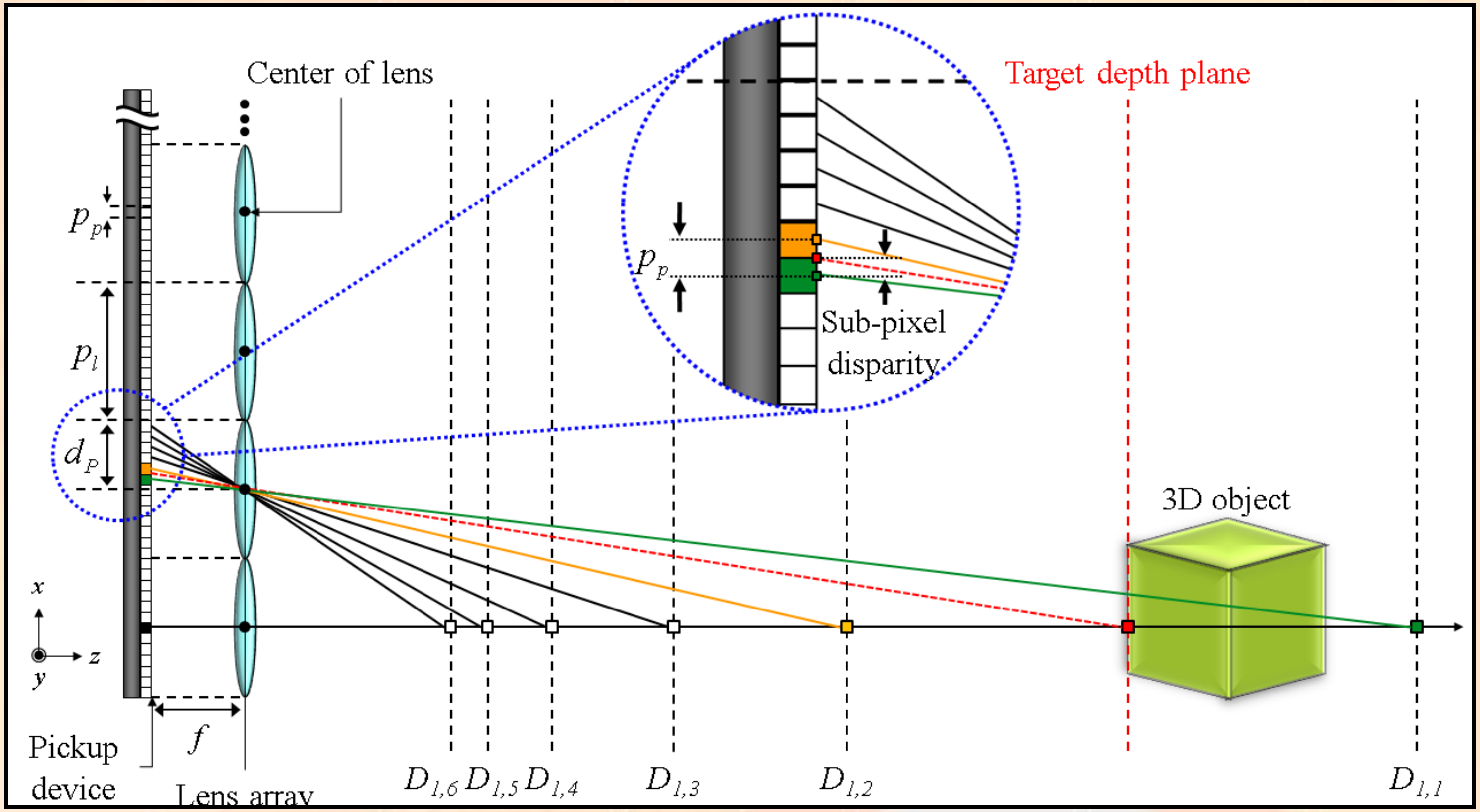
Experimental setup for pickup

- Real mode pickup – depth extraction near the central depth plane
  - Extracted depth limitation

$$D_{CDP} = \frac{fg}{g - f}.$$

- Focal mode pickup – infinite extracted depth range
  - Low resolution pickup image

Depth quantization problem in integral imaging

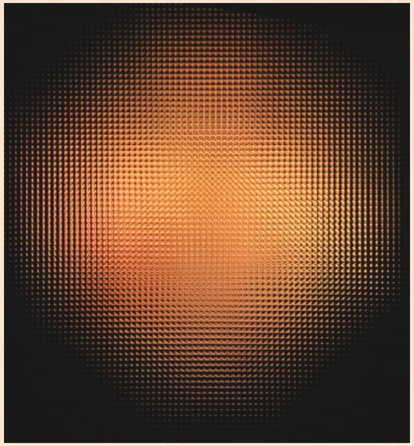


- Depth extraction in integral imaging

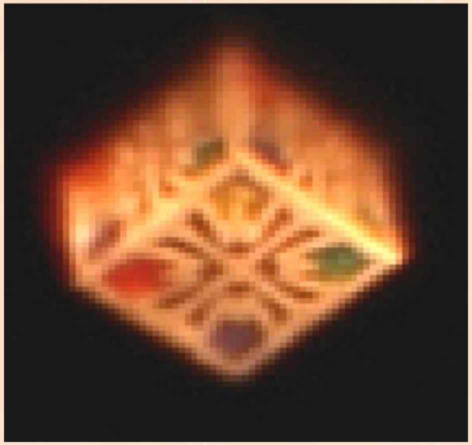
$$D_{d_l,d_p} = \frac{f d_l p_l}{d_P p_p}, \ (d_l = 1)$$

- Sum of squared difference (SSSD) is common method in finding corresponding points.
- Extracted depth map is quantized by the finite size of pixels.
- **The depth extraction method based on sub-pixel disparity is key issue in depth extraction of integral imaging.**

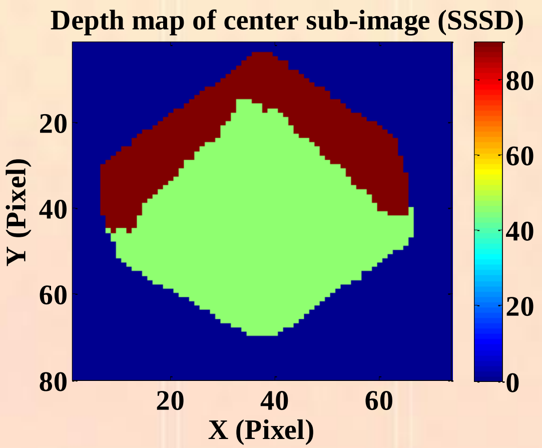
Depth quantization problem in integral imaging



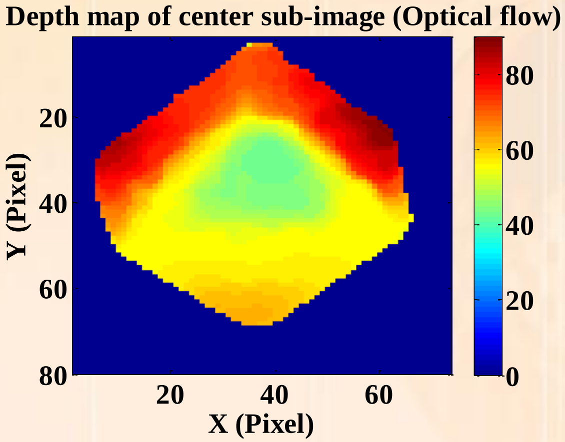
Elemental image



Center sub-image



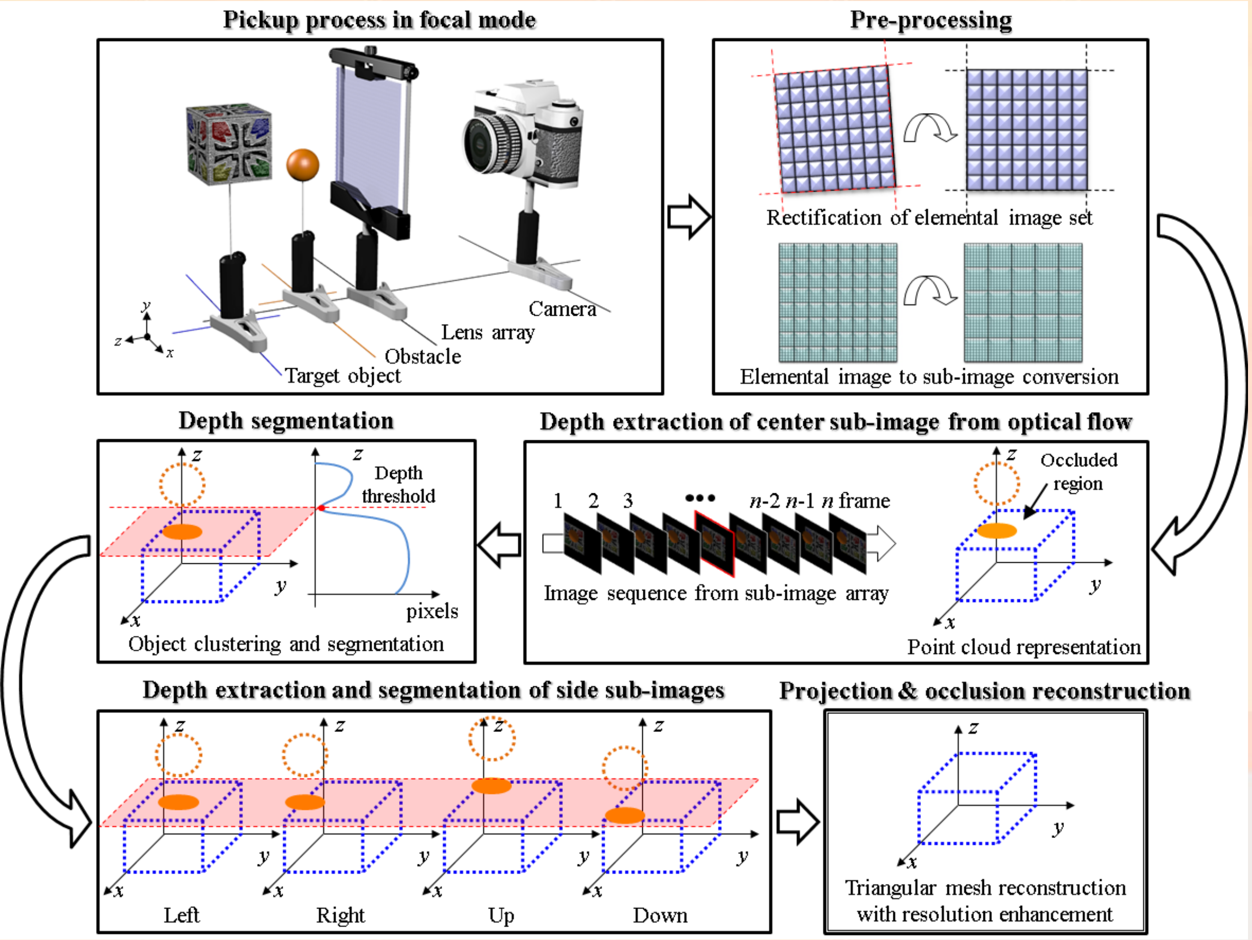
Extracted depth map (SSSD)



Extracted depth map (Optical flow)

- Improvement of depth extraction in integral imaging using optical flow
  - Conversion of elemental image to sub-image for reducing distortion in perspective geometry
  - Finding the corresponding points with sub-pixel accuracy using optical flow algorithm
  - Gathering of the depth information between each sub-images
  - The depth map from the conventional method (SSSD) is quantized and has discontinuity. However, the optical flow based method can calculate more accurate and continuous depth map than the conventional method.

Reconstruction of occluded object in integral imaging



Process of occluded reconstruction in integral imaging

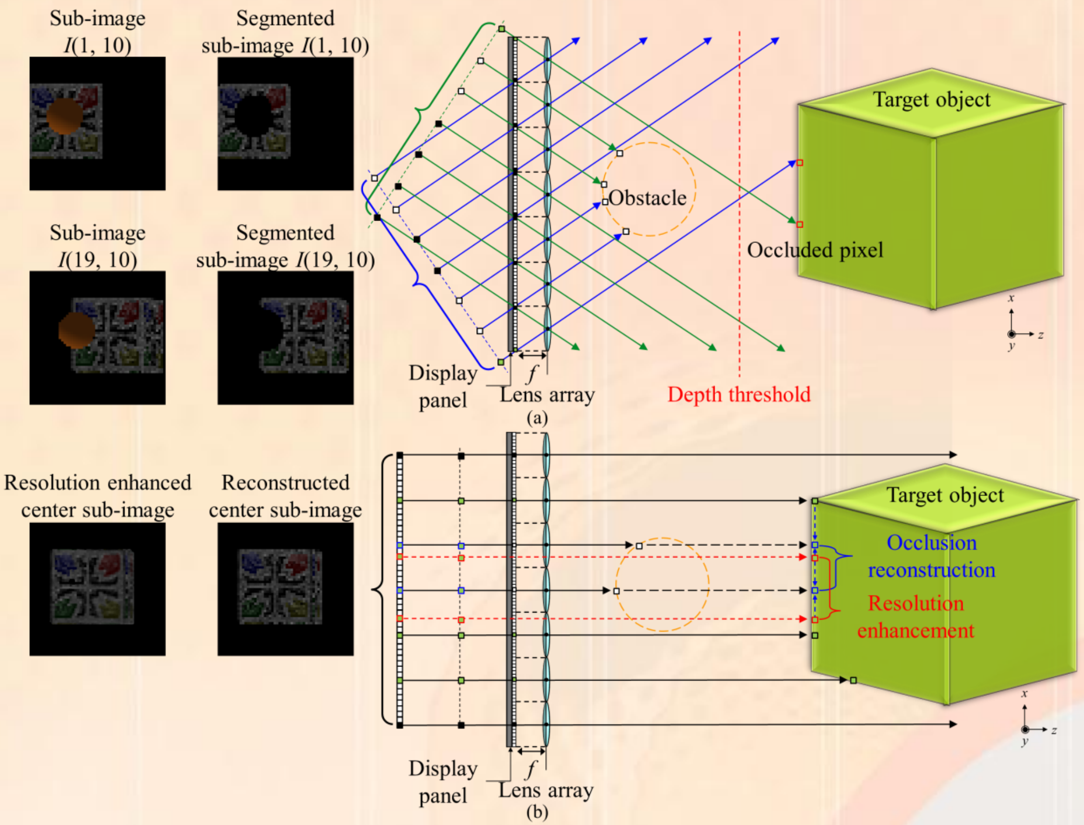
Occluded image

Reconstructed image

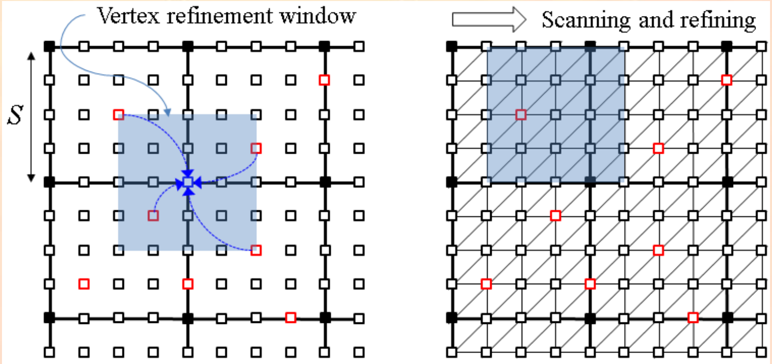
- **Occluded 3D object reconstruction using depth extraction and triangular mesh reconstruction in integral imaging**
- Depth extraction based on optical flow with sub-pixel accuracy in sub-image
- Object clustering and segmentation
- Triangular mesh reconstruction with resolution enhancement

J.-H. Jung, K. Hong, G. Park, I. Chung, J.-H. Park, and B. Lee, "Reconstruction of three-dimensional occluded object using optical flow and triangular mesh reconstruction in integral imaging," Optics Express, vol. 18, no. 25, pp. 26373-26387, 2010.

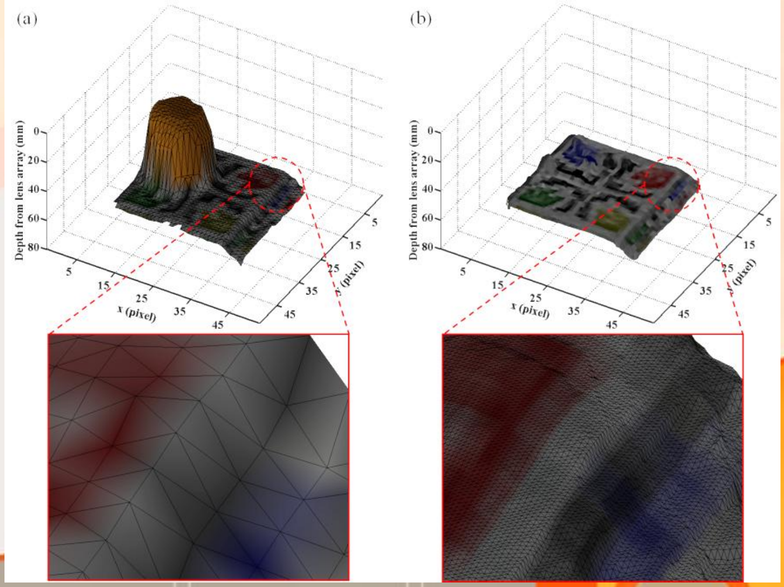
Reconstruction of occluded object in integral imaging



Reconstruction of 3D occluded object using optical flow and triangular mesh reconstruction in integral imaging



- Refinement of vertex of occluded region in center sub-image using projected point clouds
- Resolution enhancement using refinement of all vertexes using point clouds in center sub-image and projected point clouds



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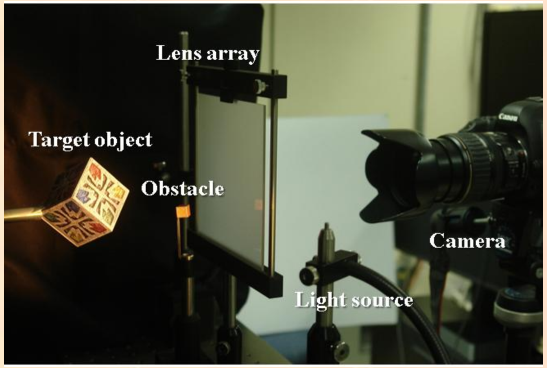
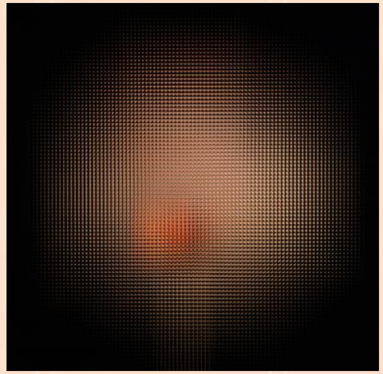
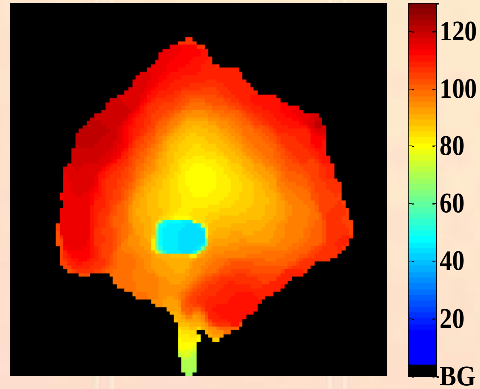
Reconstruction of occluded object (SNU)

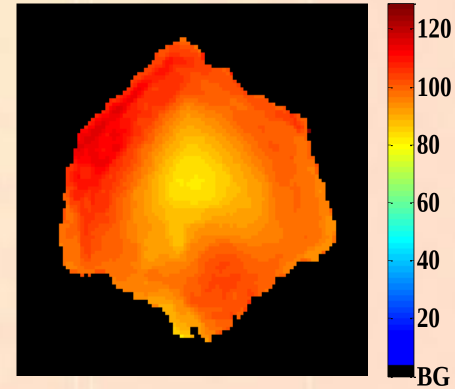


Experimental setup

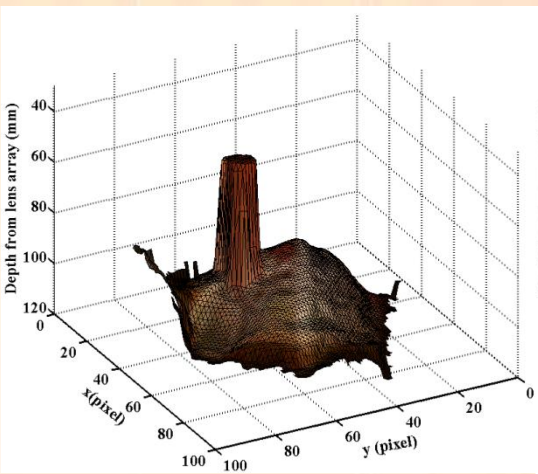

Elemental image



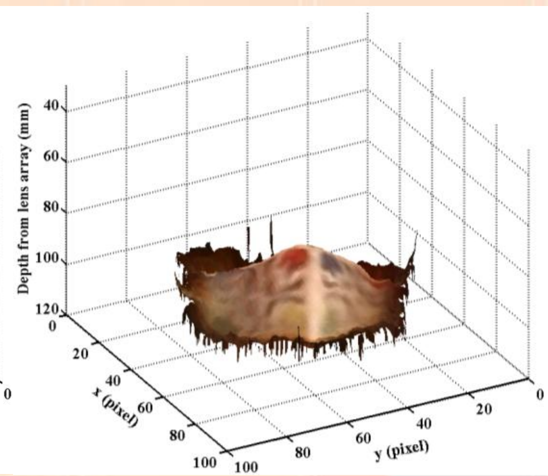
Extracted depth map (optical flow)



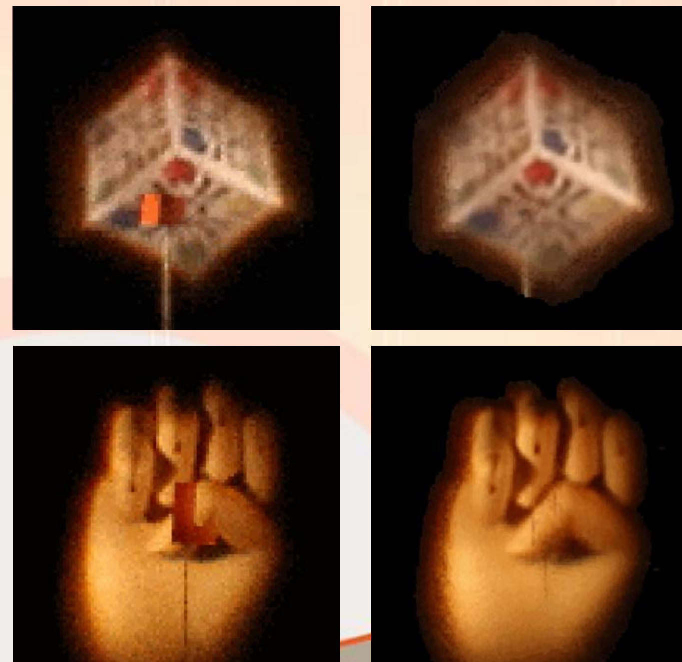
Reconstructed depth map with resolution enhancement



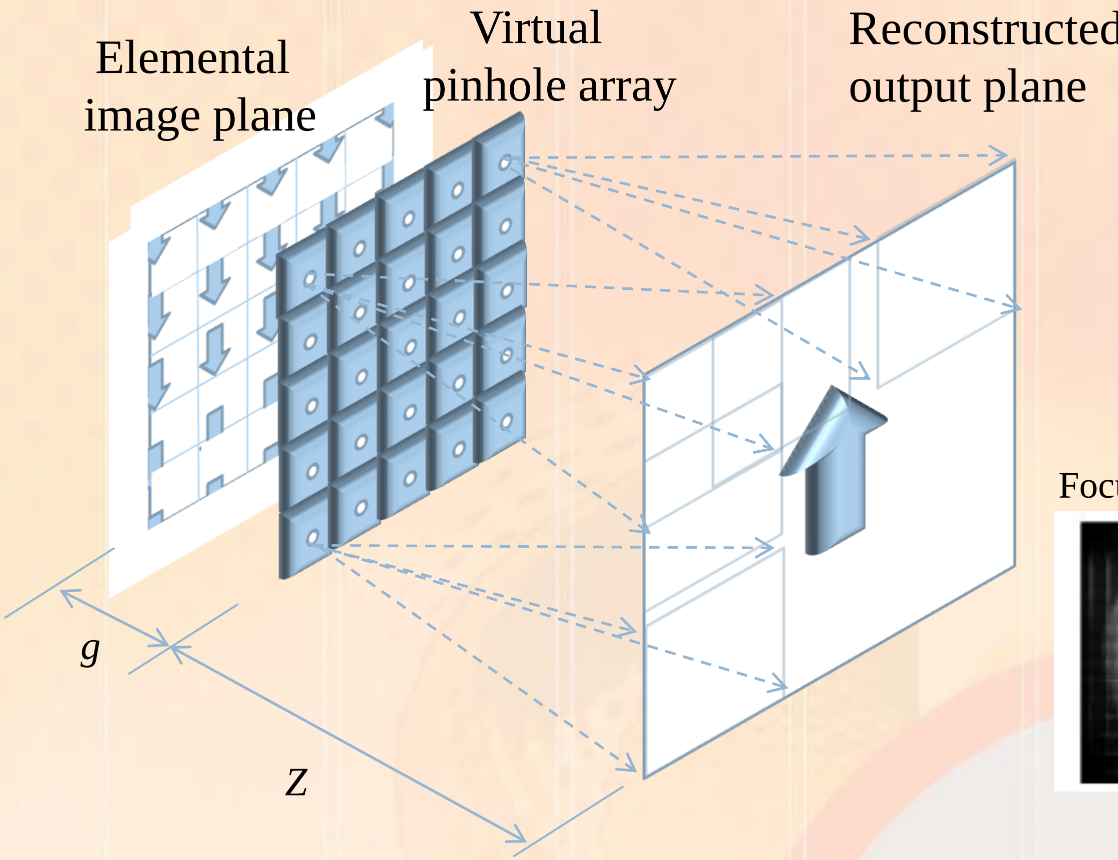
Triangular mesh reconstruction (occluded object)



Triangular mesh reconstruction (reconstructed object)

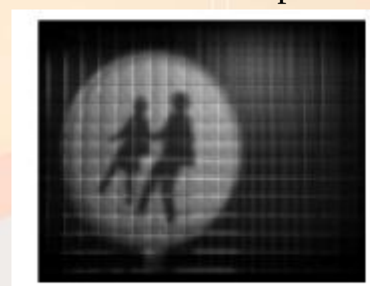

Occluded 3D object Reconstructed 3D object

Depth plane reconstruction (CIIR)

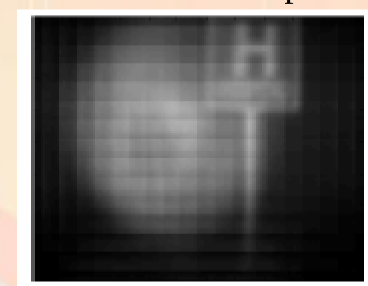


Original image (depth plane)

Focused on front plane

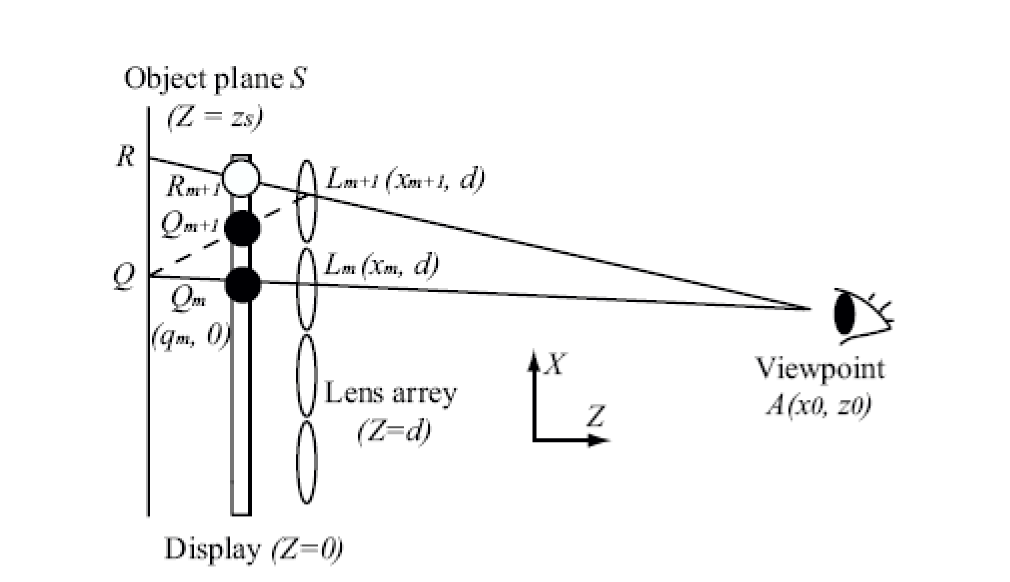


Focused on rear plane



S. Hong, J. Jang, and B. Javidi, "Three-dimensional volumetric object reconstruction using computational integral imaging," Opt. Express 12, 483-491 (2004)

View image reconstruction



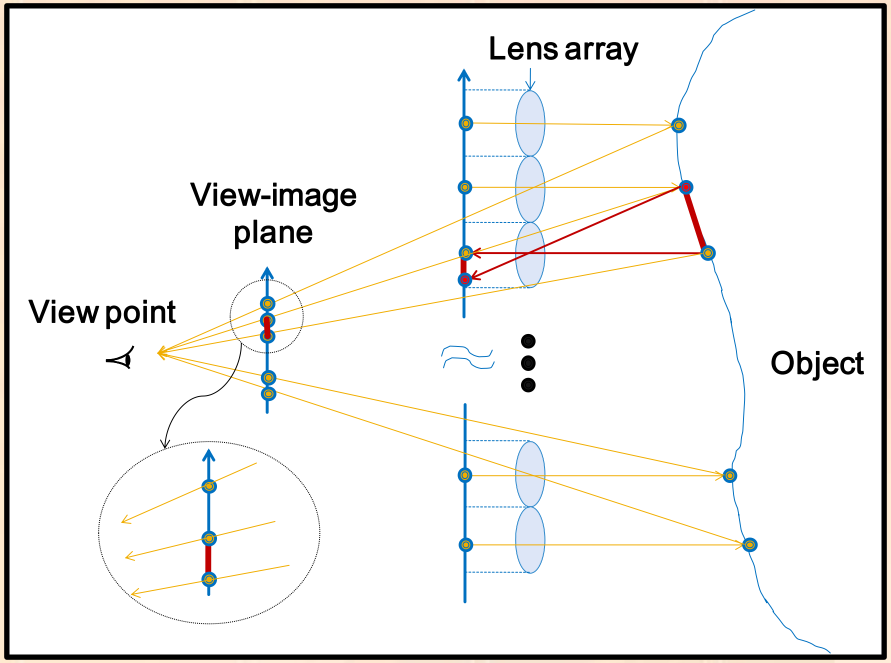
Synthesized arbitrary views from integral photography images captured by HDTV camera

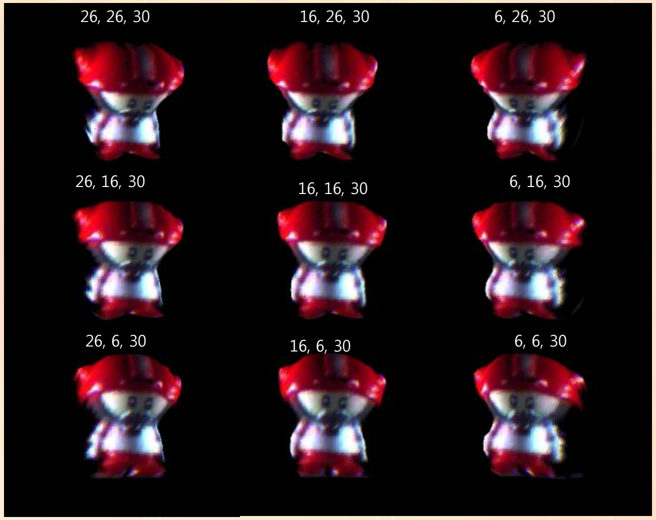
Focused on rear plane

Focused on front plane

T. Naemura, T. Yoshida, and H. Harashima, "3-D computer graphics based on integral photography," Opt. Express 8, 255-262 (2001)

View image reconstruction





Arbitrary view image generations in perspective and orthographic geometry based on integral imaging system with high resolution and wide field of view.

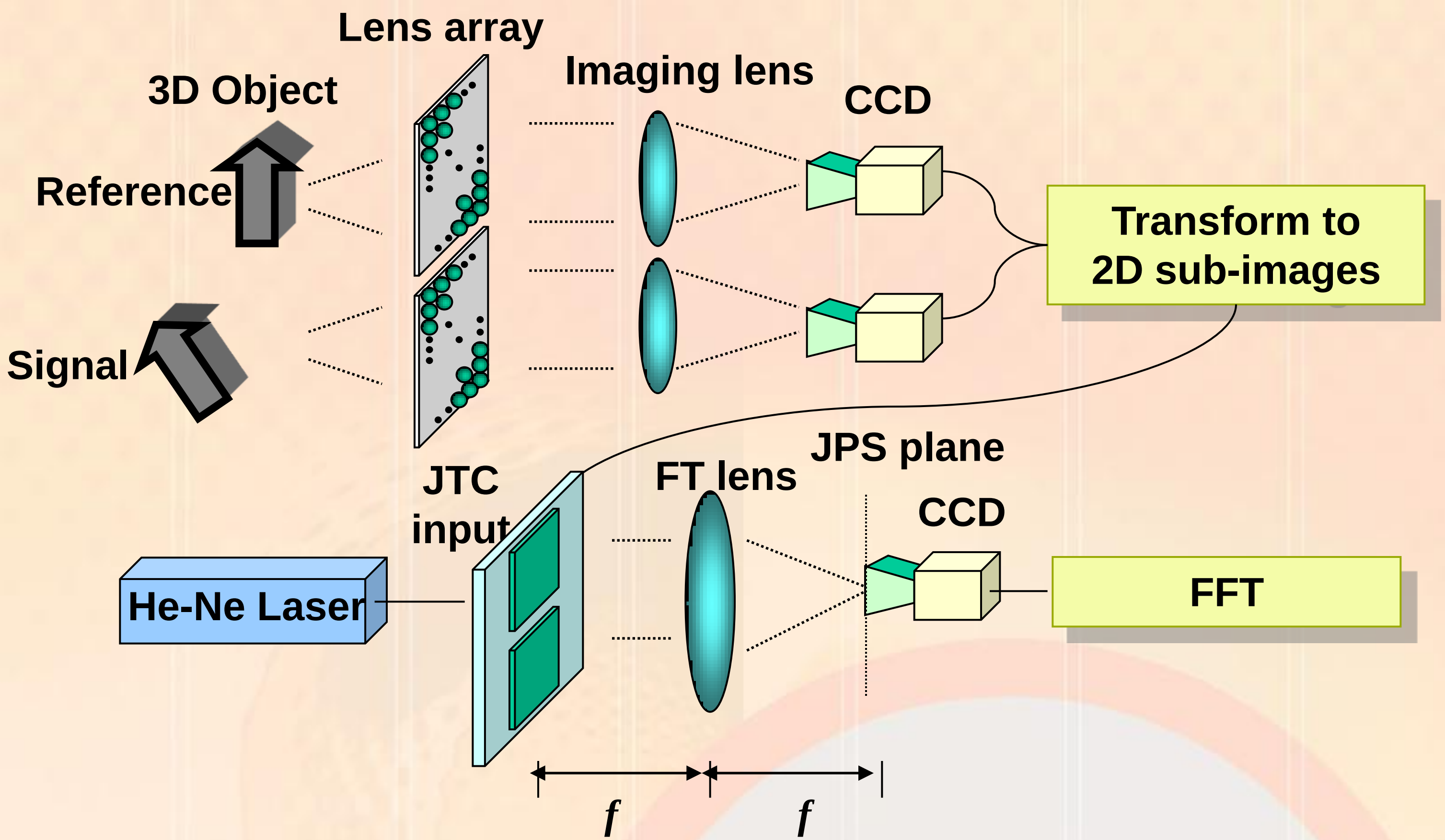
J.-H. Park, G. Baasantseren, N. Kim, G. Park, J. Kang, and B. Lee, "View image generation in perspective and orthographic projection geometry based on integral imaging," Opt. Express 16, 8800-8813 (2008).

Present status of 3D display

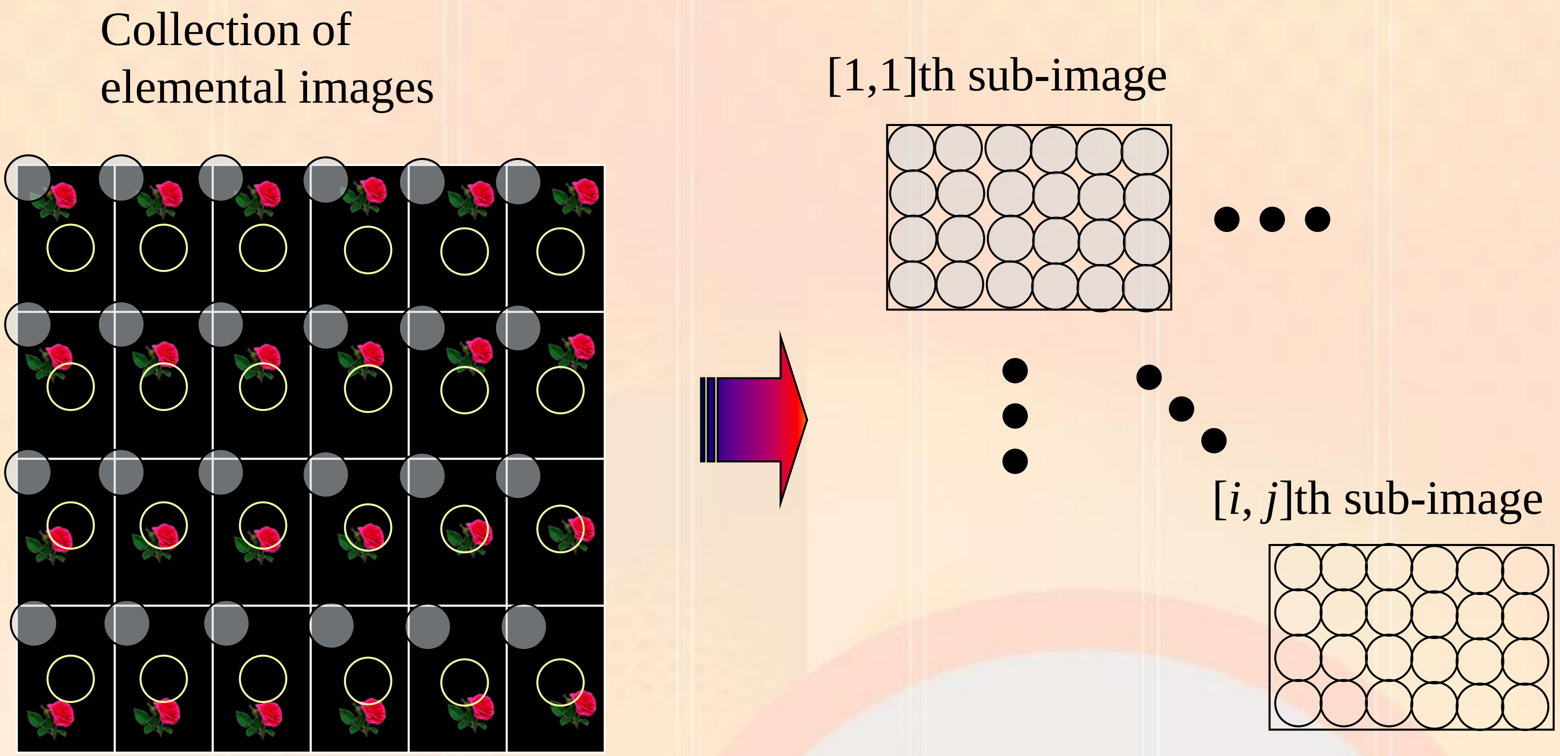
Software system

3D information processing
3D correlator using 2D sub-images
2D to 3D conversion

3D correlator using 2D sub-images



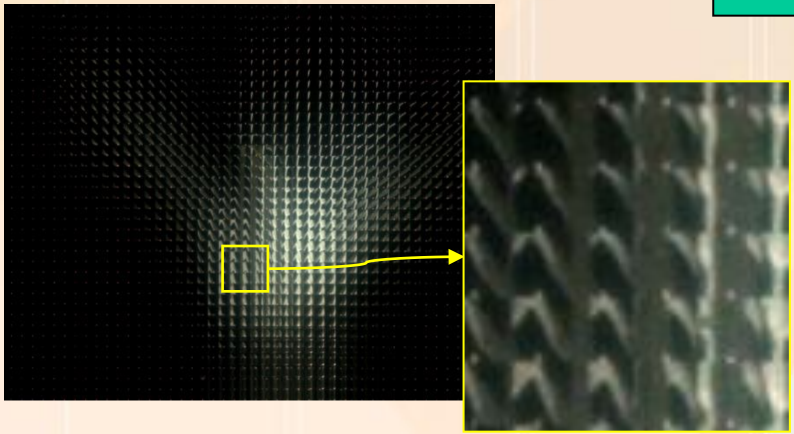
Generation of 2D sub-image



Example of 2D sub-images

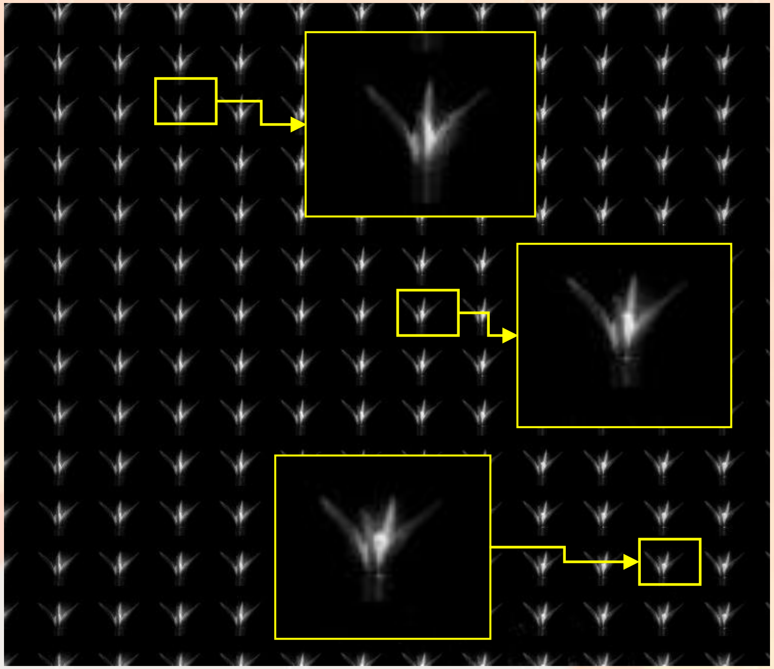
Object

Elemental images

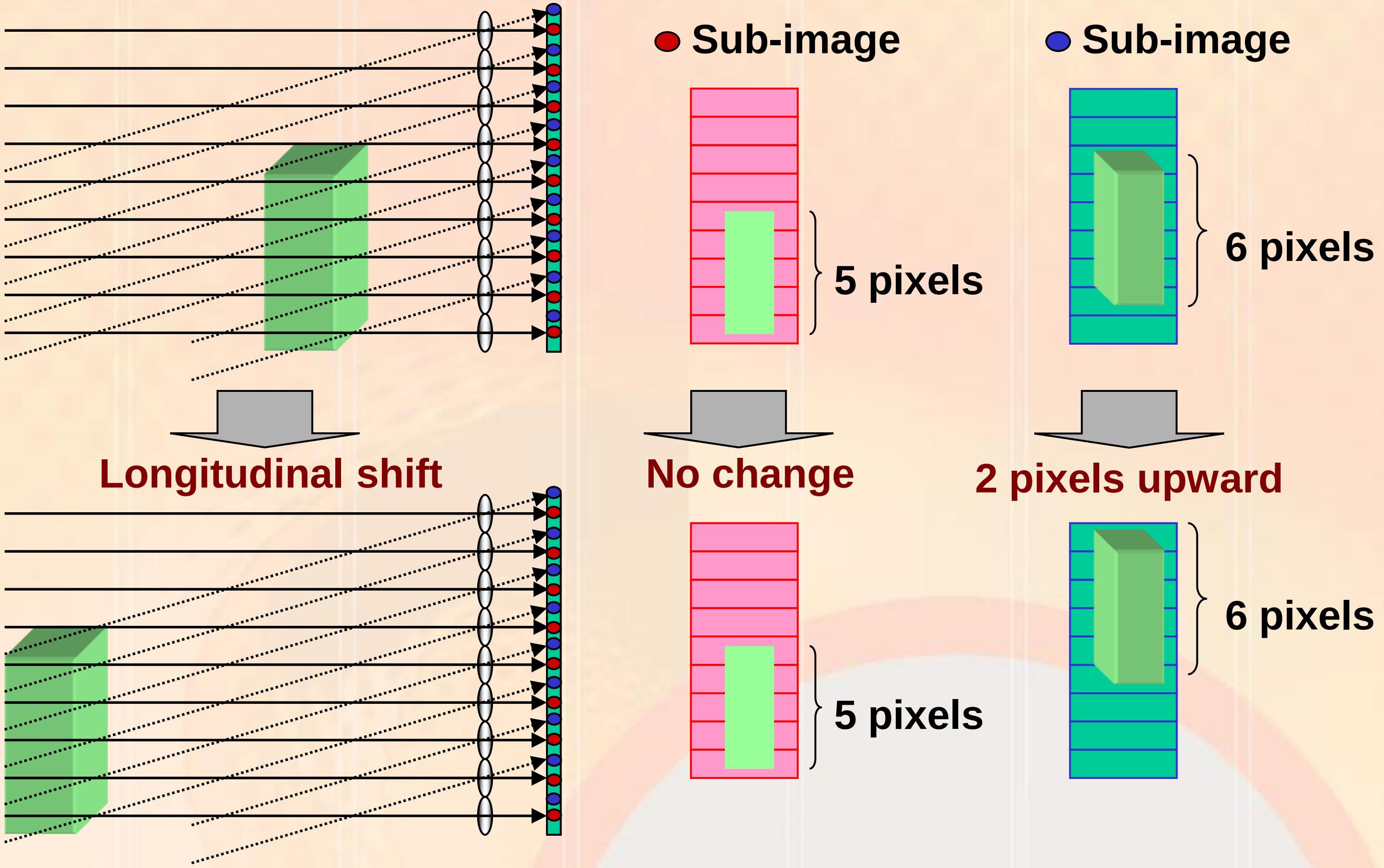


- Lens array: φ=1 mm, f=3.3 mm, Spherical

2D sub-images

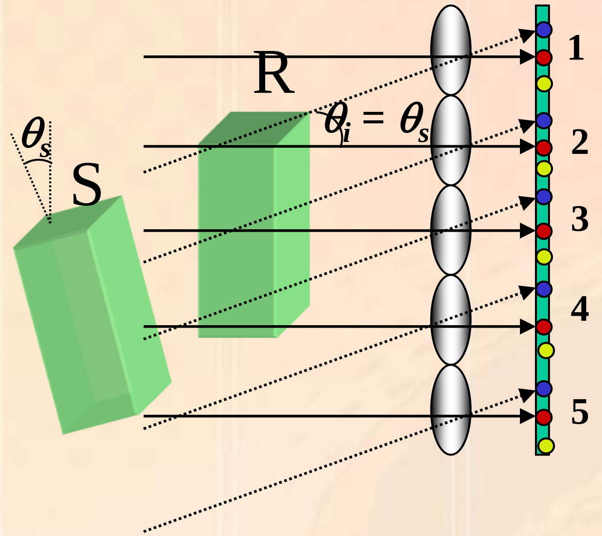


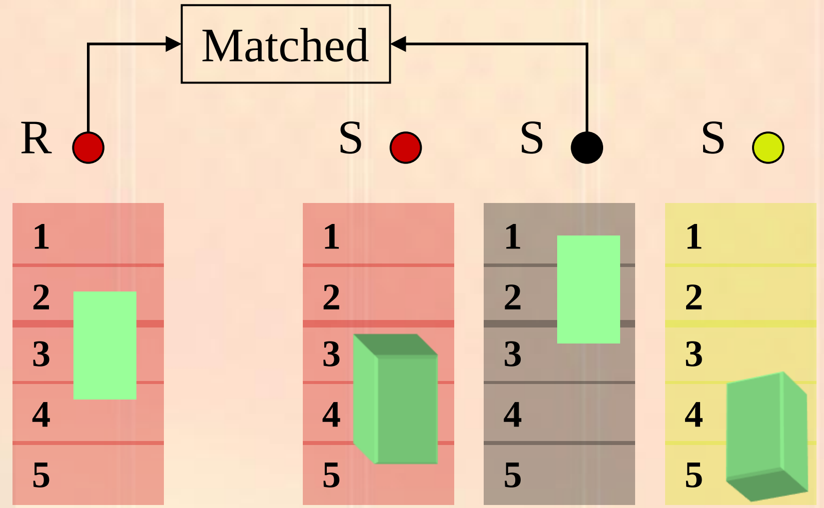
Scale invariance



W/ out-of-plane rotation

- Pixel of center sub-image
- Pixel of *i*-th (θ_i) sub-image
- Pixel of j-th (θ_j) sub-image





$$\Delta u_{i,i+rotation} = \frac{(x_s - x_r) + z_s \tan(\theta_{rotation} + \theta_i) - z_r \tan\theta_i}{\varphi}$$

1 Find matched pair with center view of reference and oblique views of signal → Out-of-plane rotation angle

2 Same procedure with previous case considering out-of-plane rotation angle → Transverse & longitudinal position

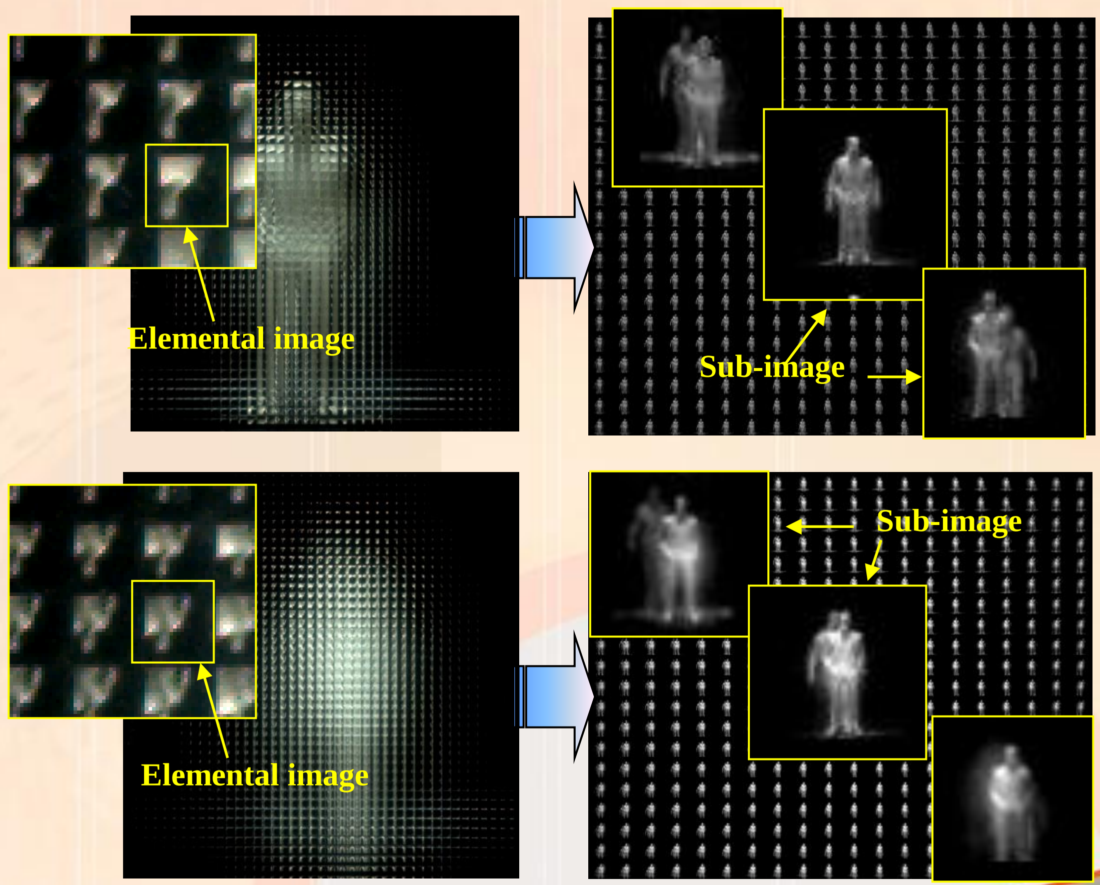
Experimental result

▪ Lens array: φ=1 mm, f=3.3 mm, Spherical

Reference
centered at
(**0**mm,**0**mm,**25**mm) with **0**°
rotation

Signal
centered at
(**5**mm,**0**mm,**44**mm) with **6**°
rotation

Elemental images **2D sub-images**



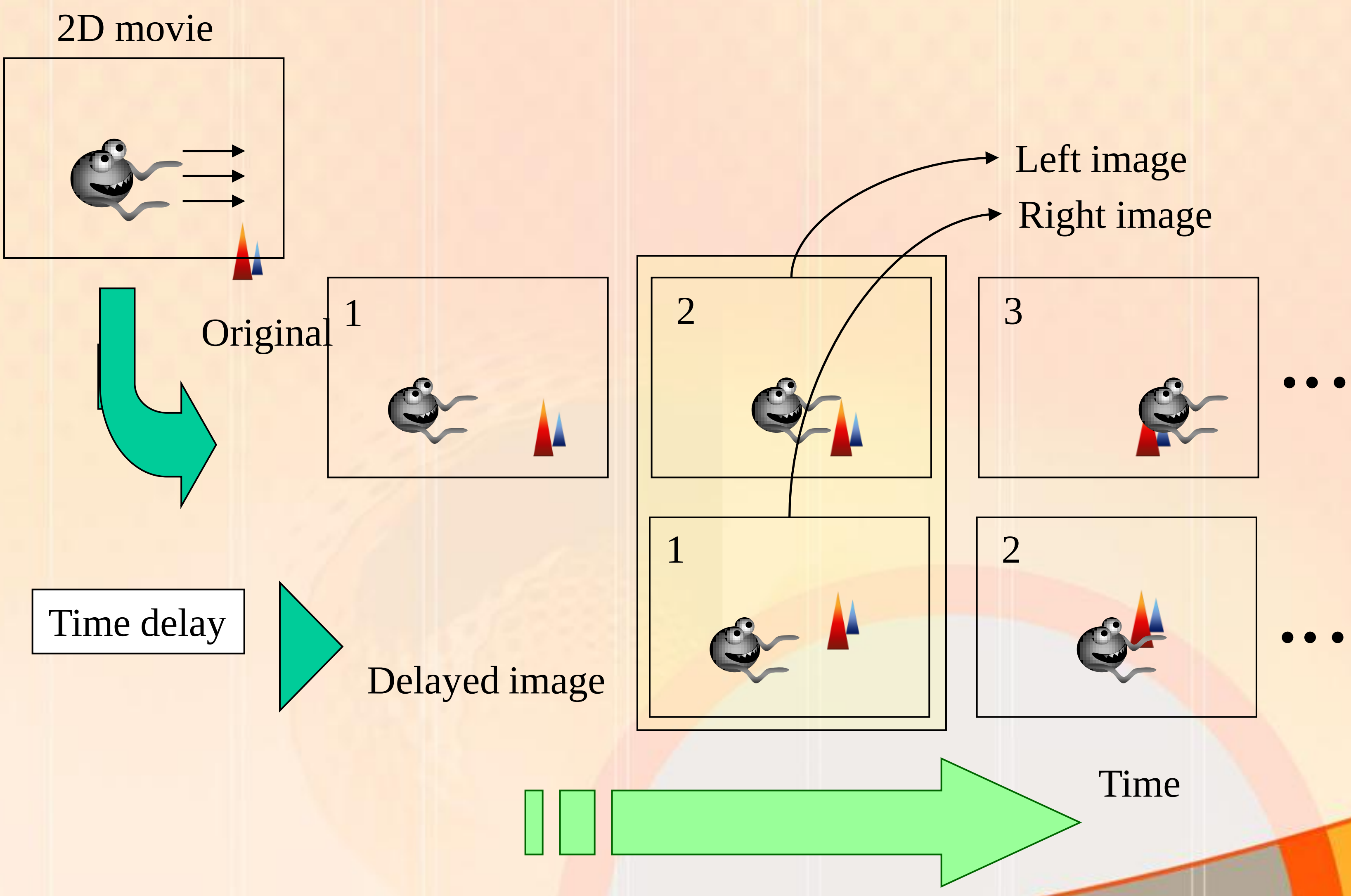
J.-H. Park, J. Kim, and B. Lee, "Three-dimensional optical correlator using a sub-image array," Optics Express, vol. 13, no. 13, pp. 5116-5126, 2005.

Present status of 3D display

Software system

3D information processing
3D correlator using 2D sub-images
2D to 3D conversion

2D movie to 3D conversion



2D movie to 3D conversion

Image Sampling

↓

Motion Detection and Region Segmentation

↓

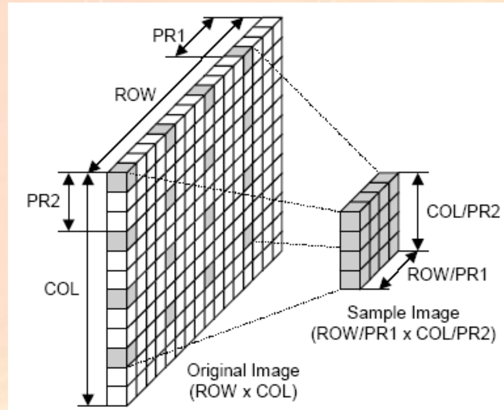
Depth Map Generation

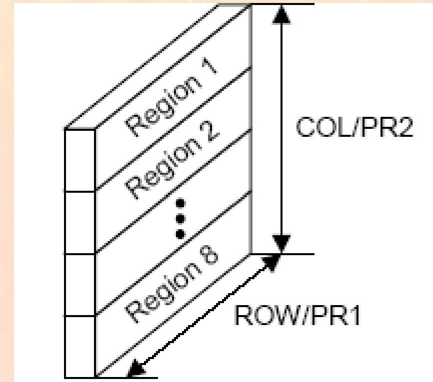
↓

Mask Filtering

↓

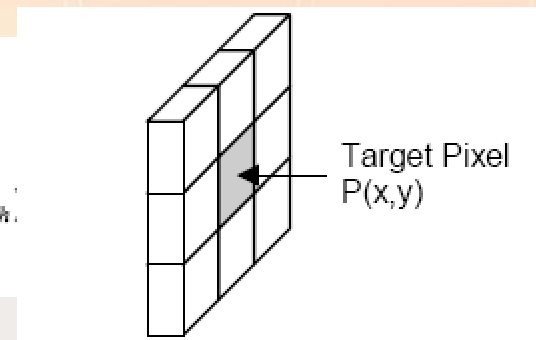
Parallax Processing





$$D_{Pixel} = \left| P_{(N)th} - P_{(N-1)th} \right|$$

$$P_{(N)th} = \begin{cases} Moving\ Pixel & \text{if } (D_{pixel} > D_{th}) \\ Static\ Pixel & \text{otherwise} \end{cases}$$



C.–H. Choi *et al*. "A Real-Time Field-Sequential Stereoscopic Image Converter," IEEE Transactions on Consumer Electronics, **50** (3), pp. 903-910 (2004).

Contents processing: 2D/3D conversion technology

- Motion vector analysis
  - Determine motion type of camera or object
  - Store motion information

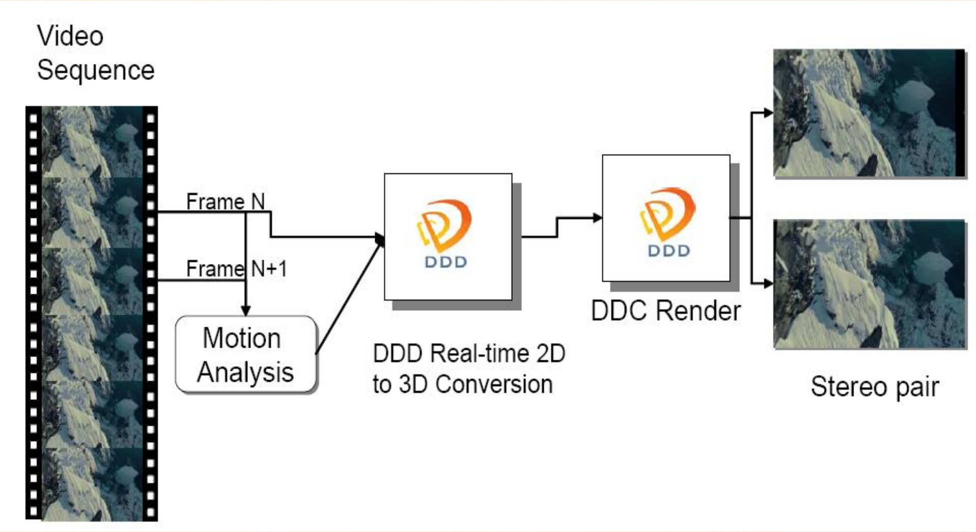
- Synthesis
  - Use motion information

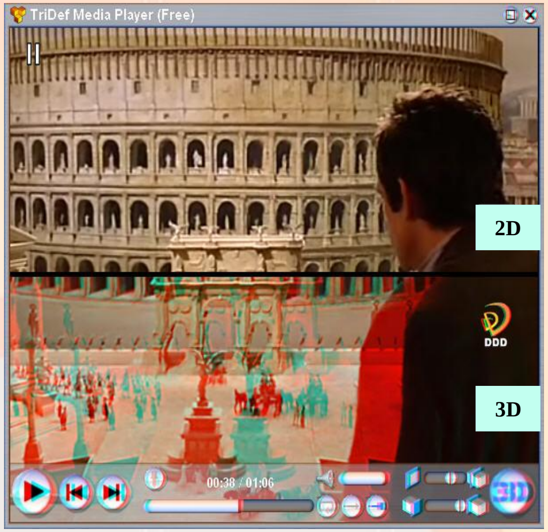
[DDD (Dynamic Digital Depth)]

- Realtime 2D-3D conversion
- Software : Tridef Media Player (3D conversion media player)
- Hardware : Tridef Vision+ (3D Conversion in a Set Top Box)

Dynamic digital depth (DDD)

- Dynamic Depth Cueing Algorithm
  - Object Identification & Object Outlining
  - Defining depth map
  - Displacing each object according to depth map





[Tridef Media Player]

Conclusion

- Present status of 3D display
  - Hardware system
    - Stereoscopic display
    - Autostereoscopic display
    - Volumetric display
    - Other recent techniques
  - Software
    - 3D information processing: depth extraction, depth plane image reconstruction, view image reconstruction
    - 3D correlator using 2D sub-images
    - 2D to 3D conversion

Much more to come!