Next-Generation and Ultimate 3D Display

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Outline

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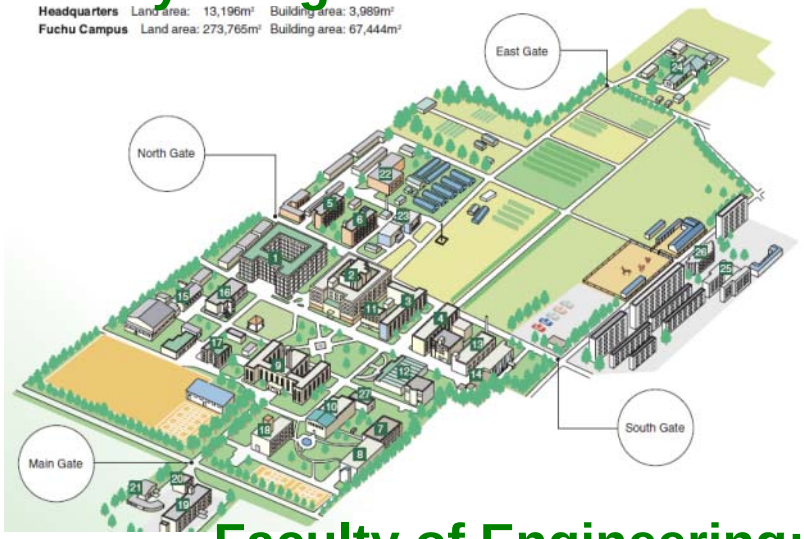
2. *Human 3D Perception*
3. *Multi-View Displays*
4. *Integral Imaging (Integral Photography)*
5. *Holography*
6. *Summary*

TUAT

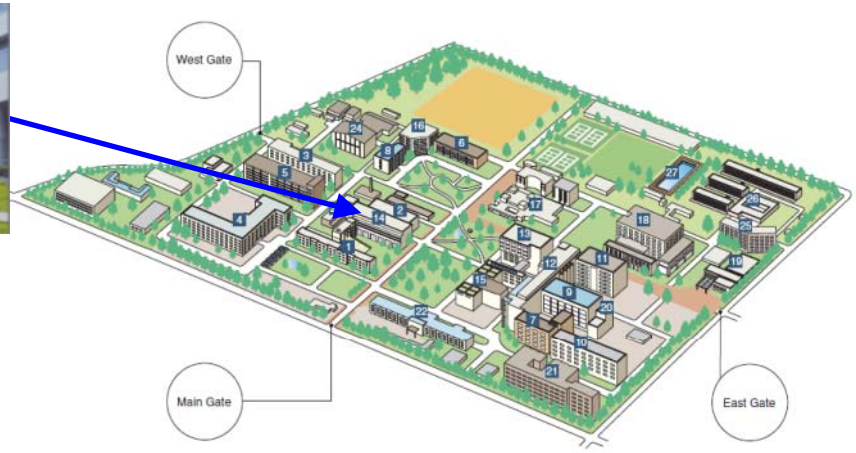
Tokyo University of Agriculture and Technology http://www.tuat.ac.jp

Established in 1877, one of the national universities in Japan.

Faculty of Agriculture: Fuchu Campus



Faculty of Engineering: Koganei Campus



We are here !

40 min from Tokyo Station

Undergraduate: 4,029
Master: 1,381
Doctor: 571
Faculty & Staff: 1,237
(2008)

Who am I ?

Yasuhiro Takaki

高木 康博

타카기 야스히로

Associate Prof. of TUAT

Leader, 3D image technology working group of Ultra-Realistic Communications Forum (URCF), Japan

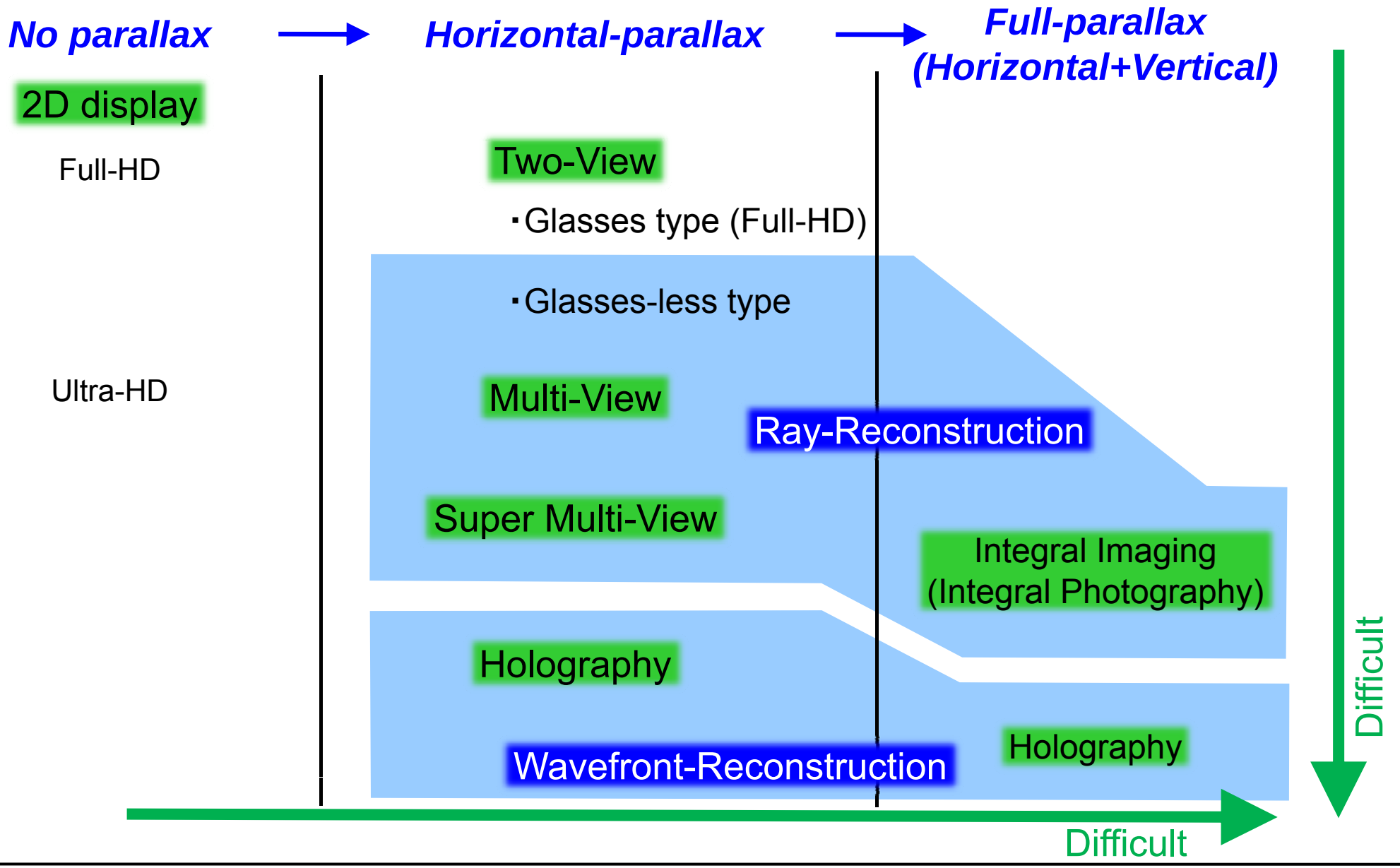
Chairperson, Consortium of 3-D Image Business Promotion, Japan

Chairperson, 3D image technology research group of the Institute of Image Information and Television Engineers (ITE), Japan.

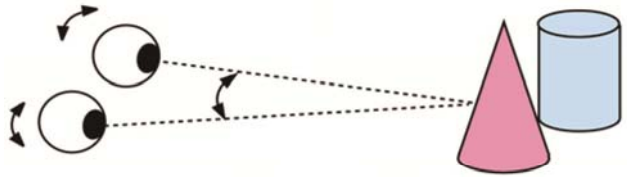
IMID & SID	***3D display***	
IMID 2002, invited	2002 64-view / Projection	
	2004 72-view / Flat-panel	
	2004 128-view / QVGA	
IMID 2005, invited	2005 30-view / Mobile	
	2006 72-view / VGA	***Electronic Holography***
	2007 128-view / SVGA	2007 15º / 1.0”
SID 2009, keynote	2008 60-view / Time-multiplex	2008 15º / 3.5”
IMID 2009, invited	2009 36-view / Automobile	
IMID 2010, keynote	2009 256-view	2010 15º / 4.2”

(viewing zone angle / screen size)

Classification of 3D Displays



3D Perception by Physiological Factors

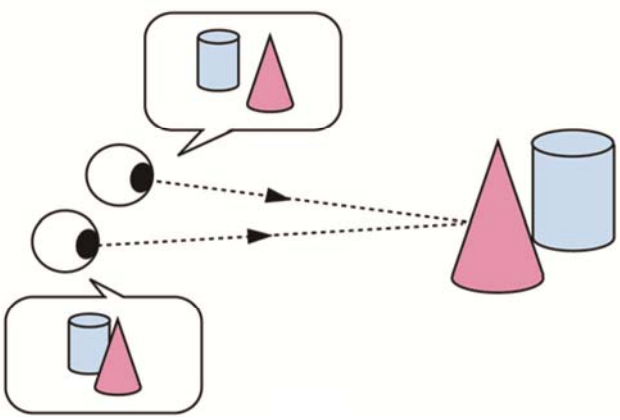


Vergence

the angle between the lines of sight of the left and right eyes

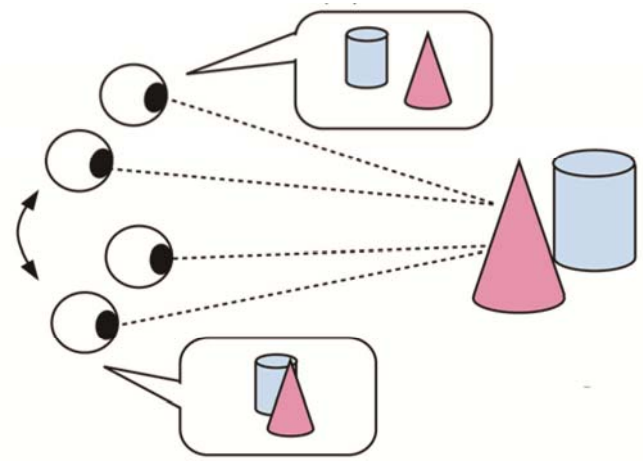
Accommodation

changing the focal length of the lenses in the eyes when focusing on an object



Binocular Disparity

the horizontal displacement in the retinal images between the left and right eyes



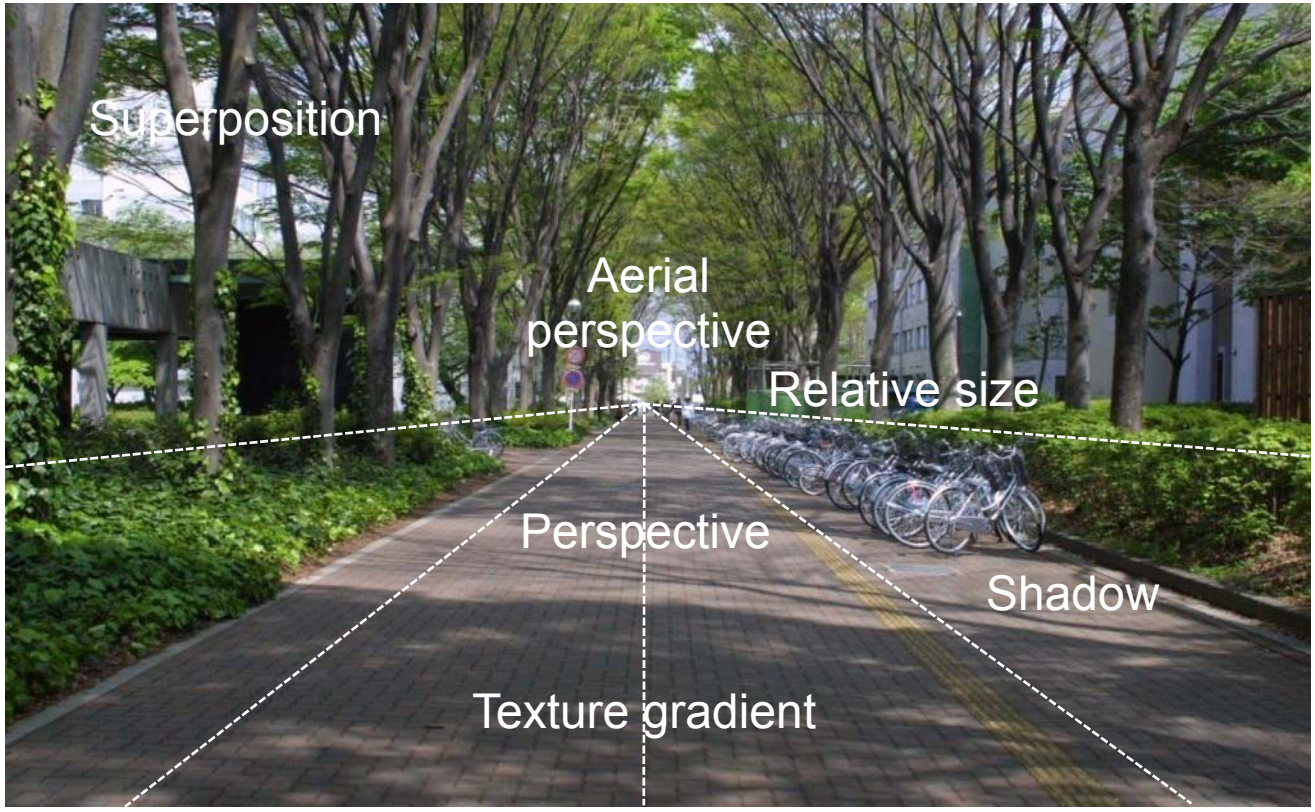
Motion parallax

a change in the retinal image due to the movement of the eyes

Harmony among these four factors is the key to developing comfortable 3D displays.

3D Perception by Psychological Factors

Relative Size, Perspective, Superposition, Texture Gradient, Shadow, Aerial Perspective, etc.

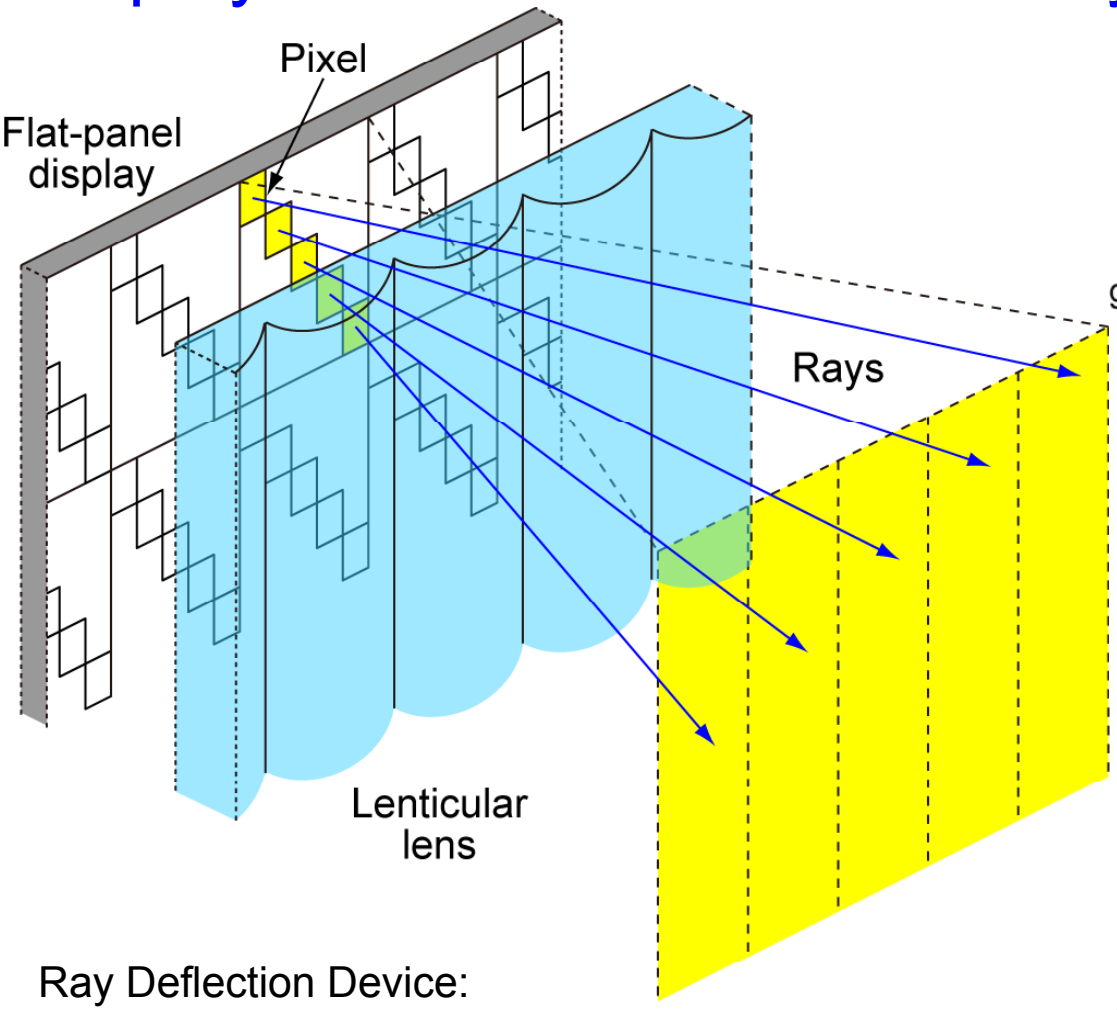


Psychological factors are important in the creation of effective 3D content.

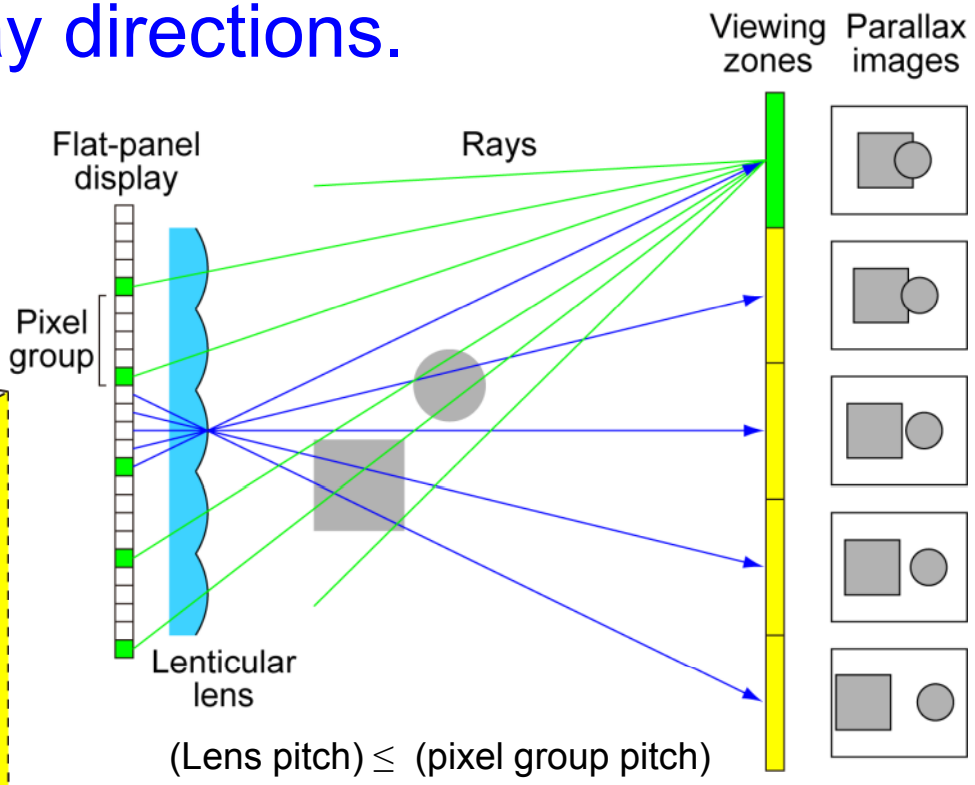
Ray-reconstruction: Horizontal-parallax-type

Multi-View Display

Display controls the horizontal ray directions.



Ray Deflection Device:
Lenticular Lens, Parallax Barrier



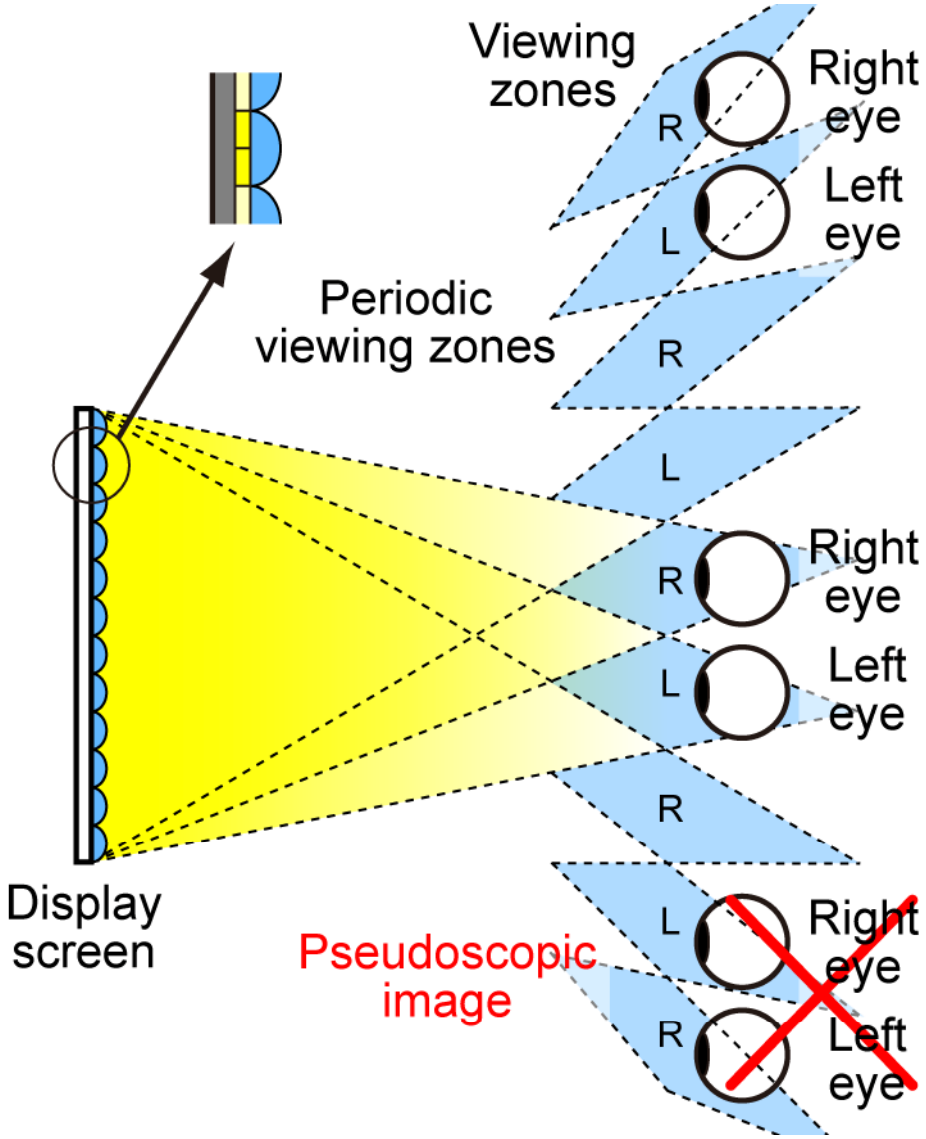
The rays converge at the viewing zones.

Parallax images are displayed with the converging rays.

A 3D image is reconstructed with rays that have true horizontal directions.

Glasses-free Two-view Display

Two viewing zones are generated for left and right eyes.



Glasses-free observation is possible, however, the observation position is limited.

Vergence	○
Binocular disparity	○
Accommodation	×
Motion parallax	×

The viewing zones appear periodically with typical 3D display systems.

→ Multiple viewers

→ Pseudoscopic image

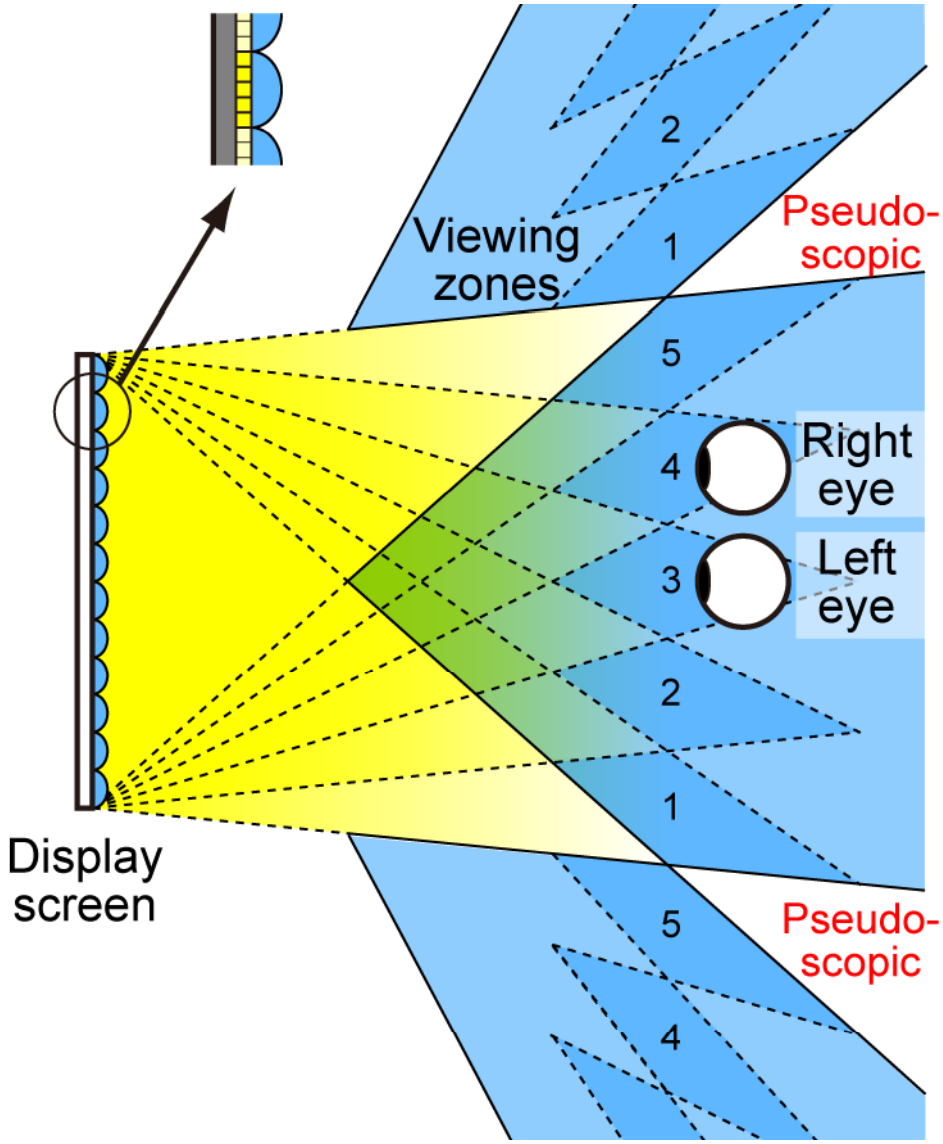
Problem of Psuedoscopic images:

Unacceptable: TV, PC monitor

Acceptable: Mobile game, Mobile phone

Multi-view Display

A multi-view display generates more than two viewing zones.



The pitch of viewing zones is set to the inter-ocular distance (65 mm on average) or less.

Motion parallax is obtained.

Vergence	○
Binocular disparity	○
Accommodation	×
Motion parallax	Δ*

Viewing position freedom also increases in the depth direction.

Probability of viewing pseudoscopic images decreases.

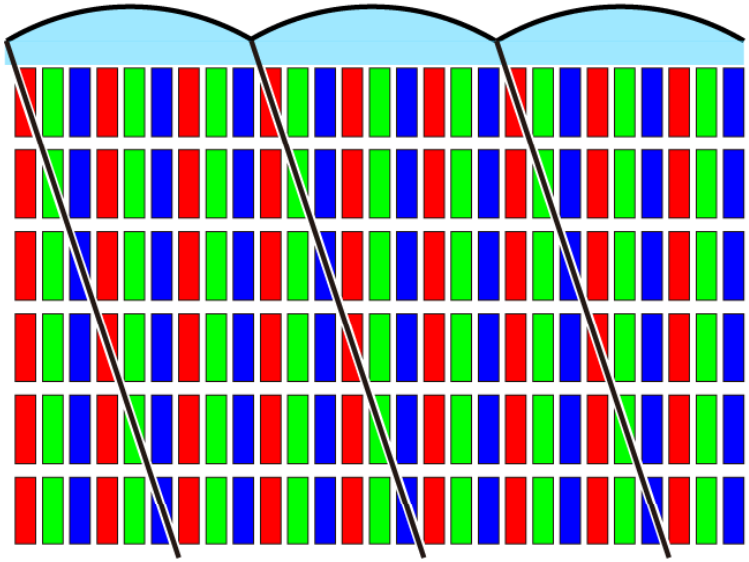
Probability: $1/n$

(n: number of views)

* Discontinuous motion parallax might reduce the presence and realism of 3D images.

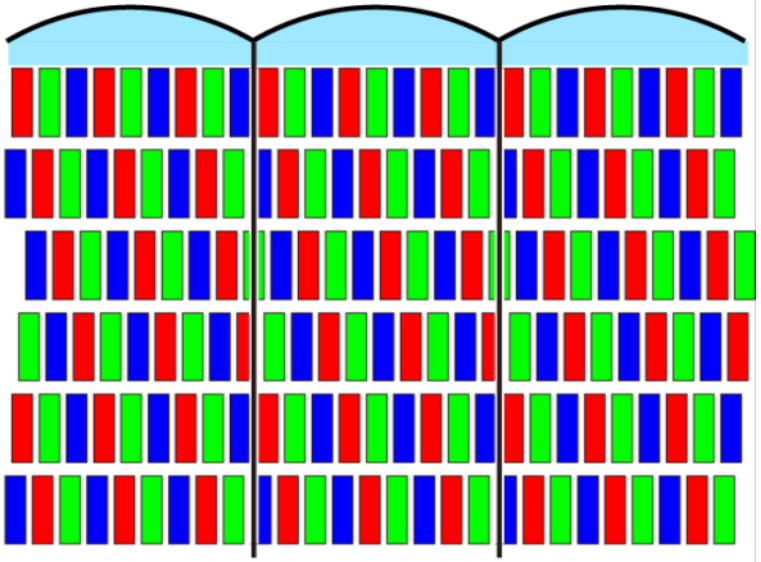
Flat-panel-type Multi-view Display

Slanted lenticular lens



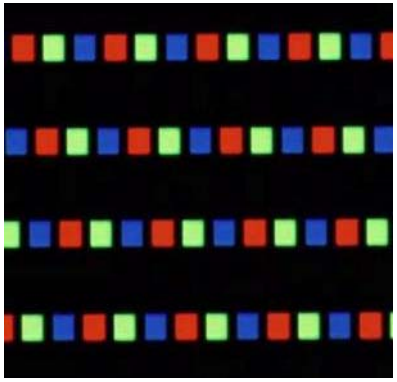
Flat-panel display
RGB stripe arrangement

Straight lenticular lens



Flat-panel display
Slanted subpixel arrangement

Philips
9-view

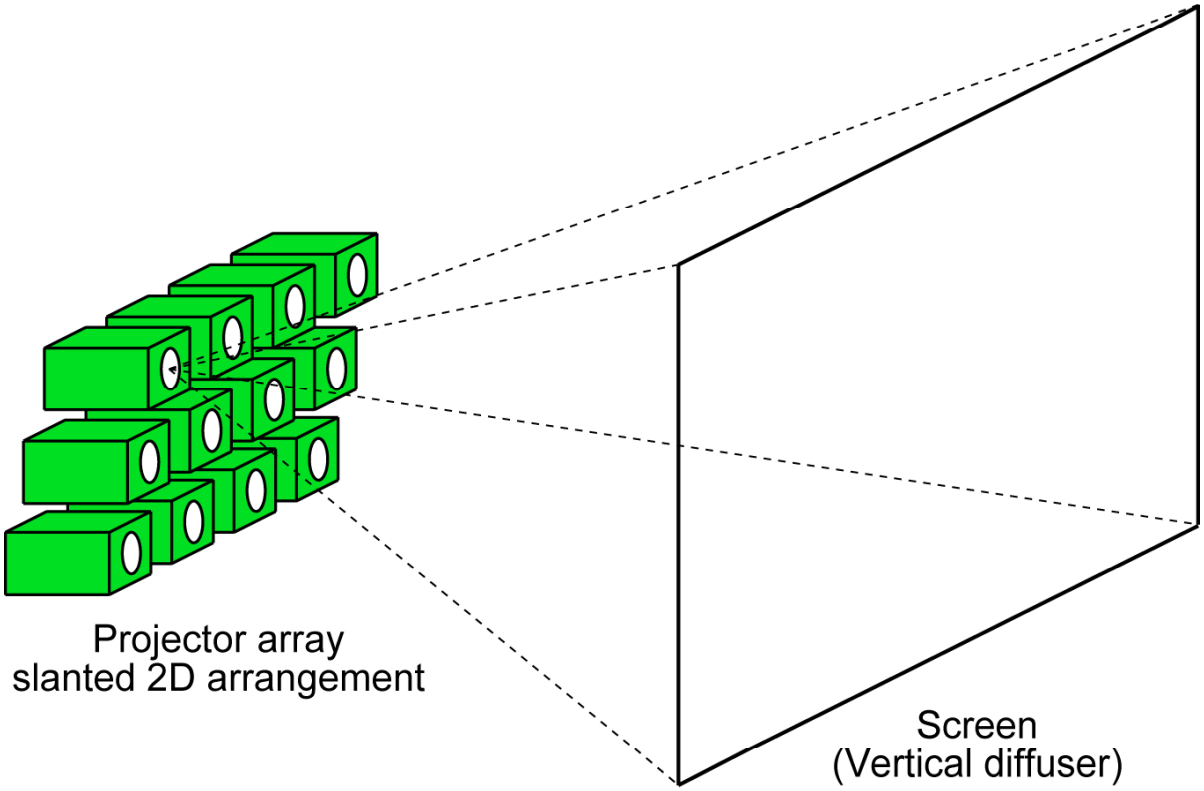


16-view display

Seiko EPSON & TUAT Joint Development

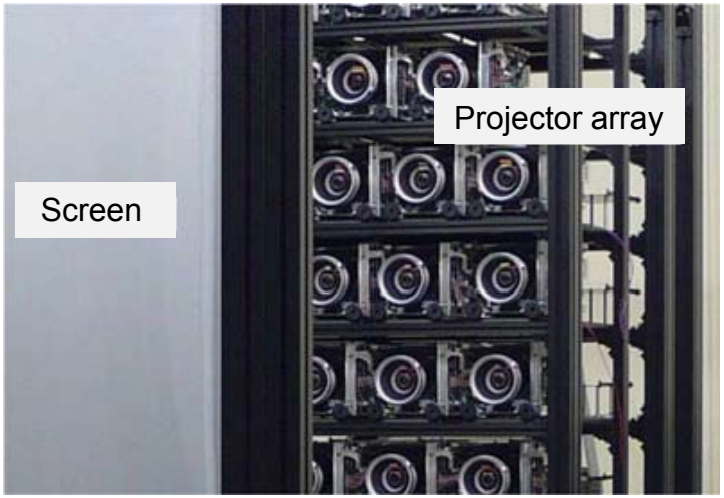
C. van Berkel et al., Proc. SPIE **3012**, 179 (1997) Y. Takaki, J. Soc. Inf. Display **18**, 476 (2010)

Projection-type Multi-view Display



HoloVizio (Holografika)

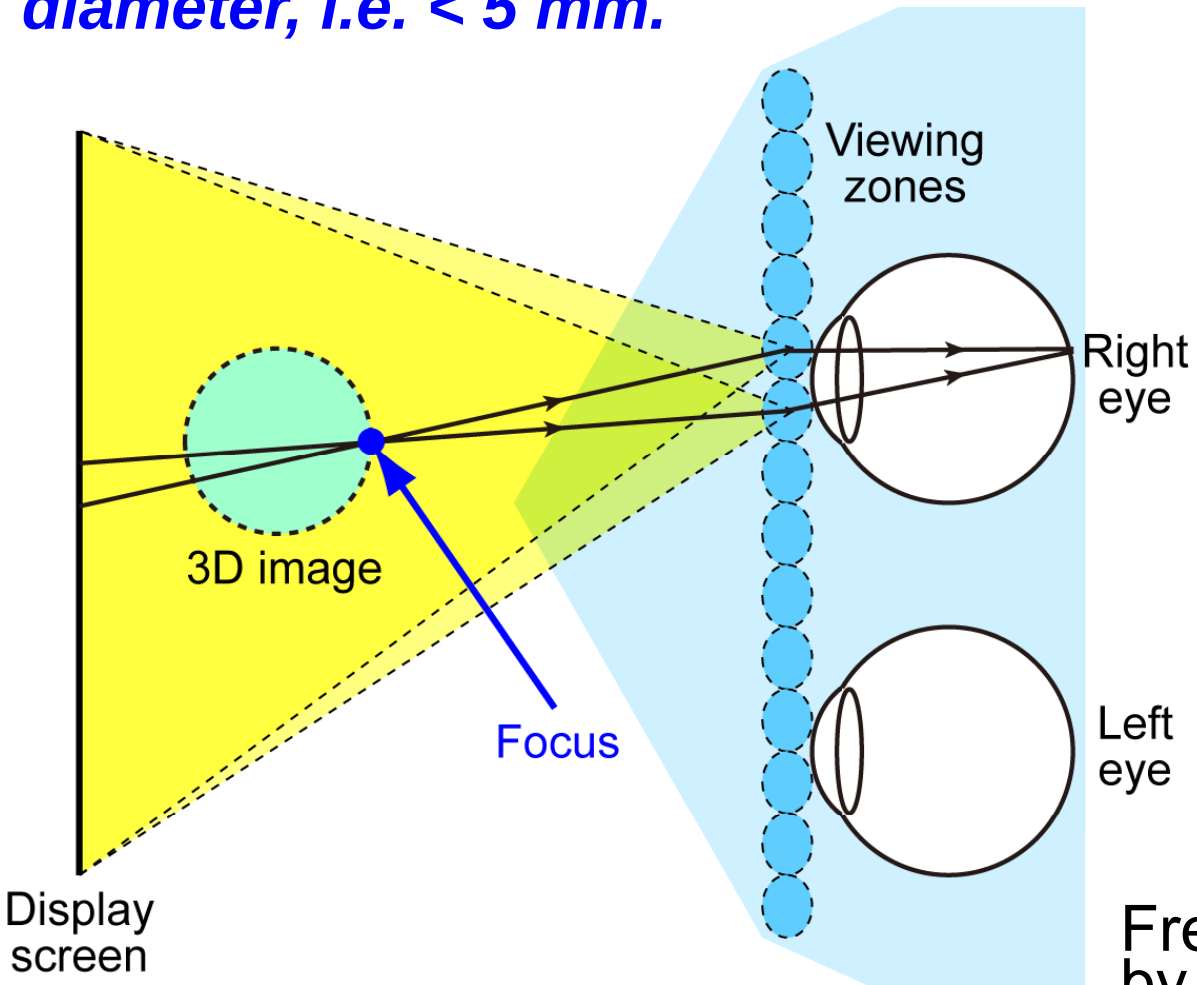
	Advantage	Disadvantage
Flat-panel System	Simple	Trade-off between resolution and number of views
Multi-projection System	Scalability	Complex



NICT, JAPAN, 2008

Super Multi-View Display

The interval of viewing zones is kept smaller than the pupil diameter, i.e. < 5 mm.



Required number of views:
> 50 ~ 100（horizontal）

The fundamental idea:

"When two or more rays passing through the same point in space enter the pupil simultaneously, the eye focuses on that point."

Extremely smooth motion parallax is obtained.

Vergence	○
Binocular disparity	○
Accommodation	○
Motion parallax	○

Free from visual fatigue caused by ***"accommodation-vergence conflict."***

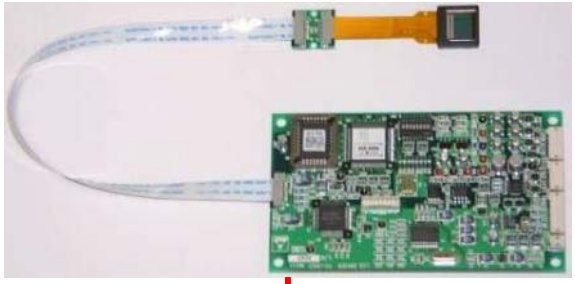
SMV(Super Multi-View) Displays

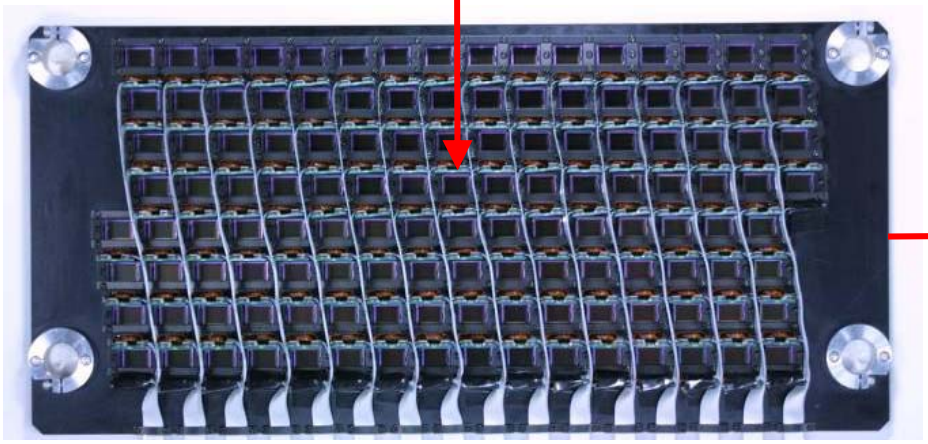
Number of views	64	128	128	72	72	30*
System type	Projection	Projection	Projection	Flat-panel	Flat-panel	Flat-panel
Horizontal ray angle pitch	0.34°	0.23°	0.28°	0.38°	0.38°	0.71°
Horizontal viewing angel	21.6°	29.6°	35.7°	27.6°	27.6°	21.2°
3D resolution	~QVGA	~QVGA	SVGA	320 × 400	640 × 400	256 × 128
Screen size	9.25”	13.2”	12.8”	22.2”	22.2”	7.2”
Photo						

* Joint-development with NTT DoCoMo

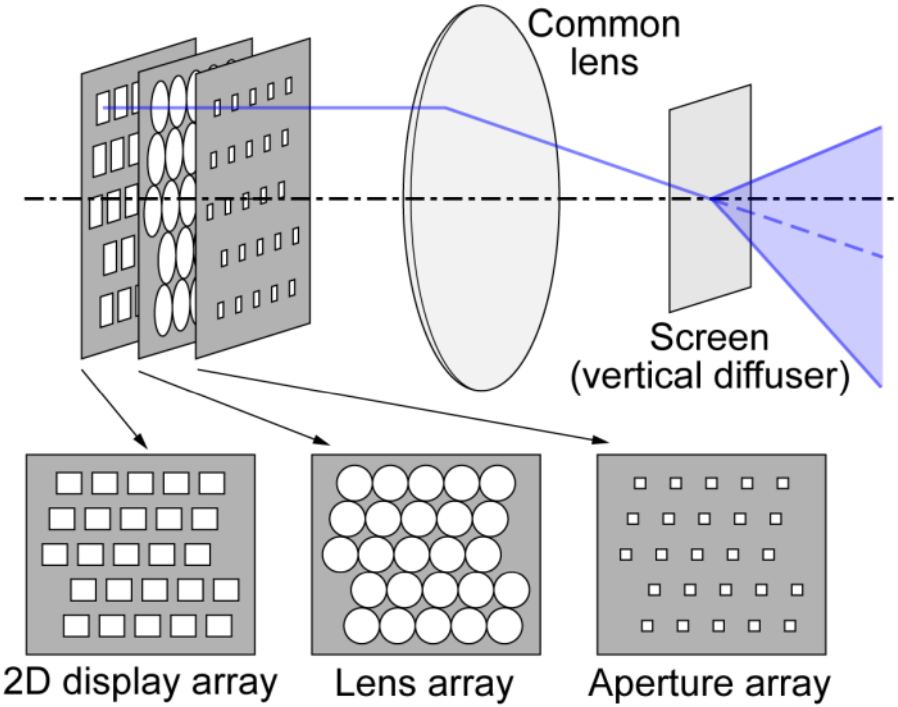
128-view QVGA Display

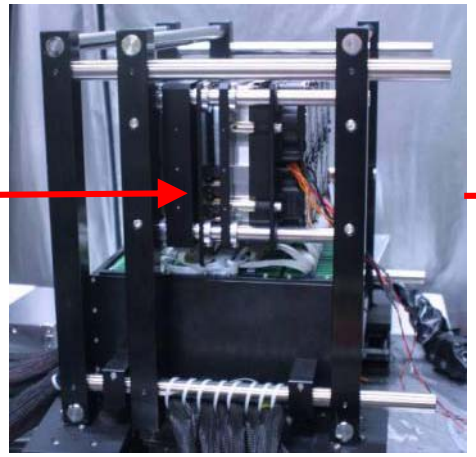
0.44” color LCD
Resolution: ~QVGA
（SONY　LCX033AK）





16×8 LCD Panels in
Modified 2D Arrangement





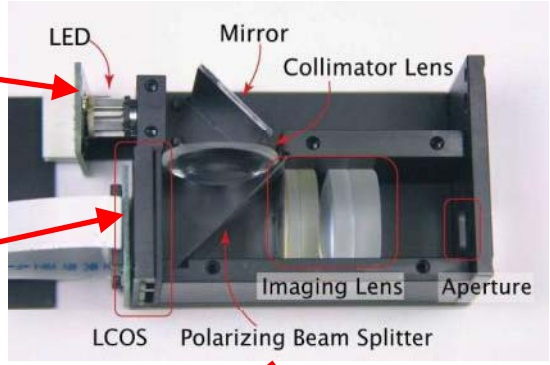
Optical Engine

Display System

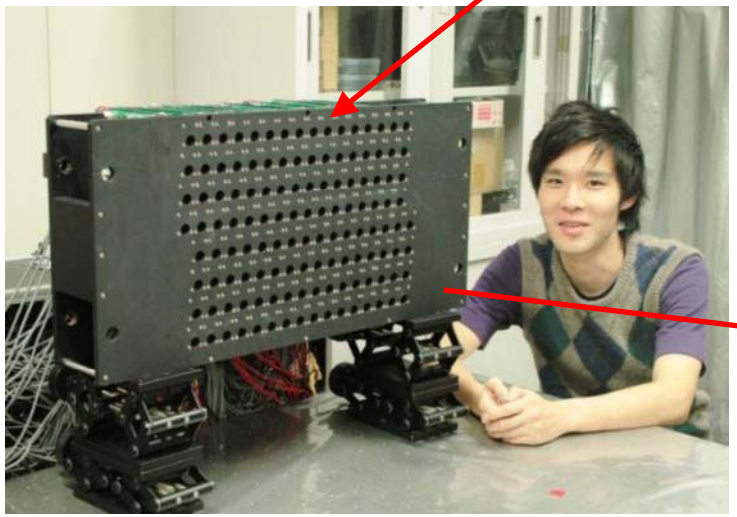
128-view SVGA Display

RGB LED
Nichia, NSSM016CT

0.49” LCOS
MD800(MicroDisplay Tec.)
Resolution : 800 × 600
Frame Rate: 180 Hz
(Field Sequential Color)



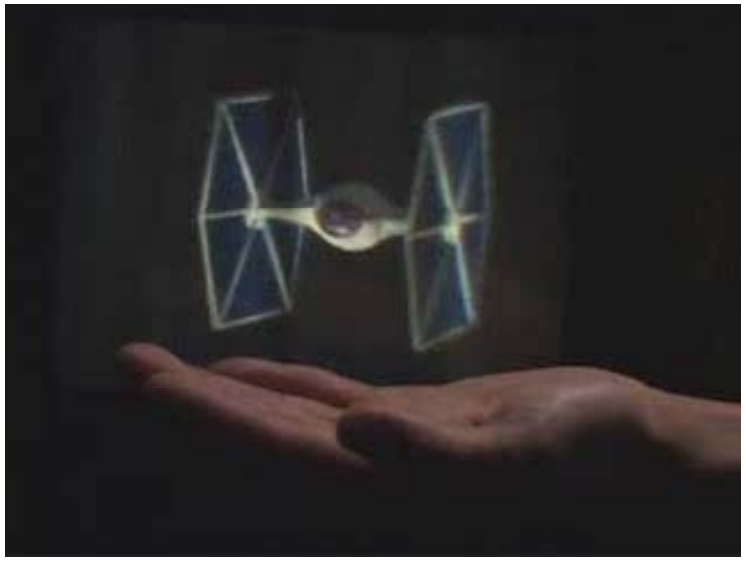
Small Projector Unit
26 × 38 × 63 mm^3



16×8 Projector Units
in Modified 2D Arrangement

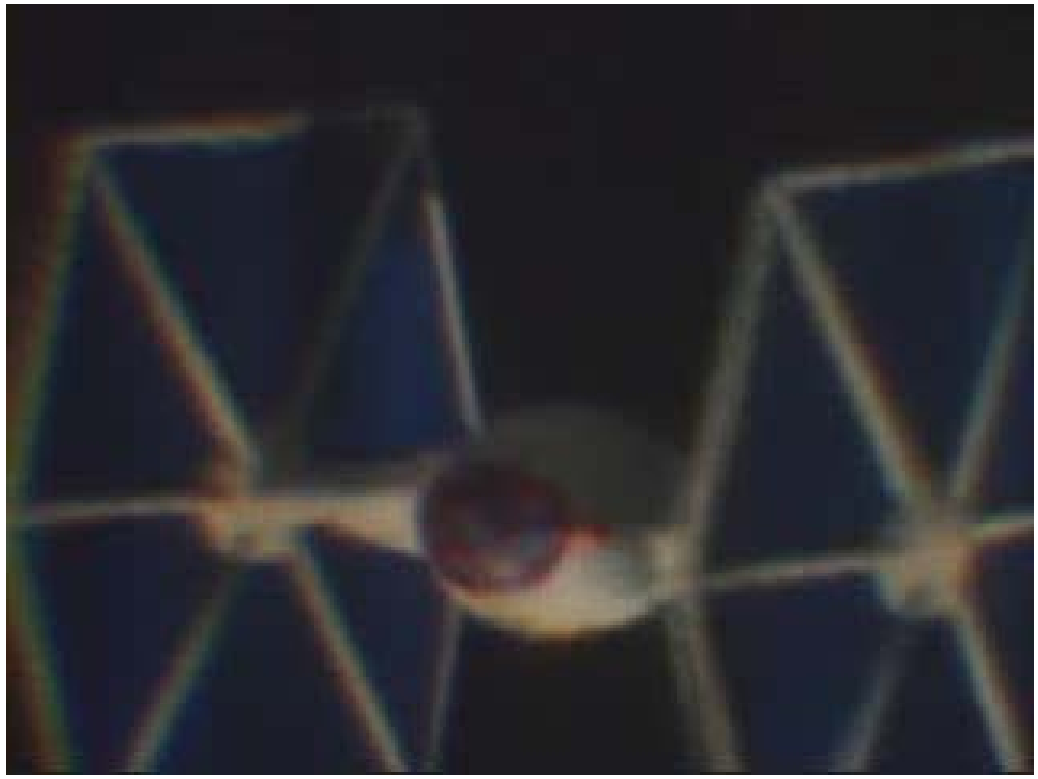
Display System

3D Images by 64-view QVGA Display



3D image with absolute depth position

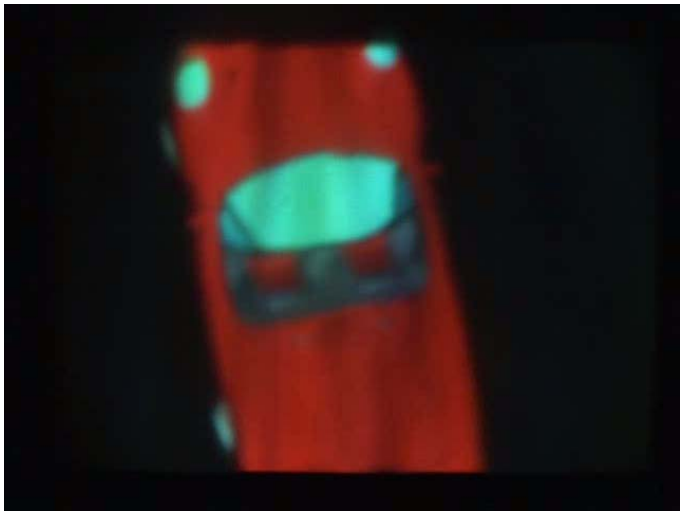
Wide observation depth range



Focus changes between body and wing

Y. Takaki, Proc. IEEE **94**, 654 (2006)

3D Images by 128-view QVGA Display



Interactive Manipulation of 3D images

PC Cluster for Real-Time
3D Image Generation

Fingertip Manipulation

3D Drawing by Fingertip

Fingertip Detection System

72-view Display

72-view Half-VGA Display

High-resolution LCD

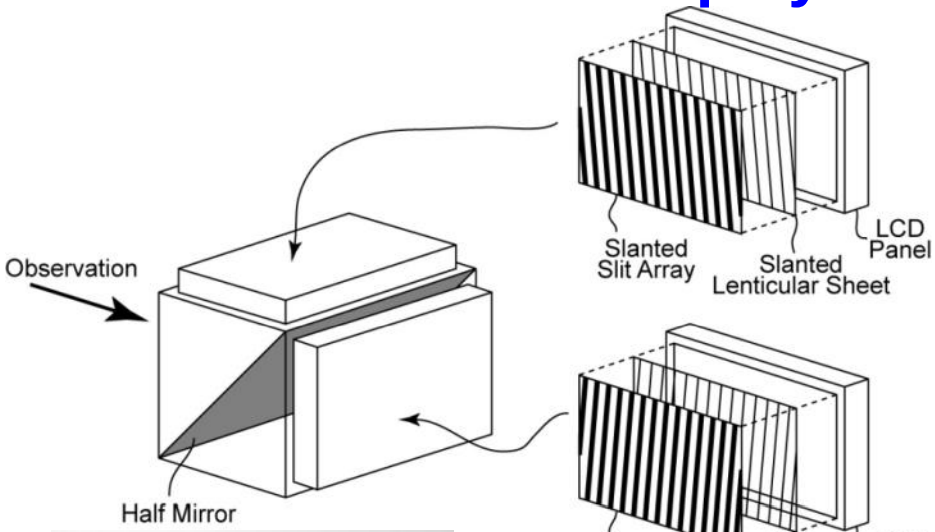
Slanted lenticular lens

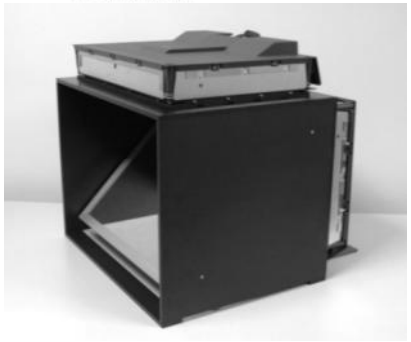
Resolution	3, 840 × 2,400 (WQUXGA)
Pixel pitch	0.1245 mm
Screen	22.2”

Number of lenses	320
Lens pitch	1.494 mm
Slant angle	9.46º

Number of views	72
3D resolution	320 × 400
Horizontal ray angle pitch	0.38°

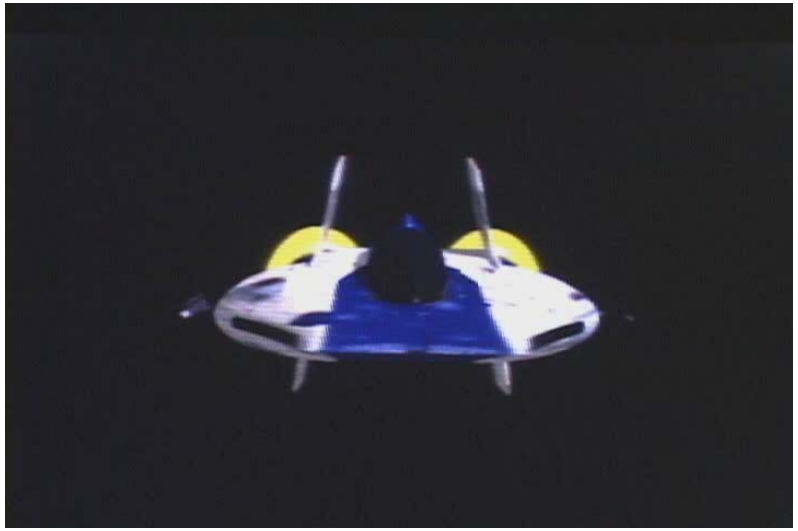
72-view VGA Display

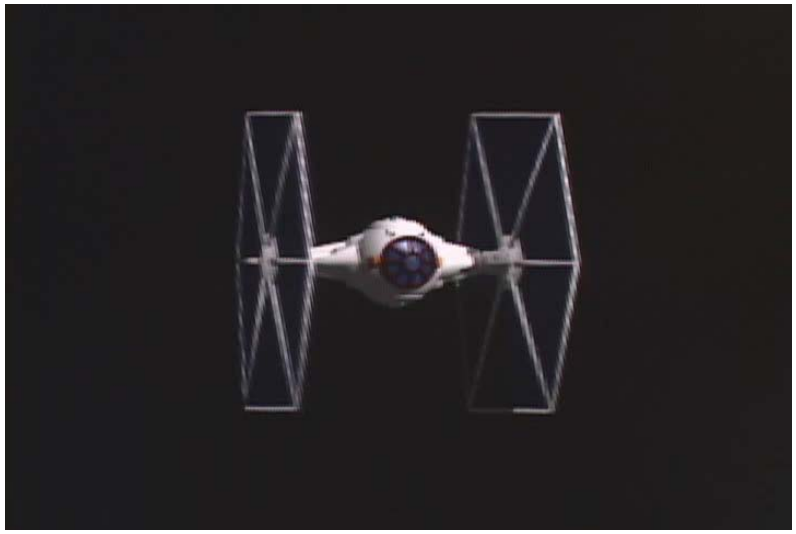


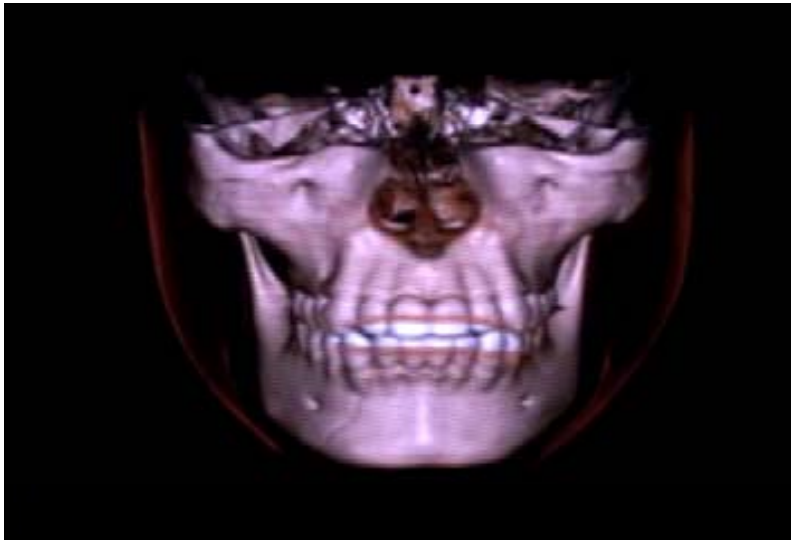


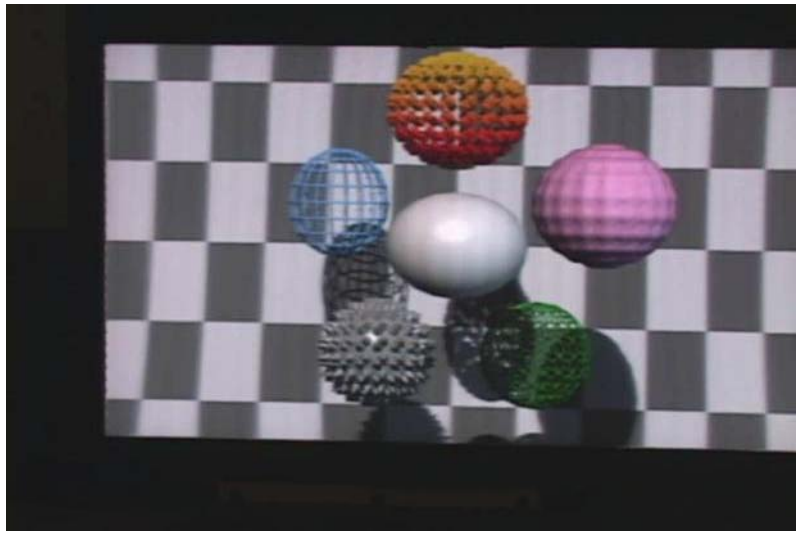
Number of views	72
3D resolution	640 × 400
Horizontal ray angle pitch	0.38°

3D Images by 72-view Half-VGA Display

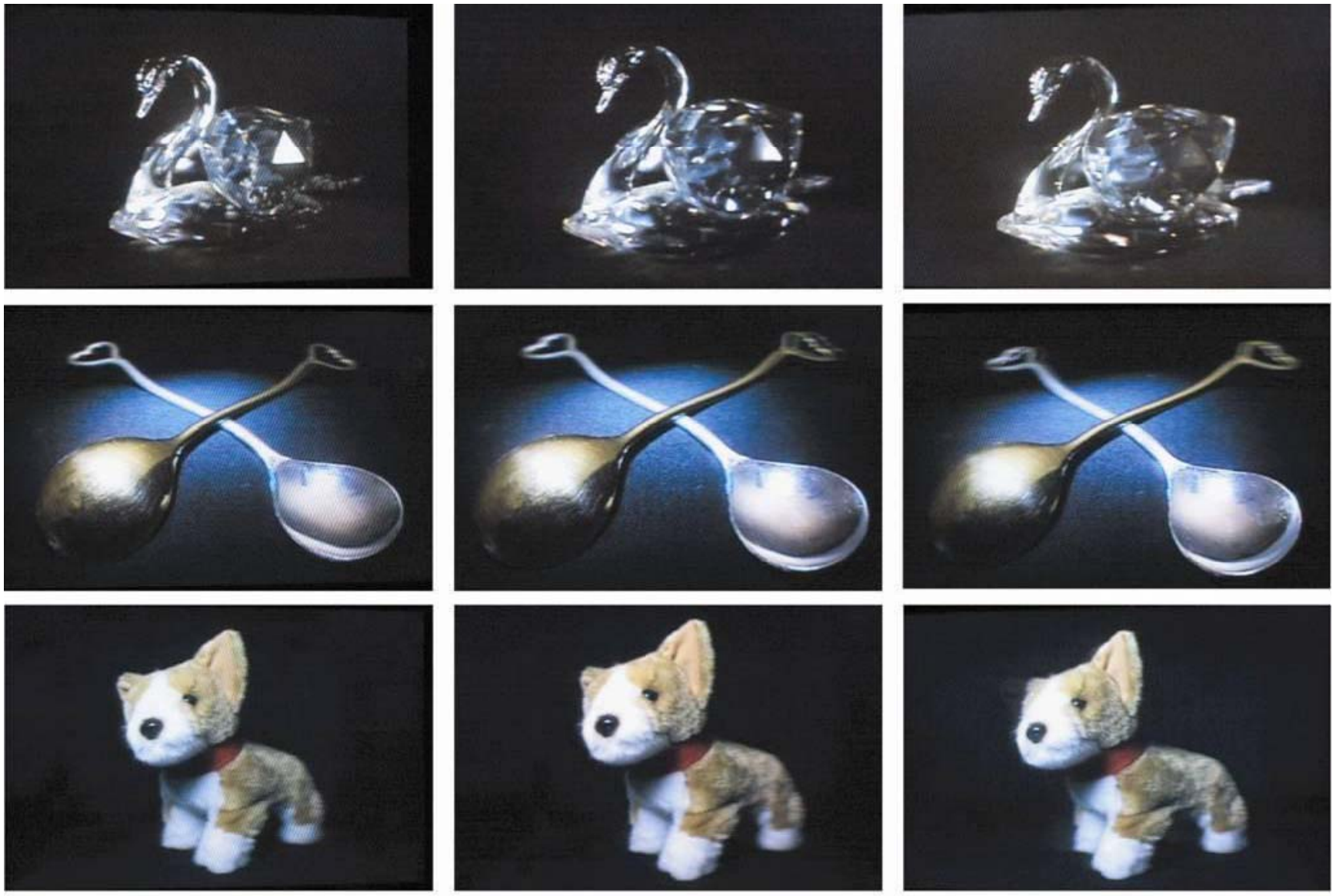




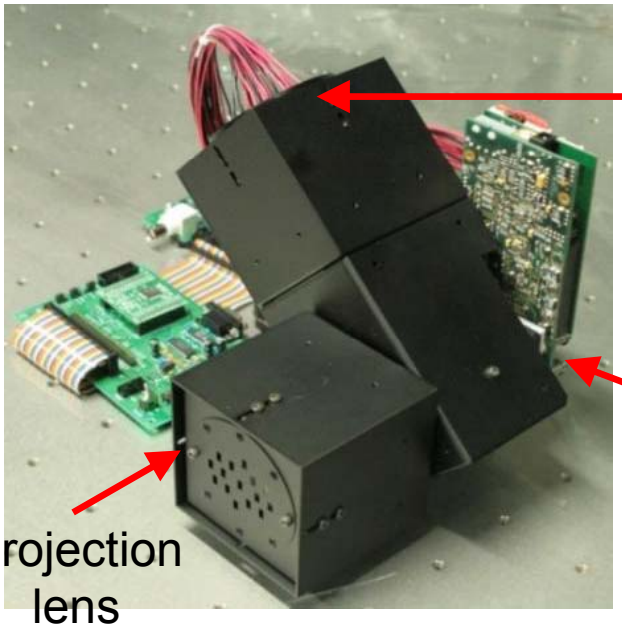




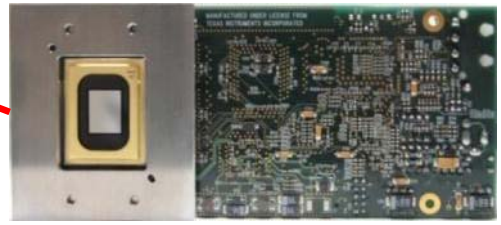
3D Images by 72-view VGA Display



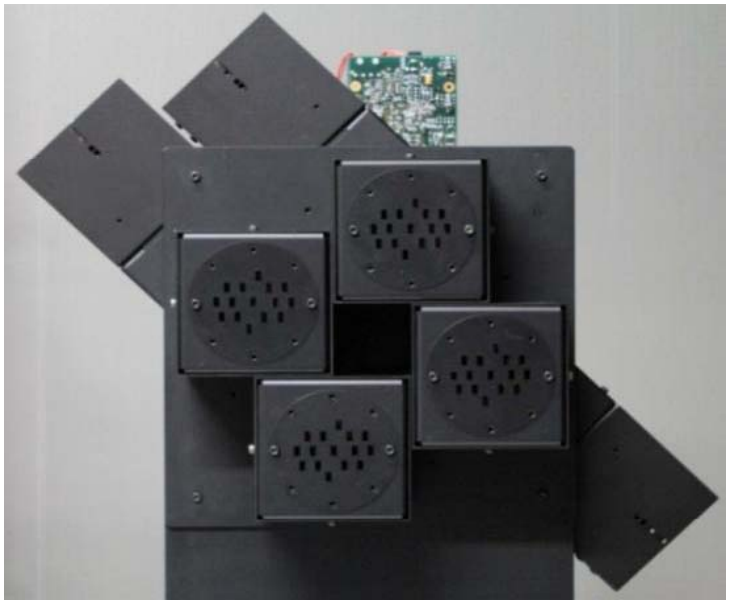
Time-multiplexed Display Module



15 LEDs



High frame rate DMD Discovery™1100



Time-multiplexed Display Module

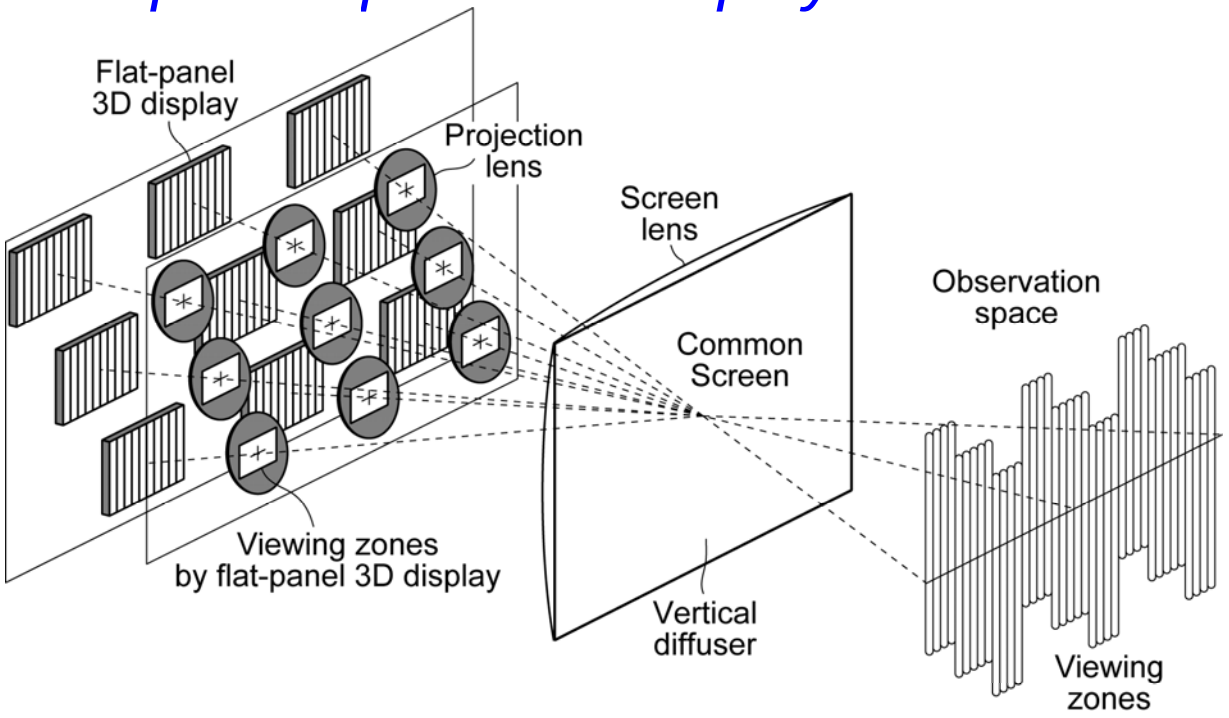
Number of images	15
Resolution	XGA
Frame rate	60 fps
Number of gray levels	5 bits
Frame rate of DMD	900 fps
Number of LEDs	15

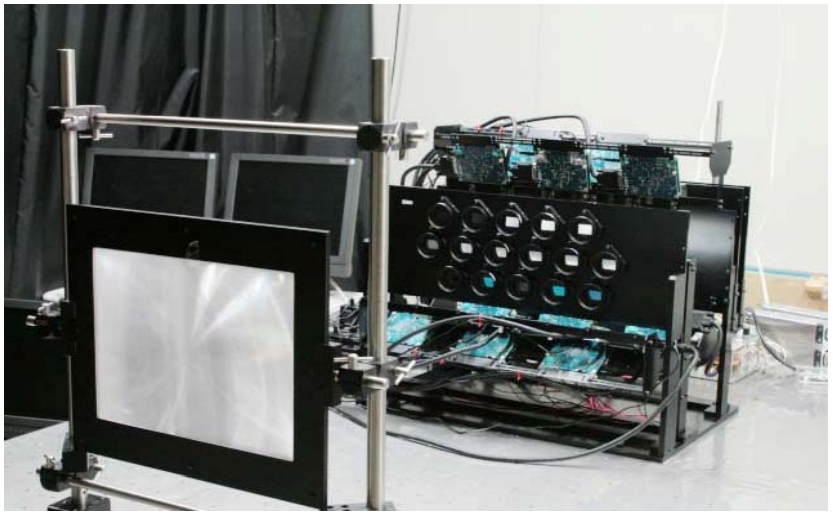
Optical Engine

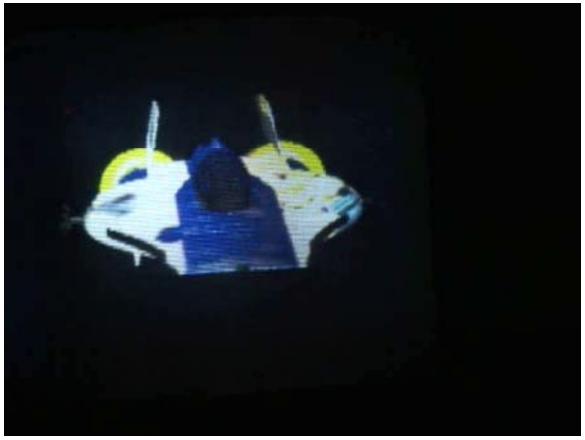
Number of images	60
Horizontal display angle pitch	0.31˚
Horizontal viewing angle	18.3˚
Resolution	XGA
Frame rate	60 fps
Number of modules	4

SMV256 (SMV Display with 256 Views)

Multiple flat-panel 3D displays are combined by multi projection system.





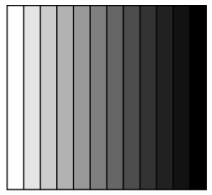


Number of views	256
3D resolution	256 × 192
Screen size	10.3 in.
Interval of views	1.31 mm
Number of flat-panel 3D displays	16
Number of views of flat-panel 3D displays	16

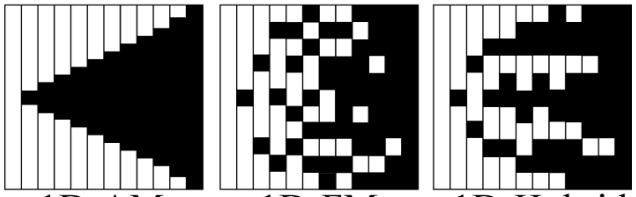
Y. Takaki et al., Opt. Express **18**, 8824 (2010)

Applications of SMV Technique

3D Print



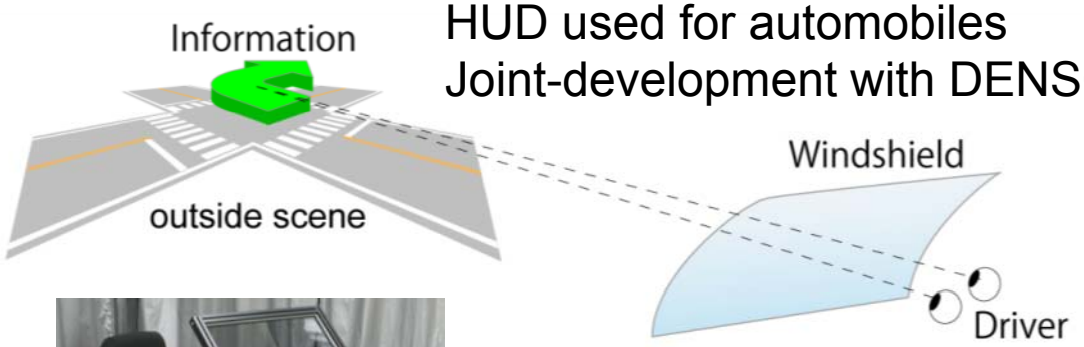
Gray scale image



1D Screening Method
that can generate 48~60 images

DynaCube 3D™
(Commercialized by DNP Co., Ltd.)
Jpn.J.Appl.Phys. **47**, 5486 (2008)

SMV Windshield Display



HUD used for automobiles
Joint-development with DENSO Corp.

36-view SMV-WSD

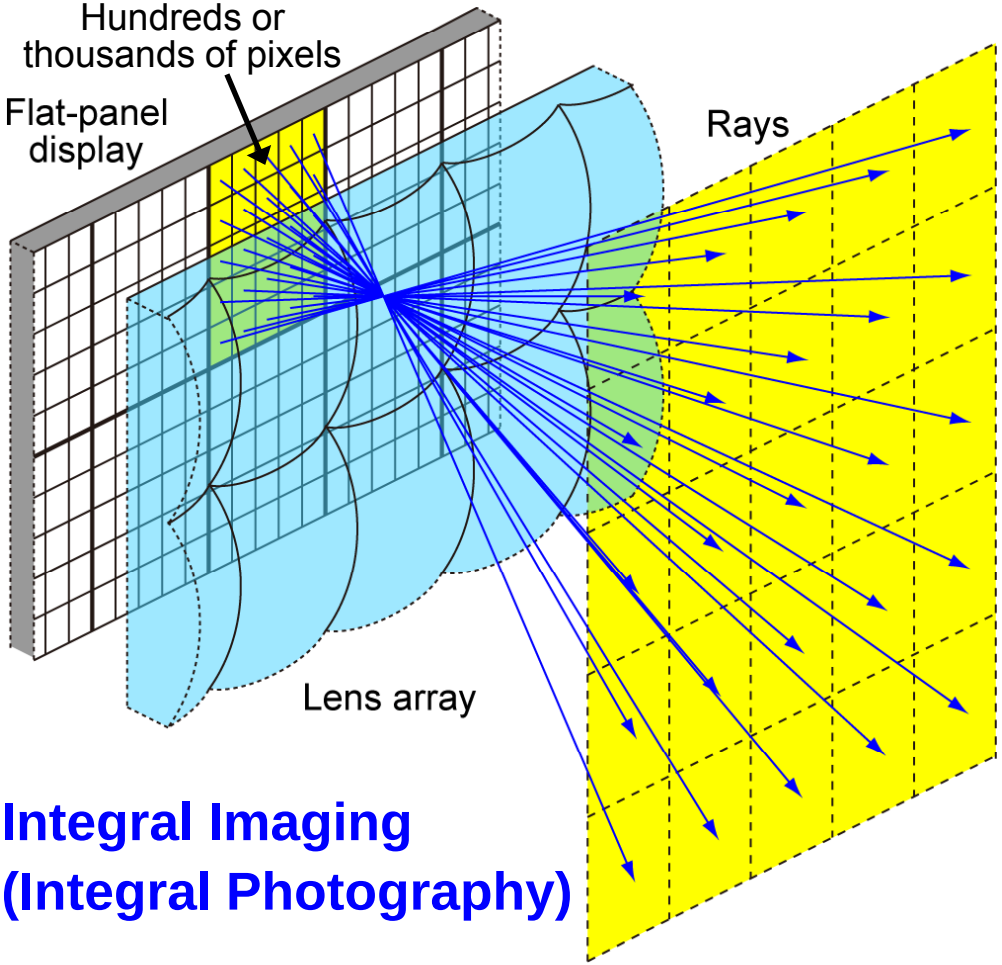
Motion parallax is the last physio-logical cue to perceive the depth of long-distance 3D images.

Will be presented at Session "Auto stereoscopic display II" (Wednesday)

5 m

20 m

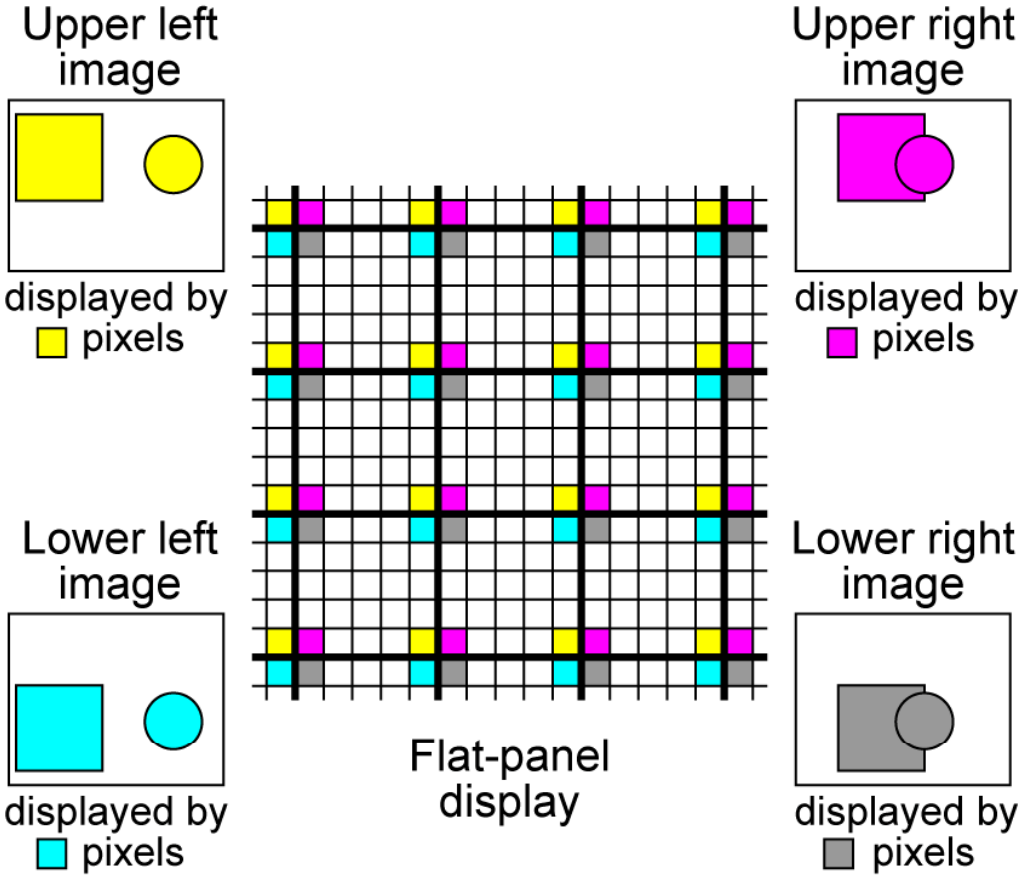
Ray reconstruction: Full-parallax-type



Integral Imaging
(Integral Photography)

Full parallax (horizontal +vertical parallax) is provided.

Extremely high resolution is required for the flat-panel display.



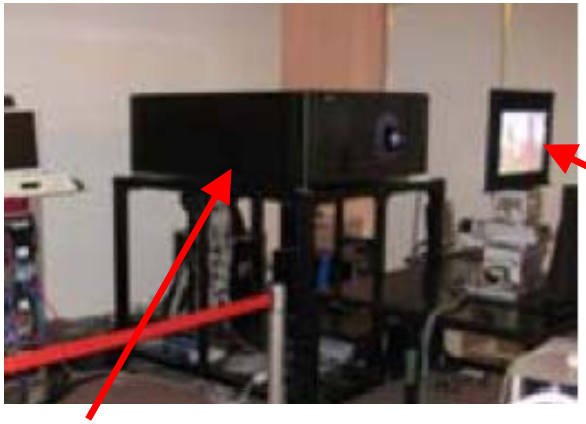
Vergence	○
Binocular disparity	○
Accommodation	×*
Motion parallax	Δ*

* ○ if SMV condition was satisfied.

Integral Imaging Display Systems

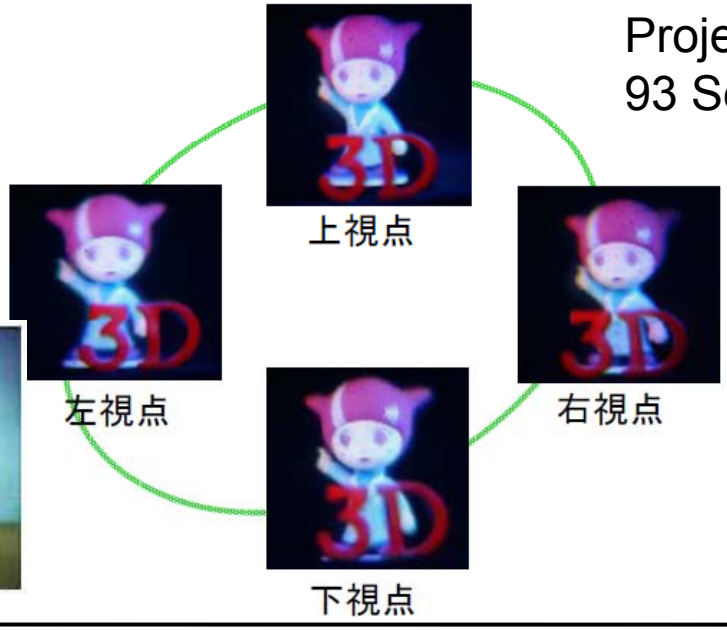
NHK

Developing as a future TV

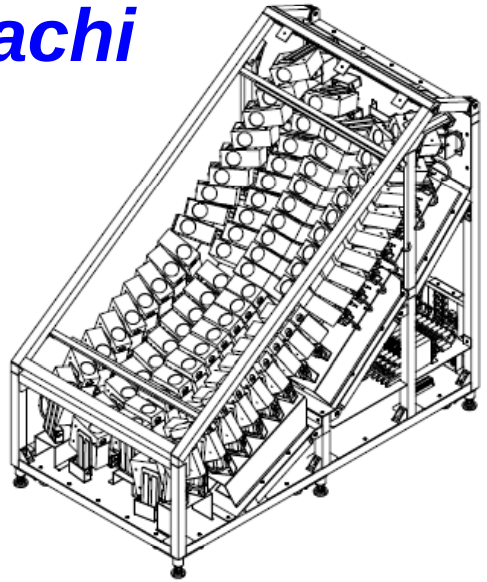


Lens Array
400 × 250

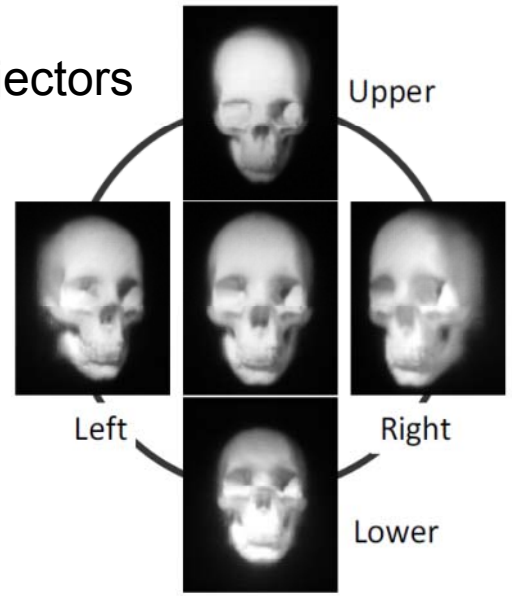
Super HD
Projector
7,680 × 4,320



Hitachi



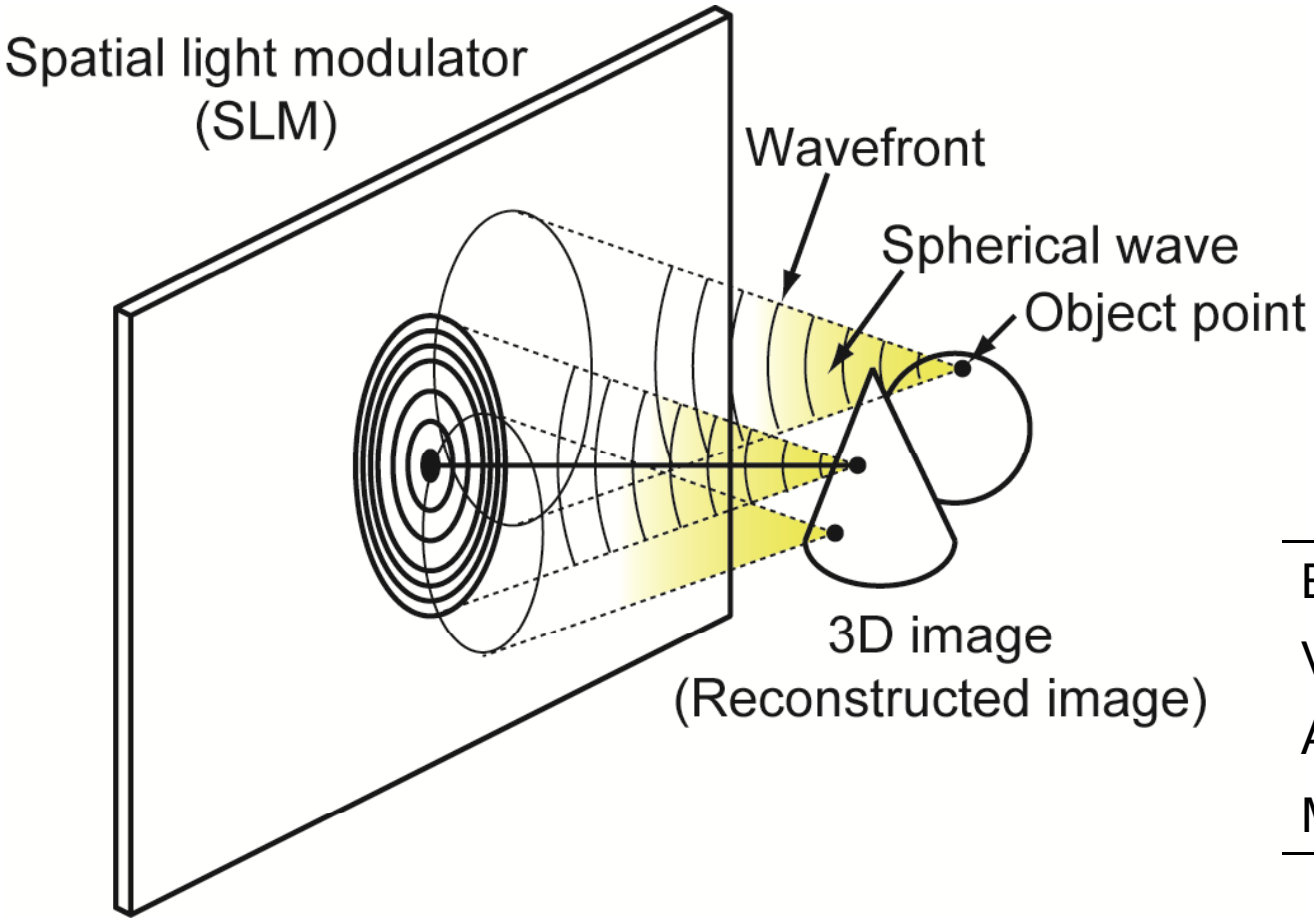
Projector array
93 Sets of SVGA Projectors



Wavefront Reconstruction: Holography

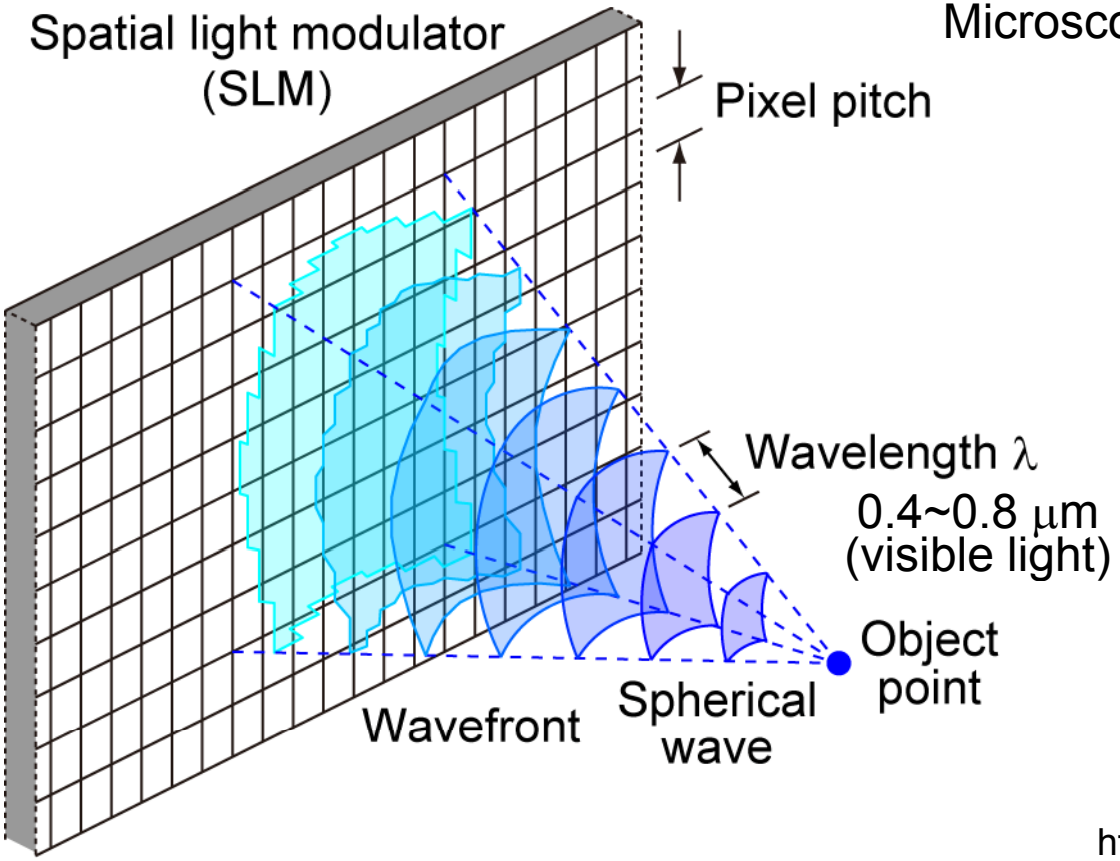
Holography is an ideal 3D display technique.

Because holography reconstructs the wavefront of light, physically accurate 3D images can be produced.

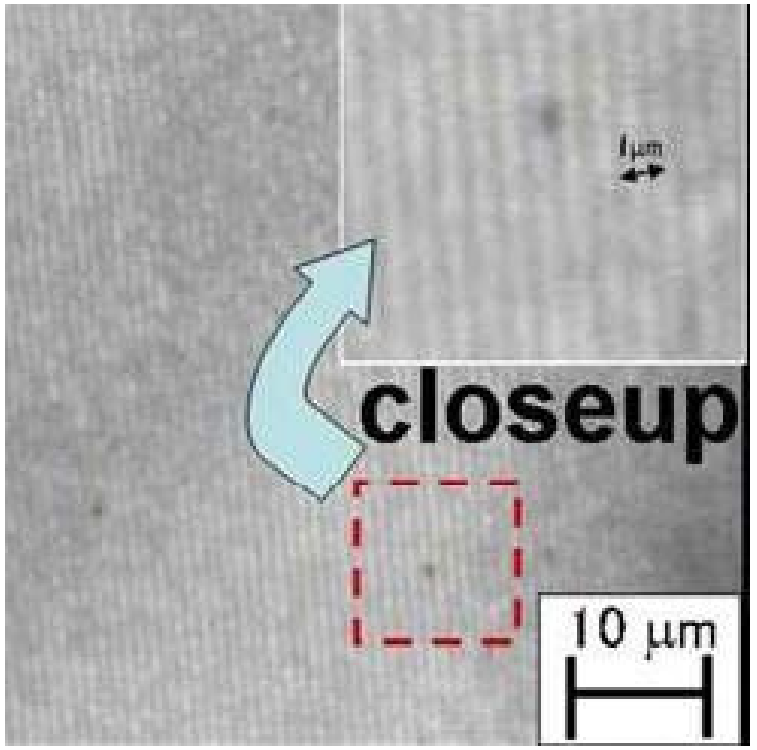


Binocular disparity	○
Vergence	○
Accommodation	○
Motion parallax	○

Requirements for SLM



Microscopic image of optically recorded hologram



http://www.maglab.eee.tut.ac.jp/research-magholo.html

The pixel pitch of SLM needs to be ~1 μm.

To increase the screen size, the number of pixels must be proportionally increased.

SLM requires an extremely high resolution.

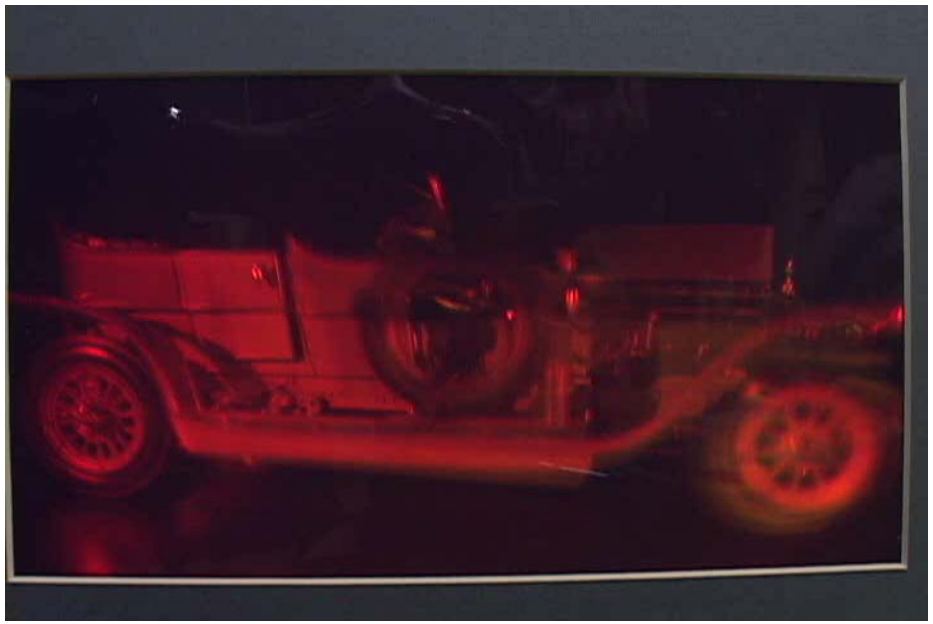
Ray-reconstruction v.s. Wavefront-reconstruction

Holography has the potential to provide very sharp 3D images, because light converges to generate very small spots in space.

Ray-reconstruction

Lenticular display

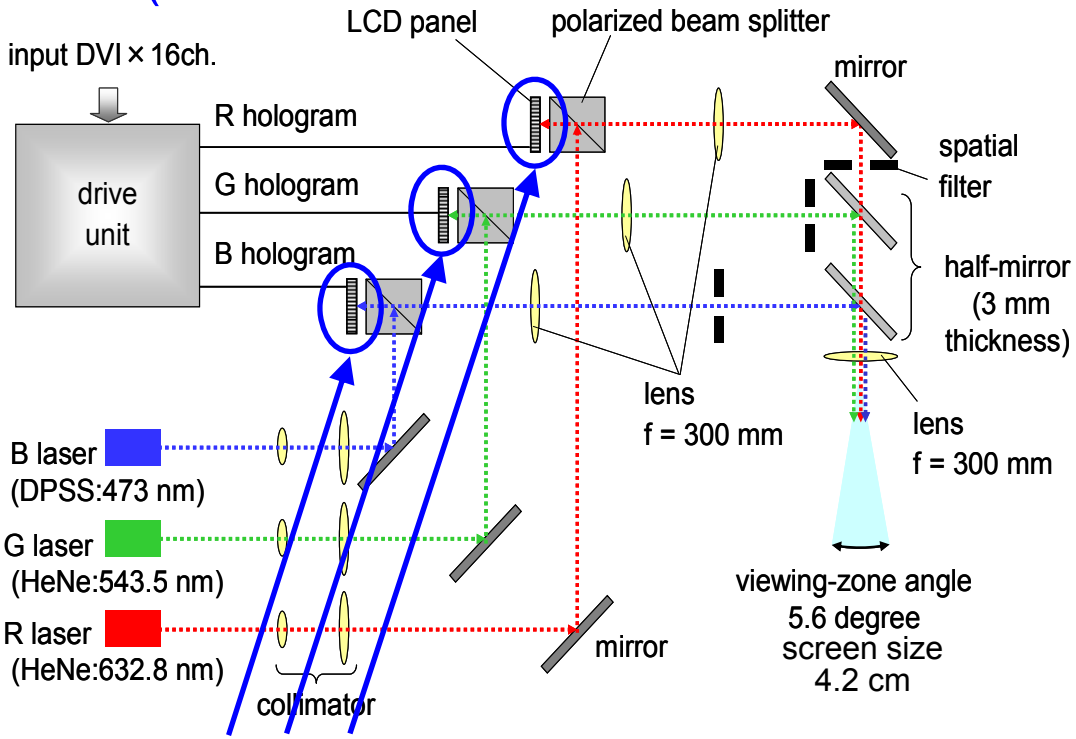
Wavefront-reconstruction

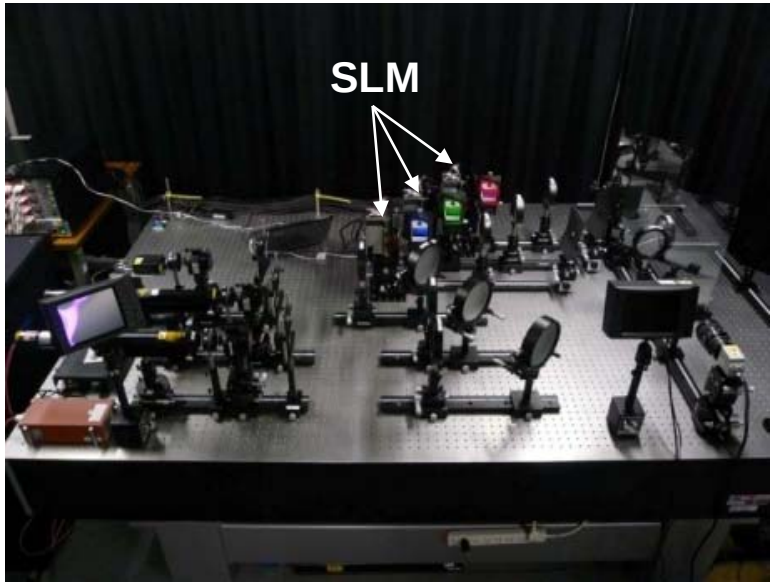


Optical hologram
Not electronic hologram

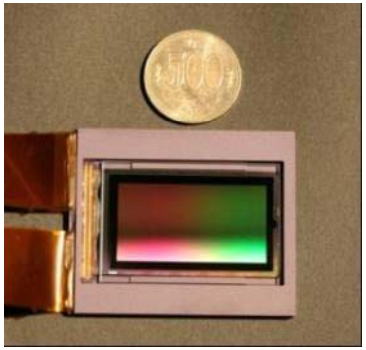
Electronic Holography Using 8k4k SLM

NICT (National Institute of Information and Communications Technology, Japan)





Experimental System



8k4k SLM

Pixel pitch: 4.8 μm
Resolution: 7,680 × 4,320

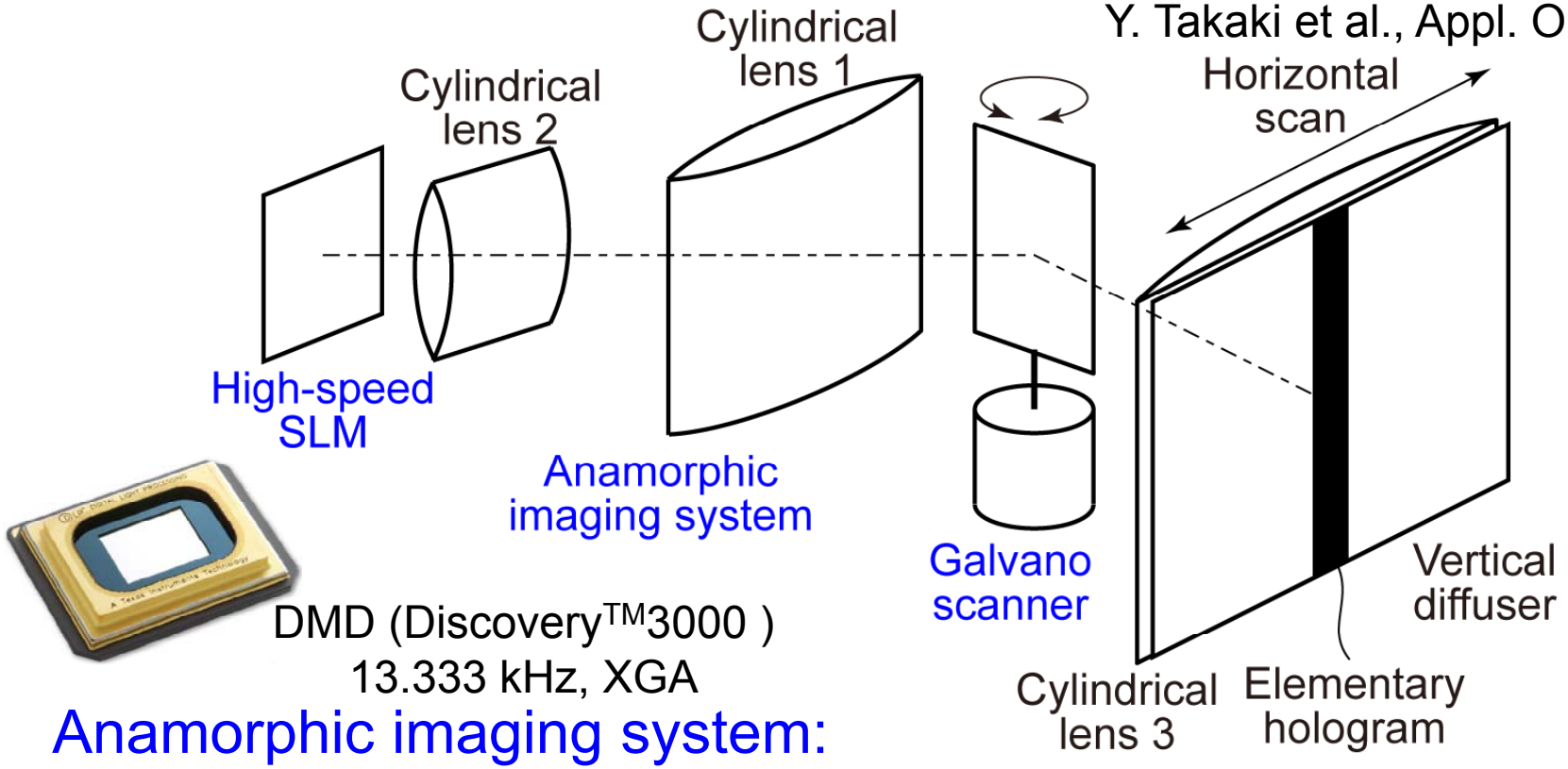
Viewing zone angle: 5.6°
Screen size: 1.7 inches

Color reconstructed image

Horizontal-parallax Holography

Horizontally Scanning Holography by TUAT

Y. Takaki et al., Appl. Opt. **48**, 3255 (2009)



DMD (Discovery™3000)
13.333 kHz, XGA

Galvano Scanner
60 scans/s

Anamorphic imaging system:

Horizontal: reduce pixel pitch → Viewing zone angle increases

Pixel pitch: 2.5 μm

Viewing zone angle: 15°

Vertical: increase image height

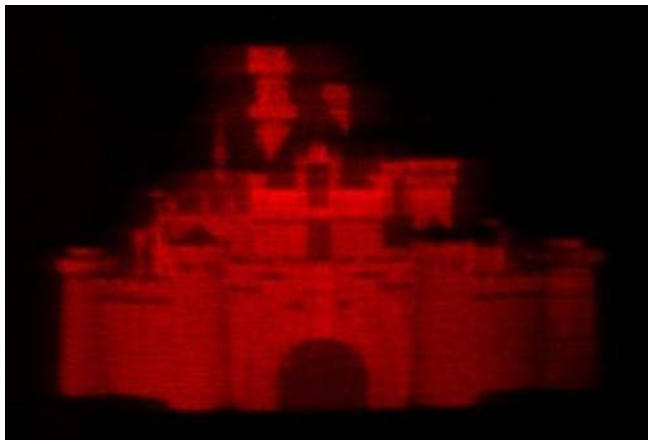
Horizontal Scanning:

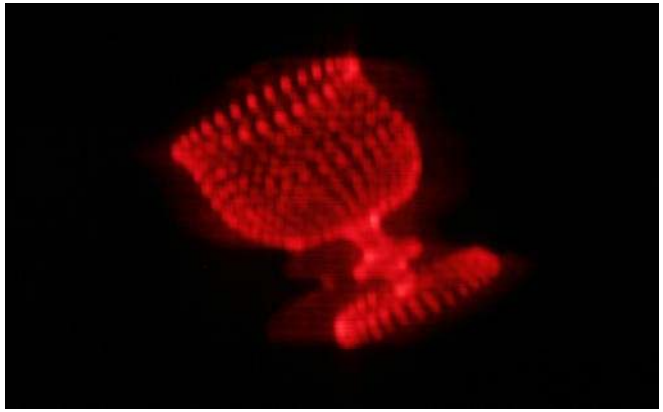
Increase image width → Screen size enlarges

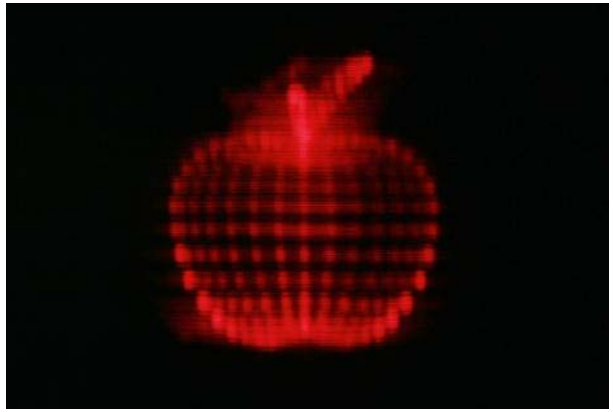
Screen size: 4.1 inches

Reconstructed Images

Viewing zone angle: 15°
Screen size: 4.1 inches
Frame rate: 60 Hz





Summary

Next-generation 3D displays should be glasses-free and reasonably satisfy physiological factors of human 3D perception.

The most promising technologies are multi-view, super multi-view, and integral imaging displays.

Holography, which produces physically accurate 3D images, provides the ultimate 3D display.

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