Three-Dimensional Displays: Present and Future

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Outline

1. Introduction
2. Human Factors
3. Current 3D display techniques

   two-view display, multi-view display
4. Future 3D display techniques

   natural 3D display, integral photography, holography
5. Future Prospects

Why 3D ?

2D displays have achieved sufficiently high resolution, high dynamic range, and high frame rate.

Full HD resolution, 12-bit gray-level, 120 Hz frame rate

Is Super HDTV required ?

Resolution 7,680 × 4,320, Screen size 100”

The cinema industry has moved to 3D.

Audiences and profits have increased.

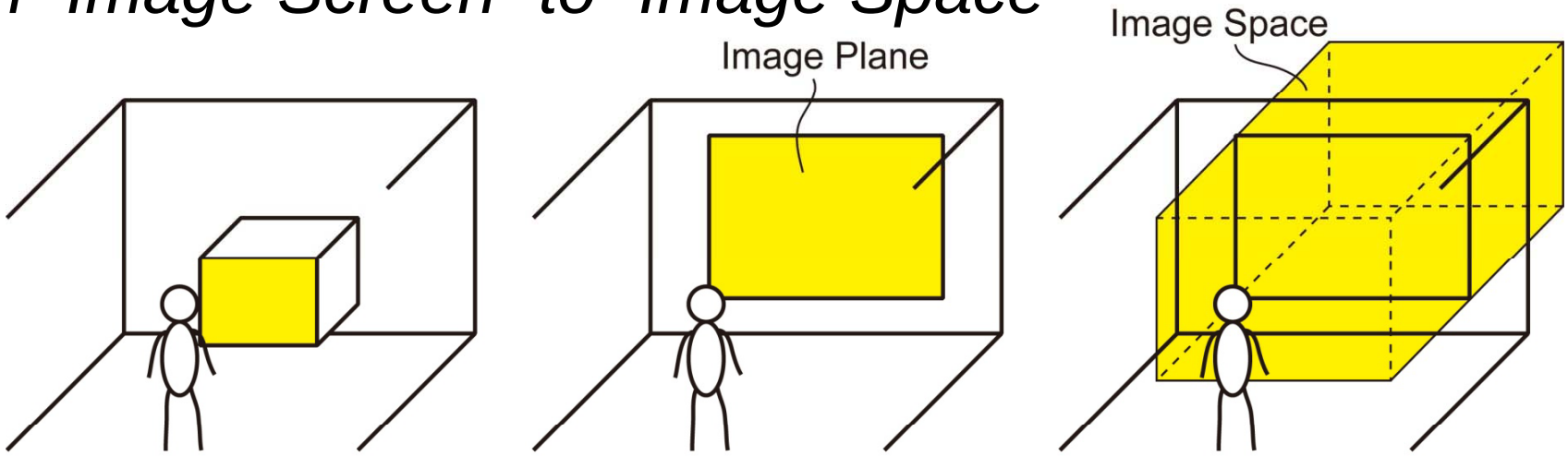
"The Polar Express,"
"Chicken Little,"
"Beowulf,"
"Center of the Earth,"
"Bolt"…

ShoWest, March 2005

L to R: Doug Darrow (TI), George Lucas, Robert Zemeckis, Randal Kleiser, Robert Rodriguez, James Cameron

Advantages of 3D Displays

From "Image Screen" to "Image Space"



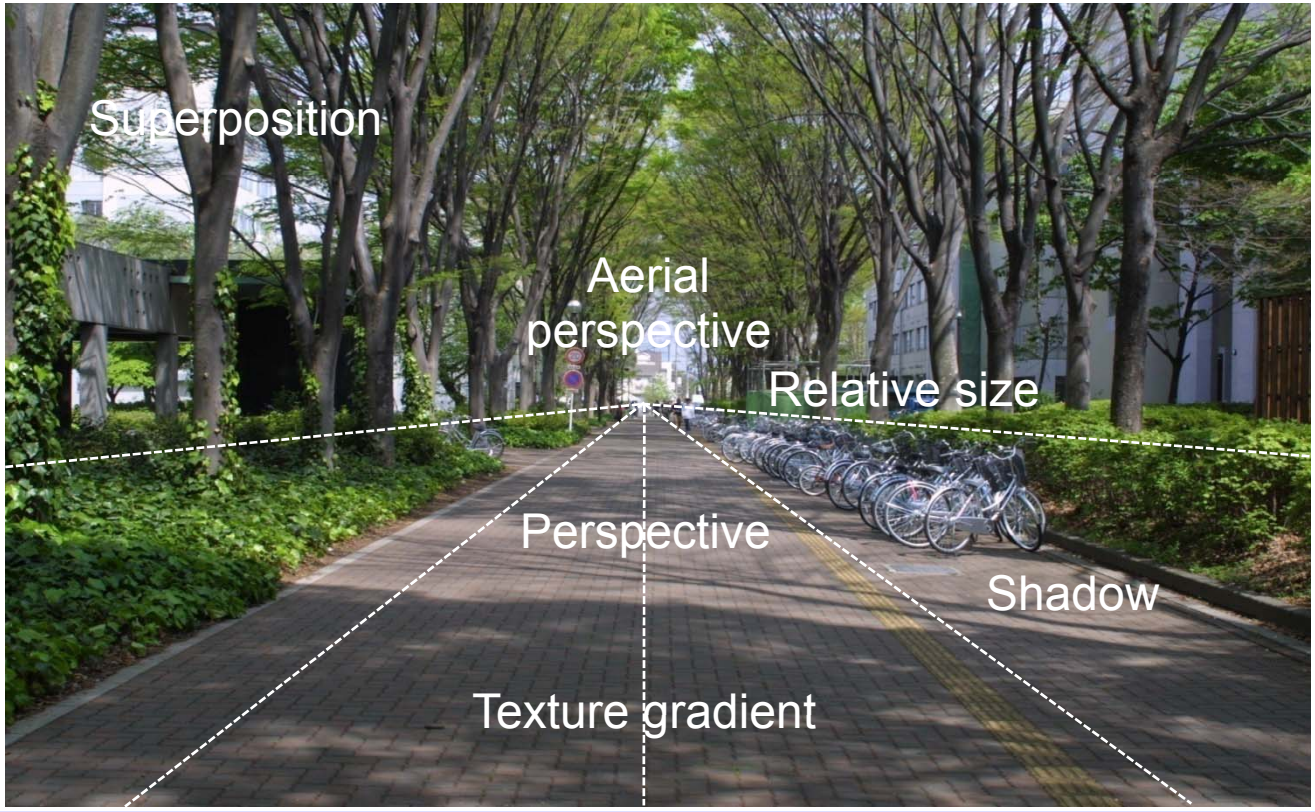
High presence, Ultra reality

Courtesy by URCF

Faithful reproduction of appearances (explained later)

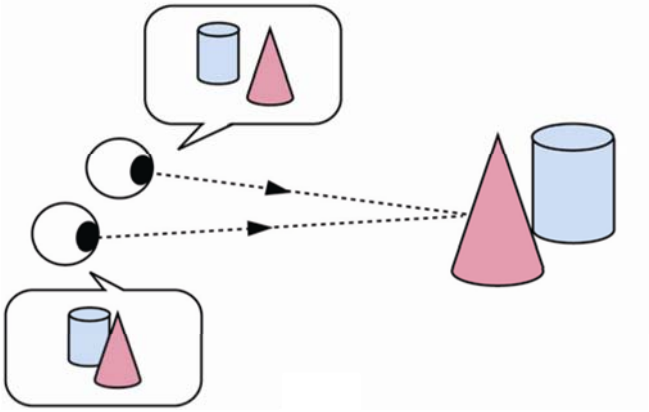
3D Perception by Psychological Factors

Perspective, Relative size, Superposition, Texture gradient, Shadow, Aerial perspective, etc.



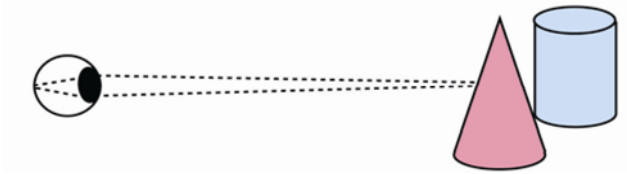
Psychological factors are important in the creation of effective 3D content.

3D Perception by Physiological Factors



Binocular disparity

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

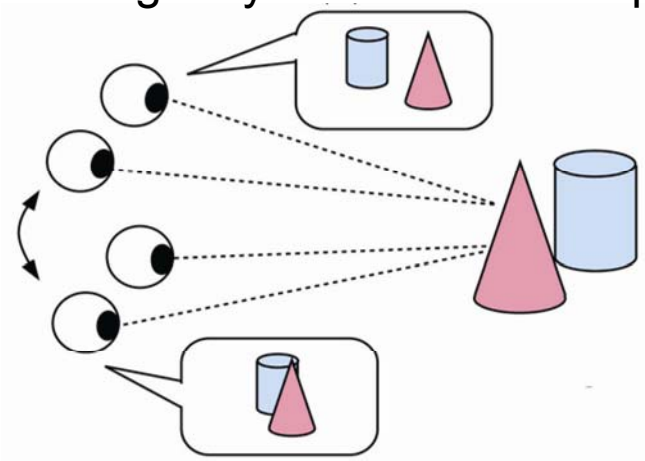


Accommodation

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

Vergence

the angle between the lines of sight when the left and the right eyes see the same point



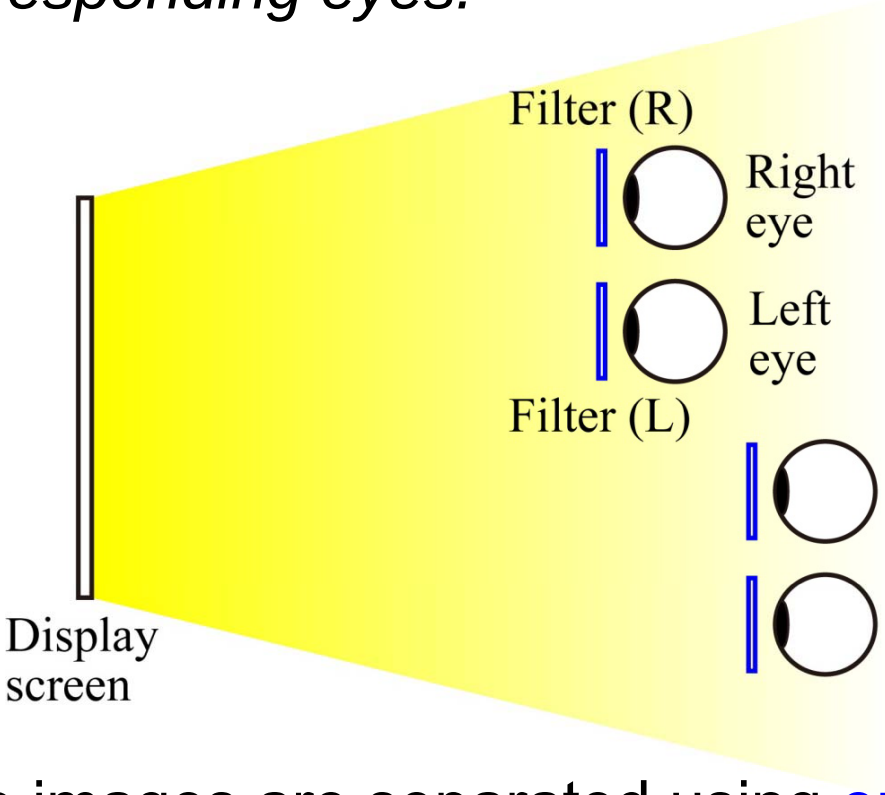
Motion parallax

the change in a retinal image due to the movement of a viewpoint or an object

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

Two-View Display: Glasses Type

Two different images for the left and right eyes are displayed for the corresponding eyes.



Binocular disparity	○
Vergence	○
Accommodation	×
Motion parallax	×

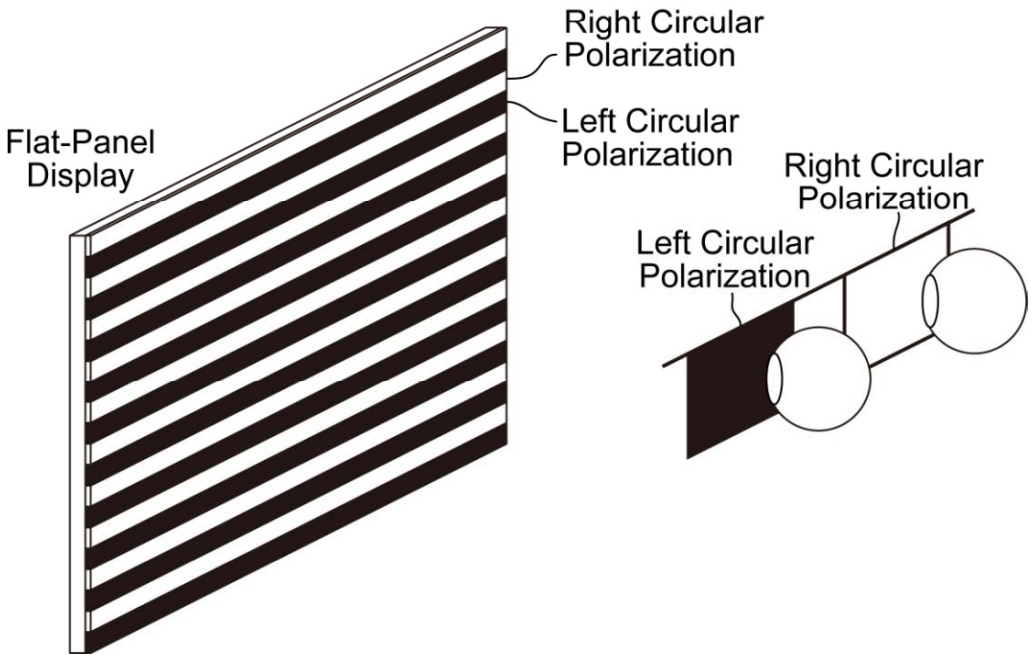
Two images are separated using optical filters.

- Polarization filters: X-pol, RealD
- Wavelength filters: Anaglyph, Dolby 3D
- High-Speed shutters: XpanD

□ 3D Movie Theaters

Glasses Type Two-View Using Flat-Panel

Polarization glasses technique



Vertical resolution decreases by half.

Nippon BS Broadcasting Corporation (BS11) is currently providing 3D TV programs for this type of display.

Time-multiplexing technique

Liquid crystal shutter glasses

103” plasma Frame rate 120 Hz

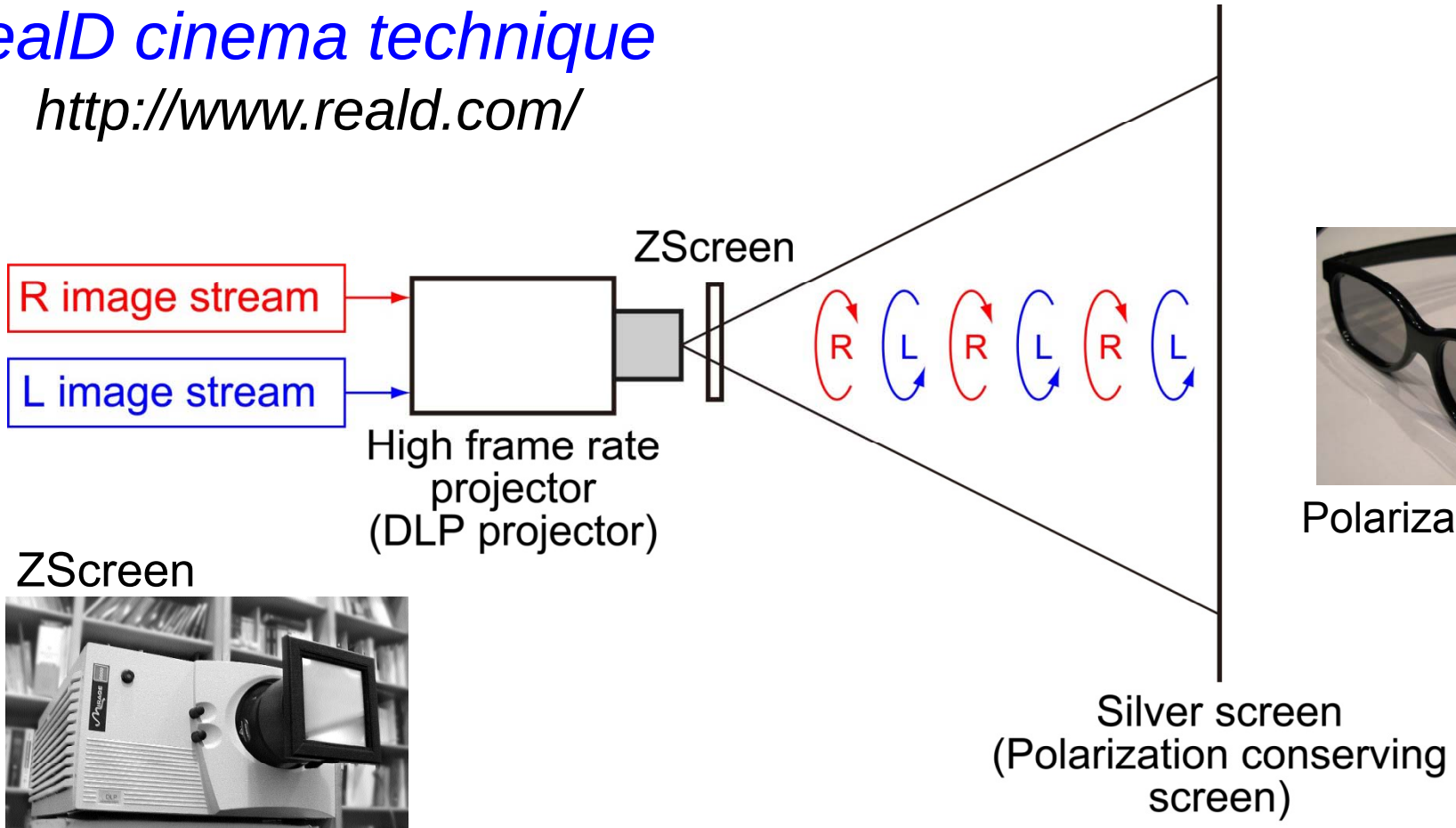
CEATEC 2008, Panasonic

Resolution does not decrease.

Digital 3D Cinema Technique

RealD cinema technique

http://www.reald.com/



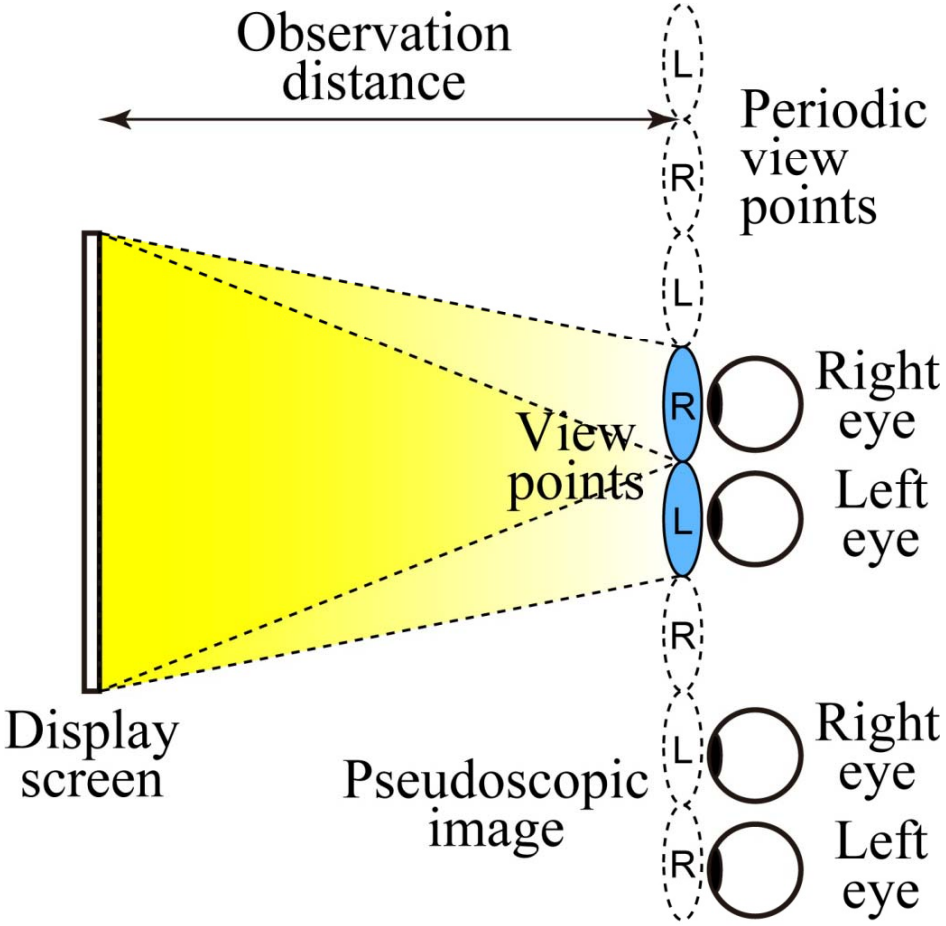
Polarization glasses

ZScreen

ZScreen changes the polarization of light between left and right-handed circularly polarized light.

Glassless Two-View Display

Without using optical filters to separate two images,
two viewpoints are located at a set distance from the display screen.



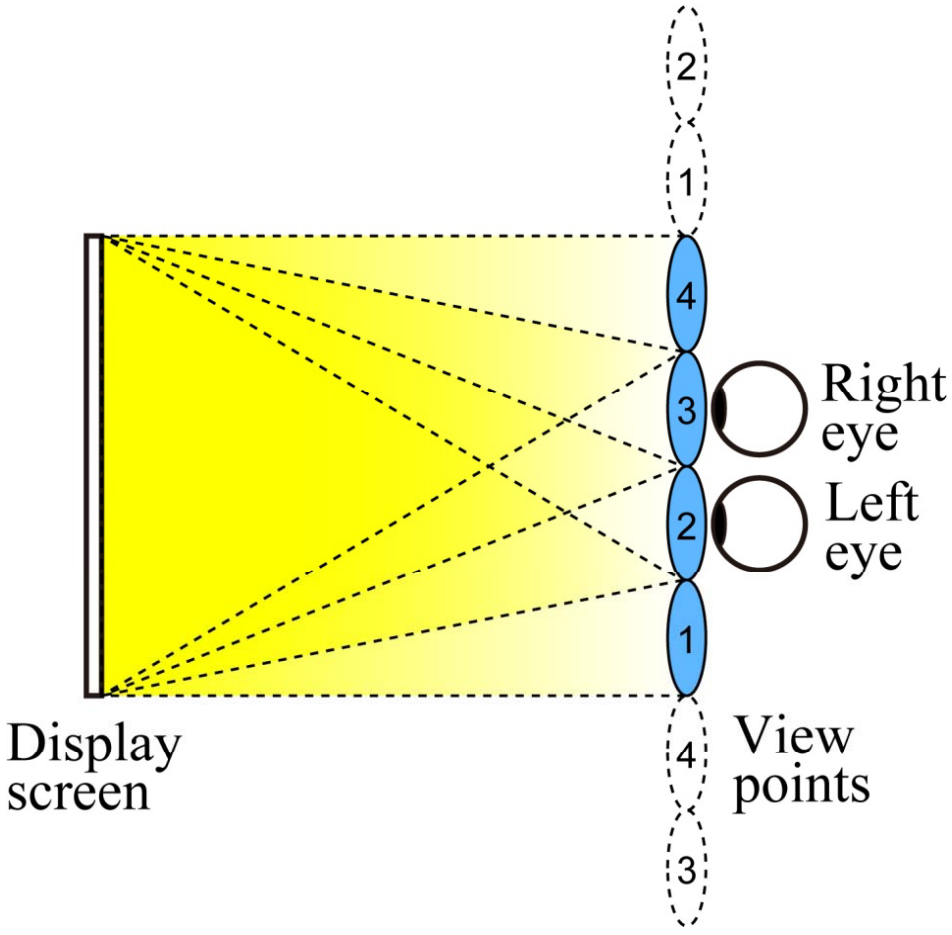
The viewing position is limited.

Binocular disparity	○
Vergence	○
Accommodation	×
Motion parallax	×

The viewpoints appear periodically with typical glassless 3D displays.
→ Multiple viewers
→ Pseudoscopic image

Multi-View Display

A multi-view display generates more than two viewpoints.



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

Motion parallax is obtained.

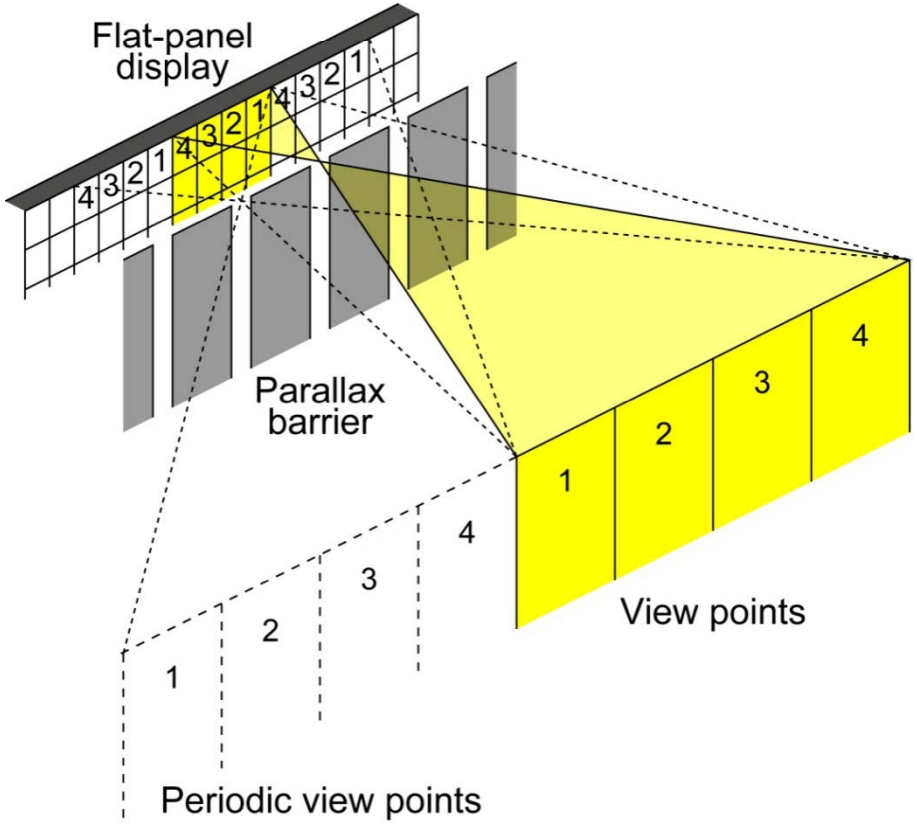
Binocular disparity	○
Vergence	○
Accommodation	×
Motion parallax	Δ

Probability of seeing pseudoscopic images decreases.

Jerky motion parallax reduces the presence and realism of 3D images.

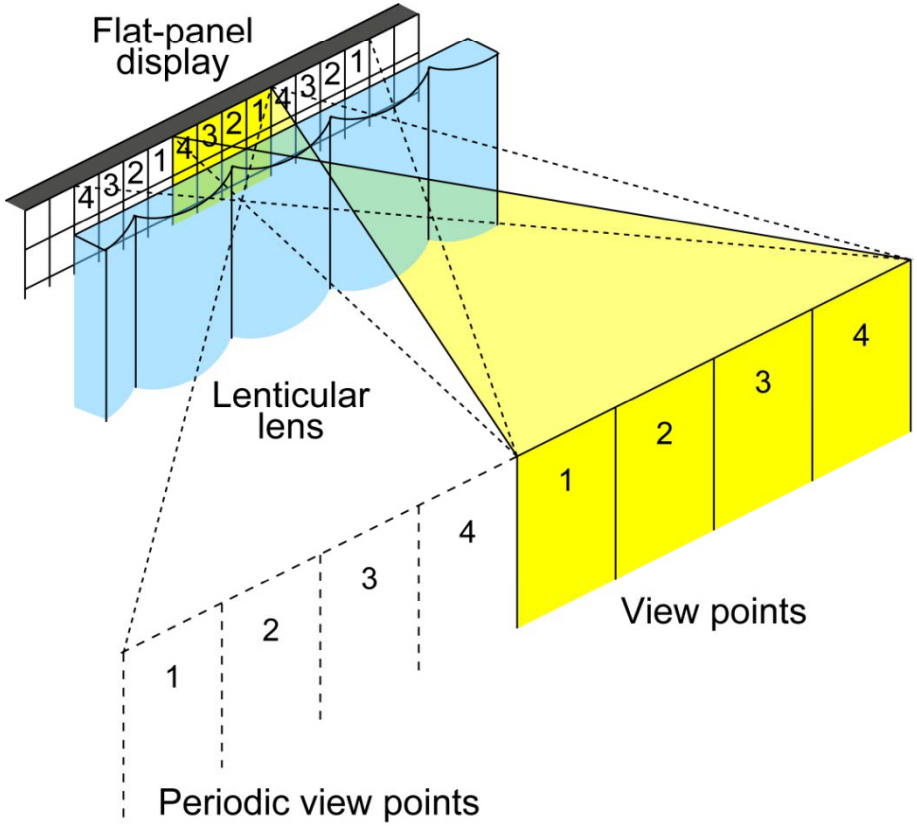
Glassless Flat-Panel 3D Display Systems

Parallax barrier system



High shape accuracy
Low light efficiency

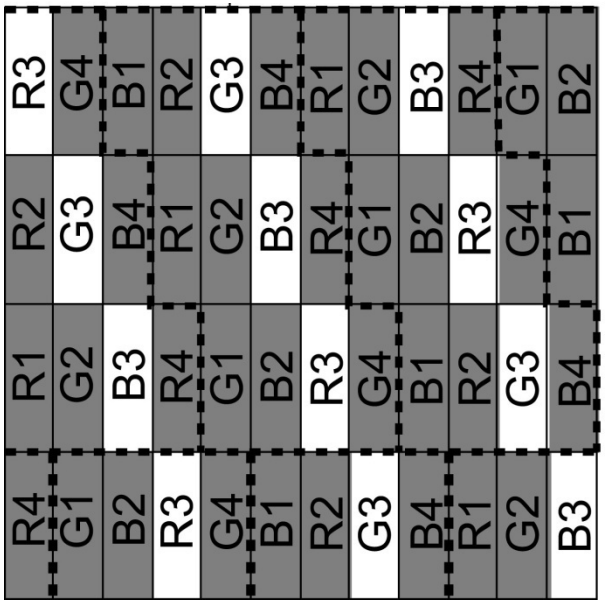
Lenticular lens system



Shape deformation due to humidity and temperature
High light efficiency

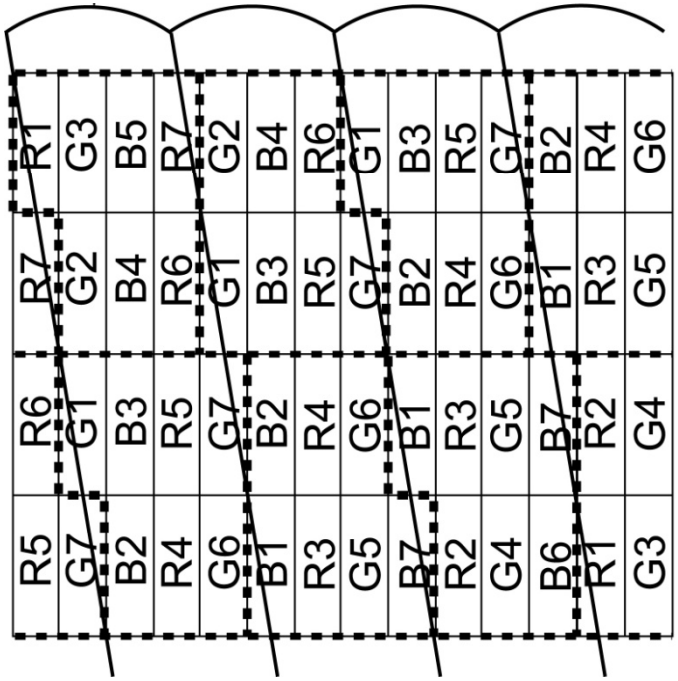
Increase of Viewpoints

Step barrier technique



proposed by SANYO

Slanted lenticular technique



proposed by PHILIPS

Resolution is reduced both in the horizontal and vertical directions in order to increase the number of viewpoints.

Example: Glassless Two-View Displays

Nov. 2002 — Oct. 2003 — Jan. 2009

Sharp
SH-251is

Sharp
PC-RD3D

Parallax Barrier

Mitsubishi
Scan backlight
3D LCD

NEC LCD
Technologies
HDDP

Lenticular

Hitachi
H001

Parallax Barrier

Most of these products are 2D/3D switchable.

Example: Multi-View Displays

4D Vision
8-view
Parallax Barrier

Sanyo
4-view, 7-view
Parallax Barrier

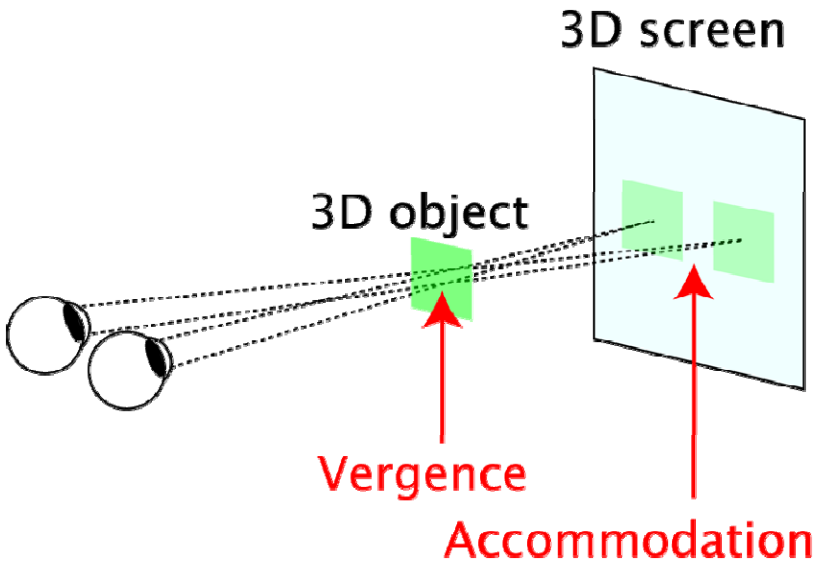
Philips
9-view
Lenticular

Toshiba
12-, 16-, 30-view
Lenticular

NTT DoCoMo
30-direction
Lenticular

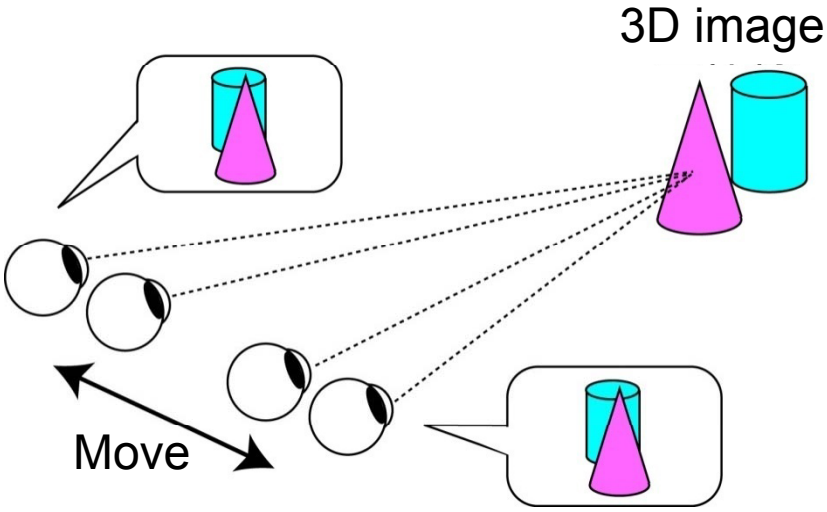
Seiko EPSON
8-view, 2.57”
Lenticular

Problems of Conventional 3D Displays



Accommodation-vergence conflict

⇒ Visual fatigue



Absence or imperfection of motion parallax

⇒ Low realism

***A natural 3D display**, which is free from these two problems, needs to be developed as a future 3D display.*

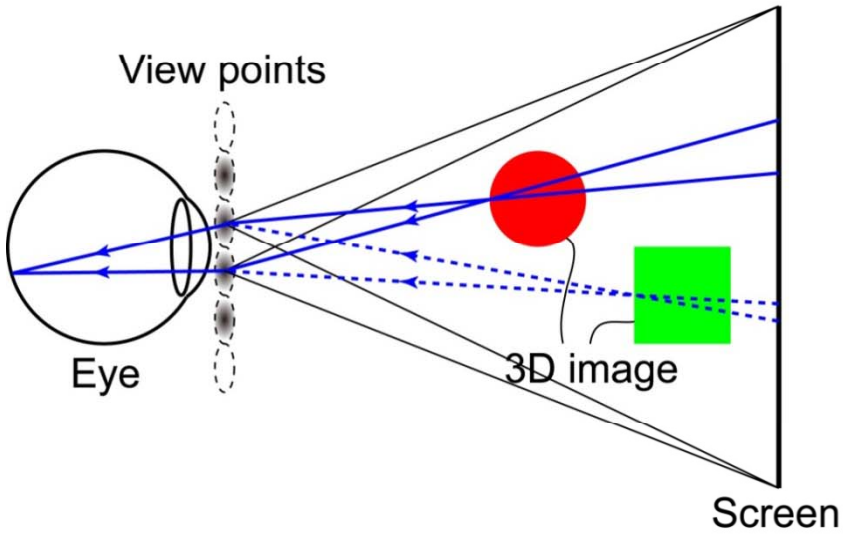
Natural 3D Displays

All four physiological factors should function properly with a natural 3D display.

	Two-view display	Multi-view display	Natural 3D display
Binocular disparity	○	○	○
Vergence	○	○	○
Accommodation	×	×	○
Motion parallax	×	Δ	○

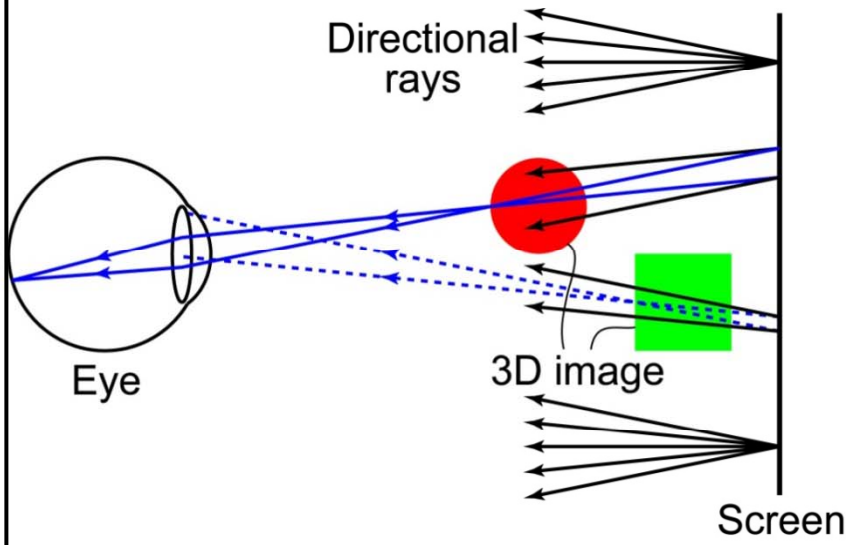
Natural 3D Display Techniques

SMV (Super Multi-View) Display



The interval of viewpoints is made smaller than the pupil diameter, i.e. < 5 mm.
A large number of parallax image (perspective projections) are displayed to corresponding viewpoints.

HDD (High-Density Directional) Display



The sampling pitch of the ray proceeding direction is made small, i.e. < 0.4°.
A large number of directional images (orthographic projections) are displayed with nearly parallel rays.

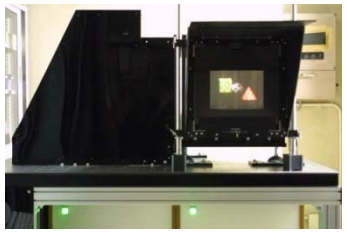
Required number of images: approximately 50 ~ 100（horizontally）

The fundamental idea: "When two or more rays passing through the same point in space enter the pupil simultaneously, the eye can focus on that point."

Project: Development of Natural 3D Display

supported by SCOPE (Strategic Information and Communications R&D Promotion Programme) by Ministry of Internal Affairs and Communications, JAPAN, 2002-2006

3D Displays



64-directional
~QVGA

128-directional
~QVGA

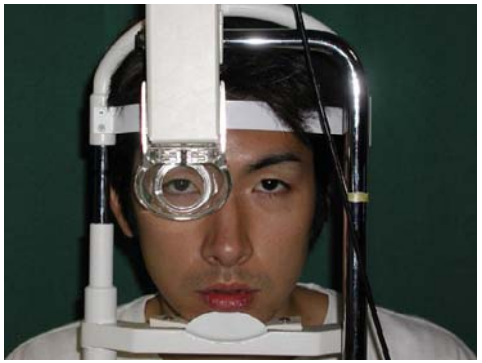
128-directional
SVGA

PC Clusters

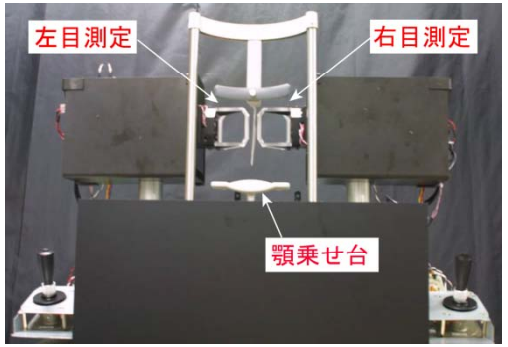
64 PC for
64-directional
display

16 PC for
128-directional
display

Visual Function Measurement



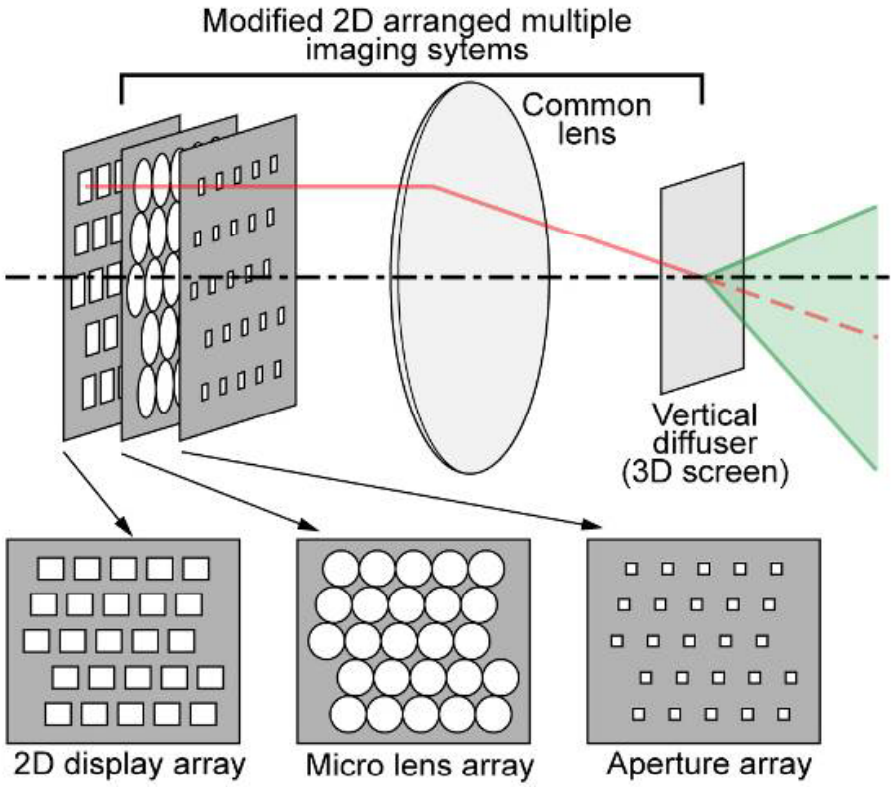
Accommodation measurement



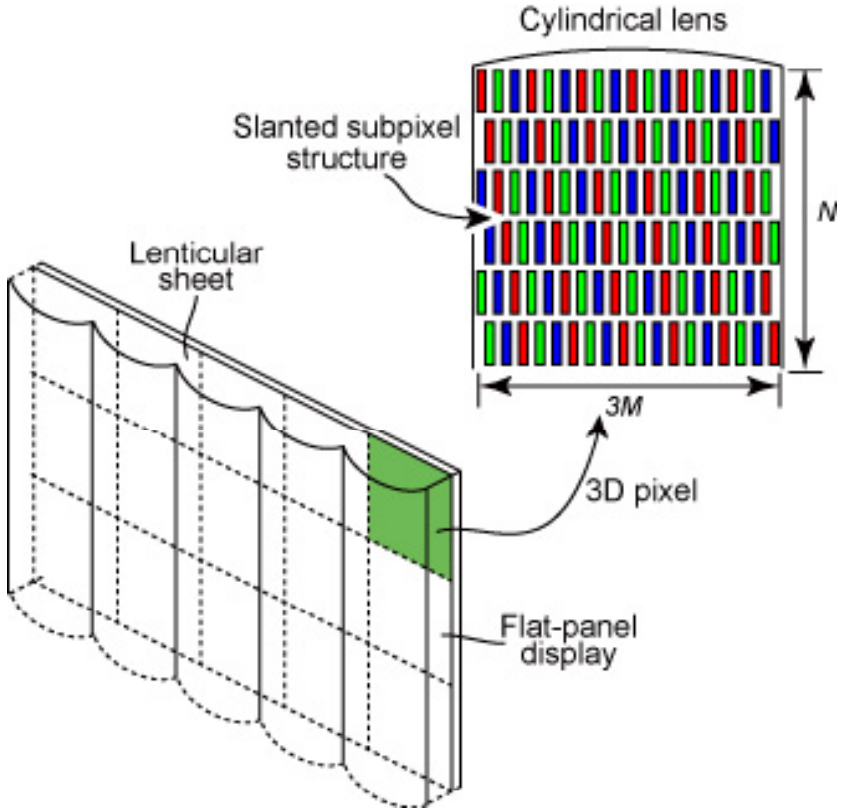
Accommodation+Vergence+Pupil
diameter measurement
(Jointly developed with TOPCON Corp.)

Research target: Exploration of Natural 3D Display Conditions

HDD Displays

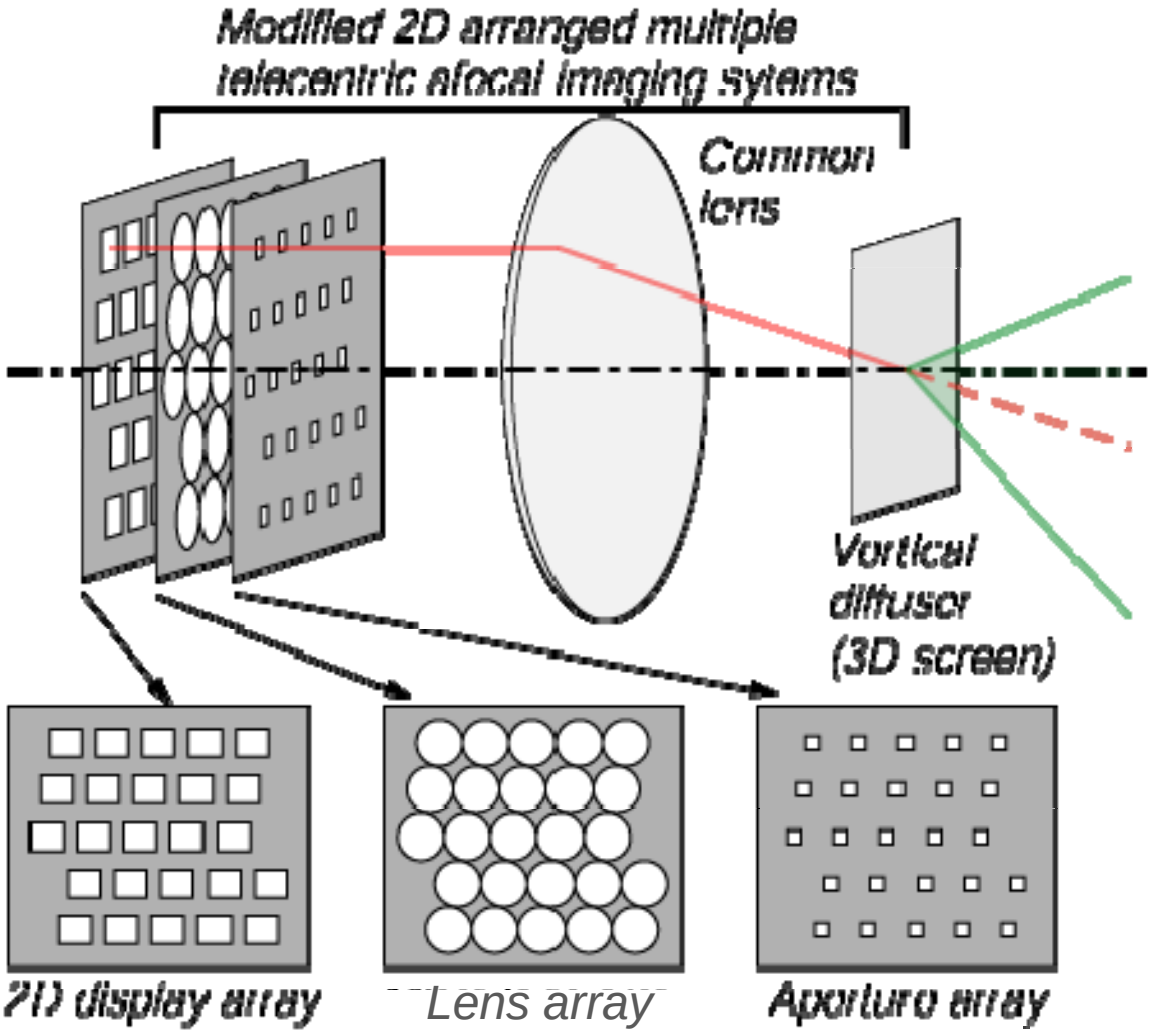


Multi-projection system

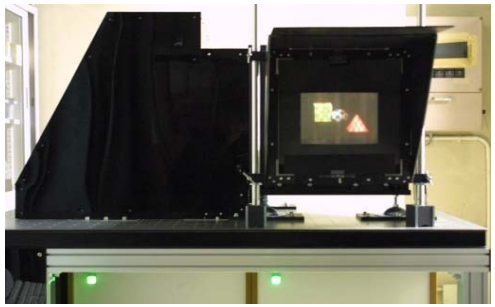
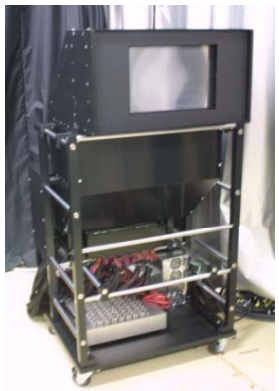


Flat-panel system

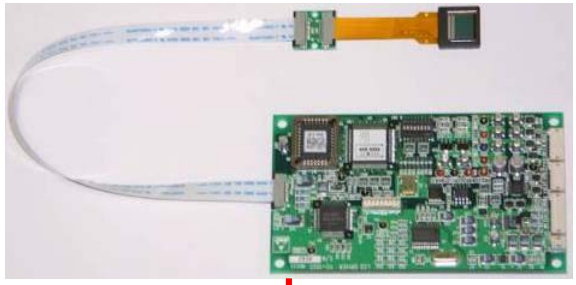
Multi-Projection HDD Display System



Prototype Multi-Projection HDD Displays

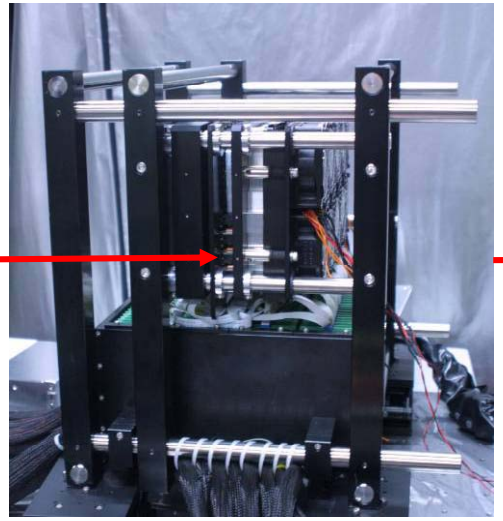
Number of ray directions	64	128	128
Horizontal ray angle pitch	0.34º	0.23º	0.28º
Horizontal viewing angel	21.6º	29.6º	35.7º
3D resolution	~QVGA	~QVGA	SVGA
Screen size	9.25”	13.2”	12.8”
Photo			

128-Direction QVGA Display



0.44” color LCD
（SONY　LCX033AK）

16×8 LCD panels with
modified 2D arrangement



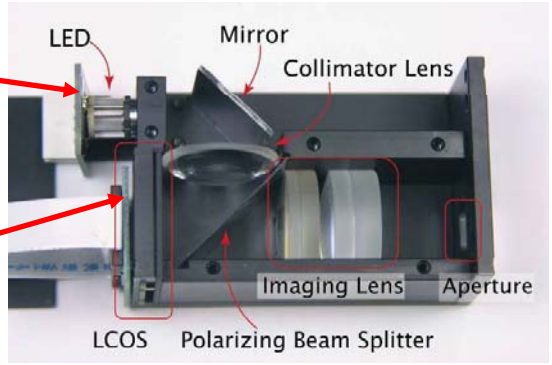
Optical engine

Display system

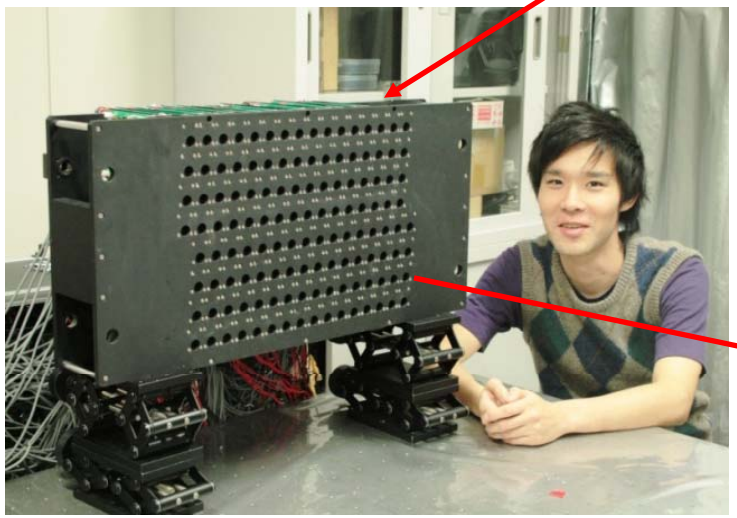
128-Direction SVGA Display

RGB LED
Nichia, NSSM016CT

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



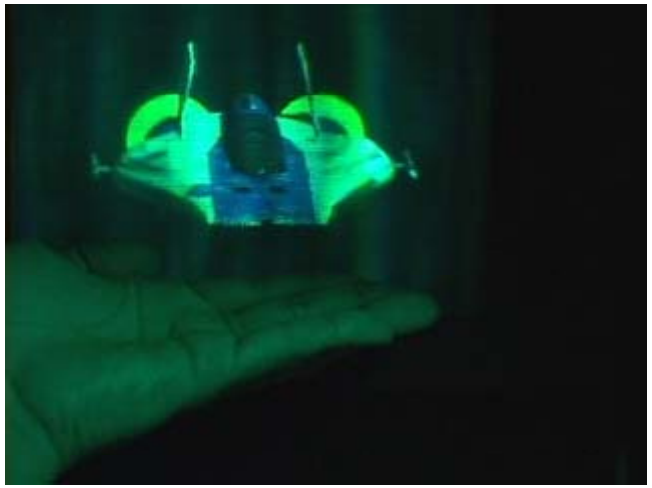
Small projector unit
26 × 38 × 63 mm^3

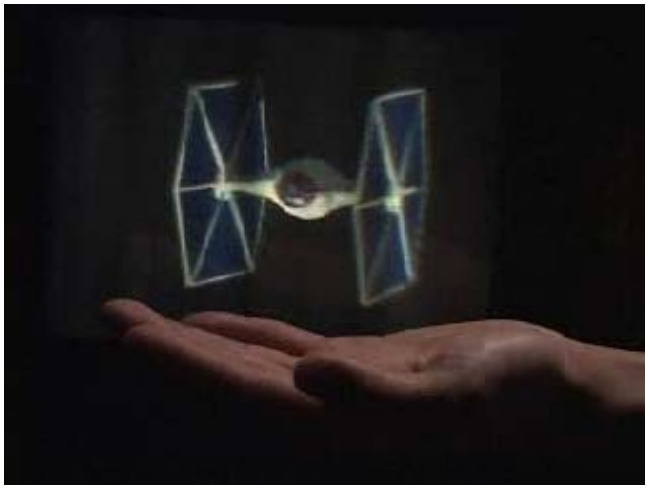


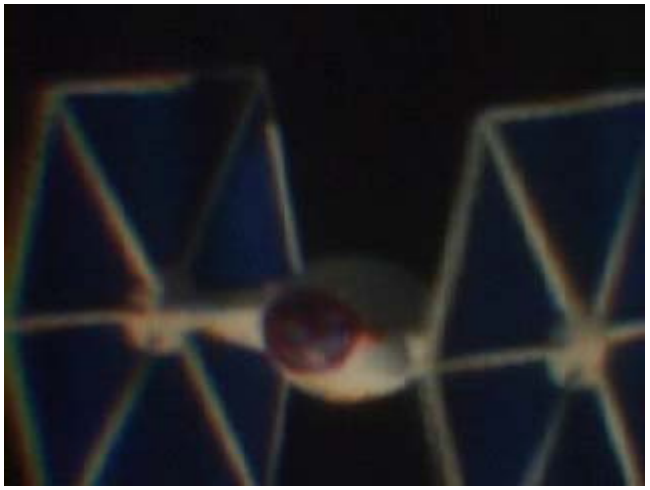
16×8 projector units
with modified 2D arrangement

Display system

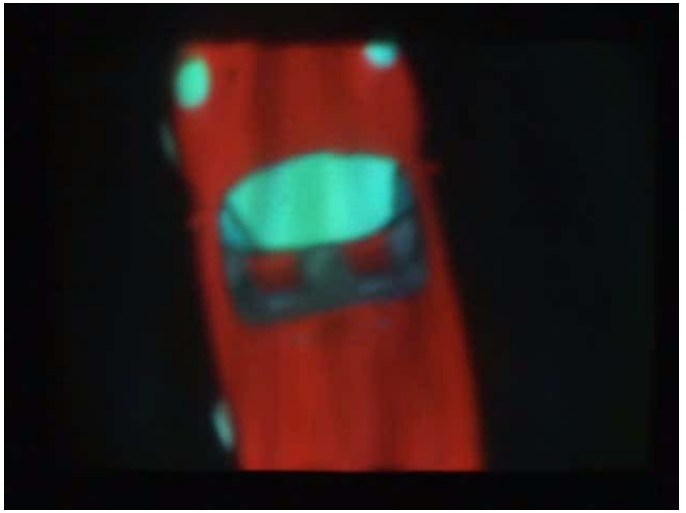
3D Images by 64-direction QVGA Display







3D Images by 128-direction QVGA Display

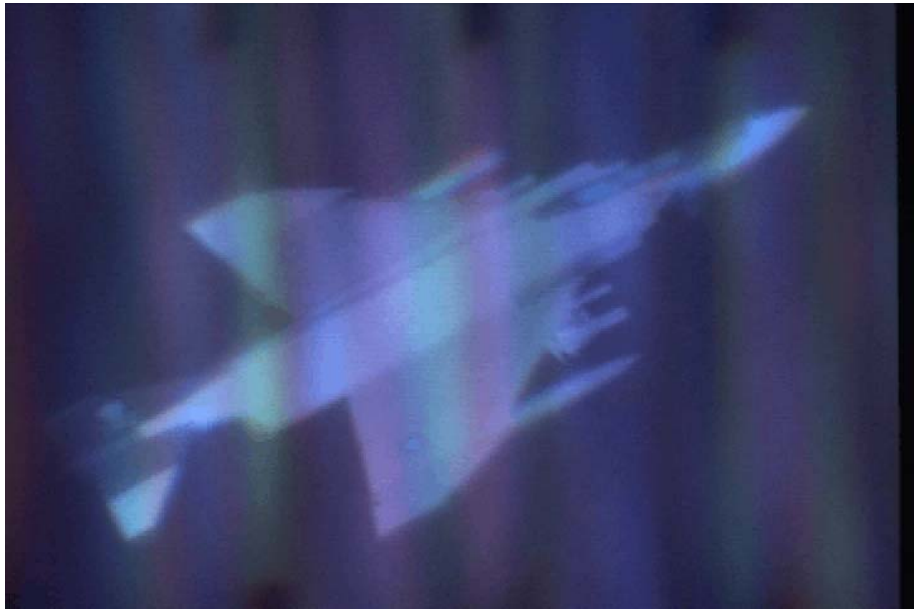


Interactive manipulation of 3D images

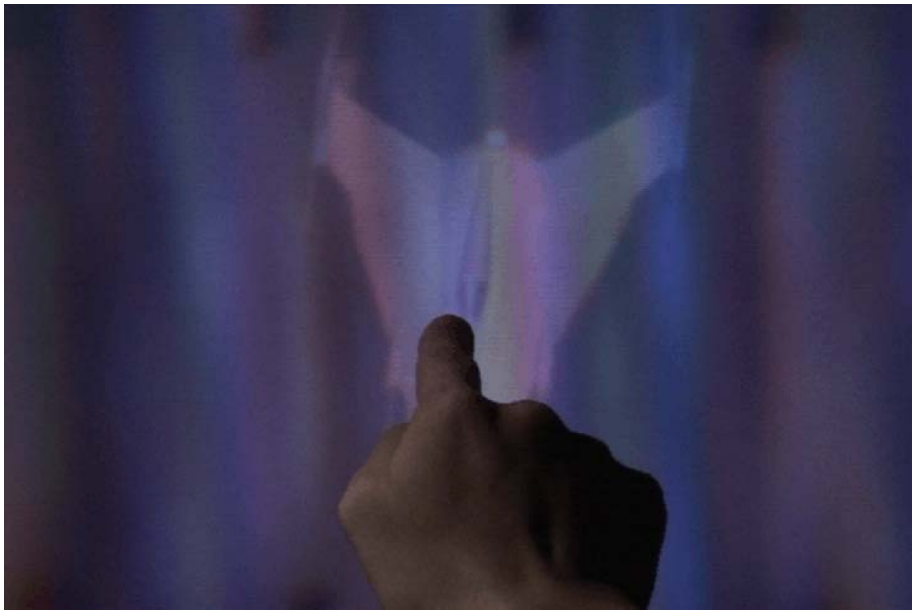
Fingertip manipulation

3D drawing by fingertip

3D Images by 128-direction SVGA Display

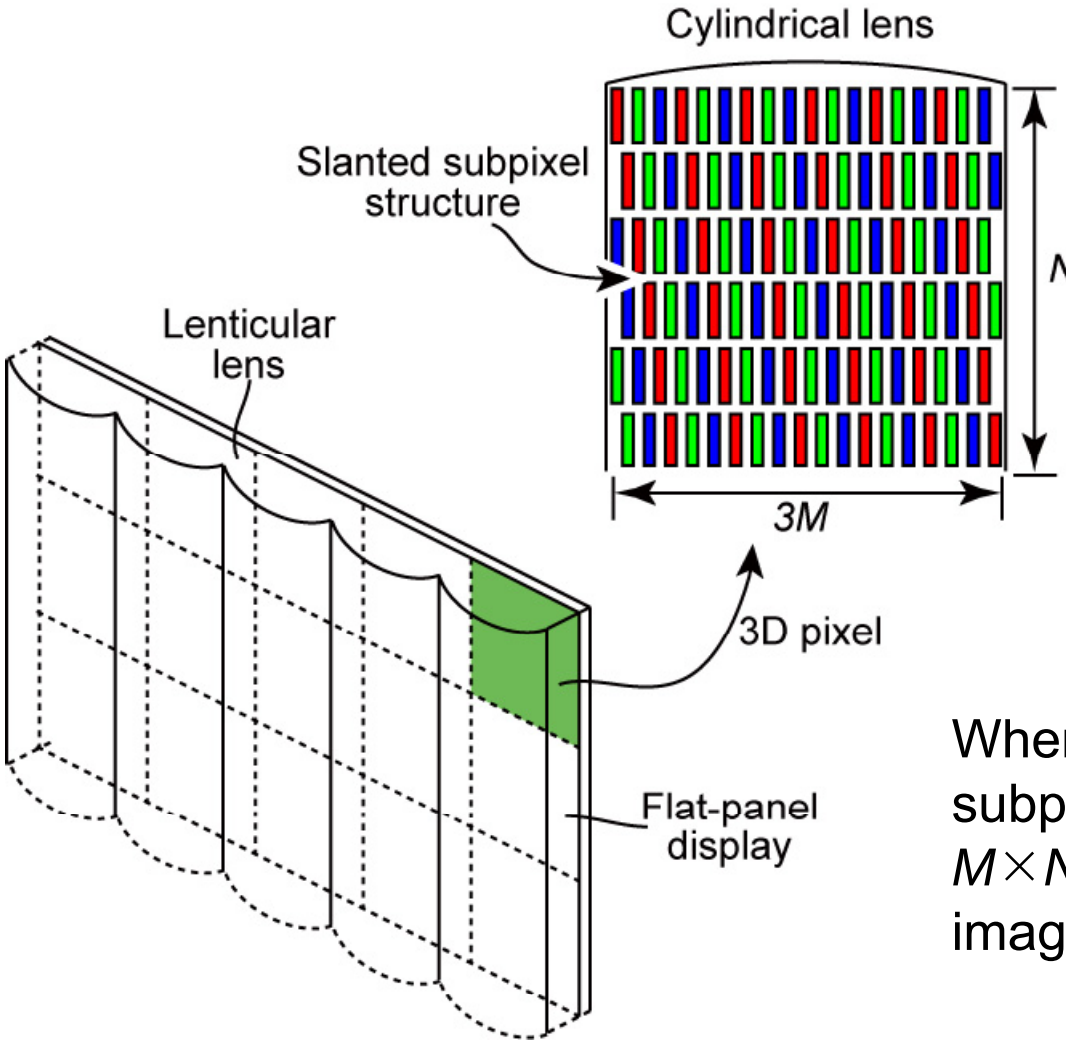


3D input device: 3D mouse
3D data format: VRML
Frame rate: 15-20 fps



3D input device: fingertip detection system
3D data format: VRML
Frame rate: 15-20 fps

Flat-panel HDD Display System



Slanted subpixel arrangement:

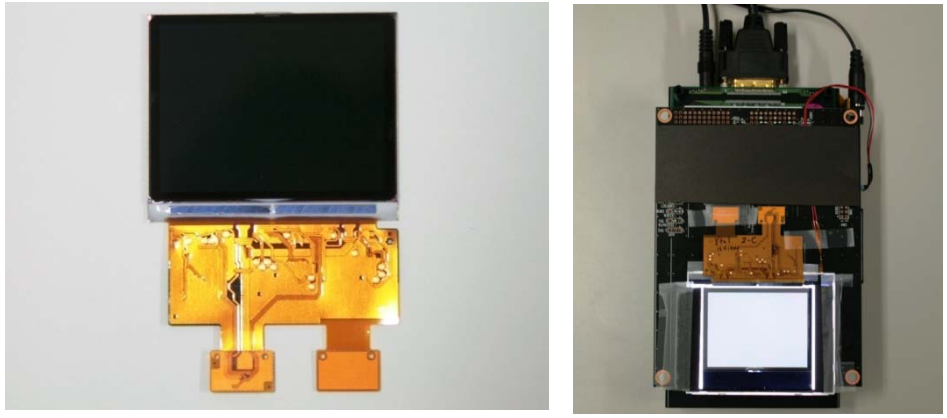
The horizontal positions of all subpixels are different for each color.

The light-emitting area of the subpixels is continuous in the horizontal direction in each color.

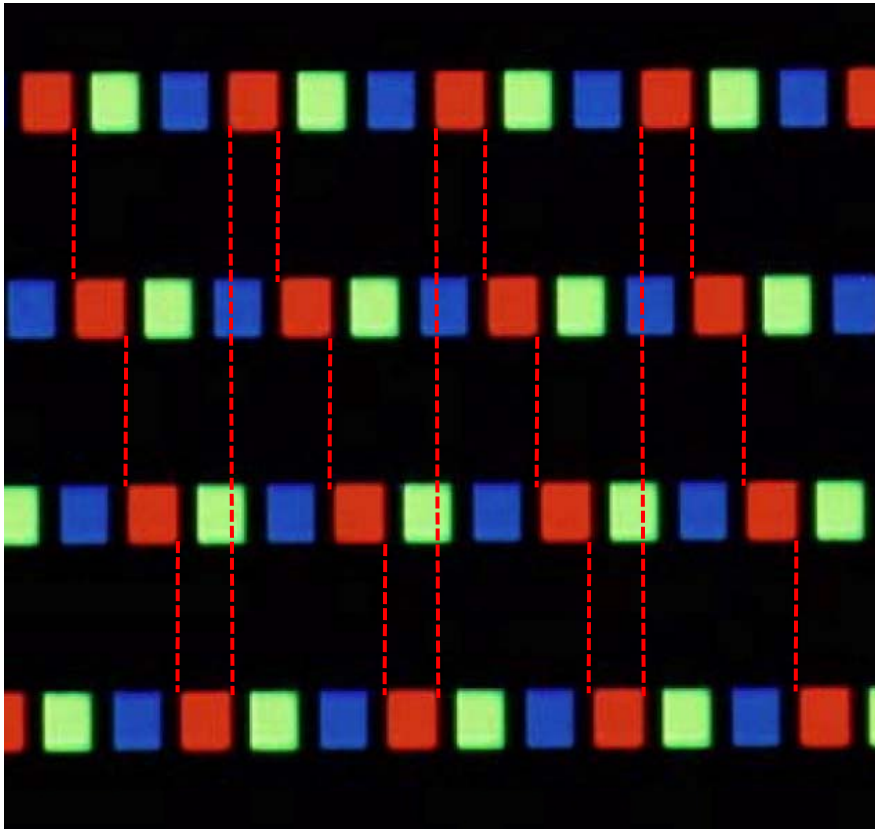
When each 3D pixel consists of $3M \times N$ subpixels, rays are emitted in different $M \times N$ horizontal directions, and $M \times N$ images are displayed horizontally.

Slanted Subpixel Arrangement

Screen size	2.57”
Number of viewpoints	16
3D resolution	256 × 192
Pixel density	500 ppi
Width of subpixel	12.75 μm
Width of black matrix region	4.25 μm



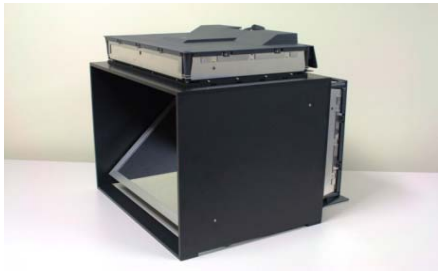
Joint development with Seiko EPSON



Photograph of subpixel structure of fabricated LCD panel

Proc. SPIE, vol.7237 (2009)

Prototype Flat-panel HDD displays

Number of ray directions	72	72	30*
Horizontal ray angle pitch	0.38º	0.38º	0.71º
Horizontal viewing angel	27.6º	27.6º	21.2º
3D resolution	320 × 400 ~half VGA	640 × 400 ~VGA	256 × 128
Screen size	22.2''	22.2''	7.2''
Photo			

*Joint development with NTT DoCoMo

72-direction Display

High-resolution LCD

Resolution	3, 840 × 2,400 (WQUXGA)
Pixel pitch	0.1245 mm
Subpixel pitch	0.0315 mm
Screen size	22.2”

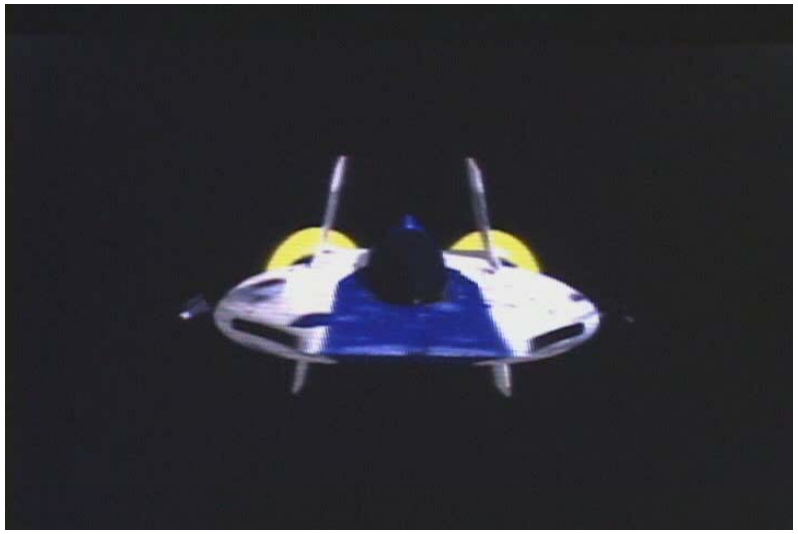
Slanted lenticular sheet

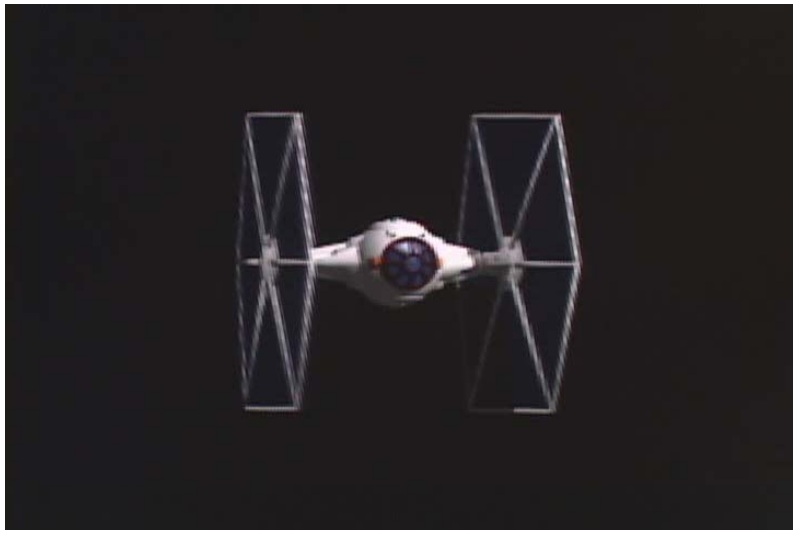
Number of cylindrical lenses	320
Lens pitch	1.494 mm
Lens surface	aspherical
Slant angle	9.46º

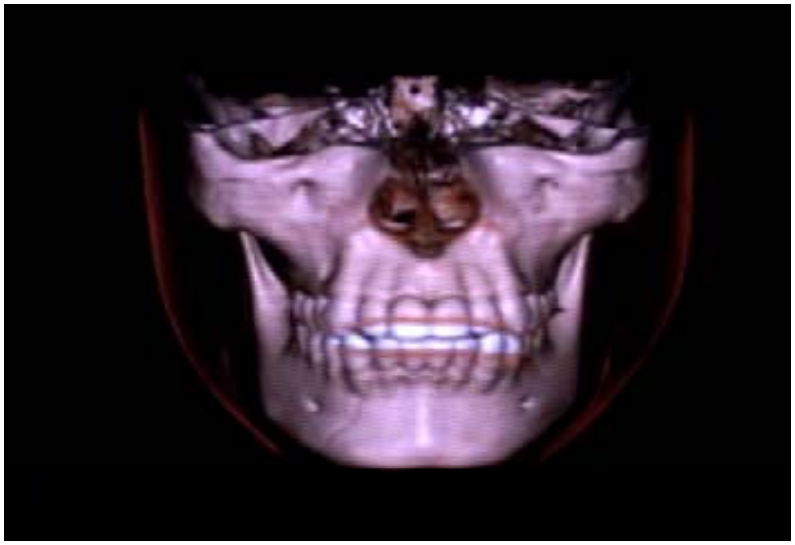
72-directional HDD display

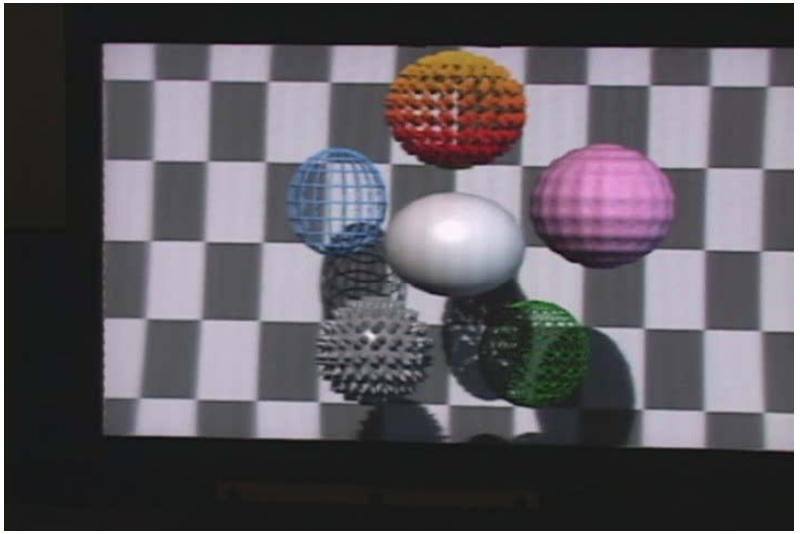
N	6
M	12
Number of ray directions	72
Number of 3D pixels	320 × 400
Horizontal ray angle pitch	0.38°
Horizontal viewing angle	27.6°
Screen size	22.2”

3D Images by 72-direction Display



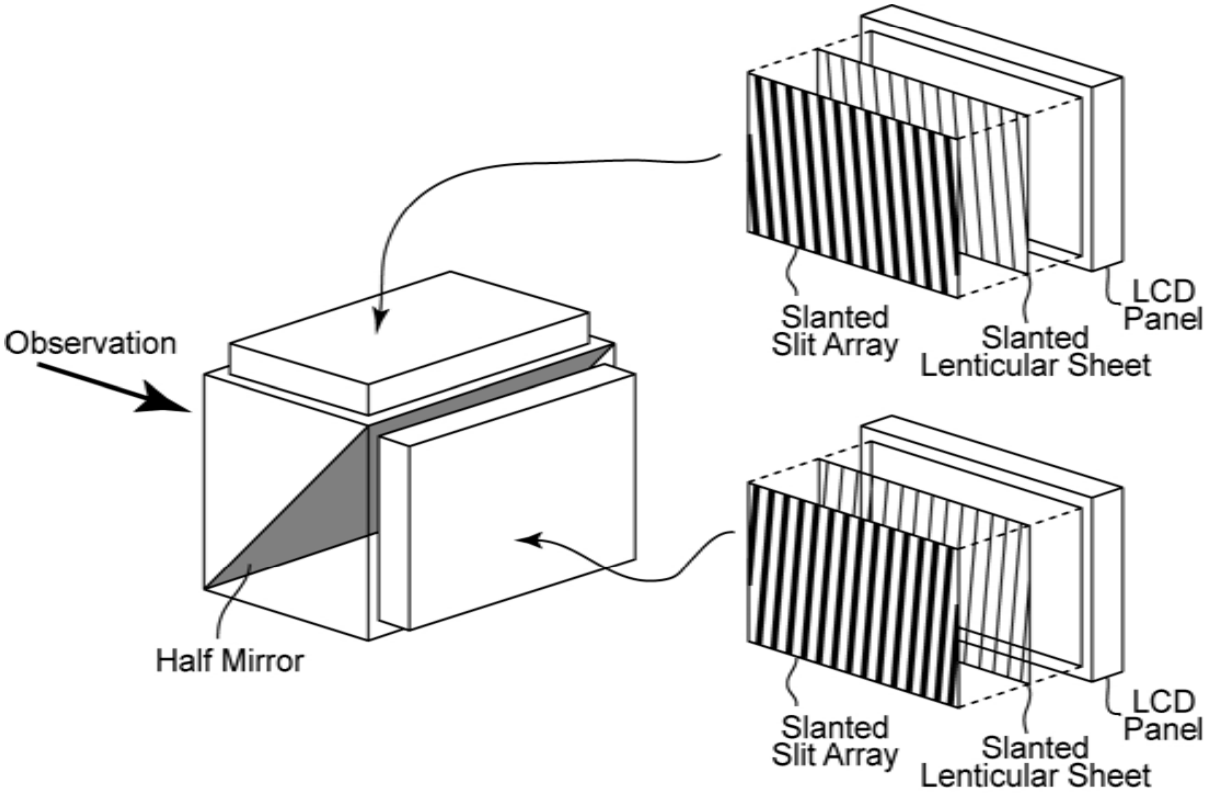






72-direction VGA Display

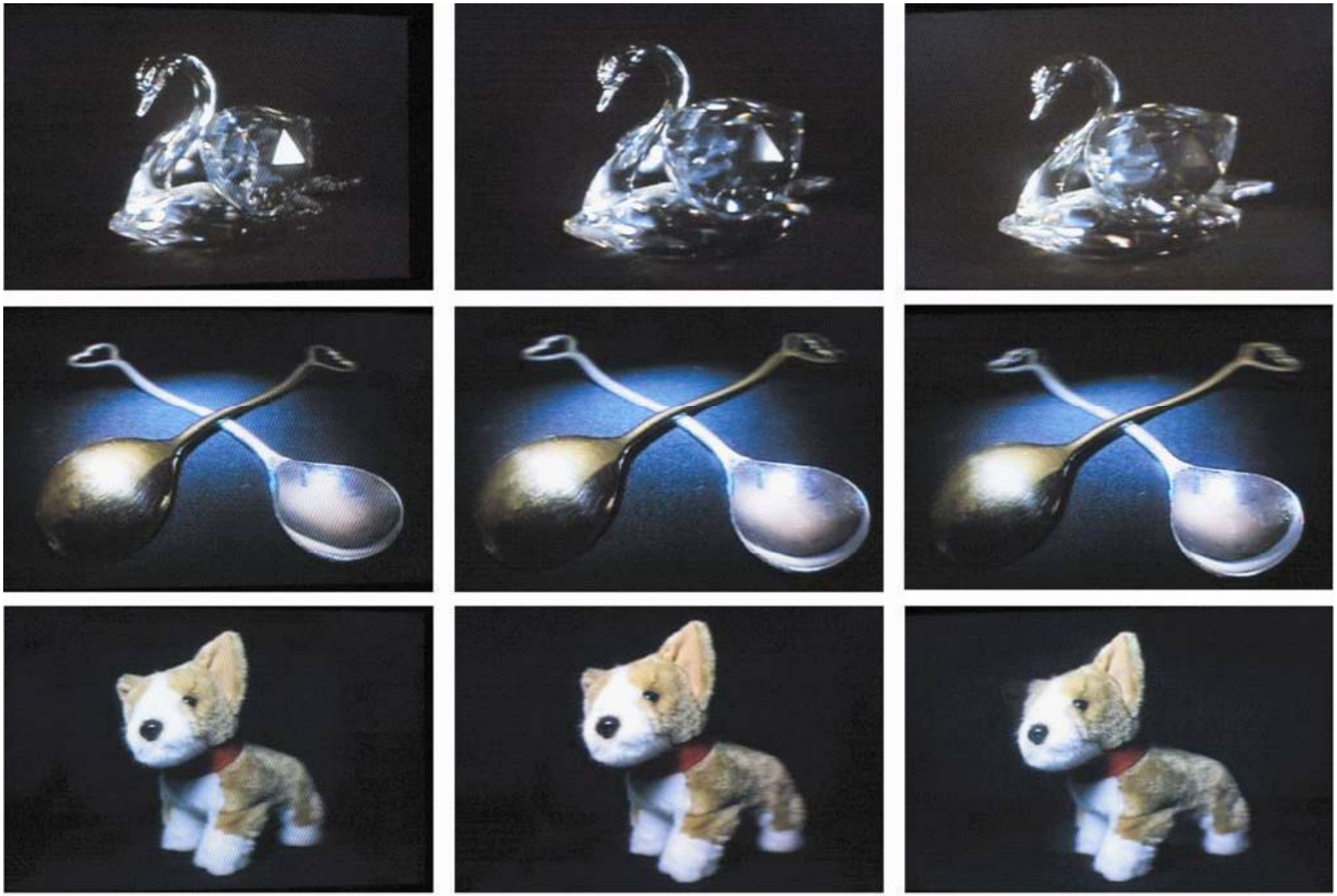
Two 72-direction displays are combined using a half mirror.



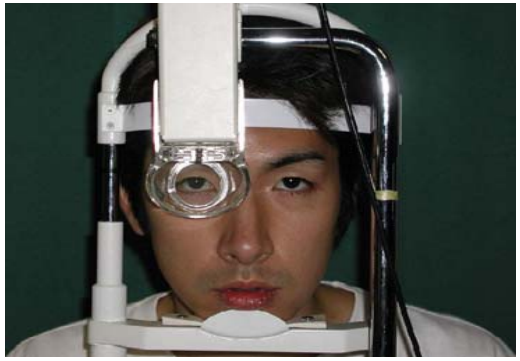
Specifications	
3D resolution	640 × 400
Number of ray directions	72
Horizontal ray angle pitch	0.38°
Horizontal viewing angle	27.6°
Screen size	22.2”

Slit arrays are located at the focal planes of the lenticular lenses to reduce crosstalk among 3D pixels.

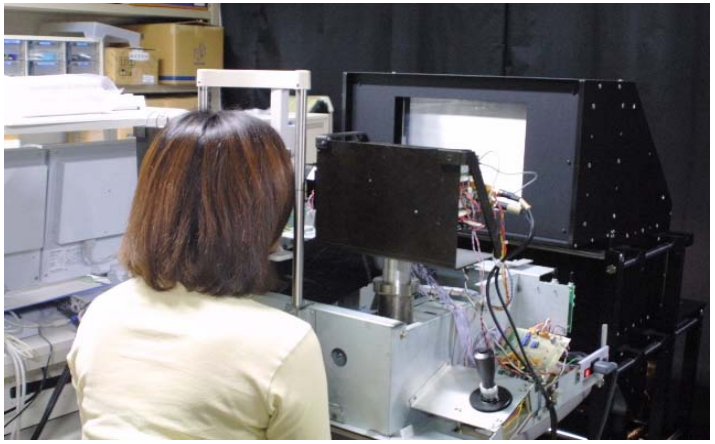
3D Images by 72-direction VGA Display

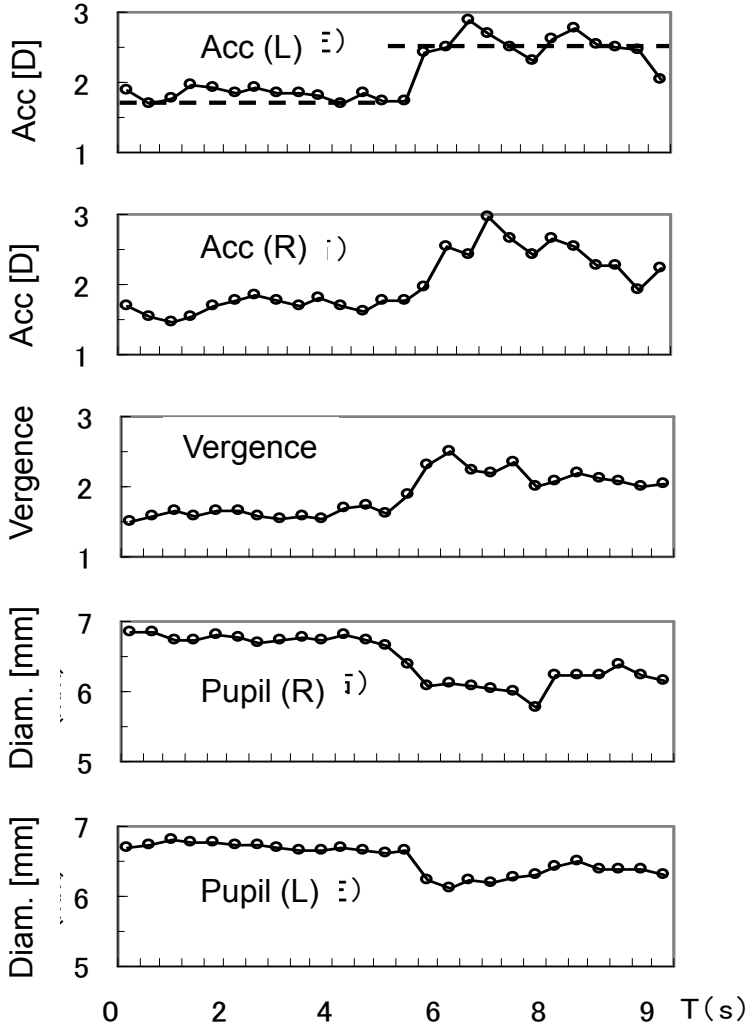


Accommodation Measurement



Auto refractometer



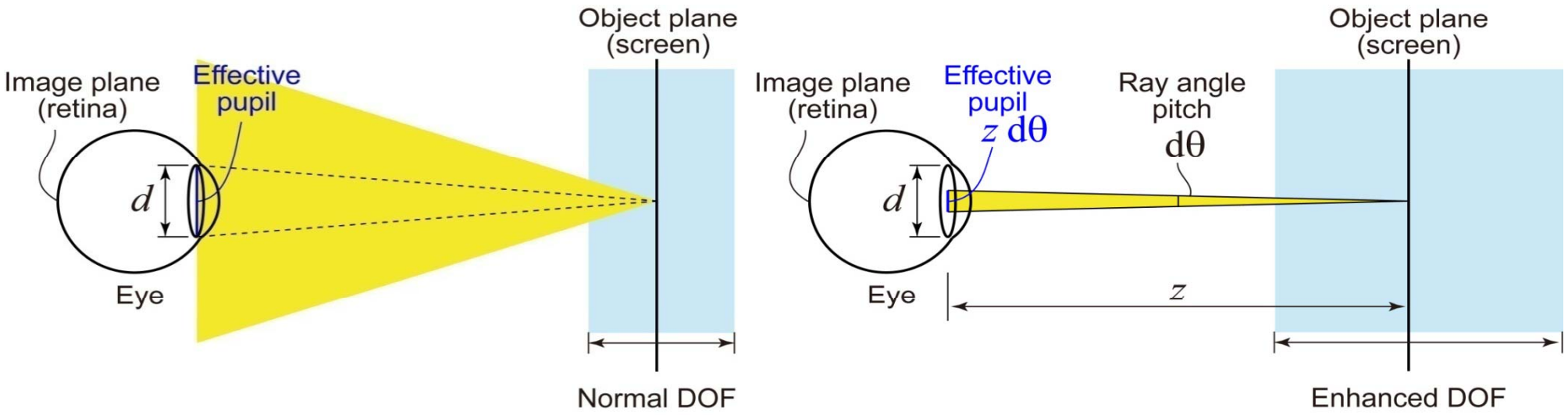


Visual function measurement equipment specialized for 3D displays
(Jointly developed with TOPCON Corp. under the SCOPE project)

R & L Accommodation + Vergence
+ R & L Pupil diameters

Enhancement of Eye's DOF

Depth of Field (DOF) of an eye-imaging system



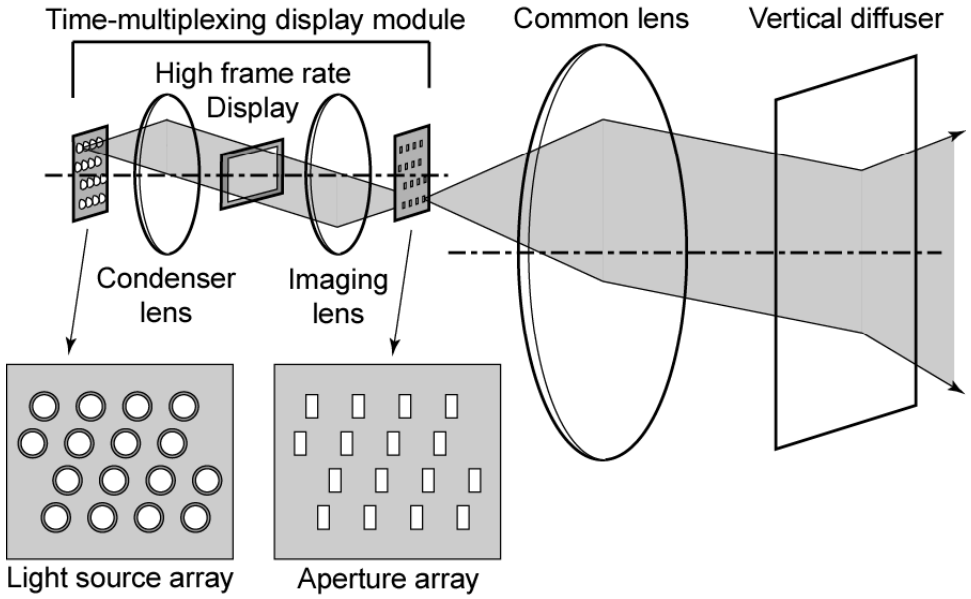
Conventional 3D

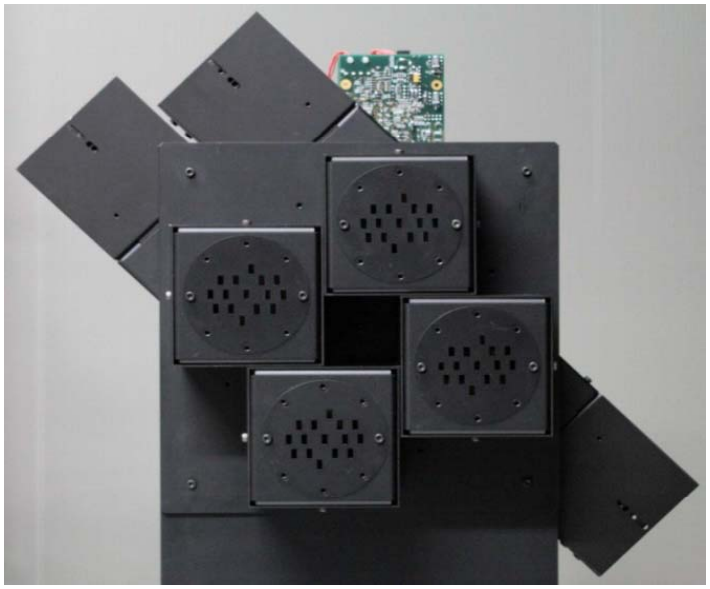
SMV/HDD

The SMV and HDD display techniques decrease the width of rays at the pupil of an eye, so that the DOF range of an eye-imaging system increases.

When a 3D image is displayed in this enhanced DOF range, the eye can focus on a 3D image and the accommodation-vergence conflict does not occur.

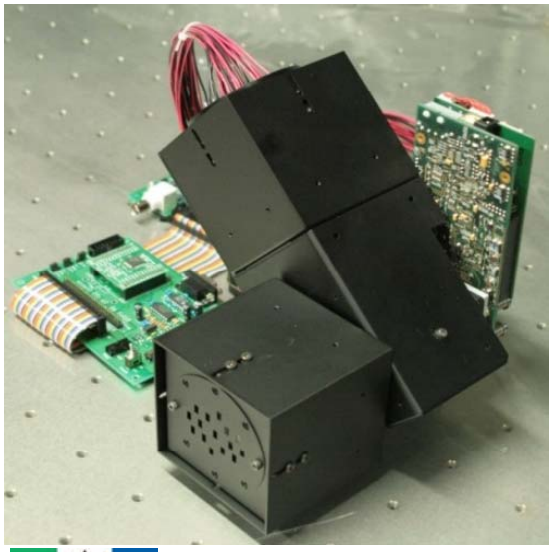
Time-Multiplexing Display Module





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



Time-Multiplexing 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

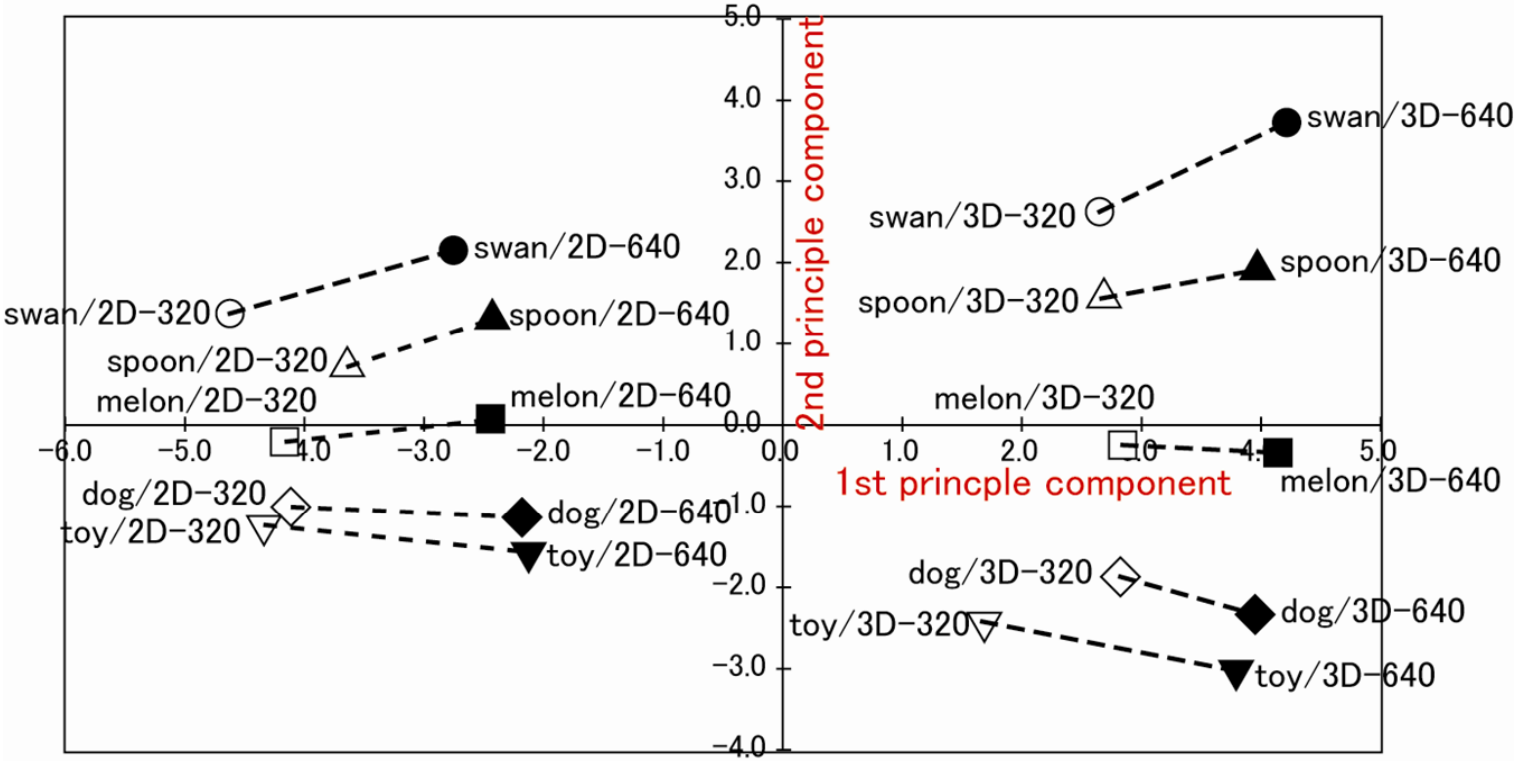
Faithful Appearance Reproduction

The appearances of objects, such as glare, gloss, transparency, softness are the results of reflection, refraction, and diffusion of rays on the object surfaces.

Natural 3D displays precisely control the ray directions so that they can faithfully reproduce the appearances of objects.

Subjective Analysis

Principle component analysis shows that natural 3D displays provide higher appearances and higher presence than 2D displays.

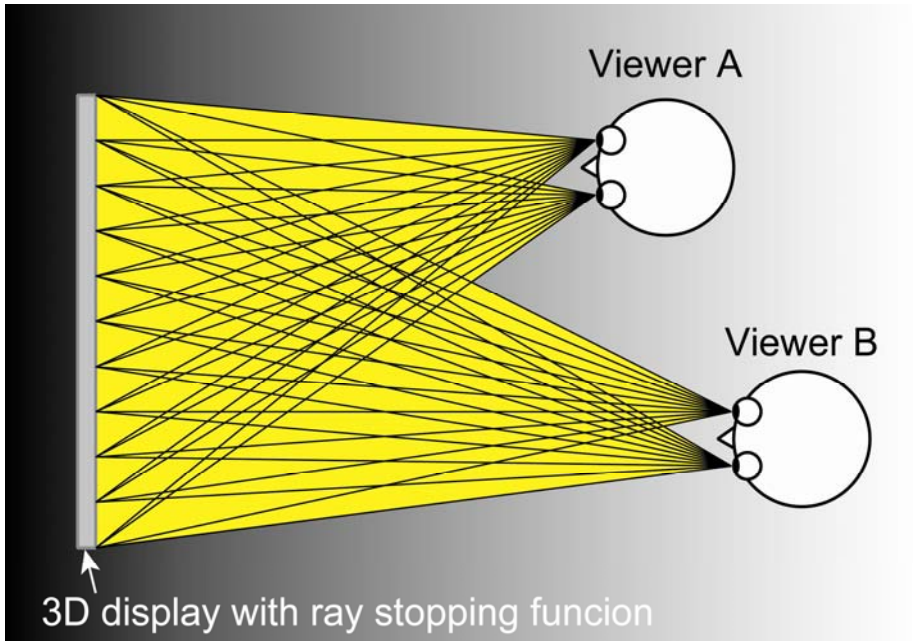


1st principle component: presence, reality
2nd principle component: appearances

2D-320: 2D, 320×400
2D-640: 2D, 640×400
3D-320: HDD, 320×400
3D-640: HDD, 640×400

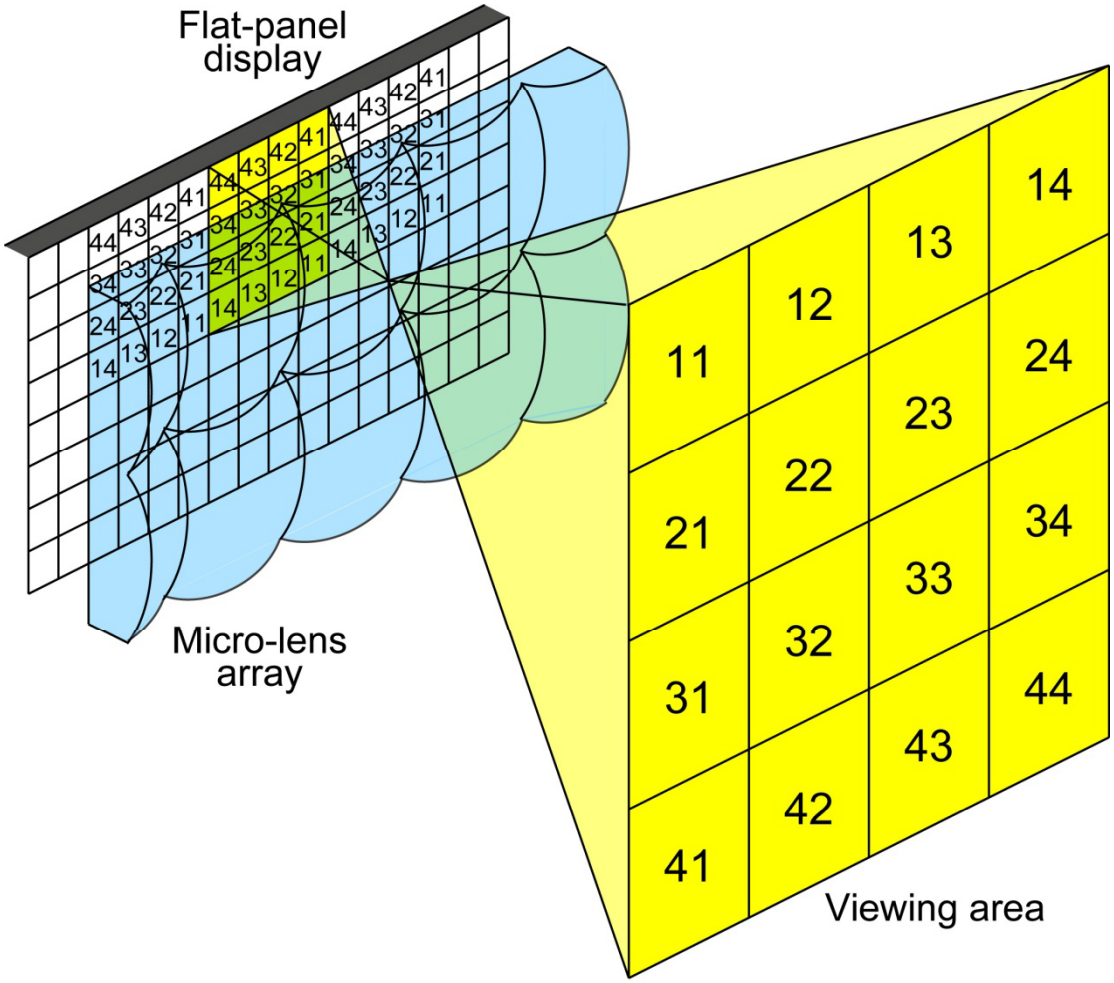
Ray Saving

2D display: rays diffuse on the display screen
3D display: directions of rays are controlled
When the positions of viewers' eyes can be detected, only rays entering viewers' eyes are produced. → ***Rays can be saved***



3D displays have the potential to be ***extremely low-energy displays****.*

Integral Photography



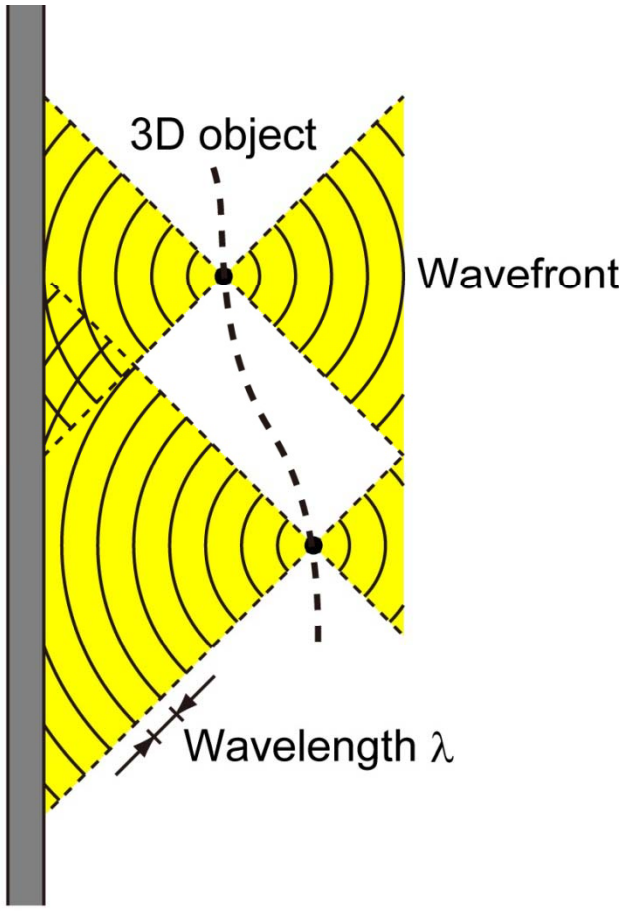
Integral photography offers full parallax (horizontal parallax + vertical parallax.)

The resolution of the flat-panel display must be extremely high.

Binocular disparity	○
Vergence	○
Accommodation	×
Motion parallax	Δ

When ray sampling satisfies the SMV or HDD display conditions, accommodation will work and motion parallax will become very smooth.

Holography



Flat-panel display
(Spatial Light Modulator)

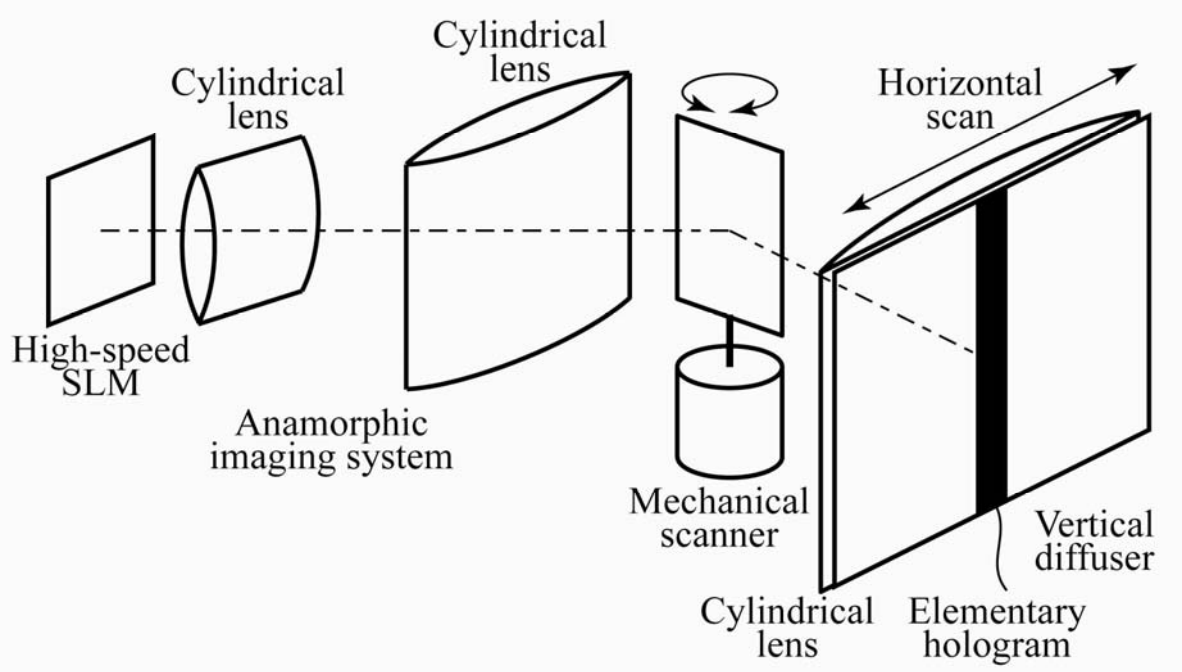
Holography is an ideal 3D display technique, because it reconstructs the wavefront of light.

The pixel pitch of a display device needs to be ~1 μm.

In order to increase the screen size, the number of pixels must be proportionally increased.

Binocular disparity	○
Vergence	○
Accommodation	○
Motion parallax	○

Horizontal-Parallax-Only Holography



Horizontal-parallax-only (HPO) holography dramatically reduces the number of pixels required for a display device.

Horizontally scanning holography reduces the horizontal pixel pitch to 2.5 μm.

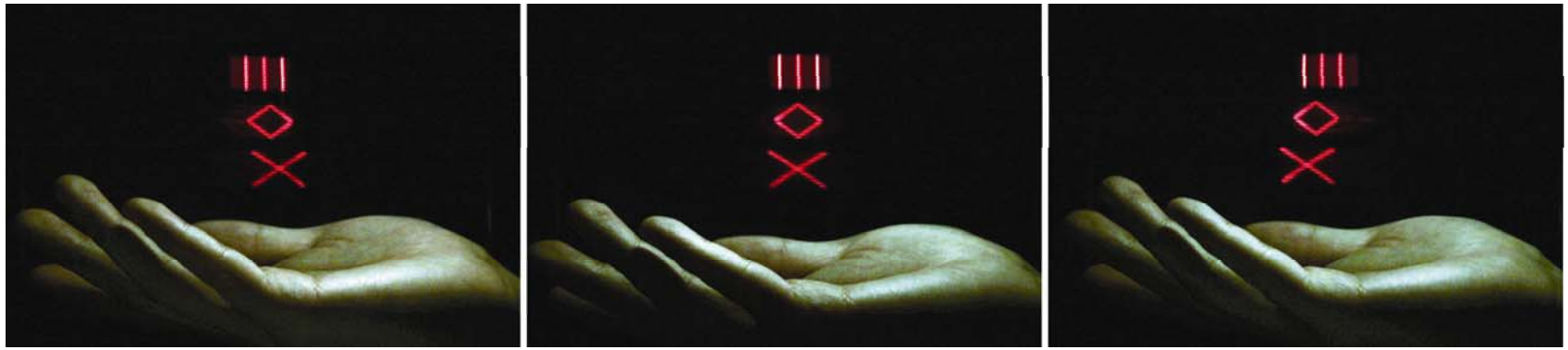
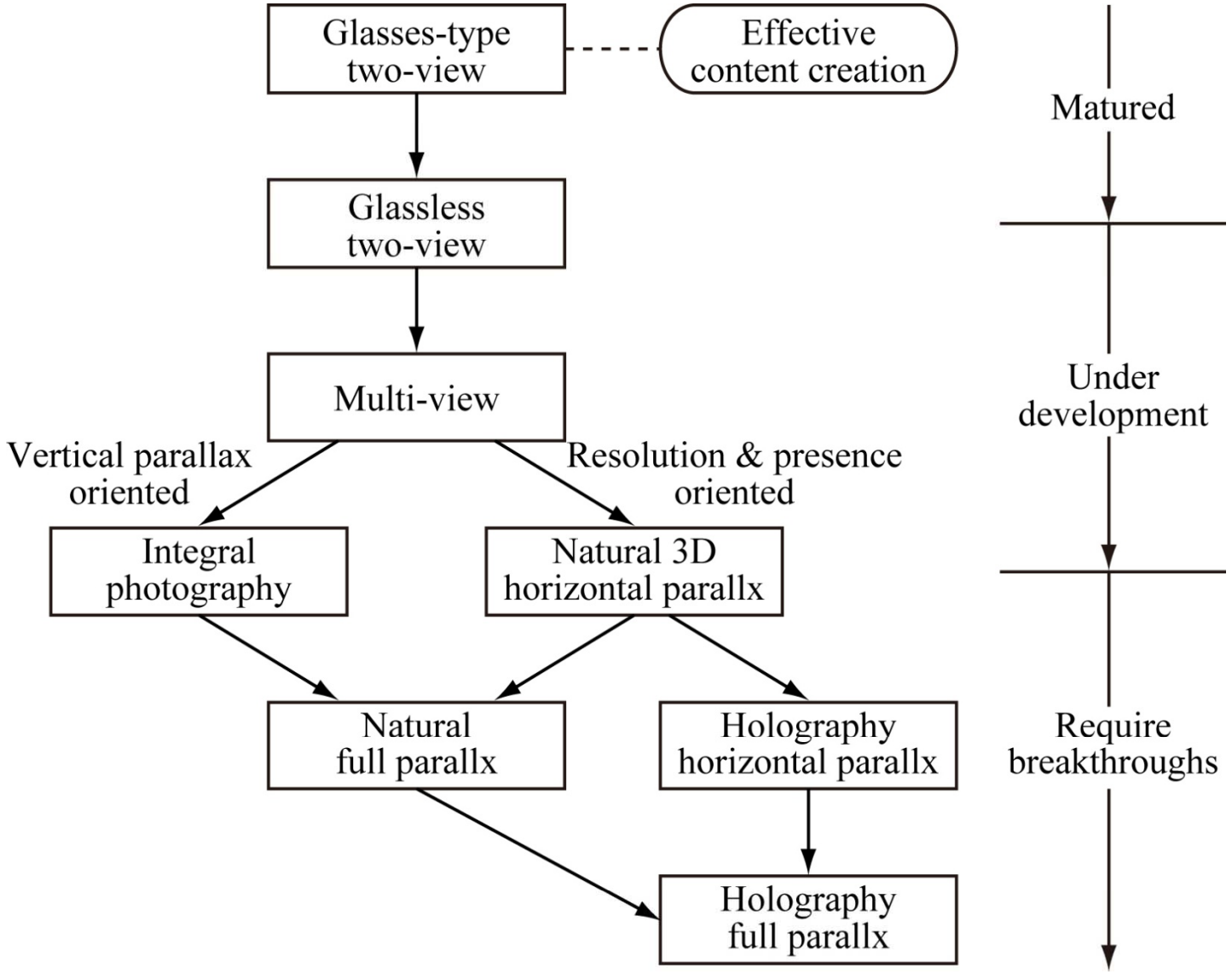


Image size： 70×50 mm^2, Viewing angle: 15°

Evolution and Future Prospects



Standardization of stereoscopic displays

Ergonomics point of view

Quality control

Image safety

Reducing **visual fatigue** and **motion sickness in 3D images**

support

promotion

Recent signs of expansion of the 3D market

3D movie

3D game

3D display

Internet ads

medical field

and others…

ISO International Workshop on Image Safety

organized by Japan

- Photosensitive seizures
- Visually induced motion sickness
- Visual fatigue from stereoscopic images

Discussions are continued in the following groups in ISO

ISO/TC 159/SC 4/WG 2
ISO/TC 159/SC 4/Study Group

Recent movements in standardization and active involvement by Japan

- IEC: Discussions for standardizing measuring methods of 3D displays.
- ICDM: Discussions on measurement methods in 3D stereo subcommittee.
- ISO: Preparation of Technical Report on “Optical characteristics of autostereoscopic display,” by Finland and Japan.

Thank you !