Super multi-view display and its applications

Yasuhiro Takaki

Institute of Engineering
Tokyo University of Agriculture and Technology

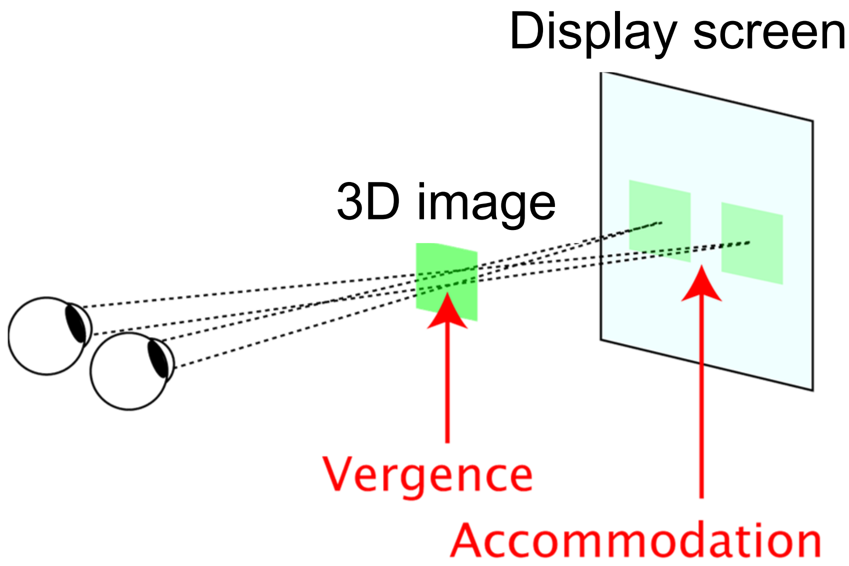
Outline

1. Problems of current 3D displays
2. Super multi-view display systems
3. Accommodation measurements
4. Reproduction of material appearances
5. SMV head-up display
6. 360-degree table-screen SMV display
7. Tiled large-screen autostereoscopic display
8. Summary

Problems of Current 3D Displays

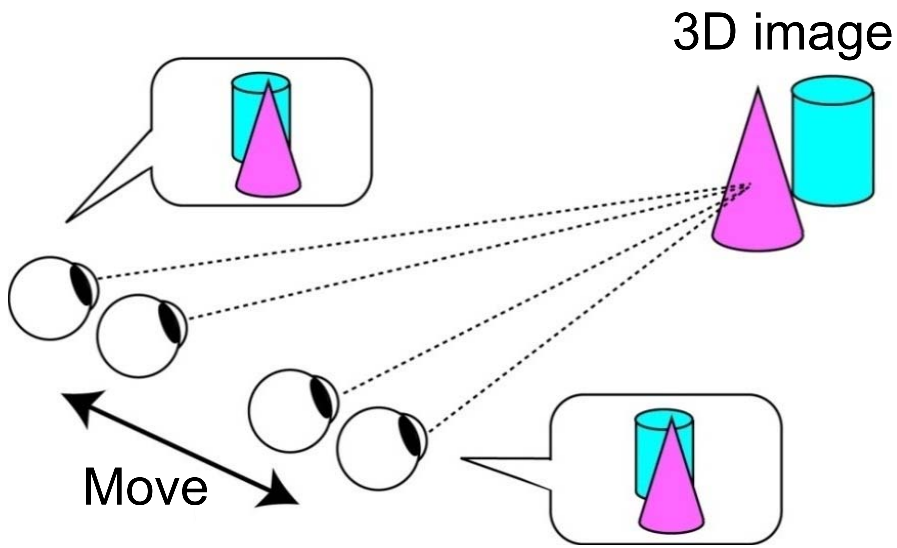
Problems of conventional 3D displays with respect to human 3D perception

Accommodation-vergence conflict



⇒ Visual fatigue

Absence or imperfection of motion parallax



⇒ Lower reality

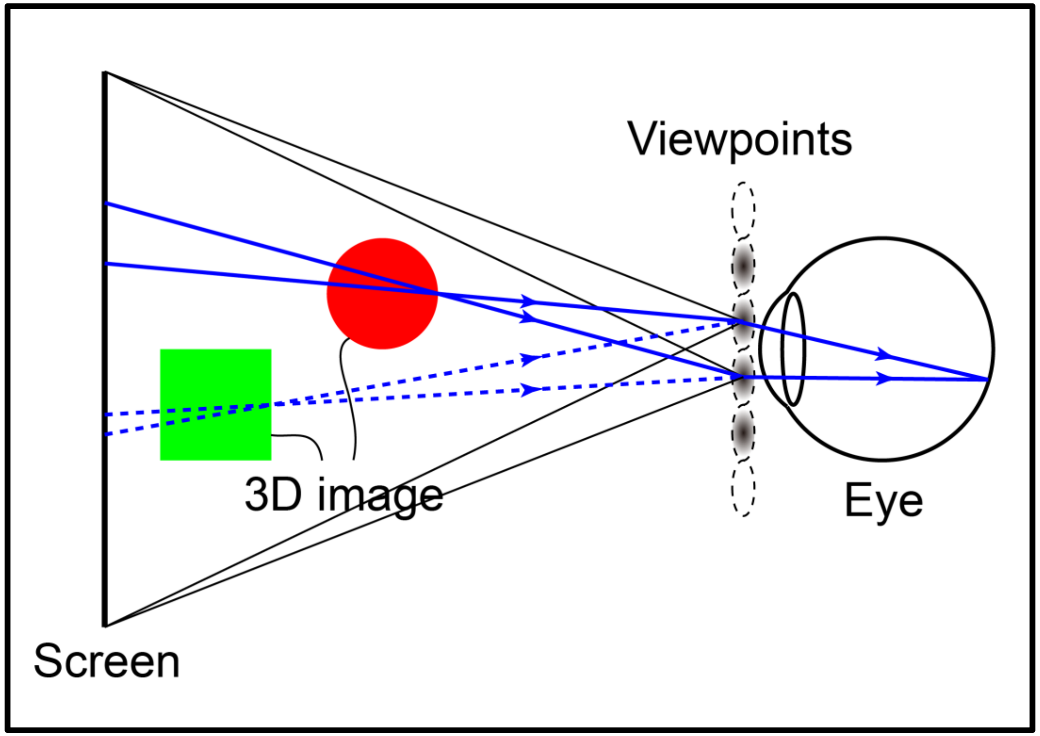
In this presentation, the solution for the accommodation-vergence conflict is described.

Evaluation of motion parallax smoothness: Y. Takaki, et al. Opt. Express **20**, 27180 (2012).

Super Multi-View Display and Holography

Two 3D display techniques have been developed to solve the accommodation-vergence conflict.

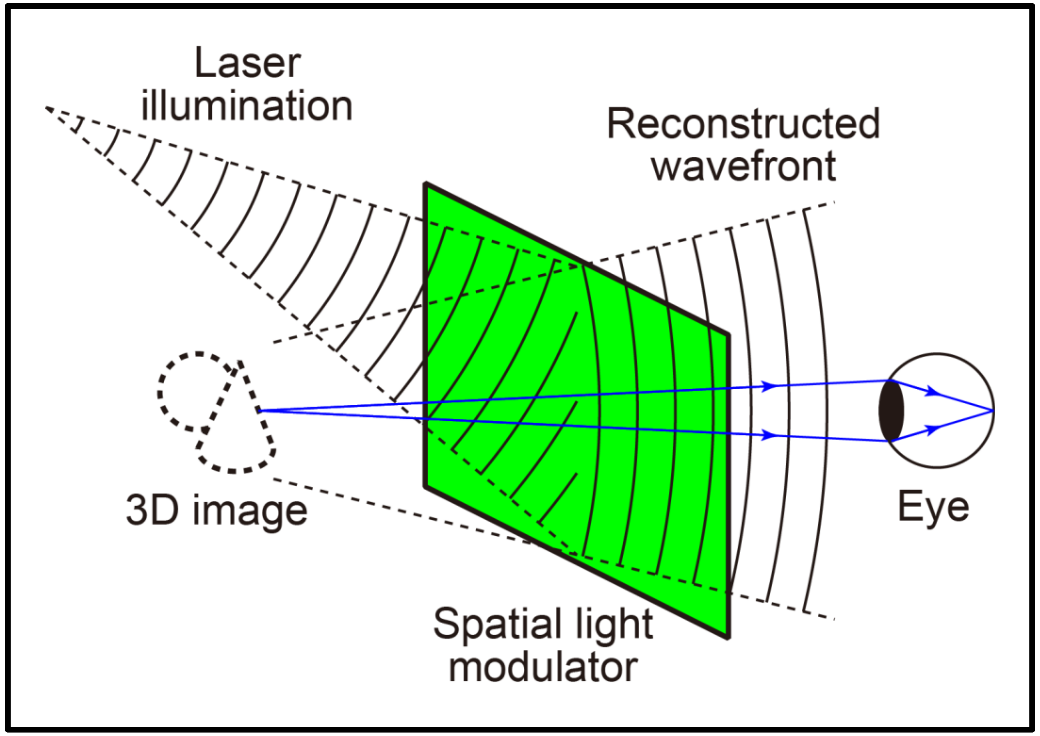
Super Multi-View Display



Based on ray reconstruction

It might be commercialized more quickly than holography.

Holography



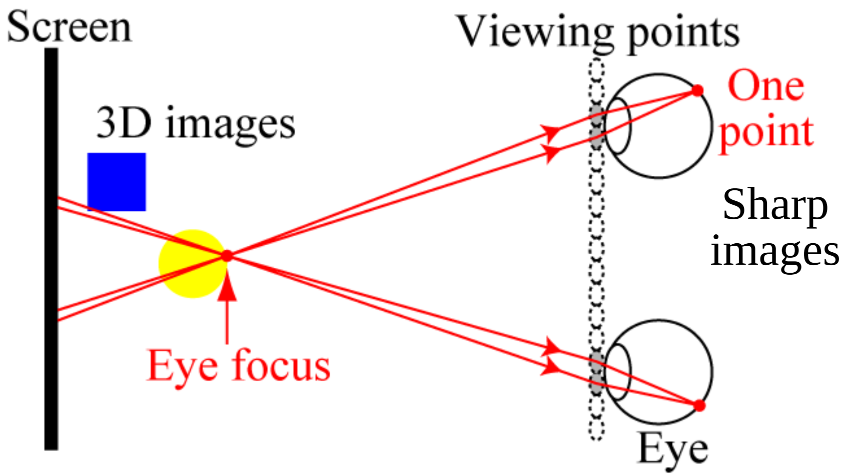
Based on wavefront reconstruction

Screen size and viewing area are limited.

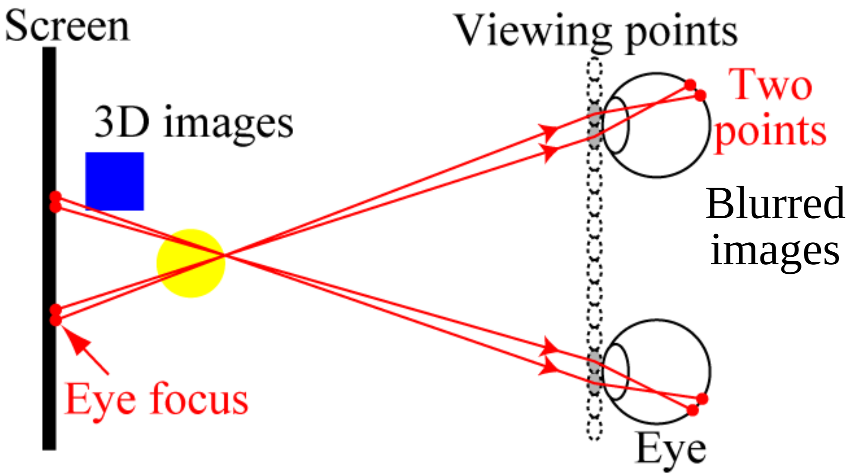
Super Multi-View Display Technique

The interval of viewpoints is made smaller than the pupil diameter of eyes. → Eyes can focus on 3D images.

When eyes focus on 3D images

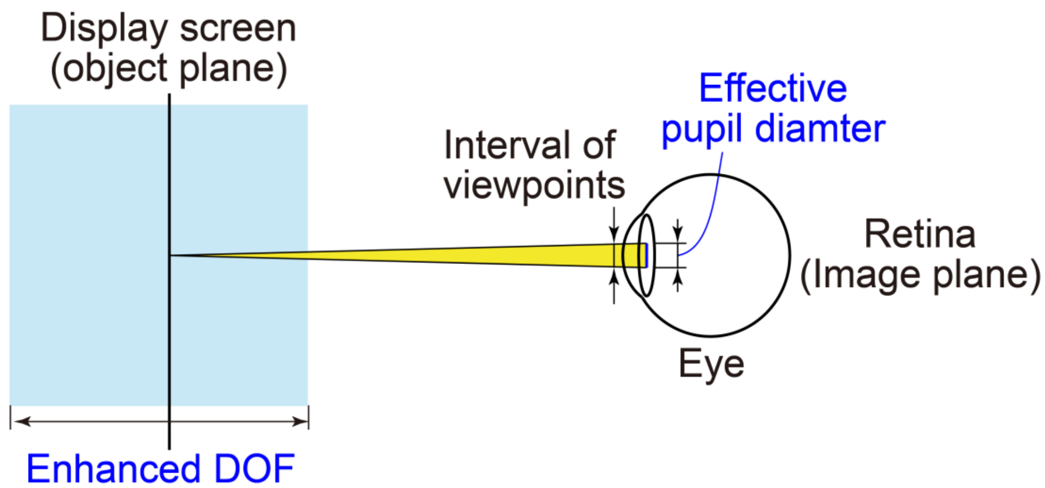


When eyes focus on display screen



Pupil diameter: 2 ~ 8 mm (average 5 mm)
→ Interval of viewpoints: < 5 mm

Depth of field (DOF) range of eye



Because the interval of viewpoints becomes the effective pupil diameter, the DOF range of eyes increases.

Super Multi-View Displays

A large number of viewpoints have to be generated.

Multi-projection system

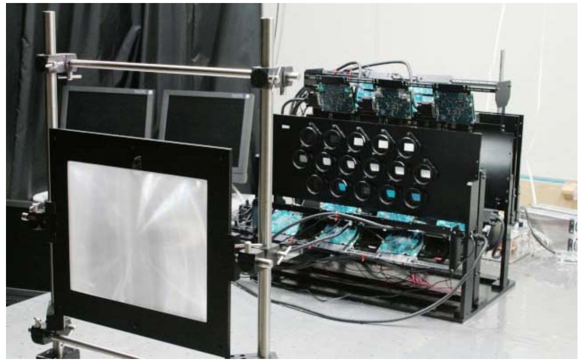
- Array of projectors
- 64 and 128 view systems

Proc.SPIE, vol.5664, 28(2005)
Proc.IEEE, vol.94, 654(2006)
Proc.SPIE, vol.6490, 64900U(2007)

Hybrid system

- Combination of multi-projection and flat-panel systems
- 256 view system (16 view × 16)

Opt.Express, vol.18, 8824(2010)



Flat-panel system

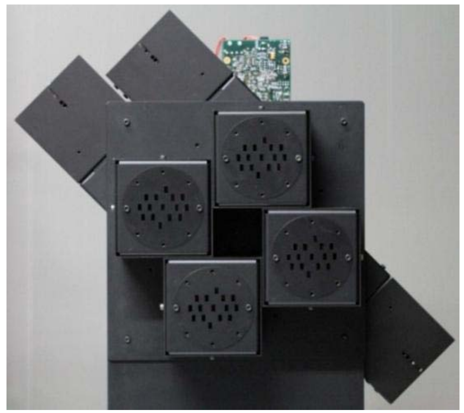
- Lenticular lens and high resolution LCD
- 36 and 72 view systems

Proc.SPIE, vol.5664, 56(2005)
Proc.SPIE, vol.6055, 60550X(2006)
J.Soc.Inf.Display, vol.18, 476(2010)

Time-multiplexing system

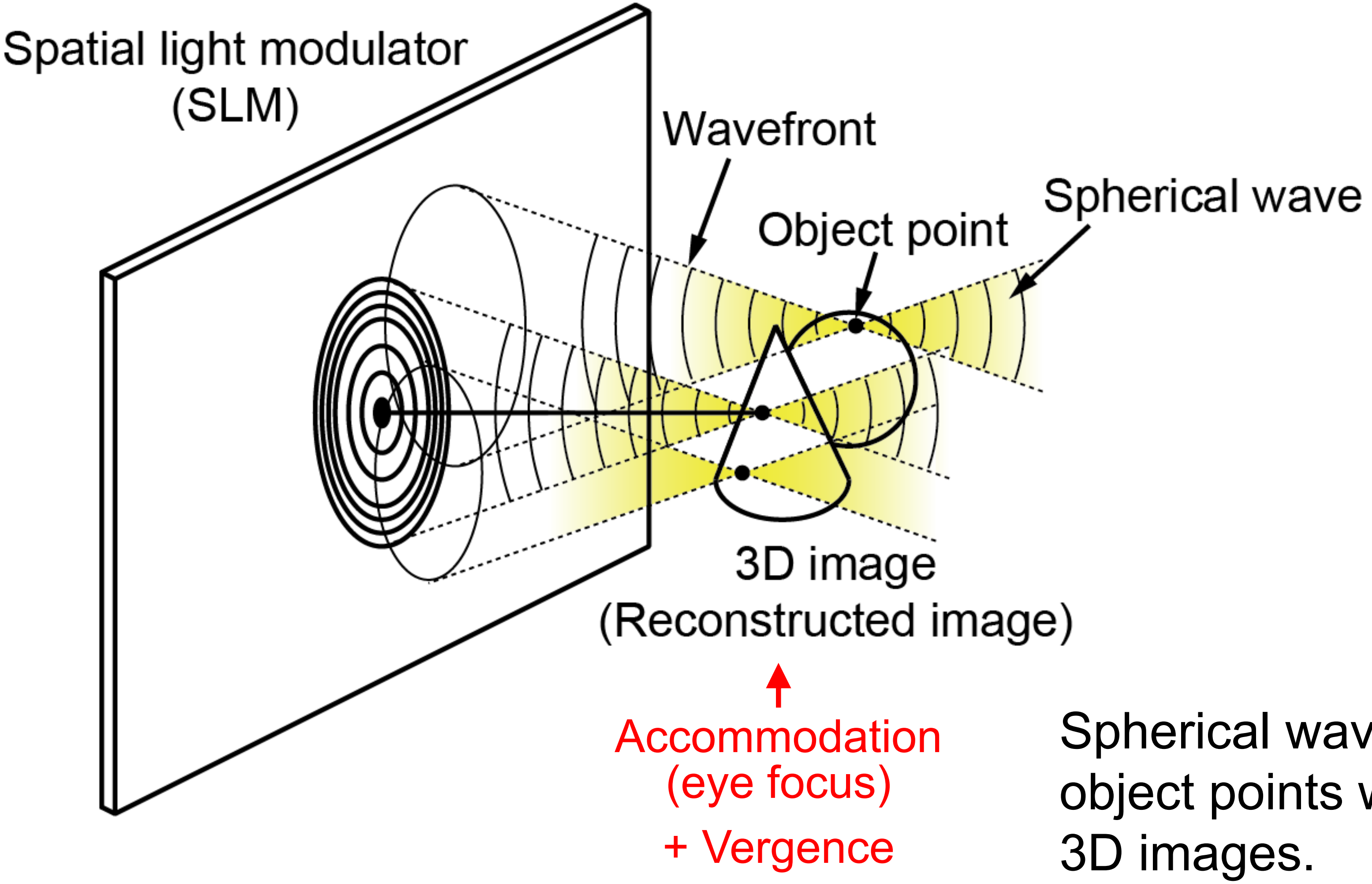
- High speed SLMs and LED arrays
- 64 view system (16 view × 4)

Proc.SPIE, vol.6803, 68030P(2008)



Holography

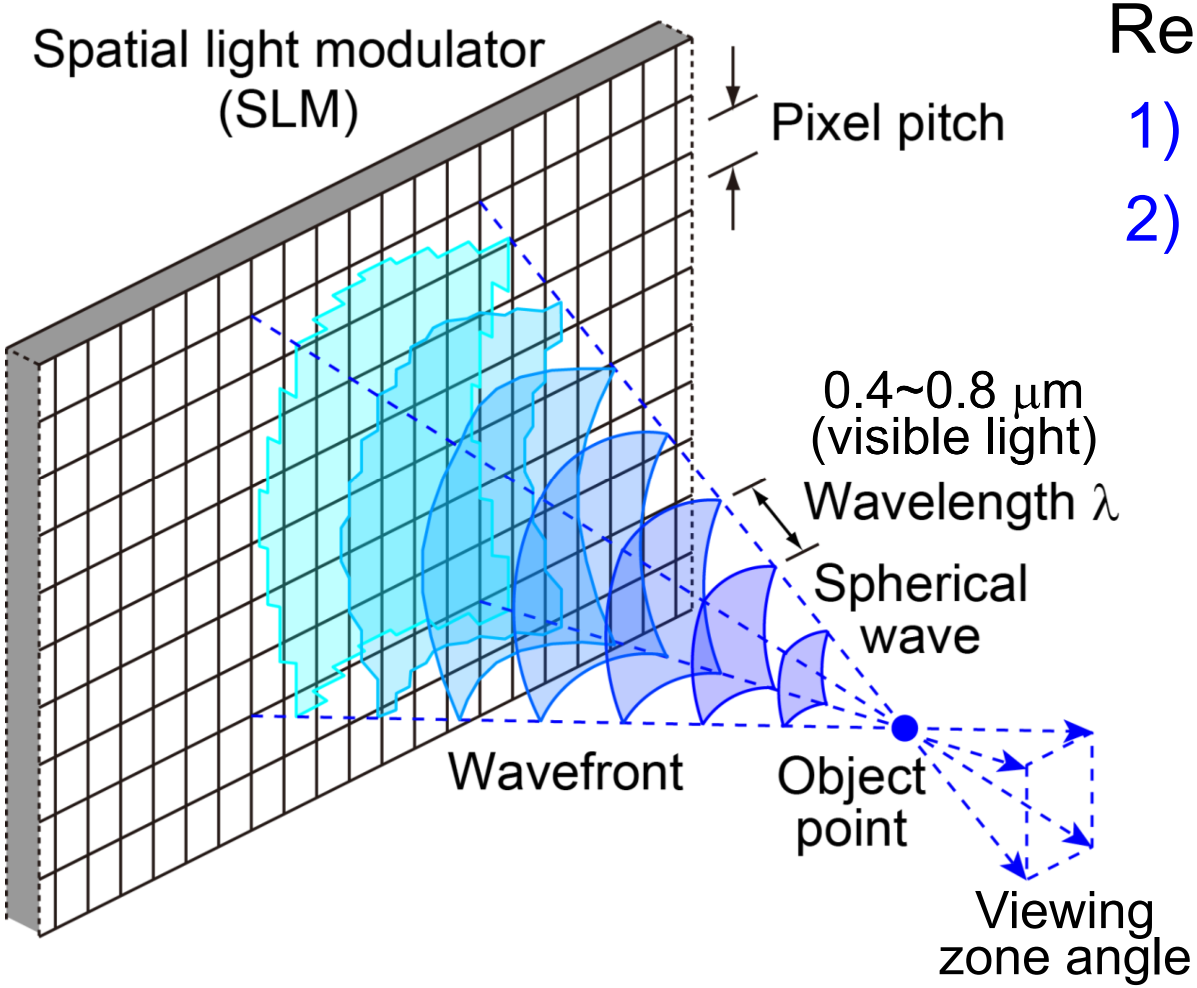
Holography can reconstruct wavefront emitted from 3D objects.



Spherical waves produce sharp object points which consists of 3D images.

→ Eyes can focus on 3D images.

Problems of Electronic Holographic Display



Requirements for SLM:

1) Pixel pitch needs to be ~1 μm.
2) To increase the screen size, the number of pixels must be proportionally increased.

Viewing zone angle:

$$\Phi = 2\sin^{-1}(\lambda/2p)$$

Screen size:

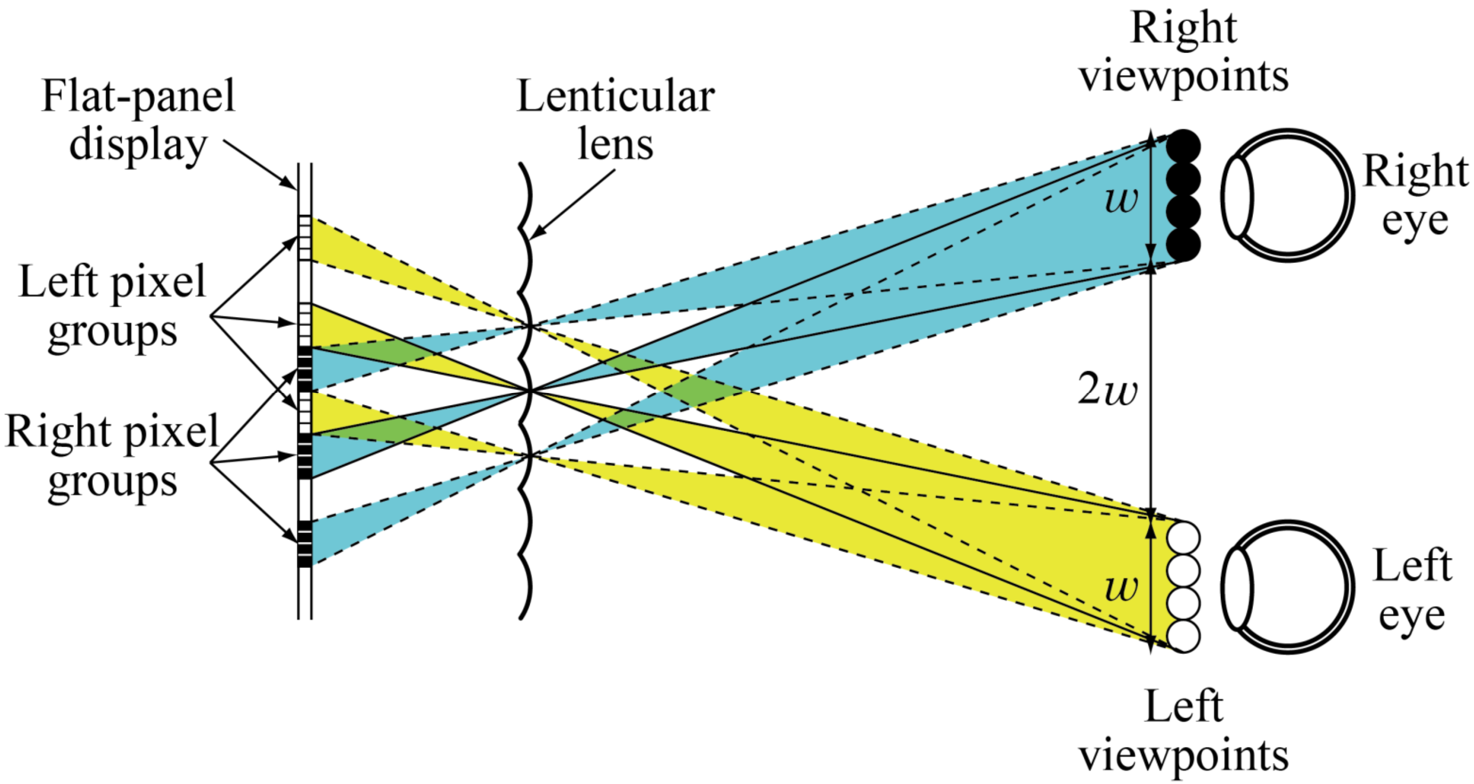
$$Np \times Mp$$

Pixel pitch of SLM: p
Resolution of SLM: $N \times M$
Wavelength of light: λ

Screen 40'', viewing zone angle 30° (λ = 0.6 μm)
Pixel pitch: p = 0.97 μm
Resolution: $N \times M$ = 764,000 × 430,000

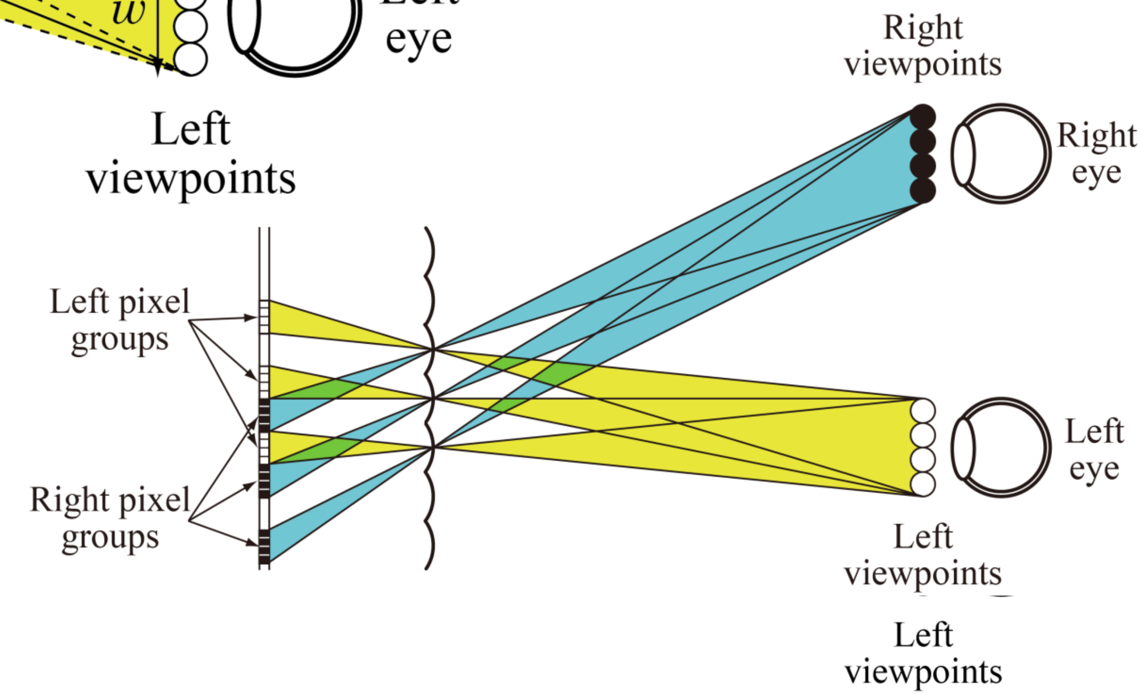
Super Hi-Vision (Ultra HD)
Resolution: 7,680 × 4,320

Reduced-view SMV Display



Viewpoints are generated only around left and right eyes.

The resolution required for the flat-panel display is reduced.



The eye tracking and the movement of display positions of the pixel groups increase the freedom of the viewing position.

Experimental System

Stereo camera

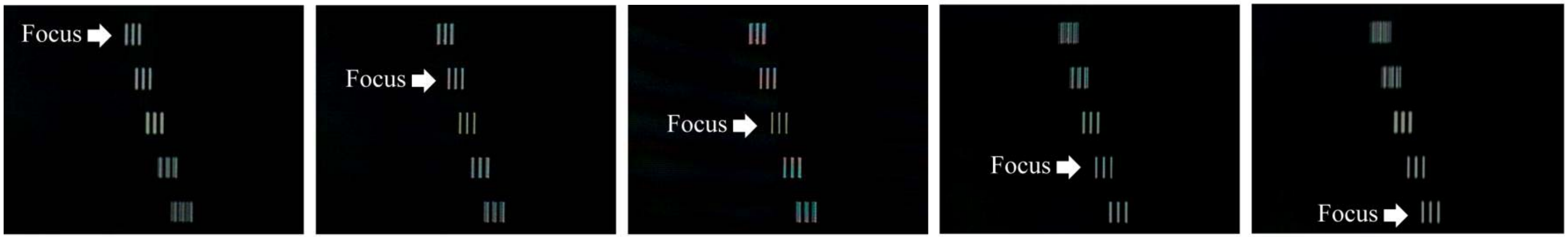
Y. Takaki et al., Opt. Express **19**, 4129 (2011)

Interval of viewpoints	2.6 mm
Number of viewpoints	Left 8 + Right 8
3D resolution	256 × 192
Screen size	2.57 inch
Observation distance	350 mm

Left viewpoints

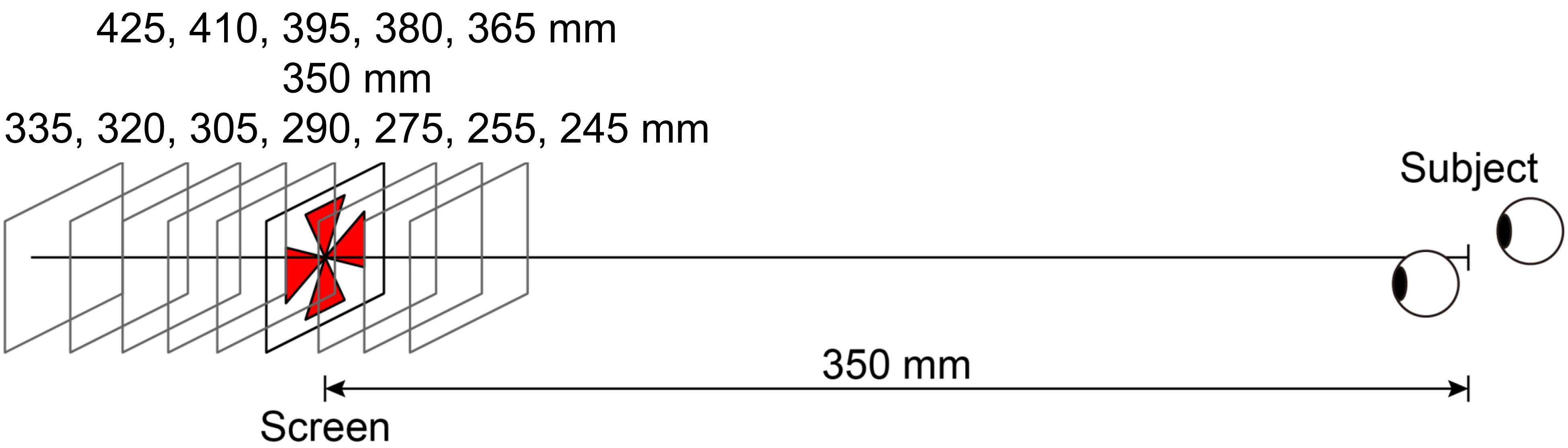
Right viewpoints

Focus to 3D images



Focus position –40 mm –20 mm 0 mm +20 mm +40 mm

Accommodation Measurements



Auto refractometer
(Grand Seiko FR-5000S)

Size of test target: 2.6° × 2.6°

Interval of viewpoints: 2.6, 5.3, 7.9 mm

J. Nakamura, K. Tanaka, and Y. Takaki, Appl. Phys. Express **6**, 022501 (2013).

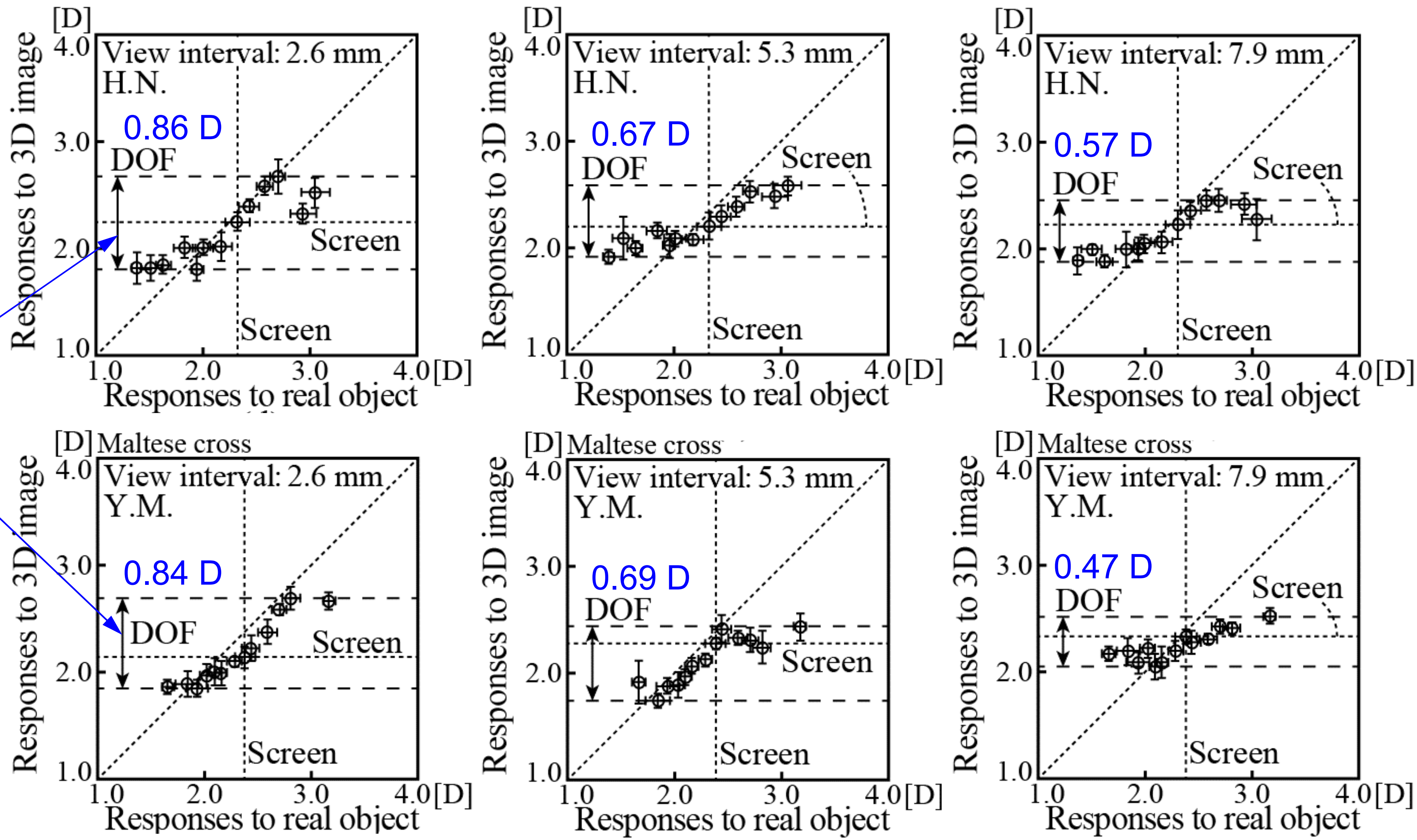
Accommodation Responses to SMV Display

Interval of viewpoints 2.6 mm 5.3 mm 7.9 mm

H.N.

Y.M.

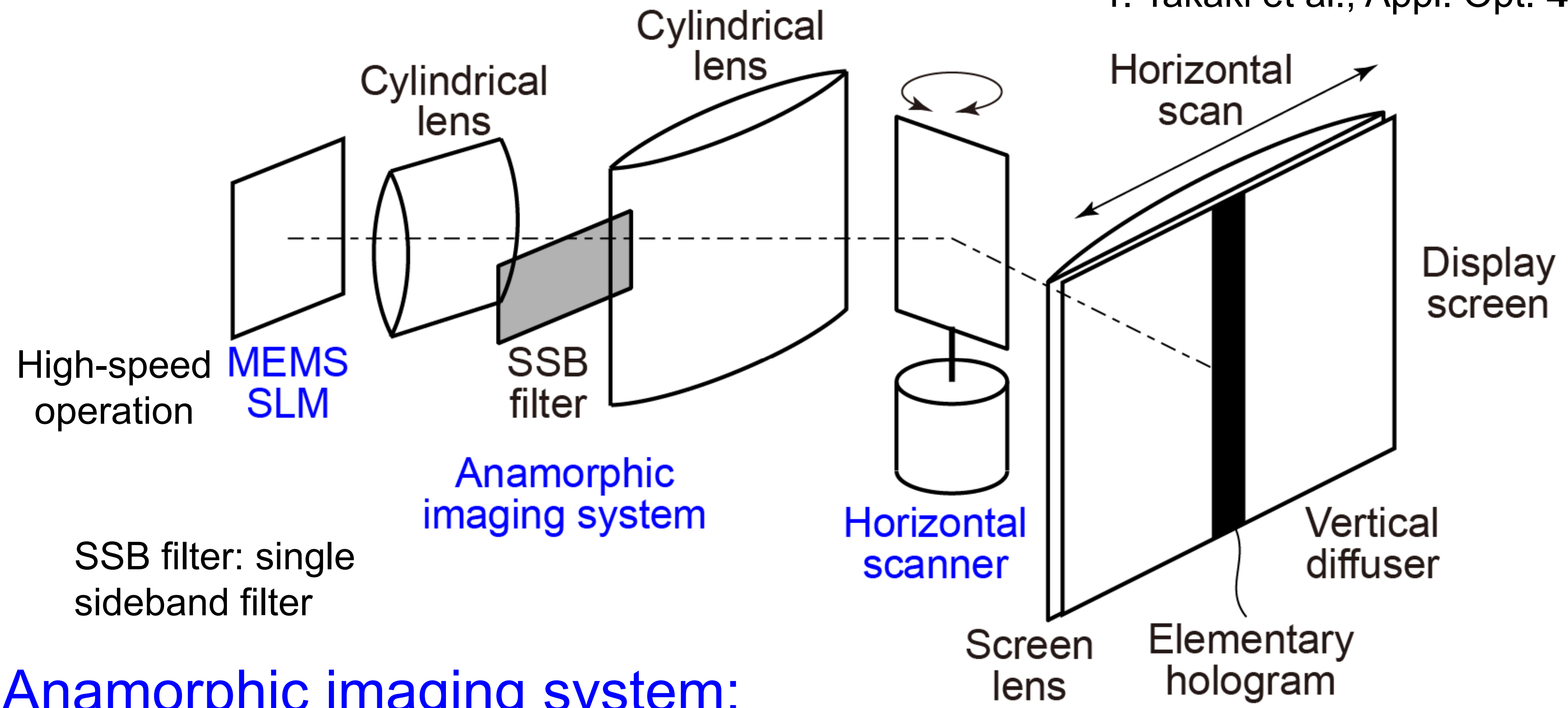
Enhanced DOF range of eye



Diopter [D] = 1/Length [m]

Horizontally Scanning Holographic Display

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



SSB filter: single sideband filter

Anamorphic imaging system:

Horizontal: reduce pixel pitch → Viewing zone angle increases

Vertical: increase image height

Horizontal Scanning:

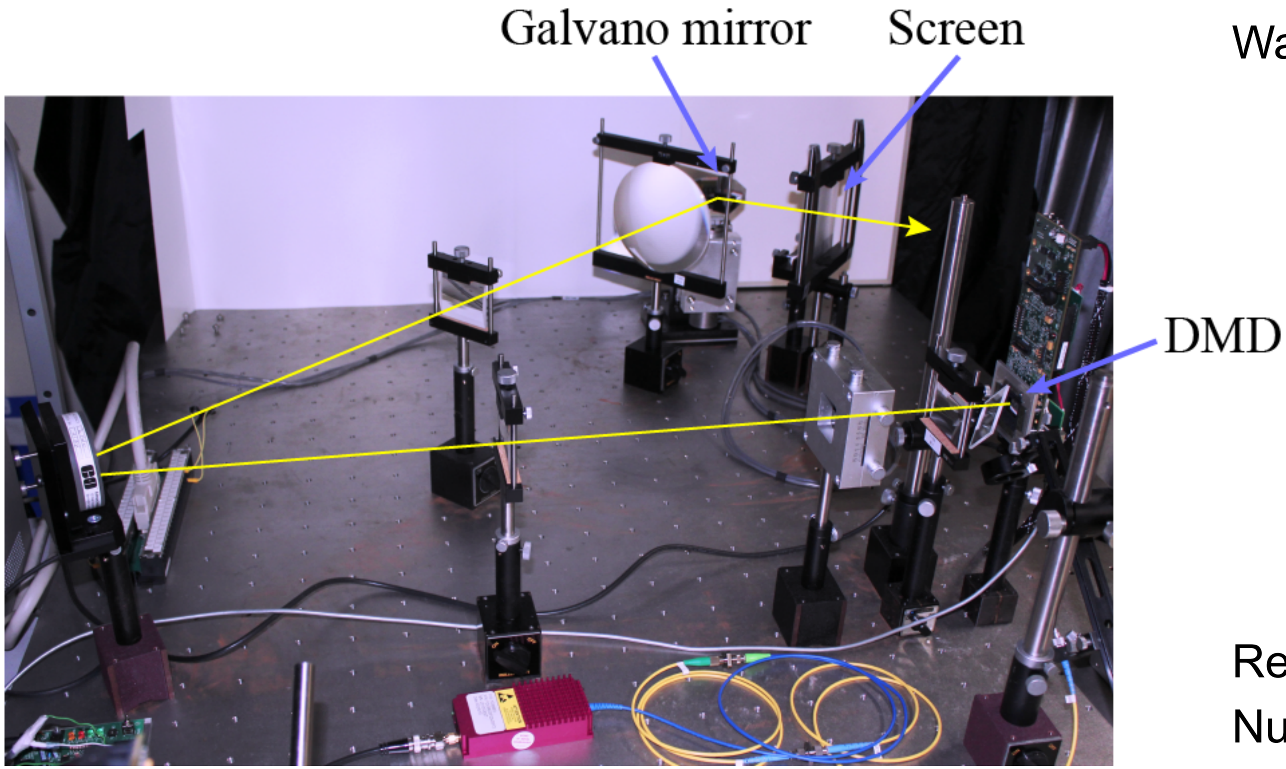
Increase image width

→ Screen size increases

Experimental System

Galvano mirror
MicroMax™Series671

Scanning frequency: 60 Hz
Scan angle: ±18.1°



Wavelength of light: 635 nm

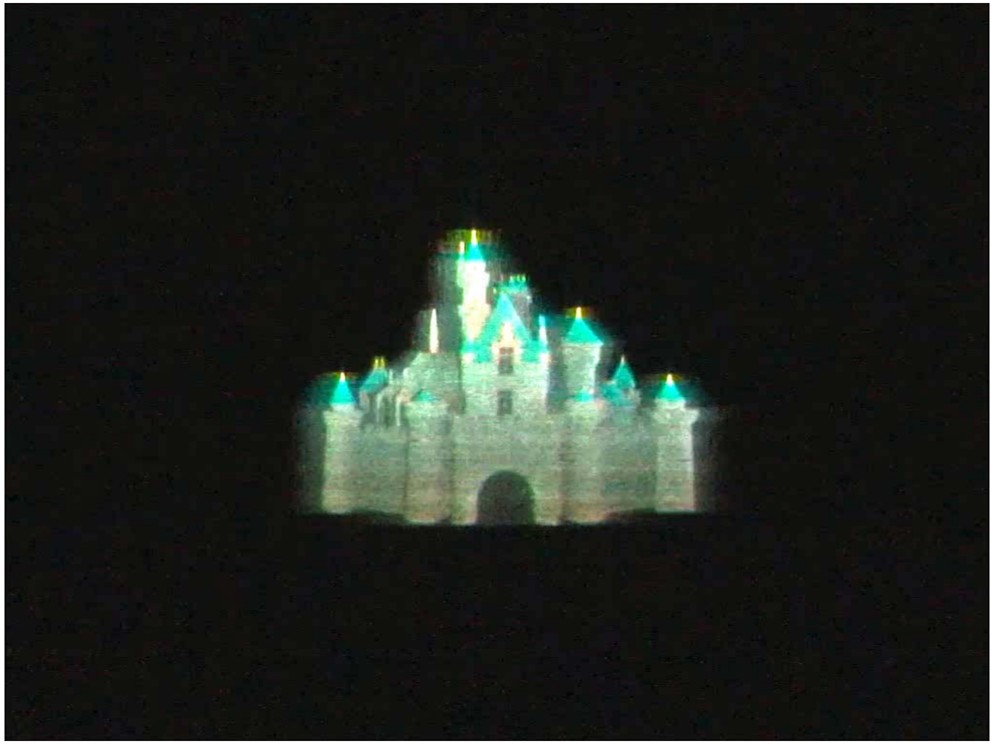
Digital Micromirror Device (DMD)
Discovery™3000

- Frame rate: 13.333 kHz
- Resolution: 1,024 × 768
- Pixel pitch: 13.68 μm
- Screen size: 0.7 in.

Reduced horizontal pixel pitch: 2.5 μm
Number of elementary holograms: 133

Viewing zone angle: 15°
Screen size: 3.5 in.
Frame rate: 60 Hz

Color Reconstructed Images



Castle

Earth

DMD, Discovery™4100

Frame rate: 22.727 kHz

Resolution: 1,024 × 768

Pixel pitch: 13.68 μm

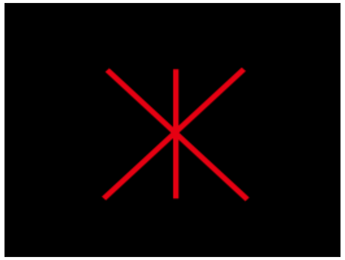
Screen size: 6.2 in.

Viewing zone angle: R 14.7°, G 11.8°, B 11.2°

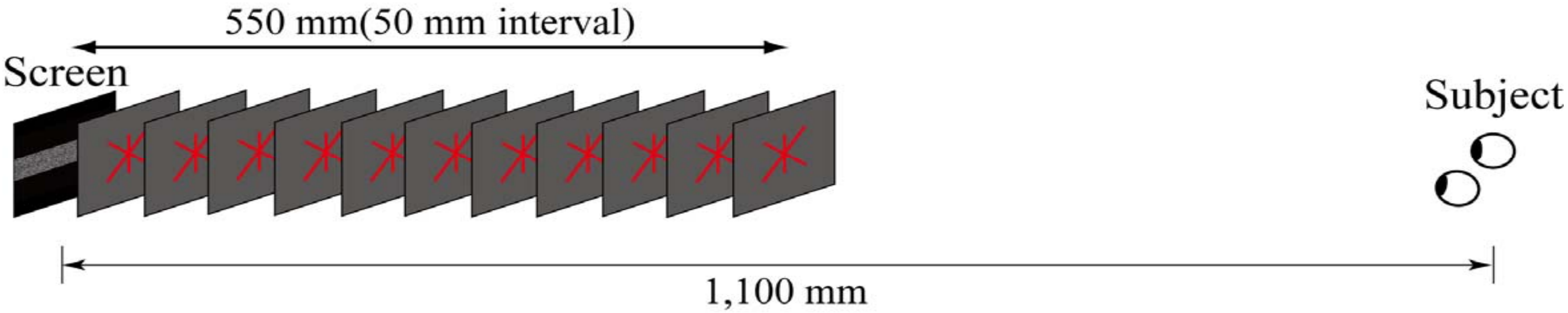
Frame rate: 30 Hz

T. Nakajima, et al., Digital Holography and Three-Dimensional Imaging 2013

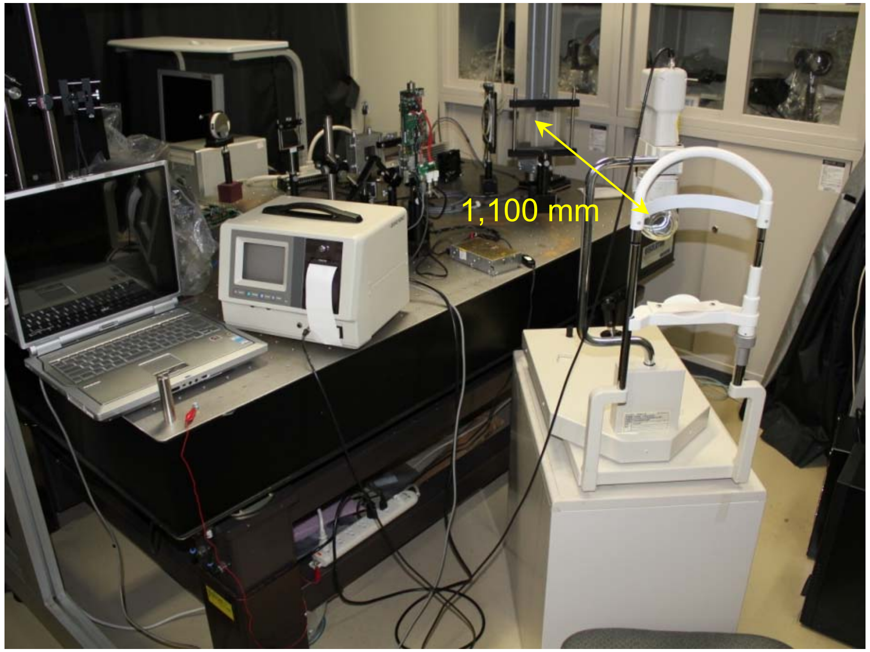
Accommodation Measurements



Test image
(1.1°× 1.1°)



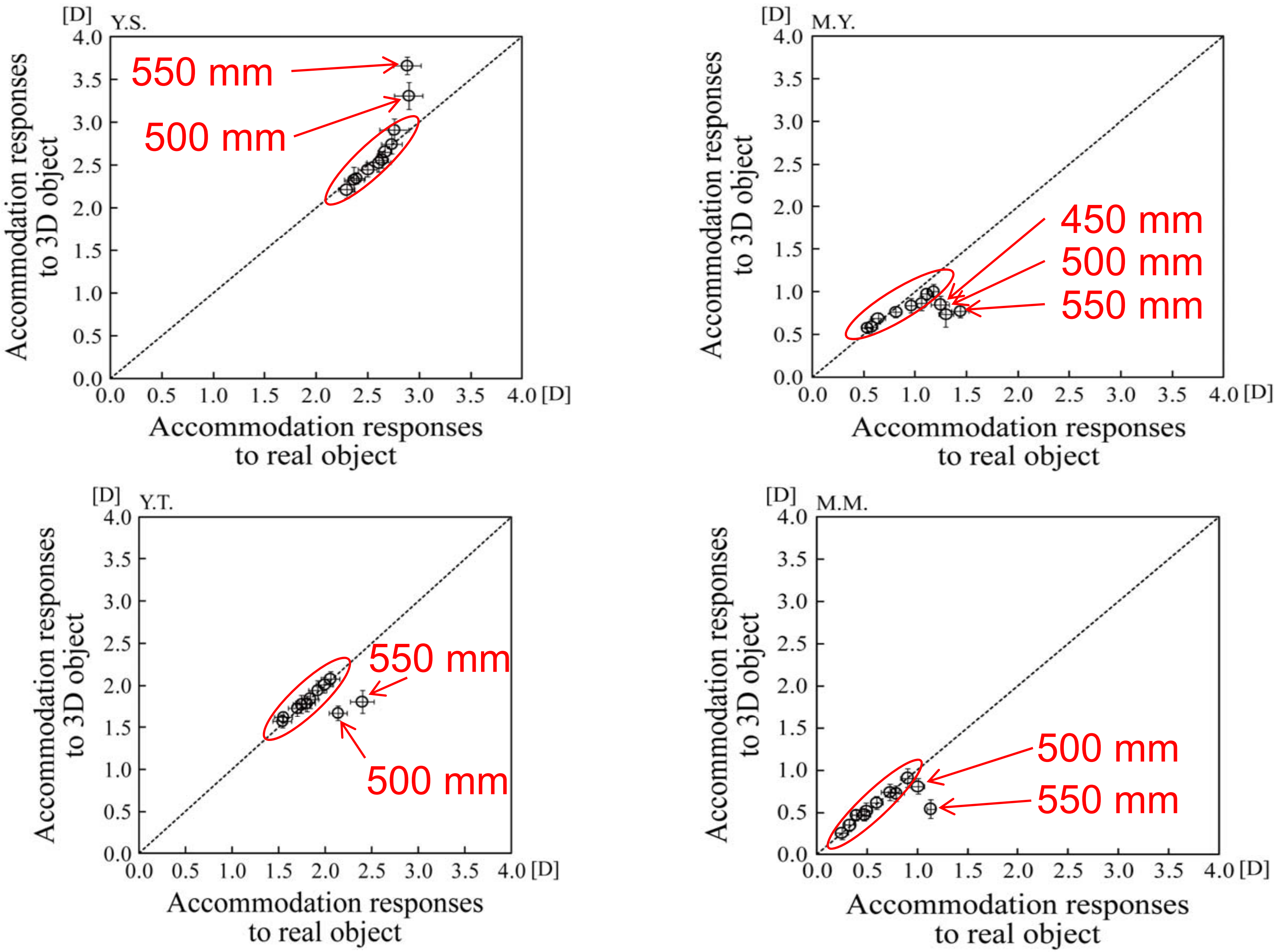
The measurements were performed for 10 s, and the responses for 2 s without blink were averaged to obtain an experimental result.



Auto refractometer: FR-5000S (Grand Seiko Co., Ltd.)

Y. Takaki and M. Yokouchi, Opt. Express **20**, 3918-3931 (2012)

Measured Accommodation Responses

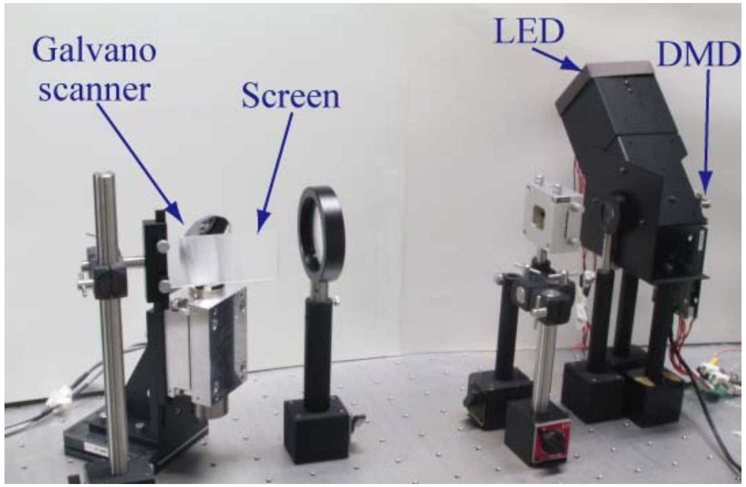


Scanning SMV Display

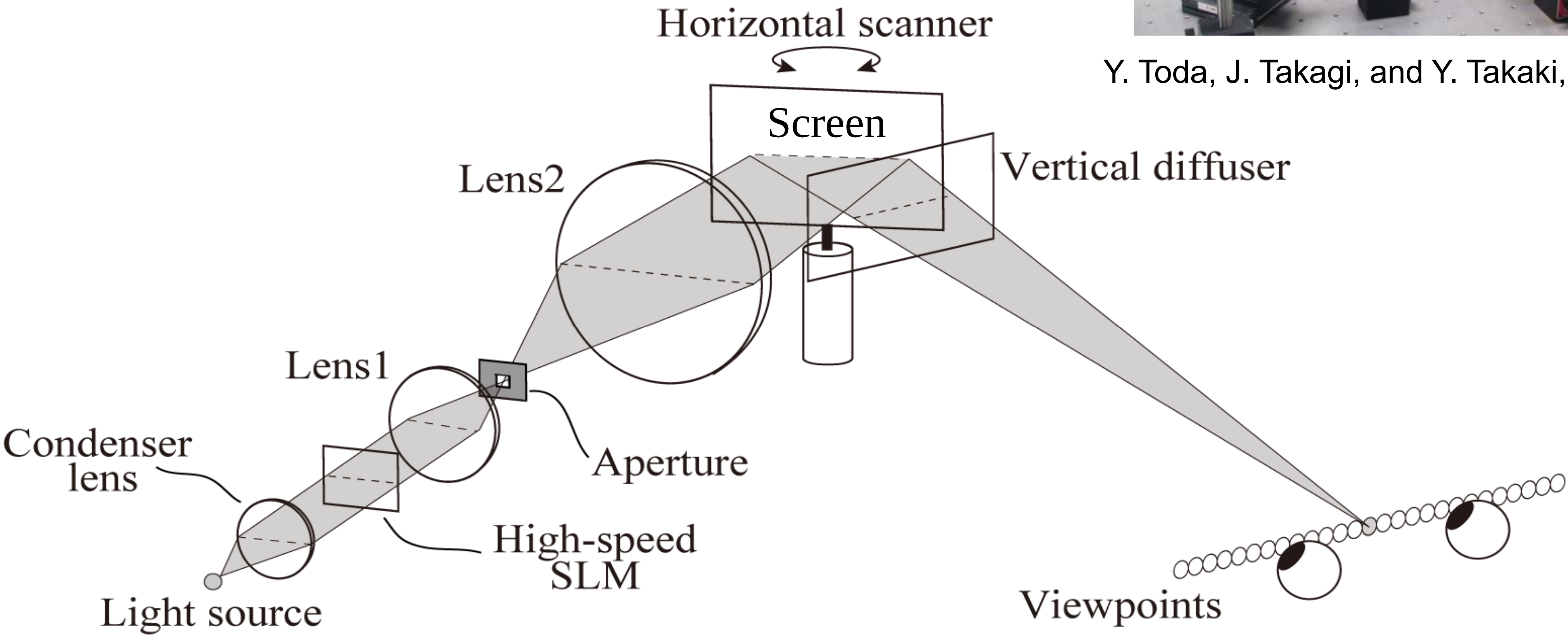
Images generated by the high-speed SLM are projected onto the mirror of the horizontal scanner.

Rays are converged to generate a viewpoint.

The viewpoints are scanned horizontally by the horizontal scanner to generate massive viewpoints.



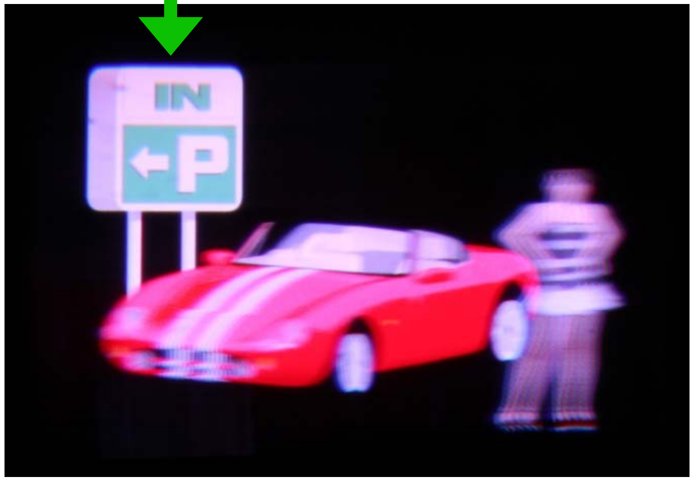
Y. Toda, J. Takagi, and Y. Takaki, IDW2013

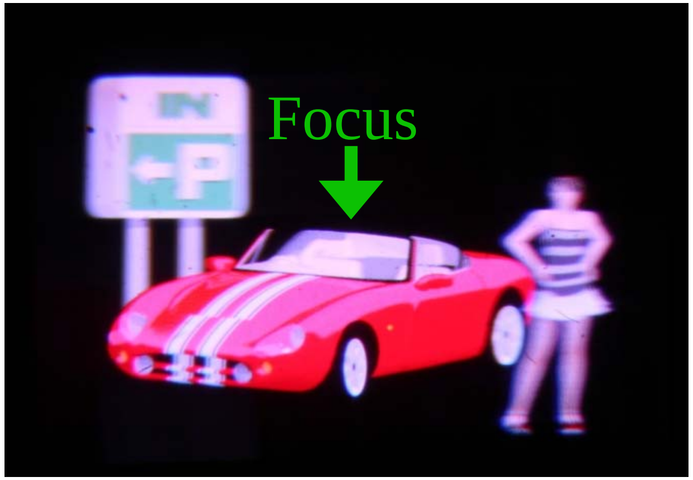


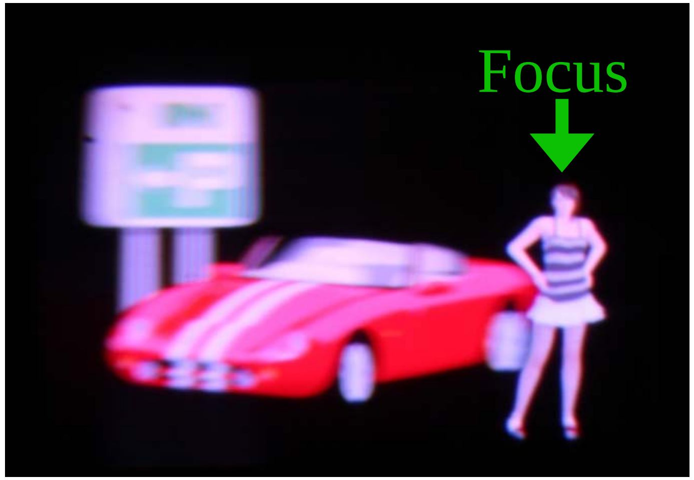
SMV Image by Scanning SMV Display

T. Ueda, Y. Toda, and Y. Takaki, IDW2012

Focus



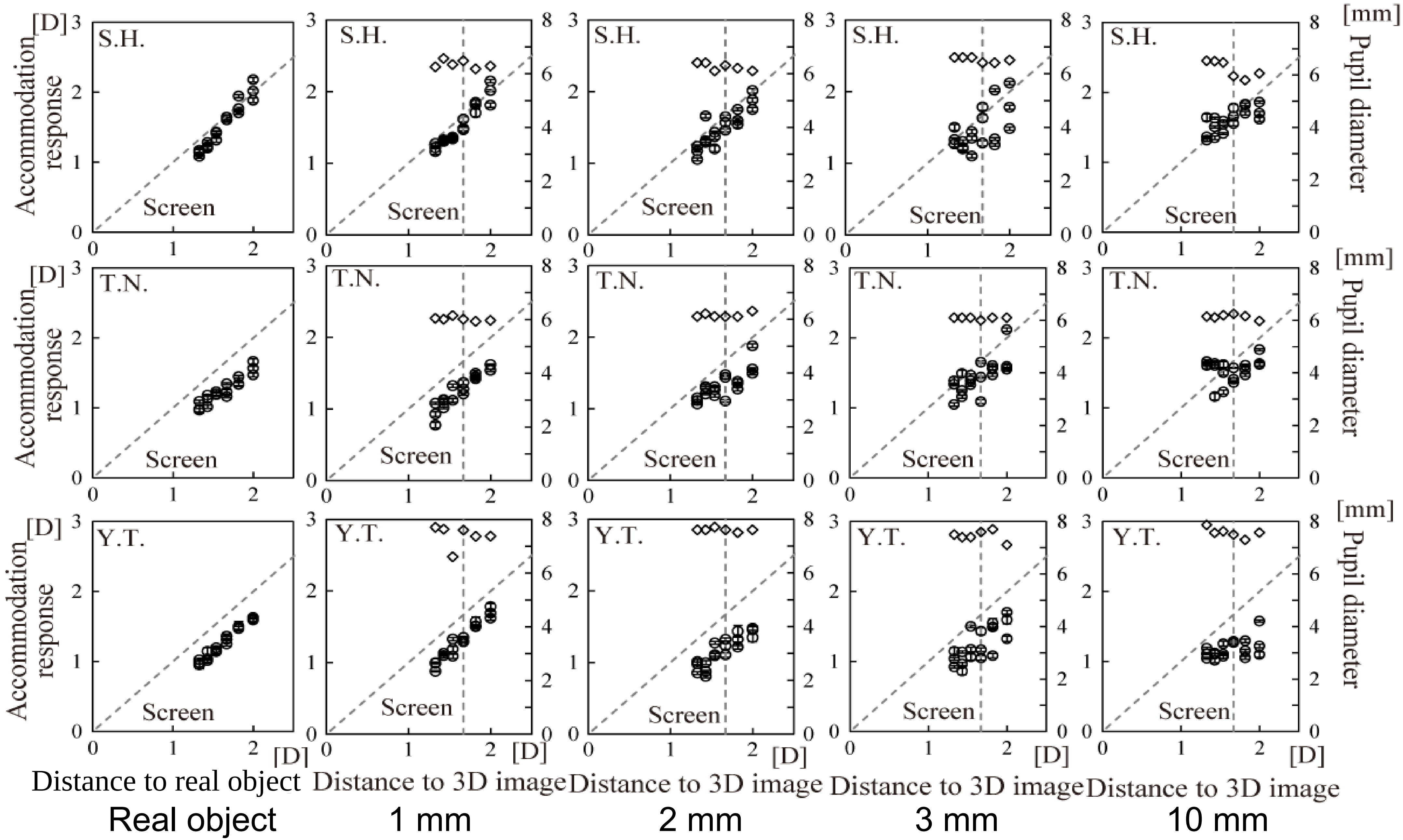




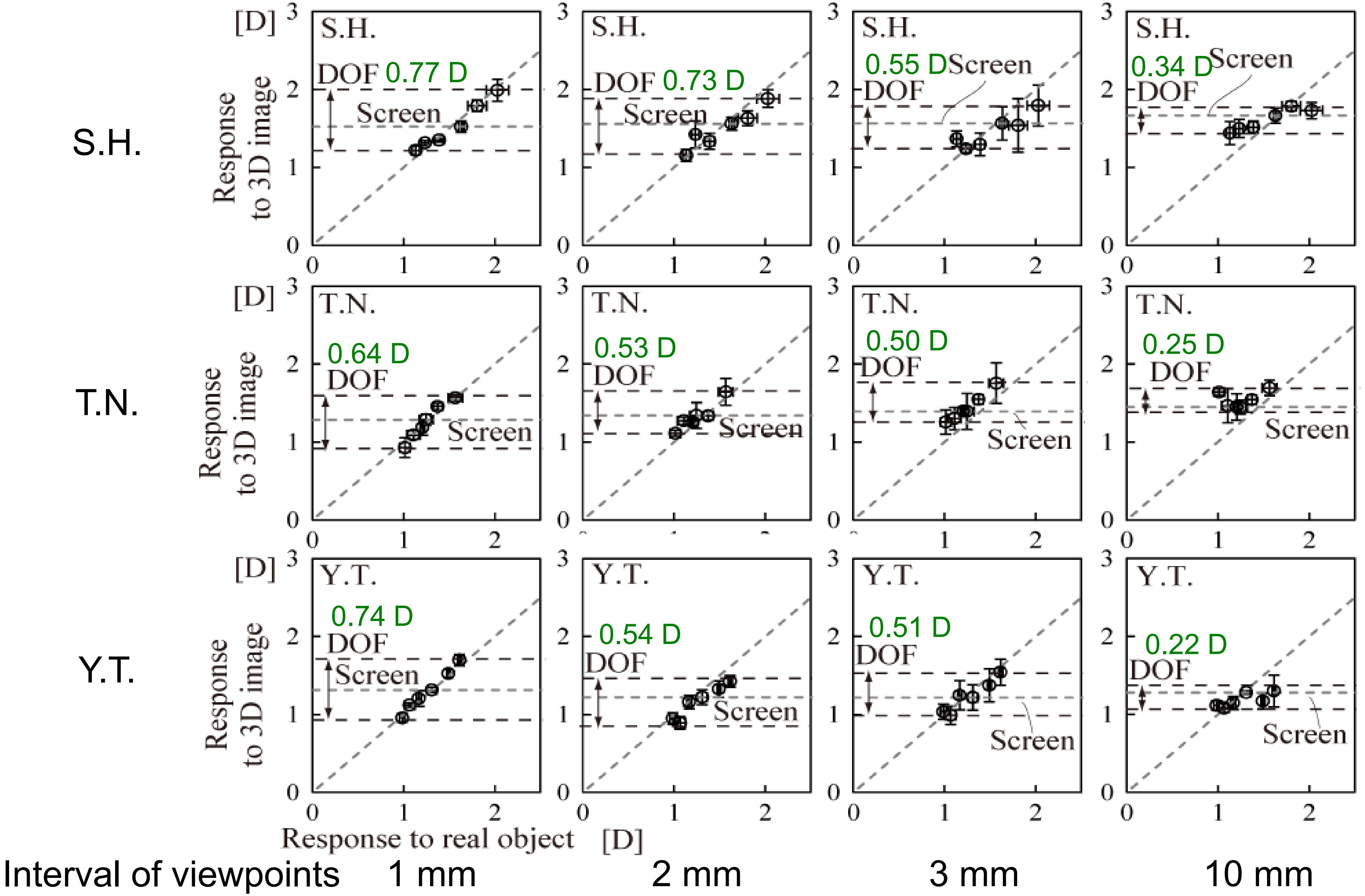
Without vertical diffuser

Number of viewpoints	55 for each R,G and B
Resolution	1,024 × 768
Width of viewing zone	182 mm
Interval of viewpoints	3.3 mm
Screen size	40 × 30 mm^2 (2.0 in.)
Refresh rate	48.5 Hz

Measured Accommodation Responses

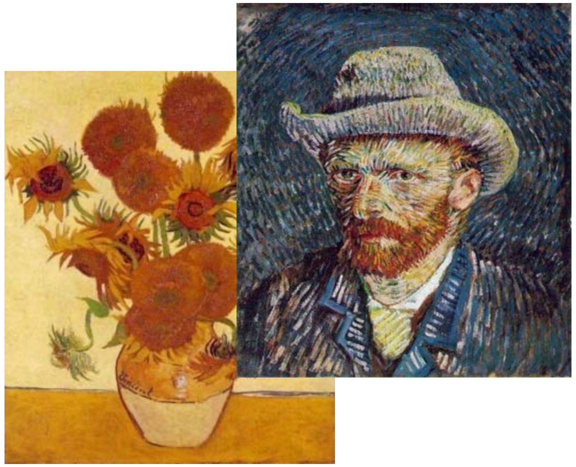


Measured Accommodation Responses



Reproduction of Material Appearances

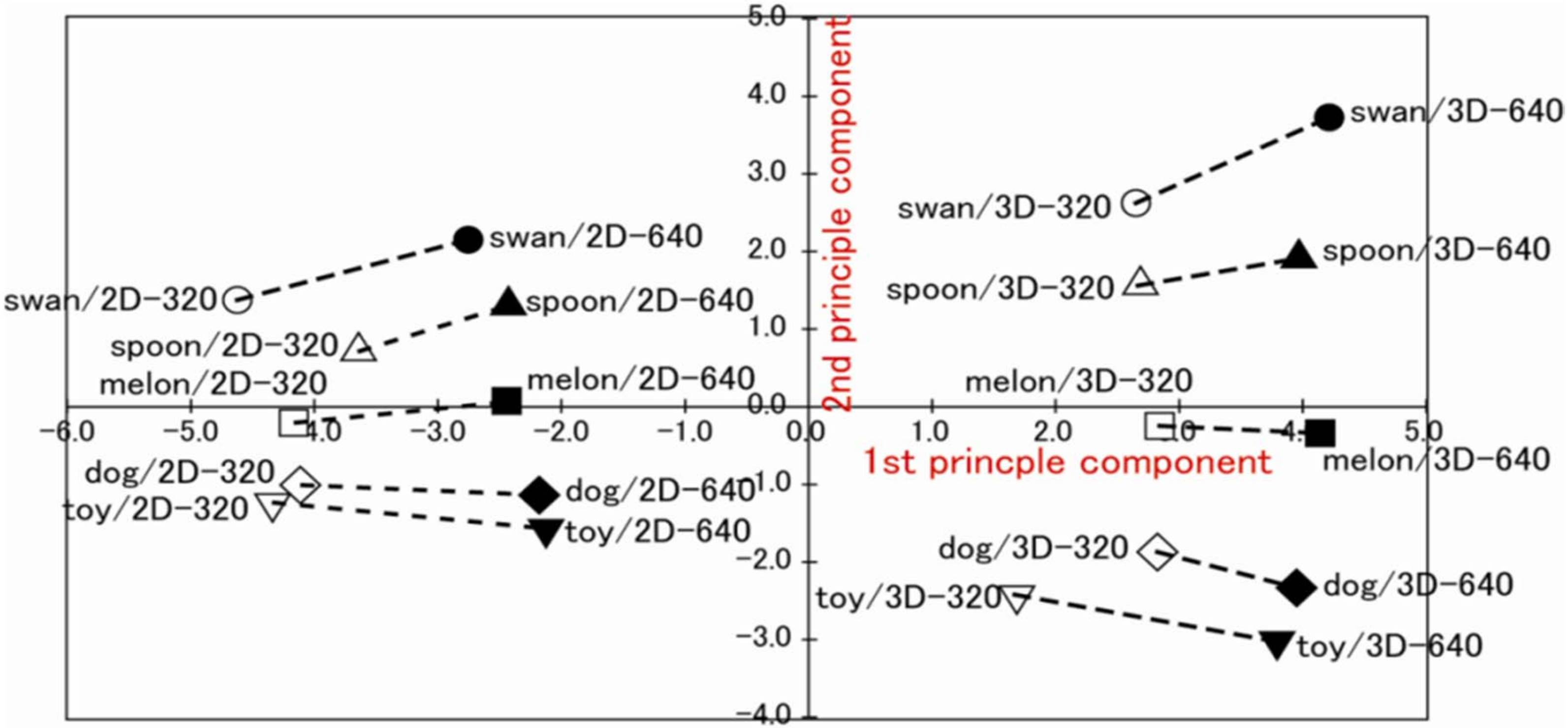
Because the SMV displays can control the ray directions precisely, they can reproduce not only the depth of objects but also the appearances of objects, such as, glare, transparency, and softness.



Subjective Evaluation of Reproduced Appearances

The subjective evaluation was performed in order to evaluate the object appearances reproduced by the SMV displays.

Twelve kinds of adjective pairs were used to evaluate the impressions, and the principle component analysis was performed.



1st principle component: depth sensation

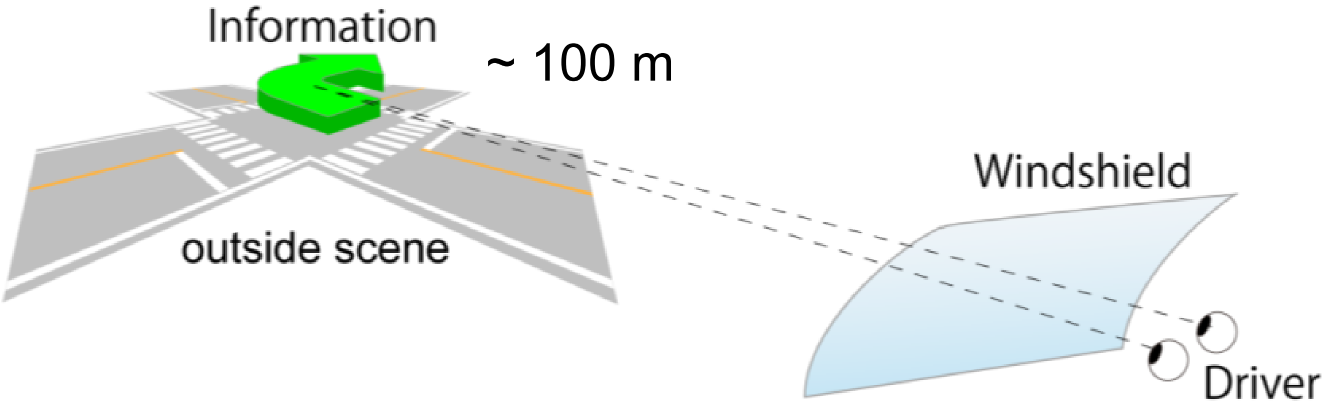
2nd principle component: appearance reproduction

Y.Takaki and T.Dairiki, IDW 2005, 1777-1780, (2005)

Y.Takaki and T.Dairiki, Proc. SPIE **6055**, 60550X (2006)

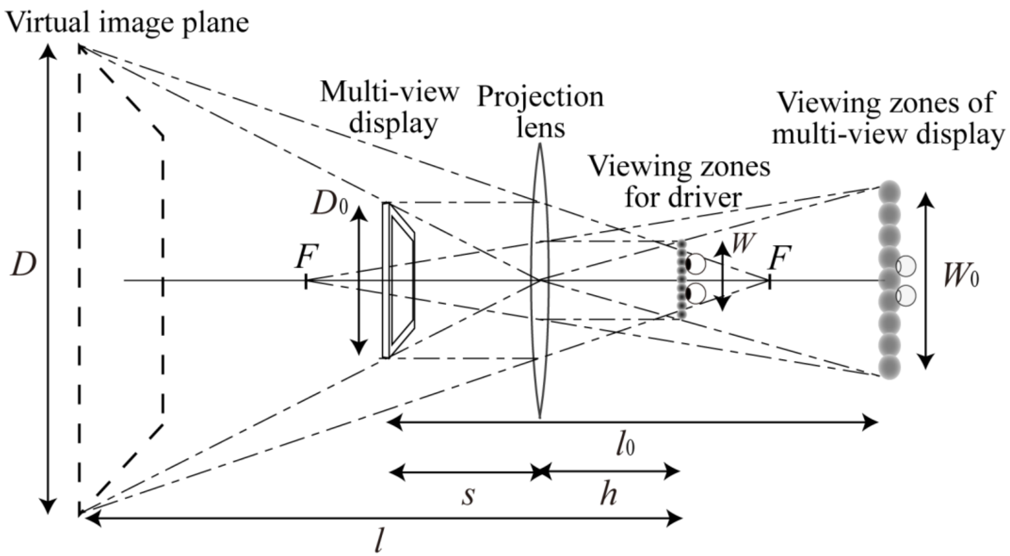
Super Multi-view Head-up Display

SMV windshield display: SMV head-up display for automobiles
Joint-development with DENSO Corp.



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

A flat-panel SMV display and a virtual imaging system were combined.



36-view SMV-WSD

Y. Takaki et al., Opt. Express **19**, 704 (2011)

Augmented Reality by SMV Head-up Display

SMV images were superposed on real scene.

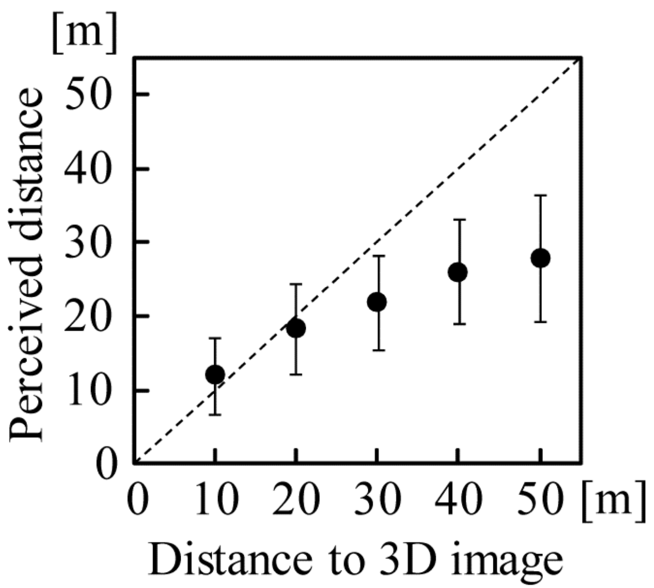
z = 5 m

z = 20 m

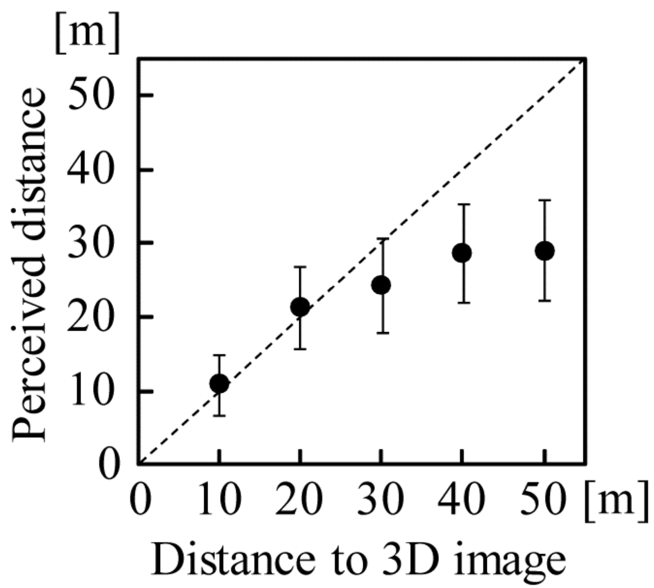
z = 50 m

Accuracy of Depth Perception for SMV Images

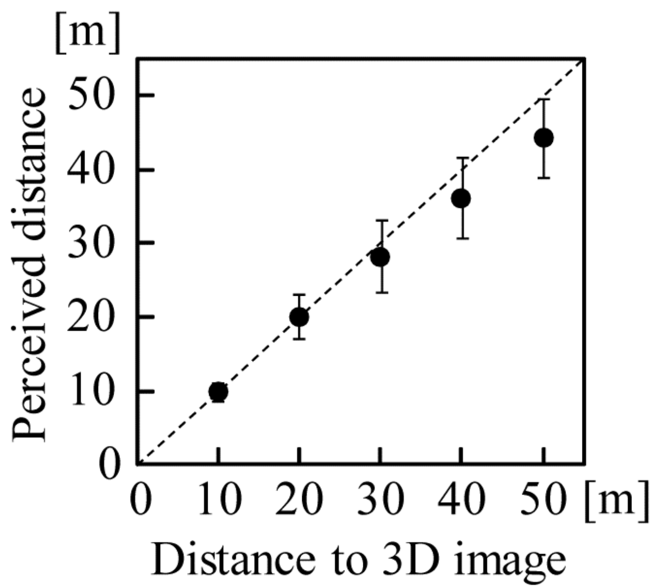
The displayed depth was changed and the perceived depth was measured.



2-view mode



18-view mode

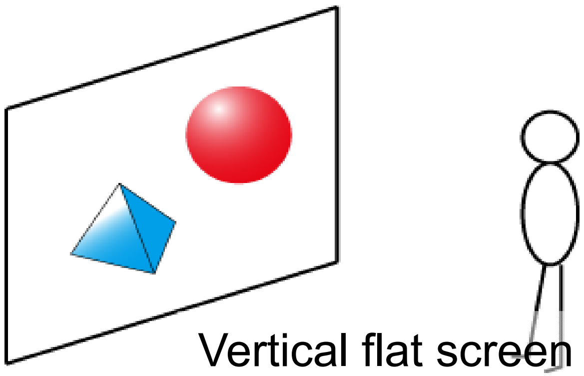


36-view mode

Subjects could perceive the depths of the 3D images even when the images were displayed as far away as 50 m.

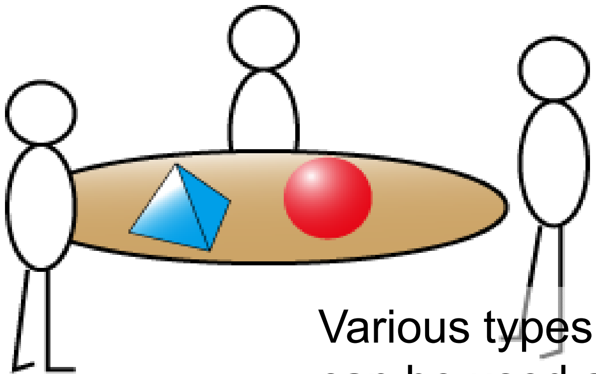
360-degree Table-screen SMV Display

Present 3D display



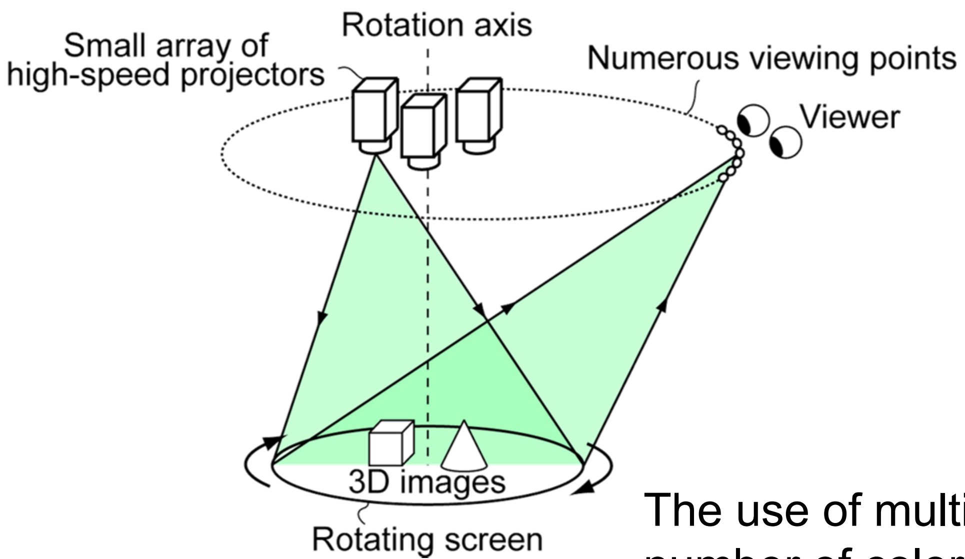
Vertical flat screen is seen from the direction normal to the screen.

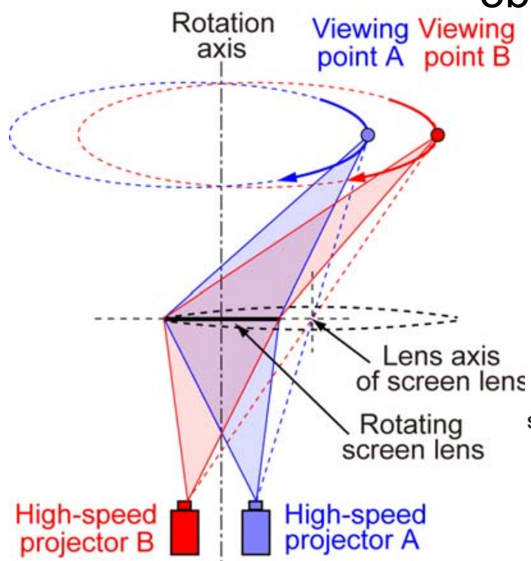
Future 3D display

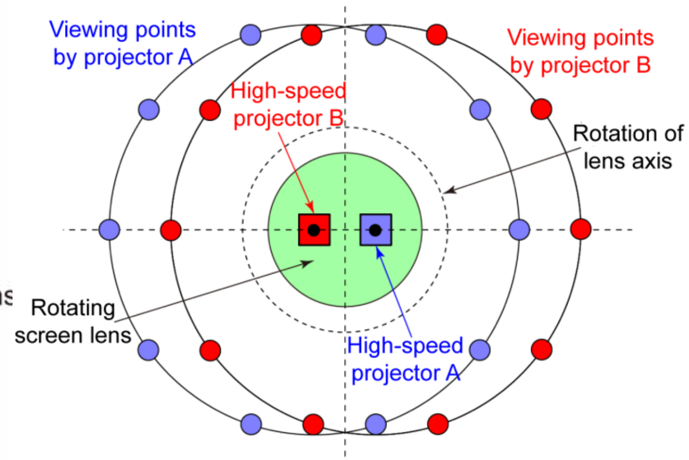


Various types of screen surfaces can be used and different observation styles can be offered.

Small array of high-speed projectors



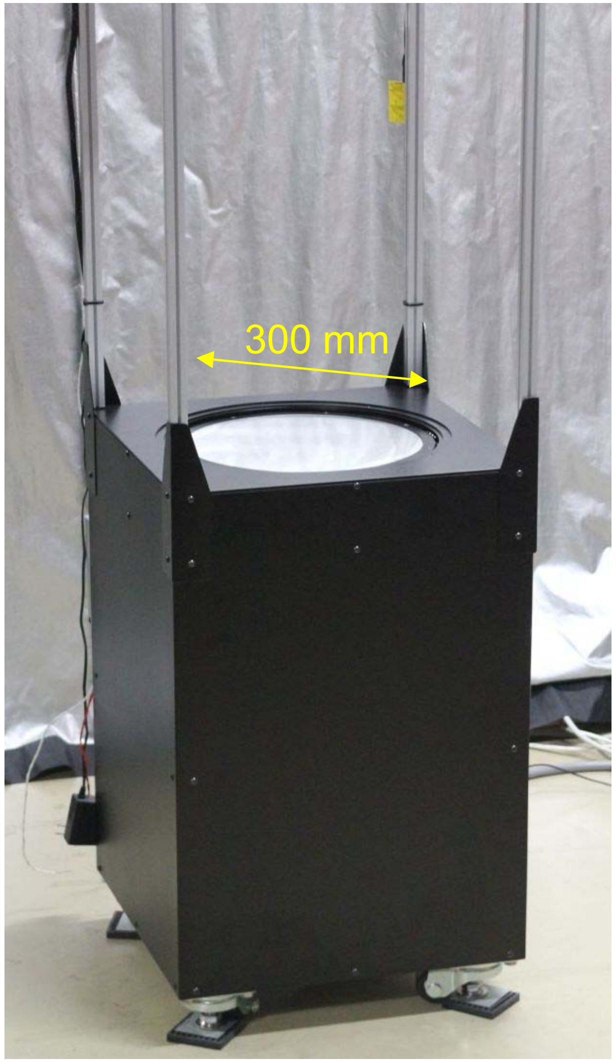




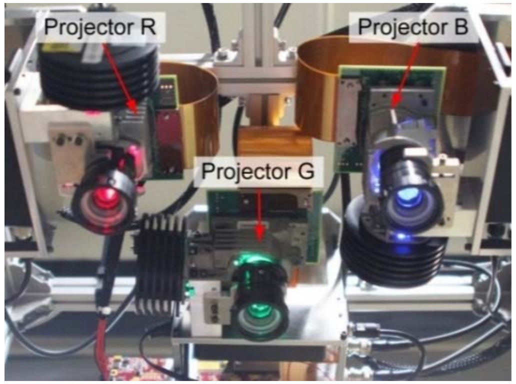
The use of multiple projectors enables an increase in the number of colors, an increase in the number of viewpoints, and a reduction in the screen rotation speed.

360-degree Color 3D Display

Three DMD projectors are used to generate 360-degree color 3D images.



Rotating screen



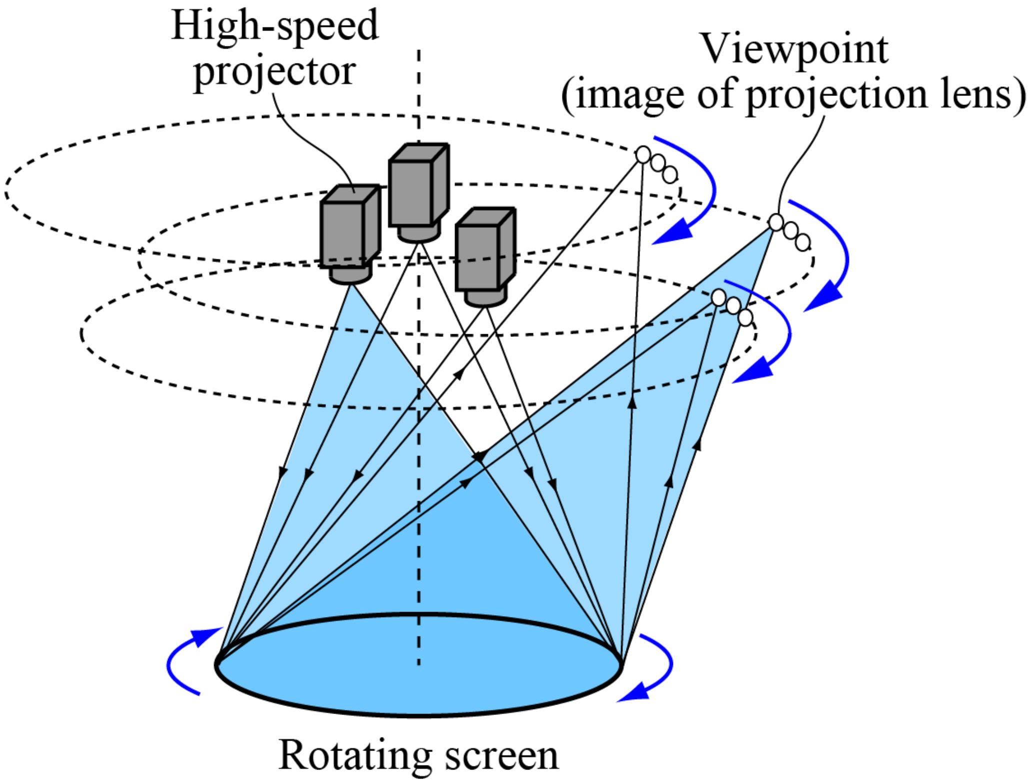
RGB projector array
Resolution: 1,024 × 768
Frame rate: 22.222 kHz

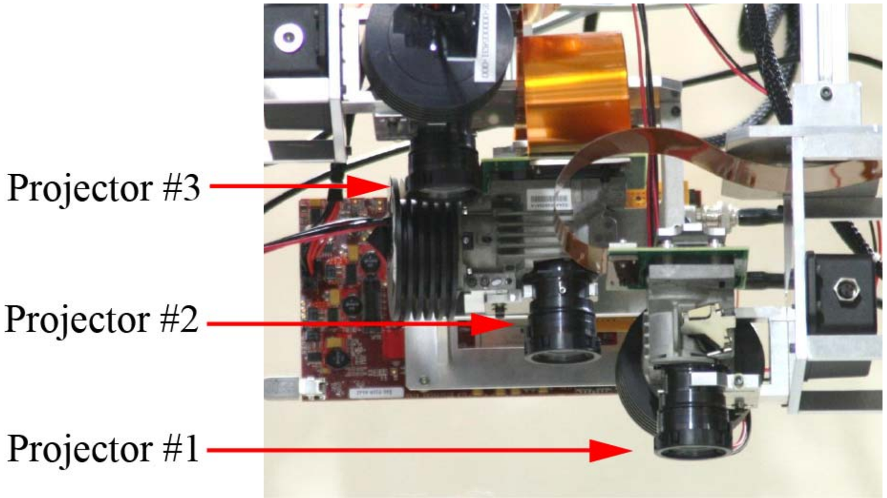
Number of projectors	3
3D resolution	768 × 768
Number of views	800/projector
Interval of views	3.1 mm
Frame rate	27.8 Hz

Y. Takaki and S. Uchida, Opt. Express **20**, 8848 (2012)

Vertical Parallax Added 360-degree SMV Display

Multiple projectors are used to provide vertical parallax.





All projectors are located at different heights.

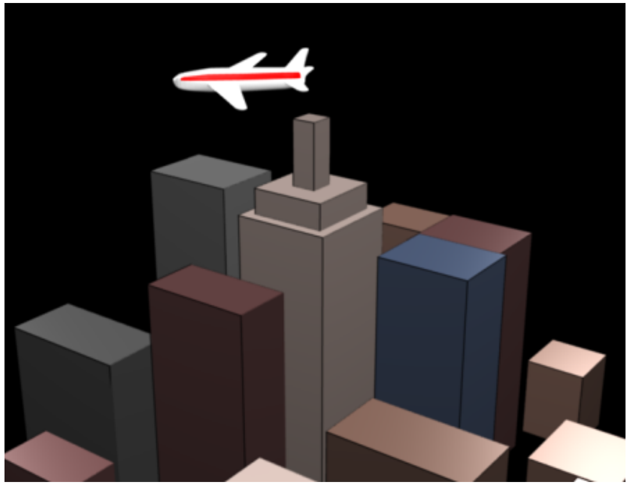
Viewpoints are generated on circles at different heights.

Multiple viewpoints are aligned vertically.

Each projector can generate color images using the time-sequential technique.

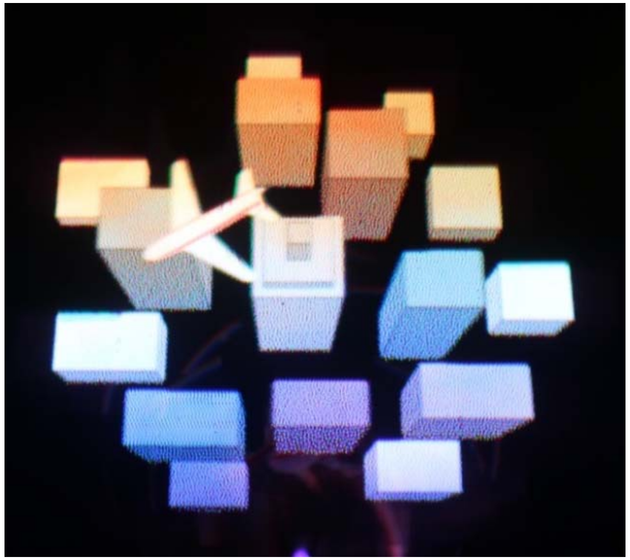
Y. Takaki and J. Nakamura, Opt. Express **22**, 8779-8789 (2014).

Vertical Parallax Added 360-degree SMV Images

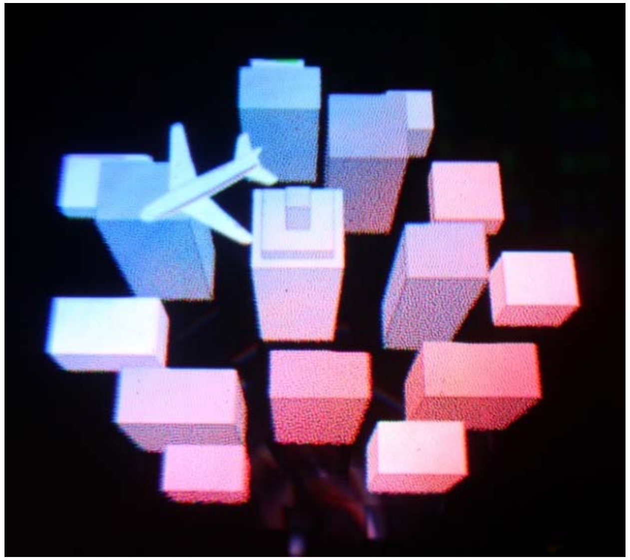


3D model “Plane”

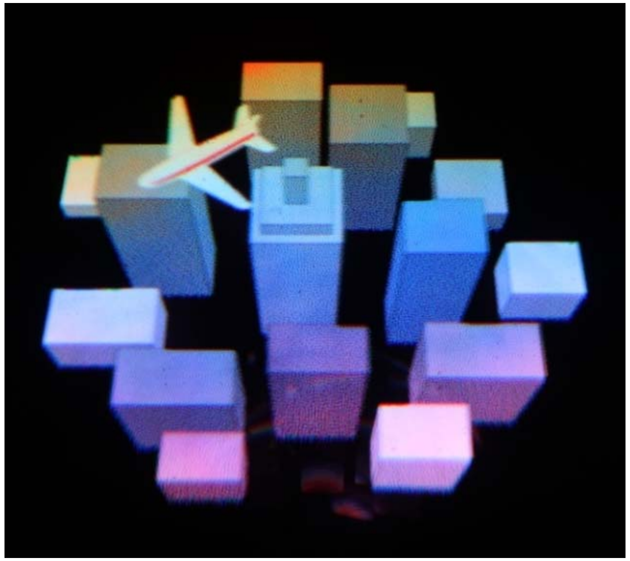
Three projectors were aligned at the different heights.



Position A (height 774 mm)



Position B (height 699 mm)



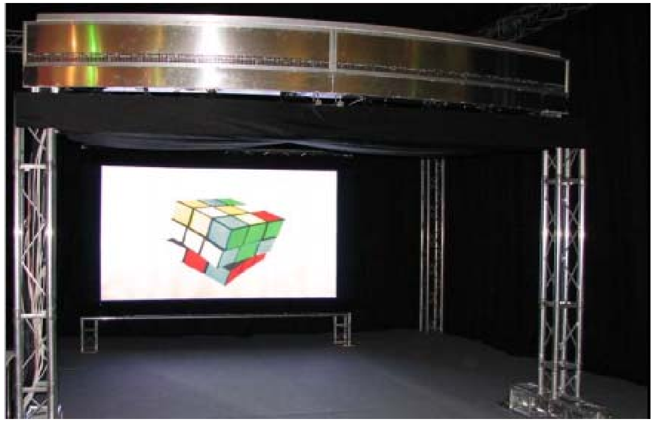
Position C (height 640 mm)

Large-screen Autostereoscopic Displays

NICT (Japan)

Screen size: 200 in.
Projection length: 8.0 m
S. Iwasawa. et al., *Digital Holography and 3D Imaging* (2013).

Holografika (Hungary)



Screen size: 140 in.
Projection length: 5.6 m
T. Balogh, Proc. SPIE **6055**, 60550U-1 (2006).

SAMSUNG (Korea)

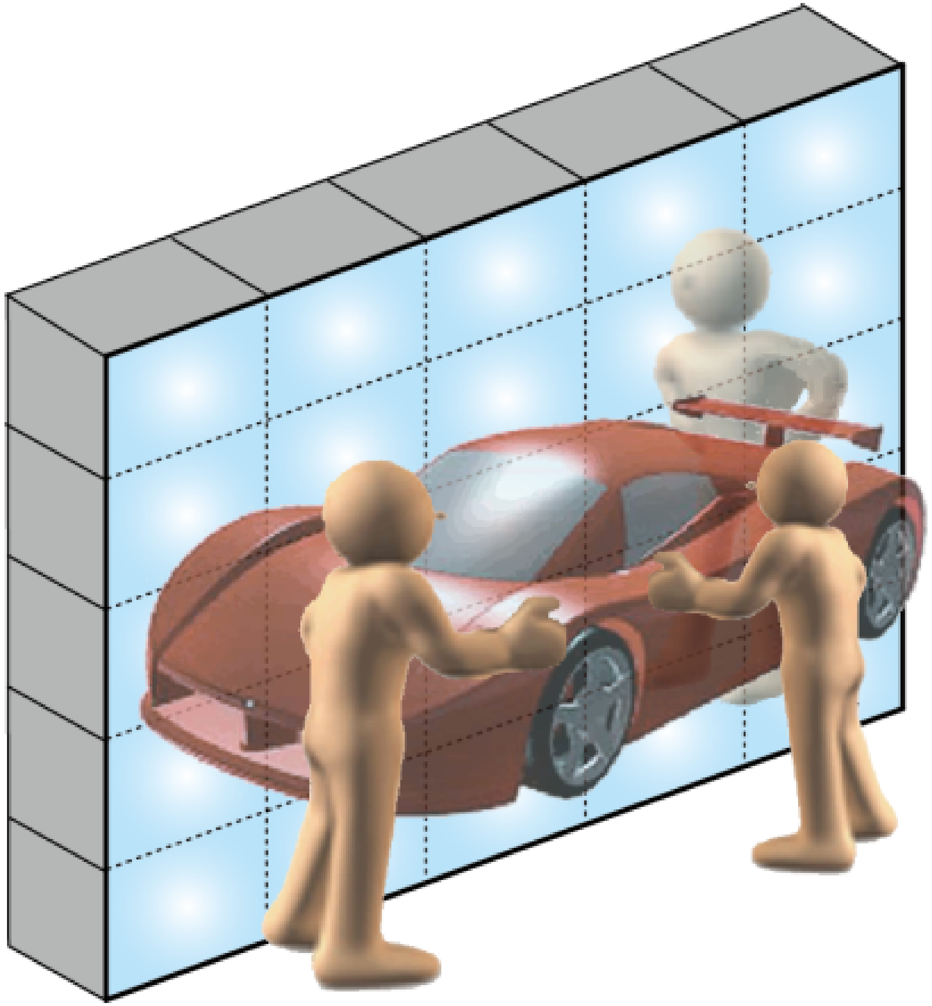
Screen size: 100 in.
Projection length: 3.4 m
J.-H.Lee. et al., Opt. Express **21**, 26820 (2013).

Most large-screen systems are based on the multi-projection system.

A long projection distance and large space are required to obtain a large screen size.

The installation and relocation are not easy.

Tiled Large-Screen Autostereoscopic Display

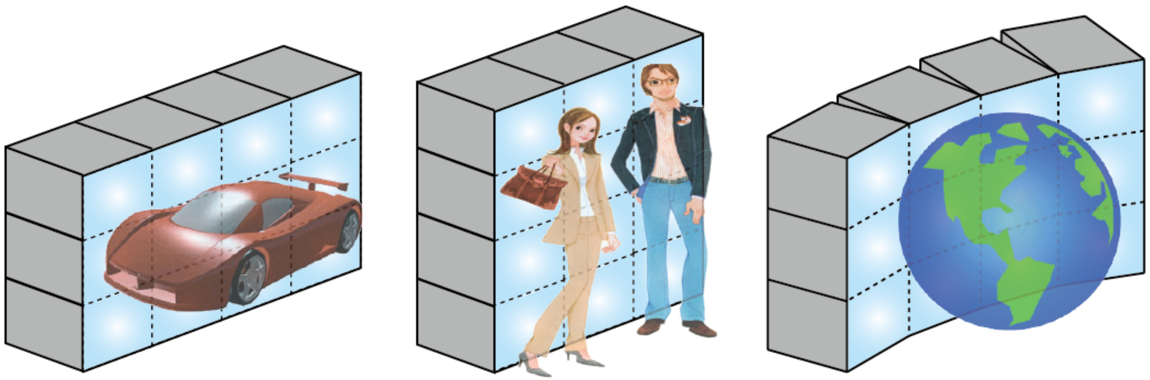


The tiling of frameless multi-view display modules has been proposed to construct a large-screen autostereoscopic display.

It requires a short system depth.

The installation and relocation are easy.

The tiled screen can be configured in various ways.

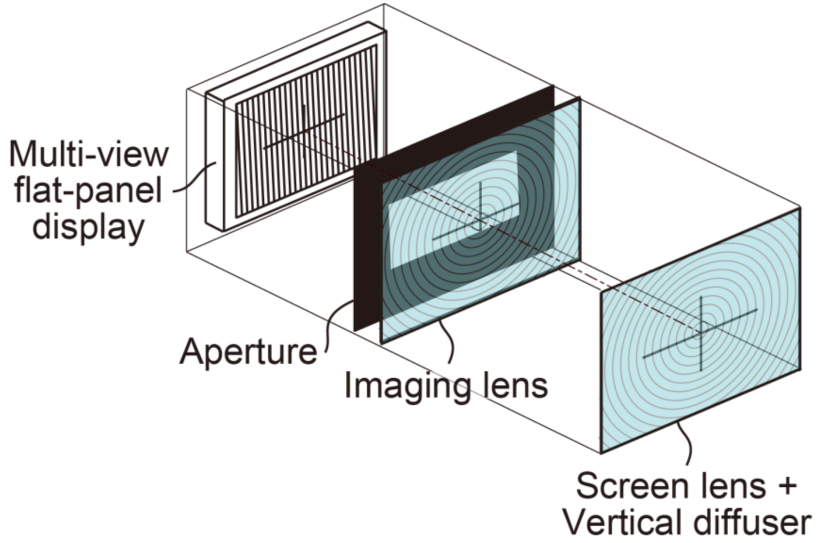


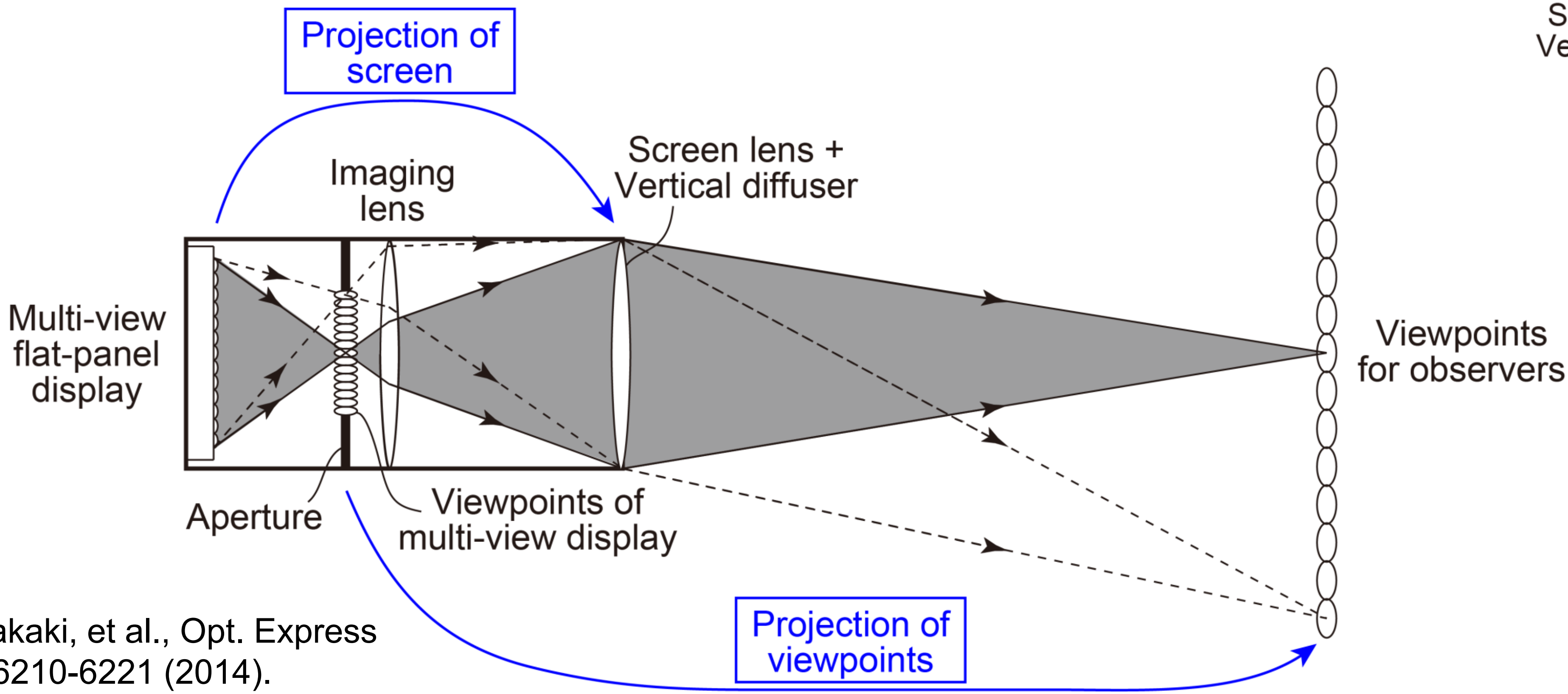
Landscape Portrait Curved

Frameless Multi-View Display Module

The screen of the multi-view display is enlarged to obtain a frameless screen.

Viewpoints of the multi-view display are projected in the observation space to produce viewpoints for viewers.



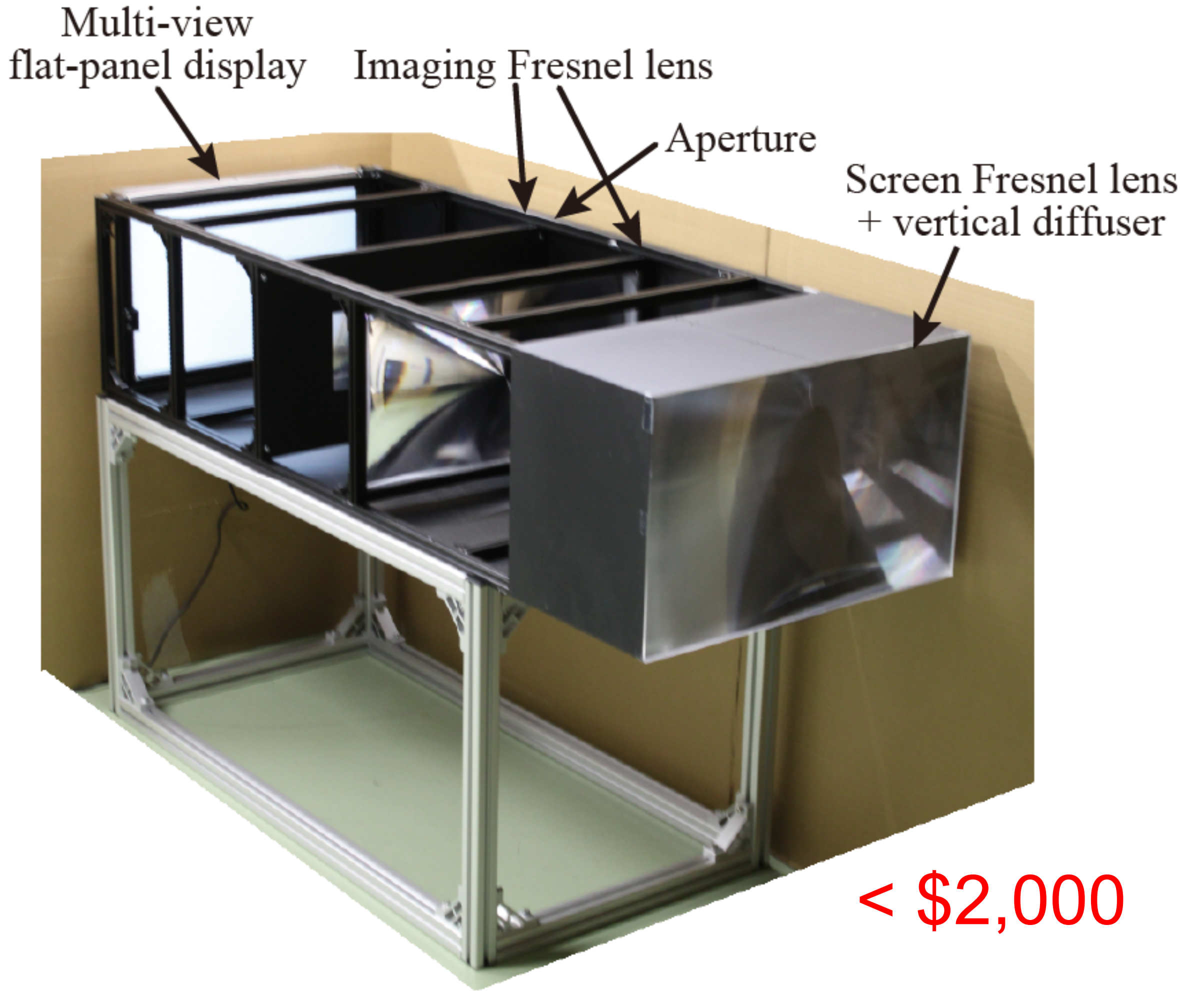


Y. Takaki, et al., Opt. Express **22**, 6210-6221 (2014).

Constructed Frameless Multi-View Display Module

The modules were constructed using a 4K flat-panel display and four plastic lenses (lenticular lens and Fresnel lenses).

4K flat-panel + lenticular lens



< $2,000

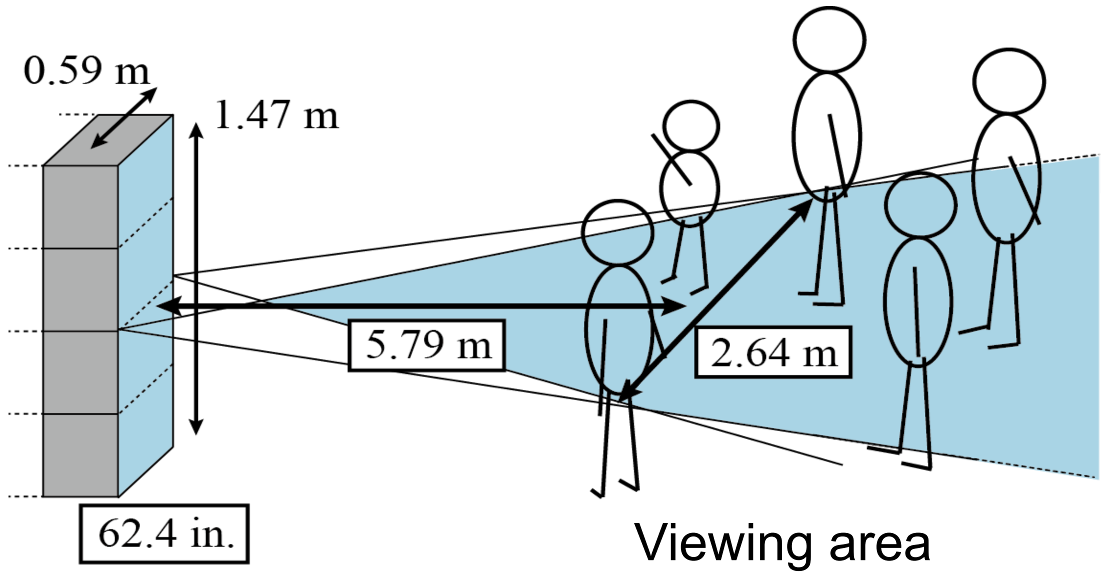
Specifications

Screen size	589 mm × 368 mm (27.3 in.)
3D Resolution	320 × 200
Number of viewpoints	144
Distance to viewpoints	5.79 m
Viewing area width	2.64 m
Interval of viewpoints	18 mm
Module length	1.5 m

3D Display with Human-size Screen

Four modules were tiled vertically to obtain a human-size screen.

Human-size 3D image



Resolution: 320 × 800

Human-size 3D Images

Specifications	
Screen size	62.4 in.
3D Resolution	320 × 800
Number of viewpoints	144
Distance to viewpoints	5.79 m
Viewing area width	2.64 m
Interval of viewpoints	18 mm
System length	1.5 m

最先端IT・エレクトロニクス総合展
CEATEC JAPAN

Summary

SMV displays have been developed to solve the accommodation-vergence conflict that causes visual fatigue.

Several SMV displays have been developed to provide a large number of viewpoints from 36 to 256, and a small interval of viewpoints from 1 to 5 mm.

The accommodation responses to the developed SMV displays have been measured and compared with those to real objects, and also compared with those to holographic images.

Various display systems based on the SMV displays have been developed, such as, the head-up display, the 360-degree display, and the tiled large-screen 3D display.

ACKNOWLEGEMENTS

Grant-in-Aid for Scientific Research, No.(B) 13555106, JSPS (2001~2002)

SCOPE, Ministry of Internal Affairs and Communications, Japan (2002~2006)

Grant-in-Aid for Scientific Research, No.(B) 15360183, JSPS (2003~2004)

Grant-in-Aid for Scientific Research, No.(B) 18360165, JSPS (2006~2007)

Grant-in-Aid for Scientific Research, No.(B) 20360153, JSPS (2008~2010)

Grant from NICT, Japan (2008~2011)

Grant-in-Aid for Scientific Research, No.(B) 23360148, JSPS (2011~2013)

Grant-in-Aid for Challenging Exploratory Research, No. 23656234, JSPS (2011~2012)

Collaborative R & D: NTT DoCoMo, Seiko EPSON, DENSO