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.

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

<table>
<thead>
<tr>
<th>Screen</th>
<th>Viewing points</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D images</td>
<td>One point (Sharp images)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Depth of field (DOF) range of eye

When eyes focus on display screen

<table>
<thead>
<tr>
<th>Screen</th>
<th>Viewing points</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D images</td>
<td>Two points (Blurred images)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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


**Flat-panel system**
- Lenticular lens and high resolution LCD
- 36 and 72 view systems


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


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

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.

Accommodation (eye focus) + Vergence

Spatial light modulator (SLM)
### 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:**

$$\Phi = 2 \sin^{-1}\left(\frac{\lambda}{2p}\right)$$

**Screen size:**

$$Np \times Mp$$

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

Screen 40”, viewing zone angle 30º ($\lambda = 0.6$ μm)

Pixel pitch: $p = 0.97$ μm
Resolution: $N \times M = 764,000 \times 430,000$

Super Hi-Vision (Ultra HD)
Resolution: 7,680 \times 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

- **Interval of viewpoints**: 2.6 mm
- **Number of viewpoints**: Left 8 + Right 8
- **3D resolution**: $256 \times 192$
- **Screen size**: 2.57 inch
- **Observation distance**: 350 mm

### Stereo camera

<table>
<thead>
<tr>
<th>Focus to 3D images</th>
<th>Left viewpoints</th>
<th>Right viewpoints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus position</td>
<td>-40 mm</td>
<td>-38 mm</td>
</tr>
<tr>
<td></td>
<td>-25 mm</td>
<td>-20 mm</td>
</tr>
<tr>
<td></td>
<td>+25 mm</td>
<td>+33 mm</td>
</tr>
<tr>
<td></td>
<td>+38 mm</td>
<td>+40 mm</td>
</tr>
</tbody>
</table>

Accommodation Measurements

Size of test target: 2.6° × 2.6°

Interval of viewpoints: 2.6, 5.3, 7.9 mm

Accommodation Responses to SMV Display

Interval of viewpoints 2.6 mm

Diopter [D] = 1/Length [m]

Enhanced DOF range of eye

Global 3D Tech Form 2014 Symposium
Takaki Lab., Tokyo Univ. of Agri. & Tech.
Horizontally Scanning Holographic Display


Anamorphic imaging system:
- Horizontal: reduce pixel pitch
- Vertical: increase image height

High-speed operation

MEMS SLM

SSB filter: single sideband filter

Anamorphic imaging system

Screen lens

Elementary hologram

Horizontal scan

Display screen

Vertical diffuser

Horizontal Scanning:
- Increase image width

→ Viewing zone angle increases

→ Screen size increases
**Experimental System**

- **Galvano mirror**
  - **MicroMax™Series671**
  - Scanning frequency: 60 Hz
  - Scan angle: ±18.1°

- **Screen**

- **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

- **Wavelength of light**: 635 nm

**Viewing zone angle**: 15°

**Screen size**: 3.5 in.

**Frame rate**: 60 Hz
Color Reconstructed Images

Castle

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

Earth

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.)

Measured Accommodation Responses

- Y.S.: 550 mm, 500 mm
- M.Y.: 450 mm, 500 mm, 550 mm
- Y.T.: 550 mm, 500 mm
- M.M.: 500 mm, 550 mm
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

[Diagram of the Scanning SMV Display]
SMV Image by Scanning SMV Display

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

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 mm² (2.0 in.)
Refresh rate: 48.5 Hz
Measured Accommodation Responses

Distance to real object

Real object | 1 mm | 2 mm | 3 mm | 10 mm

Accommodation response

Screen
Measured Accommodation Responses

S.H.

T.N.

Y.T.

Response to 3D image

Response to 3D image

Response to 3D image

Interval of viewpoints 1 mm 2 mm 3 mm 10 mm

Response to real object

DOF

0.77 D

0.64 D

0.74 D

Screen

Screen

Screen

Screen

0.73 D

0.53 D

0.54 D

0.77 D

0.55 D Screen

0.50 D

0.51 D

0.34 D Screen

0.50 D

0.25 D

0.22 D

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

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

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

Augmented Reality by SMV Head-up Display
SMV images were superposed on real scene.
Accuracy of Depth Perception for SMV Images

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

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

Small array of high-speed projectors

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.

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.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of projectors</td>
<td>3</td>
</tr>
<tr>
<td>3D resolution</td>
<td>768 × 768</td>
</tr>
<tr>
<td>Number of views</td>
<td>800/projector</td>
</tr>
<tr>
<td>Interval of views</td>
<td>3.1 mm</td>
</tr>
<tr>
<td>Frame rate</td>
<td>27.8 Hz</td>
</tr>
</tbody>
</table>

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

Rotating screen

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.

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  

**Holografika (Hungary)**

Screen size: 140 in.  
Projection length: 5.6 m  

**SAMSUNG (Korea)**

Screen size: 100 in.  
Projection length: 3.4 m  

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.

**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

**Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen size</td>
<td>589 mm × 368 mm (27.3 in.)</td>
</tr>
<tr>
<td>3D Resolution</td>
<td>320 × 200</td>
</tr>
<tr>
<td>Number of viewpoints</td>
<td>144</td>
</tr>
<tr>
<td>Distance to viewpoints</td>
<td>5.79 m</td>
</tr>
<tr>
<td>Viewing area width</td>
<td>2.64 m</td>
</tr>
<tr>
<td>Interval of viewpoints</td>
<td>18 mm</td>
</tr>
<tr>
<td>Module length</td>
<td>1.5 m</td>
</tr>
</tbody>
</table>

< $2,000
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**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen size</td>
<td>62.4 in.</td>
</tr>
<tr>
<td>3D Resolution</td>
<td>$320 \times 800$</td>
</tr>
<tr>
<td>Number of viewpoints</td>
<td>144</td>
</tr>
<tr>
<td>Distance to viewpoints</td>
<td>5.79 m</td>
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<td>18 mm</td>
</tr>
<tr>
<td>System length</td>
<td>1.5 m</td>
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</tbody>
</table>
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.
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