AUTOSTEREOSCOPIC DISPLAYS: 2011
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• Joel E. Welch
  Director of Professional Development
  SMPTE

Upcoming SMPTE Events

• SMPTE Regional Seminars
  – Montreal, Toronto, Atlanta and Greater Boston

• 2nd Annual International Conference on Stereoscopic 3D for Media and Entertainment
  – New York; 21 - 22 June 2011

• IBC
  – Amsterdam, The Netherlands; 8 - 13 September 2011:

• SMPTE Annual Technical Conference and Exhibition
  – Hollywood, CA, USA; 24 - 27 October 2011

For more information or to register, please visit www.smpte.org
SMPTE PDA Now: Autostereoscopic Displays: State of the Art and the Way Forward

SMPTE PDA Now

• Series of monthly 1-hour online, interactive webcasts covering a variety of technical topics
• Free professional development benefit for SMPTE members
• Sessions are recorded for member viewing convenience.

Housekeeping

• Please use the text chat to submit questions to the speaker
• Please feel free to add to the discussion or offer additional information via text chat
• In the rare instance that the slides seem to not progress, try closing your browser and signing in again
Today’s Speaker

Gregg Favalora
Principal
Optics for Hire
Where are we relative to the dream?

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We’re beginning to cross the chasm

Handheld Desktop Living Room Cinema

Pragmatists

Sharp

Masterimage

3M

Visionaries

Several, e.g. Alioscopy [SETRED]

R&D

Major CE companies are trying R&D [Holografika]

[ * ] = I haven’t seen it in person.

• You’ll see interesting “extreme examples” of each
• You’ll get suggestions on lesser ‐ publicized work
• You’ll see a list of recommended reading

Geoffrey A. Moore, Crossing the Chasm: Marketing and Selling High ‐ Tech Products to Mainstream Customers (1991)
Gregg Favalora / Optics for Hire

OFH improves and invents optics-based products for its clients
LED optics – lens systems – biomedical instruments – Fortune 10 / White Label
Acquired Actuality’s autostereo display & processing patent portfolio

John Ellis
President

Gregg Favalora
Principal

About Gregg
• Founder, Actuality Systems (1997-2009) - Principal, OFH
• Co-chair, SPIE-IS&T SD&A Conference
• Technology Review young innovator award (1999)
• Specialties: volumetric displays; beam-steering “light field” displays using geometric or diffractive optics

Agenda

• Fundamentals
  – Define autostereoscopic
  – Goals / quantify the challenge
  – Enabling technologies
  – Less-obvious depth cues
  – Window Violations
• Display-Type & Recent Examples
  – Spatially multiplexed displays
    – Parallax-barrier displays
    – Integral photography
    – Lenticular displays
  – Specular displays
    – Multi-projector
    – Fourier-plane
    – Vibrating lenticular
    – Directional backlight

  – (Continued)
    • Volumetric Displays
    • Holographic / Quasi-holo.
• Hot Topics
• Wrap-up / resources

Thank you for providing material & updates:
Tibor Balough (Holografika)
Jesse Eichenlaub (DTI)
Takashi Kawai (Waseda Univ.)
Vincent King (3M)
Michael Klug (Zebra Imaging)
Douglas Lanman (MIT Media Lab)
Hagen Stolle (SeeReal)
When I say “autostereoscopic,” I mean:

A display is **autostereoscopic** if it gives the viewer an impression of a 3-D image using the natural “unaided” eye. Provides at least two “views.”

- Polarized eyewear
- Volumetric
- Multi-projector / scanned light
- Lenticular
- Parallax barrier

### Agenda

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IMHO this is a bad definition
Quantifying the Challenge

- If you want: 30 cm x 30 cm x 30 cm image @ 120 Hz and 24-bit color.
- Slice-stacking (27 Megavoxel volumetric)
  - 1 mm³ resolution: 78 Gbits/sec
- Multi-view
  - 120° field-of-view, 1 view/degree: 453 Gbits/sec
- Holography (i.e. “traditional”)
  - Needs 1500-2000 lpmm: 43 Tbits/sec, neglecting color

Tools that we either have or need

- Pixel bandwidth
  - Projection? TI DLP (e.g. ViALUX ALP-4 0.55 XGA binary 22,727 Hz)
  - Holography? HOLOEYE Photonics (PLUTO has 8 μm pixels)
  - Emissive backplane? (Customize?)
- Improve multi-view image quality with camera-based characterization step
  - (Build) > (Characterize) > (Make LUT) > (Invert) > (Operate)
  - Create a map between the 4D space of lightfields and all controllable aspects of your display
- Out of scope: multiview content generation
You already know: monocular depth cues

Credit: N. A. Dodgson, Cambridge Univ.

The Delivery of the Keys (Pietro Perugino, 1481-2)

“Illusory” depth cues

(That is, due to environmental factors or viewing conditions.)

• Using one eye
• Seeing larger pictures farther away
• Changing the convergence of the eyes (from normal)
• Looking through a small hole
• Intentional defocus
• Looking at a picture in a mirror
• Blurring one eye’s focus when viewing in stereo
There are limits...
A Real Limit: Window Violations

“Our current understanding of physics does not include a practical way of forcing photons to change direction in the absence of an optical medium. Thus, a fundamental and general statement can be made about all spatial displays, whatever its particular technology:

A display medium or element must always lie along a line of sight between the viewer and all parts of a spatial image.”

A Real Limit: Window Violations


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  • Volumetric Displays
  • Holographic / Quasi-holo.
  • Hot Topics
  • Wrap-up / resources
Some spatially-multiplexed displays

<table>
<thead>
<tr>
<th>Parallax Barriers</th>
<th>Integral Photography</th>
<th>Lenticular Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1902) F. E. Ives</td>
<td>(1908) G. Lippmann</td>
<td>(1913) W. Hess</td>
</tr>
<tr>
<td>Sharp</td>
<td>NHK</td>
<td>Alioscopy</td>
</tr>
<tr>
<td>Masterimage 3D</td>
<td>Toshiba (“1-D II”)</td>
<td>Philips WOWvx</td>
</tr>
<tr>
<td>Yendo et al</td>
<td>de Montebello (Integram)</td>
<td>RealID (SynthaGram)</td>
</tr>
<tr>
<td>MIT Camera Culture group</td>
<td>Univ. Tokyo (Liao)</td>
<td></td>
</tr>
<tr>
<td>Tom Peterka “Varrier”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Content-adaptive parallax barriers


Two 1680 x 1050 Viewsonic FuHzion 120 Hz LCD panels 282 micron pixel pitch. Panel sep = 1.5 cm.

as a viewer moves in smmam airaeons. A ram-y accentonst produces a set of mask pairs. (Middle) A rear-panel mask. (Right) A front-panel mask. Note that optimization appears to produce a local parallax barrier, rotated to align with the step edge.

“Seelinder” – T. Yendo

Figure 2. Cylindrical multi-view display made of a cylindrical parallax barrier and a one-dimensional light source array. Display rotates along inside of cylindrical parallax barrier with synchronous intensity modulation.

Figure 1. (a) Light going through the aperture is scanned by the movement of the light source. (b) When the aperture is seen from position 1, light reaches viewer’s eye only at a moment when the light source passes position A. When the aperture is seen from Position 2, light reaches the viewer’s eye only when the light source passes position B.
### Integral Photography / Integral Imaging

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NHK publishes consistently high quality research results in a variety of publications.</td>
<td>The best IP I’ve ever seen. Demonstrated at SPIE SD&amp;A 2005 [5664A-40]</td>
</tr>
</tbody>
</table>

**Image Depth:** 5.7 m

---

### Liao et al. long-distance IP (cont’d)

1. Excellent lenslets
2. Film near array focal plane
3. Expose film one lenslet at a time
4. Develop film
5. Playback (reconstruction) uses same lens array

---

Figure 3. Configuration of IV image generating device.

Figure 5. A 3D computer graphics image produced by the IV autostereoscopic display for distant viewing. Viewed from the left to right.

The club stands out in mid-air on the palm of the viewer’s hand about two meters away (yellow) and four meters inside the display.
Lenticular Displays

Sharp Actius

Alioscopy

Toshiba
(They call it IP)

Philips “WOWvx”

Autostereo cell phones! Ocuity, Toshiba...

---

THE GADGET BLOG FROM CNET
What’s Hot: iPad 2 | Xperia Play | Honeycomb | Sony NGP | Nintendo 3DS

March 7, 2011 5:00 PM PST

Toshiba discloses more on its glasses-free 3D TVs

by Philip Yang

Toshiba is currently offering smaller 12- and 20-inch glasses-free 3D TVs only in Japan for $1,509 and $2,990, respectively. It’s not hard to estimate the premium on a 46-inch using these prices as benchmarks, though the Japanese TV maker may be able to keep costs down by mass-producing these panels.

(From: Crave Able)
Good analytical papers for spatially multiplexed displays:


With Zograph Corporation (Northampton, MA)

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    - Parallax-barrier displays
    - Integral photography
    - Lenticular displays
  - Specular displays
    - Multi-projector
    - Fourier-plane
    - Vibrating lenticular
    - Directional backlights
- (Continued)
  - Volumetric Displays
  - Holographic / Quasi-holo.
  - Hot Topics
  - Wrap-up / resources
Specular (in some cases, “Light Field”) Displays

<table>
<thead>
<tr>
<th>Fourier-plane scanning</th>
<th>Vibrating lenticular</th>
<th>Scanned illumination / wedge</th>
<th>Multiple Projectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travis / Dodgson</td>
<td>OFH / Actuality</td>
<td>3M</td>
<td>Holografika</td>
</tr>
<tr>
<td>Cossairt @ Media Lab</td>
<td>Zecotek</td>
<td>Microsoft</td>
<td>MERL</td>
</tr>
<tr>
<td>SETRED</td>
<td>Brussels Photonics</td>
<td></td>
<td>MUTED / HELIUM</td>
</tr>
</tbody>
</table>

Multi-projector display

– one projector for “each view”

Credit: N. A. Dodgson, Cambridge Univ.
Multiple Projectors (Holografika)

HoloVizio C80 cinema system
3 m x 1.8 m
63 Mpixel, 11 kW
40° HFOV, 1500 cd/m²

Projection onto corrugated screens

<table>
<thead>
<tr>
<th>Start with the classics, for example Okoshi</th>
<th>Apple</th>
<th>National Chiao Tung Univ. Prism-patterned screen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US Pat 7,843,449</td>
<td>W Mphepo, Y-P Huang, H-P D Shieh, &quot;An autostereoscopic 3D display system based on prism patterned projection screen,&quot; JDT 6(3) (Mar 2010)</td>
</tr>
</tbody>
</table>

Table 1: Synoptic Loss Chart and Maximum Resolution of automatic lens and tri-polarized screen

<table>
<thead>
<tr>
<th>Resolution (m)</th>
<th>0.5</th>
<th>0.3</th>
<th>0.15</th>
<th>0.1</th>
<th>0.05</th>
<th>0.03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Loss</td>
<td>25.4</td>
<td>25.4</td>
<td>19.4</td>
<td>15.5</td>
<td>8.8</td>
<td>9.2</td>
</tr>
<tr>
<td>Projection Loss</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>

* Only the diffusion and the recycling effect are measured.

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  – Spatially multiplexed displays
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    – Integral photography
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  – Specular displays
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(Continued)

• Volumetric Displays
  – Holographic / Quasi-holo.

• Hot Topics

• Wrap-up / resources

Time sequential display: practical implementation

– replace the fast transparent display screen with a fast (1kHz) CRT and a dynamic optical system

Credit: N. A. Dodgson, Cambridge Univ.
Vibrating lenticular

- **BENEFITS:**
  - Provides >100 “views” (ray trajectories per pixel)
  - Each “view” has much higher resolution than spatially-multiplexed systems. 1024 x 768 is straightforward.
  - Inexpensive opto-mechanical beam steering.

- **METHODOLOGY**
  - High frame-rate image source, e.g. DMD at 16 kHz
  - Beam-steering system at image plane, e.g. dual-lenticular sandwich with one lenticular oscillating left-and-right at, say, 30 Hz

- **WHO DID IT?**
  - Brussels Photonics Team (Bogaert et al, Optics Express 18(25) 6 Dec 2010)
Time-multiplexed view scanning (2005)

US 7,864,419 – OFH / Ellis Amalgamated

Your eyes perceive intersecting rays as points

Rendering
Reconstruction
Piecewise lightfield reconstruction

Time-multiplexed view scanning (2005)
Time-multiplexed view scanning (2005)

Successful Output Images
Agenda

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  - Less-obvious depth cues
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  - Spatially multiplexed displays
    - Parallax-barrier displays
    - Integral photography
    - Lenticular displays
  - Specular displays
    - Multi-projector
    - Fourier-plane
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Two systems with directional backlights

Two viewing zones with μPol
@ Waseda Univ & Sophia, Inc.

Kawai, Shibata, Shimizu, Kawata, Suto,
“Development and evaluation of
amusement machine using
autostereoscopic 3D display,” SPIE-IS&T

Elliptical reflector, dual backlights
@ Eizo NANA

full-panel resolution autostereoscopic LCD
with a novel directional backlight system,”
JSID 18/7 (2010).
Flat systems with directional backlights

3M’s alternating illumination autostereo
US Pat No 7,847,869 (Nelson & Brott)

Several groups pursuing “wedge” autostereo: Microsoft, LG, ...

Dimension Technologies Inc. (Rochester, NY)

- Jesse Eichenlaub reports that they are building a 22” eight-view display using time-multiplexed illumination, with 1680 x 525 resolution in 3D mode.
- They also have an SBIR to develop an autostereo projection display using a single projector.
- They currently sell 19” two-view 2D/3D displays, and 22” nine-view and five-view 2D/3D displays.
- (Available for licensing)
- ...via email
ATTEST / 3D TV Network of Excellence
MUTED & HELIUM3D


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  – Spatially multiplexed displays
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    – Fourier-plane
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• (Continued)
  • Volumetric Displays
  • Holographic / Quasi-holo.
  • Hot Topics
  • Wrap-up / resources
Volumetric Displays

<table>
<thead>
<tr>
<th>Multiplanar</th>
<th>Upconversion, Laser Excitation of Air, etc.</th>
<th>Re-Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFH / Actuality (Perspecta)</td>
<td>3D Icon (Tulsa, OK)</td>
<td>“Optic Mirage”</td>
</tr>
<tr>
<td>ESKI (Revolver)</td>
<td>3D Technology Laboratories</td>
<td>Satoshi Maekawa et al</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPIE 6392-0E (2006)</td>
</tr>
</tbody>
</table>

Multiplanar: Perspecta® - 100 Mvoxels
A new type of optical element (?!)

Transmissive Optical Imaging Device with Micromirror Array
Satoshi Masumoto, Kenzou Nitta and Osami Masukura
National Institute of Information and Communications Technology, AIST Hitotsubashi, Saitama, 332-0012, Japan
Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe, Japan
Proc. of SPIE Vol. 6392 63920E-1

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Earlier work in holographic cinema

- Russian autostereo
  - Victor Komar NIKFI Holographic Laboratory (Moscow) 24 viewing zones – holocinema.com

Electro-holography needs small and/or numerous modulators

Example
Steering green light 45°:
\[ d = \frac{(510 \text{ nm})}{\sin 45} \]
\[ = 721 \text{ nm} \]
\[ = 1386 \text{ lines per mm} \]
Holograms eat pixels

Example

Steering green light 45°:
\[ d = \frac{510 \text{ nm}}{\sin 45} \]
\[ = 721 \text{ nm} \]
\[ = 1386 \text{ lines per mm} \]

...so a 30 cm x 30 cm hologram would need a resolution of:

416,000 x 416,000.

A traditional (glass) hologram has 1000s of pixels/mm

Computer-Generated Holograms

Zebra Imaging (Austin, TX)
MIT HoloVideo (Mark II)

The hologram’s underlying diffraction patterns are created here

http://www.media.mit.edu/spi/spiPubs.htm

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SeeReal: Combines holography + tracking

Note: 2D photo of holographic 3D scene live converted from stereo 3D content
(killer caused by camera lens larger than Viewing Window)
Used with kind permission of SeeReal

Holographic Imaging, LLC (QinetiQ)

Projector chips as holograms

Hologram created on 1,408 x 1,050 LCD panel. 10.4 micron pixels.
(!! The diffracted angle is therefore only about 3 degrees !!)

Data computed on custom FPGA board; each 10,000-point scene took 0.02 sec (on a Pentium 4 it would have taken 24.7 sec).

Projector chips as holograms

Fig. 8. Snapshot of a real-time electroholography by HORN-5: (a) the original graphics, (b) the CGH and (c) the constructed image.

Advances in hologram chemistry

- [ibid] “Materials for an updatable holographic 3D display,” JDT 6(10) 510-516 (Oct 2010)
Time-sequential holography by illuminating “basis holograms”

Radiation Conditioning System
OFH / Ellis Amalgamated
US Pat No 6,940,653

Data processing for three-dimensional displays
OFH / Ellis Amalgamated
US Pat No 7,525,541

Other unusual 3-D display systems

Theta-parallax-only displays
OFH / Ellis Amalgamated
US Pat No 7,364,300

Uses a flat horizontal turntable to direct views to a circular arrangement of observers:

1 fast projector, many relay stations
OFH / Ellis Amalgamated
US Pat No 7,283,308

Exploit excess projector speed. Relay sequential “views” to an array of relays:
Agenda

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  – Specular displays
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    – Fourier-plane
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Hot Topics

Acquisition:
View interpolation with good occultation-repair

Compression / Broadcast:
Ray space / EPIs

Display:
Subpixel / lens array tweaking
Pixels/sec via view-scanning
Honest quality control (3M)

Perception:
Safety, comfort, accommodation / vergence


But start with:
• Michael Halle’s PhD Thesis (MIT Media Lab)
• Bolles, Baker, “Epipolar-plane image analysis” (1985)
So what?

- Today, *handheld* autostereo makes sense.
- Today, autostereo on the desktop, living room, and cinema is not yet widely believed to have been “solved.”
- You ought to focus just as much on the software dev’t, for (1) calibrating your display, and (2) making a “whole product”
- Depending on your “image source bias,” progress limited by:
  - **Flat-panel backplane?** Resolution in pixels/mm & lenslet quality
  - **Projection?** SLM resolution and frame rate, and beam-steering

“It is not advisable, James, to venture unsolicited opinions. You should spare yourself the embarrassing discovery of their exact value to your listener.” (Ayn Rand, *Atlas Shrugged*)

Thank You!

**Gregg Favalora – Optics for Hire**
gregg [at] opticsforhire.com

Want to learn more?

E-mail me, and introduce yourself.

Attend [www.stereoscopic.org](http://www.stereoscopic.org) (SPIE-IS&T Stereoscopic Displays & Applications) and SMPTE’s Conference on Stereoscopic 3D (June, NYC)


SPIE MS 162: *Three-Dimensional Displays* (Benton)

SPIE SD&A 20-yr Anniv. DVD - [http://stereoscopic.org/proc/index.html#dvd](http://stereoscopic.org/proc/index.html#dvd)
Q & A

Gregg Favalora
Principal
Optics for Hire

Joel E. Welch

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Autostereoscopic Displays

Recommended reading on particular topics as mentioned in SMPTE PDA

Gregg Favalora, Optics for Hire
Autostereoscopic Displays

Recommended reading on particular topics as mentioned in SMPTE PDA

Introductory Materials - Start here if you’re new to the field


T. Okoshi, Three-Dimensional Imaging Techniques, Academic Press (1976). (This is out-of-print, but worth waiting for. Some online book retailers will put you on a waiting list and alert you when they locate a discarded copy.)


Entrepreneurship (High-tech)


Spatial Vision


Spatially-multiplexed displays: analytical papers


Burckhardt, "Optimum parameters and resolution limitation of integral photography," J. OSA 58(1) 71-76 (Jan 1968).

**Parallax Barrier Displays**


**Integral Imaging / Integral Photography**


**Lenticular Displays**


**Volumetric Displays**


**Re-imaging optics**


**Specular and Cinema displays**


**Tabletop / Conference Room Displays**

Directional Backlights and Wedge Displays


M. Sykora, J. Schultz, and R. Brott, "Optical characterization of autostereoscopic 3D displays," Proc. SPIE 7863, 78630V (2011). (This is the paper from 3M about how they QC their alternating autostereo displays.)


Holographic Display


**Software for Multiview / Lightfield / Holographic Displays**

W. Chun and O. S. Cossairt, "Data processing for three-dimensional displays," U.S. Pat. 7,525,541.


**Ray Space / EPIs**


GREGG FAVALORA (Arlington, MA)

gregg@opticsforhire.com

If that doesn't work: gregg.favalora.sy.96@aya.yale.edu