NEW TECHNIQUES IN HIGH-DEFINITION COMPUTER HOLOGRAPHY

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Outline

- Background: High-definition computer-generated holograms (HD-CGH)
- Several techniques developed after the last meeting, ISDH2012
  - The switch-back technique for occlusion processing
  - Techniques for reduction of memory usage in calculation of HD-CGHs
  - High-definition Color CGH
- Kandai Digital Holo-Studio (Printing service of HD-CGH for research and creating artworks)
High-Definition Computer-Generated Holograms

- More than billion pixels
- Viewing angle of 45° in horizontal and vertical (full-parallax)
- Strong sensation of depth
- Natural and continuous motion parallax
- Calculation by the polygon-based method
- Print by laser writer & lithography

The Venus
4 G Pix (64K × 64K)

The Metal Venus I
8 G Pix (128K × 64K)

The Metal Venus II
4 G Pix (64K × 64K)

Bear II
4 G Pix (64K × 64K)

Five Ring
4 G Pix (64K × 64K)
Brothers exhibited in MIT museum

Exhibition of Brothers

Brothers is on display at MIT museum up to March 2015 at least.

Brothers, 2012
25 G pix (196,608 x 131,072)
A fast and powerful technique for occlusion processing

THE SWITCH-BACK TECHNIQUE
Object-by-Object (O-O) silhouette light-shielding

Wave field

Hologram
Drawback of object-by-object shielding

- If the object have self-occlusion, there may be see-through portion. In this case, viewer may see partial phantom image.
- Object-by-object shielding cannot be applied to complicated-shape objects. This problem is resolved by shielding polygon-by-polygon.
Drawback of object-by-object shielding

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- Object-by-object shielding cannot be applied to complicated-shape objects.
- This problem is resolved by shielding polygon-by-polygon.
Polygon-by-polygon (P-P) light-shielding

Propagation

\[ u_{m+1}(x, y) = \mathbf{P}_{m+1,m} \{ M_m(x, y) u_m(x, y) + O_m(x, y) \} \]

- \( A_{\text{silhouette}} \): Area of silhouette
- \( A_{\text{field}} \): Area of wave field

\[
\text{Filling ratio } = \frac{A_{\text{silhouette}}}{A_{\text{field}}}
\]

<table>
<thead>
<tr>
<th>Shielding unit</th>
<th>Number of masks</th>
<th>Size of silhouette (Filling ratio)</th>
<th>Distance between silhouettes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object-by-object</td>
<td>1~10</td>
<td>Large (10~80%)</td>
<td>Long</td>
</tr>
<tr>
<td>Polygon-by-polygon</td>
<td>100~100,000</td>
<td>Very small (0.01~10%)</td>
<td>Short</td>
</tr>
</tbody>
</table>
Babinet's low

Silhouette mask

Propagation $\times 2$

$z_{n-1}$ $z_n$ $z_{n+1}$

Silhouette aperture

$A_n(x, y) = 1 - M_n(x, y)$

Propagation $\times 3$
Babinet's law

Silhouette mask

Propagation $\times 2$

Silhouette aperture

$A_n(x, y) = 1 - M_n(x, y)$

Propagation $\times 3$
Babinet's low

Silhouette mask

Propagation $\times 2$

Silhouette aperture

$A_n(x, y) = 1 - M_n(x, y)$

Propagation $\times 3$
Advantage of silhouette aperture

- In silhouette-mask cases, the whole object field must be propagated to the next plane.
- In silhouette-aperture cases, only a small part of the field must be propagated to the next plane.
- Number of samplings can be reduced by using apertures instead of masks.
Advantage of silhouette aperture

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Two types of procedure

Procedure (I)

(i) Forward propagation

Subtraction

(ii) Forward propagation

(iii) Masking & Forward propagation
Two types of procedure

Procedure (I):
(i) Forward propagation
(ii) Forward propagation
(iii) Masking & Forward propagation

Procedure (II):
(i) Forward propagation
(ii) Backward propagation

Subtraction
Procedure for processing multiple-polygons

Object plane

Wave field for polygons 0 to n - 1

Polygons 0 to n - 1
Procedure for processing multiple-polygons

- Object plane
- Wave field for polygons 0 to \( n - 1 \)
- Polygons 0 to \( n - 1 \)
- Polygon \( n \)
- Additional polygon \( n \)
Procedure for processing multiple-polygons

Object plane
Wave field for polygons 0 to \( n - 1 \)

Polygons 0 to \( n - 1 \)
Additional polygon \( n \)
Polygon \( n \)
Procedure for processing multiple-polygons

Polygons 0 to \( n-1 \)

Object plane

Wave field for polygons 0 to \( n-1 \)

Additional polygon \( n \)
Procedure for processing multiple-polygons

- Polygons 0 to n-1
- Polygon n
- Additional polygon n

Object plane
- Wave field for polygons 0 to n-1
- Subtraction
- Wave field for polygon 0 to n
Procedure for processing multiple-polygons

- Polygons 0 to \( n-1 \)
- Polygon
- Additional polygon \( n \)
- Additional Polygon \( n+1 \)
- Object plane
- Wave field for polygons 0 to \( n-1 \)
- Subtraction
- Wave field for polygon 0 to \( n \)
The switch-back technique

\( u_n(x, y) = P_{n, \text{obj}} \{ u_n^{\text{obj}}(x, y) \} \)

Backward propagation from object plane to plane \( n \)

\( u_{n+1}^{\text{obj}}(x, y) = u_n^{\text{obj}}(x, y) + P_{\text{obj}, n} \{ O_n(x, y) - A_n(x, y) u_n(x, y) \} \)

Forward propagation from plane \( n \) to object plane

Accumulated field from plane 0 to \( n \)

Object plane
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Forward propagation from plane \( n \) to object plane

Accumulated field from plane 0 to \( n \)

Object plane
The switch-back technique

\[ u_n(x, y) = P_{n, obj} \{ u_n^{obj}(x, y) \}, \]

Backward propagation from object plane to plane \( n \)

\[ u_{n+1}^{obj}(x, y) = u_n^{obj}(x, y) + P_{obj, n} \{ O_n(x, y) - A_n(x, y)u_n(x, y) \}, \]

Forward propagation from plane \( n \) to object plane

The procedure is called switch-back technique, because field is propagated back and forth.

Accumulated field from plane 0 to \( n \)

Object plane
Measurement of performance

Object planes

Hologram

5000 Polygon

Units: mm

90

52

52

Five Ring

Model | No. of pixels
--- | ---
Full-size | 64K x 64K (4.3 x 10^9)
1/32 scale | 2K x 2K (4.2 x 10^6)

Indicated sizes are of the full-size model.

Pixel pitch: 0.8 µm x 0.8 µm

Wavelength: 633 nm

1K = 1024

This CGH is on display in the back of this room
Speedup by splitting object

- Switch back technique works better when the object depth is smaller, because polygons are located close to the object plane.
- Splitting the object definitely reduce the computation time.
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Measured computation time

High-definition CGH (64Kx64K)

- Xeon X5675 3.07GHz
- Numerical propagation
- Polygon field computation

- 64Kx64K: 1.70 hours

Electro-Holography (2Kx2K)

- i7-3930K 3.20GHz
- Numerical propagation
- Polygon field computation

- 2Kx2K: 4.5 seconds
Measured computation time

High-definition CGH (64Kx64K)
- Xeon X5675 3.07GHz
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Electro-Holography (2Kx2K)
- i7-3930K 3.20GHz
- Numerical propagation
- Polygon field computation

(a) 64Kx64K
(b) 2Kx2K

Number of sub-objects

64Kx64K: 1.70 [h]
2Kx2K: 4.5 [s]
Simple transformation of CG model to CGH by *Switch-Back technique*

- Switch back technique make it possible to compute the field of very complex models and simply convert the model to CGH.

Simple transformation of CG model to CGH by **Switch-Back technique**

- Switch back technique makes it possible to compute the field of very complex models and simply convert the model to CGH.

Optical reconstruction by white light

- No wavelength-selectivity unlike traditional volume-type holograms.
- Rainbow-like images
  - The size of the reconstructed image changes dependently on illuminated wavelength.
Techniques for full-color reconstruction

- Dichroic mirror
  - B
  - G
  - R
  - Illumination

- Color filter
  - RGB

- Layered dichroic fringe
  - Illumination
  - RGB

- Time-division display
  - Switching colors
  - RGB
Full-color reconstruction using dichroic mirrors

- White light branches into RGB illumination by dichroic mirrors
- Reconstructed lights reversely travel along the illumination path and are combined by dichroic mirrors
Full-color reconstruction using dichroic mirror

- Very good optical reconstruction
- No portability
- Optical system for superposition is complicated, heavy and expensive.
Full-color reconstruction using color filter

- Red CGH
- Green CGH
- Blue CGH

Partial fringe pattern

- Single plate hologram
- RGB fringes are split into many blocks.
- RGB color filters cover up the corresponding fringe blocks.
Full-color reconstruction using color filter

- Red CGH
- Green CGH
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Full-color reconstruction using color filter

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Full-color reconstruction using color filter

Red CGH  Green CGH  Blue CGH

Partial fringe pattern

White light Illumination

RGB fringes are split into many blocks.
RGB color filters cover up the corresponding fringe blocks.
Example of full-color CGH using color filter

- Dark reconstructed image
- Difficulty in accurate positioning of filter with fringe block
- Double filtering in case of reflection reconstruction
HD-CGH printing service for research and creating artwork

KANDAI DIGITAL
HOLO-STUDIO
Invitation to joint research and creation

- Difficulty in studying techniques and creating artwork in computer holoography
  - No way to fabricate high-definition CGHs and view the optical reconstruction
- Fund from Japanese government and Kansai University
  - Establishment of Kandai Digital Holo-Studio equipped with newest model of laser writer (DWL66+)
- We provide the method for fabricating HD-CGHs with joint research.
Facility provided for joint research

Contact: matsu@kansai-u.ac.jp

<table>
<thead>
<tr>
<th>Laser writer</th>
<th>Model</th>
<th>Heidelberg Instruments DWL 66+</th>
</tr>
</thead>
<tbody>
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<td>Maximum drawing area [mm²]</td>
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<td>200 × 200</td>
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<tr>
<td>Minimum address grid [nm]</td>
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<tr>
<td>Alignment accuracy [nm]</td>
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<td>Minimum structure size [μm]</td>
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<td>Write speed [mm²/min]</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
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Facility provided for joint research

Printing is free of charge
You must provide fringe pattern generated by yourself

**Laser writer**

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Summary

- Formulation and improvement of the switch-back technique for fast occlusion processing.
  - The switch-back technique calculates 64Kx64K HD-CGH less than 2 hour and 2Kx2K CGH less than 5 second.
  - We can calculate any CGH for any complicated object by using the switch-back technique.
  - Some new HD-CGHs created by the switch-back technique are on display in the back of this room.

- Attempt to full-color reconstruction of HD-CGH
  - Unfortunately, portability and stability or brightness are not enough for practical exhibition at this stage.
  - We are still working on this subject.

- Establishment of Kandai Digital Holo-Studio
Thank you!
(Sorry for poor English)

Ask me question later!

Prof. Sumio NAKAHARA