Single lens dual-aperture 3D imaging and the color remapping

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Outline

• Advantages in single lens dual-aperture 3D imaging
• Switching viewpoints through complementary bandpass Filters
• Problems in color mismatching
• Mitigation through color remapping
• 3-mm lens dual-aperture 3D camera
Motivation

SBI_vid1.mp4

<table>
<thead>
<tr>
<th></th>
<th>Open Surgery</th>
<th>Minimally Invasive Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical Opening</td>
<td><strong>Large</strong> – Segment of skull</td>
<td><strong>Small</strong> – Keyhole opening (endoscope 4 mm O.D.)</td>
</tr>
<tr>
<td>Patient recovery</td>
<td><strong>Lengthy</strong> – weeks</td>
<td><strong>Short</strong> – a few days</td>
</tr>
<tr>
<td>Visual feedbacks</td>
<td><strong>Strong</strong> – Full binocular vision, auditory, and haptic sensory</td>
<td><strong>Weak</strong> – Dependence on 2D endoscope and remote tools with limited feedback</td>
</tr>
</tbody>
</table>
Objectives

• Build a 3D camera that:
  – Provides high definition, real-time, binocular (left- and right-viewpoint), images
  – Has dimensions no bigger than 4-mm in diameter.

• Examples close to the dimensions:
  Distal camera borescopes and endoscopes
## Comparisons

<table>
<thead>
<tr>
<th>Two-camera 3D</th>
<th>Dual-aperture 3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two sets of objective lenses</td>
<td>Single objective lens (Simpler fabrication)</td>
</tr>
<tr>
<td>Two focal planes</td>
<td>One focal plane (High definition at the FPA)</td>
</tr>
<tr>
<td>Parallel viewpoints</td>
<td>Natural vergence</td>
</tr>
</tbody>
</table>

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Past work to open half-apertures

<table>
<thead>
<tr>
<th>Mechanisms</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical shutter</td>
<td>Complete open/block</td>
<td>Bulk, not instantaneous</td>
</tr>
<tr>
<td>Liquid crystal block</td>
<td>Fast switching</td>
<td>Incomplete open/block</td>
</tr>
<tr>
<td>Orthogonal polarizer pair</td>
<td>Passive</td>
<td>Light randomization</td>
</tr>
<tr>
<td>Complementary filter pair</td>
<td>Passive</td>
<td>Monochromatic images</td>
</tr>
</tbody>
</table>

- Some of these require an extra space for the installation
- Some still have a problem with crosstalk between two channels
Complementary Multiband Bandpass Filters

<table>
<thead>
<tr>
<th>Past work</th>
<th>Proposed work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single band bandpass filters</td>
<td>Multi-band bandpass filters</td>
</tr>
<tr>
<td>2 spectral light source</td>
<td>6 spectral light sources</td>
</tr>
<tr>
<td>Single band spectral image</td>
<td>RGB color expression</td>
</tr>
</tbody>
</table>

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Problems

• Color rivalry (1-3)
  – Def.: two different colors competing in our brain when each presented to the eye.
  – The missing spectral bands creates the color difference between the two binocular images

Mitigations

• Use bandpass containing more passbands
• Remap the colors, using Image processing

Spectral transmission of the dual-band bandbass filters under Xe lamp
After remapping to look without the filters

Without the filters, under Xe lamp

Raw image through blue bias filter

Remapped

Raw image through red biased filter

Remapped
Remapped to look under daylight

Simulated image under daylight

Remapped blue biased image

Remapped red biased image
Dual-band results

<table>
<thead>
<tr>
<th></th>
<th>$\Delta E$ Lab raw</th>
<th>$\Delta E$ remap to D65</th>
<th>$\Delta E$ remap to Xe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color diff.</td>
<td>46±25</td>
<td>25±14</td>
<td>23±14</td>
</tr>
</tbody>
</table>

Simulation results

<table>
<thead>
<tr>
<th>Complementary filter pairs</th>
<th>$\Delta E$ raw</th>
<th>$\Delta E$ of remapped values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-band</td>
<td>82</td>
<td>48</td>
</tr>
<tr>
<td>Triple-band</td>
<td>163</td>
<td>43</td>
</tr>
<tr>
<td>Quadruple-band</td>
<td>57</td>
<td>19</td>
</tr>
</tbody>
</table>

More the passbands that each filter has, smaller the color difference between the two channels

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First generation CMBF 3D system

25-mm lens monochromatic camera, half-moon shape CMBFs, 6 multispectral images combined to produce a 3D

Half-moon shape CMBF

A ring light connected to a tunable filter

Lens system, two achromats + CMBF

Overall system
Current prototype

3-mm lens color camera, 9.35-mm overall Dia., custom fabricated CMBF, 2 multispectral images combined to produce 3D

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Summary

• The dual-aperture has advantage in providing natural vergence and miniaturization
• Complementary bandpass filters (CBF) were used for opening the dual-aperture alternately
• The CBF results in producing unwanted color rivalry
• This was mitigated through using a simple remapping
• The dual-aperture concept was applied to building a 3D camera with 3-mm lens elements along with the remapping
Acknowledgement

• I’d like to thank Dr. Shahinian and Skull Base Institute for sponsoring the project.
• I’d like to thank my supervisor Harish Manohara for his advice and administration.
• I’d like to thank Professor Harold Monbouquette for his guidance in my PhD pursuit with this project
Back up slides
Dual-aperture Concept

• Disparity created by apertures offset from the optical axis:

\[
\frac{1}{d} = \frac{h}{v} \left( \frac{1}{F} - \frac{1}{D} \right) + \frac{1}{D}
\]

Where \( F \) & \( D \) and \( d \) & \( g \) are pairs of conjugate planes

• Needs a mechanism to open/close half-apertures

*Adelson EH and Wang JYA, 1992
Past work using the color filters

- Amari used Red/green dual aperture and white light to estimate depths (1)
- Koh used Red/blue dual aperture and white light (2)
- Chen used RGB tri-aperture and white light (3)
- Bando used RGB tri-aperture and white light (4)

Dual-aperture 3D camera

Open halves of the aperture one at a time

- Two viewpoints are created in a single objective lens camera
  - Uses a single image plane. High definition.
  - Built-in vergence when focused. Natural binocular vision.
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<th>$\Delta E_{\text{remap to D65}}$</th>
<th>$\Delta E_{\text{remap to Xe}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe and D65</td>
<td>37±14</td>
<td>23±9</td>
<td></td>
</tr>
<tr>
<td>Blue and Dest.</td>
<td>29±12</td>
<td>20±8</td>
<td>18±11</td>
</tr>
<tr>
<td>Red and Dest.</td>
<td>53±18</td>
<td>24±14</td>
<td>25±13</td>
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