Single-shot Multidomain Camera

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Background

- Megapixel race has resulted in an excess of pixels
- Other types of useful information that a camera can capture:
  - Multispectral
  - Polarization
  - High Dynamic Range

Can all of this be captured in a single image?
Background

- Presented with a dimensionality mismatch during multidimensional information capture:

  7D
  4D light field
  Temporal
  Spectral
  Polarization

  ▪ There are many different methods of encoding/decoding spectral and polarimetric information

  ▪ One of the most direct methods is through the temporal domain

  ▪ Full 2D spatial resolution preserved at the expense of time response

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Below are some images for reference:

- Kinemacolor [7]
  Images: public domain

- Image removed due to copyright restrictions. See reference [8].

- Pushbroom Hyperspectral [8]
Background

- There are many spatial encoding/decoding schemes:

  1. **At the focal plane:**
     - **Tradeoffs:** Fixed, Integration
     - **Images removed due to copyright restrictions.**

  2. **Multi-aperture:**
     - **Tradeoffs:** Registration, Alignment
     - **Images removed due to copyright restrictions.**

  3. **Code-division multiplexing:**
     - **Tradeoffs:** Computation, SNR
     - **Images removed due to copyright restrictions.**

- Reduced spatial resolution $\propto$ number of samples
Background

- Basic idea of a light field camera:

Sensor integrates over all rays originating from a particular object point
Background

• Basic idea of a light field camera:

- Misfocus reintroduces \((u,v)\) info, but it is not distinguishable from structure of light from object
Our Approach:

- Encode over ray angle (spatial frequency variable)
- Basic idea of a light field camera:

  - Pinhole is imaging pupil plane, providing \((u,v)\) angular info
  - Used for depth (Adelson and Wang [16]), refocusability (Ng et al. [17]) glare removal (Raskar et al. [18])
Our Approach

- Place a filter array in the camera’s pupil plane:

- Now, each pinhole at a particular \((s,t)\) creates an image of the filter array in the \((u,v)\) plane
Our Approach

- Color information (e.g.) is available at each spatial location in \((s, t)\) from each filter array image
- Spatial resolution from # pinholes, filter resolution from # filters
Camera Design

- A conventional setup sets P and Q:
  \[ P' \approx 50 \text{ mm} \quad \text{(standard lens)} \]
  \[ Q = 1.14 \text{mm} \quad \text{(cover glass)} \]

\[
\begin{array}{c|c|c|c|c|c}
S & R & F & M_2 & W \\
25.32\mu & 38.83\mu & 1.51\text{mm} & 1.15 & 3.61\text{cm}
\end{array}
\]

- Tradeoff between synthesized image resolution and number of filters similar to \((u,v)\) and \((s,t)\) tradeoff in refocusing light field systems

- Pinholes = optics-limited \((R > \text{pixel size})\)
Image Reconstruction Process

(Portion of) raw image roughly resembles scene

Close up, images of filter array apparent (3x3 square array)

Combine similarly filtered areas from every pinhole

Filtered Synthetic Images
Camera Setup

- Use conventional Nikon 50mm f/1.8 lens, 10Mpix 9µ CCD
- Pinhole arrays printed on transparencies, varying size + pitch
- Filters cut and arranged on laser-cut plastic holders, placed inside lens over aperture stop

Experimental Results

- **Six filters:** R, G, B, 0°, 45°, 90° (pinhole r = 25µ, pitch = 200µ)
Experimental Results

- Sixteen filters:

<table>
<thead>
<tr>
<th>Angle</th>
<th>B</th>
<th>G</th>
<th>M</th>
<th>C</th>
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<tbody>
<tr>
<td>0°</td>
<td>R</td>
<td>No Filter</td>
<td>Y</td>
<td>IR</td>
</tr>
<tr>
<td>45°</td>
<td>RC</td>
<td>0.4</td>
<td>0.6</td>
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<td>135°</td>
<td>90°</td>
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</table>

Experimental Results

- An example of foveation

- A total of 12 filters used to create color image, extend dynamic range, and find “regions of interest”

- Error associated with low pixel values, angular diversity of compared images

Experimental Results

- An example of spectral imaging

- With Spectral filter in aperture, have roughly 25 spectral channels per pixel

Another example: Changing the lighting causes a shift in spectrum:

References

References


