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:

Polarization

Images removed due to copyright restrictions.

See references [1], [2], [3].

[1-3]

Multispectral

Images removed due to copyright restrictions.

See references [4], [5].

[4,5]

High Dynamic Range

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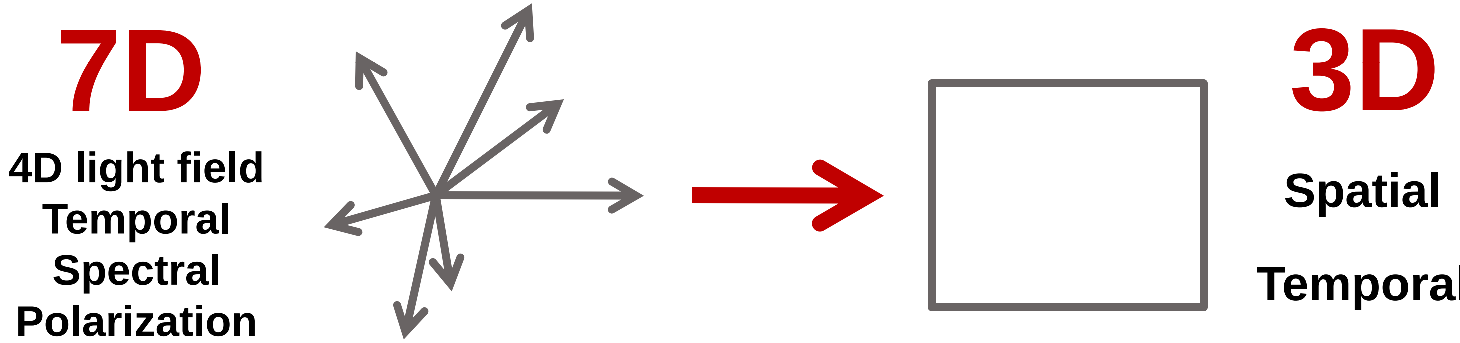
See reference [6].

[6]

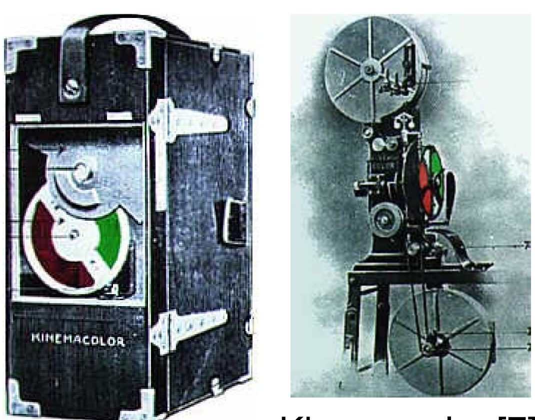
- **Can all of this be captured in a single image?**

Background

- Presented with a dimensionality mismatch during multidimensional information capture:



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



Kinemacolor [7]
Images: public domain

- One of the most direct methods is through the temporal domain
- Full 2D spatial resolution preserved at the expense of time response

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.

Bayer Filter [11] Polarization [10] Assorted Pixels [9]

2. Multi-aperture :

Tradeoffs: Registration, Alignment

Images removed due to copyright restrictions.

PERIODIC [12] TOMBO [13]

3. Code-division multiplexing:

Tradeoffs: Computation, SNR

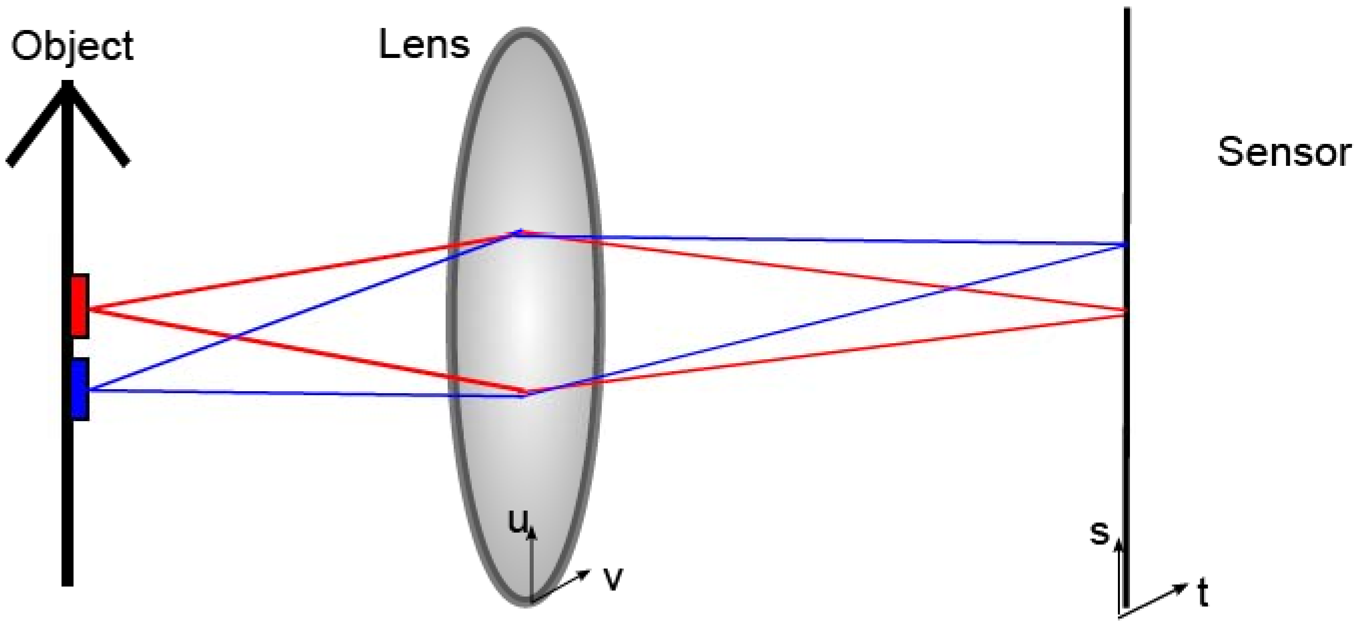
Images removed due to copyright restrictions.

CASSI [14] CTIS [15]

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

Background

- Basic idea of a light field camera:

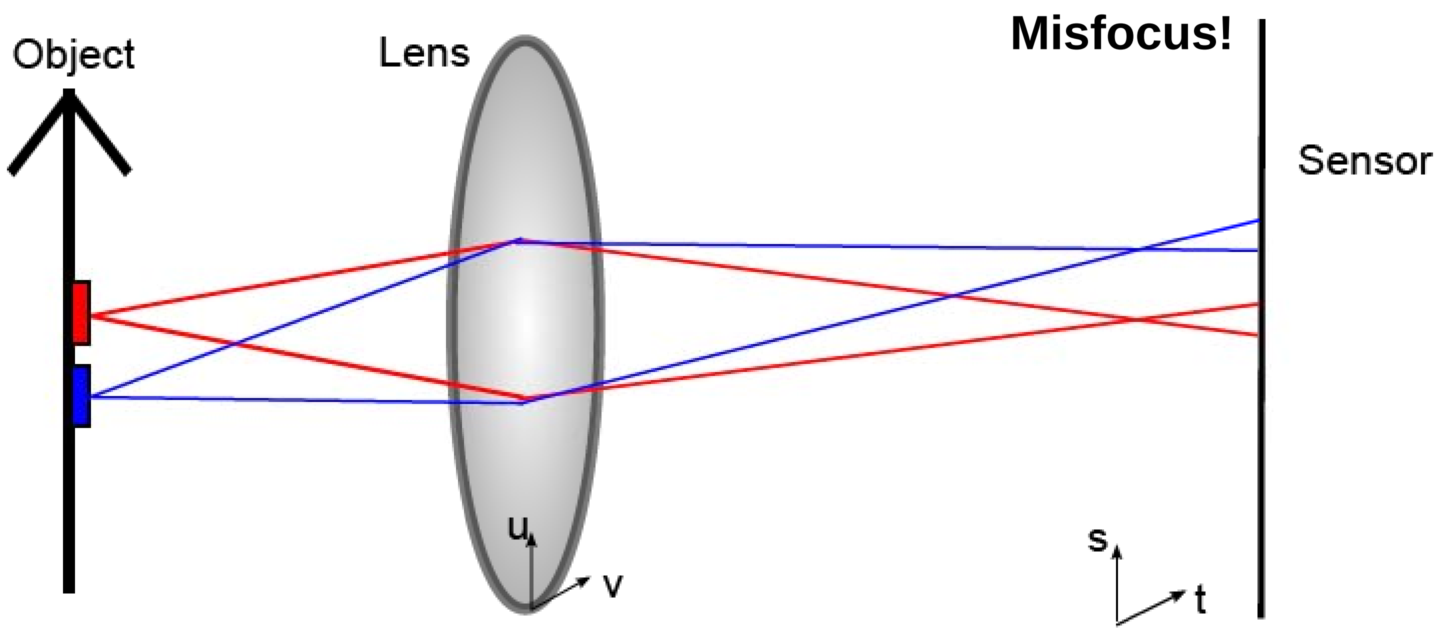


***(s,t)* information only**

- **Sensor integrates over all rays originating from a particular object point**

Background

- Basic idea of a light field camera:

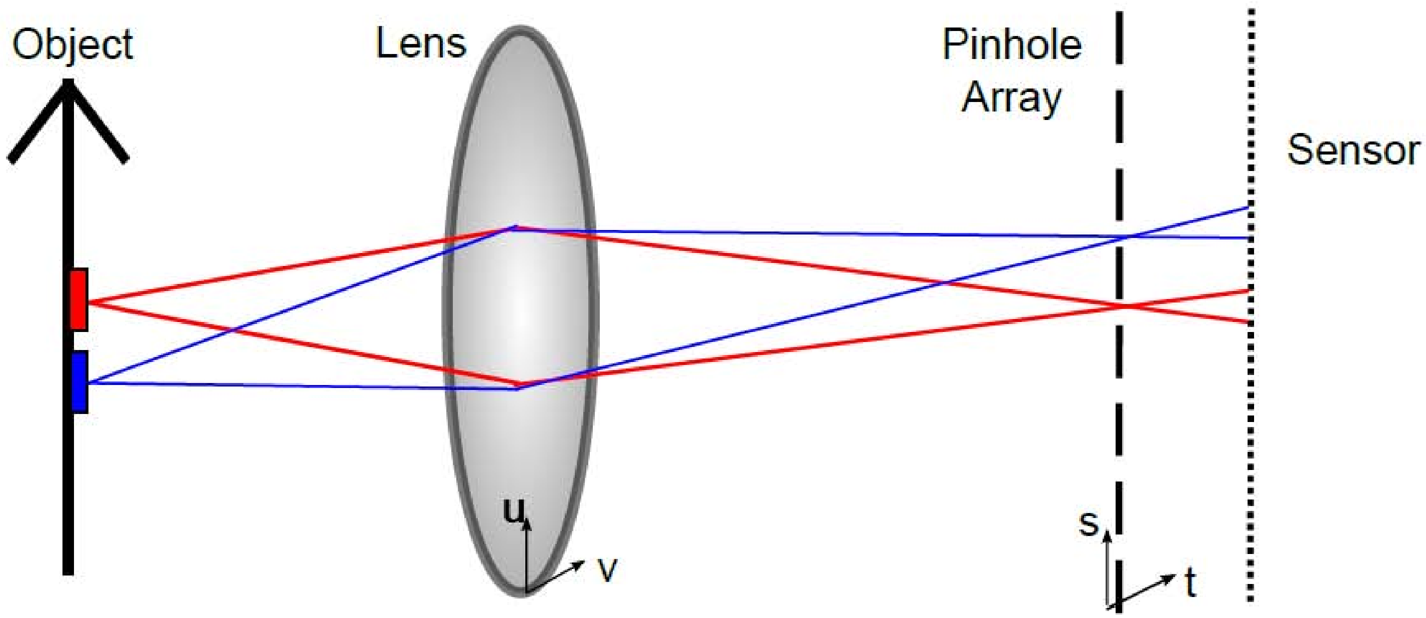


***(s,t)* and *(u,v)* information mixed**

- **Misfocus reintroduces *(u,v)* info, but it is not distinguishable from structure of light from object**

Our Approach:

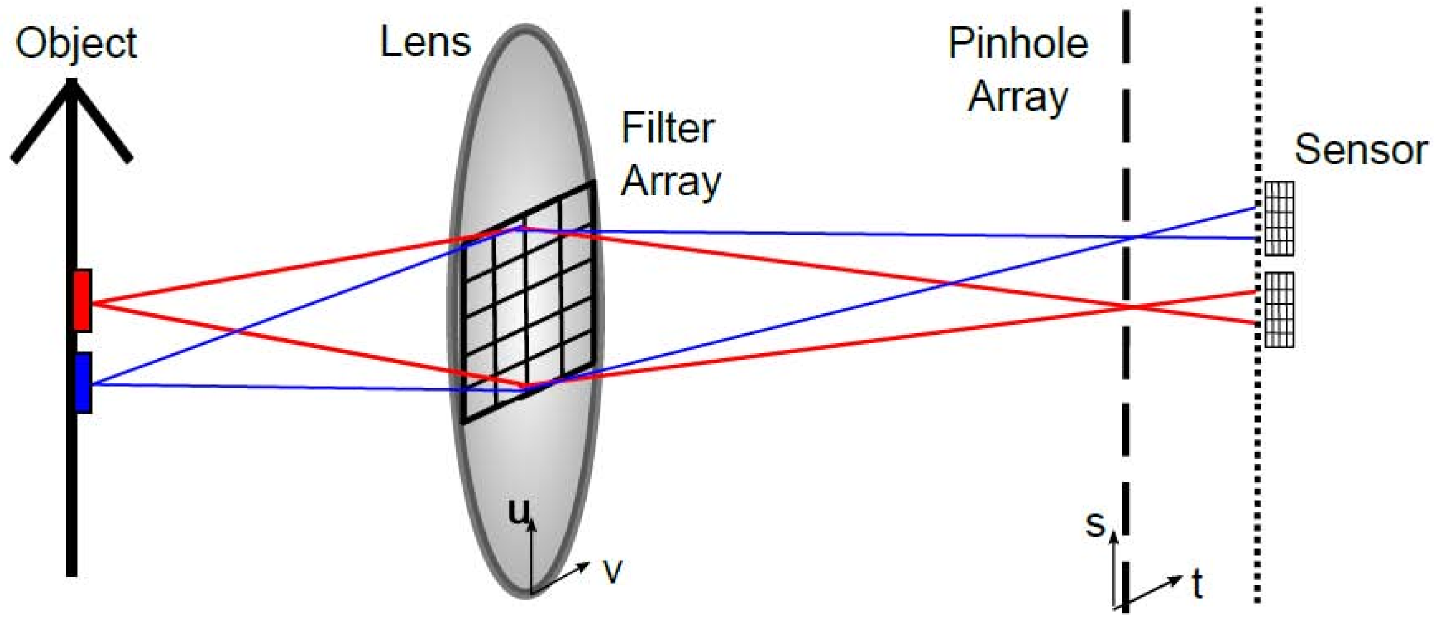
- Encode over ray angle (spatial frequency variable)
- Basic idea of a light field camera:



- **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])**

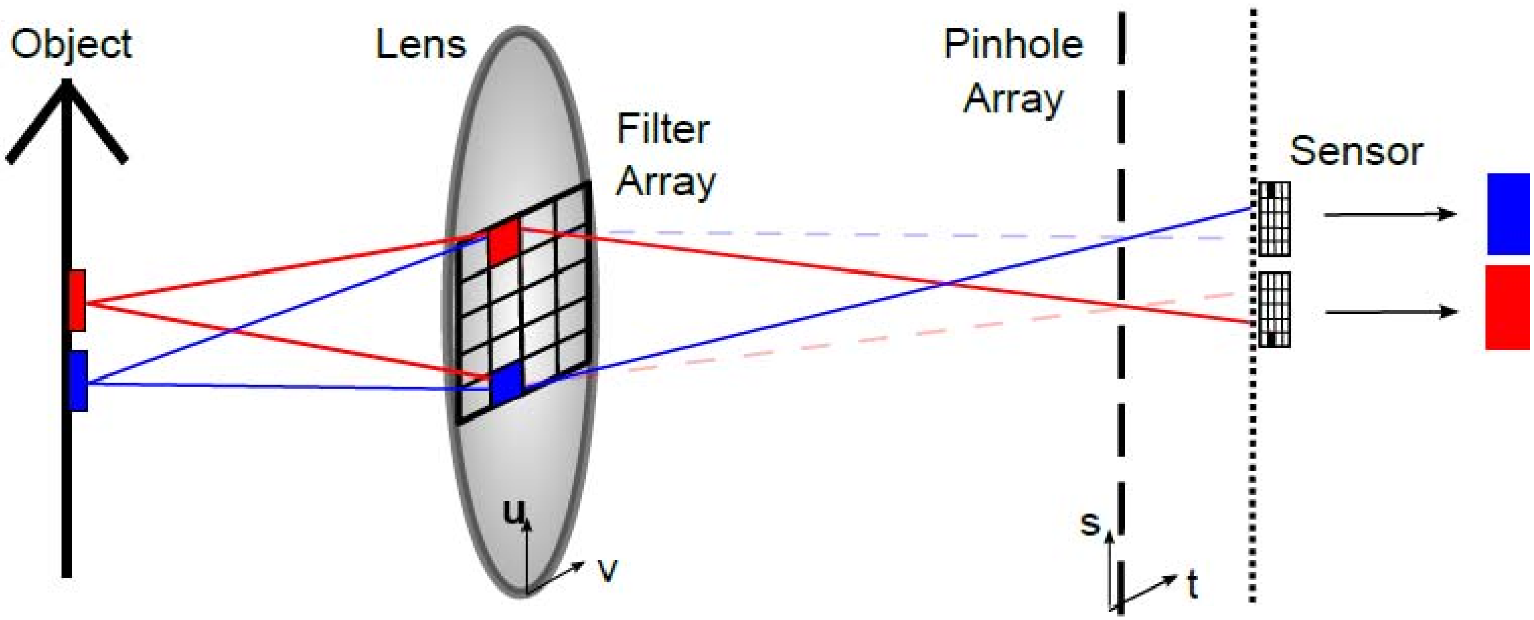
Our Approach

- 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



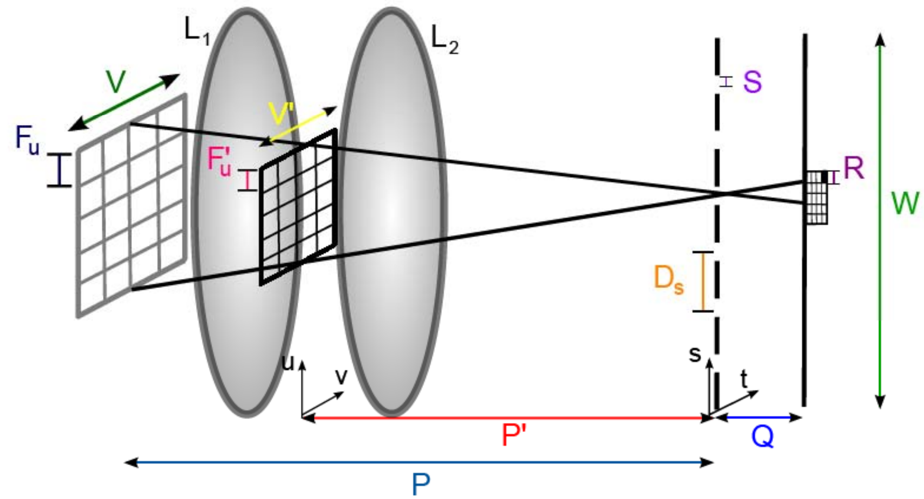
- Color information (e.g.) is available at each spatial location in *(s,t)* from each filter array image
- Spatial resolution from # pinholes, filter resolution from # filters

Camera Design

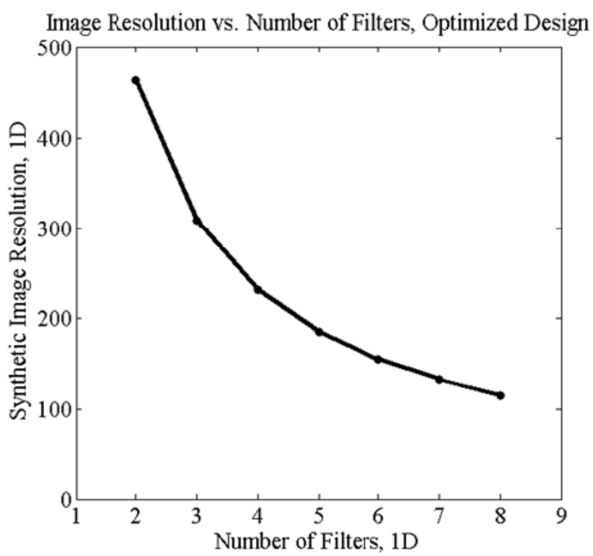
- A conventional setup sets P and Q:

  P′ ≈ 50 mm (standard lens)

  Q = 1.14mm (cover glass)

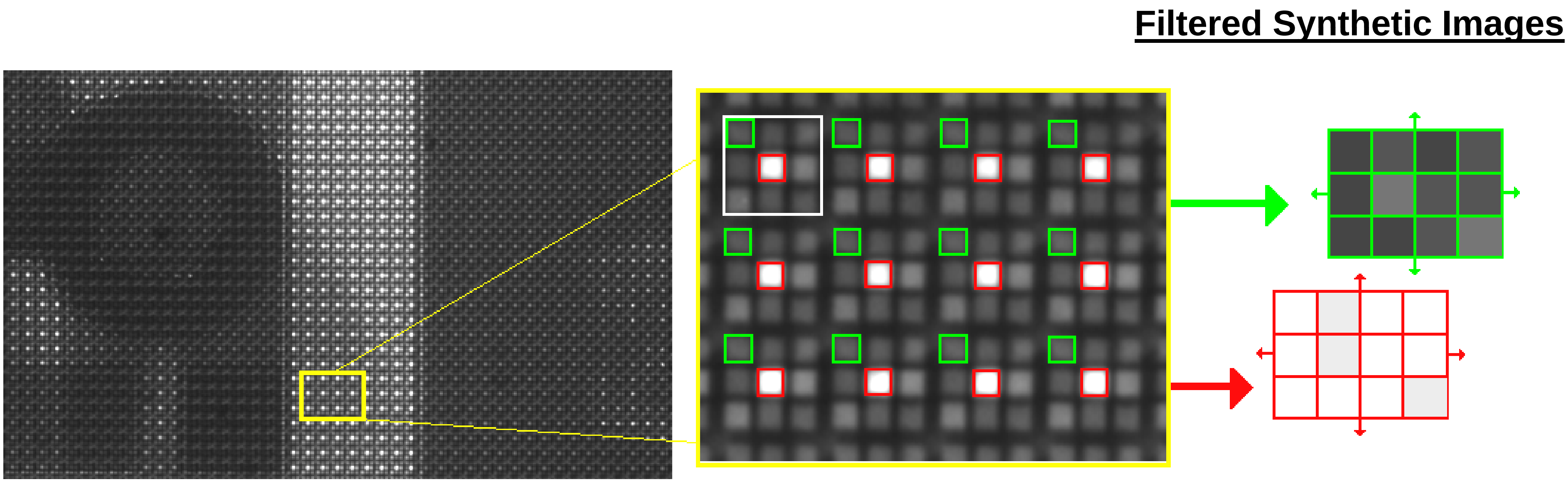


S	R	F	M_2	W
25.32µ	38.83µ	1.51mm	1.15	3.61cm



- **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 > pixel size)***

Image Reconstruction Process



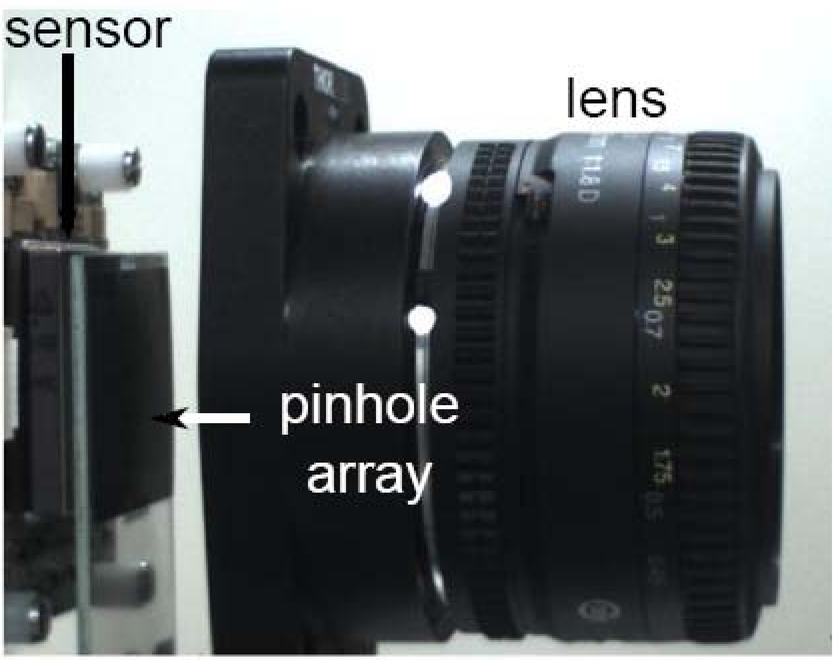
(Portion of) raw image roughly resembles scene

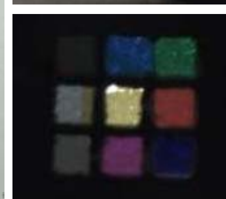
Close up, images of filter array apparent (3x3 square array)

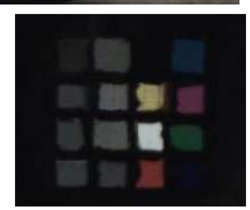
Combine similarly filtered areas from every pinhole

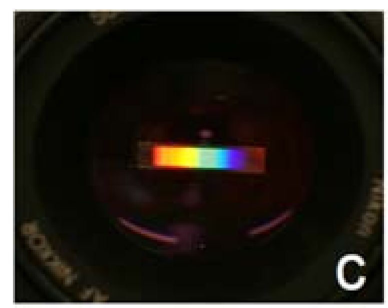
Camera Setup

- 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



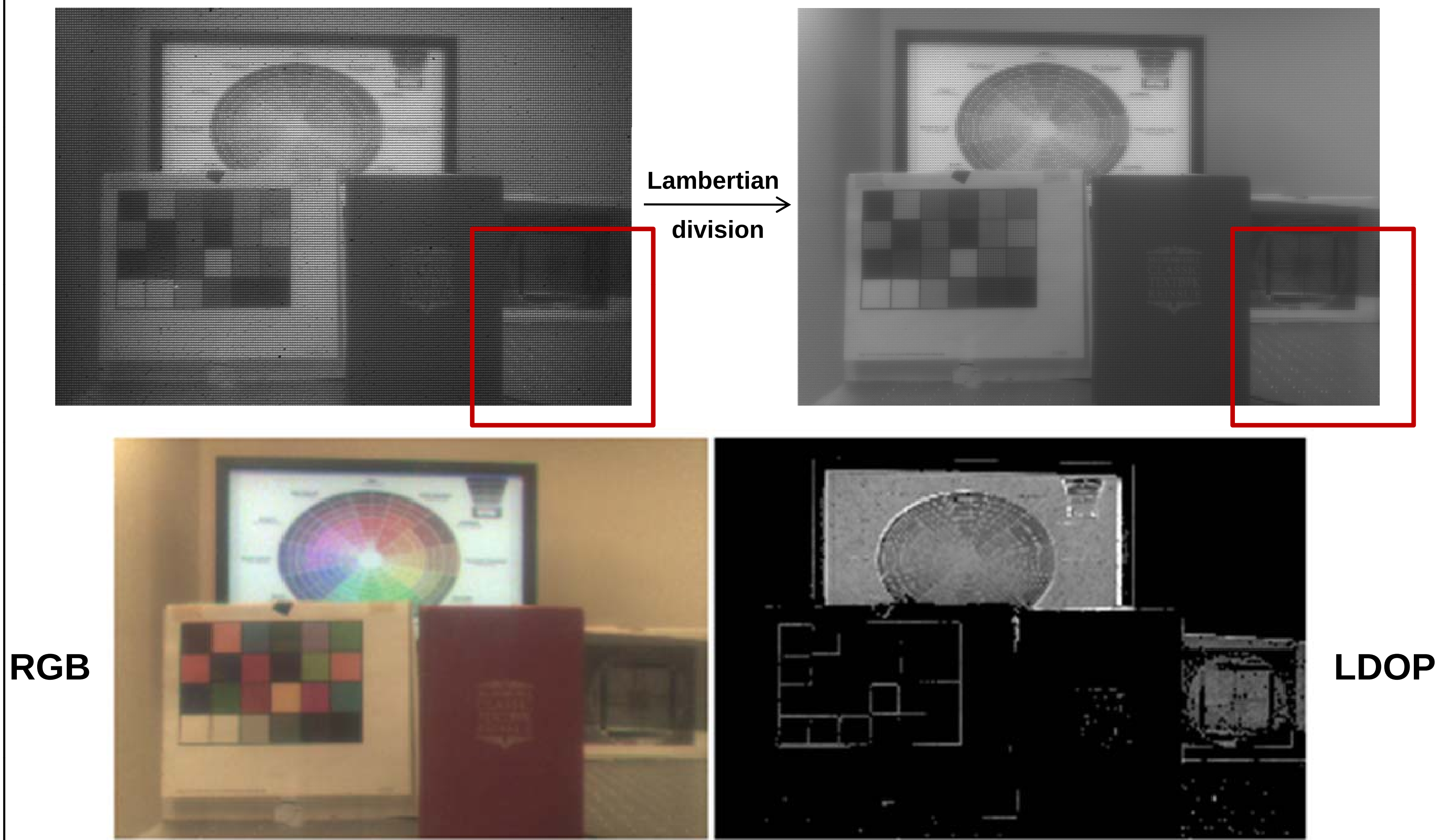






Experimental Results

- <u>Six filters</u>: R, G, B, 0º, 45º, 90º (pinhole r = 25μ, pitch = 200μ)



Experimental Results

layout

B	G	M	C
R	No Filter	Y	IR
0°	RC	0.4	0.6
45°	135°	90°	1

- <u>Sixteen filters</u>:

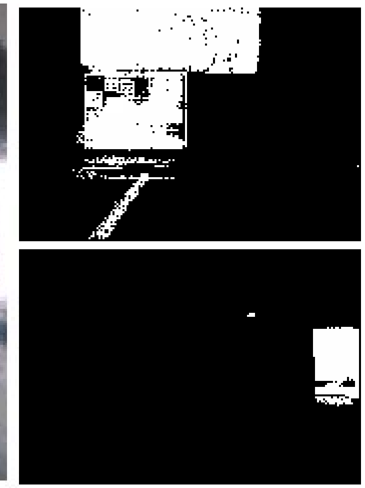
Experimental Results

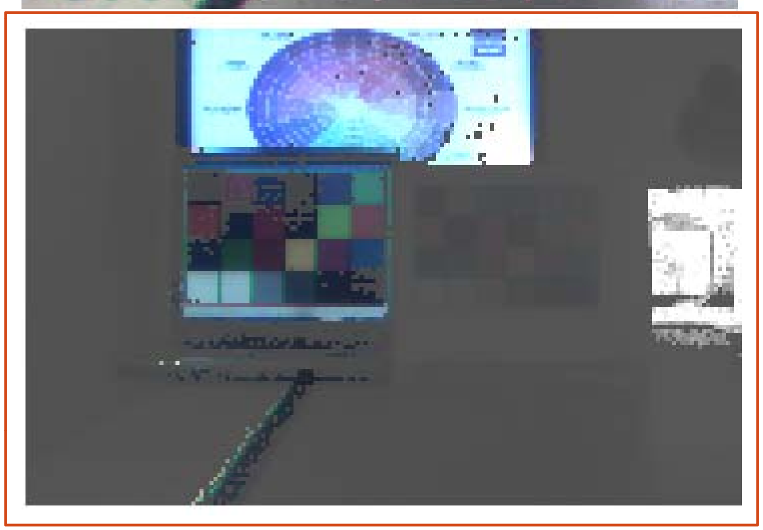
- <u>An example of foveation</u>

RGB

RGB HDR

DOP + NIR





- **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**

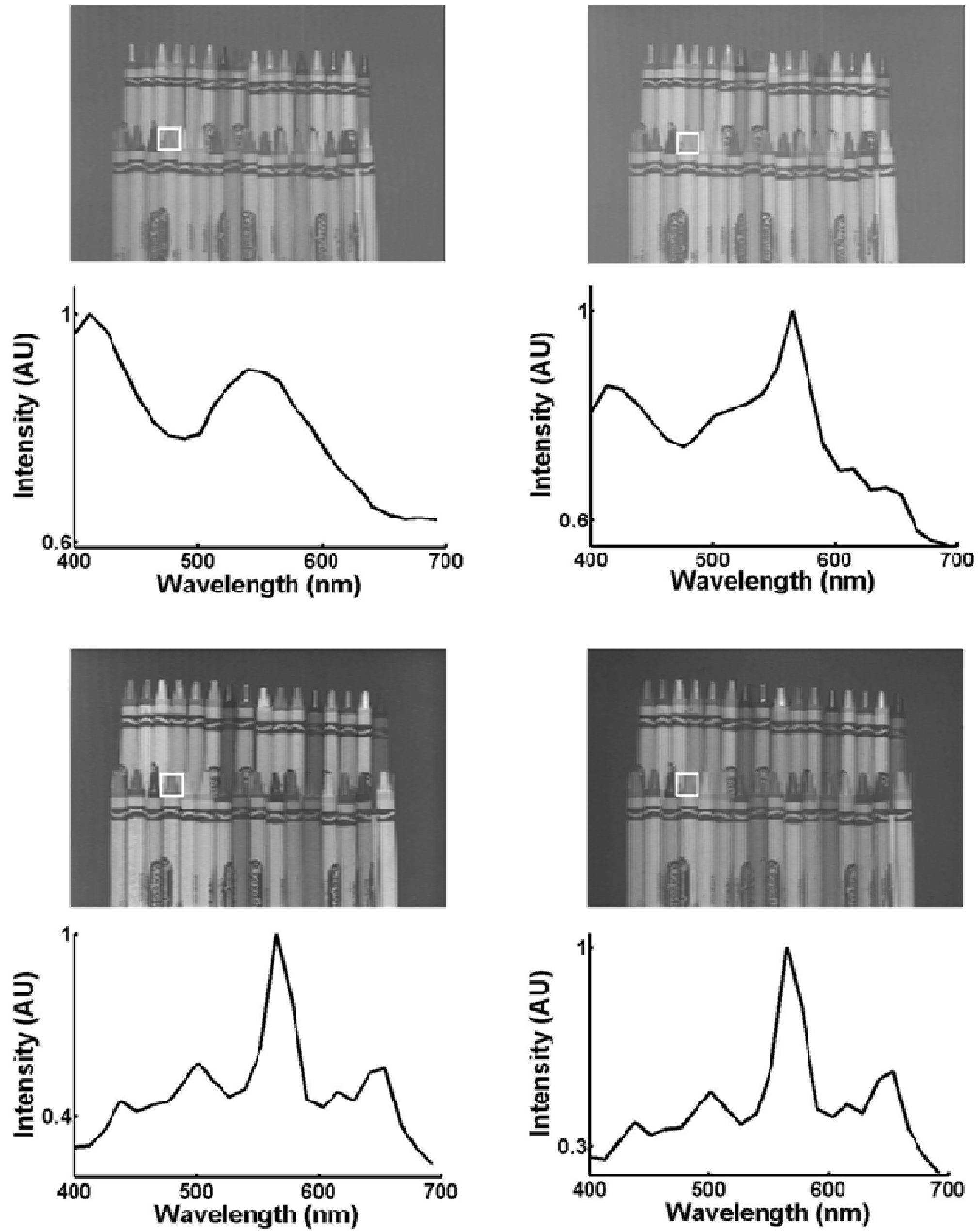
Experimental Results

- <u>An example of spectral imaging</u>

Courtesy of SPIE. Used with permission. Source: Horstemeyer, R., R. A. Athale, and G. Euliss. "Light Field Architecture for Reconfigurable Multimode Imaging." Proc. of SPIE 7468, August 2009. doi: 10.1117/12.828653

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

- <u>Another example:</u> Changing the lighting causes a shift in spectrum:



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