Plenoptic camera and its Applications

Agenda:

1. Introduction
2. Single lens stereo design
3. Plenoptic camera design
4. Depth estimation
5. Synthetic refocusing
6. Fourier slicing
7. References

MO-ISL, CU Boulder – 11/11/2005

Introduction

- What is a plenoptic camera?

  A camera that records information from all possible view points within the lens aperture. plenoptic originates from the roots “complete” and “view”

- Motivation behind the invention:

  Initial motivation was depth estimation
  Applications in synthetic refocusing (recent development)

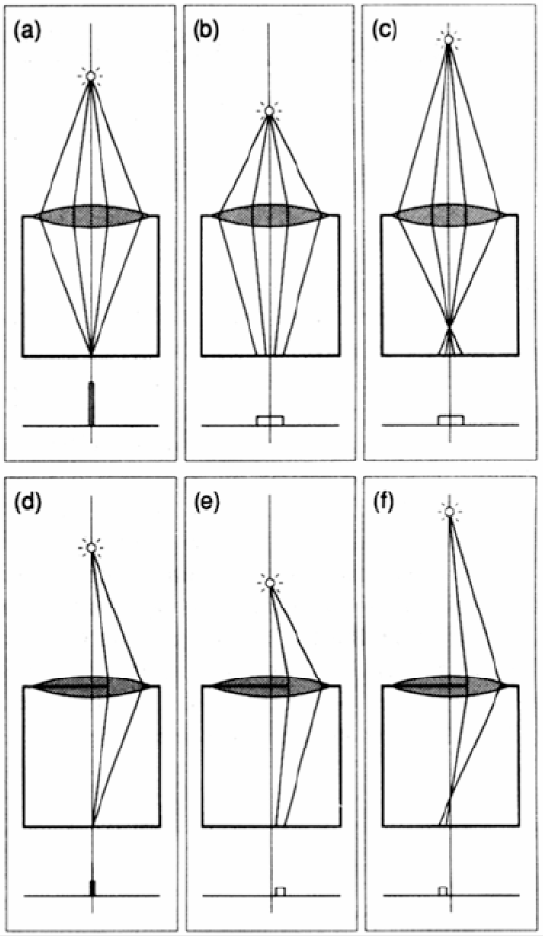
- Inventors:

  Edward Adelson and John Wang of MIT. Their original paper was published in 1992

  Recently (Feb 2005) the plenoptic camera design was enhanced by Ren Ng et al of Stanford.

Single lens stereo design

- Image of a point with a conventional lens.
- Image with an eccentric lens.
- When the aperture is displaced to the left, the image of a near object displaced to the left and image of a far object displaced to the right.
- In short, a near object "follows" the aperture displacement, while a far object "opposes" it.
- Can be used as a depth estimator.



[1] ADELSON, T., AND WANG, J. Y. A. 1992. Single lens stereo with a plenoptic camera. *IEEE Transactions on Pattern Analysis and Machine Intelligence 14*, 2 (Feb), 99–106.

Depth estimation with Single lens

- Depth can be measured by using simple geometric analysis.
- Disadvantage: Numerous snapshots are required for a complete depth estimation
- Can we obtain “everything” at once?
- Yes, welcome to the plenoptic camera!

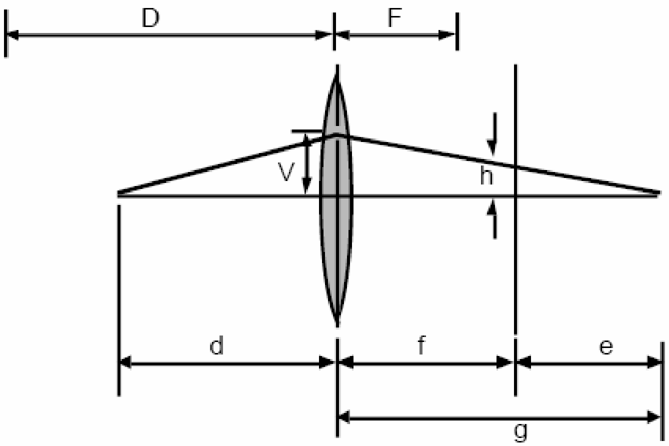
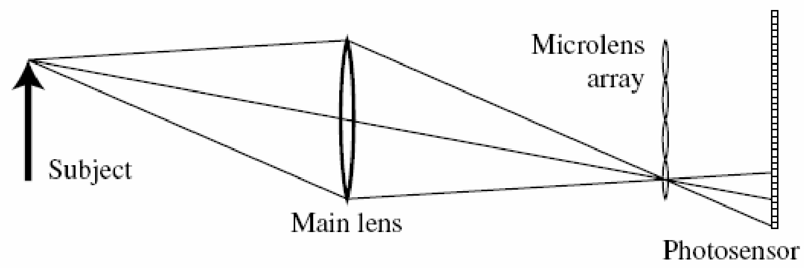


Fig. 4. Geometry of single lens stereo.

[1] ADELSON, T., AND WANG, J. Y. A. 1992. Single lens stereo with a plenoptic camera. *IEEE Transactions on Pattern Analysis and Machine Intelligence 14*, 2 (Feb), 99–106.

Plenoptic camera design

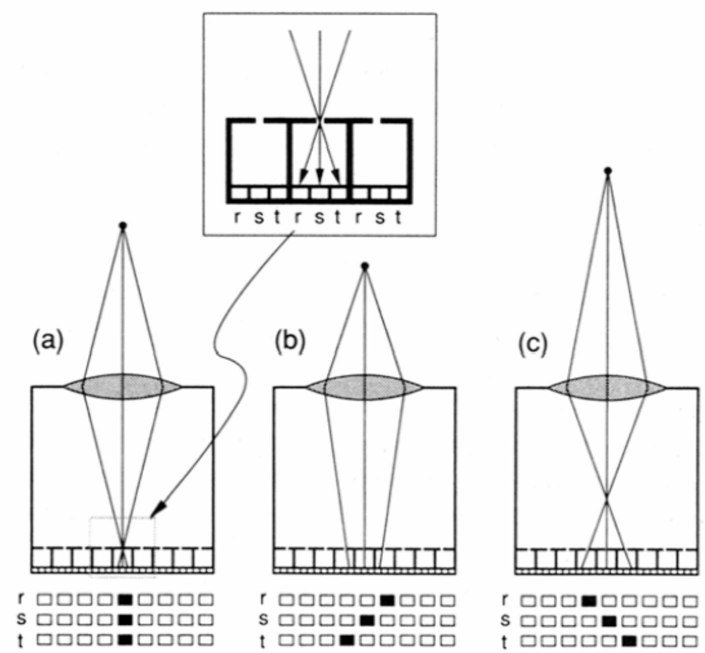
- Image formation in an ordinary camera
- Insert a microlens array before the sensor
- Why microlens?
  To capture the directional lighting distribution arriving at each sensor location.
- What is the use of knowing the direction?
  With the direction information, we can rearrange the pixel values in any order we want.
- What can be achieved by rearranging the pixel values?
  Every pixel is associated with a ray. Rearranging the pixels is equivalent to rearranging the rays.
- What can be done by rearranging the rays?
  Synthetic refocusing!



[3] NG, R., LEVOY, M., BR´EDIF, M., DUVAL, G., HOROWITZ, M., AND HANRAHAN, P. 2005. Light field photography with a hand-held plenoptic Camera. Tech. Rep. CSTR 2005-02, Stanford Computer Science.

Depth estimation

- Consider every microlens to be a pinhole camera.
- Notice the way in which rays from different directions fall on different pixels inside the pinhole camera.
- When a particular pixel (say, "r") value of all pinhole cameras are accumulated, we would get the topview of the object.
- Similarly, accumulating "s" and "t" pixel values would give center and bottom views respectively.
- When the object is near, the images are displaced to the left and when the object is far, the images are displaced to the right.
- Depth can hence be estimated.



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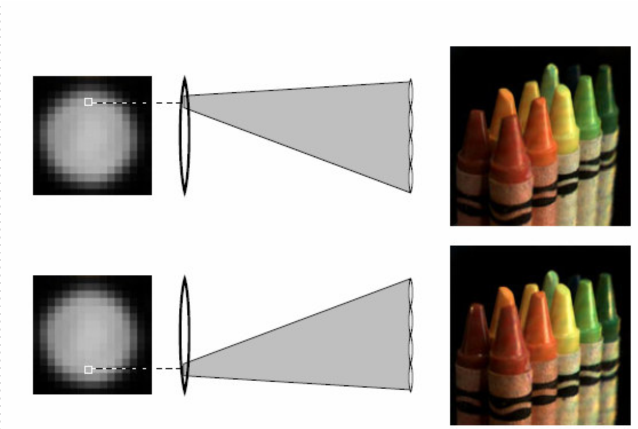
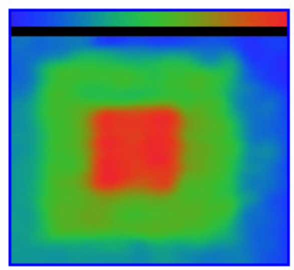
Depth estimation



- By performing a displacement analysis on successive images obtained from horizontal and vertical pixels, a depth map can be formed.

- Horizontal displacement

- Vertical displacement



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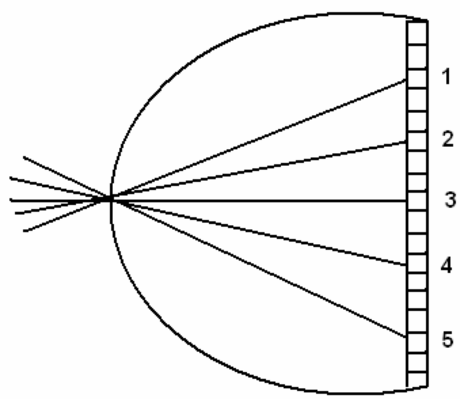
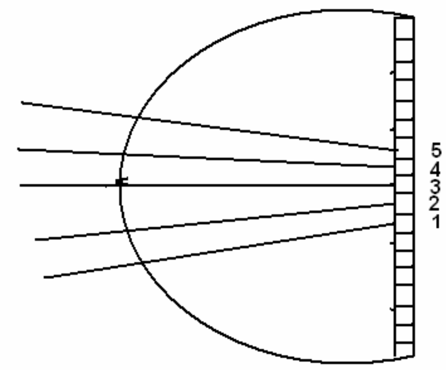
Synthetic refocusing

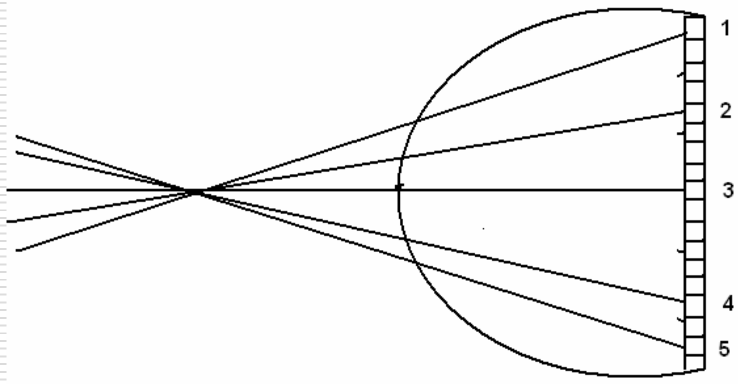
- What is synthetic refocusing?

  Capure an image once with plenoptic camera, and generate numerous images foused at different depths.





- The figures illustrate the fact that resorting pixels is equivalent to resorting the rays and hence identical to refocusing.



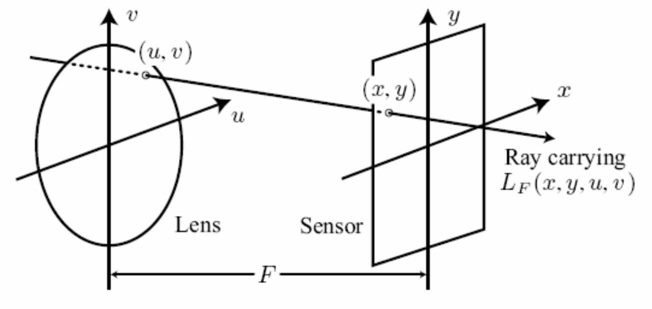
Some refocused images

[3] NG, R., LEVOY, M., BR´EDIF, M., DUVAL, G., HOROWITZ, M., AND HANRAHAN, P. 2005. Light field photography with a hand-held plenoptic Camera. Tech. Rep. CSTR 2005-02, Stanford Computer Science.

Fourier Slicing

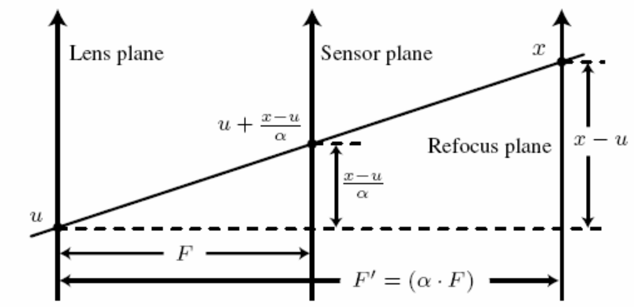
- Image in a camera is proportional to the irradiance.

$$E_F(x,y) = \frac{1}{F^2} \iint \overline{L}_F(x,y,u,v) \cos^4\phi \, du \, dv$$



- When refocused to F',

$$\mathcal{P}_\alpha [L_F](x,y) = E_{(\alpha\cdot F)}(x,y) = \quad (3)$$
$$\frac{1}{\alpha^2 F^2} \iint L_F\left(u(1-1/\alpha)+x/\alpha,\ v(1-1/\alpha)+y/\alpha,\ u,\ v\right) du\, dv.$$



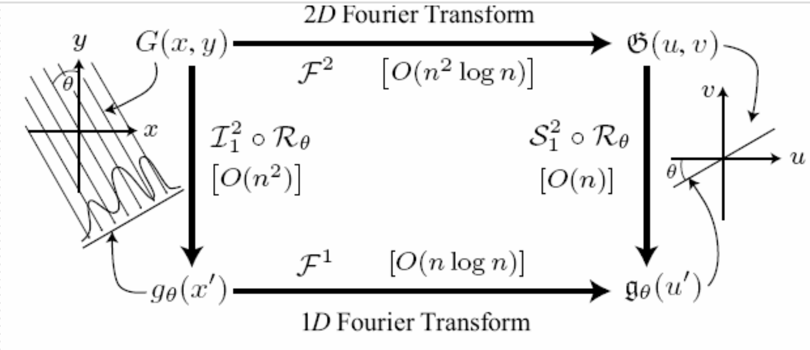
- P(x,y) is nothing but a 2D projection of of the 4D light field.

[4] NG, R., Fourier slice photography.
[2] LEVOY, M., AND HANRAHAN, P. 1996. Light field rendering. In *SIGGRAPH 96*, 31–42.

Fourier slicing

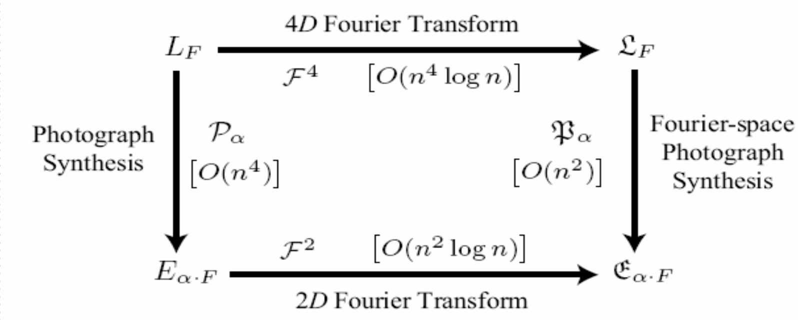
- Fourier slice theorem in two dimensions.

  1D slice of a 2D function's fourier transform is the fourier transform of an orthographic integral projection of the 2D function.



> Fourier slice theorem can be extended to higher dimensions.

$$\mathcal{F}^M \circ \mathcal{I}_M^N \circ \mathcal{B} \equiv \mathcal{S}_M^N \circ \frac{\mathcal{B}^{-T}}{|\mathcal{B}^{-T}|} \circ \mathcal{F}^N$$



> Consequently, P can be expressed as

$$\mathcal{P}_\alpha [L_F] \equiv \frac{1}{\alpha^2 F^2} \mathcal{I}_2^4 \circ \mathcal{B}_\alpha [L_F]$$

$$\equiv \frac{1}{F^2} \mathcal{F}^{-2} \circ \mathcal{S}_2^4 \circ \mathcal{B}_\alpha{}^{-T} \circ \mathcal{F}^4$$

[4] NG, R., Fourier slice photography.
[2] LEVOY, M., AND HANRAHAN, P. 1996. Light field rendering. In *SIGGRAPH 96*, 31–42.

References

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[4] NG, R., Fourier slice photography.

[5] MALZBENDER, T. 1993. Fourier volume rendering. *ACM Transactions on Graphics 12*, 3, 233–250.

Thank You!