Plenoptic Modeling: An Image-Based Rendering System

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(Presentation by Ezra Davis)

Major Contributions

- Introduces the idea of the Plenoptic function (to IBR)
  - Allows systematic evaluation of IBR methods by breaking them up into 3 parts:
    - "Sampling, reconstructing, and resampling the plenoptic function"
- Implements a new IBR method − using cylindrical panoramas

Contributions: Plenoptic function

- The plenoptic function (Adelson and Bergen)

$$p = P(\theta, \varphi, \lambda, Vx, Vy, Vz, t)$$

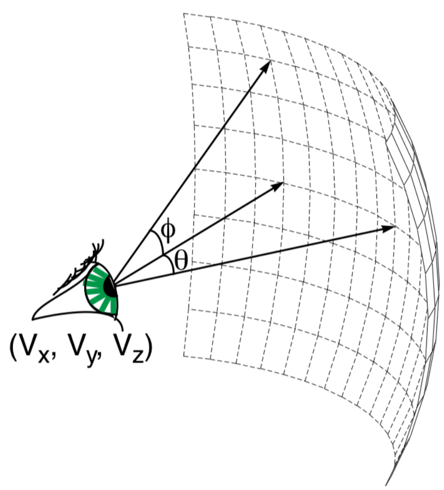


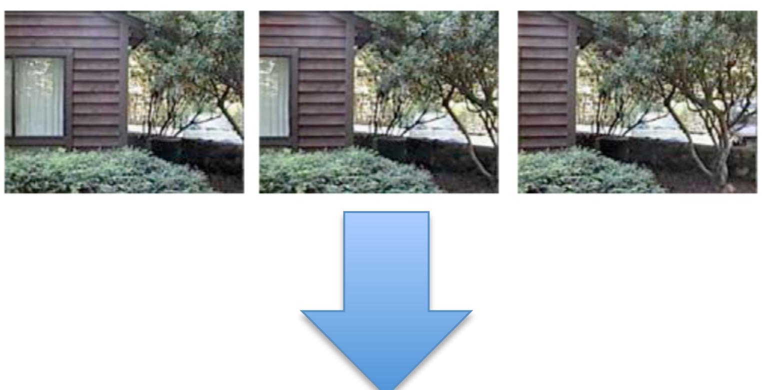
FIGURE 1. The plenoptic function describes all of the image information visible from a particular viewing position.

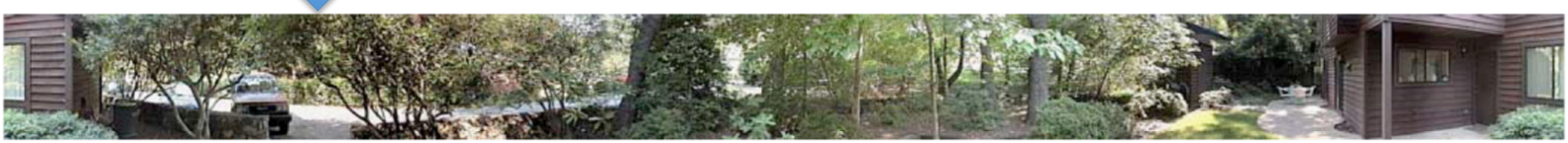
Contributions:
Plenoptic modeling method

Plenoptic modeling method: Creating cylindrical panoramas

Video panorama → **Stitch to cylindrical panorama** → Determine camera relationships → Project panoramas to new location → Convert panorama to planar image

1. Find rotation angle between pairs of images
   - Estimate focal length
2. Find matrix describing camera parameters





Aside: Transformation Matrices

$$\mathbf{x}' = A\mathbf{x}$$

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} cos(\theta) & -sin(\theta) & 0 \\ sin(\theta) & cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Rotation Transformation

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & s \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Scale transformation

$$\mathbf{x}' = RSx$$

Scale, then rotate

$$R_\theta = \begin{bmatrix} cos(\theta) & -sin(\theta) & 0 \\ sin(\theta) & cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Rotation Matrix

$$S_s = \begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & s \end{bmatrix}$$

Scale Matrix

How do we perform translation?

Aside: Homogeneous Coordinates

$$\begin{bmatrix} x' \\ y' \\ z' \\ w' \end{bmatrix} = \begin{bmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

A homogeneous transformation

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & v_x \\ 0 & 1 & 0 & v_y \\ 0 & 0 & 1 & v_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

3D Translation

$$\begin{bmatrix} \frac{x'}{w'} \\ \frac{y'}{w'} \\ \frac{z'}{w'} \end{bmatrix}$$

Converting from homogeneous coordinates

Aside: Homogeneous Coordinates

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

$$x' = \frac{u}{w} \qquad y' = \frac{v}{w}$$

2D Homogeneous coordinates

$$\begin{bmatrix} \cos\omega_z & -\sin\omega_z & 0 \\ \sin\omega_z & \cos\omega_z & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

A rotation matrix in 2D homogeneous coordinates

Plenoptic modeling method: Creating cylindrical panoramas

1. Video panorama
2. **Stitch to cylindrical panorama**
3. Determine camera relationships
4. Project panoramas to new location
5. Convert panorama to planar image

$$\bar{u} = H_i \bar{x} = S^{-1} R_i S \bar{x}$$

S: Intrinsic transform (camera properties)

***R**$_i$*: Rotation around the center of projection

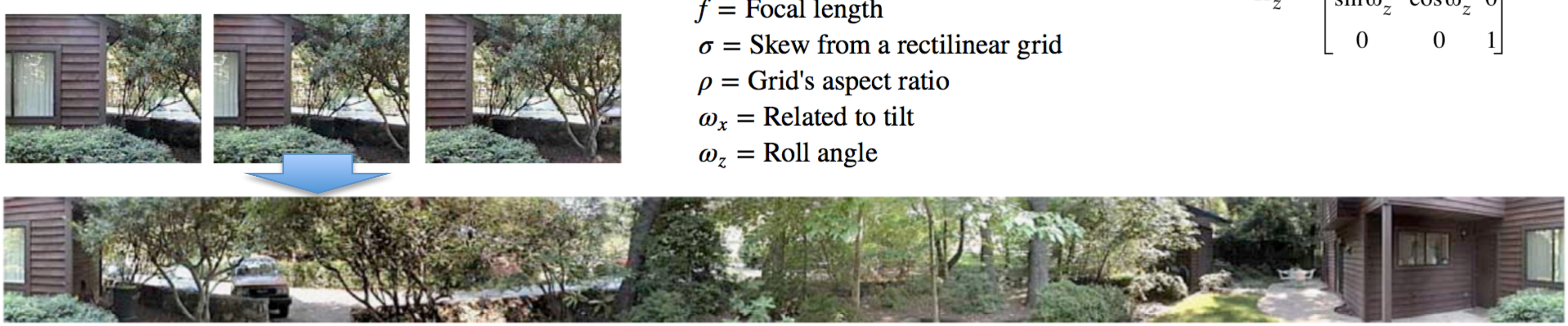
$$R_y = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$$

$$S = \Omega_x \Omega_z P \qquad P = \begin{bmatrix} 1 & \sigma & -C_x \\ 0 & \rho & -C_y \\ 0 & 0 & f \end{bmatrix}$$

$$\Omega_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega_x & -\sin\omega_x \\ 0 & \sin\omega_x & \cos\omega_x \end{bmatrix}$$

$$\Omega_z = \begin{bmatrix} \cos\omega_z & -\sin\omega_z & 0 \\ \sin\omega_z & \cos\omega_z & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

C_x, C_y = Center of the viewplane
f = Focal length
σ = Skew from a rectilinear grid
ρ = Grid's aspect ratio
ω_x = Related to tilt
ω_z = Roll angle

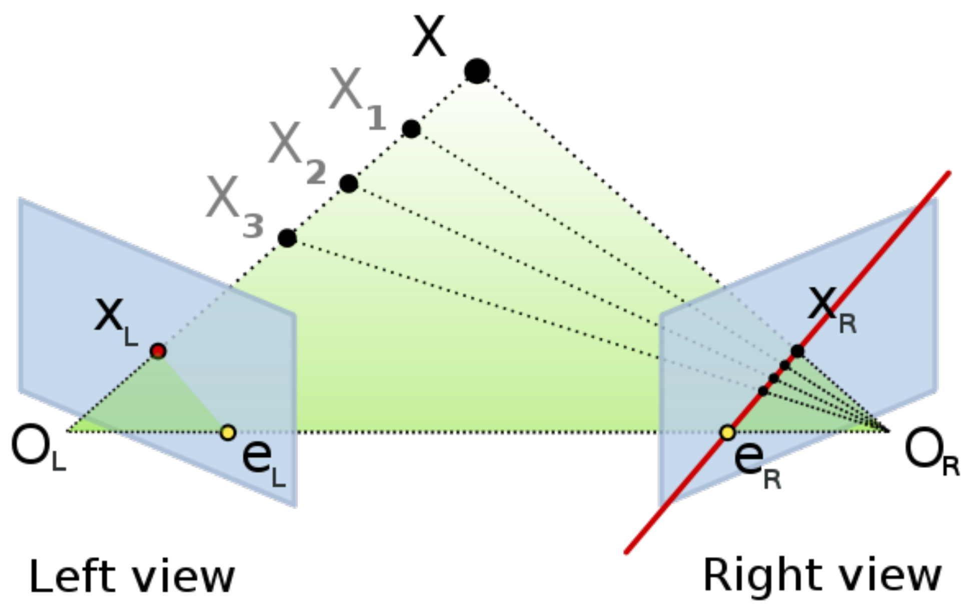


Plenoptic modeling method: Determining camera relationships

Video panorama → Stitch to cylindrical panorama → **Determine camera relationships** → Project panoramas to new location → Convert panorama to planar image

1. Determine "tiepoints" in pairs of panoramas
    - Take advantage of cylindrical epipolar geometry
2. Use these (12-500) points to determine relationship between cylindrical panoramas via an optimization problem
    - We also get a disparity image

Aside: Epipolar Geometry



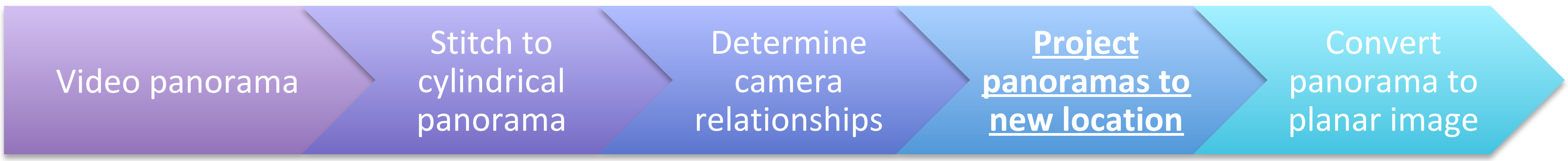
Cylindrical Epipolar Geometry

$$v(\theta) = \frac{N_x \cos(\phi_a - \theta) + N_y \sin(\phi_a - \theta)}{N_z k_a} + C_{v_a}$$

where

$$\overline{N} = (\overline{C}_b - \overline{C}_a) \times \overline{D}_a(\theta_a, v_a)$$

Plenoptic modeling method: Projecting to new location



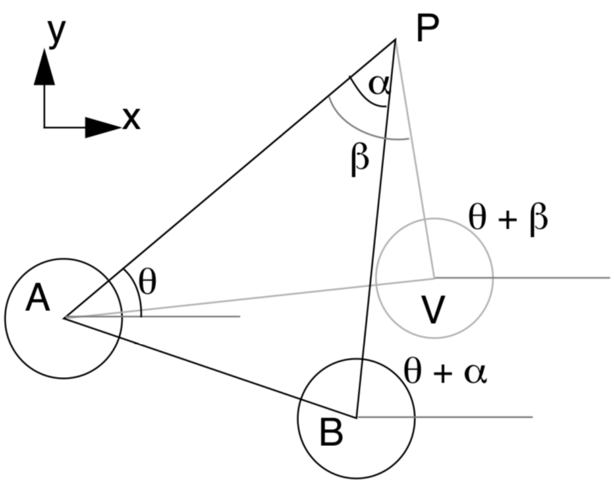


FIGURE 2. Diagram showing the transfer of the known disparity values between cylinders A and B to a new viewing position V.

1. Project images (and disparity image) onto new location
2. Paint the new image in occlusion compatible order
3. Fill in holes with a nearby pixels

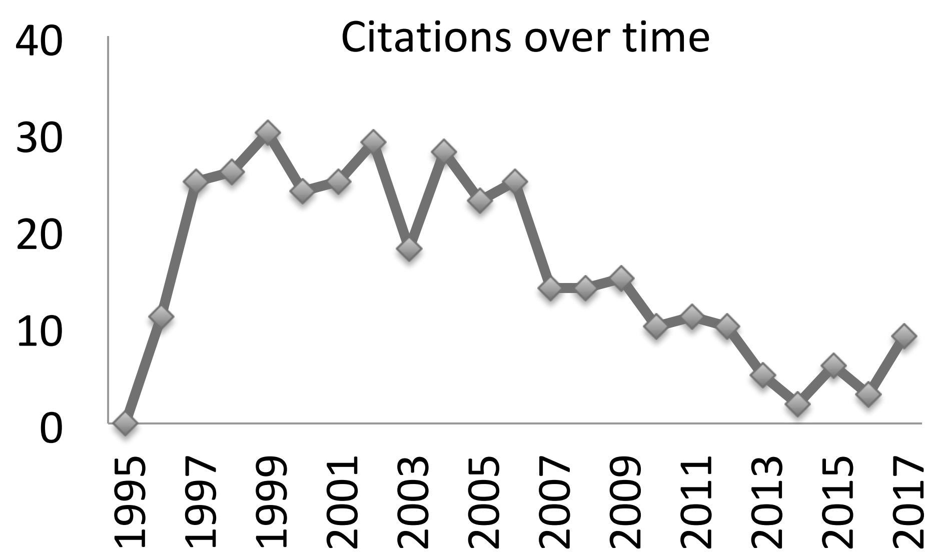
Strengths and weaknesses

- Uses cylinder panoramas
  - No looking up or down
  - Centers must be roughly coplanar
  - Easy to acquire & store data
    - Just need a tripod

- It's IBR with all its advantages and disadvantages

Further research

- Cited by 357 papers
  - 7 of these from 2017



Some Further research (in 2017)

- Real-time IBR on a distributed system
  - Wenhui Zhou, Jiaqi Pan, Pengfei Li, Xuehui Wei, and Zhen Liu. 2017. A Distributed Stream Computing Architecture for Dynamic Light-Field Acquisition and Rendering System. In LNCS on Transactions on Edutainment XIII - Volume 10092, Zhigeng Pan, Adrian David Cheok, Wolfgang Müller, and Mingmin Zhang (Eds.), Vol. 10092. Springer-Verlag New York, Inc., New York, NY, USA, 123-132. DOI: https://doi.org/10.1007/978-3-662-54395-5_11
- Removing redundancy in IBR source images
  - Naiwen Xie, Lili Wang, and Voicu Popescu. 2017. Non-redundant rendering for efficient multi-view scene discretization. Vis. Comput. 33, 12 (December 2017), 1555-1569. DOI: https://doi.org/10.1007/s00371-016-1300-6
- Determining sampling rate for plenoptic function using geometry and spectral analysis
  - Chang-Jian Zhu and Li Yu. 2017. Spectral analysis of image-based rendering data with scene geometry. Multimedia Syst. 23, 5 (October 2017), 627-644. DOI: https://doi.org/10.1007/s00530-016-0515-8
- Disocclusion hole filling
  - Jianjun Lei, Cuicui Zhang, Min Wu, Lei You, Kefeng Fan, and Chunping Hou. 2017. A divide-and-conquer hole-filling method for handling disocclusion in single-view rendering. Multimedia Tools Appl. 76, 6 (March 2017), 7661-7676. DOI: https://doi.org/10.1007/s11042-016-3413-3
- Panning and zooming VR panoramas
  - Huiwen Chang and Michael F. Cohen. 2017. Panning and Zooming High-Resolution Panoramas in Virtual Reality Devices. In Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology (UIST '17). ACM, New York, NY, USA, 279-288. DOI: https://doi.org/10.1145/3126594.3126617
- Image based representation for networked virtual environments
  - Minhui Zhu, Géraldine Morin, Vincent Charvillat, and Wei Tsang Ooi. 2017. Sprite tree: an efficient image-based representation for networked virtual environments. Vis. Comput. 33, 11 (November 2017), 1385-1402. DOI: https://doi.org/10.1007/s00371-016-1286-0
- Mixed reality lighting for panoramic videos
  - Taehyun Rhee, Lohit Petikam, Benjamin Allen, and Andrew Chalmers. 2017. MR360: Mixed Reality Rendering for 360° Panoramic Videos. IEEE Transactions on Visualization and Computer Graphics 23, 4 (April 2017), 1379-1388. DOI: https://doi.org/10.1109/TVCG.2017.2657178

Sources

- McMillan, L., & Bishop, G. (1995, September). Plenoptic modeling: An image-based rendering system. In Proceedings of the 22nd annual conference on Computer graphics and interactive techniques (pp. 39-46). ACM.
- ACM (2018) *Plenoptic Modeling.* Retrieved from https://dl.acm.org/citation.cfm?id=218398
- Arne Nordmann (2007) *Epipolar geometry.svg*. Wikimedia Commons. Retrieved from https://commons.wikimedia.org/wiki/File%3AEpipolar_geometry.svg