

*SIGGRAPH 99 Course on
3D Photography*

Camera Calibration

*Steve Seitz
Carnegie Mellon University*

<http://www.cs.cmu.edu/~seitz>

Camera Calibration

Geometry

- Where is the camera?
- Where is it pointing?
- What are the internal parameters?
- What's the point spread function?

Radiometry

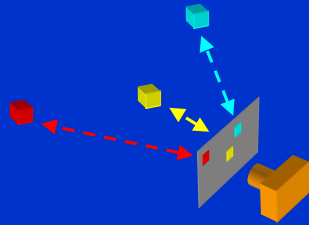
- What is the mapping from light to pixel values?
- [Debevec 97]

If Only Cameras Were "Smart" . . .

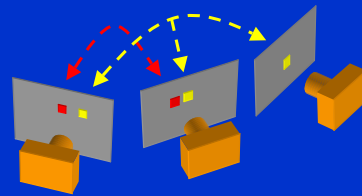
Geometric Camera Calibration

Augmented pin-hole camera model

- Focal point, orientation
- Focal length, aspect ratio, center, lens distortion



2D \Leftrightarrow 3D
correspondence
“Classical” calibration

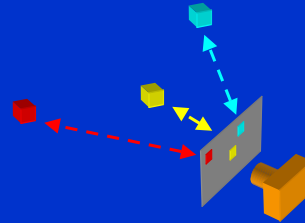


2D \Leftrightarrow 2D
correspondence
SFM, “Self-calibration”

Linear Geometric Calibration

Know 3D coords, 2D coords

- Find projection matrix Π



$$d \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$\mathbf{u} = \Pi \mathbf{X}$

11 unknowns (up to scale)
2 equations per point
(eliminate d)

6 points is sufficient

Nonlinear Methods

Problems with Linear Method

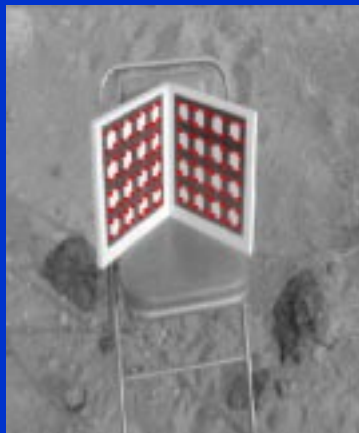
- Too many free parameters
- Doesn't model lens distortion

Nonlinear Methods [Tsai, 1985]

- Parameterize Π in terms of
 - > rotation: θ, ϕ, ψ
 - > translation: X, Y, Z
 - > intrinsics: f , aspect ratio, image center
 - > radial lens distortion: k_1, k_2

Code Available Via Course Web Page

Calibration Patterns

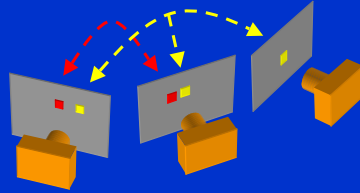


Calibration grid
Z. Zhang, Microsoft Research



Chromaglyphs
Bruce Culbertson, HP-labs

Calibration From 2D Motion



Structure From Motion (SFM)

- Track points over a sequence of images
- Solve for 3D positions and camera positions
- Calibrate internal parameters beforehand

Self-Calibration

- Solve for internal *and* external parameters
- E.g., [Pollefeys, 98]

Resources

Computer Vision Home Page

- <http://www.cs.cmu.edu/afs/cs/project/cil/ftp/html/vision.html>

Matlab and C Implementations

- Via course web page
- <http://www.cs.cmu.edu/~seitz/course/3DPhoto.html>

Bibliography

Geometric Calibration

- R. J. Tsai, A Versatile Camera Calibration Technique for High Accuracy 3D Machine Vision Metrology Using Off-the-Shelf TV Cameras and Lenses, IEEE Journal of Robotics and Automation, Vol. 3, No. 4, 1987, pp. 323-344.

Radiometric Calibration

- Paul E. Debevec and Jitendra Malik, "Recovering High Dynamic Range Radiance Maps from Photographs", Proc. SIGGRAPH 97, pp. 369-378.

Structure-from-Motion

- Carlo Tomasi & Takeo Kanade, "Shape and Motion from Image Streams Under Orthography: A Factorization Method", Int. Journal of Computer Vision, 9(2), 1992, pp. 137-154.

Self-Calibration

- Marc Pollefeys, Reinhard Koch, and Luc Van Gool, "Self-Calibration and Metric Reconstruction in spite of Varying Unknown Internal Camera Parameters", Proc. Sixth Int. Conf. on Computer Vision, 1998, pp. 90-91.