The Photogrammetric Process

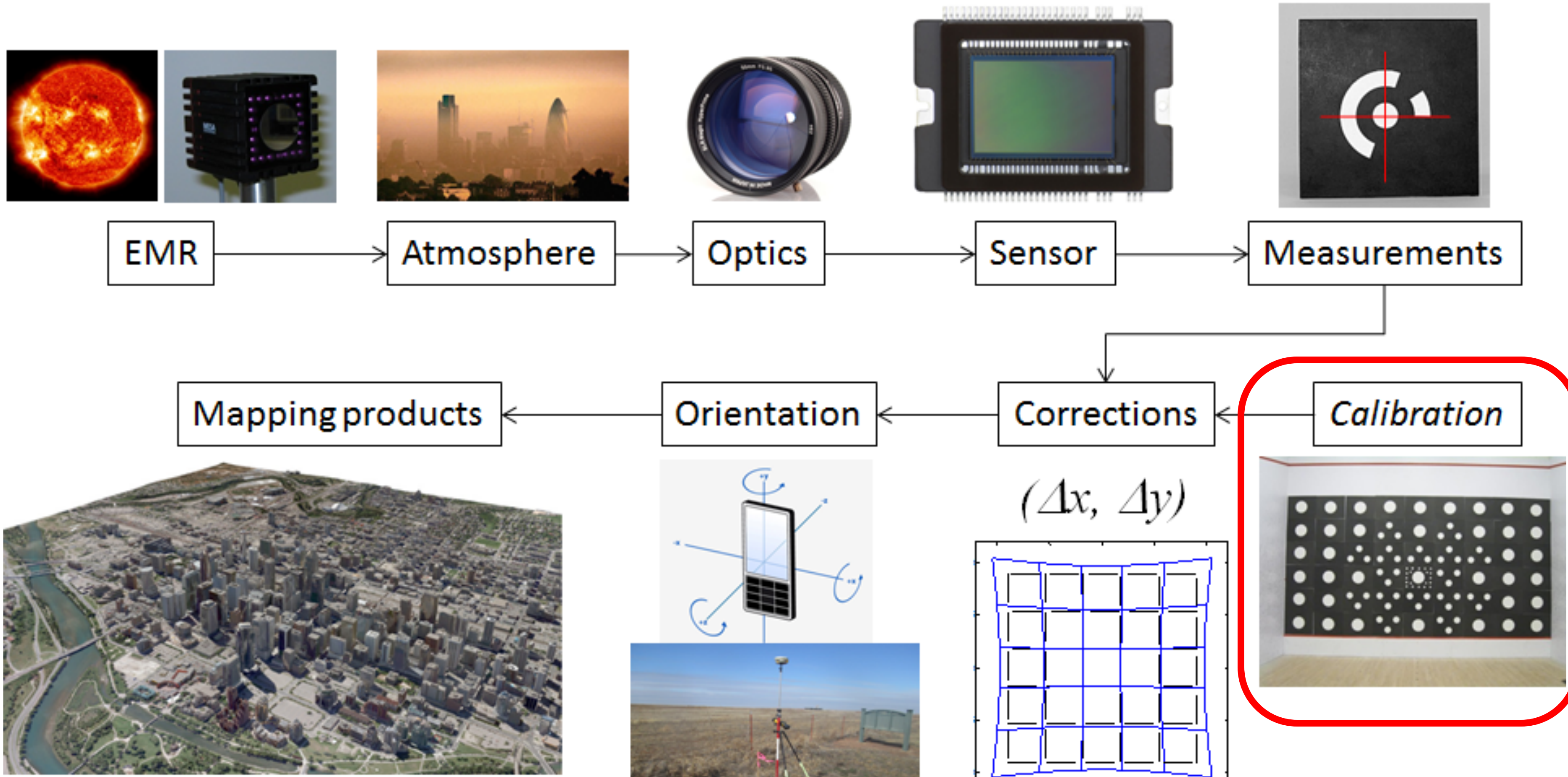


Image sources
http://blogs.mcgill.ca/osscontributors/tag/sun/
http://www.dcmtechservices.com/Targets.htm
http://www.theguardian.com/environment/2011/jan/28/europe-air-quality-pollution
https://www.ephotozine.com/article/slr-magic-50mm-f-0-95-hyperprime-lens-review-23001
http://oneslidephotography.com/ccd-vs-cmos-dslr-camera-wich-one-is-better/
http://www.rpsurveying.com/img/proj/ControlPoint.Full.png
http://www.3dcadbrowser.com/download.aspx?3dmodel=20756

All Slides Courtesy of:

Dr. Derek Lichti
University of Calgary

Camera Calibration

- How are these calibration parameters determined?

I. Calibrated Focal Length: $\boxed{153.358 \text{ mm}}$

II. Lens Distortion

Field angle:	7.5°	15°	22.7°	30°	35°	40°
Symmetric radial (μm)	-2	-3	-2	0	2	3
Decentering tangential (μm)	0	0	1	1	2	2

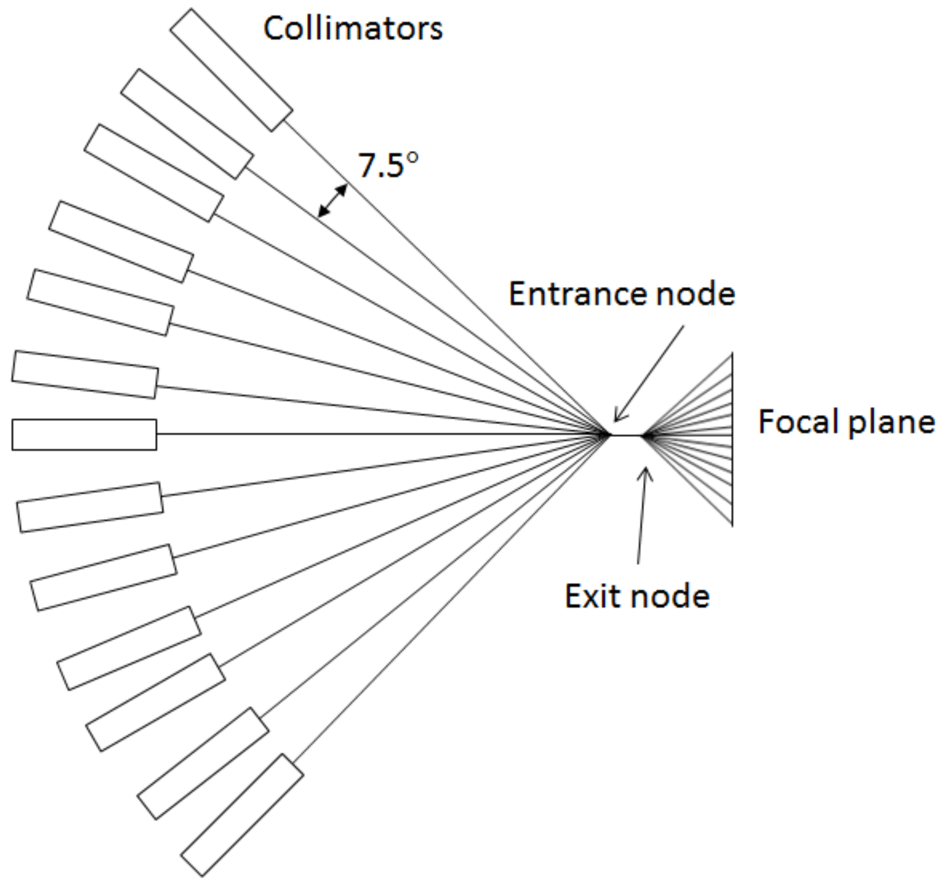
Symmetric radial distortion	Decentering distortion	Calibrated principal point
K_0 = 0.8878E-04	P_1 = 0.1346E-06	x_p = -0.006 mm
K_1 = -0.1528E-07	P_2 = 0.1224E-07	y_p = 0.006 mm
K_2 = 0.5256E-12	P_3 = 0.0000	
K_3 = 0.0000	P_4 = 0.0000	
K_4 = 0.0000		

The values and parameters for Calibrated Focal Length (CFL), Symmetric Radial Distortion (K_0,K_1,K_2,K_3,K_4), Decentering Distortion (P_1,P_2,P_3,P_4), and Calibrated Principal Point [point of symmetry] (x_p,y_p) were determined through a least-squares Simultaneous Multiframe Analytical Calibration (SMAC) adjustment. The x and y-coordinate measurements utilized in the adjustment of the above parameters have a standard deviation (σ) of ±3 microns.

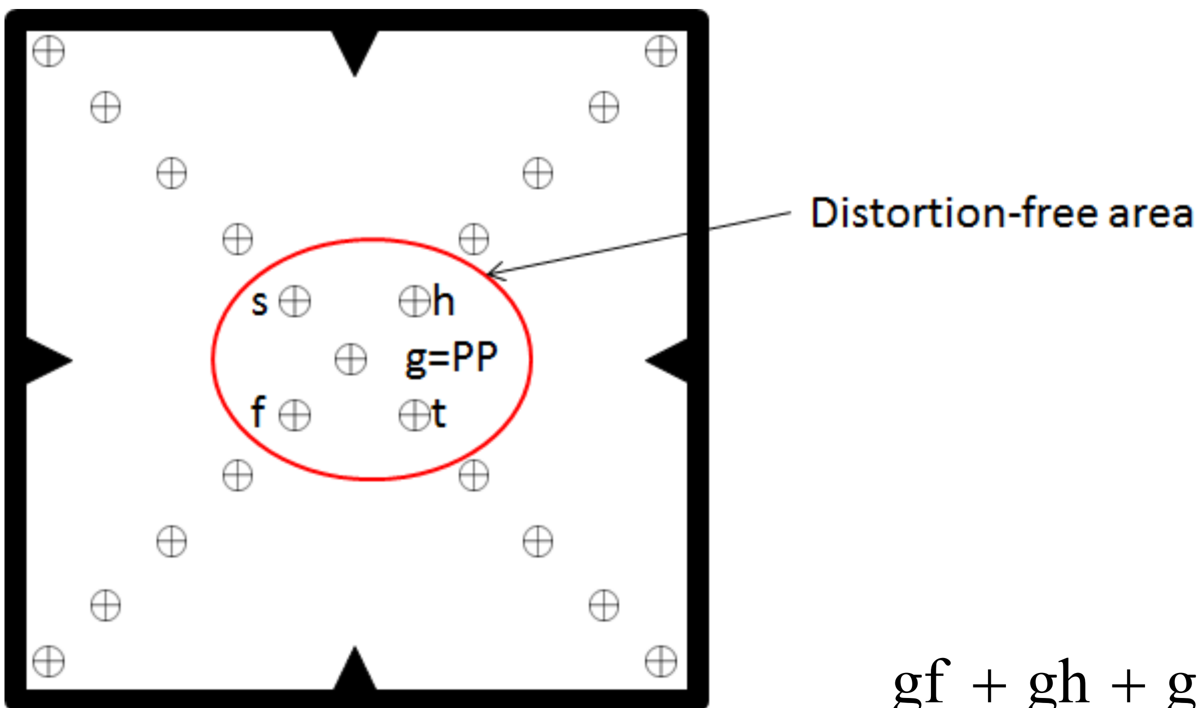
Laboratory Calibration: Multi-Collimators

http://calval.cr.usgs.gov/osl/background.php

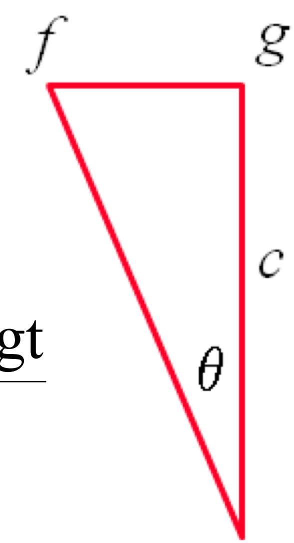
Laboratory Calibration (cont’d)



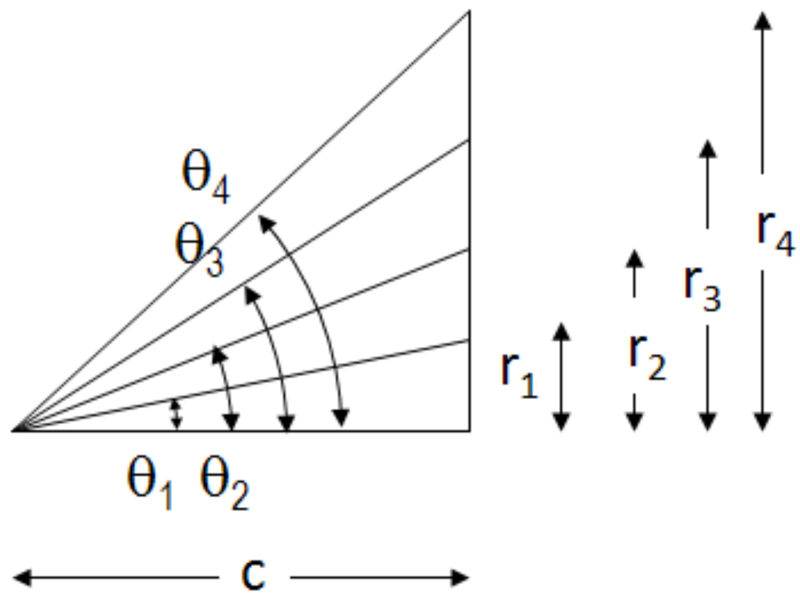
Laboratory Calibration (cont'd)



$$c = \frac{gf + gh + gs + gt}{4\tan\theta}$$

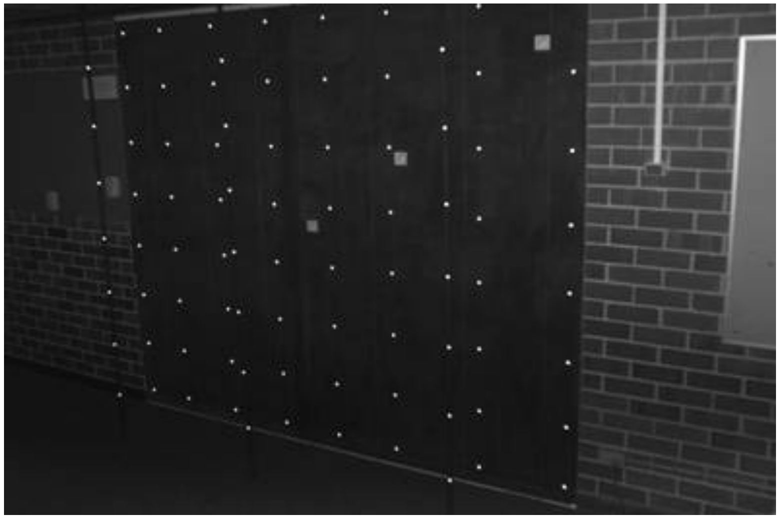


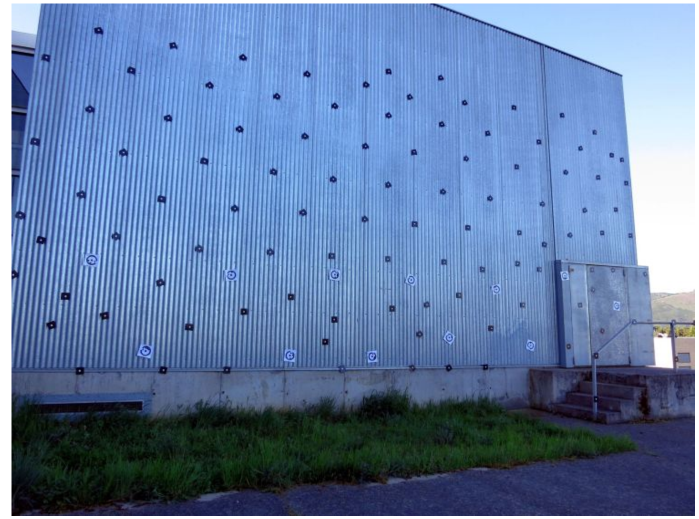
Laboratory Calibration (cont'd)



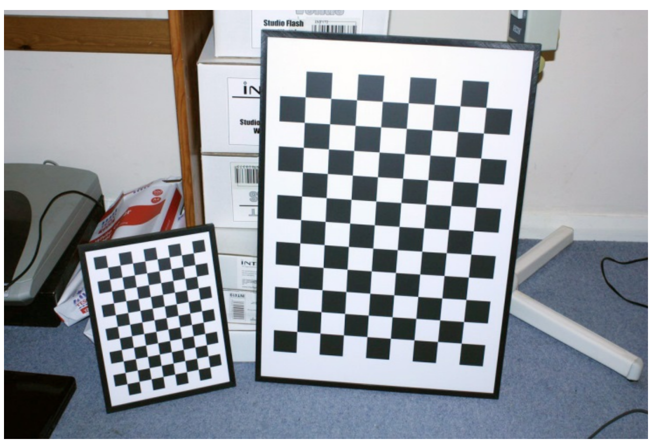
$$\tan\theta_i = \frac{r_i}{c} \qquad r_{meas} - c\tan\theta_i = \Delta r = f(r)$$

Calibration Test Fields

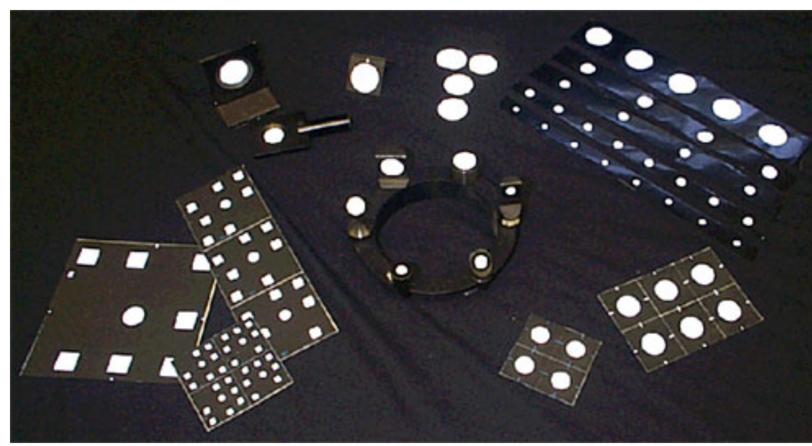




http://diydrones.com/profiles/blogs/geometric-camera-calibration-for-use-in-photogrammetry



http://ir-ltd.net/my-digital-journey-prt2/



http://www.vibrodynamics.net/Close_Range.htm

Scale Control

- The scale bar is designed for theodolite use in optical tooling, but can also be used in close-range photogrammetry
- The concentric circle target design lends itself to centroid-based (or other type) sub-pixel measurement in digital imagery

$$s = 899.954 \text{ mm} \pm 0.002\ (1\sigma) \text{ mm at } 20.5\ ^\circ\text{C}$$

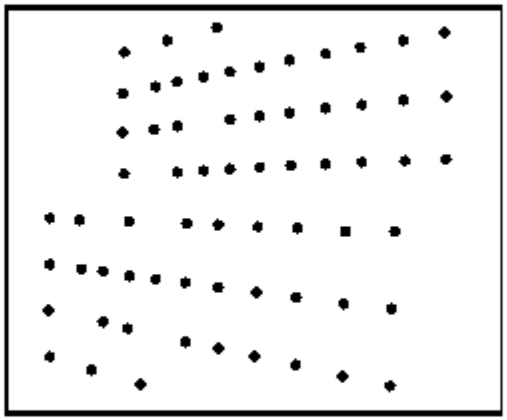
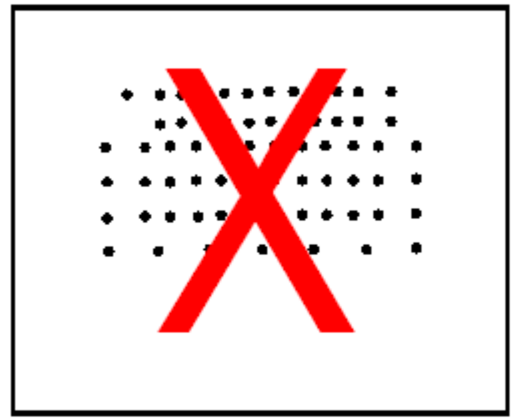
Target Detail

Self-Calibration Procedure

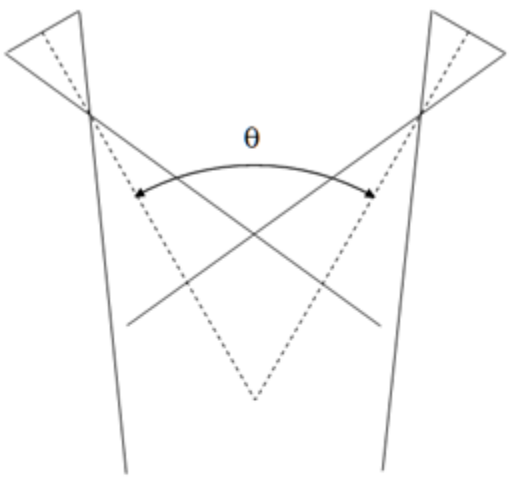
- Data collection:
  - Acquisition of several images of a targeted calibration range
  - Fixed focus camera
  - A 3D target field is desirable but not required
  - The target field need not be surveyed

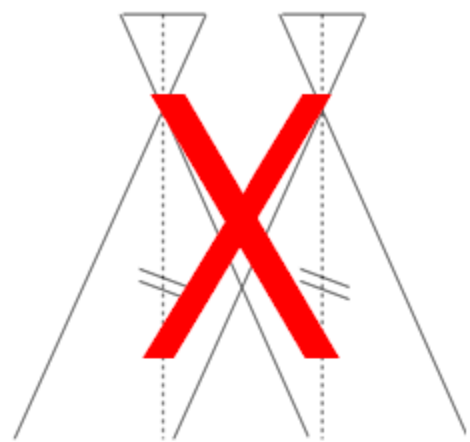
Self-Calibration Procedure (cont'd)

- Image format filled with targets

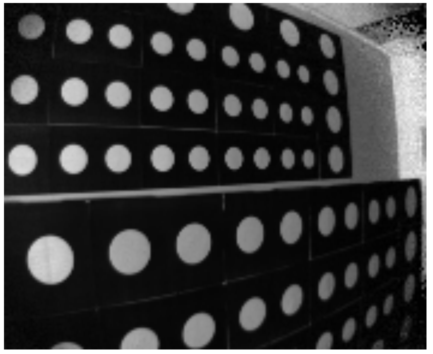
- Convergent imagery



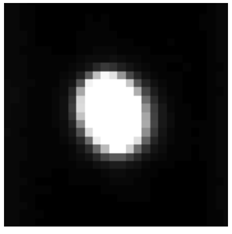


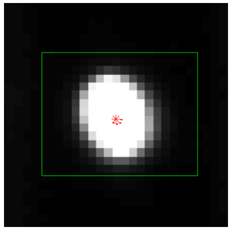
Self-Calibration Procedure (cont'd)

- Portrait and landscape images (orthogonal κ angles)



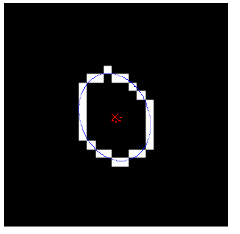
- Precise measurement of target centres





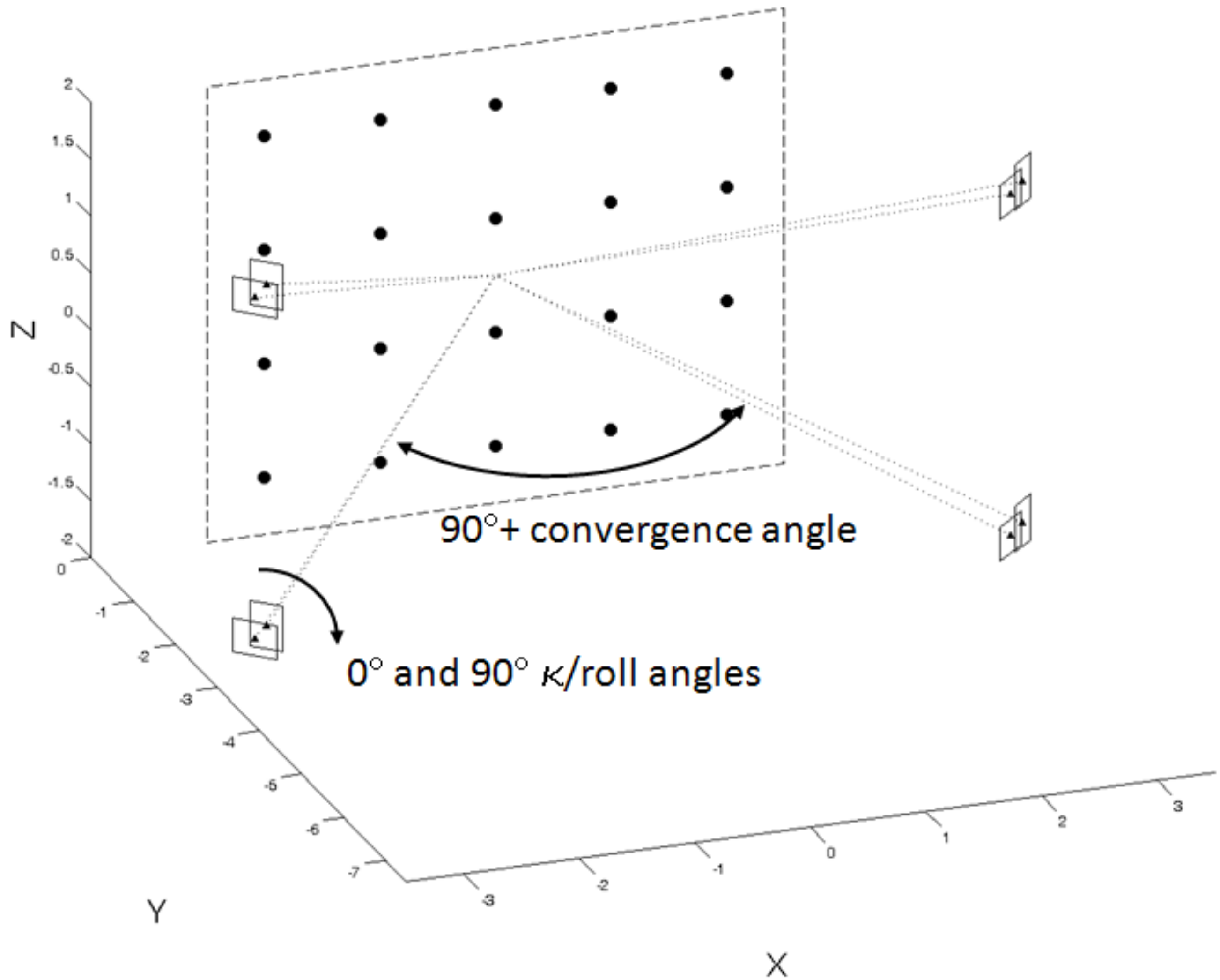
Weighted centroid

Ellipse fit



- Choose a set of minimum datum constraints
- Determine approximate parameter values
- Perform simultaneous least-squares solution

Self-Calibration Network

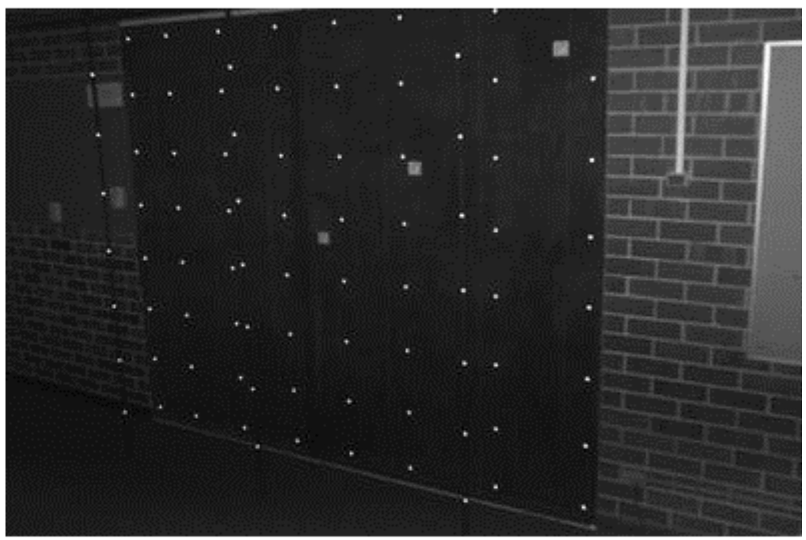


Self-Calibration Example

- Self-calibration of a Kodak DC 260
  - 16 convergent images of a calibration field were acquired from 8 nominal locations
  - 2 images were captured at each location: one with κ=0° and one with κ =90°
  - The object space calibration array comprised 85 points, all of which were estimated (inner constraints imposed)
  - IO model:
    - The PD
    - The PP
    - 3 radial lens distortion terms
    - 2 decentring distortion terms

Self-Calibration Example (cont'd)

Source: http://www.kodak.com/



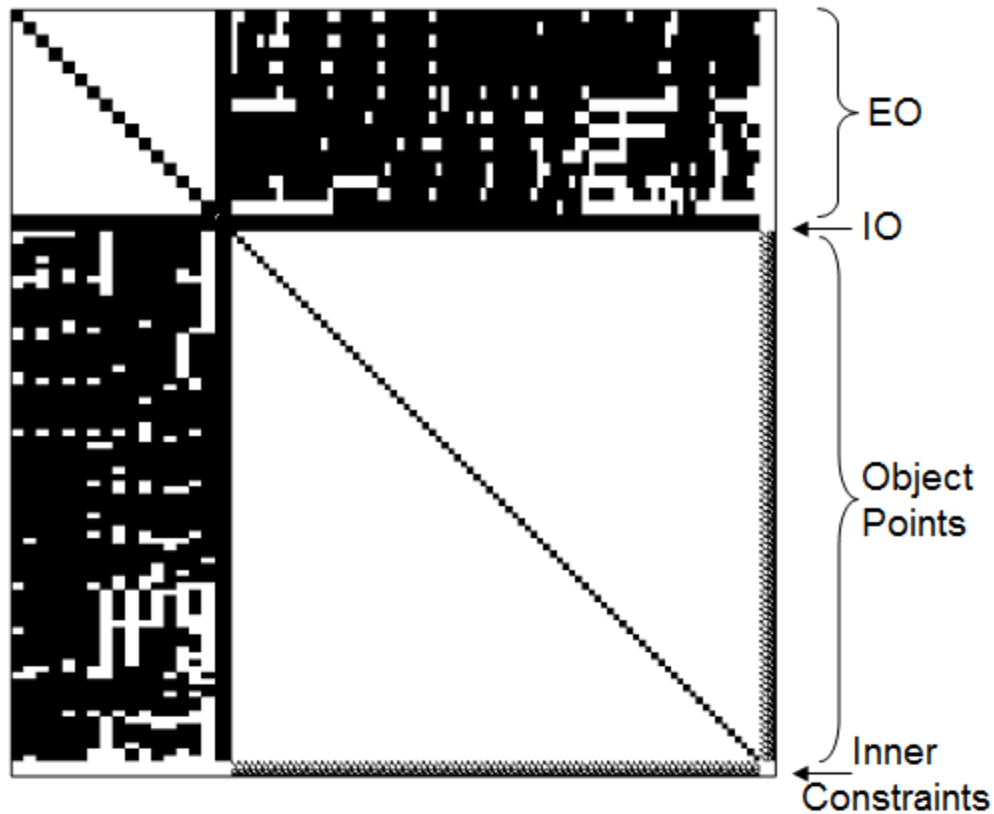
Indoor Calibration Field

Self-Calibration Example (cont'd)

- DC 260 self-calibration network summary

Observations		
Image points	2 x 1141	2282
Total observations (n)		**2282**
Datum constraints (d)		**7**
Unknowns		
EO parameters	6 x 16	96
Object points	3 x 85	255
IO parameters	1 x 8	8
Total Unknowns (u)		**359**
Redundancy (r=n+d-u)		**1930**

- DC 260 self-calibration network normal-equations matrix



Self-Calibration Example (cont'd)

- Selected results
  - Estimated variance factor = 1.06
  - Interior orientation parameters

$$y = \left| \frac{\text{Est}}{\sigma} \right|$$

Parameter	Estimate	σ	y
x_p (pixels)	28.35	±0.23	123.43
y_p (pixels)	3.67	±0.19	19.60
c (pixels)	1710.73	±0.18	9542
k_1	-4.0084e-08	±5.4079e-10	74.12
k_2	2.0081e-14	±1.5919e-15	12.61
k_3	4.8771e-21	±1.4737e-21	3.31
p_1	1.6482e-06	±2.6442e-08	62.33
p_2	1.1843e-06	±2.0975e-08	56.46

Self-Calibration Example (cont'd)

- Correlation matrix of IO parameters

xp	1							
yp	-0.07	1						
c	-0.08	0.02	1					
k1	0.02	0.03	-0.64	1				
k2	0.00	-0.04	0.51	-0.96	1			
k3	0.00	0.04	-0.44	0.90	-0.98	1		
p1	0.90	-0.07	-0.01	-0.02	0.01	-0.01	1	
p2	-0.01	0.82	-0.07	0.05	-0.03	0.02	-0.01	1

- High correlation exists between
  - Radial lens distortion coefficients
  - PP and decentring distortion parameters

Summary of Equations

- Observation equations

$$\underset{n,u_e}{A_e}\,\underset{u_e,1}{\hat{\delta}_e} + \underset{n,u_o}{A_o}\,\underset{u_o,1}{\hat{\delta}_o} + \underset{n,u_i}{A_i}\,\underset{u_i,1}{\hat{\delta}_i} + \underset{n,1}{w} = \underset{n,1}{\hat{v}}$$

- Normal equations

$$\begin{bmatrix} A_e^T P A_e + P_e & A_e^T P A_o & A_e^T P A_i \\ & A_o^T P A_o + P_o & A_o^T P A_i \\ \text{sym.} & & A_i^T P A_i + P_i \end{bmatrix} \begin{bmatrix} \hat{\delta}_e \\ \hat{\delta}_o \\ \hat{\delta}_i \end{bmatrix} + \begin{bmatrix} A_e^T P w + P_e w_e \\ A_o^T P w + P_o w_o \\ A_i^T P w + P_i w_i \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$