Photogrammetric Block Adjustment

Chapter 1
Photogrammetry Review

Farhad Samadzadegan, Ph.D
Department of Surveying and Geomatics Engineering,
Faculty of Engineering, University of Tehran
Email: samadz@ut.ac.ir

2006

Content

Definitions & concepts

- Classical Definition
- Contemporary Definition
- Type
- Objective

Mathematical Model

- Image Coordinate System: **Analog Images**
- Image Coordinate System: **Digital Images**
- Mathematical Model
- Objective
- Collinearity Equations

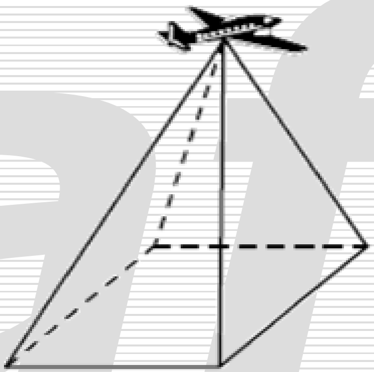
Theory of Orientation

- Maps Versus Images
- Theory of Orientation
- Interior Orientation
- Exterior Orientation
- Relative Orientation Dependent Relative Orientation
- Independent Relative Orientation
- Absolute Orientation
- Resection
- Intersection
- Resection - Intersection

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Definition

- The art and science of determining the position and shape of objects from photography.
- The process of reconstructing objects without touching them.
- Non contact positioning method.



Type

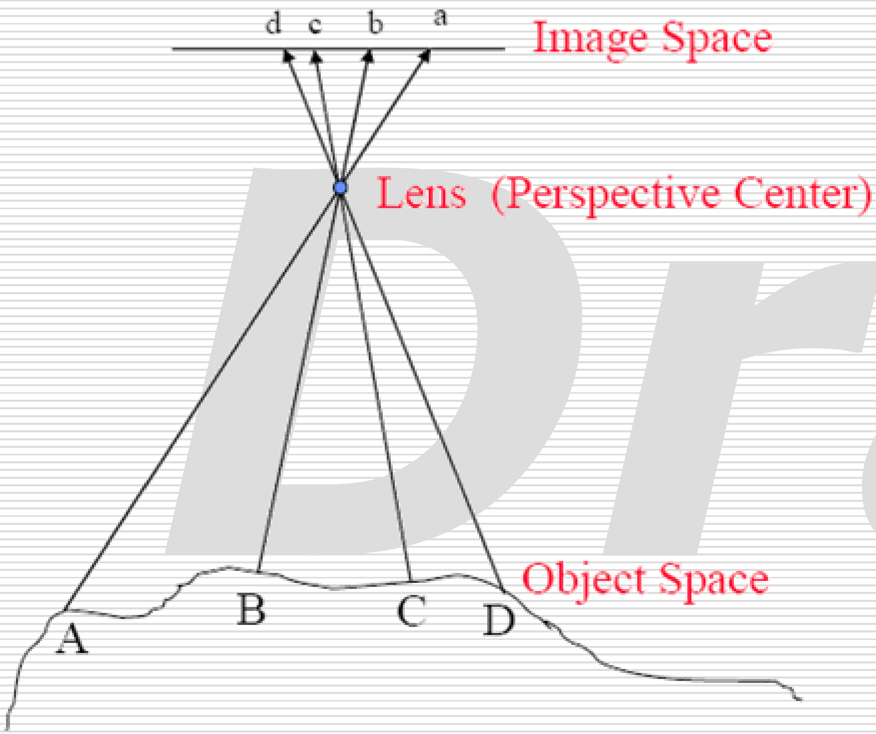
- Space Imagery
- Aerial Imagery
- Terrestrial (Close Range) Imagery

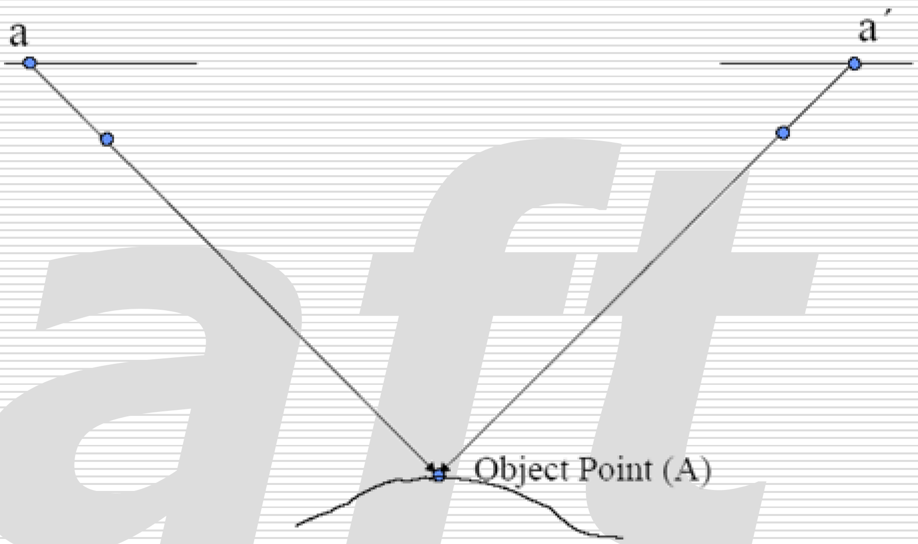
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Definitions & Concepts

Objective

- Inverse the process of photography (i.e. we would like to reconstruct the object space from imagery).





Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Mathematical Model

Objective

To develop a general mathematical relationship between image and object

Alternatives

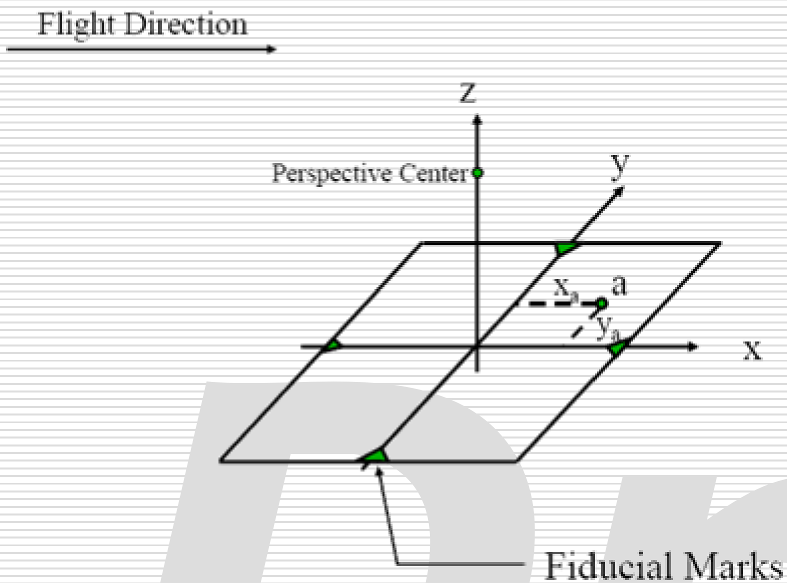
- *Projective Transformation.*
- *Collinearity Equations.*
- *Direct Linear Transformation (DLT).*

The mathematical model of choice for most of the photogrammetric applications is the ***Collinearity Equations.***

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

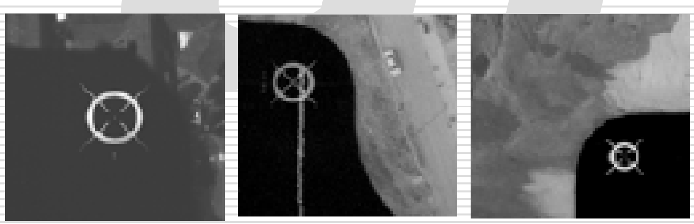
Mathematical Model

Image Coordinate System: Analog Images



Analogue Camera: RC30

Sample Fiducial Marks in Metric Cameras

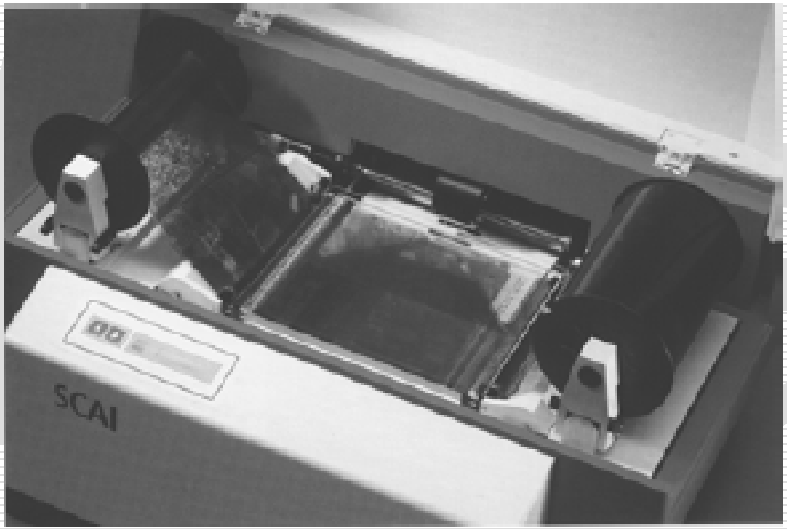


Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Image Coordinate System: Digital Images

Digital images can be acquired through either:

- Scanning analog images.
- Direct use of digital cameras.



Photogrammetric Scanner

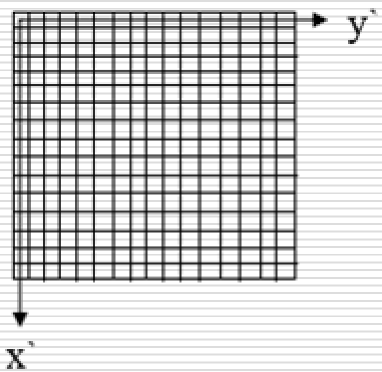
Digital Camera: DMCTM

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Mathematical Model

Image Coordinate System: Digital Images captured by Digital Cameras

Pixel to Image Coordinate Transformation



Pixel Coordinates

$$x = (y' - n_c / 2.0) \times y\_pix\_size$$

$$y = (n_r / 2.0 - x') \times x\_pix\_size$$

where :

n_c	Number of columns
n_r	Number of rows
x_pix_size	Pixel size along the row direction
y_pix_size	Pixel size along the column direction

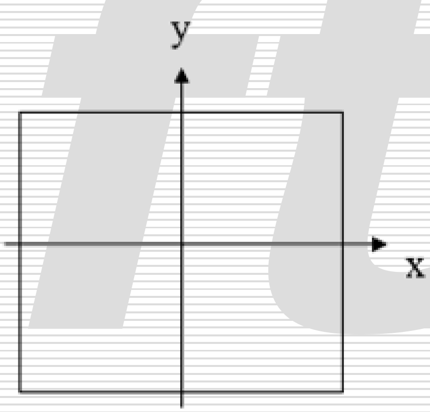
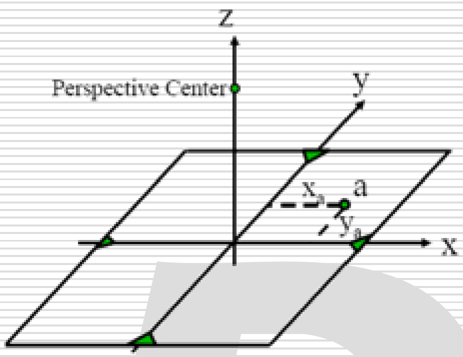
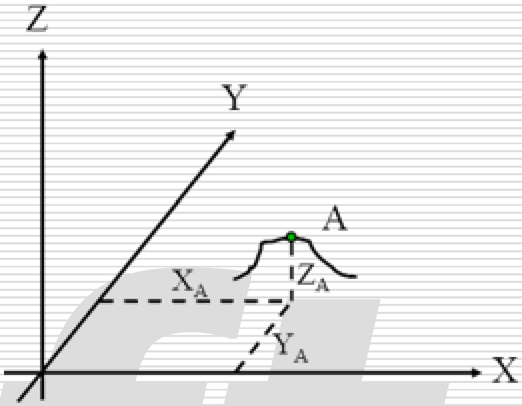


Image Coordinates

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Mathematical Model





$$x_a = f_x(X_A, Y_A, Z_A, \dots\dots\dots)$$
$$y_a = f_y(X_A, Y_A, Z_A, \dots\dots\dots)$$

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Mathematical Model

Collinearity Equations

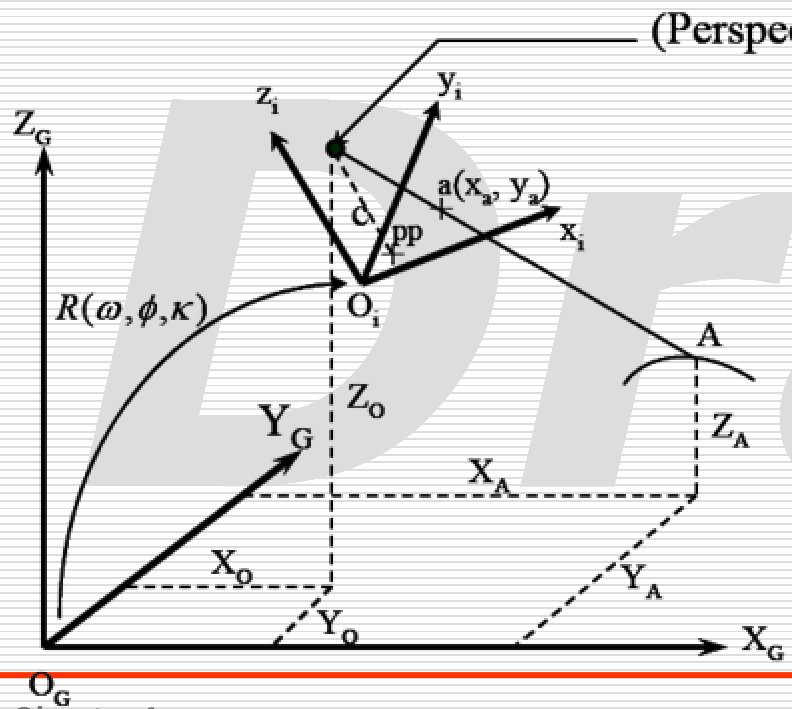
Objective:

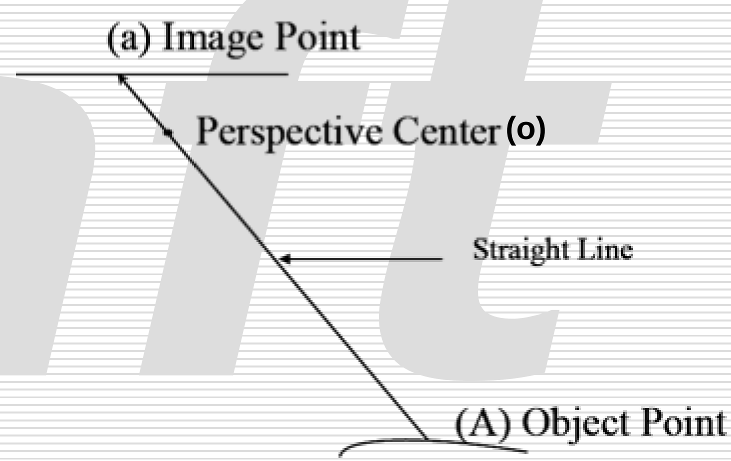
- *Mathematically represent the general relationship between image and ground coordinates.*

$$\vec{oa} = \lambda \ \vec{oA}$$

Concept:

- *Image Point, Object Point, and the Perspective Center are collinear.*





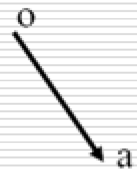
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Mathematical Model

Collinearity Equations

1. The vector connecting the perspective center to the image point

$$\vec{v}_i = \begin{bmatrix} x_a \\ y_a \\ 0 \end{bmatrix} - \begin{bmatrix} x_p \\ y_p \\ c \end{bmatrix} = \begin{bmatrix} x_a - x_p \\ y_a - y_p \\ -c \end{bmatrix}$$



In the image coordinate system

2. The vector connecting the perspective center to the object point

$$\vec{V}_o = \begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} - \begin{bmatrix} X_O \\ Y_O \\ Z_O \end{bmatrix} = \begin{bmatrix} X_A - X_O \\ Y_A - Y_O \\ Z_A - Z_O \end{bmatrix}$$

In the ground coordinate system

These vectors should be defined in the same coordinate system.

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Mathematical Model

Collinearity Equations

$$\vec{v}_i = \lambda \ M(\omega, \phi, \kappa) \ \vec{V}_O$$

$$\begin{bmatrix} x_a - x_p \\ y_a - y_p \\ -c \end{bmatrix} = \lambda \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} X_A - X_O \\ Y_A - Y_O \\ Z_A - Z_O \end{bmatrix}$$

Where: λ is a scale factor

$$x_a = x_p - c\frac{m_{11}(X_A - X_O) + m_{12}(Y_A - Y_O) + m_{13}(Z_A - Z_O)}{m_{31}(X_A - X_O) + m_{32}(Y_A - Y_O) + m_{33}(Z_A - Z_O)}$$

$$y_a = y_p - c\frac{m_{21}(X_A - X_O) + m_{22}(Y_A - Y_O) + m_{23}(Z_A - Z_O)}{m_{31}(X_A - X_O) + m_{32}(Y_A - Y_O) + m_{33}(Z_A - Z_O)}$$

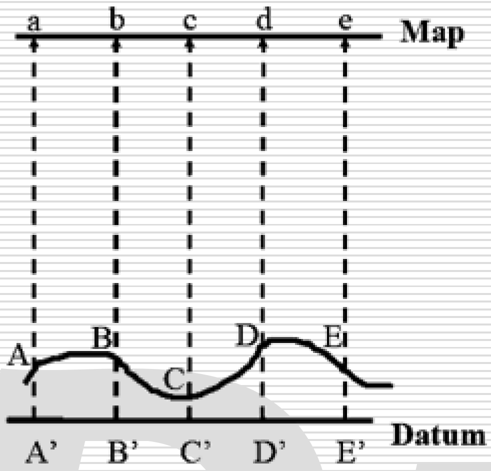
Involved parameters:

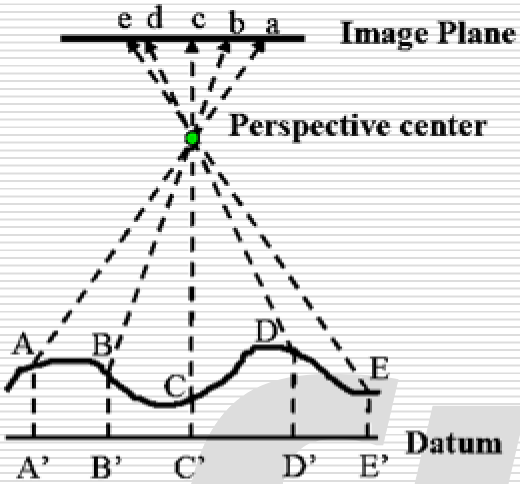
- *Image coordinates (x_a, y_a).*
- *Ground coordinates (X_A, Y_A, Z_A).*
- *Exterior Orientation Parameters (X_O, Y_O, Z_O, ω, φ, κ).*
- *Interior Orientation Parameters (x_p, y_p, c).*

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation

Maps Versus Images





- Orthogonal projection.
- Uniform scale.
- No relief displacement

- Perspective projection.
- Non-uniform scale.
- Relief displacement.

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

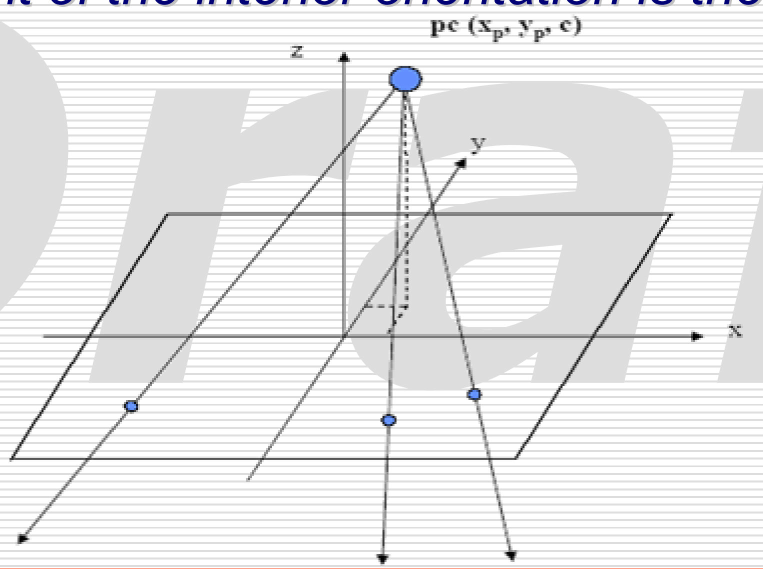
Theory of Orientation

Interior Orientation

- *Purpose: Reconstruct the bundle of light rays (as defined by the perspective center and the image points) in such a way that it is similar to the incident bundle on the camera at the moment of exposure.*

- *Interior orientation is defined by the position of the perspective center in the image plane (x_p, y_p, c).*

- *Another component of the interior orientation is the distortion parameters*



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Distortion Parameters

Assumed perspective geometry: the perspective center, the object point, and the corresponding image point are collinear.

During camera calibration, we try to compensate for all deviations from the assumed perspective geometry:

- *Radial Lens Distortion.*
- *Decentric Lens Distortion.*
- *Atmospheric Refraction.*
- *Affine Deformations.*
- *Out of Plane Deformations.*

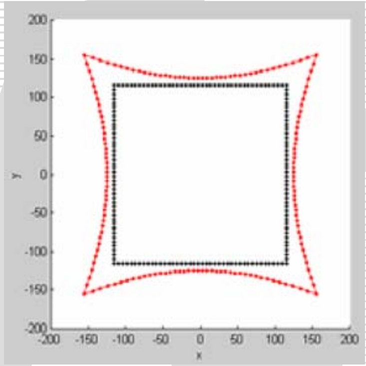
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Interior Orientation

Distortion Parameters

Radial Lens Distortion

- The light ray changes its direction after passing through the perspective center.
- Radial lens distortion is caused by:
  - – Large off-axial angle.
  - – Lens manufacturing flaws.
- Radial lens distortion occurs along a radial direction from the nadir point.
- Radial lens distortion increases as we move away from the nadir point.



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Interior Orientation

Distortion Parameters

Radial Lens Distortion

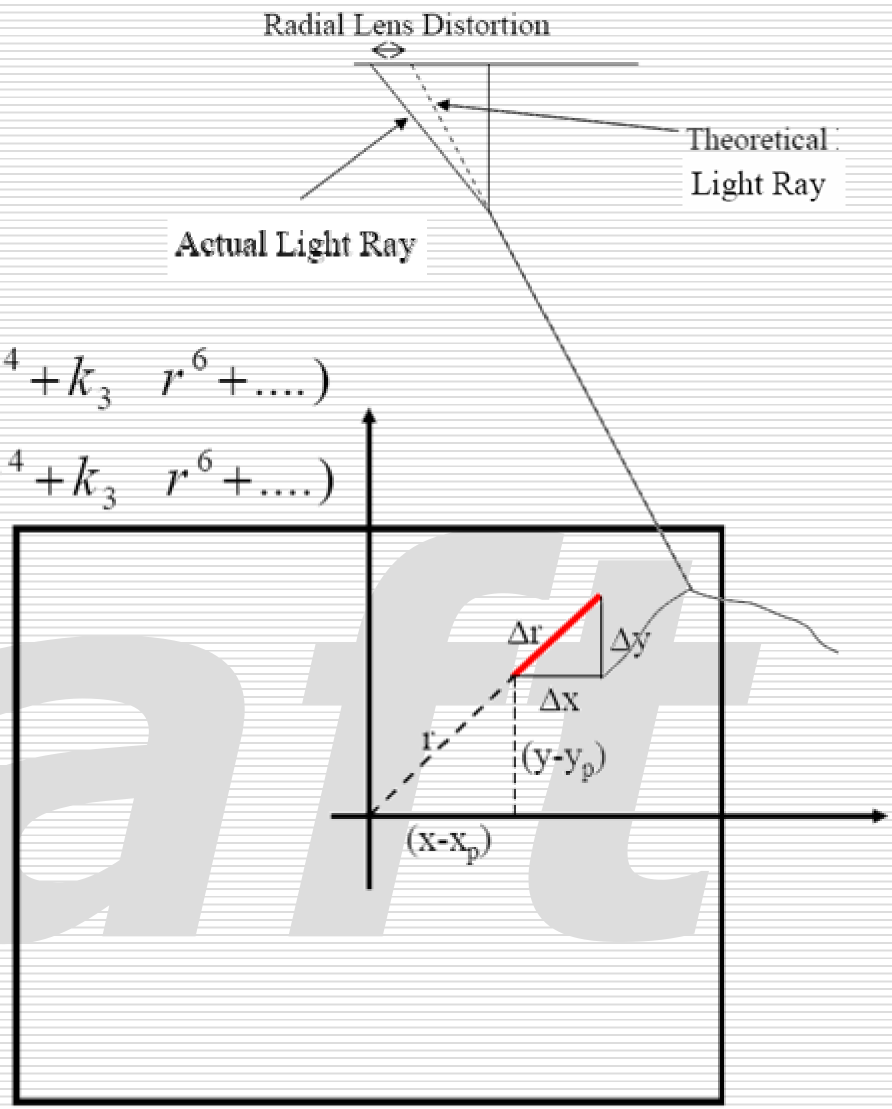
$$\Delta x = \Delta r * (x - x_p) / r$$

$$\Delta y = \Delta r * (y - y_p) / r$$

$$\Delta x_{Radial\ Lens\ Distortion} = x (k_1 r^2 + k_2 r^4 + k_3 r^6 + \ldots)$$

$$\Delta y_{Radial\ Lens\ Distortion} = y (k_1 r^2 + k_2 r^4 + k_3 r^6 + \ldots)$$

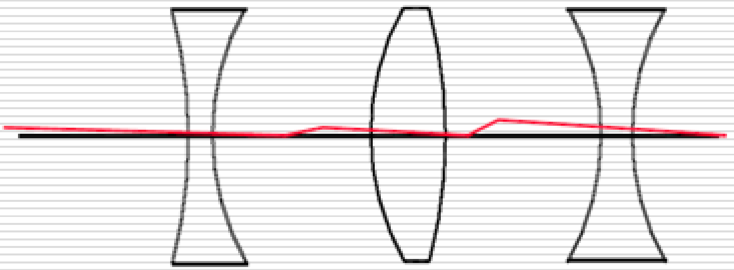
where: $r = \{(x - x_p)^2 + (y - y_p)^2\}^{0.5}$



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

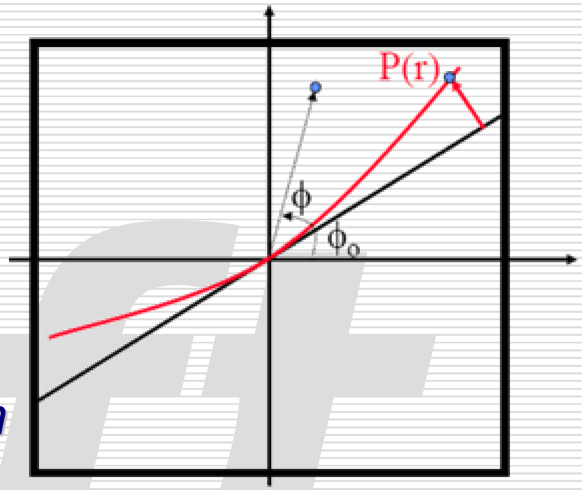
Theory of Orientation - Interior Orientation

Distortion Parameters



Decentric Lens Distortion

- Decentric lens distortion is caused by miss alignment of the components of the lens system.
- Decentric lens distortion has two components:
  - Radial component.
  - Tangential component.



- P (r) is the profile along the axis with the maximum tangential distortion.
- φ_o is the direction of the axis with the maximum tangential distortion.

$$P(r) = J_1 r^2 + J_2 r^4 + \ldots\ldots\ldots$$

$$\Delta r = 3\ P(r)\ \sin(\phi - \phi_o)$$

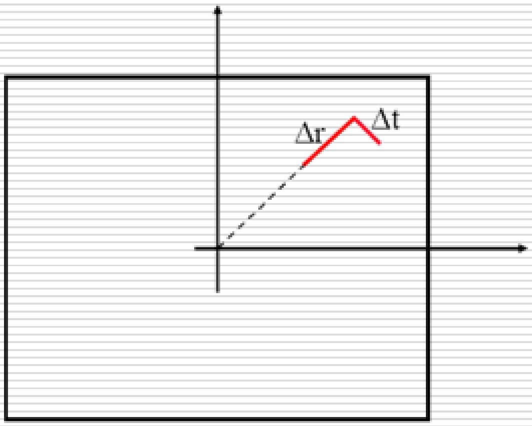
$$\Delta t = P(r)\ \cos(\phi - \phi_o)$$

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation -Interior Orientation

Distortion Parameters

Decentric Lens Distortion

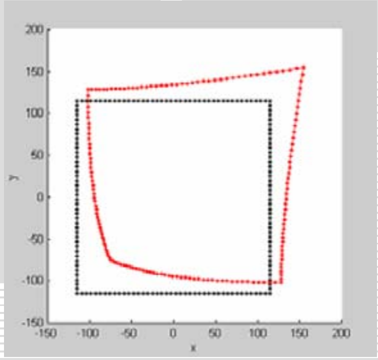


$$\Delta x_{Decentric\ Lens\ Distortion} = (1 + p_3^2 r^2)\{p_1(r^2 + 2x^2) + 2p_2 x\ y\}$$

$$\Delta y_{Decentric\ Lens\ Distortion} = (1 + p_3^2 r^2)\{2p_1 x\ y + p_2(r^2 + 2y^2)\}$$

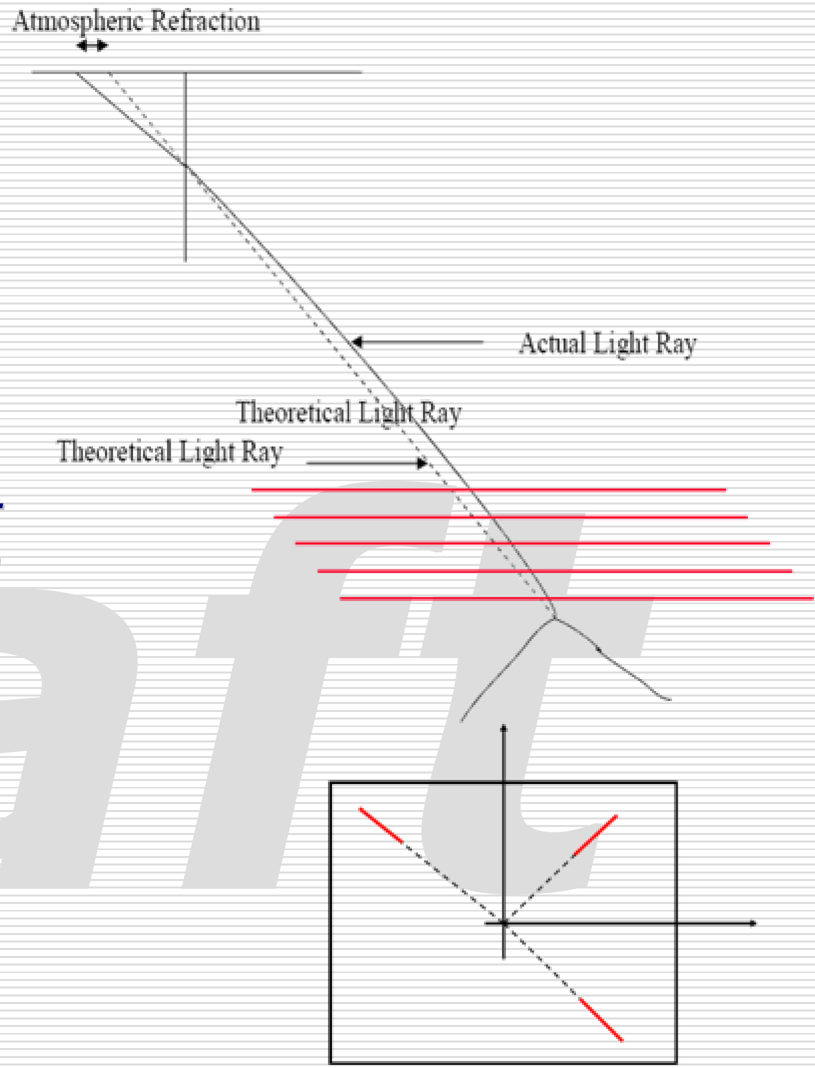
where: $r = \{(x - x_p)^2 + (y - y_p)^2\}^{0.5}$

- $p_1 = -J_1 \sin\phi_o$.
- $p_2 = J_1 \cos\phi_o$.
- $p_3 = J_2 / J_1$.



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Distortion Parameters



Atmospheric Refraction

- *The light ray from the object point to the perspective center passes through layers with different temperature, pressure and humidity.*
  - *Each layer has its own refractive index.*
  - *Consequently, the light ray will follow a curved not a straight path.*
  - *The distortion occurs along the radial direction from the nadir point.*
- *It increases as the radial distance increases.*

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Interior Orientation

Distortion Parameters

Atmospheric Refraction

- K: is the atmospheric refraction coefficient. $\Delta r = k\, r\, \{1 + r^2 / c^2\}$
- Image points are always displaced outwardly along the radial direction.
- The above equation is only valid for almost vertical photography.

$$k = 0.00241 \left\{ \frac{Z_o}{Z_o^2 - 6\, Z_o + 250} - \frac{Z^2}{Z_o(Z^2 - 6\, Z + 250} \right\}$$

$$\Delta x = k\ x\ (\frac{r^2}{c^2} + 1)$$

$$\Delta y = k\ y\ (\frac{r^2}{c^2} + 1)$$

Where Z & Z_0 are in Km above the sea level

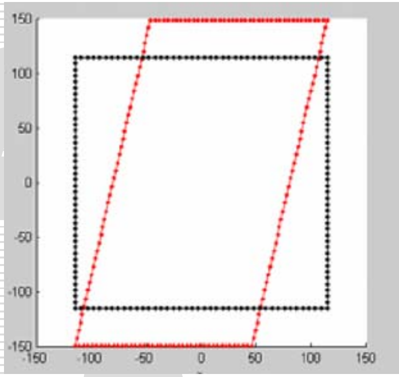
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Distortion Parameters

Affine Deformations

Affine Deformations in the focal plane will be manifested in:

- Non-uniform scale along the x and y directions.
- Non orthogonality between the xy-axes.



$$\Delta x_{AD} = -A_1\ x + A_2\ y$$

$$\Delta y_{AD} = A_1\ y$$

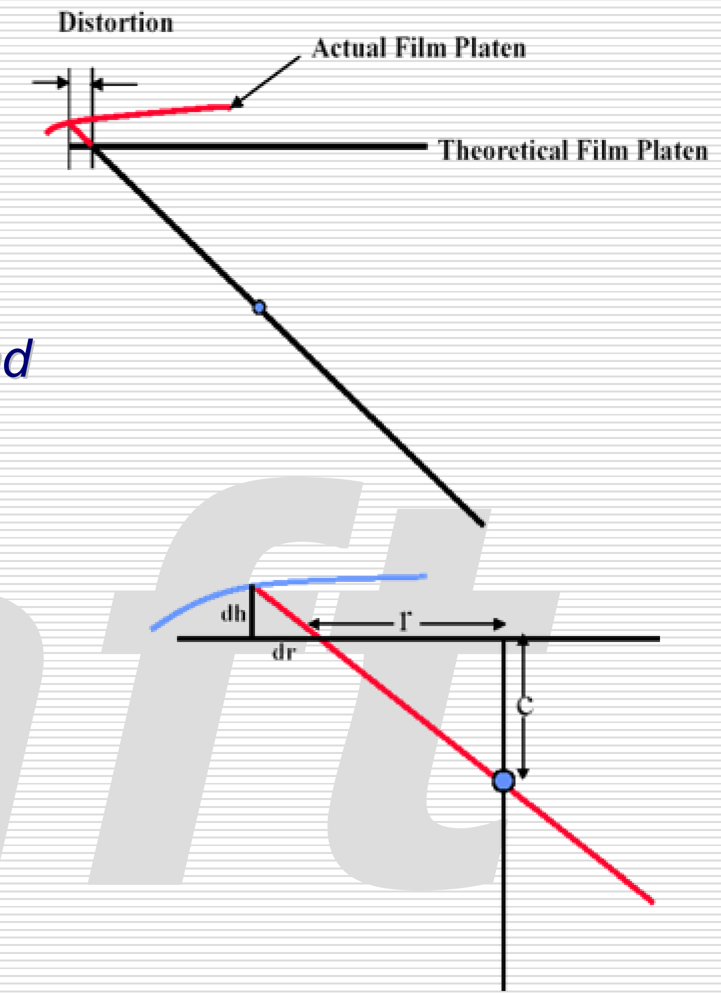
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Interior Orientation

Distortion Parameters

Non Planar Film Platen

- *dh: The deviation of the film platen from a perfect plane.*
- *Using height gages, dh can be measured and modeled by a high order polynomial.*
- *We can assure that the film is positioned tightly against the focal plane using either:*
  - *Glass plates (not recommended).*
  - *Suction mechanisms.*



$$r/c = dr/dh$$
$$dr = dh * r/c$$

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Interior Orientation

Mathematical Model

$$x_a = x_p - c\frac{r_{11}(X_A - X_O) + r_{21}(Y_A - Y_O) + r_{31}(Z_A - Z_O)}{r_{13}(X_A - X_O) + r_{23}(Y_A - Y_O) + r_{33}(Z_A - Z_O)} + \Delta x$$

$$y_a = y_p - c\frac{r_{12}(X_A - X_O) + r_{22}(Y_A - Y_O) + r_{32}(Z_A - Z_O)}{r_{13}(X_A - X_O) + r_{23}(Y_A - Y_O) + r_{33}(Z_A - Z_O)} + \Delta y$$

$$\Delta x = \Delta x_{\text{Radial Lens Distortion}} + \Delta x_{\text{Decentric Lens Distortion}} + \Delta x_{\text{Atmospheric Refraction}} + \Delta x_{\text{Affine Deformation}} + \text{etc....}$$

$$\Delta y = \Delta y_{\text{Radial Lens Distortion}} + \Delta y_{\text{Decentric Lens Distortion}} + \Delta y_{\text{Atmospheric Refraction}} + \Delta y_{\text{Affine Deformations}} + \text{etc....}$$

$$\Delta x_{\text{Radial Lens Distortion}} = x_t(k_1 r_t^2 + k_2 r_t^4 + k_3 r_t^6 + \ldots)$$

$$\Delta y_{\text{Radial Lens Distortion}} = y_t(k_1 r_t^2 + k_2 r_t^4 + k_3 r_t^6 + \ldots)$$

where: $r = \{(x_t - x_p)^2 + (y_t - y_p)^2\}^{0.5}$

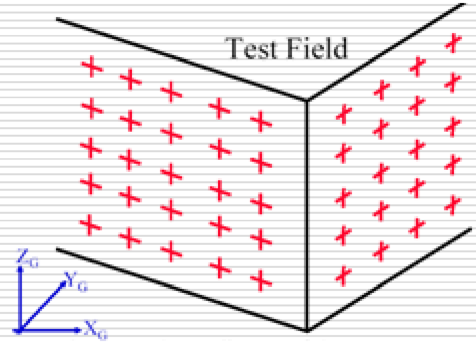
$$\Delta x_{\text{Decentric Lens Distortion}} = (1 + p_3^2 r_t^2)\{p_1(r_t^2 + 2x_t^2) + 2p_2 x_t y_t\}$$

$$\Delta y_{\text{Decentric Lens Distortion}} = (1 + p_3^2 r_t^2)\{2p_1 x_t y_t + p_2(r_t^2 + 2y_t^2)\}$$

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Interior Orientation

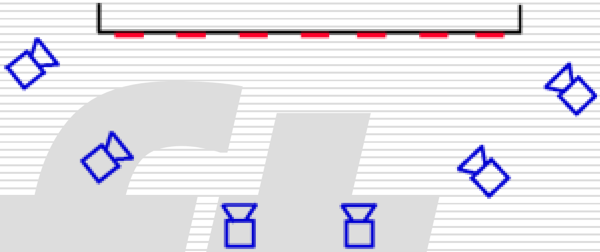
Analytical Camera Calibration

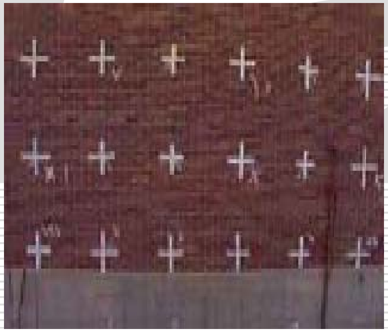


The ground coordinates of those targets are accurately surveyed using geodetic measurements.

Sample

- Aerial Calibration Test Field



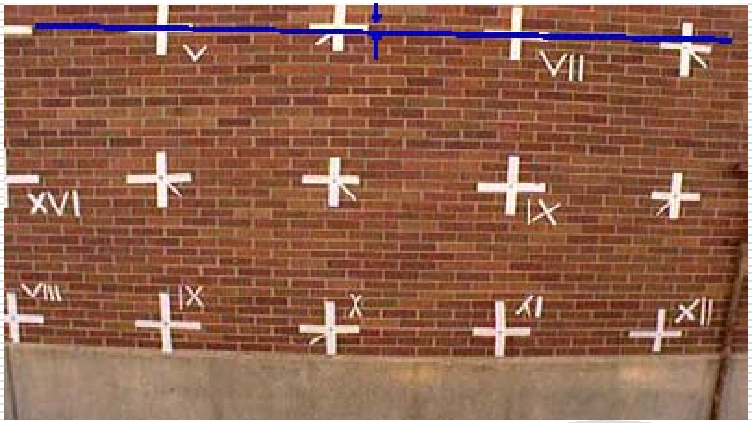


Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

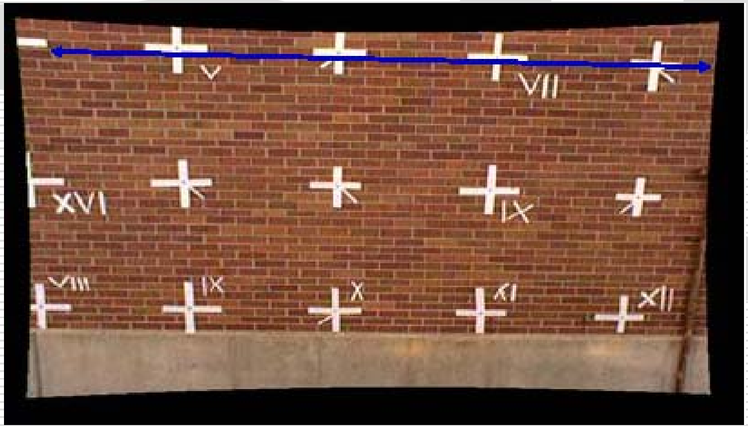
Theory of Orientation - Interior Orientation

Analytical Camera Calibration

Before Calibration



After Calibration



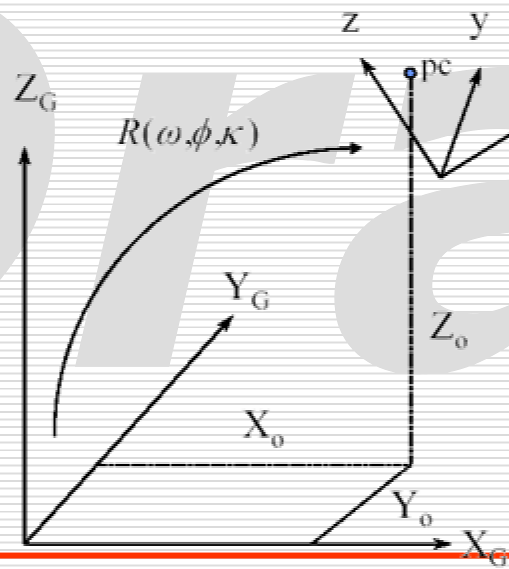
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Exterior Orientation

Exterior Orientation has two components:

- The position of the perspective center in the ground coordinate system (X_o, Y_o, Z_o).
- The rotational relationship between the image and the ground coordinate systems (ω, φ, κ).

These are the rotation angles we need to apply to the ground coordinate system to make it parallel to the image coordinate system.



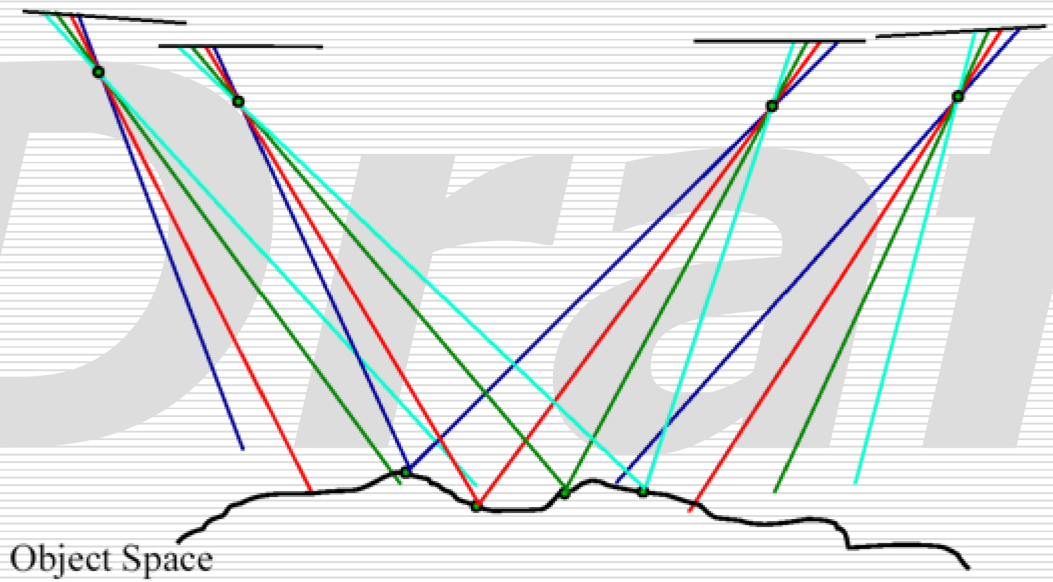
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Exterior Orientation

Stereo Pair

Exterior Orientation of a stereo pair is defined by 12 parameters and can be decomposed into:

- *Relative Orientation (five parameters).*
- *Absolute Orientation (seven parameters).*

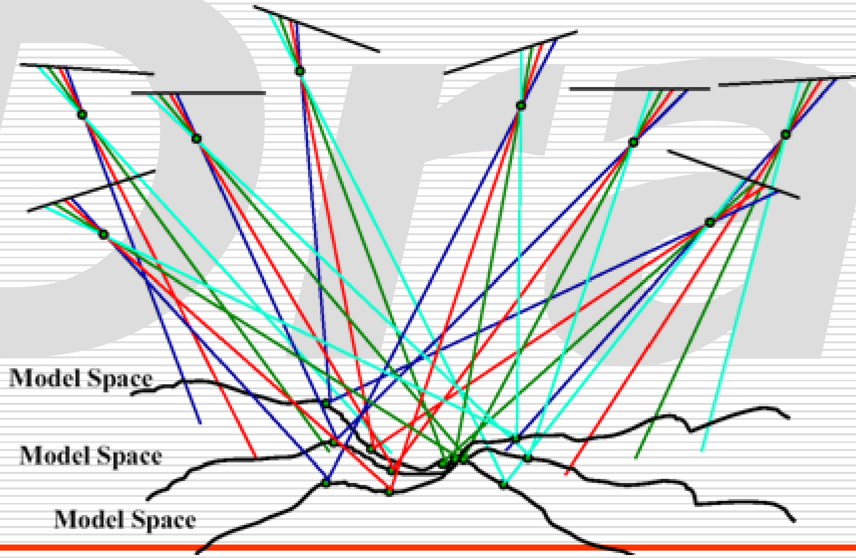


Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation - Exterior Orientation

Stereo Pair

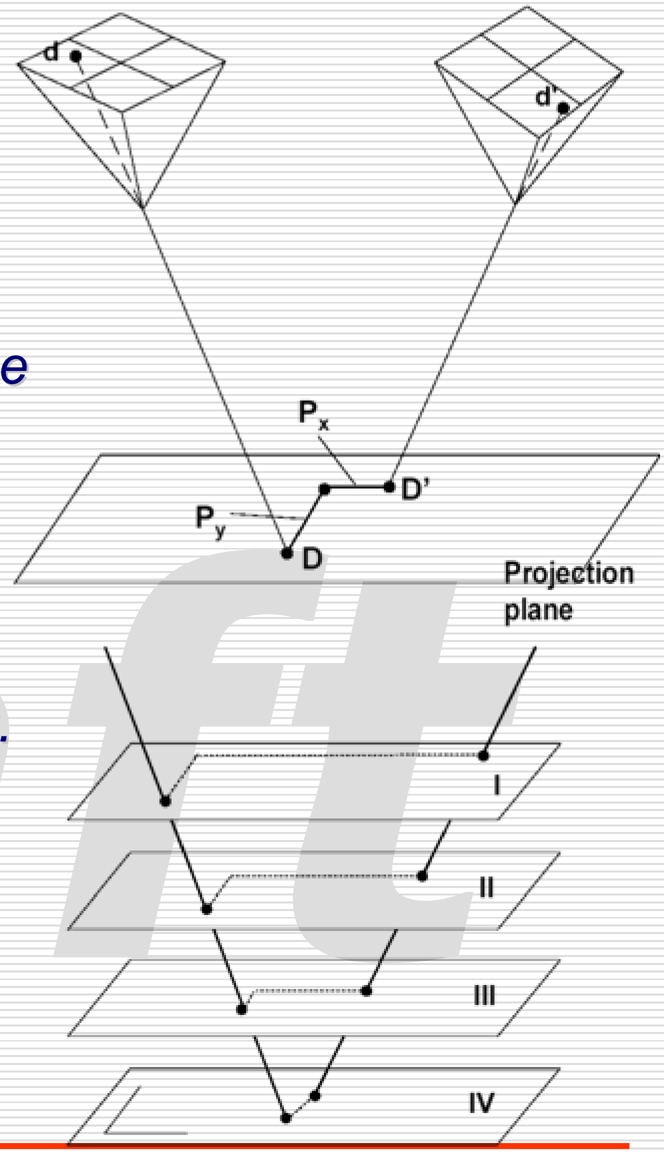
- Objective: Orient the two bundles of a stereo pair relative to each other in such a way that all conjugate light rays intersect.
- Result: A stereo Model, which is a 3-D representation of the object space w.r.t. an arbitrary local coordinate system.
- If we make at least five conjugate light rays intersect, all the remaining light rays will intersect at the surface of the stereo-model.



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation

x-parallax & y-parallax



Two conjugate light rays will be separated at any projection plane (DD`).

This separation can be decomposed into:

- x-parallax (along the base connecting the two perspective centers).
- y-parallax (along the perpendicular direction).

x-parallax is responsible for depth perception.

During relative orientation, we clear the y-parallax.

X-Parallax & Height

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation

Relative Orientation of a Stereo-Pair

Question: – Do we need ground control points to establish the relative orientation?

Answer: – No.

Question: – What do we need to establish the relative orientation?

Answer: – Measure the image coordinates of at least five tie points. (why?)

Question: – How can we establish the relative orientation?

Answer: – For a stereo-pair, we have 12 degrees of freedom to position and orient the two bundles of a stereopair in space.

– X_{ol}, Y_{ol}, Z_{ol}, ω_l, φ_l, κ_l .

– X_{or}, Y_{or}, Z_{or}, ω_r, φ_r, κ_r .

These twelve parameters establish the relative and absolute orientation of that stereo-pair.

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Relative Orientation of a Stereo-Pair

- *The absolute orientation establishes the ground coordinate system (datum).*
- *Any ground coordinate system is defined by:*
  – Origin (three parameters).
  – Orientation in space (three parameters).
  – Scale (how long is one unit along the axes of this coordinate system - one parameter).
- *For relative orientation, we can define any arbitrary coordinate system (model coordinate system).*
- *Therefore, we need to fix seven parameters (out of the twelve) to any arbitrary values. During relative orientation, we solve for the remaining five parameters.*
- *Alternatives for Relative Orientation (RO):*
  - *– Dependent Relative Orientation.*
  - *– Independent Relative Orientation.*

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation

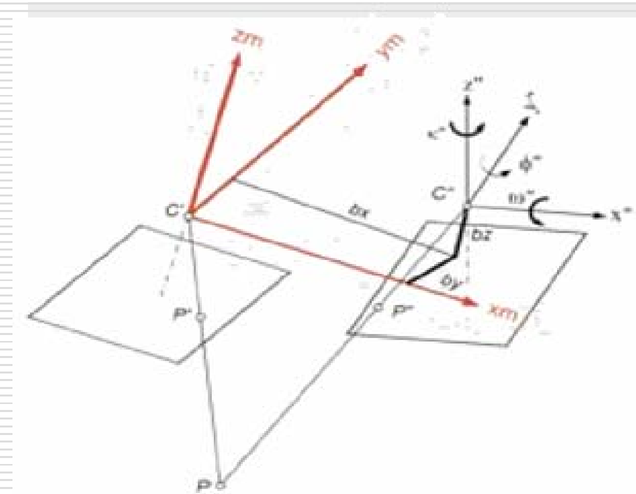
Dependent Relative Orientation

Fix the following parameters to any arbitrary values:

– X_{ol}, Y_{ol}, Z_{ol}, ω_l, φ_l, κ_l, X_{or}.

Solve for:

– Y_{or}, Z_{or}, ω_r, φ_r, κ_r.



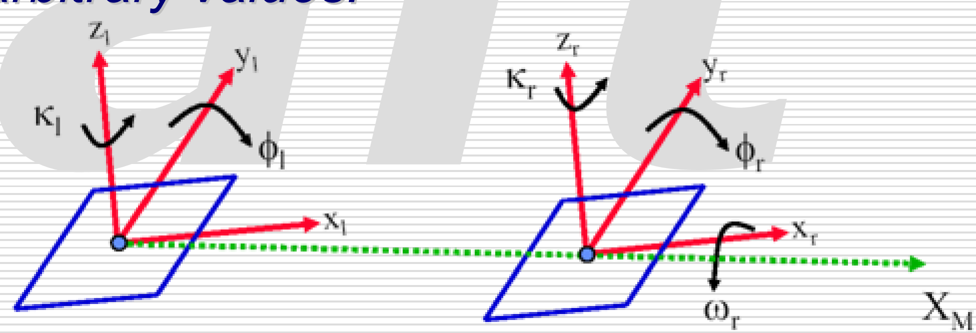
Independent Relative Orientation

Fix the following parameters to any arbitrary values:

– X_{ol}, Y_{ol}, Z_{ol}, ω_l, X_{or}, Y_{or}, Z_{or}.

Solve for:

– φ_l, κ_l, ω_r, φ_r, κ_r.



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation

Absolute Orientation

Purpose:

rotate, scale and shift the stereo model resulting from relative orientation) until it fits at the location of the control points.

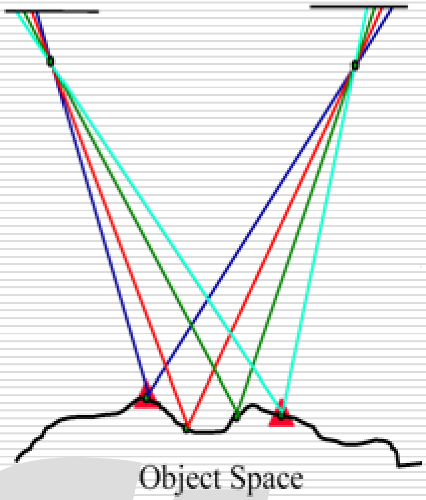
Absolute Orientation is defined by:

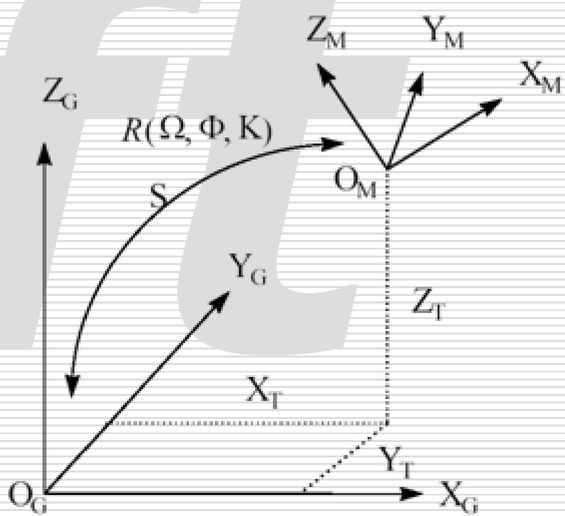
Three Rotations,

One Scale factor,

Three Shifts.

The absolute orientation is described mathematically by 3-D similarity transformation.





$$\begin{bmatrix} X_G \\ Y_G \\ Z_G \end{bmatrix} = \begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} + S \;\; R(\Omega\Phi\mathrm{K}) \begin{bmatrix} X_M \\ Y_M \\ Z_M \end{bmatrix}$$

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation

Resection

We are dealing with one image.

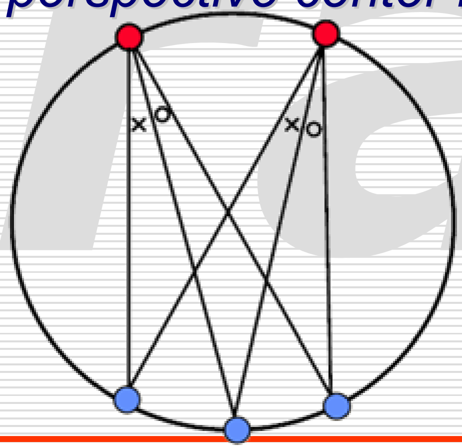
We would like to determine the EOP of this image using GCP.

Q: What is the minimum GCP requirements?

- At least 3 GCP are required to estimate the 6 EOP.
- At least 5 GCP are required to estimate the 6 EOP and the 3 IOP (x_p, y_p, c).

Critical surface:

- The GCP and the perspective center lie on a common cylinder.



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Theory of Orientation

Intersection

We are dealing with two images.

The EOP of these images are available.

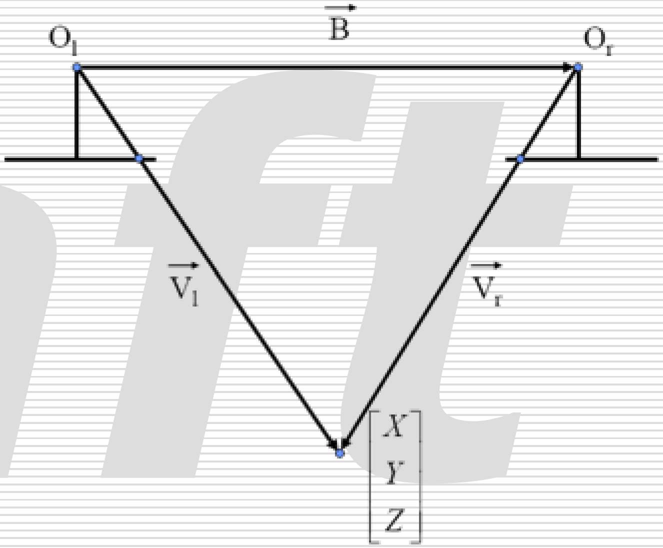
The IOP of the involved camera(s) are also available.

We want to estimate the ground coordinates of points in the overlap area.

For each tie point, we have:

- 4 Observation equations.
- 3 Unknowns.
- Redundancy = 1.

Non-linear model: approximations are needed.



Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

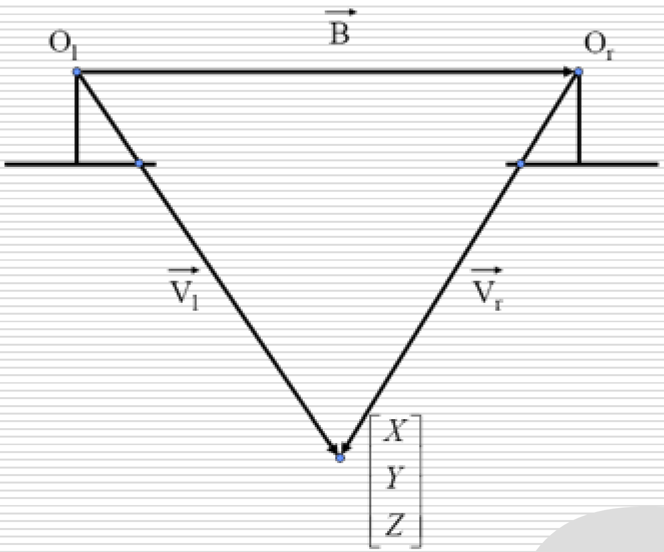
Theory of Orientation

Intersection

$$\vec{V}_l = \lambda\, R_{(\omega_l,\phi_l,\kappa_l)} \begin{bmatrix} x_l - x_p \\ y_l - y_p \\ -c \end{bmatrix}$$

$$\vec{V}_r = \mu\, R_{(\omega_r,\phi_r,\kappa_r)} \begin{bmatrix} x_r - x_p \\ y_r - y_p \\ -c \end{bmatrix}$$

$$\vec{B} = \begin{bmatrix} X_{O_r} - X_{O_l} \\ Y_{O_r} - Y_{O_l} \\ Z_{O_r} - Z_{O_l} \end{bmatrix}$$



$$\vec{V}_l = \vec{B} + \vec{V}_r$$

$$\begin{bmatrix} X_{O_r} - X_{O_l} \\ Y_{O_r} - Y_{O_l} \\ Z_{O_r} - Z_{O_l} \end{bmatrix} = \lambda\, R_{(\omega_l,\phi_l,\kappa_l)} \begin{bmatrix} x_l - x_p \\ y_l - y_p \\ -c \end{bmatrix} - \mu\, R_{(\omega_r,\phi_r,\kappa_r)} \begin{bmatrix} x_r - x_p \\ y_r - y_p \\ -c \end{bmatrix} \rightarrow$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{O_l} \\ Y_{O_l} \\ Z_{O_l} \end{bmatrix} + \lambda\, R_{(\omega_l,\phi_l,\kappa_l)} \begin{bmatrix} x_l - x_p \\ y_l - y_p \\ -c \end{bmatrix}$$

or

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{O_r} \\ Y_{O_r} \\ Z_{O_r} \end{bmatrix} + \mu\, R_{(\omega_r,\phi_r,\kappa_r)} \begin{bmatrix} x_r - x_p \\ y_r - y_p \\ -c \end{bmatrix}$$

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Resection - Intersection

Given:

- Stereo-pair: two images with at least 50% overlap.
- Image coordinates of some tie points.
- Image and ground coordinates of control points.

Required:

- The ground coordinates of the tie points.
- The EOP of the involved images.

It is like Mini-Bundle Adjustment Procedure.

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Photogrammetric Block Adjustment

Non-Traditional Sensors

Farhad Samadzadegan, Ph.D
Department of Surveying and Geomatics Engineering,
Faculty of Engineering, University of Tehran
Email: samadz@ut.ac.ir
2006

Introduction

Digital Sensors

Digital frame cameras

Limitation of digital frame cameras:

– Small array size: There is no digital frame camera commercially available that has geometric and radiometric resolutions similar to these associated with metric analog cameras.

Linear array scanners

Alternative: Linear array scanners (line cameras).

– Single push broom scanners (SPOT, IKONOS).

– Three-line scanners (MOMS, ADS40).

– Panoramic linear array scanners.

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Introduction

Multi-Sensor Photogrammetric Triangulation

Objective:

– Reconstruct the object space from imagery.

– To create an environment capable of integrating data from all the above mentioned sensors.

Mathematical Model:

– Collinearity equations.

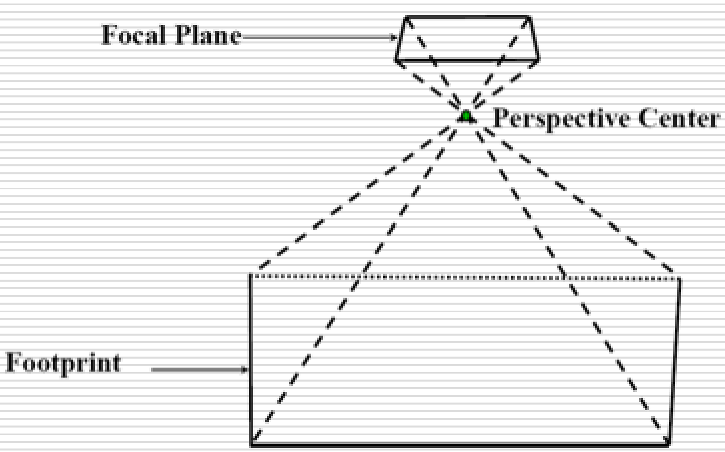
The perspective geometry for three-line scanners, single push broom scanners, and frame imagery can be derived as special cases of that associated with panoramic linear array scanners.

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Digital Frame Camera

The Digital Mapping Frame Camera

- Digital frame camera developed by Z/I Imaging
- The Digital Mapping Camera (DMC™) system is a turnkey digital camera designed to support aerial photogrammetric missions.
- Resolution: 14kx8k.
- The image footprint is captured through a single exposure.
- Math Model: Collinearity Equations (Frame Camera)

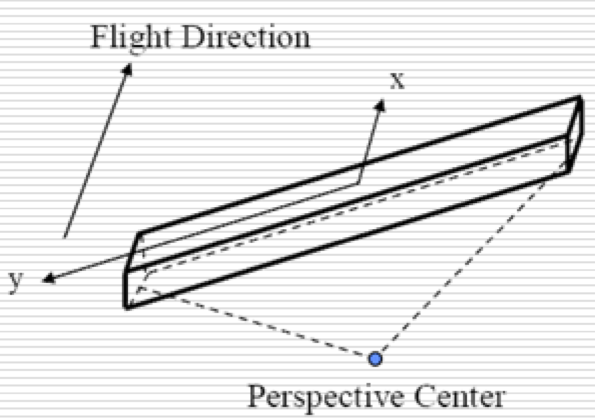


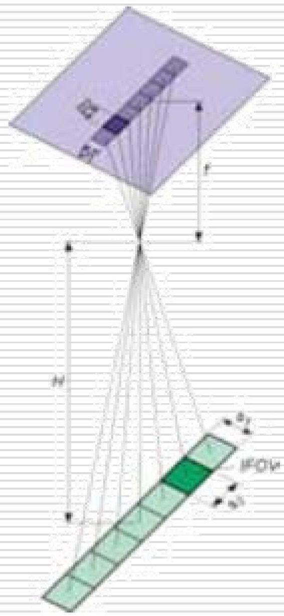
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Line Camera

Linear Array Scanners

- Digital frame cameras capture images through a single exposure of a two-dimensional CCD array.
- Linear array scanners capture scenes with large ground coverage and high geometric and radiometric resolutions through multiple exposures of few scan lines along the focal plane.



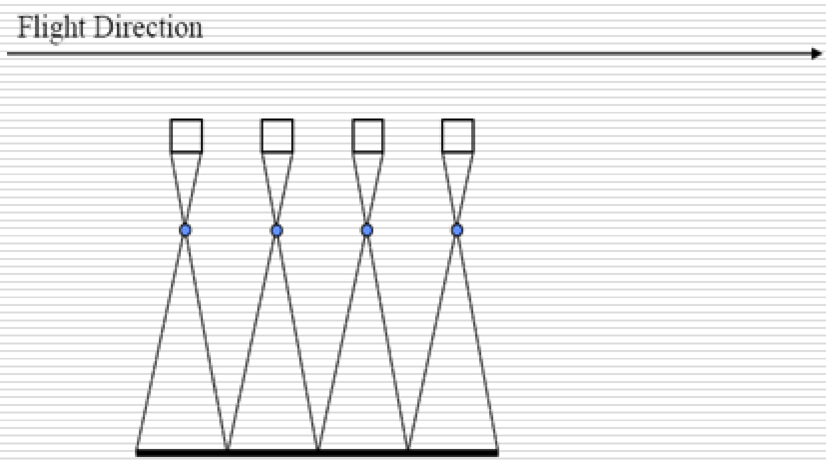


Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Line Camera

Linear Array Scanners

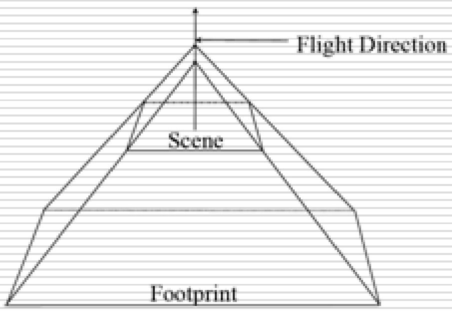
- Successive coverage of different areas on the ground is achieved either through:
  - The motion of the imaging platform.
  - The motion of the sensor relative to the imaging platform.
- The scene footprint is captured through multiple exposures.

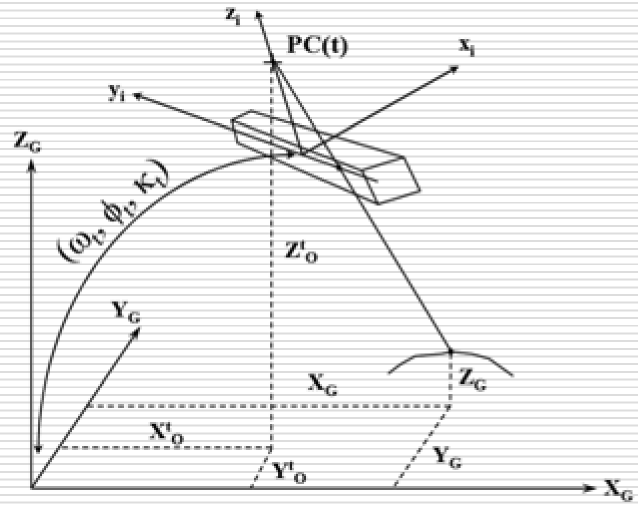


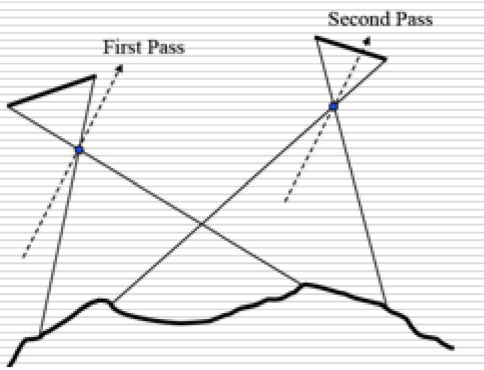
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Line Camera

Single Line Scanner

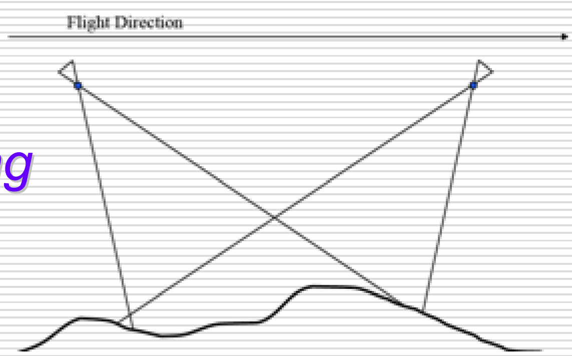






Stereo coverage is achieved by tilting the sensor across the flight direction.

SPOT Stereo Coverage



Stereo coverage is achieved by tilting the sensor along the flight direction.

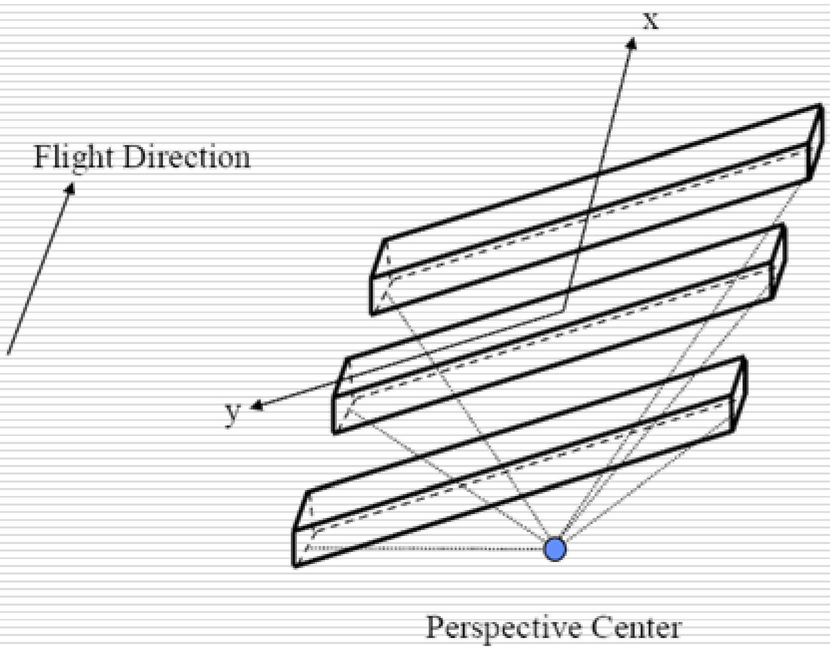
IKONOS Stereo-Coverage

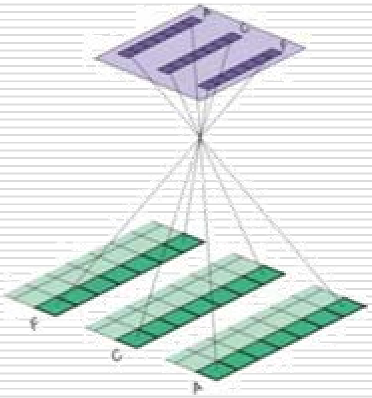
Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

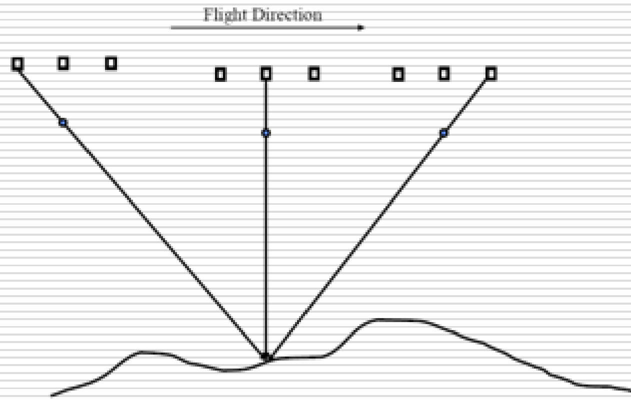
Line Camera

Three-Line Scanner

- *Triple coverage is achieved by having three scanners in the focal plane.*







Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Line Camera

Stereo Coverage of Single/Three-Line Push Broom Scanners:

- *Stereo coverage can be obtained through:*
  - *Tilting the sensor across the flight direction (SPOT).*
- *The stereo is captured in two different orbits.*
- *Problem: Significant time gap between the stereo images (possible variations in the object space and imaging conditions).*
  - *Tilting the sensor along the flight direction (IKONOS).*
- *The stereo is captured along the same orbit.*
- *Short time gap between the stereo-images (few seconds).*
- ***Problem:** reduced geometric resolution (scale = f * cos(α) / H).*
- ***Problem:** Non-continuous stereo-coverage*

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Line Camera

Stereo Coverage of Single/Three-Line Push Broom Scanners:

- Stereo coverage can be obtained through:
  - – Implementing more than one scan line in the focal plane (MOMS & ADS 40).
- The stereo images are captured along the same flight line.
- For three-line scanners, triple coverage is possible.
- Short time gap between the stereo images (few seconds).
- Continuous stereo/triple coverage.
- Same geometric resolution (scale = f/H).
- Problem: Reduced radiometric quality for the forward and backward looking scanners (quality degrades as we move away from the camera optical axis).

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

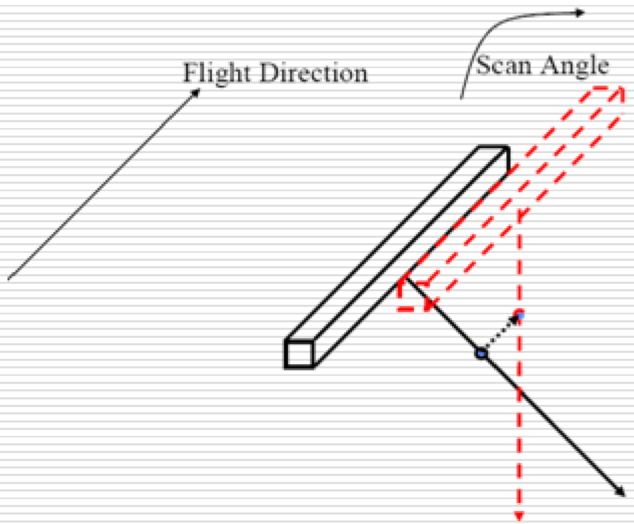
Line Camera

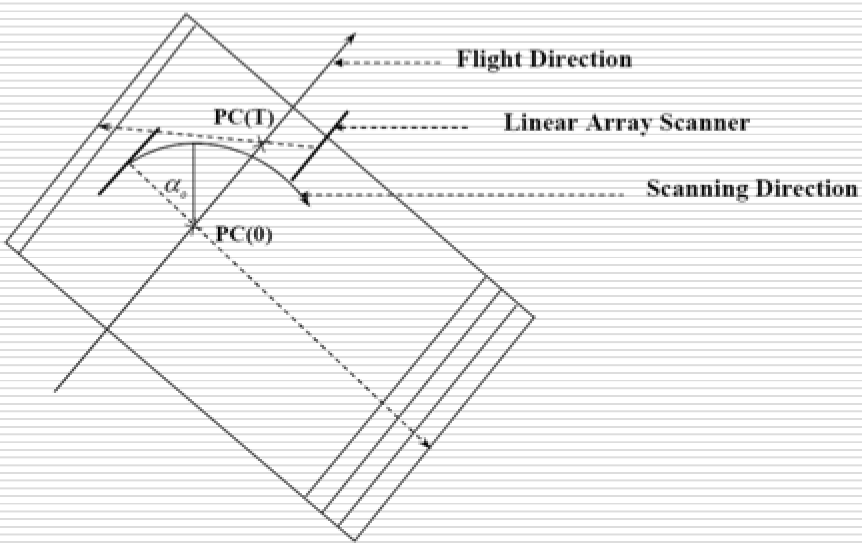
Panoramic Linear Array Scanner

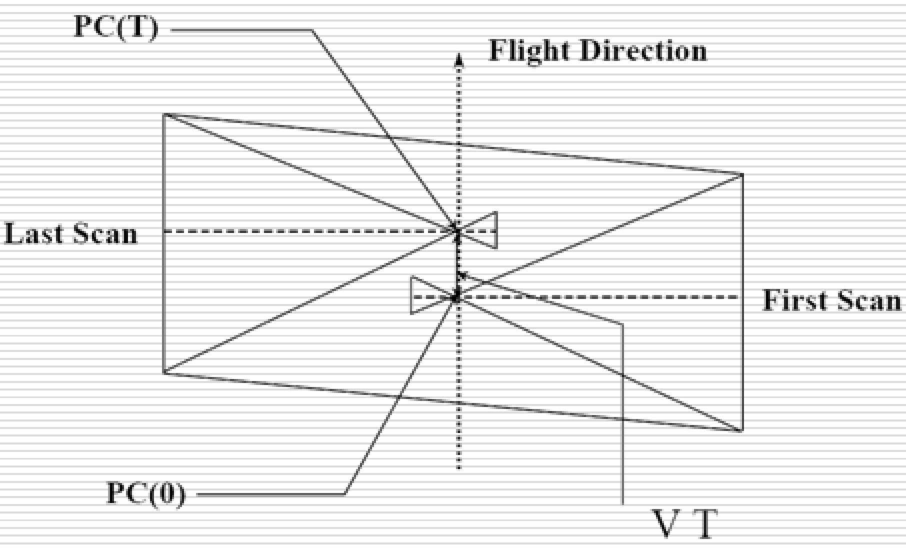
The scan line is parallel to the flight direction.

Coverage of successive areas on the ground is established by rotating the sensor across the flight direction.

The imaging platform moves forward as we rotate the scan line across the flight direction.



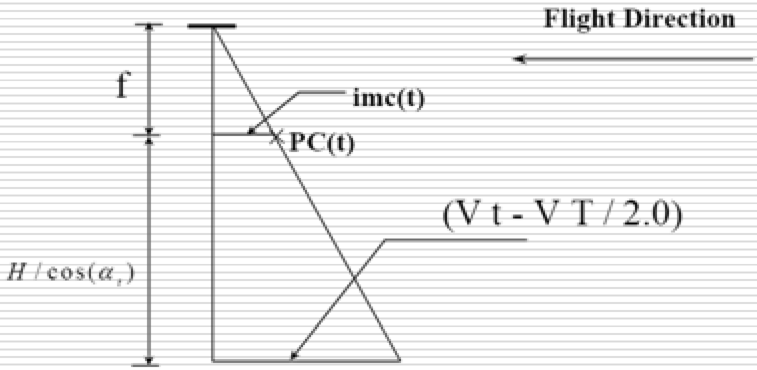




Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran

Line Camera

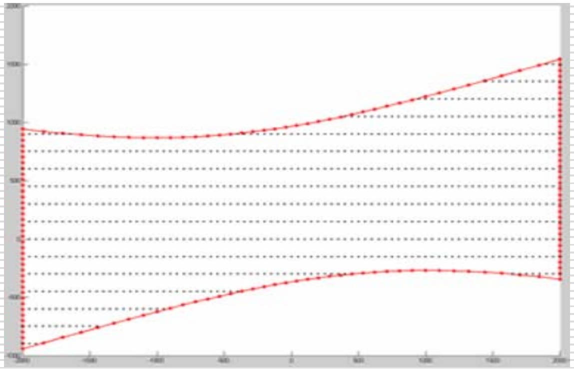
Panoramic Linear Array Scanner
Image Motion Compensation



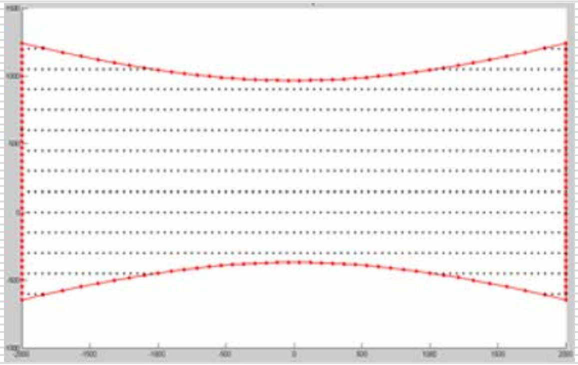
$$imc(t) = (Vt - VT/2)\frac{f}{f + H/\cos(\alpha_t)} \approx (Vt - VT/2)\,\frac{f\cos(\alpha_t)}{H}$$

Scene Footprint

No Motion Compensation →



With Motion Compensation →



Stereo coverage for panoramic linear array

scanners can be obtained in the same way as frame cameras.

- *Overlap between successive images along the same flight line.*
- *Side lap between images along adjacent strips.*

Farhad Samadzadegan
Department of Surveying and Geomatics
Faculty of Engineering, University of Tehran