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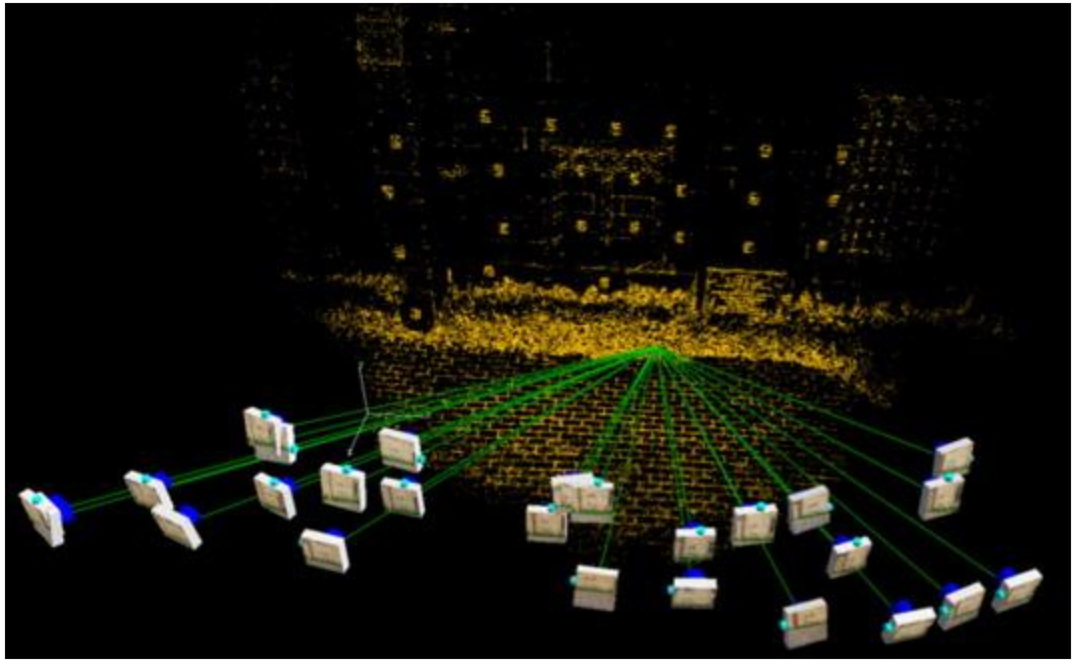

Close-Range Photogrammetry- Analytical Solution

BSc - 4th Stage

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Lecture 5

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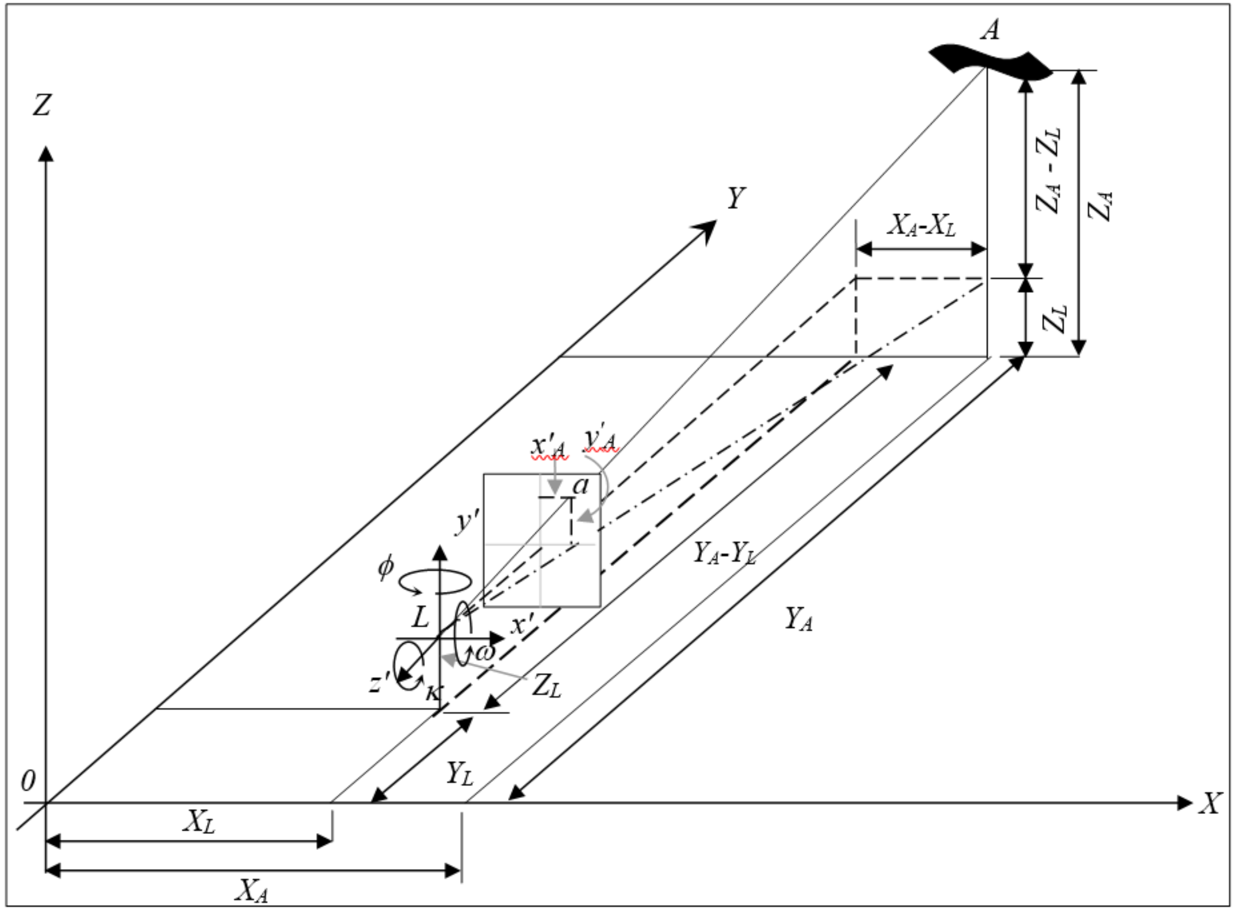
Analytical self-calibration Solution

- Collinearity condition equations.

$$x = -f * \left[\frac{m_{11}(X - X_L) + m_{12}(Z - Z_L) + m_{13}(Y_L - Y)}{m_{31}(X - X_L) + m_{32}(Z - Z_L) + m_{33}(Y_L - Y)} \right]$$

$$y = -f * \left[\frac{m_{21}(X - X_L) + m_{22}(Z - Z_L) + m_{23}(Y_L - Y)}{m_{31}(X - X_L) + m_{32}(Z - Z_L) + m_{33}(Y_L - Y)} \right]$$



Analytical self-calibration Solution

- Analytical self-calibration is a computational process where camera calibration parameters are included as unknowns in the photogrammetric solution, generally in a combined interior-relative absolute orientation referred to as a *self-calibrating bundle adjustment*.
- This process can be used for both aerial and terrestrial photos.
- The process of analytical self-calibration uses collinearity equations that have been augmented with additional terms to account for adjustment of the calibrated focal length, principal-point offsets, and symmetric radial and decentering lens distortions.

Analytical self-calibration Solution

- The classic form of the augmented collinearity equations is:

$$x_a = x_0 - \bar{x}_a\left(k_1 r_a^2 + k_2 r_a^4 + k_3 r_a^6\right) - \left(1 + p_3 r_a^2\right)\left[p_1\left(2\bar{x}_a^2 + r_a^2\right) + 2p_2\bar{x}_a\bar{y}_a\right] - f\frac{r}{q}$$

$$y_a = y_0 - \bar{y}_a\left(k_1 r_a^2 + k_2 r_a^4 + k_3 r_a^6\right) - \left(1 + p_3 r_a^2\right)\left[2p_1\bar{x}_a\bar{y}_a + p_2\left(2\bar{y}_a^2 + r_a^2\right)\right] - f\frac{s}{q}$$

where

x_a, y_a = measured photo coordinates related to fiducials

x_0, y_0 = coordinates of the principal point

$\bar{x}_a = x_a - x_0$

$\bar{y}_a = y_a - y_0$

$r_a^2 = \bar{x}_a^2 + \bar{y}_a^2$

k_1, k_2, k_3 = symmetric radial lens distortion coefficients

p_1, p_2, p_3 = decentering distortion coefficients

f = calibrated focal length

r, s, q = collinearity equation terms as defined in Eqs. (D-11) and (D-12)

$$q = m_{31}(X - X_L) + m_{32}(Z - Z_L) + m_{33}(Y_L - Y)$$
$$r = m_{11}(X - X_L) + m_{12}(Z - Z_L) + m_{13}(Y_L - Y)$$
$$s = m_{21}(X - X_L) + m_{22}(Z - Z_L) + m_{23}(Y_L - Y)$$

Linearization of collinearity CRP Equations

$$0=(F_1)_0+\left(\frac{\partial F_1}{\partial x}\right)_0 dx+\left(\frac{\partial F_1}{\partial \omega}\right)_0 d\omega+\left(\frac{\partial F_1}{\partial \phi}\right)_0 d\phi+\left(\frac{\partial F_1}{\partial \kappa}\right)_0 d\kappa$$
$$+\left(\frac{\partial F_1}{\partial X_L}\right)_0 dX_L+\left(\frac{\partial F_1}{\partial Z_L}\right)_0 dZ_L+\left(\frac{\partial F_1}{\partial Y_L}\right)_0 dY_L+\left(\frac{\partial F_1}{\partial X}\right)_0 dX$$
$$+\left(\frac{\partial F_1}{\partial Z}\right)_0 dZ+\left(\frac{\partial F_1}{\partial Y}\right)_0 dY$$

$$0=(F_2)_0+\left(\frac{\partial F_2}{\partial y}\right)_0 dy+\left(\frac{\partial F_2}{\partial \omega}\right)_0 d\omega+\left(\frac{\partial F_2}{\partial \phi}\right)_0 d\phi+\left(\frac{\partial F_2}{\partial \kappa}\right)_0 d\kappa$$
$$+\left(\frac{\partial F_2}{\partial X_L}\right)_0 dX_L+\left(\frac{\partial F_2}{\partial Z_L}\right)_0 dZ_L+\left(\frac{\partial F_2}{\partial Y_L}\right)_0 dY_L+\left(\frac{\partial F_2}{\partial X}\right)_0 dX$$
$$+\left(\frac{\partial F_2}{\partial Z}\right)_0 dZ+\left(\frac{\partial F_2}{\partial Y}\right)_0 dY$$

حيث أن :

$(F_1)_0$ and $(F_2)_0$: تمثل قيم المعادلتين (أ−9) و (أ−10) بعد تعويض القيمة التخمينية للمجاهيل فيهما .

$\left(\frac{\partial F_1}{\partial}\right) \& \left(\frac{\partial F_2}{\partial}\right)$: تمثل المشتقات الجزئية للدوال (F_1) و (F_2) على التوالي .

$dx, dy, d\omega, \dots,$: تمثل مقدار التصحيحات للمجاهيل .

بما أن (dx, dy) تمثل قيم التصحيحات للاحداثيات المقيسة على الصورة لذلك يمكن اعتبارها كخطأ متبقي للقياسات وعليه يصبح $(V_x=dx)$ و $(V_y=dy)$. بعد التعويض في المعادلتين (ب−9) و (ب−10) وتبسيطهما سيأخذان الشكل التالي :

$$V_x=b_{11}d\omega+b_{12}d\phi+b_{13}d\kappa-b_{14}dXL-b_{15}dZL+b_{16}dYL+b_{14}dX+b_{15}dZ-b_{16}dY+J \qquad (11\text{-أ})$$

$$V_y=b_{21}d\omega+b_{22}d\phi+b_{23}d\kappa-b_{24}dXL-b_{25}dZL+b_{26}dYL+b_{24}dX+b_{25}dZ-b_{26}dY+K \qquad (12\text{-أ})$$

Linearization of collinearity CRP Equations

$$b_{11} = \frac{x}{q}(-m_{33}\Delta Z + m_{32}\Delta Y) + \frac{f}{q}(-m_{13}\Delta Z + m_{12}\Delta Y)$$

$$b_{12} = \frac{x}{q}[\Delta X \cos\phi + \Delta Z(\sin\omega\cdot\sin\phi) + \Delta Y(-\sin\phi\cdot\cos\omega)] +$$

$$\frac{f}{q}[\Delta X(-\sin\phi\cdot\cos\kappa) + \Delta Z(\sin\omega\cdot\cos\phi\cdot\cos\kappa) + \Delta Y(-\cos\omega\cdot\cos\phi\cdot\cos\kappa)]$$

$$b_{13} = \frac{f}{q}(m_{21}\cdot\Delta X + m_{22}\cdot\Delta Z + m_{23}\cdot\Delta Y)$$

$$b_{14} = \frac{x}{q}(m_{31}) + \frac{f}{q}(m_{11})$$

$$b_{15} = \frac{x}{q}(m_{32}) + \frac{f}{q}(m_{12})$$

$$b_{16} = \frac{x}{q}(m_{33}) + \frac{f}{q}(m_{13})$$

$$J = \frac{(q.x + r.f)}{q}$$

$$b_{21} = \frac{y}{q}(-m_{33}\Delta Z + m_{32}\Delta Y) + \frac{f}{q}(-m_{23}\Delta Z + m_{22}\Delta Y)$$

$$b_{22} = \frac{y}{q}[\Delta X.\cos\phi + \Delta Z(\sin\omega.\sin\phi) + \Delta Y(-\cos\omega.\sin\phi)] +$$

$$\frac{f}{q}[\Delta X(\sin\phi.\sin\kappa) + \Delta Z(-\sin\omega.\cos\phi.\sin\kappa) + \Delta Y(\cos\omega.\cos\phi.\sin\kappa)]$$

$$b_{32} = \frac{f}{q}(-m_{11}.\Delta X - m_{12}.\Delta Z - m_{13}.\Delta Y)$$

$$b_{24} = \frac{y}{q}(m_{31}) + \frac{f}{q}(m_{21})$$

$$b_{25} = \frac{y}{q}(m_{32}) + \frac{f}{q}(m_{22})$$

$$b_{26} = \frac{y}{q}(m_{33}) + \frac{f}{q}(m_{23})$$

$$K = \frac{(q.y + s.f)}{q}$$

$$\Delta X = (X - X_L)$$

$$\Delta Y = (Y_L - Y)$$

$$\Delta Z = (Z - Z_L)$$

Initial Approximations for Least Squares Adjustment

- Initial approximations are needed for all unknowns, and these are usually easily obtained by making certain assumptions, such as vertical photography.
- The initial approximations do not have to be extremely close, but the closer they are to the unknowns, the faster and a satisfactory solution will be reached; and the result is a savings in computer time.
- In solving a system of collinearity equations of the form of Eq. (D-15) and (D-16) for any problem, the quantities that are determined are corrections to the initial approximations.
- After the first solution, the computed corrections are added to the initial approximations to obtain revised approximations.
- The solution is then repeated to find new corrections.
- This procedure is continued (iterated) until the magnitudes of the corrections become insignificant.

Initial Approximations for Least Squares Adjustment

- As mentioned in the previous slides, initial approximations of all unknown parameters are required for a least squares adjustment when using linearized observation equations. Thus, one must have sufficient preliminary estimates of the position and angular orientation of the camera stations ω, φ, κ, *XL*, *YL*, and *ZL*), object space coordinates of all imaged points (*XA*, *YA*, and *ZA*), and values of all camera calibration parameters (*x0*, *y*0, *f*, *k1*, *k2*, *k3*, *p1*, *p*2, and *p*3) prior to implementation.

Initial Approximations for Least Squares Adjustment

- Obtaining initial approximations for terrestrial photography can be much more difficult than for aerial photography.
- This is not only stems from the inherent differences in geometry of the configurations, but also from the fact that in many close range and terrestrial applications, the photography was taken without the intention of using it for photogrammetry (e.g., historical photos and photos used for accident reconstruction).
- In these instances, the photographer likely did not note the position and angular orientation of the camera during exposure.
- There are, however, both **manual and automatic (Resection-intersection) methods** for obtaining initial approximations for terrestrial and close range photogrammetric adjustment.
- See **Wolf** book section 19-5 for details!!!

Manual approximation of E.O.P.

1. Compute ground coordinates of GCP with respect to principal point:

$$X = \frac{Y}{f} x_1$$

$$Y = \frac{B \times f}{p}$$

$$Z = \frac{Y}{f} y$$

p : تمثل فرق الابتعاد السيني (x-parallax) ويساوي x_2-x_1 .

f : تمثل البعد البؤري للكاميرا .

2. Apply conformal transformation to compute transformation parameters between (E&N)-original and (X&Y)-computed in step 1 above coordinate systems:

$$E = aX - bY + c$$
$$N = aY + bX + d$$

$$k = \tan^{-1} \frac{a}{b}$$

$$X_L = c$$

$$Y_L = d$$

Automatic Self-calibration solution

- Carrying out a self-calibrating bundle adjustment of terrestrial/close range photography can be a complicated task.
- The approach is designed for a bundle adjustment program that has **input** consisting of pass point measurements, control point measurements, initial approximations, and a priori standard deviations of all observations and camera calibration parameters.
- Typically, there are no direct observations of the camera calibration parameters. However, treating them as observations allows one to constrain them in the adjustment by weighting.
- Approximations for the focal length, f, can be determined using the camera manufacturer's specifications. The remaining calibration parameters can be initialized at zero.

Automatic Self-calibration solution

- The first step of the approach is to adjust two photos.
- The photos selected for this initial adjustment should be convergent with a large amount of overlap between them and a sufficient amount of control points.
- Starting with two photos instead of attempting to adjust the entire set of photos reduces the chances of having multiple blunders, and therefore simplifies troubleshooting.
- One can attempt to adjust the two images with the calibration parameters “loosened,” giving them high a priori standard deviations, and thus allowing them to be solved in the adjustment.
- However, this often leads to divergence due to a combination of insufficient distribution of tie points throughout the photos, homogeneous depth of field, inadequate redundancy, and poor geometric configuration (non-convergence) of the photos.
- In this case, the calibration parameters should be constrained by assigning them very small a priori standard deviations.
- If the adjustment fails to converge with constrained parameters, check for blunders and make sure initial approximations are consistent.
- Once the two-photo adjustment converges, check the pass point residuals to identify any blunders, re-measuring them if found.
- Add photos one at a time, rerunning the adjustment and again checking for blunders with each addition.
- Previously estimated initial approximations can be updated using their solved values after each adjustment.
- This will speed up subsequent solutions by reducing the number of iterations required.
- After many photos have been added to the adjustment, the calibration parameters can be loosened.

GCP's Establishment!!

In terrestrial photogrammetry there are basically four different methods of establishing control:

1. imposing the control on the camera by measuring its position and orientation with respect to a coordinate system or with respect to the photographed object.
2. locating control points in the object space in a manner similar to locating control for aerial photography.
3. combining camera control and object space control points.
4. using a free-network adjustment with scale control only.

- See wolf section 19-7 for details

Discussion!

Example (1-5) from Analytical photogrammetry text book, p 194!

SfM Photogrammetry- Computer Vision (CV) Tutorial

References:

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- Analytical Photogrammetry, Bashar S. Al-Jubori, Fanar M. Abed, Maitham M. Al-Bakri, 2009.
- TGA Digital https://www.youtube.com/watch?v=GEsRcFQ1_H8&t=3s