Slides 3: Aerial triangulation

Aerial Triangulation

December 2002
Yangon, Myanmar
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Objects of Aerial triangulation

- Solution for orientation parameters of each photo
- Less number of GCP
- Densification of ground controls

Construction of Survey Tower

Ground Survey

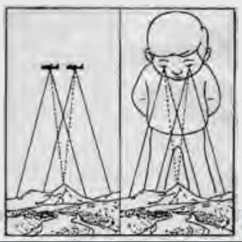
GPS Survey

Signalization

Principal of Stereo mapping

Observation by restitution of condition that aerial photos have been taken

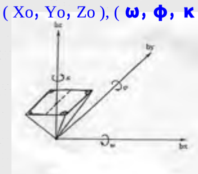
Orientation Parameters included position and inclination of Camera



Orientation Parameters

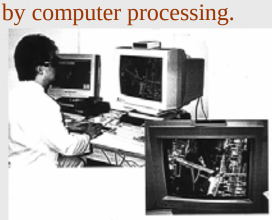
6 elements

Position of aerial camera and inclination of axes as
(Xo, Yo, Zo), (ω, ϕ, κ)



Analytical Photogrammetry

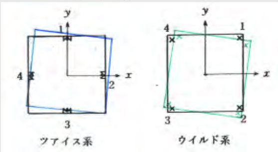
Orientation parameters were decided by universal plotters once, but now they are computed analytically by computer processing.



Procedure of Aerial triangulation

Inner Orientation
⇩
Relative Orientation
⇩
Models connection
⇩
Strip adjustment
⇩
Bundle block Adjustment

Inner Orientation



Conformal transformation or Affine transformation is applied

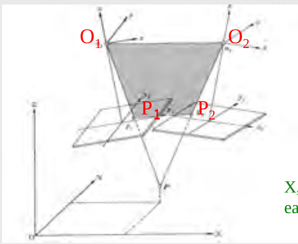
$$\begin{pmatrix} a & -b \\ b & a \end{pmatrix}\begin{pmatrix} \mathbf{x} \\ y \end{pmatrix} + \begin{pmatrix} Xo \\ Yo \end{pmatrix} = \begin{pmatrix} X \\ Y \end{pmatrix} \qquad \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} \mathbf{x} \\ y \end{pmatrix} + \begin{pmatrix} Xo \\ Yo \end{pmatrix} = \begin{pmatrix} X \\ Y \end{pmatrix}$$

(x, y) :Image coord., (X,Y):Photo coord.

Relative Orientation

3D models are performed by coplanarity condition equation

Four points of O_1,O_2,P_1 and P_2 are lied on the same plane.



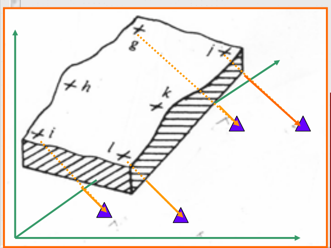
$$\begin{vmatrix} X_{O1} & Y_{O1} & Z_{O1} & 1 \\ X_{O2} & Y_{O2} & Z_{O2} & 1 \\ X_{P1} & Y_{P1} & Z_{P1} & 1 \\ X_{P2} & Y_{P2} & Z_{P2} & 1 \end{vmatrix} = \mathbf{0}$$

X,Y and Z are components of each point.

$aX+bY+cZ+d=0$

Absolute Orientation

Absolute orientation is performed by 3D conformal transformation



$$S \cdot R_{xyz} \cdot \begin{pmatrix} \mathbf{x} \\ y \\ z \end{pmatrix} + \begin{pmatrix} Xo \\ Yo \\ Zo \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

S:Scale factor

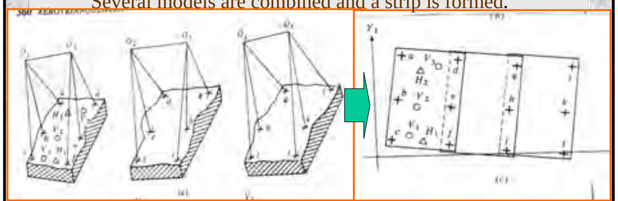
R:Rotation matrix

(x, y, z) :Model coord.

X,Y,Z:Ground coord.

Model connection and Absolute orientation

Several models are combined and a strip is formed.



$$S \cdot R_{xyz} \cdot \begin{pmatrix} \mathbf{x} \\ y \\ z \end{pmatrix} + \begin{pmatrix} Xo \\ Yo \\ Zo \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

S:Scale factor

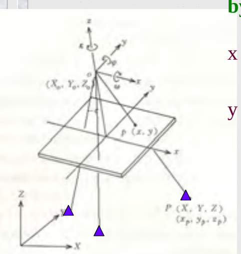
R:Rotation matrix

(x, y, z) :Model coord.

X,Y,Z:**Strip coord.**

Orientation of single photo

Orientation parameters are solved by colinearity condition equation.



$$x = C\,\frac{a_{11}(X-Xo)+a_{12}(Y-Yo)+a_{13}(Z-Zo)}{a_{31}(X-Xo)+a_{32}(Y-Yo)+a_{33}(Z-Zo)}$$

$$y = C\,\frac{a_{21}(X-Xo)+a_{22}(Y-Yo)+a_{23}(Z-Zo)}{a_{31}(X-Xo)+a_{22}(Y-Yo)+a_{23}(Z-Zo)}$$

C : Focal distance of camera

a : Components of rotation matrix

(x, y): Photo coordinates

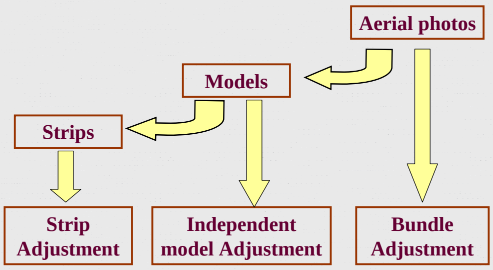
(Xo, Yo, Zo) : Psition of camera center

(X, Y, Z) :Coordinates of ground controls

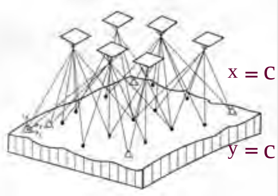
Pass-points and Tie-points

Pass-point and Tie-points are used to connect photos or models.

Block adjustment



Block adjustment by bundle adjustment

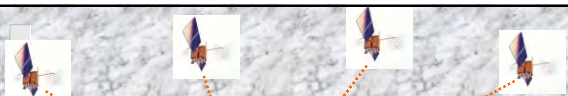


$$x = c\,\frac{a_{11}(X_p-X_o)+a_{12}(Y_p-Y_o)+a_{13}(Z_p-Z_o)}{a_{31}(X_p-X_o)+a_{32}(Y_p-Y_o)+a_{33}(Z_p-Z_o)}$$

$$y = c\,\frac{a_{21}(X_p-X_o)+a_{22}(Y_p-Y_o)+a_{23}(Z_p-Z_o)}{a_{31}(X_p-X_o)+a_{22}(Y_p-Y_o)+a_{23}(Z_p-Z_o)}$$

p=t : Tie points
p=g : Ground Controls

Airborne GPS support Aerial triangulation



Aerial triangulation is performed using ground controls and camera positions as known values.

Trails of airplane by GPS observation

GPS Antenna

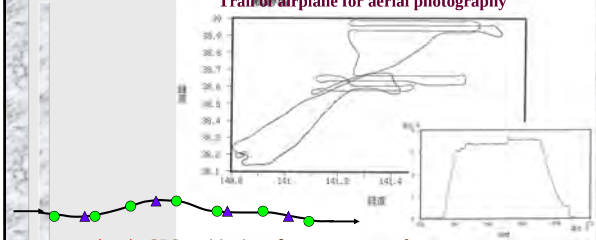
3D positions are observed by GPS continuously every 1 second

GPS loaded airplane for photography

Ground control

Trail of airplane by GPS

Trail of airplane for aerial photography



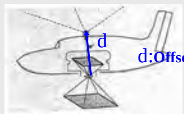
GPS positioning of every one second
Exposure position

Altitude trail

Airborne GPS support aerial triangulation

$$\begin{pmatrix}X_{GPS}\\Y_{GPS}\\Z_{GPS}\end{pmatrix} + \begin{pmatrix}V_{X\,GPS}\\V_{Y\,GPS}\\V_{Z\,GPS}\end{pmatrix} = \begin{pmatrix}X_{PC}\\Y_{PC}\\Z_{PC}\end{pmatrix} + R_{xyz}\cdot\begin{pmatrix}d_x\\d_y\\d_z\end{pmatrix} + \begin{pmatrix}a_x\\a_y\\a_z\end{pmatrix} + \begin{pmatrix}b_x\\b_y\\b_z\end{pmatrix}(t-t_0)$$

Position of GPS antenna | **Position of Camera center** | **Offset of Antenna** | **Drift of GPS observation**



d: **Offset of antenna**

Accuracy of adjustment of aerial triangulation

Theoretical error of adjustment

Plane position： $\sigma_{x,y} = 6\ \mu$ (on photo)

= 300mm(on ground)

Elevation： σ_z = 0.006% of altitude

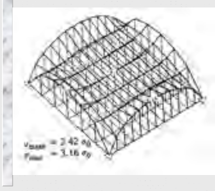
= 450mm(on ground)

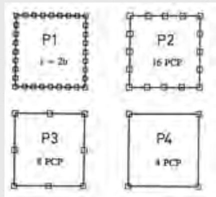
Precision of Plane Position

Periphery of block has larger errors

Inside of block has small errors

Therefore, plane ground controls should be distributed peripherally.





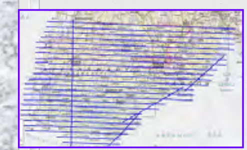
In case of P2：$\sigma = (0.83+0.02 \cdot n) \cdot \sigma_o$

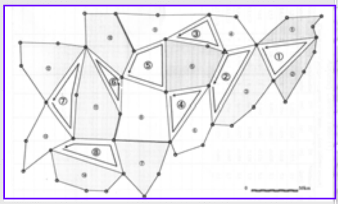
Estimated error in plane position

Flight run ： 24 runs

Ground control ：48 Pnts

Type of control points：P2





$\sigma = (0.83+0.02 \cdot 24) \cdot \sigma_o = 1.31\ \sigma_o$

Adjusted errors

	Axis	Mean Error	Max. Error
Zone46	X	0.602	1.686
	Y	0.628	1.547
Zone47	X	0.375	0.678
	Y	0.585	1.058

Unit: m

$\sigma = (0.83+0.02 \cdot 24) \cdot \sigma_o = 1.31\ \sigma_o =$ **590mm**

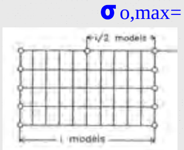
Theoretical estimated error on ground is 590mm

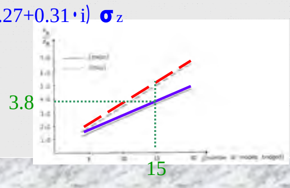
Observation errors of elevation

- **Vertical controls should be established at upper and lower side of each model.**
- **Precision of elevation depends on the interval of vertical controls**

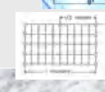
$\sigma_{o,mean} = (0.34+0.22 \cdot i)\ \sigma_z$

$\sigma_{o,max} = (0.27+0.31 \cdot i)\ \sigma_z$





Estimated precision of vertical position



Bridge Dis.=58/4=15