Geometry of Aerial photogrammetry

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Image formation - Recap

- The geometry of imaging system
Types of aerial photograph

• **Vertical**
• **Low oblique**
• **High oblique**
Types of aerial photograph

- Vertical
- Low oblique (no horizon)
- High oblique
Types of aerial photograph

- Vertical
- Low oblique
- High oblique

![High-Oblique Aerial Photograph Over Flat Terrain](image)

- Horizon is shown in the field of view
- Optical axis is shown in the photograph
- 90°
Types of aerial photograph

- In mapping application, vertical photograph is preferred.
- In some applications, particularly, close range photogrammetry or 3D modeling, oblique photographs are preferred.
Image scale (vertical image)

- Scale = \( \frac{f}{H'} = \frac{d}{D} \)
- Representative fraction (e.g., 1:50,000) = \( \frac{1}{(H'/f)} \)
- where
  \( f = \) focal length
  \( d = \) image distance
  \( D = \) ground distance
  \( h = \) terrain elevation
  \( H = \) flying height (\( h + H' \))
  \( H' = \) height above terrain
  \( = H - h \)
Image scale (vertical image)

- Datum Scale = All the points of photograph are assumed to be projected on M.S.L.
  \[ \text{Datum scale} = \frac{f}{H} \]

- Average Scale = All the points of photograph are assumed to be having average elevation above m.s.l.
  \[ \text{Average scale} = \frac{f}{(H_{\text{ave}} - h)} \]
Other methods of finding scale of vertical photograph

- By measuring Ground distance

\[
\text{Image scale} = \frac{\text{Image distance}}{\text{Ground distance}}
\]

- By determining the distance from existing map

\[
\frac{\text{Image scale}}{\text{Map scale}} = \frac{\text{Image distance}}{\text{Map distance}}
\]
Example: Image Scale vs. flying height example

If I want a ground coverage of 5km, what flying height should I use?

• Scale = \( \frac{f}{H'} = \frac{d}{D} \)

• where

  \[ f = 150 \text{ mm} \quad D = 5000\text{m} \quad d = 250\text{mm} \quad H' = ? \]
Example: Image Scale vs. flying height example

If I want a scale of 1/50,000, what flying height should I use?

• Scale = 1/50,000 = f /H’

• where

  \( f = 152 \text{ mm} \quad H’ = ? \)
Effect of flying height on ground coverage

\[ H'_1 > H'_2 \]

\[ D_1 > D_2 \]
Effect of focal length on ground coverage

\[ f_1 > f_2 \]

\[ D_1 < D_2 \]
Ground Coverage

- Ground coverage, D, of photo frame varies with f and H’
- as f decreases, ground coverage increases
  
  e.g. \( f_1 = \frac{1}{2} f_2 \quad D_1 = 2D_2 \quad A_1 = 4A_2 \)

- as H’ increases, ground coverage increases
  
  e.g. \( H'_2 = 2H'_1 \quad D_2 = 2D_1 \quad A_2 = 4A_1 \)
Ground Sampling Distance

- The Ground Sampling Distance (GSD) is the distance between two consecutive pixel centers measured on the ground.
- The higher the altitude of the flight, the bigger the GSD value.
- The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details.

\[
GSD = \frac{\text{Array element size} \times \text{Flying height}}{\text{Focal length}}
\]
Exercise

• What Flying Height (m) needed to resolve individual of 15 cm wide x 50 cm long using Sony Alpha NEX-5T at max resolution and 50mm lens?

(General Rule of Thumb: GSD at a minimum of ½ the size of smallest feature.)
Relief displacement

- Relief Displacement exists because photos are a perspective projection.
Relief displacement

• The scale of an aerial photograph is partly a function of flying height.

• Thus, variations in elevation cause variations in scale on aerial photographs. Specifically, the higher the elevation of an object, the farther the object will be displaced from its actual position away from the principal point of the photograph (the point on the ground surface that is directly below the camera lens).
Relief displacement

- Use this to determine the height of object:

\[ h = \frac{dH'}{r} \]

- \( h \) = height of object
- \( d \) = radial distance to top of object
- \( r \) = radial distance to top of object.
Aerial triangulation

- Aerial triangulation is the term applied to the process of determining \(x, y\) and \(z\) ground coordinate of individual points on measurements from the photograph.
- The bundle adjustment is performed to solve aerial triangulation problem.
What is Bundle Adjustment?

- Refines a visual reconstruction to produce jointly optimal 3D structure (x, y and z Ground coordinate of individual points) and viewing parameters (exterior orientation of camera).
- ‘bundle’ refers to the bundle of light rays leaving each 3D feature and converging on each camera center.
What is Bundle Adjustment?
What is Bundle Adjustment?

- Ground Control Points (GCPs) are used to control the result from bundle adjustment to be in the reference coordinate system.
Bundle adjustment without GCP

• Without GCP, bundle adjustment can be performed; but the recovered 3D structure and camera orientations are in independent coordinate system.

• The camera orientation estimated without GCP is called relative orientation.

• Bundle adjustment with GCP is then called absolute orientation.

• In other words, relative orientation is the process of orienting images relative to one another.

• **Without GCP, the scale of 3D object is incorrect.**
Airborne GPS support Aerial triangulation

- Airborne GPS support Aerial triangulation is performed in order to get equal precision as usual by less number of ground controls.
- Airborne GPS is used to locate the exposure positions of camera.
Airborne GPS support Aerial triangulation

- Airborne GPS support Aerial triangulation is also called “Direct geo-referencing.”
- Aerial triangulation using GCP only is also called “In-direct geo-referencing.”
Making map with UAV

Motivation: direct georeferencing!!!!!!!
Direct georeferencing: pros

• Integrated georeferencing is optimal (provides exterior orientation with best accuracy and reliability).
• Bundling sensor and direct georeferencing on one platform can increase efficiency (ease of deployment, speed of delivery, ...)
• Indirect georeferencing is not always possible or feasible
  — too low redundancy (no control points)
  — Singularity in system of observation equations (image taken over flat scene) when performing non-linear optimization.
Direct georeferencing: cons

- Direct georeferencing method needs to be adapted to environment (indoor positioning, etc.)
- Additional costs and complexity because of additional sensors.
- Mounting and possibly other as additional unknowns (constant?)
Where is the exterior orientation stored?

- To perform direct geo-referencing, the GPS/INS information (exterior orientation parameters) must be imported to processing software.
- There are two ways to store exterior orientation parameters:
  - EXIF data
  - Image geolocation file e.g., CSV text file
Sensors – EXIF Data

- The purpose of a camera is to take a picture, and EXIF data tells a story about the camera and where it was taking pictures.

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<thead>
<tr>
<th>Image Description</th>
<th>DCIM\100MEDIA\DJI_0030.JPG</th>
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<tbody>
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<td>Make</td>
<td>DJI</td>
</tr>
<tr>
<td>Camera Model Name</td>
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<td>Date/Time Original</td>
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<td>North</td>
</tr>
<tr>
<td>GPS Longitude Ref</td>
<td>West</td>
</tr>
<tr>
<td>GPS Altitude Ref</td>
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<tr>
<td>Aperture</td>
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<tr>
<td>GPS Altitude</td>
<td>74.6 m Above Sea Level</td>
</tr>
<tr>
<td>GPS Latitude</td>
<td>40 deg 32' 15.84&quot; N</td>
</tr>
<tr>
<td>GPS Longitude</td>
<td>89 deg 30' 50.63&quot; W</td>
</tr>
<tr>
<td>GPS Position</td>
<td>40 deg 32' 15.84&quot; N, 89 deg 30' 50.63&quot; W</td>
</tr>
</tbody>
</table>
Image geolocation file

- If the image EXIF data contains the image position, then the geolocation file is not needed as processing software automatically reads the geolocation from the EXIF data.

- If the EXIF data does not contain the image GPS position, then a geolocation file is needed.

- The files that can be imported in are:
  - Latitude, Longitude, Altitude (Geo-graphic coordinate system)
  - X, Y, Z (Projected coordinate system)
  - ............
Image geolocation file

• Example: WGS84 geographic coordinates

imagename,latitude [decimal degrees],longitude [decimal degrees],altitude [meter]

IMG_3165.JPG,46.2345612,6.5611445,539.931234
IMG_3166.JPG,46.2323423,6.5623423,529.823423

The latitude value is between -90° and 90°.
The longitude value is between -180° and 180°

• Example: WGS84 geographic coordinates including orientation

imagename,latitude [decimal degrees],longitude [decimal degrees],altitude [meter],omega [degrees], phi [degrees], kappa [degrees]

IMG_3165.JPG,46.2345612,6.5611445,539.931234,1.698,4.392,90.859
IMG_3166.JPG,46.2323423,6.5623423,529.823423,4.571,2.977,94.714
Photo overlap

Endlap

• Endlap, also known as forward overlap, is the common image area on consecutive photographs along a flight strip.

• This overlapping portion of two successive aerial photos, which creates the three-dimensional effect necessary for mapping, is known as a stereomodel or more commonly as a “model.”
Photo overlap

Endlap

\[ E = D \frac{H'}{f} \left( \frac{100 - L}{100} \right) \]

D = Sensor size
H' = Flying height
f = Focal length
L = Percent overlap
E = distance between exposure stations
Photo overlap

Sidelap

- Sidelap, sometimes called side overlap, encompasses the overlapping areas of photographs between adjacent flight lines.
- It is designed so that there are no gaps in the three-dimensional coverage of a multiline project.
Photo overlap

Sidelap

\[ C = D \frac{H'}{f} \left( \frac{100 - S}{100} \right) \]

D = Sensor size
H' = Flying height
f = Focal length
L = Percent overlap
C = distance between flight line center

www.gistda.or.th
Number of flight lines

\[ NL = \frac{W}{C} + 2 \]

Where

NL = number of flight line
W = width of study area
C = Distance between flight line
2 = extra flight lines (1 per side)
Number of photos per flight line

\[ NP = \frac{FL}{E} + 2 \]

Where
- \( NP \) = number of photos per flight line
- \( FL \) = Length of flight line
- \( E \) = Distance between exposure station
- 4 = extra photos (2 per end of flight line)