KIG-C1010 Introduction to geoinformatics

Lecture 7b: Photogrammetry

Petri Rönnholm

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Learning objectives

- To understand principles of photogrammetric measurements

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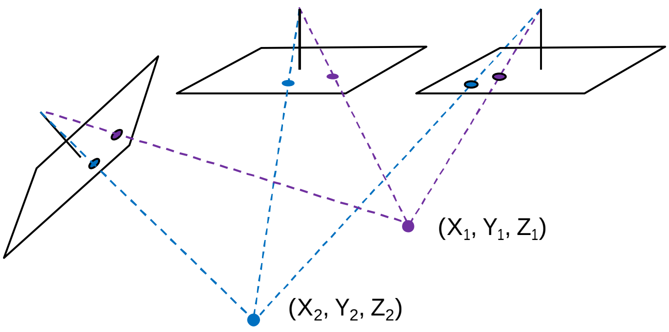
Photogrammetric measuring principles

We need to establish mathematical models that explain real phenomena. In many cases, such models can be found from geometric relations.

Two or more images enable a space forward intersection and thus measurements of 3D points



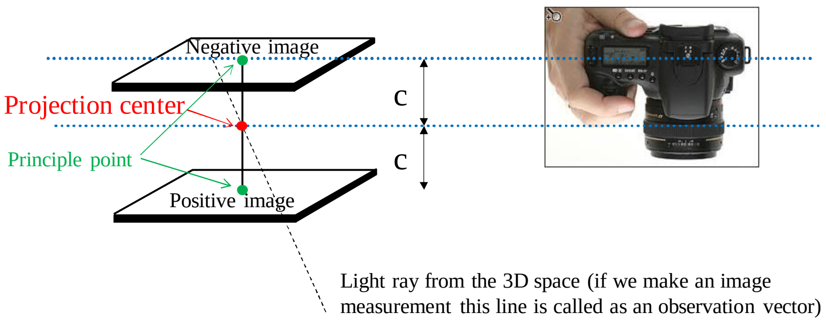
The accuracy of measurements improves if we add more images (image observations)

For photogrammetric measurements we need to know

- The internal geometry of a camera
  - Interior orientation (we can get it from a camera calibration)
- The relationship between the ground (or object) coordinate system and the camera coordinate system
  - Exterior orientation (must be solved separately or within a bundle block adjustment)
  - Typically, requires known ground control points or direct georeferencing sensors

Internal geometry of a camera

- Camera constant = c (almost equals to focal length)



- Principle point (x_0, y_0): the intersection of an image plane and a line that is perpendicular to the image plane and goes through the projection center
- In an (non-existing) ideal case, all incoming light rays remain straight and pass through the projection center

Internal geometry of a camera

- Corrections to image distortions (we try to restore an image to be an ideal central perspective image)
  - lens distortions
  - deformations of an image plane
  - atmospheric refraction
  - etc.
- E.g., a typical lens distortion correction model in photogrammetry (Brown's model)

$$dx_{tot} = x_0 - \frac{\bar{x}}{c}dc + \bar{x}a_1 + \bar{y}a_2 + \bar{x}r^2K_1 + \bar{x}r^4K_2 + \bar{x}r^6K_3 + (2\bar{x}^2 + r^2)P_1 + 2\bar{x}\bar{y}P_2$$

$$dy_{tot} = y_0 - \frac{\bar{y}}{c}dc + \bar{y}r^2K_1 + \bar{y}r^4K_2 + \bar{y}r^6K_3 + 2\bar{x}\bar{y}P_1 + (2\bar{y}^2 + r^2)P_2$$

$\bar{x} = x - x_0,\ \bar{y} = y - y_0$

$r = \sqrt{\bar{x}^2 + \bar{y}^2}$

a_1, a_2 Corrections to image plane deformations

K_1, K_2, K_3 Corrections to radial lens distortions

P_1, P_2 Corrections to decentering (tangential) lens distortions (happens when lenses of the lens system are placed in a decentering way)

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Lens corrections

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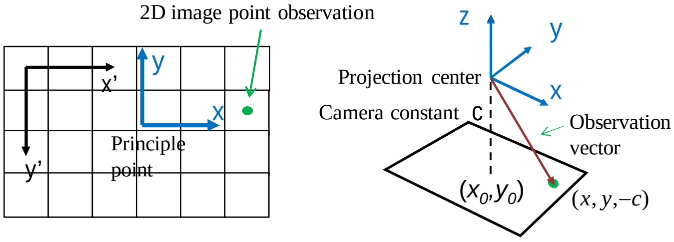
Lens corrections

lens distortions have been removed according to the camera calibration

A known interior orientation transfers 2D image observations into 3D observation vectors

- Interior orientation parameters (a camera constant, the location of a principle point and corrections to systematic image distortions) are needed when we make the coordinate transformation from the 2D image coordinate system into the 3D camera coordinate system



$$\begin{cases} x = x' - x_0 \\ y = y_0 - y' \\ z = -c \end{cases}$$

i.e., an observation vector in this case is:

$$\begin{bmatrix} x' - x_0 \\ y_0 - y' \\ -c \end{bmatrix}$$

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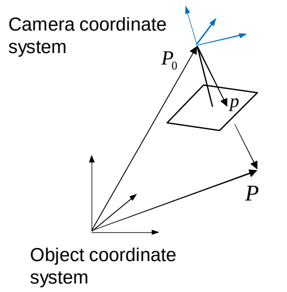
Connection between camera and ground/object coordinate systems

- If we have an ideal central projection image
  - Object point, projection center and image point lay on the same line (= collinearity condition)
  - Therefore, straight lines in the object coordinate system appear as straight lines also in the image plane = **collinearity**
- Typical coordinate transformation between the object coordinate system and the camera coordinate system (collinearity equations) is

$$\begin{bmatrix} x - x_0 \\ y - y_0 \\ -c \end{bmatrix} = \lambda R \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix}$$



x_0, y_0	principle point
c	camera constant
λ	scale factor
R	3D rotation matrix
X_0, Y_0, Z_0	projection center of the camera in the object coordinate system

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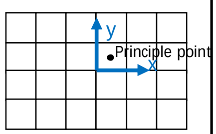
Different notations



Notice that in this equation an observation vector is written in the different image coordinate system than previously (to use the previous system, replace the left side of the equation, slide 10).

- Matrix-vector notation of collinearity equations

$$\begin{bmatrix} x - x_0 \\ y - y_0 \\ -c \end{bmatrix} = \lambda R \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix}$$

can be written also as a group of equations

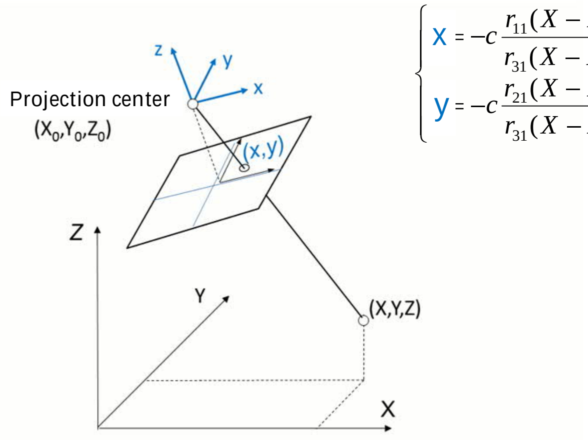
(scale is eliminated)

$$\begin{cases} x - x_0 = -c \dfrac{r_{11}(X - X_o) + r_{12}(Y - Y_o) + r_{13}(Z - Z_o)}{r_{31}(X - X_o) + r_{32}(Y - Y_o) + r_{33}(Z - Z_o)} \\ y - y_0 = -c \dfrac{r_{21}(X - X_o) + r_{22}(Y - Y_o) + r_{23}(Z - Z_o)}{r_{31}(X - X_o) + r_{32}(Y - Y_o) + r_{33}(Z - Z_o)} \end{cases}$$

- In practice, with this equation a known 3D point (in the object space) can be projected into an image plane
- This group of equations can be inverted (from the image plane to the object space)

Typical mathematical model: Collinearity equations

In this case $(x_0,y_0)=(0,0)$



$$\begin{cases} x = -c\dfrac{r_{11}(X-X_o)+r_{12}(Y-Y_o)+r_{13}(Z-Z_o)}{r_{31}(X-X_o)+r_{32}(Y-Y_o)+r_{33}(Z-Z_o)} \\ y = -c\dfrac{r_{21}(X-X_o)+r_{22}(Y-Y_o)+r_{23}(Z-Z_o)}{r_{31}(X-X_o)+r_{32}(Y-Y_o)+r_{33}(Z-Z_o)} \end{cases}$$

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Typical mathematical model: Collinearity equations

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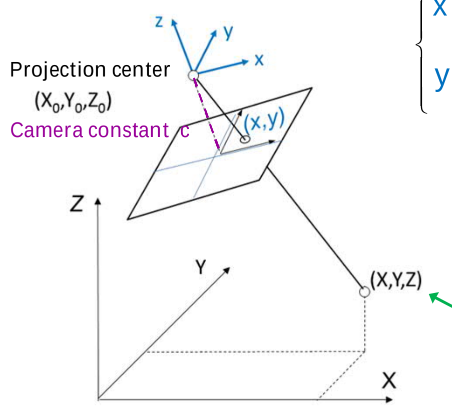

$$\begin{cases} x = -c\dfrac{r_{11}(X-X_o)+r_{12}(Y-Y_o)+r_{13}(Z-Z_o)}{r_{31}(X-X_o)+r_{32}(Y-Y_o)+r_{33}(Z-Z_o)} \\ y = -c\dfrac{r_{21}(X-X_o)+r_{22}(Y-Y_o)+r_{23}(Z-Z_o)}{r_{31}(X-X_o)+r_{32}(Y-Y_o)+r_{33}(Z-Z_o)} \end{cases}$$

3D object point

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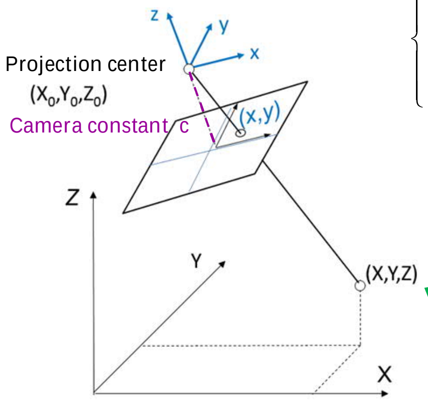
Typical mathematical model: Collinearity equations



$$\begin{cases} x = -c\dfrac{r_{11}(X - X_o) + r_{12}(Y - Y_o) + r_{13}(Z - Z_o)}{r_{31}(X - X_o) + r_{32}(Y - Y_o) + r_{33}(Z - Z_o)} \\ y = -c\dfrac{r_{21}(X - X_o) + r_{22}(Y - Y_o) + r_{23}(Z - Z_o)}{r_{31}(X - X_o) + r_{32}(Y - Y_o) + r_{33}(Z - Z_o)} \end{cases}$$

Rotation of camera

3D object point

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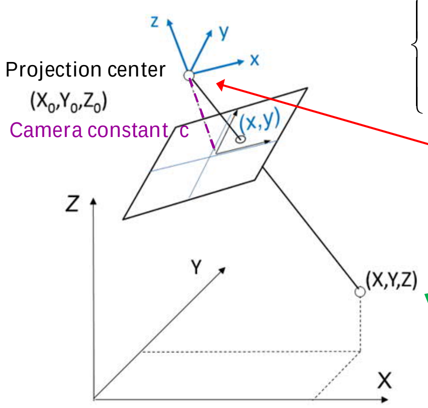
Typical mathematical model: Collinearity equations



$$\begin{cases} x = -c\dfrac{r_{11}(X - X_o) + r_{12}(Y - Y_o) + r_{13}(Z - Z_o)}{r_{31}(X - X_o) + r_{32}(Y - Y_o) + r_{33}(Z - Z_o)} \\ y = -c\dfrac{r_{21}(X - X_o) + r_{22}(Y - Y_o) + r_{23}(Z - Z_o)}{r_{31}(X - X_o) + r_{32}(Y - Y_o) + r_{33}(Z - Z_o)} \end{cases}$$

Projection center

Rotation of camera

3D object point

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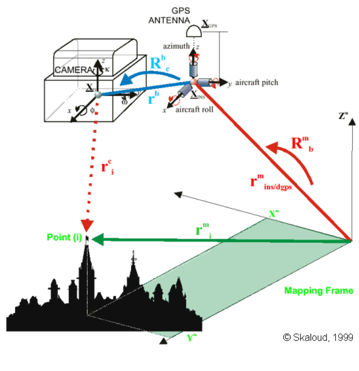
Orientation types

- Interior orientation
  - The internal geometry of a camera
- Exterior orientation
  - The location and rotations of an image (with respect to the object coordinate system)
- Relative orientation
  - The relative location and rotations of two images
  - If only relative orientation is known, the shape of 3D measurements is correct, but the scale is unknown, and the results are in a freely selectable object coordinate system
- Absolute orientation
  - After the 3D measurements from relatively oriented images, the results are transformed into the ground coordinate system
- See more from the “Photogrammetric terminology” document in MyCourses

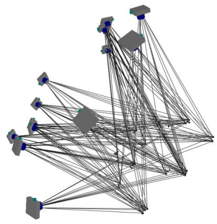
Direct georeferencing

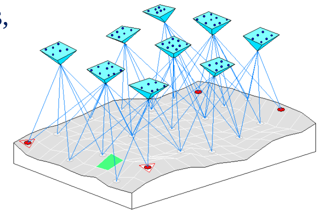
- We can get approximate exterior orientations of images by using direct georeferencing sensors
  - With frame images this is not essential as it was with laser scanning
- In aerial photographing, we use
  - GNSS (global navigation satellite system) to get location
  - inertial measurement unit (IMU) to get location and rotations



Bundle Block Adjustment (Aerial case: Aerial triangulation)

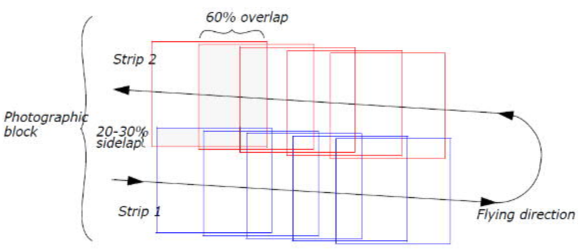
- In block adjustment, we solve simultaneously
  - Exterior orientations of all images in the block (observation ray bundle) (6*m* parameters, *m*= number of images) and
  - 3D object space coordinates of all tie points (corresponding point pairs from different images) i.e., triangulation points (3*n* parameters, *n* = number of points)
  - If all images are aerial nadir (vertical) images, the same process is called as aerial triangulation
  - In addition, if the imaging geometry is very good, we can solve also the parameters of interior orientation within bundle block adjustment (=camera calibration)!

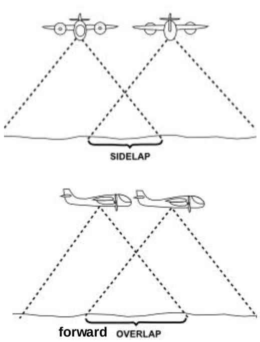




Aerial (nadir) image acquisition

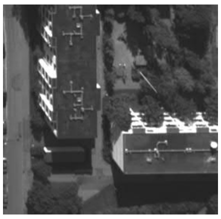
- In mapping campaigns, images are taken sequentially in such a way that we get at least 60 % forward overlap and 20%-30% side overlap



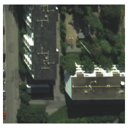


Multispectral aerial images

- Modern digital aerial cameras take
  - Panchromatic images (better resolution than in color channels)
  - RGB + IR images (R=red, G=green, B=blue, IR=infrared), lower resolution
  - Color channels can be pan-sharpened into a better resolution



Panchromatic image



RGB image composite

R image

G image

B image

IR image

False color image composite (IR R G)

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Close-range photogrammetry

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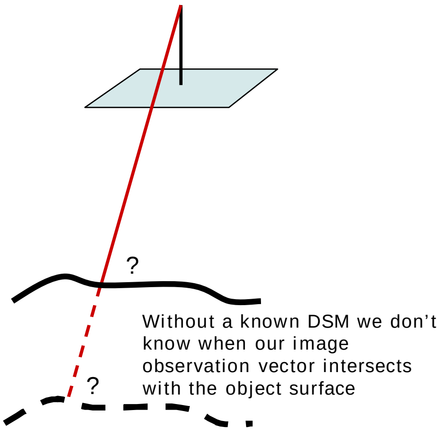
One image, monoplotting

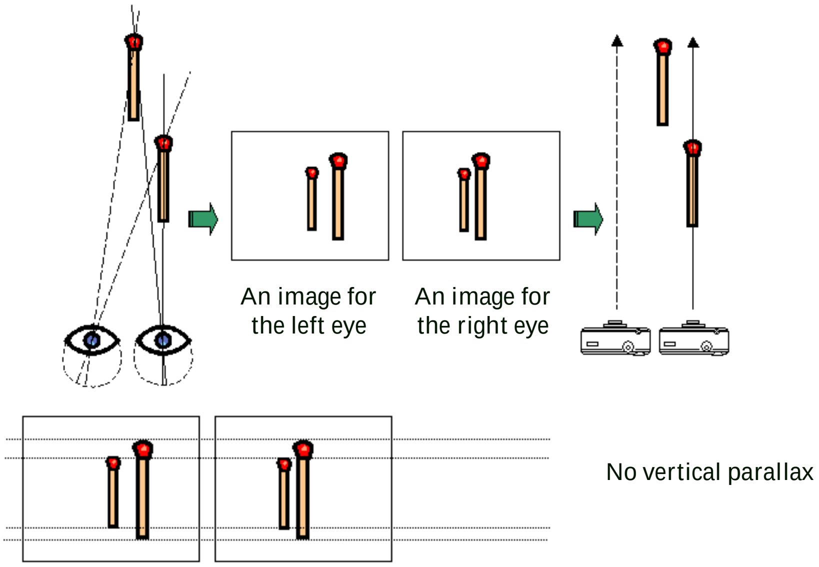
- We can make 3D measurements from a single image only if
  - We know a digital surface model (DSM)
- Otherwise, we need more than one images in order to make 3D measurements
- Pictometry
  - https://www.youtube.com/watch?v=rYzcKyIZJwE



Stereo Vision

- Stereo vision can be utilized for making photogrammetric interpretation and 3D measurements
- Stereo vision requires:
  - Two images (one for each eye)
  - The normal case of stereo imaging
    - Two images lay at the same plane (no convergence)
    - No vertical parallaxes exist (you can find corresponding points just by following a horizontal line)
    - The image base (distance between the projection centers of images) is not too wide or short

The normal case of stereo imaging



Typical stereo photogrammetric process

- Image acquisition, field work (ground control)
- Stereo imaging (footprints of images must overlap)

- Preprocessing of images
- Image orientations

- Stereoscopic restitution (3D point cloud)
- Analysis

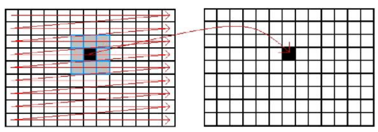
- 3D modeling
- Models, maps

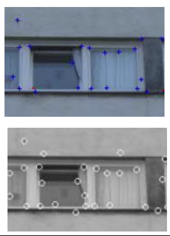
Corresponding point measurements

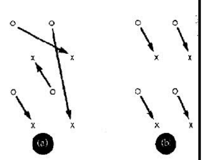
- An essential part of photogrammetric measurements is to find corresponding point pairs from stereo images (or corresponding points from many images)
- Manual measurements are usually quite robust, because human interpretation is very advanced.
  - However, manual measurements take time and effort...
- Automatic measurements reduce the amount of manual work. However, reliability is not as good as with manual measurements...

Automatic measurements

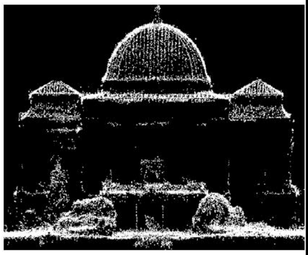
- Image processing algorithms can extract corresponding points or features
  - Area-based methods (find the best correlation)
    - We select a small sample (”mask”) from one image and slide it across another image. At each location, we compute a correlation value, and select the location of the highest correlation as corresponding point.
  - Feature-based methods
    - Find ”interesting points”, such as corners
    - Detect corresponding point pairs between images







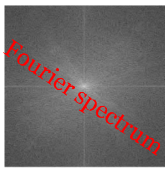
Dense image matching



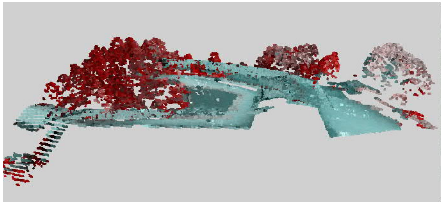
- The idea is to find the corresponding point for each pixel of an image from another image (if possible)
- As a result, we get very dense 3D point clouds
- The method is computationally intensive and if we use only two images, the result can be quite noisy
- We can use known exterior or relative orientations in order to reduce the search space of finding corresponding points
- Semi global matching is the most popular algorithm for dense image matching

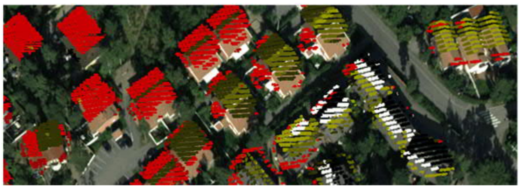
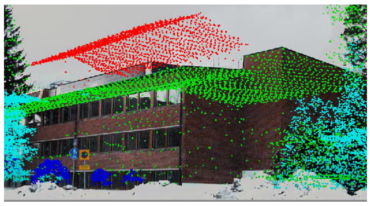
Digital image processing

- Digital image processing (signal processing) is needed in many phases within photogrammetric processes
- With image enhancements we can improve visual appearance of images
- Digital image restoration returns the ideal geometry and radiometry of images
- Feature extraction is needed for automatic image interpretation



Registration and integration with laser scanning



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How to become a professional in photogrammetry – 4 steps?

1. Come to Master's Programme in Geoinformatics
2. Select photogrammetric and laser scanning courses from elective courses including, e.g., following courses
   - Digital Image Processing and Feature Extraction
   - Advanced Photogrammetry
   - Advanced Laser Scanning
3. Select a photogrammetric topic in the course GIS-E6010 Project Course (10 op)
4. Select a photogrammetric topic for your Master's Thesis

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During Bachelor’s studies

- Select the GIS path
- Especially, the course KIG-C1040 Paikkatiedon keruu (in Finnish) reveals more about photogrammetry, laser scanning, remote sensing and geodesy
- There are topics about photogrammetry for Bachelor’s Thesis

Recommended mathematical skills for photogrammetry

- Geometry
- Solving large linear and non-linear equation systems
  - Linearization of non-linear equations
  - Least squares adjustment
- Matrix and vector computations
- Statistical analysis and error propagation
- Understanding and applying of homogeneous coordinates
- Etc.
- (Matlab programming)