ENY-C2005 Geoinformation in Environmental Modeling

Lecture 5: Photogrammetry

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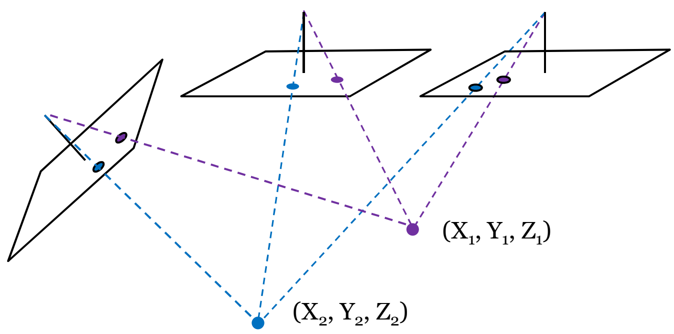
Learning objectives

- To understand principles of photogrammetric measurements

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



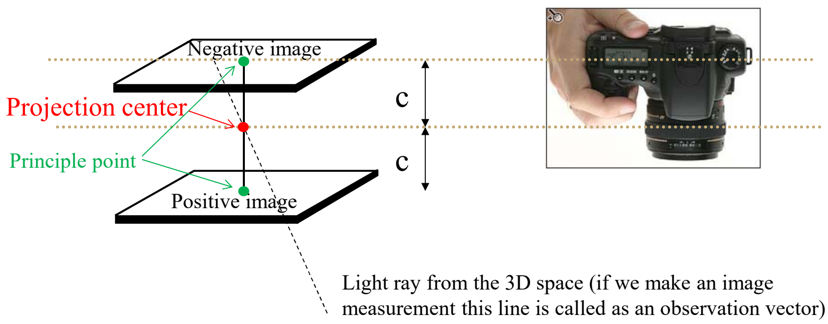
The accuracy of measurements improve if we add more images (image observations)

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 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_o, y_o): the intersection of an image plane and a line that is perpendicular to the image plane and goes through the projection center
- In (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 return 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)

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

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

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

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

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)

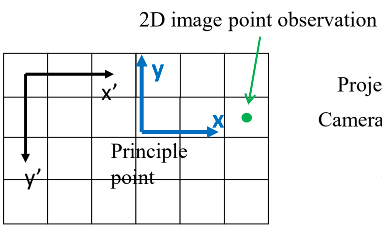
Lens corrections

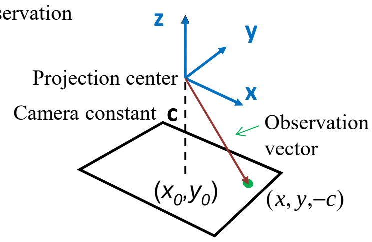
Lens corrections

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 the 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





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

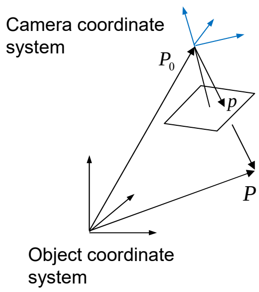
i.e. an observation vector in this case is:

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

Connection between camera and ground/object coordinate systems

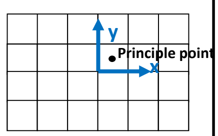
- If we have an ideal central projection image
  - Object point, projection center and image point lay on the same line (= collinearity condition)
  - Therefore, straight lines in the object coordinate system appear as straight lines also in the image plane = **collinearity**
- Typical coordinate transformation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

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

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

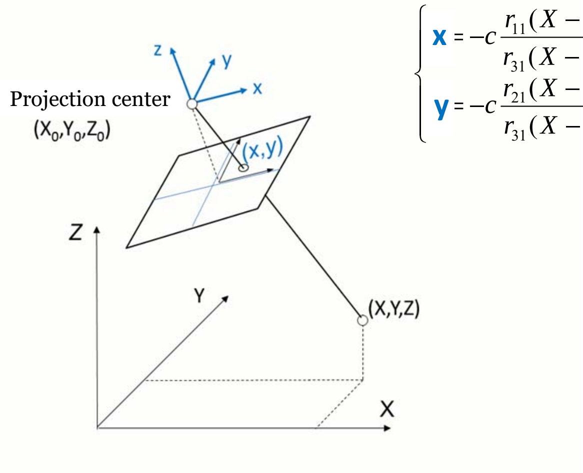
can be written also as a group of equations

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

- 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 $(x_o,y_o)=(o,o)$



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

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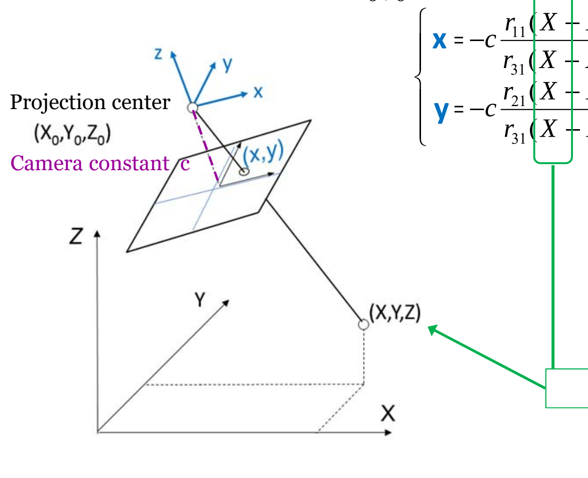
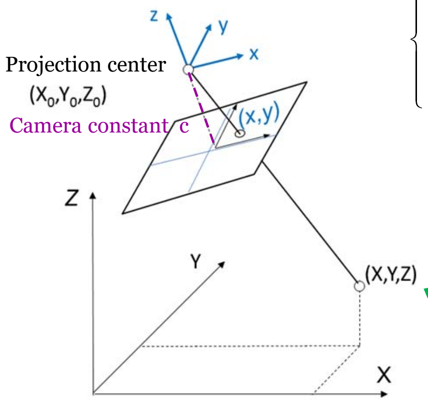


$$\begin{cases} \mathbf{x} = -c\dfrac{r_{11}\boxed{X-X_o}+r_{12}\boxed{Y-Y_o}+r_{13}\boxed{Z-Z_o}}{r_{31}\boxed{X-X_o}+r_{32}\boxed{Y-Y_o}+r_{33}\boxed{Z-Z_o}} \\ \mathbf{y} = -c\dfrac{r_{21}\boxed{X-X_o}+r_{22}\boxed{Y-Y_o}+r_{23}\boxed{Z-Z_o}}{r_{31}\boxed{X-X_o}+r_{32}\boxed{Y-Y_o}+r_{33}\boxed{Z-Z_o}}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

3D object point

Typical mathematical model: Collinearity equations

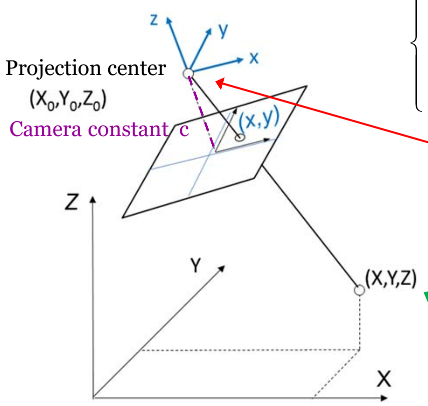


$$\begin{cases} \mathbf{x} = -c\dfrac{r_{11}(X-X_o)+r_{12}(Y-Y_o)+r_{13}(Z-Z_o)}{r_{31}(X-X_o)+r_{32}(Y-Y_o)+r_{33}(Z-Z_o)} \\ \mathbf{y} = -c\dfrac{r_{21}(X-X_o)+r_{22}(Y-Y_o)+r_{23}(Z-Z_o)}{r_{31}(X-X_o)+r_{32}(Y-Y_o)+r_{33}(Z-Z_o)} \end{cases}$$

Rotation of camera

3D object point

Typical mathematical model: Collinearity equations



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

Projection center

Rotation of camera

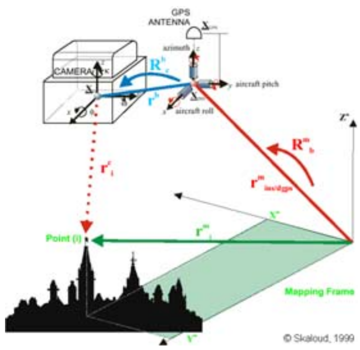
3D object point

Orientation types

- Interior orientation
  - The internal geometry of a camera
- Exterior orientation
  - The location and attitude (rotation) of an image (with respect to the object coordinate system)
- Relative orientation
  - The relative location and attitude of two images
  - If only relative orientation is known, the shape of 3D measurements are 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
- In aerial photographing, we use
  - GNSS (global navigation satellite system) to get position
  - Inertial unit to get position and attitude



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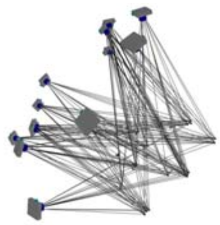
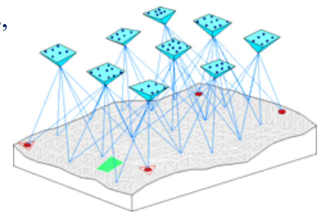
Block Adjustment (Aerial case: Aerial triangulation)

- 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)!





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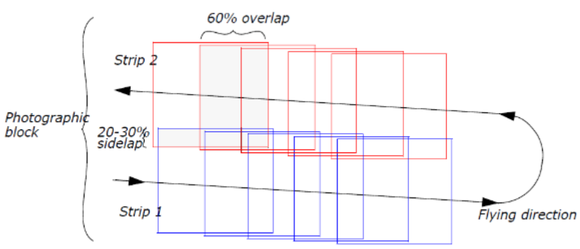
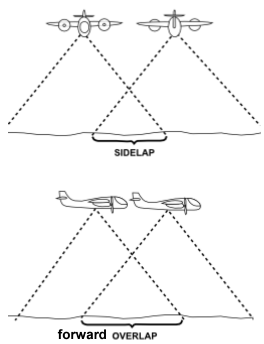
Aerial (nadir) image acquisition

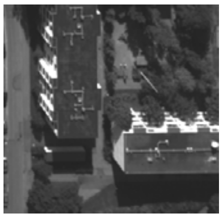
- Images are taken sequentially in such a way that we get at least 60 % forward overlap and 20%-30% side overlap





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

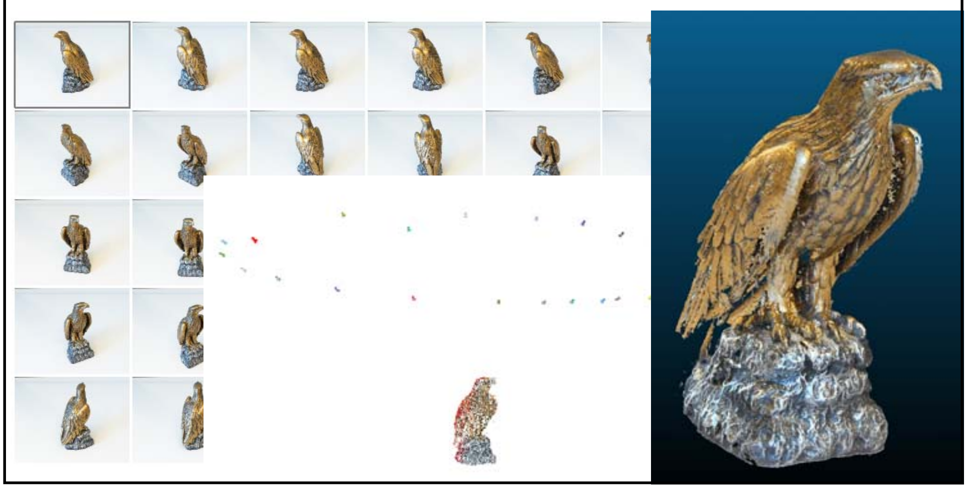

G image


B image


IR image

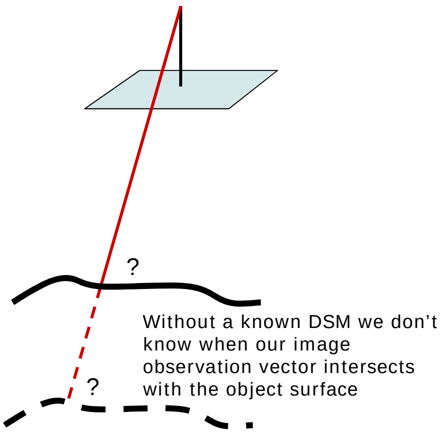

False color image composite (IR R G)

Close-range photogrammetry



One image, monoplotting

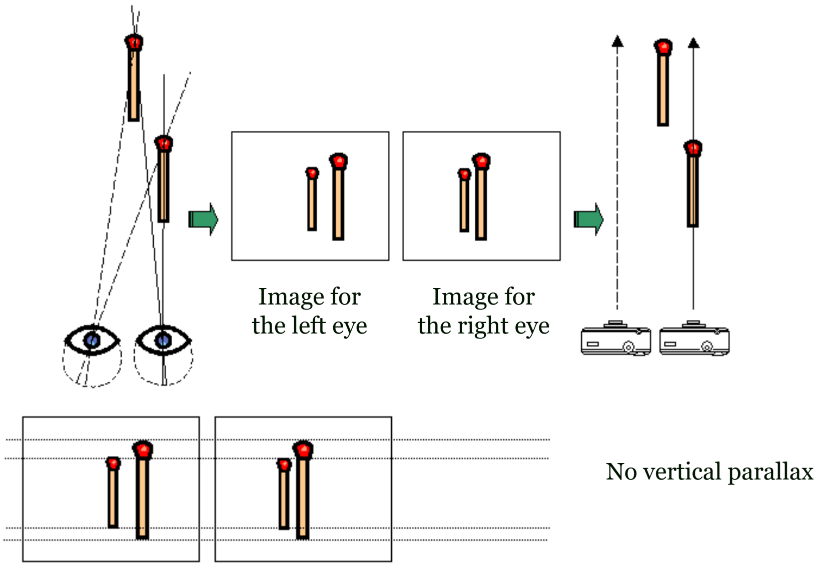
- We can make 3D measurements from a single image only if
  - We know a digital surface model (DSM)
- Otherwise we need more than one images in order to make 3D measurements
- Pictometry
  - https://www.youtube.com/watch?v=rYzcKyIZJwE



Stereo Vision

- Stereo vision can been 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



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…

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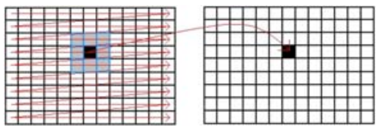
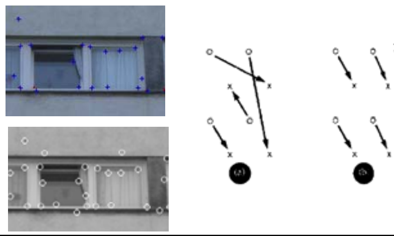
Automatic measurements

- 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





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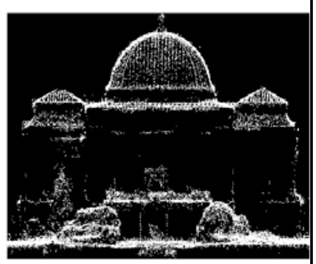
Dense image matching



- The idea is to find corresponding point for each pixel of an image (if possible)
- As a result, we get very dense 3D point clouds
- The method is computational 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 corresponding points
- Algorithms (e.g.)
  - Semi global matching
  - Global matching
  - Patch-based Multi-View Stereo
  - MicMac
  - Non Maximum Disparity
  - Etc.

Typical stereo photogrammetric process

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

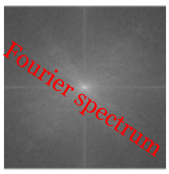
- Preprocessing of images
- Image orientations

- Stereoscopic restitution (3D point cloud)
- Analysis

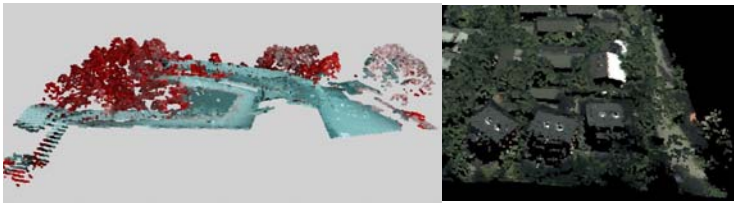
- 3D modeling
- Models, maps

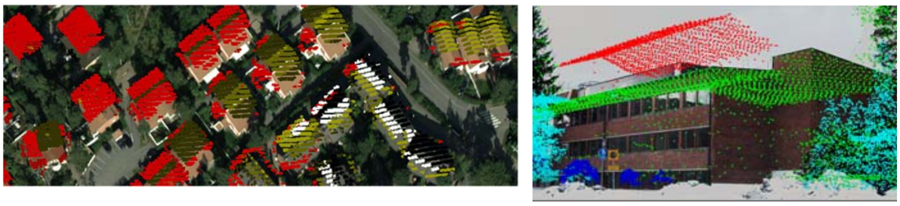
Digital image processing

- 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 measurements



Registration and integration with laser scanning





How to become a professional photogrammetrist? Four steps.

1. Select Geoinformatics as the major
2. Select suitable courses from selectable courses including following courses
   - Digital Image Processing and Feature Extraction
   - Least-Squares Methods in Geosciences
   - Advanced Photogrammetry
   - Advanced Laser Scanning
   - Advanced Remote Sensing
3. Select a photogrammetric task in the course Project Work (10 cr)
4. Select a photogrammetric title for your Master'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)