Universität Hamburg
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MIN-Fakultät
Fachbereich Informatik
Arbeitsbereich SAV/BV (KOGS)

IP2: Image Processing in Remote Sensing

8. Image Characteristics and Preprocessing

Summer Semester 2014

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Agenda

- Digital Image Characteristics
  - (Multi-) Spectral images
  - Microwave images
- Normalization
  - Sensor Normalization
  - Atmospheric Correction
- Registration
  - Image to Image
  - Based on Ground Control Points
  - Multimodal registration

Digital Images

- Sampled and quantized analogue images
  - Discrete domain, consists of pixels (picture elements)
  - Each Pixel is assigned to one (single) or multiple (intensity) values → Spectral sampling.

Note: Many image processing algorithms are defined on the analogue image!

- Resolution
  - Given by side length of a pixel (usually in m)
  - Assumption: Planar scene and equidistant objects
  - Instantaneous Field of View:

🇩🇪 *Momentanes Gesichtsfeld*

Part of the scene, which is imaged within a single pixel

Photometric Issues

- Photometry defines boundaries for acquisitions (e.g. by means of max resolution)
  - Focal length
  - Altitude
  - Aperture size
- Sharpness of imaged objects
  - Optical cameras often use fix focus objectives
  - Objects outside focal plane may be images “blurred”
  - Circle of confusion

    🇩🇪 *Zerstreuungskreis*
- More or less: comparable to well-known photography/ photographs

Sources of Geometric Distortions

- Projection based distortions
- Rotation of the Earth during acquisition
- Finite sampling velocity
- Earth curvature
- Sensor defects
- Variation of sensor orbit
  (can be ignored for non-military satellites)

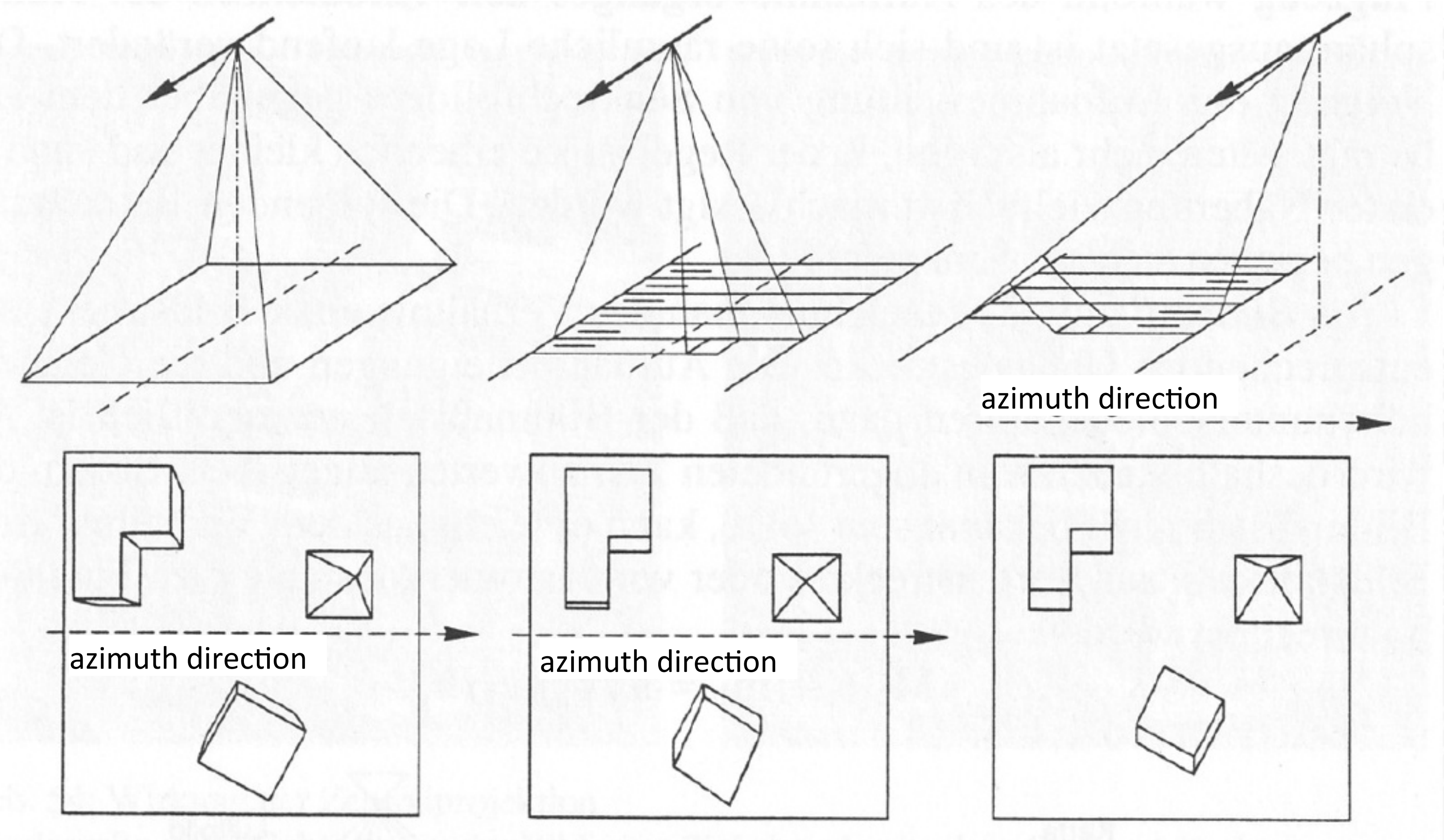
Acquisition Projections

- Real photographic systems: Central projection
- Scanning systems: Mixed projections:
  - In range direction: Central projection
  - In azimuth direction: parallel projection
- Active (microwave) systems:
  - Foreshortening
  - Layover
  - Radar Shadow
- Satellite coordinate system
  - x-Axis: range-direction
  - y-Axis: azimuth-direction

Note: Image may be "flipped upside-down" due to descending path and azimuth direction!

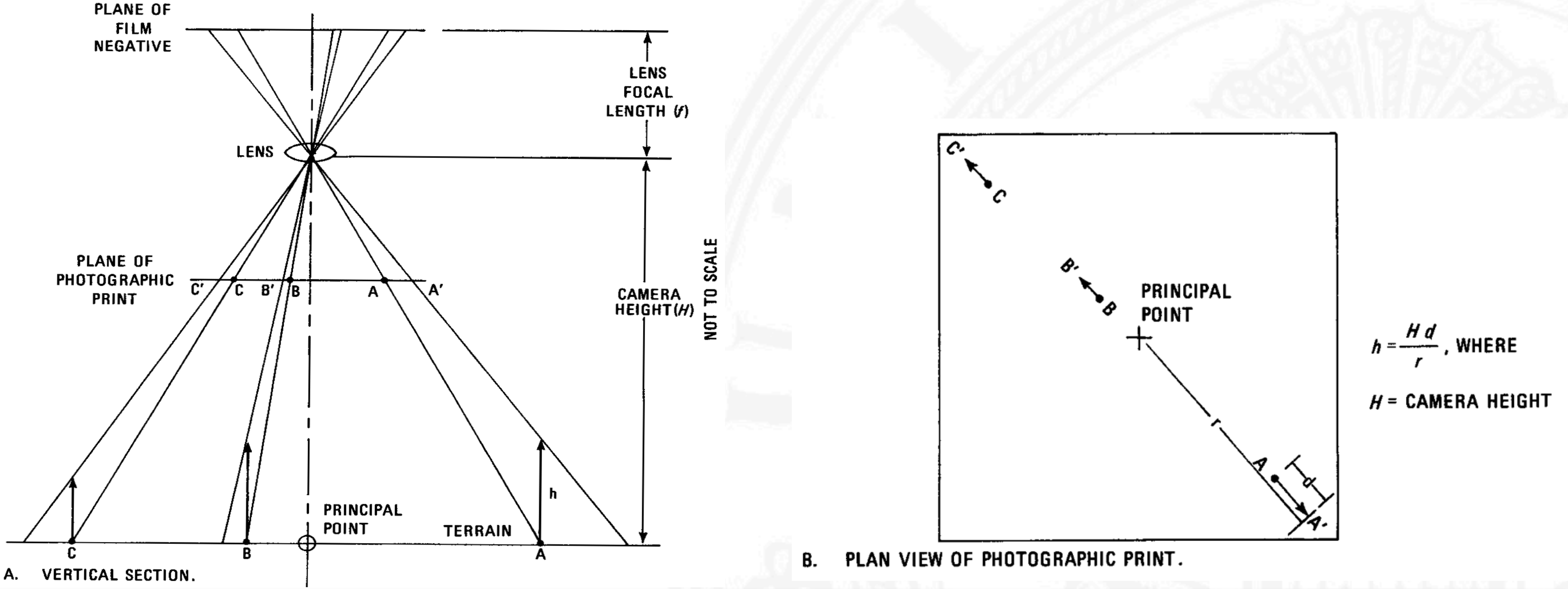
Imaging Geometries

Camera **Scanner** **Side-looking Radar**



Relief displacement in Photographs

- High objects seem to be displaced
- Advantage: Can be used for height estimation
- Disadvantage: Has to be considered for map registration
- **Example**: Use the displacement for height estimation!

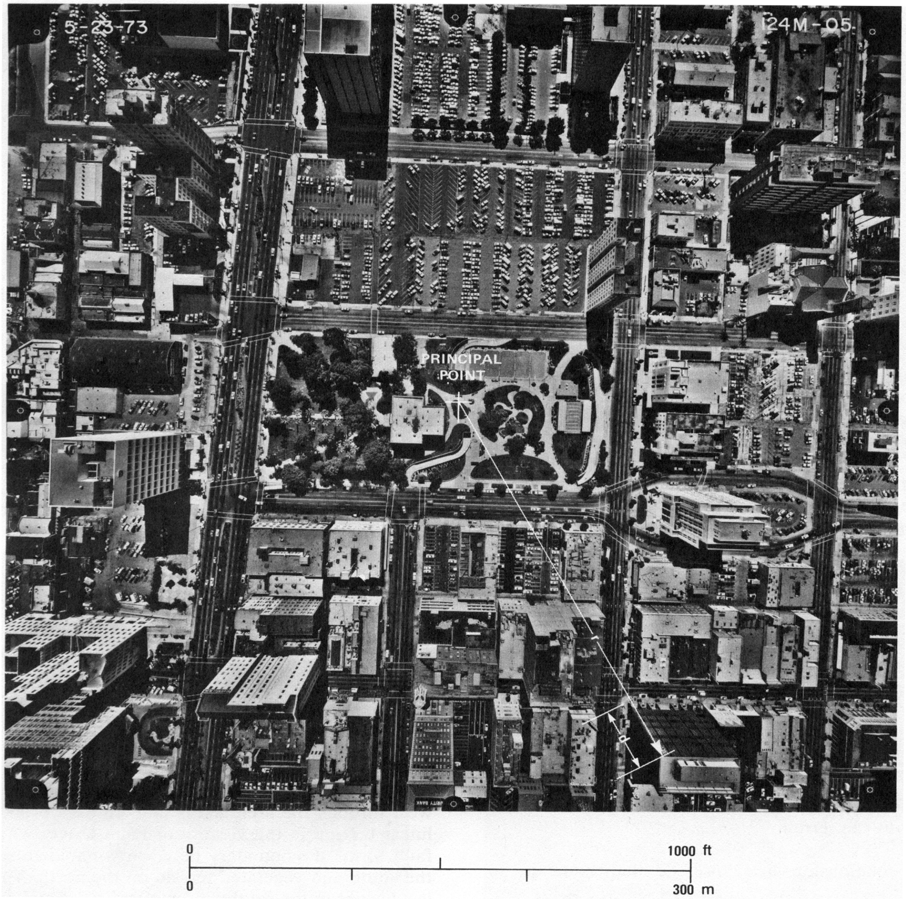


A. VERTICAL SECTION.

B. PLAN VIEW OF PHOTOGRAPHIC PRINT.

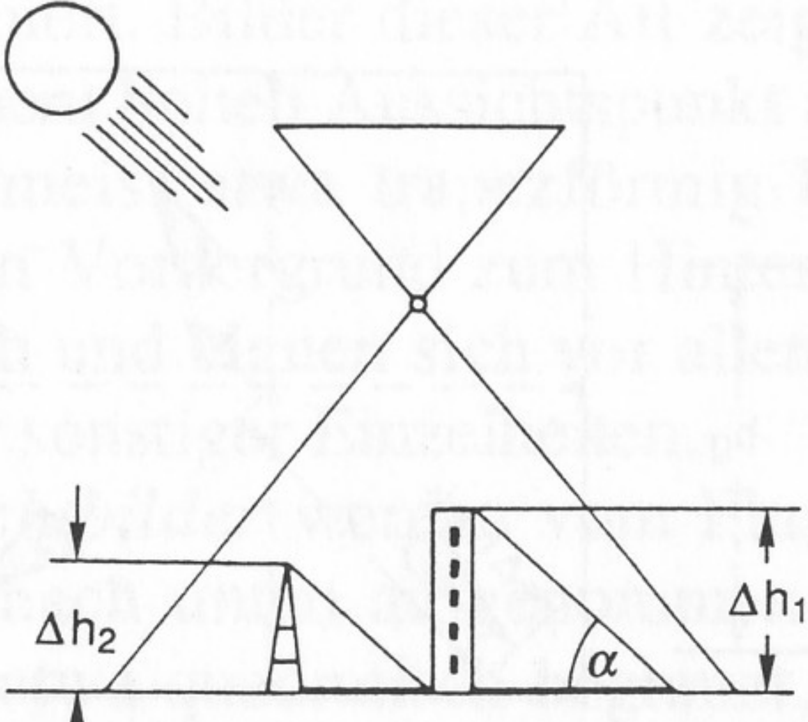
Relief Displacement in Photographs

Example: Use the displacement for height estimation!



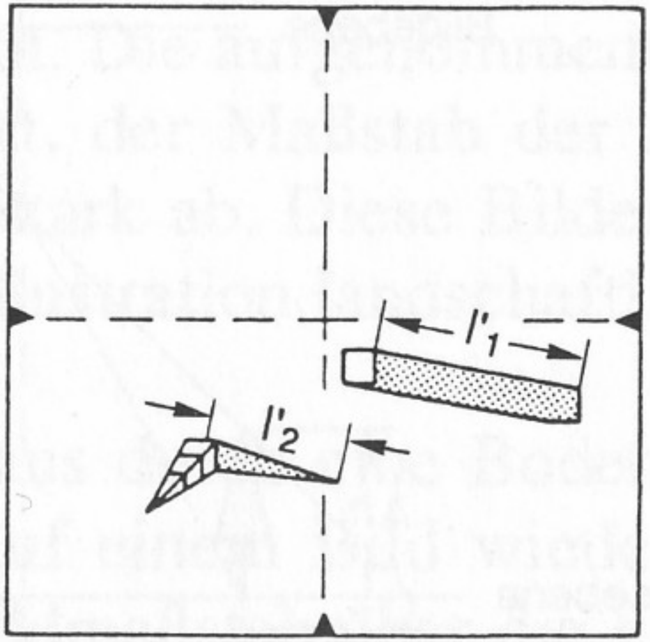
Height Estimation via Shadow Lengths

For known sun angle α



$$\Delta h = l' \cdot \underbrace{m_b}_{\text{scale of the image}} \cdot \tan(\alpha)$$

For known object height Δh_1



$$\Delta h_2 = \frac{l'_2}{l'_1} \cdot \Delta h_1$$

Panorama Distortion

- Typical distortion for scanner acquisitions

Let β be the angular diameter of the IFOV, in nadir,
p the diameter of a pixel in nadir

Then the diameter p_Θ in scan direction at angle Θ is:

$$p_\Theta = \beta \cdot h \cdot \sec^2(\Theta)$$
$$= p \cdot \sec^2(\Theta)$$

- Examples:
  - Landsat 7 ($\Theta = 7.5°$) $p_\Theta = 1.02$ px.
  - Aqua MODIS ($\Theta = 80°$) $p_\Theta = 1.70$ px.

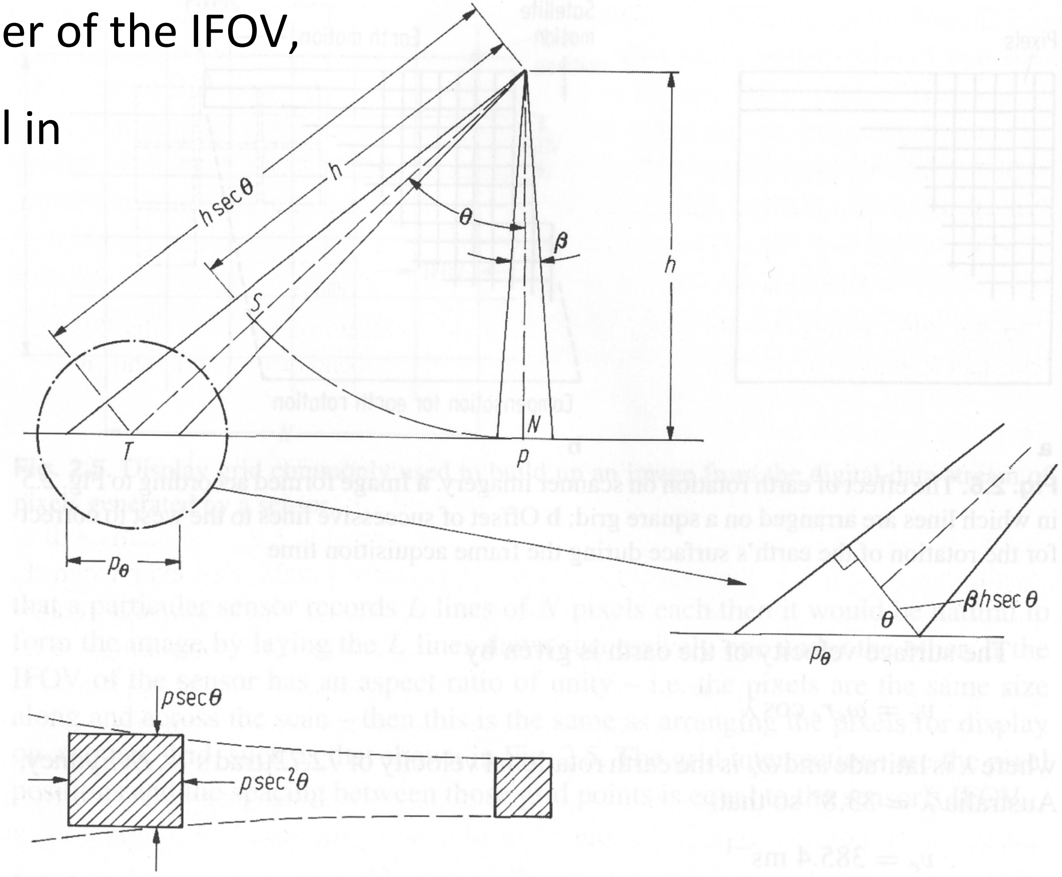
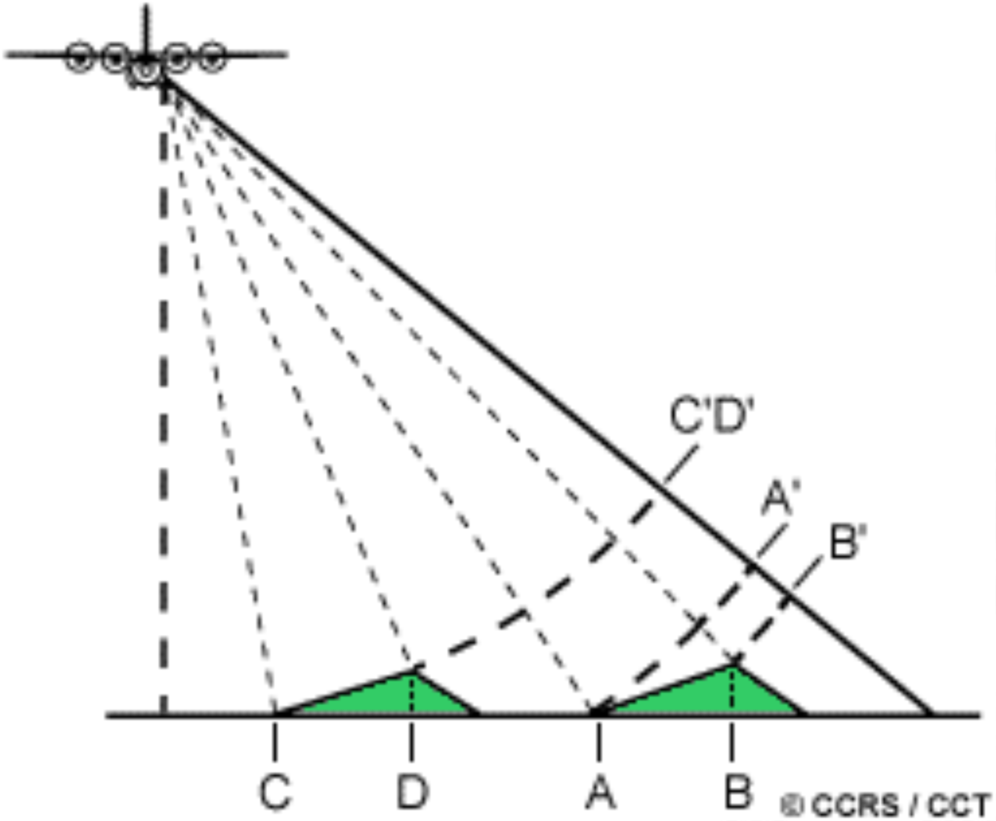
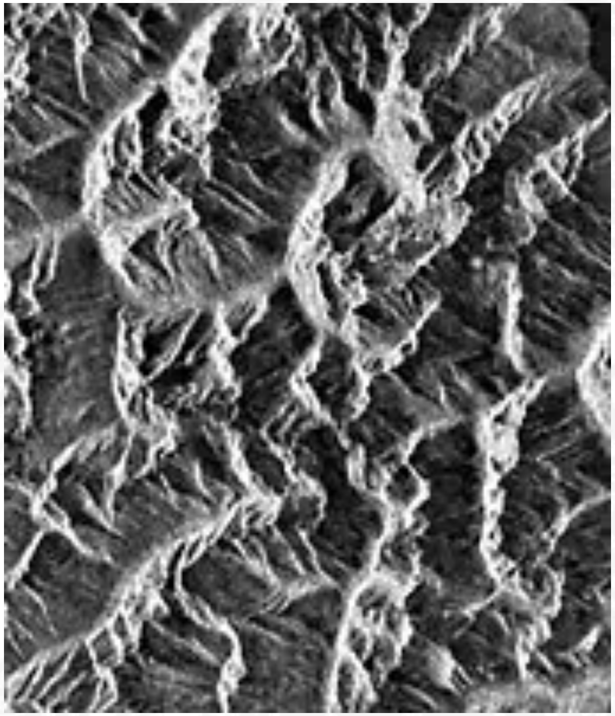


Fig. 2.7. Effect of scan angle on pixel size at constant angular instantaneous field of view

Relief displacement for Imaging Radar

1. Foreshortening

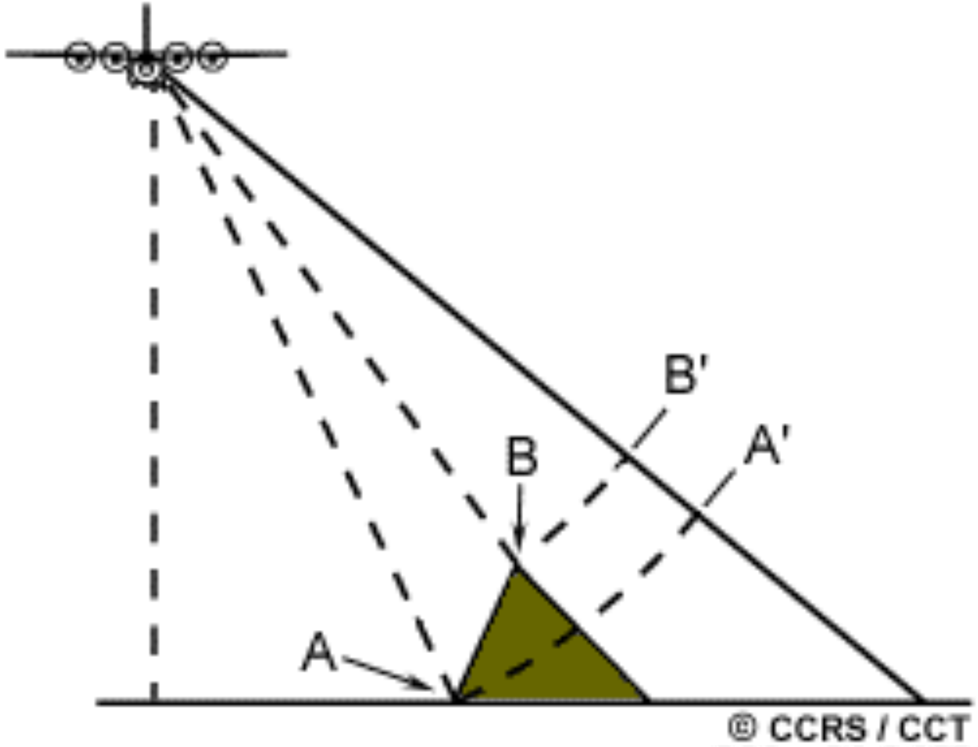




SAR image of a steep mountainous terrain

Relief displacement for Imaging Radar

1. Foreshortening
2. Layover



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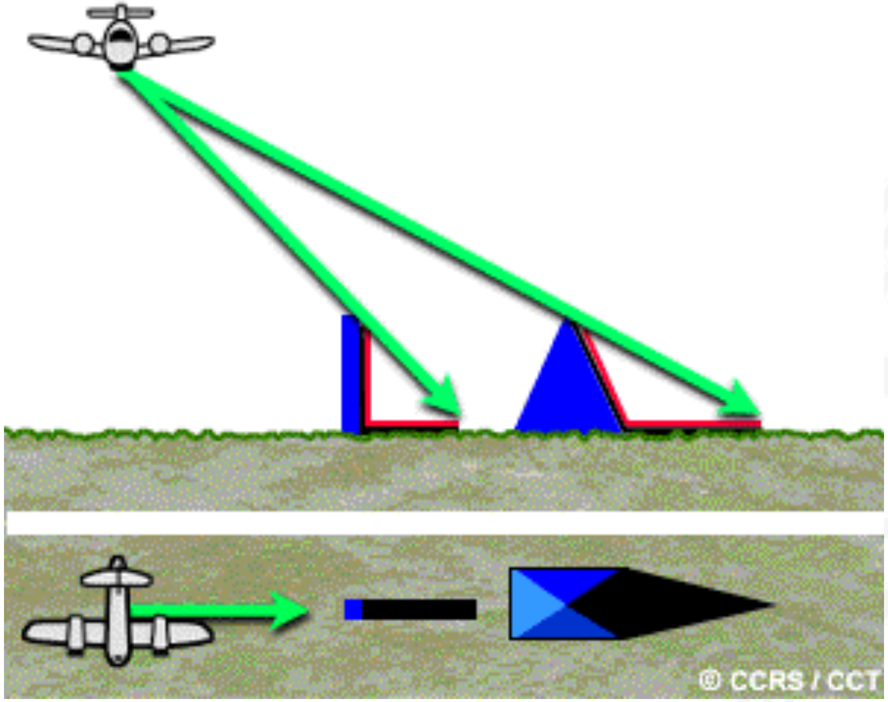
Shadowing at Imaging Radar



Influence of Earth's Rotation

- Scanning of a line takes time, in which the earth still rotates!
- **Result:** shifted scan lines of the acquisition:

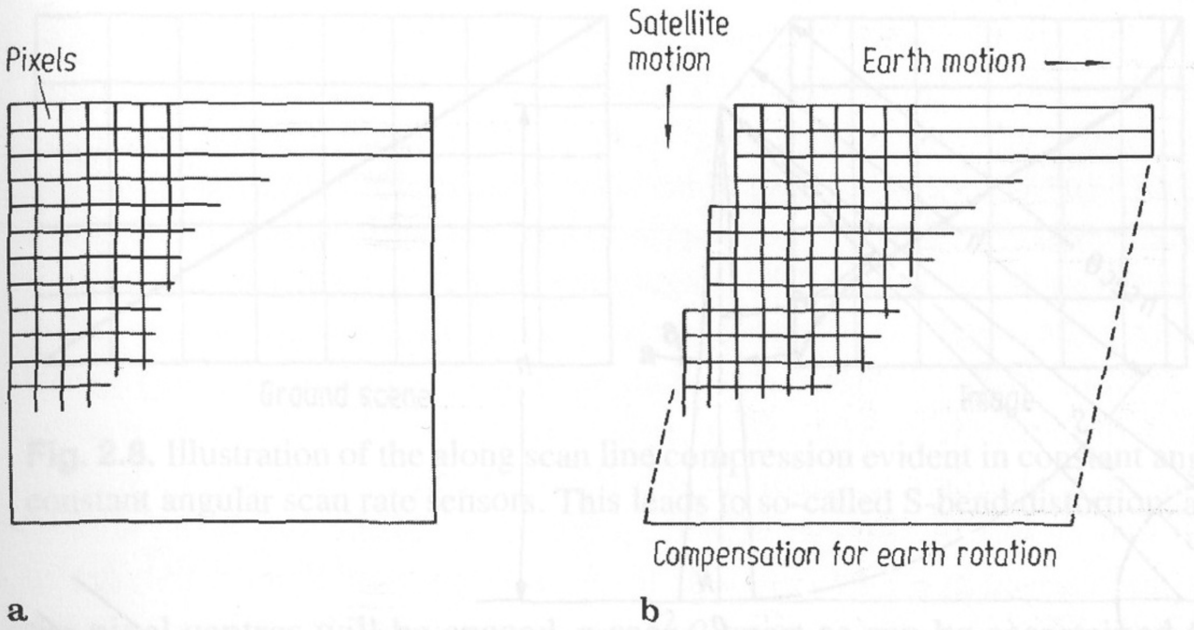


Fig. 2.6. The effect of earth rotation on scanner imagery. **a** Image formed according to Fig. 2.5 in which lines are arranged on a square grid; **b** Offset of successive lines to the west to correct for the rotation of the earth's surface during the frame acquisition time

Scan Time Skew

🇩🇪 *Scan-Zeit-Scherung*

Example:

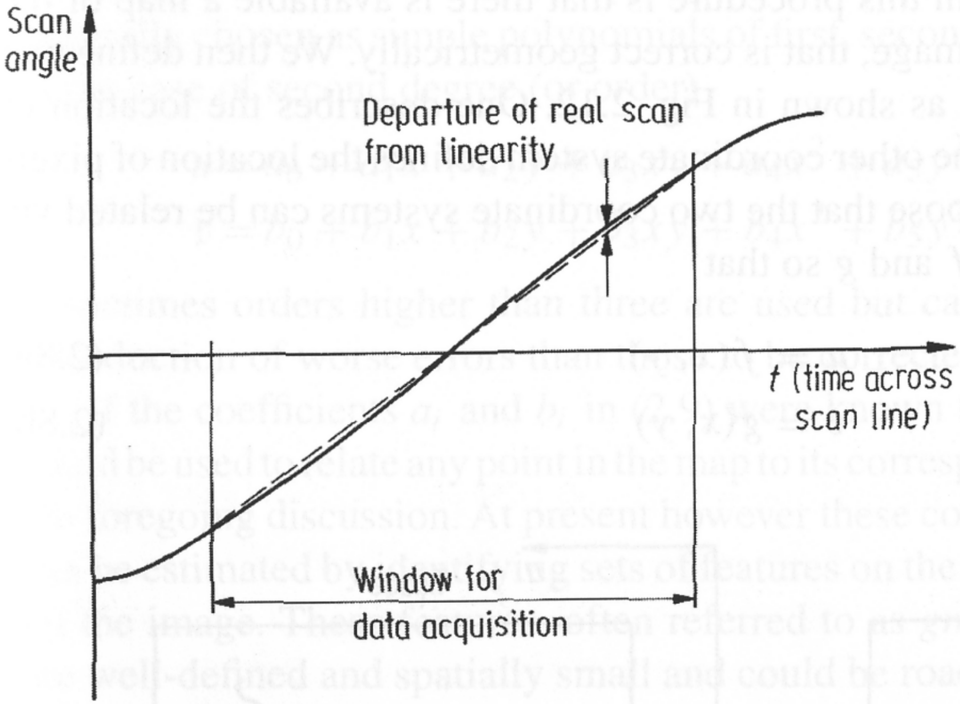
Landsat Multi Spectral Scanner (MSS):

- Scan time: 33ms,
- Velocity over ground: 6.467 km/s

⇨ The end of a scan line is displaced by the beginning of the start of the next line for 213 m in azimuth direction.

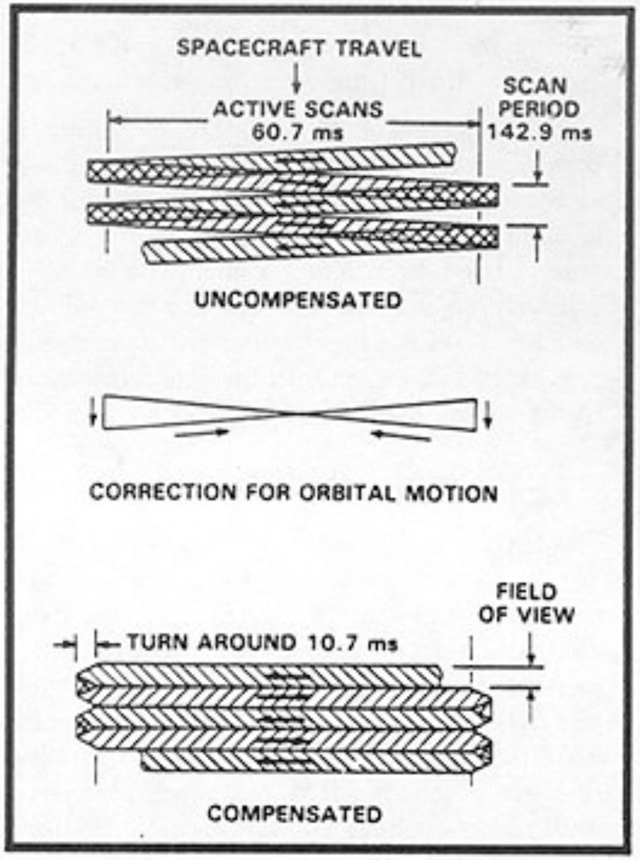
Sensor Non-Linearity

- Rotating mirrors scan lines with a constant angular velocity
- Oscillating mirrors (Landsat) need to accelerate and slow down for scanning.
- This yields to a displacements of up to 395 m (Richards).



Example: Landsat TM

- Primary scan mirror takes imagery during both its left and its right swings:
  - A zig-zag pattern results,
  - Origin: the small but steady rotation of the Earth's surface below.
- To produce an image, lines need to be parallel:
  - by using data acquired by two secondary mirrors
  - in parallel to one another
  - each rotating completely

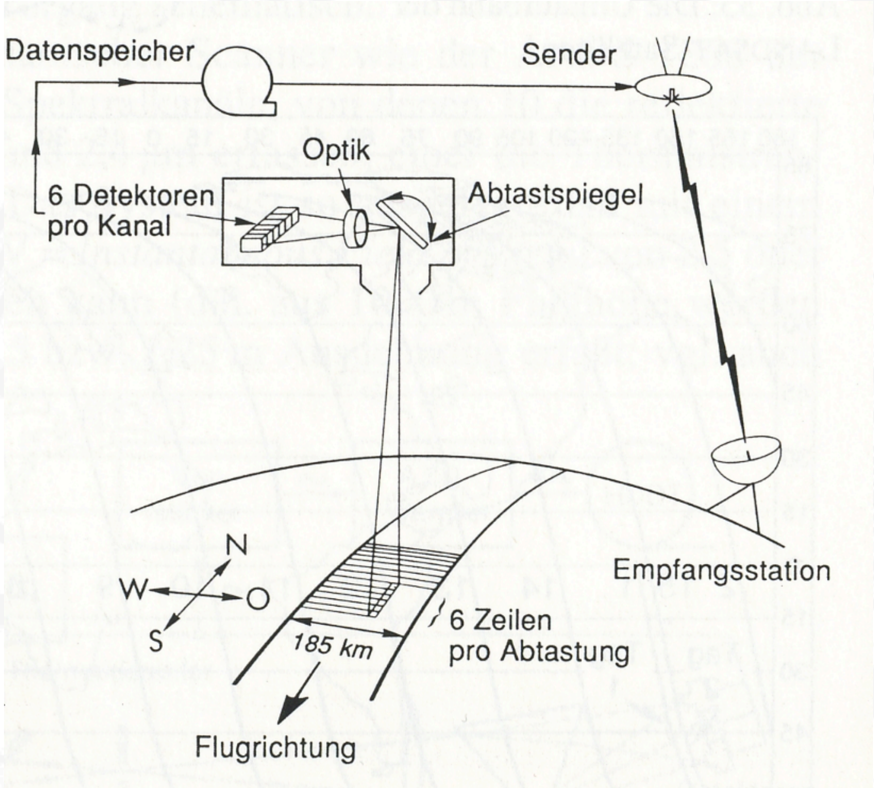


Preprocessing 1: Sensor Normalization

1. Radiometric Calibration
   - RAW-Sensor values to normalized values
     - Radiation coefficients for spectral sensors
     - Normalized Radar backscatter for MW Sensors
   - Flagging/Masking of sensor values
     - Errors of the Sensor panel
     - Cloud coverage for spectral sensors
2. Atmospheric Correction
   - Needs (high-resolution) atmospheric model
   - Local weather knowledge/measurements
   - Heuristics for basic correction tasks

Example for Sensor Normalization: Landsat MSS

- Recall: Landsat-MSS collects 6 scan lines at once
- If the six sensors have different gains or are not properly calibrated, periodical stripes will occur.



Landsat MSS-6-Line Anomaly

Sensor Data

Corrected Data

(from Albertz)

Correction of the Line Anomaly

1. Separate the images into 6 partial images, each only containing pixels of the same sensor.
2. Create an intensity histogram for each image and derive mean intensity and standard deviation
3. Select on partial image as reference and scale the intensities of the other images to fit to the (selected) reference histogram

- Derivation of the corrected values:
  - Let

m_d	the mean intensity of the reference image,
σ_d	the standard deviation of the intensities of the reference image I_d,
m_i	the mean intensity of the image to be corrected and
σ_i	the standard deviation of the intensities of the image to be corrected I_i.

$$I_i(x,y)' = \frac{\sigma_d}{\sigma_i}\left(I_i(x,y) - m_i\right) + m_d$$

Atmospheric Correction

Essential to get from sensor values to the measurement of reflectance spectra!

- Reflectance spectra are needed for spectral classification of objects
- Recall: The atmosphere does introduce (non-linear) errors to the measurement through itself
- Mainly needed for multi-spectral and infrared measurement
  - But: High-resolution models costly on unavailable
  - Thus: Use “ground truth” to enhance accuracy of available models
- Correction may also flag “unusable” values!
- Many heuristics for image enhancement of additive scattering → In general no dependency to reflectance spectra!

Heuristic Correction of Upward Sky Radiation I

Algorithm 1 – Using the darkest intensity

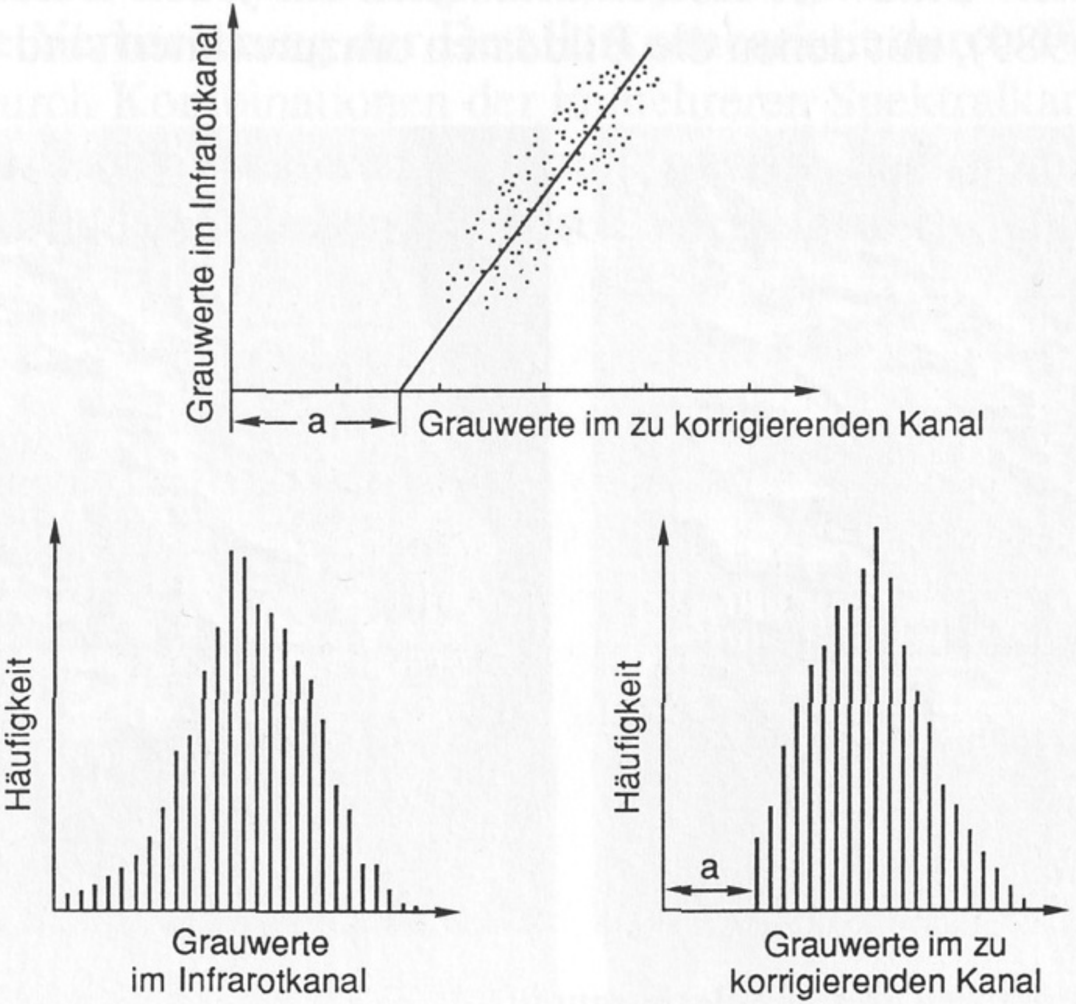
- Assumption:
  1. The lowest imaged intensity corresponds to a completely black objects
  2. The image intensities are linear correct.
  3. All additional brightness results from the atmosphere.
- Approach:
  - Correct the intensities by subtracting the value of the darkest pixel

Heuristic Correction of Upward Sky Radiation II

Algorithm 2 – Using the NIR band

- Assumption:
  1. The imaged intensities at the near infrared are only weakly influenced by the upward sky radiation
  2. The intensities to be corrected are linear dependent to those in the near infrared range.
  3. Without upward sky radiation, the regression would pass the origin of the coordinate system
- Approach:
  - Correct the intensities by subtracting the shift of the origin

Heuristic Correction of Upward Sky Radiation
Algorithm 2 – Using the NIR band



Preprocessing 2: Registration

- Spatial mapping of acquired images
- Needed for temporal studies, e.g.
  - Highly dynamic phenomena, like sea surface currents
  - Long-term observation of certain areas
  - Every kind of change detection
- Reformulation: Transformation of the image coordinate system w.r.t. a reference coordinate system
- Examples:
  - Match another image’s spatial range
  - Overlay features from maps
- Images are often annotated with approx. coordinates, so-called Tie-Points

Image to Image Registration

- If the images are of the same modality, purely image based registration is possible.
- Algorithms and algorithmic complexity depend on the degrees of freedom to be detected.
- Example: Rotation and Translation Registration
    1. Find rotation difference by means of FFT and differences in the Fourier spectrum
    2. Correct rotation on the image to be corrected.
    3. Use FFT again to detect the phase shift of the corrected and the reference image
    4. Translate the pre-corrected image w.r.t the phase shift.

Control Point based Image Registration

- Alternative formulation of the registration problem:

  Given n points of the first image, which correspond to n points of the second image

  Find a transformation, that transforms the first image onto the second
- Distinguish between
  - Rigid registration approaches (e.g. affine transformations)

    🇩🇪 *starre Registrierung*
  - Non-rigid registration approaches (e.g. Thin-Plate-Splines)

    🇩🇪 *flexible Registrierung*
- Use geographical embedding of reference image
- May also be posed as an Interpolation problem!

Rigid Registration I

- Assumption: Affine transformation between image I and reference image R: $\begin{pmatrix} x_I \\ y_I \\ 1 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_R \\ y_R \\ 1 \end{pmatrix}$
- To be determined: a_{11} … a_{23}
- Using n control points $p_i = (x'_i \; y'_i)^T$ at the image and n corresponding points $q_i = (x_i \; y_i)^T$ at the reference image we get:

$$\begin{aligned} x'_1 &= a_{11}x_1 + a_{12}y_1 + a_{13} \\ y'_1 &= a_{21}x_1 + a_{22}y_1 + a_{23} \\ &\vdots \\ x'_n &= a_{11}x_n + a_{12}y_n + a_{13} \\ y'_n &= a_{21}x_n + a_{22}y_n + a_{23} \end{aligned}$$

Rigid Registration II

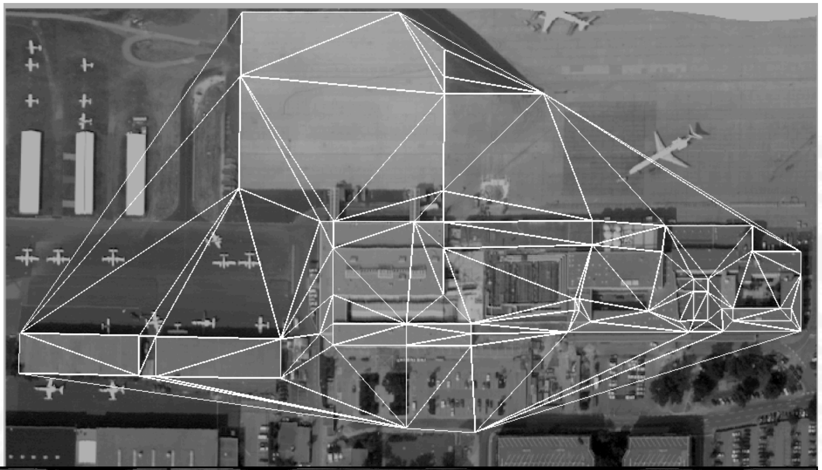
- Observations:
  - Resulting linear system of equation becomes solvable for n=3 control points
  - Less than three points: ill-posed
  - More than three points: Approximation method needed in most cases, e.g. least squared error optimization
- In practice: More points are used!
  - Mean square error of the assignment using the computed transformation is a hint for registration quality
  - odd points with high errors may be ignored.

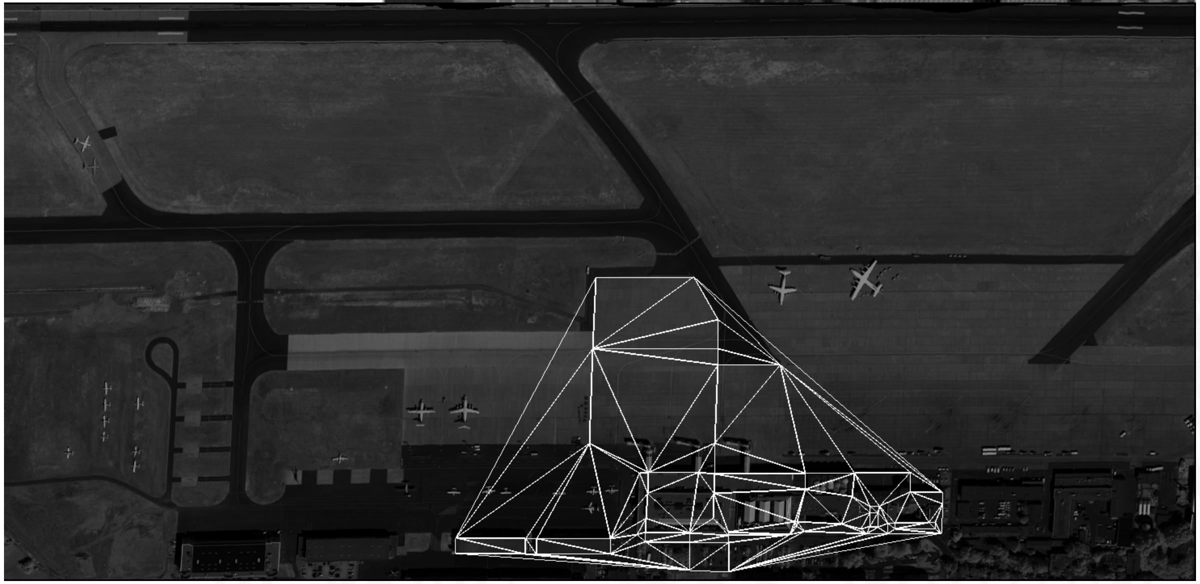
Rigid registration III

- Other models used for rigid transformations:
  - Polynomial of n^{th} degree
  - Rotate Scale Translate (RST)
  - Perspective Projection
- Combination with image processing methods: Derive candidates for the corresponding points automatically.
  - SIFT features
  - Canny features
  - etc.
- In Remote Sensing applications, control points are still selected manually for most applications

Example: Nuremberg Airport

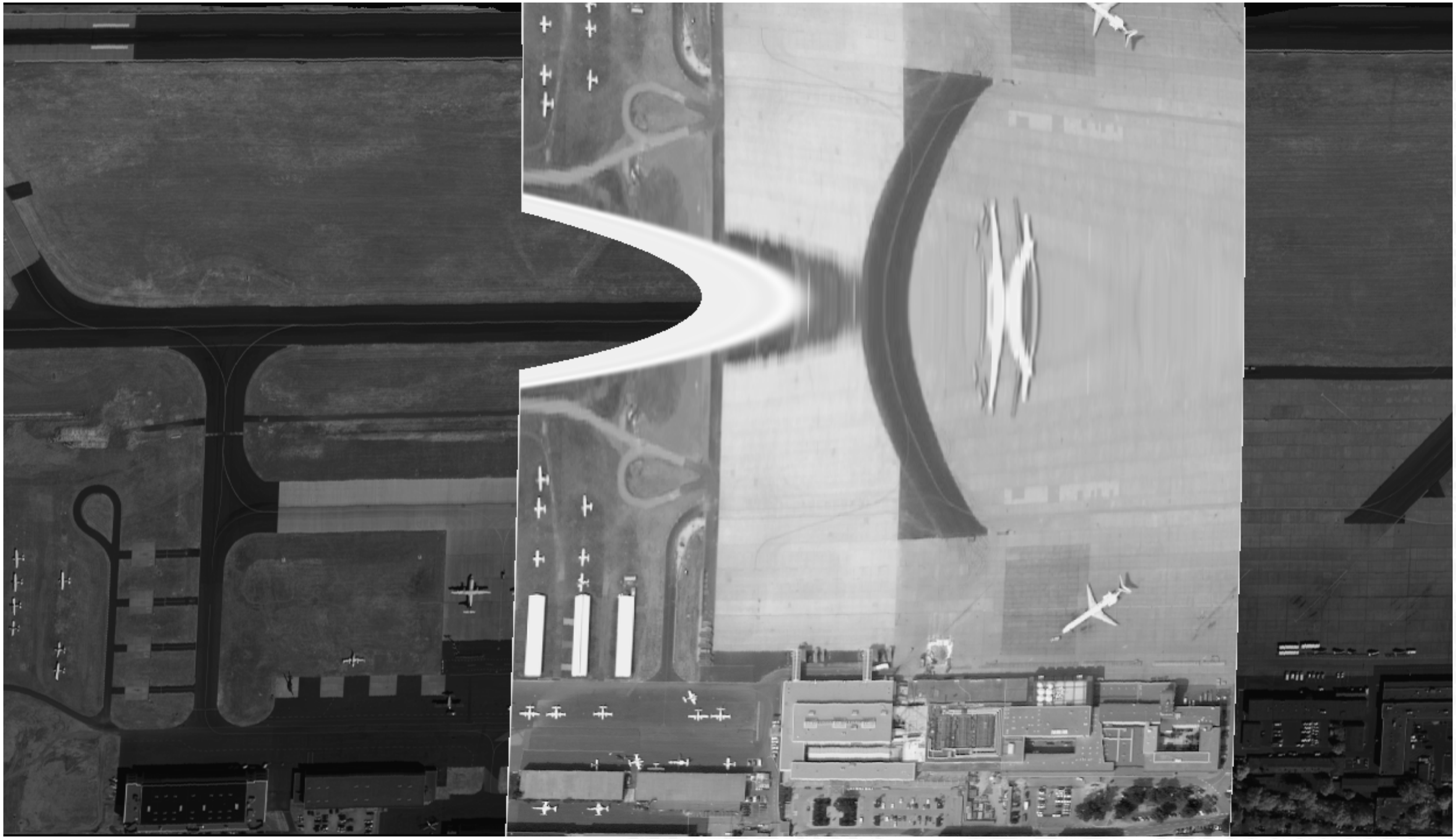
- Images were taken by different air-borne sensors
- Control points were selected manually



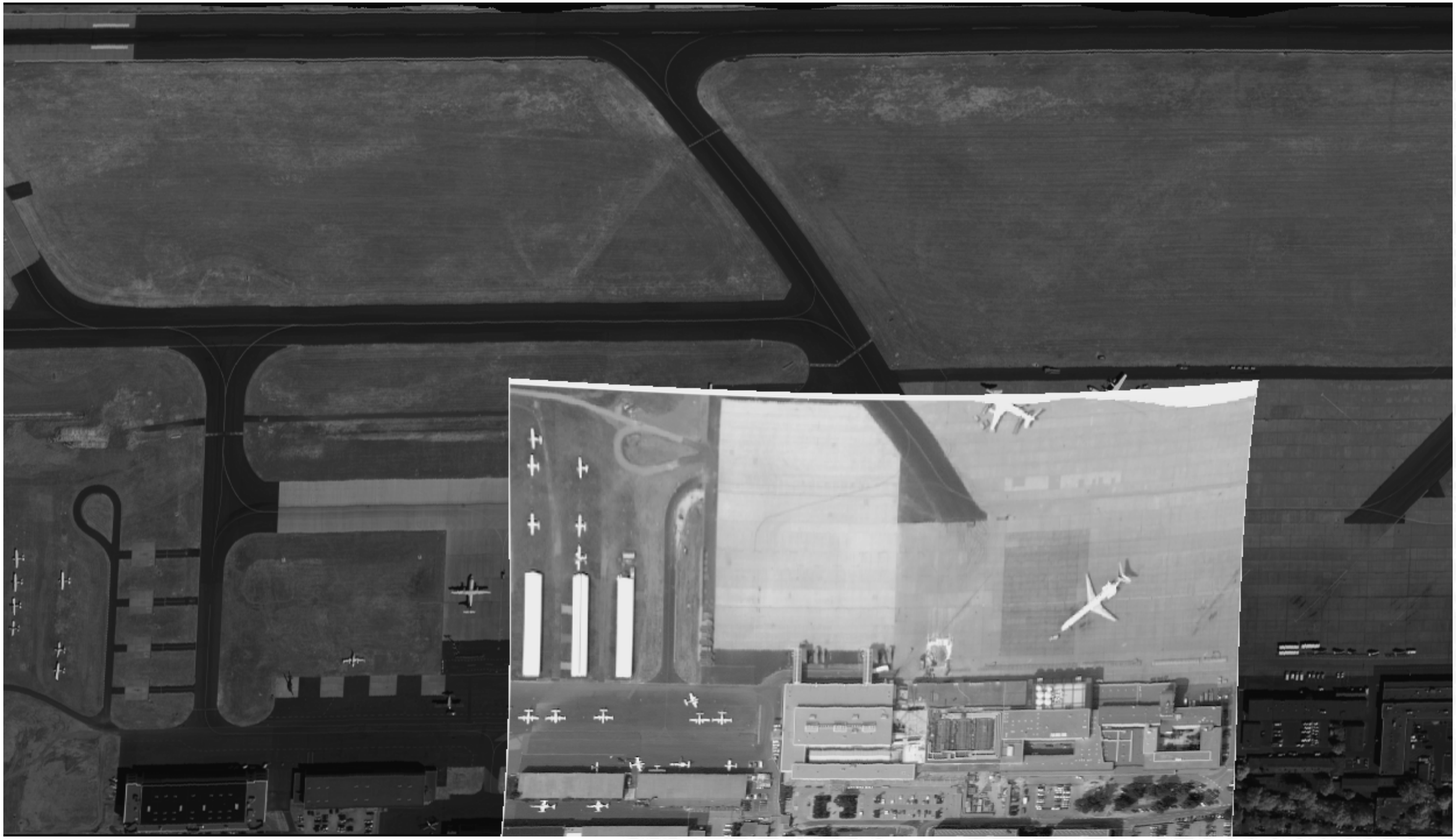


Example: Polynomial of 1^{st} degree

Example: Polynomial of 2nd degree



Example: Polynomial of 3rd degree

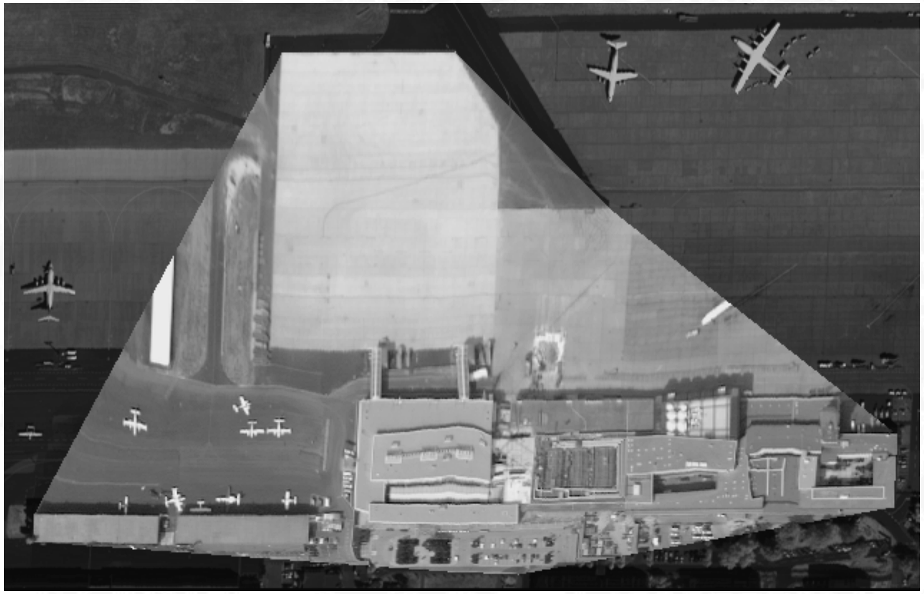


Example: Affine Transformation

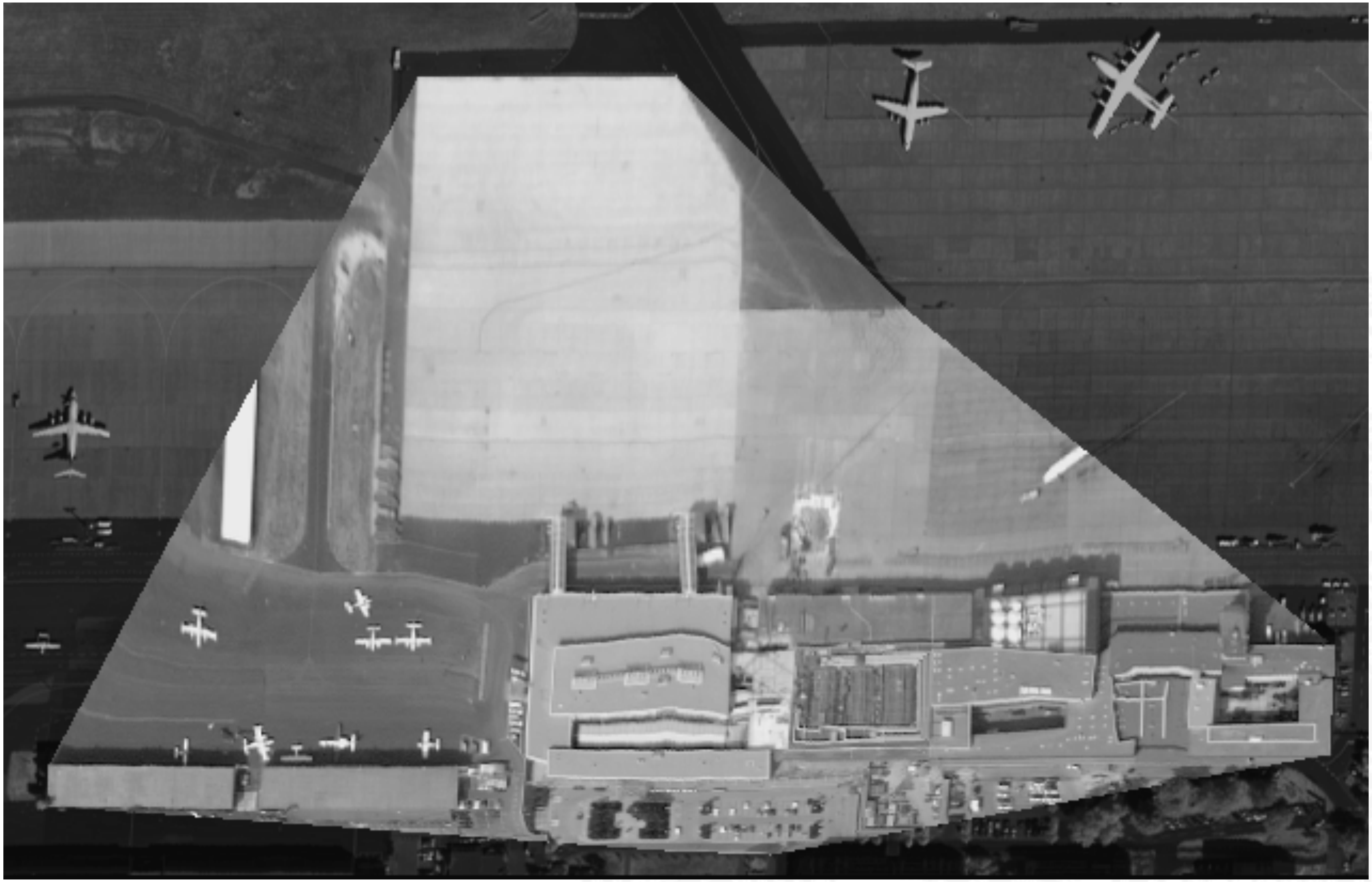
Example: Perspective Transformation

Piece Wise Rigid Registration

- Piecewise affine transformation
  1. Generate a triangle mesh for each set of control points
  2. Perform a transformation of each triangle to the reference triangle by means of an affine transformation
- Example: Nuremberg Airport
- **Note**: Artifacts at triangle boundaries!



Piece Wise Rigid Registration (Detail)



Non-Rigid Registration

- Registration based on weighted metrics between each control point set
- Usually: Radial Basis Functions (RBF) around the control points are used for weighting:
  - Thin-Plate-Splines,
  - Inverse Distance Weighted
  - etc.
- Registration of a single point refers to (possibly) all other control points
  - Large linear system of equations with > 1000 rows and columns
  - Solution needs a lot of computing power
  - Optimization via sparse matrix algorithms and decompositions

Example: Inverse Distance Weighted

Example: Thin-Plate-Spline Registration

Multimodal Registration

- Needed for a variety of applications:
  - Sensor fusion
  - Panchromatic Sharpening
    Use a panchromatic sensor of high resolution to enhance the (lower) resolution of multi spectral bands
  - Combine SAR- and multi spectral data
- Only similarity to be assumed: Two images of the same region
- Many challenges:
  - Different features are visible at different wavelengths: E.g. by combining SAR- multi spectral- and infrared data!
  - Different resolutions of different sensors
- But many advantages, too:
  - Become partially independent of clouds by fusing SAR and multispectral images
  - Support the monitoring of highly dynamical processes by a better spatio-temporal sampling rate.

Image to Digital Elevation Model (DEM) Registration

- In mountainous or highly urbanized regions, terrain corrections needs to take place!
- Can be achieved using an image to map registration:
  - Select ground control points at image and at the corresponding map
  - Transform image onto the map using:
    - A (high-resolution) digital elevation map
    - Sensor incidence angle and height
    - Sensor modality constraints (e.g. SAR or optical)
  - Result: The DEM model annotated with image intensity information at each surface element.
- Currently a lot of research in this field!
- Challenging, due to the (now) available high resolution sensors