Geometric Correction

Sources of Distortion

Sensor Characteristics
- optical distortion
- aspect ratio
- non-linear mirror velocity
- detector geometry & scanning sequence

Viewing Geometry
- panoramic effect
- earth curvature

Motion of the aircraft/satellite or target
- attitude changes (pitch, roll, yaw)
- position variations (altitude, slew)
- earth rotation

Distortions appear as:
- changes of scale over the image
- displacement of objects in an image
- irregularities in the angular relationships among the image elements
- occlusion of one image element by another

Correcting distortions can be costly
- computer & operator time
- affects spatial and radiometric resolution

The nature of the “correction” depends upon the ultimate use of the data:
- area measures $\Rightarrow$ equal area projection
- shape measures $\Rightarrow$ projection that preserves the angular relationships of the scene

Sensor Characteristics

Optical Distortion: not usually a major problem in remote systems

Note: These distortions are radially symmetric and characteristic of the optical system.
Aspect ratio: the ratio between scales in the horizontal and vertical directions.

Display/resampling with rectangular pixels matching the sampling interval

Display/resampling with square pixels with spacing greater than the original sampling interval

Display/resampling with square pixels spaced more closely than the original sampling interval

Non-linear mirror velocity:
- Uniform pixel spacing along a scan line presumes that the mirror velocity is constant.
- An oscillating mirror (MSS, TM) must stop at the end of each scan and reverse direction.

Detector geometry and scanning sequence:
A regular sampling pattern presumes
a) that the detectors are all exactly in the focal plane
b) that the scanning sequence and timing will exactly overlay detectors for different spectral bands
Whiskbroom Scanner Viewing Geometry: panoramic effect (flat earth version)

\[ \theta = \text{observation angle} \]
\[ \omega = \text{IFOV (often replaced by } \alpha \text{)} \]
\[ h = \text{altitude} \]
\[ d = \text{ground distance from nadir to the sampling point} \]
\[ p_o = \text{length of one side of a square pixel} \]

\[ \alpha = \omega^{1/2} \]
\[ p_o = \alpha h \]

\[ \text{Scale} = \frac{f}{H} \]

The scale is constant over the array.

\[ \theta = \text{observation angle} \]
\[ \omega = \text{IFOV (often replaced by } \alpha \text{)} \]
\[ h = \text{altitude} \]
\[ f' = \text{focal length} \]
\[ d = \text{ground distance from nadir to the sampling point} \]
\[ p_o = \text{length of one side of a square pixel} \]

Whiskbroom Scanner Viewing Geometry: panoramic effect (curved earth version)
Platform motion:

**Attitude changes:**
changes in the platform orientation that are significant over the time required to scan a full scene

**Pitch:**
"Vertical rotation of a sensor platform, in the 'nose up' plane." (CCRS). Changes in pitch will result in changes in the spacing of the scan lines.

**Roll:** "Rotation of a sensor platform around the flight vector, hence in a "wing down" direction." (CCRS)
Roll causes lateral shifts in the scan line position.

**Platform motion: Position changes**
- altitude - results in variations in scale
- slew - motion of the aircraft or satellite perpendicular to the intended direction of motion
Target motion
- Distortion will depend entirely on the nature of that motion relative to the sampling rate & sequence of the imaging system.
- When the motion of the scene is of the same order as the sampling rate the image will be blurred.
- A photo of a nearby building taken from the side window of a car moving at 50 mph when the shutter speed is 1/60 second, will result in a blurred image.

Earth Rotation
- The rotation of the earth is slow relative to the sampling rate of the Landsat MSS (~ 0.4 μs/pixel) and it is even slow relative to the scan rate (~33 ms/scan). Thus, there is no obvious blur in the final image.
- However, between the time that the first scan of a Landsat MSS image and the time of the last scan, the earth will have rotated a significant distance relative to the size of a resolution element.

SPOT panchromatic image – Central New York
The black wedges on the sides of the image are a result of correcting for earth rotation.
"Exact" Geometric Corrections

When enough is known about the source of the geometric distortions, it may be possible to approximate an ideal correction.

Examples:

A. Earth rotation
   1. Displacement is nearly perpendicular to the flight path (along the scan line).
   2. Rate of displacement is related to the orbital velocity and the angular velocity of the earth (predictable)

Correction

- only shifts by integral units of the sampling interval are allowed.
- no resampling (other than the pixel shift) is required.

B. Optical Distortion
   1. Displacement of each pixel is radial.
   2. Amount of displacement is defined by the optics of the system.
   - the amount of the shift is proportional to the distance from the optical axis
   - the direction of the shift varies over the image
   - requires shifts by non-integral units of the sampling interval
   - resampling is required.
General Geometric Correction Procedures

1. Select the appropriate projection or reference map (or image).
   **registration**: simple point-to-point match of an image to another image or map,
   **rectification**: correcting an image to a specific map projection.

2. Select a regular grid which fits the desired projection (i.e., determine the spacing and position of the grid points.)
   *Note: Steps 1 and 2 depend on the individual applications.*

3. Select a set of "ground control points" (GCP's) -- pixels whose locations can be determined accurately in the base map and the image.

4. Define the transformation and compute the positions of the reference grid points in the image coordinate system:
   a. Rotation, Stretch, Translation (RST - linear)
   b. Polynomial ($n^{\text{th}}$ order)
   c. Triangulation (Delaunay triangulation – fits triangles to the irregularly spaced GCPs and interpolates values to the output grid. This is the default option.)

5. Resample the image data in order to assign gray values to each grid point:
   a. Nearest neighbor
   b. Bilinear interpolation
   c. Cubic convolution

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1. Select the appropriate projection or reference map.

   **Map Projections**       **There is no perfect map projection.**

   Projections may be optimized to preserve
   area
   or shape
   or direction
   or distance

   For small enough areas, all factors may be preserved within the precision of the sampling
1. Conformal (orthomorphic) projections: Projections which represent shape correctly within certain limits.
   - Relatively small portions of the earth's surface are properly represented in shape.
   - Actually, the conformal principle applies only to each infinitesimal element of the map.
   - Angles at each point are correct, and consequently the local scale in every direction around any one point is constant.
   - The map user can measure distance and direction between near points with a minimum of difficulty.

Examples:

1A. Mercator projection:
   - Lines of constant compass bearings are plotted as straight lines.
   - Scale is true at the equator or at two standard parallels equidistant from the equator.
   - The projection is often used for marine navigation because all straight lines on the map are lines of constant azimuth.

1B. Transverse Mercator
   - Transverse Mercator projections result from projecting the sphere onto a cylinder tangent to a central meridian.
   - Often used to portray areas with larger north-south than east-west extent.
   - Distortion of scale, distance, direction and area increase away from the central meridian.
   - Lines of constant scale are straight lines parallel to the central meridian for the sphere.

1C. Universal Transverse Mercator (UTM)
   - The UTM projection divides the surface of the Earth into 6 degree zones, each mapped by the Transverse Mercator projection with a central meridian in the center of the zone.
   - UTM zone numbers designate 6 degree longitudinal strips extending from 80 degrees South latitude to 84 degrees North latitude.
   - UTM zone characters designate 8 degree zones extending north and south from the equator.
   - Eastings are measured from the central meridian (with a 500km false easting to insure positive coordinates).
   - Northings are measured from the equator (with a 10,000km false northing for positions south of the equator).
1D. Space Oblique Mercator

- Projection developed (1978) specifically for the continuous mapping of imaging from satellites.
- The ground track for the satellite is held true to scale, and mapping is made basically conformal within the narrow band (about 15 degrees) of the satellite image.
- Because of the relative motion of Earth and satellite, the ground track is curved.

2. Equal Area Projections

- Projections that show area correctly.
- These projections generally distort shape badly.

Example: Albers Equal-Area Conic

- A conic projection that distorts scale and distance except along standard parallels.
- Areas are proportional and directions are true in limited areas.
- Used in the United States and other large countries with a larger east-west than north-south extent.

3. Azimuthal projections

- Projections that correctly portray directions from a specified point.

Example: Azimuthal Equidistant

- Projections sometimes used to show air-route distances.
- Distances measured from the center are true.
- Distortion of other properties increases away from the center point.

4. Other projections

- There are projections which preserve none of the four characteristics (area, shape, direction, or distance), but which are useful for other reasons.
- For small areas of the earth's surface nearly any standard projection will accurately represent the surface.
- Locally, a simple rectangular coordinate system will often be entirely adequate.

Unprojected Latitude and Longitude
Additional comments • In satellite imagery, the size of the area imaged is often large enough that the earth's curvature cannot be ignored.
  • The most natural projection in most cases is some form of oblique Mercator projection.
  • Typical choices include
    - Space Oblique Mercator (SOM), and
    - Hotline Oblique Mercator (HOM),
    both of which are relatively distortion-free for single scenes.

Ground Control Points (GCP's) Ground Control Points are pixels whose locations can be determined accurately in the base map and the image, used to create the mapping of the image to the base map.

For each control point the pixel coordinate must be matched with the coordinate of the control point in the desired coordinate system.

Selection of Ground Control Points
  • Pixels used for GCP's should be easy to locate accurately on the base map.
  • These are usually easily recognizable features or landmarks in the image.

Examples:
  - crossroads
  - land/water boundaries
  - cultural features (airstrips, buildings, etc.)

Base Map & Image Geometric Transforms: Procedure
1. Select a set of GCP's
2. Select a transformation (linear, 2nd order, 3rd order, ...)
3. Determine the coefficients that will minimize the error.
4. Analyze the residual errors.
5. Adjust the selection and placement of GCP's.
6. Repeat steps 3-5 until the error is acceptable.
Linear Transform

Linear transforms involve translation, rotation, and magnification.

a. Translation: \[ x' = x + x_0 \quad y' = y + y_0 \]
b. Rotation: \[ x' = y \sin \theta + x \cos \theta \]
   \[ y' = y \cos \theta - x \sin \theta \]
c. Magnification \[ x' = mx \]
   \[ y' = ny \]
d. General linear transform: \[ x' = a_0 + a_1x + a_2y \]
   \[ y' = b_0 + b_1x + b_2y \]

Typically non-linear, polynomial fit such that:

\[ x' = a_0 + a_1x + a_2y + a_3xy + a_4x^2 + a_5y^2 + \ldots \]
\[ y' = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2 + \ldots \]

Non-Linear Transformations

Resampling

A process in which each data point (pixel) in the base map coordinate system is assigned a value (intensity, gray value, etc.) based on the gray values of local image pixels.

Consider an example in which an image of a checkerboard pattern is geometrically corrected.

- pixels in the original image data (checkerboard pattern)
- desired pixel locations in the base map coordinate system

Nearest-neighbor Resampling

The gray value of the image pixel is assigned to the nearest base map coordinate:

- the base map grid values correspond to actual measured values.
- the value assigned to the grid point will probably not be the same as that which would have been measured at that point.
- fastest and cheapest method of resampling.
- does the least radiometric damage to the data.
- tends to result in a blocky appearance at sharp boundaries.

Bilinear Interpolation

Two-dimensional linear interpolation

Uses the four nearest neighbors

- the base map grid values correspond to a weighted average of the four nearest neighbors.
- relatively fast computation.
- smoothes out the blocky appearance apparent with nearest-neighbor resampling (anti-aliasing).
- increases the effective resolution cell size.
- this example illustrates undersampling.
- dark squares are sets of original pixels for which there are no corresponding resampled pixels.
- The contribution of a pixel is inversely proportional to its distance from the resampled pixel.
**Bicubic Interpolation** Two-dimensional cubic interpolation

Uses the sixteen nearest neighbors

- the base map grid values correspond to a weighted average of the sixteen nearest neighbors.
- more computation than bilinear interpolation.
- smoothes out the blocky appearance apparent with nearest-neighbor resampling (anti-aliasing).
- further increases the effective resolution cell size.

**Geometric Registration: Example, image ==> map**

Source: University of Arizona Tutorial on geometric correction
http://aria.arizona.edu/courses/tutorials/geom/html/geomexp1.html

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<thead>
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<th>Control points:</th>
<th>1</th>
<th>2</th>
<th>3</th>
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</thead>
<tbody>
<tr>
<td>x, y</td>
<td>x', y'</td>
<td></td>
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<tr>
<td>198, 157</td>
<td>213, 292</td>
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<tr>
<td>105, 162</td>
<td>120, 300</td>
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<tr>
<td>260, 195</td>
<td>275, 325</td>
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</tr>
</tbody>
</table>

Number of polynomial terms: 3

Transformation Coefficients:

\[ x = -15 + x' \]
\[ y = -166 + 0.04 x' + 1.0783 y' \]

Root-Mean-Squared Error

at Control Points = 1.3610e-11

Bilinear interpolation