5. Geometric Correction

- Image includes geometric distortions
  - Internal distortions
  - External distortions
- Geometric correction is
  - To remove internal distortions
  - To remove external distortions
  - To identify the location of each pixels on the earth
    - Overlay with map and other images
  - To convert coordinate system (such as lat-lon -> UTM)
- Parameter determination
  - Systematic
  - Non-Systematic (Black box type)
  - Combined

Overlay with map and other images
- To convert coordinate system (such as lat-lon -> UTM)

Parameter determination
- Systematic
- Non-Systematic (Black box type)
- Combined

Geometric Correction at End Users

- High-resolution RS image is usually provided with UTM coordinate System after systematic geometric correction.
- However, the accuracy of the systematic geometric correction of usual product is not satisfactory. It is depending on position and attitude measurement of satellites. (Landsat: several hundred meters)
- Users must do geometric correction using GCP (Ground Control Point) to overlay the image with Maps, GPS reading and etc. (accuracy can be 1 pixel)

Distortions

- Geometric distortion is an error on an image, between the actual image coordinates and the ideal image coordinates which would be projected theoretically with an ideal sensor and under ideal conditions.
- Geometric distortions are classified into internal distortions resulting from the geometry of the sensor, and external distortions resulting from the attitude of the sensor or the shape of the object.

**Internal Distortions**

1. Radial distortion
2. Tangential distortion
3. Scale error
4. Projection distortion
5. Shear

**External Distortions**

1. Roll error
2. Scale error
3. VIT error
4. Shear
5. Roll, Pitch, Yaw error
6. Orthometric errors
7. Gravity errors
8. Atmospheric effects

**Coordinate System**

- Center of the Earth
- Roll, Pitch, Yaw measured by AMS (Attitude Measurement Subsystem)
- (Xe, Ye, Ze): Earth-based Coordinate System
- (Xo, Yo, Zo): Satellite-based Coordinate System along the orbit
- (Xe, Ye, Ze) rotate satellite orbit coordinate with Roll, Pitch and Yaw
- (Xe, Ye, Ze) of target -> Longitude, Latitude -> Map Projection such as UTM
A map projection is used to project the rotated ellipse representing the earth's shape, to a two-dimensional plane. However, there will be some distortions because the curved surface of the earth cannot be projected precisely on to a plane.

There are three major map projection techniques; perspective projection, conical projection and cylindrical projection, which are used in remote sensing. There are described as follows.

a. Perspective projection
b. Conical projection
c. Cylindrical projection

UTM is a type of Gauss-Kruger projection, with the meridian tangent to the cylinder. The UTM has an origin point at every six degrees of longitude with a scale factor of 0.9996 at the origin and 1.0000 at a distance of 90 kilometers from the central meridian.

<table>
<thead>
<tr>
<th>Ellipsoid</th>
<th>Datum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many Ellipsoid</td>
<td>Datum is a set of parameter, which defines the size and the position of the earth.</td>
</tr>
<tr>
<td>GRS80</td>
<td>Thus if Datum is different, geo-locations changes.</td>
</tr>
<tr>
<td>Everest 19XX</td>
<td>There are many datum even though they use same ellipsoid to have best applicability to the region in terms of accuracy, implementation.</td>
</tr>
<tr>
<td>Clarke 1866</td>
<td>Many countries started to implement ITRF Datum.</td>
</tr>
<tr>
<td></td>
<td>When you locate a position on your map, the datum of the position information and the datum used in the map must be same.</td>
</tr>
<tr>
<td></td>
<td>Usually RS image is being projected to UTM using WGS84 (with WGS84 ellipsoid) datum. However you can select ITRF - GRS80 as well for Landsat</td>
</tr>
</tbody>
</table>
| | GPS: Default: WGS84 for usual GPS, ITRF for high-precision GPS. You must check the datum used in your map and adjust GPS receiver to use the same datum.

UTM: Universal Transverse Mercator
Project every 8 degree of longitude to one flat plane from -80 to +80 deg latitude
Easting: measured from the center, but to ensure all coordinate be positive, 500km is added.
Northing: For north hemisphere, measure from equator, for south hemisphere, 10,000km is added

Thailand: Zone 47
UTM is a type of Gauss-Kruger projection, with the meridian tangent to the cylinder. The UTM has an origin point at every six degrees of longitude with a scale factor of 0.9996 at the origin and 1.0000 at a distance of 90 kilometers from the central meridian.

Many country started to use GRS80, which is based on satellite observation WGS84 and GRS80 is nearly same. (several 10cm and meter difference)
ITRF adopt GRS80
ITRF(International Terrestrial Reference Frames) which is 3-axis coordinate system (X,Y,Z), and the origin is the center of the gravity of the earth.
Steps of Usual Non-systematic Geometric Correction

1. Make a list of Image Coordinate and their position using GCP.
2. GCP (Ground Control Point) is taken from such as intersection, corner of reclamation, capes, small islands, river joint point and etc.
3. GCP should be able to be identified both in image and map (or GPS).
4. If Map is not available, GPS is used to obtain coordinates.
5. Select an appropriate transformation equation (usually affine is OK).
6. Re-project the image into the map coordinate
7. Usually Cubic Convolution is used as Re-sampling method.

Following types of points are often chosen for GCP:
- Boundaries of land and water, e.g., corner of reclamation, dams, breakwaters, corner of harbors, capes, lighthouses, small islands, factories, buildings, runways of airport, center of small ponds, river joint point, road cross point.

Transform formulas I

- Pseudo affine transformation
  \[ \begin{align*}
  u &= a_1 x + a_2 y + a_3 \\
  v &= b_1 x + b_2 y + b_3
  \end{align*} \]

Affine transformation

- Scale, rotate, shift, skew, linear
  \[ \begin{align*}
  u &= a_1 x + a_2 y + a_3 \\
  v &= b_1 x + b_2 y + b_3
  \end{align*} \]

Polynomials

- (n: max 3)
  \[ \begin{align*}
  u &= \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} x^{i-1} y^{j-1} \\
  v &= \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} x^{i-1} y^{j-1}
  \end{align*} \]

Transform formulas II

<table>
<thead>
<tr>
<th>Name</th>
<th>Transformation Formula</th>
<th>Number of unknown parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Homography (scale, shear)</td>
<td>( x' = ax + by + c ) ( y' = dx + ey + f )</td>
<td>6</td>
</tr>
<tr>
<td>(2) Affine</td>
<td>( a_1 x + a_2 y + a_3 ) ( b_1 x + b_2 y + b_3 )</td>
<td>6</td>
</tr>
<tr>
<td>(3) Pseudo Affine</td>
<td>( a_{ij} x^{i-1} y^{j-1} )</td>
<td>6</td>
</tr>
<tr>
<td>(4) Projective</td>
<td>( a_1 x + a_2 y + a_3 ) ( b_1 x + b_2 y + b_3 )</td>
<td>6</td>
</tr>
<tr>
<td>(5) Second-order Transformation</td>
<td>( a_{ij} x^{i-1} y^{j-1} )</td>
<td>6</td>
</tr>
<tr>
<td>(6) Polynomials</td>
<td>( a_{ij} x^{i-1} y^{j-1} )</td>
<td>6</td>
</tr>
</tbody>
</table>

To obtain good accuracy of geometric correction, GCP must be distributed equally in the image.

Distribution of GCP

- The distribution of GCP should be equalized.
**Resampling & Interpolation**

- Projection from output image to input image.
  - If output->input, some pixel will not have data
- However, the projected coordinate is not exactly on the grid of a pixel. ->
  Interpolation from single or several pixels around the projected coordinate.

**Interpolation**

- (1) Nearest neighbor (NN)
  The nearest point will be sampled. The geometric error will be a half pixel at maximum. It has the advantage of being easy and fast. The data value will not change.

- (2) Bi-linear (BL)
  The bi-linear function is applied to the surrounding four points. The spectral data will be smoothed after the interpolation.

- (3) Cubic convolution (CC)
  The spectral data will be interpolated by a cubic function using the surrounding sixteen points. The cubic convolution results in sharpening as well as smoothing, though the computation takes a longer time when compared with the other methods.

**Convolution**

- **N.N** Nearest Neighbor
  \[ h(x) = \begin{cases} 
  1 & x = 0 \\
  0 & \text{otherwise} 
  \end{cases} \]

- **B.L.** Bi-Linear
  \[ h(x) = \begin{cases} 
  1 - |x| - \frac{1}{2} & |x| < 1 \\
  0 & \text{otherwise} 
  \end{cases} \]

- **C.C** Cubic Convolution
  \[ h(x) = \begin{cases} 
  1 - |x| - \frac{1}{2} & |x| < 1 \\
  0 & \text{otherwise} 
  \end{cases} \]