APPLICATIONS ON GEOMETRIC CORRECTION OF DIFFERENT RESOLUTION SATELLITE IMAGES

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ABSTRACT

In Remote Sensing, because of some parameters correlated to platform instabilities, sensor geometry, curvature and rotation of Earth, satellite images are affected by geometric distortions. A part of them is often corrected directly by the providers, while the other ones can be limited referencing the images to existing maps. In fact, when remotely sensed data, such as Landsat or MODIS (Moderate Resolution Imaging Spectroradiometer) or IKONOS images, are acquired, they are represented in geometric scheme by rows and columns. As the relationship between this raster format and real plane or geographic coordinates system is missing, a georeferencing process must be realized to obtain this correlation.

In this paper methods to correct satellite images and to adapt them to cartographic representations are shown and the accuracy parameters are discussed with the aim to achieve results assessment. Applications are focalized on images concerning Campania Region with low (MODIS), medium (Landsat) and high (IKONOS) resolution.

1. GEOMETRIC CORRECTION AND GEOREFERENCING

To correct geometrically satellite images with low or medium resolution and to georeference them, Polynomial Functions are used. Relationship between images coordinates \((X',Y')\) and cartographic ones \((X,Y)\) is defined by:

\[
X' = p^o(X,Y) \quad Y' = p^o(X,Y)
\]  

(1)

The generic Polynomial \(p^o\) (\(n\) is the order) is represented by:

\[
p^o(X,Y) = \sum_{j=0}^{m} \sum_{k=0}^{n} a_{jk} X^j Y^k
\]  

(2)

with:

\[0 \leq m_1 \leq n; \quad 0 \leq m_2 \leq n; \quad m_1 + m_2 \leq n.\]

For example, considering \(n = 3\), the equations (1) become:

\[
X' = a_0 + a_1 X + a_2 Y + a_3 XY + a_4 X^2 + a_5 Y^2 + a_6 X Y + a_7 X^2 Y + a_8 XY^2 + a_9 Y^3
\]  

(3)

\[
Y' = b_0 + b_1 X + b_2 Y + b_3 XY + b_4 Y + b_5 X^2 + b_6 Y^2 + b_7 X Y + b_8 X^2 Y + b_9 XY^2 + b_{10} Y^3
\]  

(4)

To determine values of the polynomial coefficients in (1), Ground Control Points (GCPs) which are identifiable in the image \((X,Y)\) must be selected accurately on the map \((X,Y)\). The minimum number of GCPs depends on the order of the polynomial functions: it is supplied by \((n+1)*(n+2)/2\), with \(n\) degree of polynomial. Usually a greater number of GCPs is used, so to get the optimal transformation with the smallest overall positional error in the selected points.

Accuracy is estimated by the average of the errors in the reference points that are not only GCPs but also Check Points (CPs), different from GCPs [1].

For high resolution satellite images polynomial functions don’t supply results comparable with pixel dimensions. Better solutions can be obtained using 3d Rational Polynomial Functions. Relationship between images coordinates \((X,Y)\) and 3d object coordinates \((X,Y,Z)\) is defined by:

\[
X' = p^o(X,Y,Z) / p^o(X,Y) \quad Y' = p^o(X,Y,Z) / p^o(X,Y)
\]  

(4)

The generic polynomial \(p^o\) is expressed by:
P^n (X,Y,Z) = \sum_{j=0}^{n} \sum_{k=0}^{n} \sum_{l=0}^{n} a_{jkl} X^j Y^k Z^l \tag{5}

with:
0 \leq m_i \leq 3; 0 \leq m_j \leq 3; 0 \leq m_k \leq 3; m_i + m_j + m_k \leq 3

For example, considering n = 3, polynomial P^3 is:

\begin{align*}
P^3 &= a_0 + a_1 X + a_2 Y + a_3 Z + a_4 XY + a_5 XZ + \\
    &+ a_6 YZ + a_7 X^2 + a_8 Y^2 + a_9 Z^2 + a_{10} XYZ + \\
    &+ a_{11} X Y^2 + a_{12} X Z^2 + a_{13} Y^2 Z + a_{14} X^2 Y + \\
    &+ a_{15} X^2 Z + a_{16} Y^2 Z + a_{17} X Y^3 + a_{18} X Z^3 + \\
    &+ a_{19} Y Z^3 + a_{20} X^3 Y + a_{21} X^3 Z + a_{22} Y^3 Z + \\
    &+ a_{23} Y^2 Z^2 + a_{24} Y Z^3 + a_{25} X^2 Y^2 + \\
    &+ a_{26} X^2 Z^2 + a_{27} X Y^3 + a_{28} X Z^3 + \\
    &+ a_{29} Y Z^3 + a_{30} X^3 Y + a_{31} X^3 Z + a_{32} Y^3 Z + \\
    &+ a_{33} Y^2 Z^2 + a_{34} Y Z^3 + a_{35} X^2 Y^2 + \\
    &+ a_{36} X^2 Z^2 + a_{37} X Y^3 + a_{38} X Z^3 + a_{39} Y Z^3 \tag{6}
\end{align*}

In reference to (4), because in the polynomials P^2 and P^4 the first terms (b_0 and d_0) are assumed equal to 1, the values of 78 coefficients must be calculated. For consequence several GCPs must be considered (at least 39). Accuracy of solutions depends on the number and the distribution of GCPs. Best results, in fact, are obtained using a large number of GCPs that must be regularly distributed in reference both planimetry and altimetry [2].

2. APPLICATION ON A LOW RESOLUTION IMAGE (MODIS)

Moderate Resolution Imaging Spectroradiometer (MODIS) is a part of the NASA EOS (Earth Observing System).

With OrthoEngine (PCI GEOMATICA Software v 9.1) a MODIS RGB image (pixel dimensions: 250 m x 250 m) concerning South Italy has been georeferenced in UTM-WGS84 using 25 GCPs and 15 CPs, both on coastline. Cartographic coordinates have been derived from vector map of Italian Provincial Boundaries, scale 1:250,000. Results (Tables 1 and 2), that are comparable with geometric image resolution, are obtained with 3rd or higher order polynomial functions.

<table>
<thead>
<tr>
<th>Polynomial Functions</th>
<th>X_\text{medium}</th>
<th>X_\text{minimum}</th>
<th>X_\text{maximum}</th>
<th>\sigma_x</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st order</td>
<td>254.99</td>
<td>38.40</td>
<td>525.15</td>
<td>121.55</td>
</tr>
<tr>
<td>2nd order</td>
<td>142.12</td>
<td>63.34</td>
<td>345.97</td>
<td>71.75</td>
</tr>
<tr>
<td>3rd order</td>
<td>116.57</td>
<td>18.93</td>
<td>290.47</td>
<td>68.96</td>
</tr>
<tr>
<td>4th order</td>
<td>101.23</td>
<td>7.67</td>
<td>272.20</td>
<td>66.43</td>
</tr>
<tr>
<td>5th order</td>
<td>62.49</td>
<td>4.07</td>
<td>205.62</td>
<td>50.96</td>
</tr>
</tbody>
</table>

Tab. 1 - Residuals (in meters) obtained for the GCPs by georeferencing the MODIS image in UTM-WGS84

<table>
<thead>
<tr>
<th>Polynomial Functions</th>
<th>X_\text{medium}</th>
<th>X_\text{minimum}</th>
<th>X_\text{maximum}</th>
<th>\sigma_x</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st order</td>
<td>279.80</td>
<td>30.43</td>
<td>1124.25</td>
<td>254.47</td>
</tr>
<tr>
<td>2nd order</td>
<td>204.47</td>
<td>28.48</td>
<td>961.04</td>
<td>221.44</td>
</tr>
<tr>
<td>3rd order</td>
<td>204.18</td>
<td>40.27</td>
<td>937.38</td>
<td>231.87</td>
</tr>
<tr>
<td>4th order</td>
<td>190.57</td>
<td>10.44</td>
<td>915.89</td>
<td>216.17</td>
</tr>
<tr>
<td>5th order</td>
<td>168.71</td>
<td>67.80</td>
<td>395.68</td>
<td>80.89</td>
</tr>
</tbody>
</table>

Tab. 2 - Residuals (in meters) obtained for the CPs by georeferencing the MODIS image in UTM-WGS84

3. APPLICATION ON A MEDIUM RESOLUTION IMAGE (ETM+ LANDSAT)

The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey. Since 1972, Landsat satellites have collected information about Earth from space. The Earth observing instrument on Landsat 7, the Enhanced Thematic Mapper Plus (ETM+), replicates the capabilities of the Thematic Mapper instruments on Landsats 4 and 5. The ETM+ also includes additional features, such as a panchromatic band with 15 m spatial resolution and a thermal IR channel with 60 m spatial resolution [4]. A Landsat ETM+ panchromatic image concerning Campania Region, acquired in 2000, has been considered. This image is also georeferenced in UTM-WGS84: for consequence, only a check has been conducted using 15 CPs, which coordinates have been derived from official regional ortophotos (scale 1:10,000). Residuals (Table 3) result comparable with geometric resolution.
4. APPLICATION ON A HIGH RESOLUTION IMAGE (IKONOS PAN)

IKONOS (the term derives from the Greek word for “image”) was the first commercial satellite to gather panchromatic images (0.45 μm – 0.90 μm) with 1 m x 1 m resolution and multispectral imagery, three visible (Blue: 0.45 μm – 0.52 μm; Green: 0.52 μm – 0.60 μm; Red: 0.63 μm – 0.69 μm) and one infrared channel (IR: 0.76 μm – 0.90 μm), with 4 m x 4 m resolution. Data are collected in 11 bit radiometric resolution; the tile size for each individual scene is 11.3 km x 11.3 km. Three IKONOS satellite products are available: Carterra Geo, Carterra Orthorectified and Standard Stereo, with different levels of positional accuracy [5].

In this paper the results of geometric correction of an IKONOS panchromatic image (Carterra Geo) concerning an area of Campania Region around Salerno are considered (Tables 5 and 6). Using also in this case OrthoEngine software, Rational Functions have been applied with 77 GCPs and 15 CPs, which coordinates in UTM-WGS84 have been derived from official regional orthophotos (scale: 1:10,000).

Residuals (Tables 4 and 5) are comparable with pixel dimensions, so the corrected image can be used at 1:10,000.

5. CONCLUSIONS

Using polynomial functions, satellite images with low or medium resolution can be corrected with an accuracy comparable with pixel dimensions, as confirmed by test for MODIS and Landsat ETM+ data presented in this paper.

The test for IKONOS GEO-product confirms that appropriate accuracy can be obtained for high resolution images only using Rational Polynomial Functions. For georeferencing low and medium resolution images, coordinates of GCPs and CPs can be derived by maps at small or medium scale. For high resolution images, detailed maps are necessary: higher accuracy levels can be ensured with the use of DGPS geodetic receivers for coordinates acquisition.

6. REFERENCES


