GEOMETRIC MODELLING AND ORTHORECTIFICATION OF SPOT5 SUPER MODE IMAGES

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ABSTRACT:

The latest very high resolution satellites have an important impact in geoinformatic industry. As an alternative for the aerial photos, detailed maps in multiple scales can frequently and easily generated or updated from images with a gain in cost and time of operations. Here, we review different methods that we used to correct a very high resolution image of ORAN (ALEGERIA), in this application we used SPOT 5 Super Mode image with 2.5m ground sample distance, we test seven geometric models for the orthorectification. And we deduce the applicability of different geometric models for the orthorectification of SPOT 5 images and the reachable accuracy.

1. INTRODUCTION

The development of the society is directly related to the accessibility and the quality of the map, which is considered like a fundamental document for several applications such as natural resources exploitation, disaster management, commerce… Many other social interactions are simplified if maps are more detailed and widely distributed.

Before, the only solution for medium and large scale maps production was by exploitation of the aerial photography, but at the end of 1999 the very high resolution satellite imagery is commercially available for civil applications, this product is becoming rapidly a real concurrent of the aerial photography.

Many providers of very high resolution satellite images exist and they offer images with a ground sample distance (GSD) from 0.7 to 5 meters, Table 1 shows some very high resolution satellite and their characteristics:

Satellite	Altitude	Swath	Revisit time	GSD
Spot	830 km	60 km	3-26 Day	5 - 2.5m
Eros-a1	480 km	12.5k m	3 Day	1.8m
Orbview3	740 km	8 km	1-3 Day	1m
Ikonos	680 km	11 km	1-3 Day	1m
Quickbird	600 km	16 km	1-5 Day	0.61-2.4m

Table 1. Very high resolution satellites. (A. Puissant, 2003)

This type of images gives us all the advantages of satellite imagery technology like revisit time, it hasn't a geographical or political frontier and relatively low cost …, in the other hand different problems appear with this new technology such difficulty in the application of classic methods of classification,

occlusion, shadow, textural characteristic of the objects is more important…

All these problems are related to the extraction of information. Before the use of this information for GIS or mapping applications first we must consider the geometric aspect of this new satellite imagery technology, this is equivalent to give a response to the question "how the imaging system transform the location of the pixels on the earth to the image?". Figure 1.
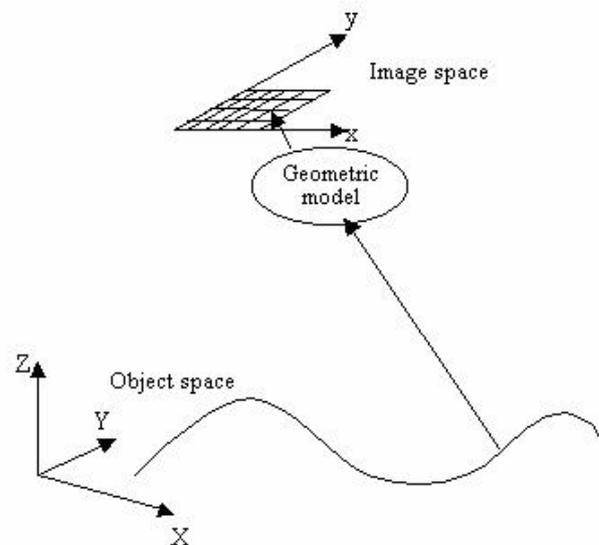
Figure 1. Geometric modelling.

Several authors were studied this problem, generally we have two categories of geometric models: physical and empirical models. The physical called also rigorous or deterministic

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models which reflect the physical reality of the viewing geometry (platform, sensor, Earth and sometimes map projection); generally in the optical imagery these models are based on the well-known collinearity condition. The empirical, implicit or non parametric models can be used when the parameters of the acquisition systems or a rigorous 3D physical model are not available. Since they do not reflect the source of distortions (Toutin, 2003), these models represent the acquisition system as a mathematical transformation between object and image spaces.

2. RATIONAL FUNCTION MODEL

As an alternative for the physical model, 3D rational functions are widely used as a geometric model for very high satellite images, this approximation of physical model is given as a set of rational polynomials expressing the normalized row and column values, as a function of normalized geodetic latitude, longitude, and height (NIMA, 2000),

The rational function polynomial equations are defined as:

$$r = \frac{P_{i1}(X,Y,Z)_j}{P_{i2}(X,Y,Z)_j}$$

$$c = \frac{P_{i3}(X,Y,Z)_j}{P_{i4}(X,Y,Z)_j}$$

Where c, r = image coordinates
X, Y, Z = object coordinates

The rational function polynomial equation numerators and denominators each are 20-term cubic polynomial functions of the form:

$$\begin{aligned}
P_{i1}(X,Y,Z) &= a_1 + a_2 \cdot Y + a_3 \cdot X + a_4 \cdot Z \\
&+ a_5 \cdot Y \cdot X + a_6 \cdot Y \cdot Z + a_7 \cdot X \cdot Z + a_8 \cdot Y^2 \\
&+ a_9 \cdot X^2 + a_{10} \cdot Z^2 + a_{11} \cdot X \cdot Y \cdot Z \\
&+ a_{12} \cdot Y^3 + a_{13} \cdot Y \cdot X^2 + a_{14} \cdot Y \cdot Z^2 \\
&+ a_{15} \cdot Y^2 \cdot X + a_{16} \cdot X^3 + a_{17} \cdot X \cdot Z^2 \\
&+ a_{18} \cdot Y^2 \cdot Z + a_{19} \cdot X^2 \cdot Z + a_{20} \cdot Z^3
\end{aligned}$$

Where a_i = polynomial coefficients
Y, X, Z = geodetic latitude, longitude, and height

The parameter a_1 for the denominators is equal to 1, In order to solve the RF coefficients (78 coefficients); at least 39 control points are required (K. Di, R. Ma and R. Li, 2002).

Space Imaging and DigitalGlobe provide with the image in TIFF format an ASCII file that contains the translation and scale factor used for coordinates normalisation and the eighty coefficients. These RPC files (Rational Polynomial Coefficients or Rapid Positioning Capability) are used by the software that supports IKONOS and QUICKBIRD geometric model for georeferencing and the orthorectification. Some other software derives Rational Polynomial Coefficients directly form ephemeris provided with the satellite images and uses the same orthorectification process as IKONOS or QUICKBIRD.

These "intelligent" polynomial functions reflect then better the geometry in both axes and reduce the over-parameterization and the correlation between terms (Toutin, 2003).

3. GEOMETRIC MODELS

3.1 Direct Linear Transformation

Direct linear Transformation known as DLT, it was developed in 1971 by Abdel-Aziz and Karara for close-rang photogrammetry applications. This model can also be used for image rectification (C. vincent Tao and Yong Hu 2001).

The DLT represents a special case of the Rational Function Model, with first-degree polynomials and common denominators. It can be expressed as:

$$r = \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_9 X + L_{10} Y + L_{11} Z + 1}$$

$$c = \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1}$$

Where c, r = image coordinates
X, Y, Z = object coordinates
$L_1 \ldots L_{11}$ = DLT parameters

With eleven parameters this model can be solved with 6 points minimum.

3.2 3D Affine Model

This model can be use to express the relationship between object and image coordinates for scanners with a narrow AFOV (Angular Field Of View) and moving with constant-velocity and constant attitude (M. Morgan , 2004).

$$r = L_1 X + L_2 Y + L_3 Z + L_4$$

$$c = L_5 X + L_6 Y + L_7 Z + L_8$$

It has eight parameters: translation (two), rotation (three), and non-uniform scaling and skew distortion within image space (three). (C.S.Fraser & T. Yamakawa 2003).

3.3 The Parallel Perspective Model

Since the acquisition instruments are line scanning systems, a simplification of the DLT which limits the above equation to one line seems to be justified (Vozikis, G., Fraser, C., Jansa, J., 2003).

$$r = \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1}$$

$$c = L_1 X + L_2 Y + L_3 Z + L_4$$

This may be interpreted as if the image has the perspective projection in rows (scan line direction) and affine in columns (along-track).

3.4 2D Affine model

When the image area is flat, low-order polynomials can offer good results, in the case of 2D affine transformation the Z coordinate is set to 0 so the expression become:

$$r = L_1 X + L_2 Y + L_3$$

$$c = L_4 X + L_5 Y + L_6$$

3.5 Projective transformation

This transformation describe the projectivity between tow plans
(H.B. HANLEY and C.S. FRASER, 2001).

$$r = \frac{L_1 X + L_2 Y + L_3}{L_7 X + L_8 Y +}$$

$$c = \frac{L_4 X + L_5 Y + L_6}{L_7 X + L_8 Y + 1}$$

The object plane and the image plane do not have to be parallel. 2-D DLT guarantees accurate plane- to-plane mapping regardless of the orientation of the planes. The control points must not be collinear and must form a plane. (Y.H Kwon. 1998)

4. EXPERIMENTS

4.1 Overview

The data used in this study is an image of Oran (Algeria) that was acquired at 10:50am local time on April 24th, 2004. A subset has been taken over the area of ARZEW, this subset has a size of 5105*2825 pixels (Figure 2.), the south of this region is relatively flat, and the northern zone is mountainous with an elevation range from 0 to 310 meters above mean sea level.

Figure 2. The sub-set over ARZEW.

A raster DTM used for the orthorectification was been generated form a digitalisation of contours from a georeferenced map in 1/25 000 scale, and also 19 Points was been extracted from this map used as control and check points.

4.2 Tests and results

The geometric models that we evaluate in this study are: DLT (Direct linear Transformation), 3D affine model, parallel

	Xmax	Xmin	X rms	Ymax	Ymin	Y rms
DLT	3.3513	0.3769	1.6872	1.7639	0.0977	0.8177
3D Affine	2.6404	0.0129	1.3502	2.4752	0.3384	1.3405
Parallel	2.2661	0.0378	0.9207	2.4752	0.3384	1.3405
2nd order Poly	1.1775	0.0087	0.5651	0.9488	0.0138	0.4653
1st order RFM	2.2661	0.0378	0.9207	1.2764	0.0081	0.5397
2D Affine	4.7977	0.2881	2.5731	2.9848	0.0545	1.427
plane Proj	3.1274	0.0189	1.6281	2.9251	0.1207	1.4853

perspective model, 3D Second -Order Polynomial model, first order 3D RF (Rational Function) Model, plan projective model and plan affine model.

The first test is realized with 15 control points and 4 check points (Table 2., Table 3.), we note that the perspective parallel model provide a RMS of 0.9 pixel in the x direction and 1.3 pixels in the y direction; the RFM and 3D Second-Order Polynomial gave an RMS of 0.5-0.4 pixel for the control points but 0.4 -0.9 for check points. About plan projective model we have 1.6 pixels in x and 1.4 pixels in y direction, a weak precision, but only 6 point without elevation are needed to extract the model parameters.

Table 2. First test results for control points.

Table 3. First test results for check points.

	Xmax	Xmin	X rms	Ymax	Ymin	Y rms
DLT	3.4377	0.1019	2.6753	2.4259	0.046	1.3479
3D Affine	2.2346	0.5809	1.6926	2.2487	0.0898	0.95
Parallel	1.527	0.2323	0.9644	2.2487	0.0898	0.95
2nd order Poly	2.3421	0.2139	1.1051	2.119	0.3491	1.5289
1st order RFM	1.527	0.2323	0.9644	1.9363	0.9517	1.5138
2D Affine	4.7977	1.8701	3.1151	1.5091	0.0545	0.9277
plane Proj	3.1274	0.3895	1.6281	1.128	0.2751	0.7643

In the second test (Table 4.) we use all the 19 points as control points, the best RMS is given by 3D Second Order Polynomial model (0.6 pixel) and RFM, the projective parallel model gave 0.9 and 1.2 pixels and for plan projective model 1.6 and 1.4 pixels in x and y direction respectively.

	Xmax	Xmin	Xemq	Ymax	Ymin	Yemq
DLT	2.6246	0.0073	1.6665	2.4259	0.0296	1.0269
3D Affine	2.8537	0.0806	1.4218	2.7017	0.1839	1.2811
Parallel	2.1603	0.049	0.9035	2.7017	0.1839	1.2811
2nd order Poly	1.5275	0.0144	0.692	1.5233	0.0123	0.6423
1st order RFM	2.1603	0.049	0.9035	1.7346	0.0663	0.7642
2D Affine	4.7977	0.2881	2.5731	2.9848	0.0545	1.427
plane Proj	3.1274	0.0189	1.6281	2.9251	0.1207	1.4853

Table 4. Second test results.

In the third test (Table 5.) we use the 19 control points, and same 19 points for check points but we set their elevation as 0, this give us an idea about the influence of z variation in the different models, in this test we deduce that the 3D Second-Order Polynomial model is very sensitive to the variation in elevation, the maximum displacement in points position is 41 and 59 pixels in x and y respectively; The RFM and the perspective parallel mod el gives 19 pixels in x direction but for y the first give 18 pixels and the second 7 pixels for the same point.

	Xmax	Xmin	Xemq	Ymax	Ymin	Yemq
DLT	31.159	0.7229	10.212	10.451	0.1106	3.2949
3D Affine	18.931	0.0396	5.4018	7.2066	0.0002	1.9935
Parallel	19.244	0.1863	7.2005	7.2066	0.0002	1.9935
2nd order Poly	41.233	0.011	14.453	59.698	0.4521	19.922
1st order RFM	19.244	0.1863	7.2005	18.931	0.0244	8.3472

Table 5. Third test results for check points.

In the final test (Table 4.) we change the latitude and longitude of one of 19 points about 0°0'1" to study the ability of these models to detect the erroneous point; here we can see that all these models are able to detect the erroneous point.

	Dmax	Demq	Derr
DLT	6.1591	1.2447	6.1591
3D Affine	5.9015	1.2752	5.9015
Parallel	4.9593	1.1618	4.9593
2nd order Poly	2.7873	0.7551	2.7873
1st order RFM	4.7701	1.1005	4.7701
2D Affine	6.1130	1.4339	6.1130
plane Projective	5.4888	1.1347	5.4888

Table 6. Last test results (Dmax is the maximum displacement and Derr the displacement of the erroneous point).

Since the third order 3D FRM is the general case of all the precedent models, the module that calculate each model generate an equivalent RPC file by giving 0 to all the coefficient that must be removed , for example for the second order 3D polynomial all the coefficients of third order terms are set to 0.

This file is loaded with the SPOT5 image as an IKONOS or QUICKBIRD image in images processing software that support these satellites models (RFM).

Finally the first order model is used to generate an orthoimage using the DTM generated from 1/25 000 map, the resulted orthoimage is superimposed with the map to facilitate the updating (Figure 3.)
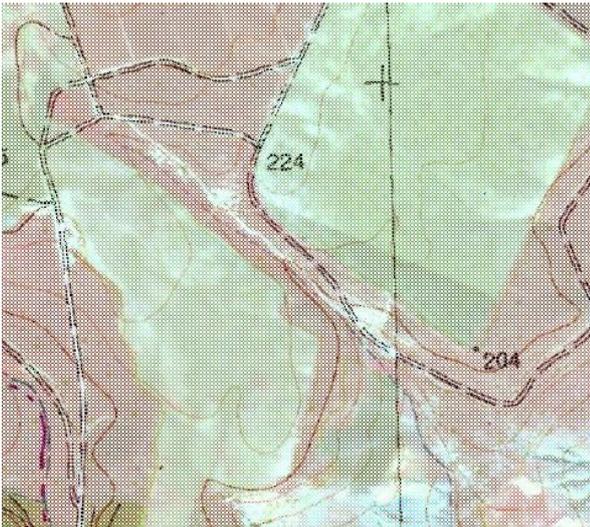
Figure 3. Superimposition with transparency of the map and orthoimage.

5. CONCLUSION

In this paper we studied the applicability and the accuracy that we can achieve with different geometric models for the orthorectification SPOT5 images and we can deduce that:

The parallel projective model gave better results then the 3D affine and DLT model.

The second order 3D polynomial and first order 3D RFM gave are better but we must have at least 10 and 8 points uniformly distributed over the image.

The 2D affine and projective transformation gives an interesting since we haven't to measure the elevation of the points.

The second order 3D polynomial is the most sensitive to the variation in elevation.

The creation of RPC files can be an intermediary solution for geometric modelling, because it represent the general case of many models, reflect then better the geometry in both axes and it is supported by many software.

Future work will be focused on the matching and the extraction of DTM from VHRS imagery and more detailed study for geometric modelling using large set of images.

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