Orthorectification of SPOT5-2.5m Image and Result Comparison

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ABSTRACT: The 2.5m resolution data of SPOT5 can be used to produce image maps in large scale. The geometric correction is the key point, especially on the loessial area in northern Shanxi province, because of the rough landform with sharp relief and hundreds of dongas. The orthorectification has to be used. The intrinsical difference between physical model of orthorectification and normal polynomial algorithm is discussed theoretically and practically. Result images corrected by different methods are checked carefully. The accuracy of orthorectified image can be 3~5 times better than that of normal rectified method.

1. INTRODUCTION

SPOT5 panchromatic band data with 2.5m spacial resolution are good enough to produce image maps of 1:50000 ~1:10000 scales. A SPOT raw image is distorted and must be corrected because of the movement of the satellite, defects of instrument, refraction and so on. The key point in the data application is the accuracy of geometric correction. But the traditional rectification methods can't meet the accuracy expectation. Orthorectification is the necessary and the only way in the situation.

Polynomial transformation is the most common way used on image correction, now. The transformation requires that polynomial equations be fitted to the ground control points (GCPs), using least squares criteria to model the correction in the image domain, without identifying the source of the distortion. One of several polynomial orders may be chosen, based on the desired accuracy and the available number of GCPs. The following equations show the polynomials (Feng, 1992):

$$u = \sum_{p=0}^{n} \sum_{q=0}^{n-p} a_{pq} x^p y^q$$

$$V = \sum_{p=0}^{n} \sum_{q=0}^{n-p} b_{pq} x^p y^q$$

Where: u,v: pixel coordination of input image (row, column or p, l)
x, y: coordination of output image or map
a, b: coefficient of polynomial; n: order of polynomial

The number of required GCPs depends on the order of the polynomial. The following chart lists the minimum required number of GCPs.

Required GCPs	Order
4	1st
7	2nd
11	3rd
16	4th
22	5th

In general, polynomial transformations with the first order, can model a rotation, a scale and a translation. By higher order (up to 3~5th order) polynomials, more complex warping can be achieved. Normally, the $n \leq 3$ should be used.

2. MODEL OF ORTHORECTIFICATIAON

Difference from the normal correction methods, the orthorectification algorithm of SPOT5 images is based on the physical model which is established according to the parameters of satellite (the orbit, attitude, height, viewangle and so on), sensor, earth project and image coordinate, as the raw data obtained.

To each image pixel (l, p), it is possible to associate a viewing direction, calculated using the N acquisition parameters θ^0_k (datation, orbitography, attitude, viewing angles). The (λ, φ) geographic coordinates of the corresponding point on the ground are then obtained by intersection of the viewing direction with a model of the Earth (ellipsoid) at the altitude h. The relations can be gotten (CNES, 2001):

$$\lambda = F_\lambda(l, p, h, \theta^0_1, \ldots\ldots, \theta^0_N) \qquad (2.1)$$
$$\varphi = F_\varphi(l, p, h, \theta^0_1, \ldots\ldots, \theta^0_N)$$

where $F = (F_\lambda, F_\varphi)$ is the direct geometrical viewing model.

The accuracy of this method depends of course only on the accuracy of the acquisition parameters. In the case that some acquisition parameters are uncertain:

$$\theta^0_k = \theta^0_k + \delta\theta_k k = (1, N_k) \qquad (2.2)$$

with: $\delta\theta_k$: difference between the a priori (given) value θ^0_k and the real one θ_k.

N_k: number of registration parameters to be determined.

The uncertain parameters are adjusted using the GCPs, in order to enhance the accuracy of the geometrical model. If N_g is the number of GCPs (with $N_g > N_k$), A system of $2N_g$ equations with N_k unknowns to be determined can be obtained.

$$\lambda_1 = F_\lambda(l_1, p_1, h_1, \theta_1, \ldots\ldots, \theta_N)$$
$$\varphi_1 = F_\varphi(l_1, p_1, h_1, \theta_1, \ldots\ldots, \theta_N)$$
$$\ldots\ldots \qquad (2.3)$$
$$\lambda_{Ng} = F_\lambda(l_{Ng}, p_{Ng}, h_{Ng}, \theta_1, \ldots\ldots, \theta_N)$$
$$\varphi_{Ng} = F_\varphi(l_{Ng}, p_{Ng}, h_{Ng}, \theta_1, \ldots\ldots, \theta_N)$$

This system is not linear, so it is necessary to linearize it around the a priori values.
The registration parameters are then calculated by resolving the system with the least squares method (LSM). At the end, the relations can be obtained as:

$$\lambda = F_{\lambda}(l, p, h, \theta^0_1,\ldots\ldots, \theta^0_N, \delta\theta_1,\ldots\ldots, \delta\theta_{Nk}) \quad (2.4)$$
$$\varphi = F_{\varphi}(l, p, h, \theta^0_1,\ldots\ldots, \theta^0_N, \delta\theta_1,\ldots\ldots, \delta\theta_{Nk})$$

The accuracy of this method depends essentially on the GCPs accuracy. It may reach R/2 with very accurate GCPs (R = resolution of the raw image).

The physical model calculates a satellite image representing the correspondence law between the raw image and the terrain, and takes the landform relief into account. The 3-dimension (3D) ground control points (GCPs) and DEM data are utilized to correct the raw images. On this method, 3D GCPs are used to improve the accuracy of the physical model and a raw image is re-projected to an ortho-view image. But on traditional algorithms, the 2D GCPs are used to calculate the coefficients of transformation polynomials or equations. A raw image is computed to a new image. On the plain or smooth areas, there perhaps is not much difference between the results of traditional correction and orthorectification for satellite images such as Landsat data with middle special resolutions and point center project model. But big difference certainly exists between the results of the different geometric correction methods for SPOT5 data, which have high resolution and are obtained from side-glance models, especially on relief and rolling areas.
The parameters of satellite and sensor are needed to geometric correct satellite data by physical model. SPOT 1A level data productions have the necessary parameter information, which is the first condition for remote sensing image orthorectification.

3. ORTHORECTIFICATION AND ANALYSIS

3.1 Area and Data

The work area locates on the loessial region in northern Shanxi province, China, which is famous for the varied landform with sharp relief and hundreds of deep dongas. The application of remote sensing technology especially the remote sensing images of middle and large scales is difficult in the area because of the complex landform. The accuracy of geometric corrected images is the key factor.
In the work, SPOT5 HRG pan 2.5m resolution data, acquired on Nov. 2002, is used. The 1A production with parameter data is read into image processing system. 1:50,000 maps are utilized to find GCPs and 1:250,000 DEM is used to correct the images by physical model method. Bilinear interpolation is the re-sampling function for image geocoding. The processing is performed by PCI software, “OrthoEngine”, which is based on the way of physical model but has a little difference from SPOT software on the detail algorithm.

3.2 Accuracy Comparison

3.2.1 Error of GCPs: Ground control points (GCPs) are the important factor on image geometric correction. They are the most important factor on orthorectification by physical model. The accuracy of the model depends basically on the veracity of GCPs, and defines the accuracy of corrected images.

The GCP error statistic and error compare between different methods are as table 1.

Table 1 Error statistic of GCPs (Unit: pixel)

SPOT5 image	Incidence angle	Num. of GCPs	Physical model (+DEM)				Polynomial (2order)			Polynomial (3order)		
			Res*.	RMS**			Error	RMS		Error	RMS	
					X	Y		X	Y		X	Y
Pan (2.5m)	L26.15	22	8.77	6.39	4.04	4.95	33.5	24.4	5.5	27.08	17.95	4.37

*Res: resolution. **RMS: root-mean-square

The main reason resulting in errors is the complex landform with acute relief. The GCPs especially those on tops of plateaus and mountains are difficult to find and locate correctly. The table 1 shows that the polynomial method has worse error than physical model. The error of 1-order polynomial is more terrible. The difference between the different methods is quite clear.

3.2.2 Comparison of result accuracies: This orthorectifed image is examined by 1:50,000 maps for accuracy assessment. First, every GCP is checked by comparing the coordinates between maps and corrected and geocoding image. Then, 15 another checking points are selected and used as exam points, by the same way as above.
The accuracy statistics of the result image is as table 2.

Table 2 Result accuracy of orthorectifed image

Image	Orthorectification GCPs	Num.	Type		Max error (m)		Σ|△|/n (m)	
			Peak	Valley	△X	△Y	△X	△Y
SPOT5 Pan(2.5m)	Control point	22	10	12	70	23	19.5	10
	exam point	15	7	8	26	30	13.3	13.4

The errors of the 37 pairs of control and exam points, except one point, are $\leq$ 30m, which accords with the above academic conclusion of correction error. The point with worst error in X direction is located at an intersection of a city in a valley. The city expanding and street widened and rebuilt is one of the causes of the big error happened, because the maps used are produced in 1970s.
This image is corrected again by the traditional polynomial transformation method for comparison. The same GCPs are used but only with 2D coordinate (X, Y) and except the 6 points with worst errors. The remained GCP set of 16 pair 2D control points has the error, on 3 order polynomials, as: Error: 8.97 pixels, RMS: X=8.11 pixels, Y= 4.0 pixels.
The result accuracy of the normal correction image is as table 3.

Table 3 Result accuracy of normal polynomial correction

Image	Polynomial GCPs	Num.	Type		Max error (m)		Σ|△|/n (m)	
			Peak	Valley	△X	△Y	△X	△Y
SPOT5 Pan(2.5m)	Control point	16	7	9	98	-49	17.06	7.0
	Exam point	15	7	8	140	-94	70.9	41.8

As shown in table 2 and 3:

a) The rectified image errors of the two different correction methods are similar at the locations of ground control points. The result of normal polynomial correction is a little better than that of orthorectification because the points with worst error are canceled.
b) The errors at the places of exam points have large difference between orthorectified image and traditional corrected image. In X (longitude) direction, the error of former to later is 19.2%. And it is 32% in Y (latitude) direction. This means that the errors decrease 5 times in X direction and 3 times in Y direction.

The offsets at control and exam points are similar in the orthorectified image, but very different in the normal corrected image. The cause is the different correction methods. The traditional algorithm corrects raw images by polynomial transformation and 3-order polynomial causes the 3-dimension distortion within rectified images. Although offsets at GCPs are similar as orthorectified image, the deviations in the places without GCPs are increased rapidly.

4. RESULT AND CONCLUSION

The image maps of 1:50,000 are produced by the orthorectified image and used to translate well locations of oil fields. Satisfied result is obtained. Comparing the result images corrected by different methods, some clear difference can be found:

a) There are curves along the borders of the orthorectified image with the different landform, especially in Y direction. The normal corrected image has not such phenomena.
b) Plotting oil-wells onto the corrected images according to accurate coordinates, the different accuracy can be displayed clearly as figure 1. On figure 1, every left image in a pair of image is an orthorectified image and right one is a normal corrected image. Red points represent oil wells.

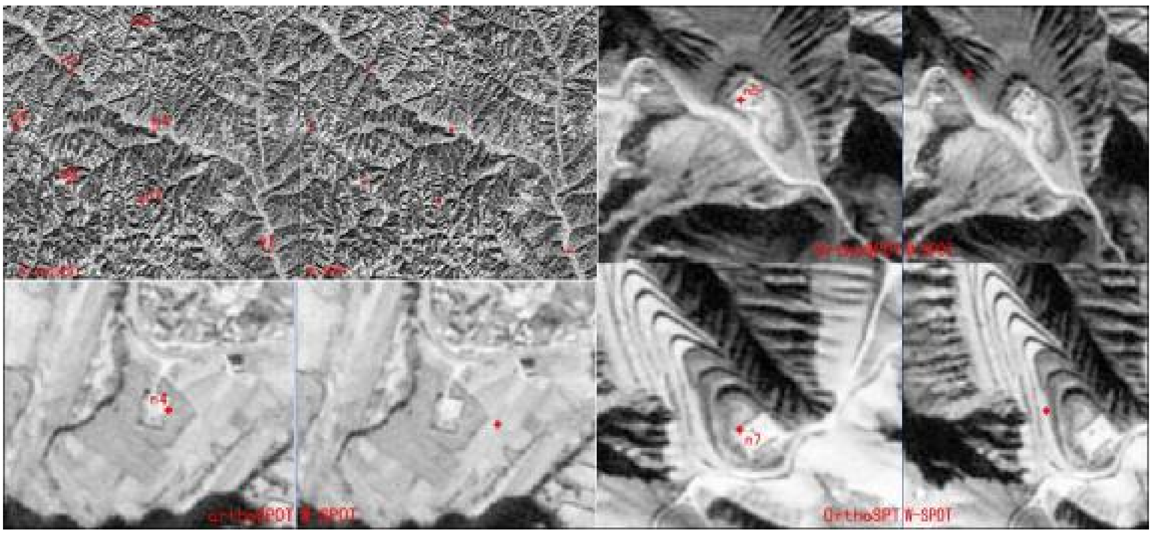

Figure 1 Result images corrected by different methods
(Red points: wells, OrthoSPOT: orthorectifed images, W-SPOT: normal corrected images)

In most situations, an oil well is built on a platform constructed by concrete or sand and stone. It displays usually as a light rectangular mark in SPOT panchromatic image. All wells are located on the platforms on the orthorectified image. But offsets are very different on normal corrected image, and some of them are very terrible, such as the three wells shown in figure 1. The accuracy of former is much better than that of later.

In conclusion, orthorectification bases on the way of physical model and uses 3D GCPs. The result accuracy is 3~5 times better than that of traditional correction by polynomial transformation. On the loessial area, orthorectification is the only way to meet the expectant accuracy of 1:50,000 image maps.

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