Geometric Assessment and Correction of SPOT5 Imagery

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Abstract: In this paper, we present our implementation of the direct camera model (image to ground) for SPOT5 and use it to assess the geometric accuracy of SPOT5 imagery. Our assessment confirms the location accuracy of SPOT5 imagery (without use of GCPs) is less than 50m. We further introduce a few attitude parameters to refine the camera model with GCPs. The model is applied to two SPOT5 supermode images, one near vertical, incidence angle of 3 degrees, and one far oblique, incidence angle of 27 degrees. The results show that accuracy (rms of check points) of about one pixel (2.5m) can be achieved with about 4 GCPs by using only 3 parameters to correct the yaw, pitch and roll of the satellite.

Keywords: SPOT5, location accuracy, camera model

1. Introduction

The SPOT5 is the latest SPOT satellite launched in May 2002. SPOT5 satellite carries two High Resolution Geometric instruments (HRG) which are able to image at a very high resolution of up to 2.5m in panchromatic mode. SPOT5 satellite also carries a DORIS payload enabling it to locate itself precisely and star trackers enabling it to have precise pointing knowledge. With these, the location accuracy of SPOT5 imagery is claimed to be better than 50m without GCPs.

In this paper, we present our implementation of the direct camera model (image to ground) for SPOT 5 and used it to assess the geometric accuracy of SPOT5 imagery. We then introduce some parameters for refinement of the camera model and present some results of the geometric assessment, before and after refinement of the imaging parameters.

2. The Direct Camera Model

The direct model is a mathematical model to compute the geo-location (λ, φ) of a ground point according to its image coordinate (l, p) in the level 1A image.

$$\begin{cases} \lambda = f_\lambda(l,p,h) \\ \phi = f_\phi(l,p,h) \end{cases} \quad (1)$$

Details of the direct camera are described in the "SPOT Satellite Geometry Handbook" [1].

The direct camera model is computed by performing a series of elementary coordinate transforms as following.

1. *Line dating*: to compute the acquisition time t of any pixel (l, p) of the image.
2. *Ephemeris interpolation*: to determine the position vector P (t) and velocity vector V (t) of the satellite at the time t.
3. *Look direction in navigation in the Navigation Reference Coordinate System*: to compute the look direction of any pixel (l, p) within a reference system firmly attached to the satellite (similar to so called *Image Space Coordinate System*).
4. *Look direction in the Orbital Coordinate System*: to express the look direction of any pixel (l, p) with a reference system.
5. *Look direction in the Terrestrial Coordinate System*: to connect the look direction of any pixel (l, p) with the ITRF earth reference system.
6. *Geo-location on the earth*: to compute the intersection of the look direction of any pixel (l, p) with the earth model (ellipsoid and DEM).

3. Mathematical Model for the Refinement of the Direct Camera Model

The purpose of the refinement of the camera imaging model is to remove the remaining systematic errors in the auxiliary data of the SPOT5 data. This can be done by refining certain imaging parameters $\vec{X}$, usually selected from the 3 positional coordinates of the satellite ($\Delta X_p \Delta Y_p \Delta Z_p$), 3 component velocities of the satellite ($\Delta V_{X_p} \Delta V_{Y_p} \Delta V_{Z_p}$), pitch, roll and yaw (attitude) of the sensor ($\Delta a_p \Delta a_r \Delta a_y$), and rates in pitch, roll or yaw ($\Delta Va_p \Delta Va_r \Delta Va_y$). The refinement is solve by least squares adjustments with know ground control points (GCPs).

In matrix form, the equations for the refinement are usually expressed as follows:

$$B\vec{V} + A\vec{X} + \vec{L} = 0$$

Where,

$\vec{V} = [V_\lambda V_\varphi V_h V_l V_p]^T$ is the correction vector of observations (λ, φ, h, l, and p);

$\vec{X}$ is the correction vector of the position, velocity, attitude and angular speed of the satellite ;

$\vec{L}$ is the constant vector ;

B and A are coefficient matrixes.

The least squares solution for the above equations is:

$$\vec{X} = -[A^T(BP_V^{-1}B^T)^{-1}A]^{-1}A^T(BP_V^{-1}B^T)^{-1}\vec{L}$$

4. Results

Two SPOT5 images of Singapore were used to assess the geometric accuracy of SPOT5 imagery. One was captured with -3.2 degrees of incidence angle on March 17, 2003. The other was captured with -26.8 degrees of incidence angle on May 19, 2003. To assess the geometric accuracy of SPOT5 imagery, we measured some high accurate GPS points visible in the images. As there are a lot of clouds on the images, GPS points selected in two images were not the same same.

The table 1 and 2 show the residual errors of all GPS mark points on two images by using auxiliary data of SPOT5 to define the direct imaging model (note -- without use of any ground control points). The results show the accuracy is better than 50 meters, which is in accordance to the geometric accuracy specifications of SPOT5 imagery.

The table 3, 4 show the results after refinement of selected parameters with some ground control points. The results show that the refinement of just the satellite 3 attitude (pitch, roll and yaw) parameters is sufficient to achieve the optimum results.

Table 1 Errors of GPS points on the image with 3.2^0 incidence angle (**Unit:** meter)

No	**3415**	**3353**	**3413**	**3459**	**3405**	**3357**	**3371**	**3418**	**3408**	**3377**	**3370**	**3600**
ΔX	48.1	45.9	48.4	46.3	48.1	47.3	46.0	48.1	-48.4	54.5	51.9	48.6
ΔY	-5.6	-4.9	-6.0	-1.0	-10.0	-1.9	-1.5	-7.7	-3.3	5.0	4.6	-17.3
No	**3452**	**3470**	**3383**	**3446**	**3440**	**3427**	**3426**	**3422**	**3420**	**3419**	**3417**	**3414**
ΔX	46.4	48.3	48.6	43.5	49.6	50.8	42.9	48.5	49.7	48.1	51.8	46.9
ΔY	-13.3	-1.2	-20.8	-9.7	-6.1	-11.9	-12.0	-11.3	-12.3	-8.7	-7.3	-4.0
No	**3454**	**3363**	**3462**	**3464**	**3412**	**3421**	**3410**	**3467**	**3476**			
ΔX	49.5	49.8	46.9	51.2	51.9	45.7	47.0	45.1	48.2			
ΔY	-10.8	2.7	-4.1	-1.3	-3.9	-9.1	-2.9	-2.2	-15.1			

Table 2 Errors of GPS points on the image with 26.8^0 incidence angle (**Unit:** meter)

No	**3383**	**3410**	**3465**	**3459**	**3415**	**3371**	**3418**	**3408**	**3600**	**3452**	**3446**	**3426**
ΔX	-11.8	-12.1	-12.0	-14.0	-12.3	-14.5	-12.1	-12.6	-10.5	-10.3	-12.1	-11.8
ΔY	-31.4	-20.3	-16.6	-17.7	-18.3	-18.9	-24.4	-20.6	-30.4	-28.5	-26.5	-24.1
No	**3422**	**3417**	**3414**	**3412**	**3476**	**3402**	**3403**	**3404**	**3424**			
ΔX	-12.5	-12.7	-12.8	-13.0	-12.1	-12.8	-11.2	-8.5	-9.2			
ΔY	-27.7	-24.2	-18.2	-20.8	-26.2	-14.9	-20.6	-21.4	-28.5			

Table 3 Results of the 3-parameter refinement for the image with 3.2^0 inclination angle

Parameters and Corrections						**Control Point Number**	**Check Points**		
Position(m)			**Attitude(micro-radian)**				**No**	**Accuracy(m)**	
XS	**YS**	**ZS**	**Pitch**	**Roll**	**Yaw**			**X**	**Y**
-54.6	-9.7	-5.9	0.0	0.0	0.0	6	27	2.50	5.98
0.0	0.0	0.0	-0.000021	-0.000063	-0.000495	6	27	2.46	1.43
0.0	0.0	0.0	-0.000021	-0.000063	-0.000472	4	29	2.38	1.71

Table 4 Results of the 3-parameter refinement for the image with 26.8 inclination angle

Parameters and Corrections						**Control Point Number**	**Check Points**		
Position(m)			**Attitude(micro-radian)**				**No**	**Accuracy(m)**	
XS	**YS**	**ZS**	**Pitch**	**Roll**	**Yaw**			**X**	**Y**
-50.2	72.4	-31.1	0.0	0.0	0.0	5	16	1.27	3.67
0.0	0.0	0.0	-0.000191	0.000003	-0.000380	5	16	2.09	1.77
0.0	0.0	0.0	-0.000180	0.000003	-0.000354	3	18	1.98	1.74

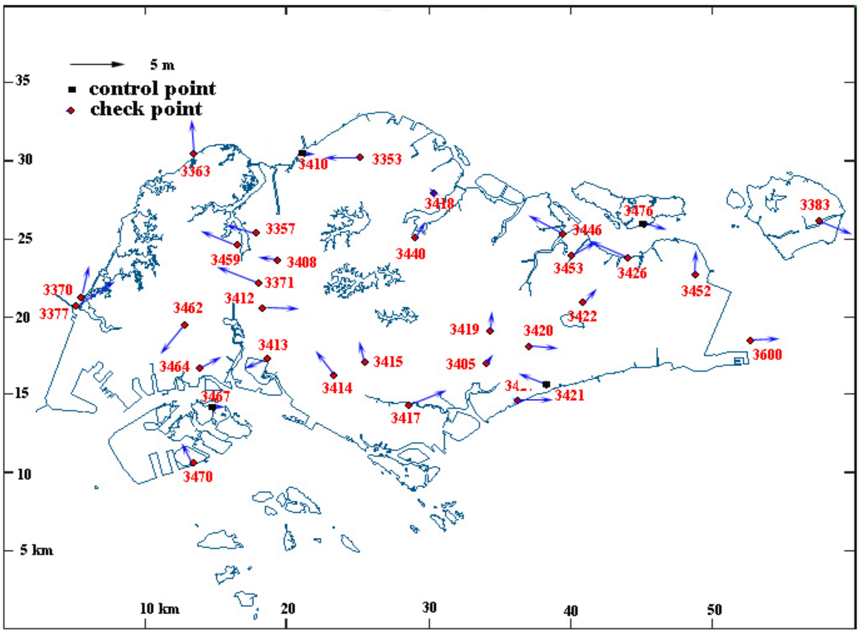

Fig.1 GCP residual error distributions on the image with 3.2^0 incidence angle

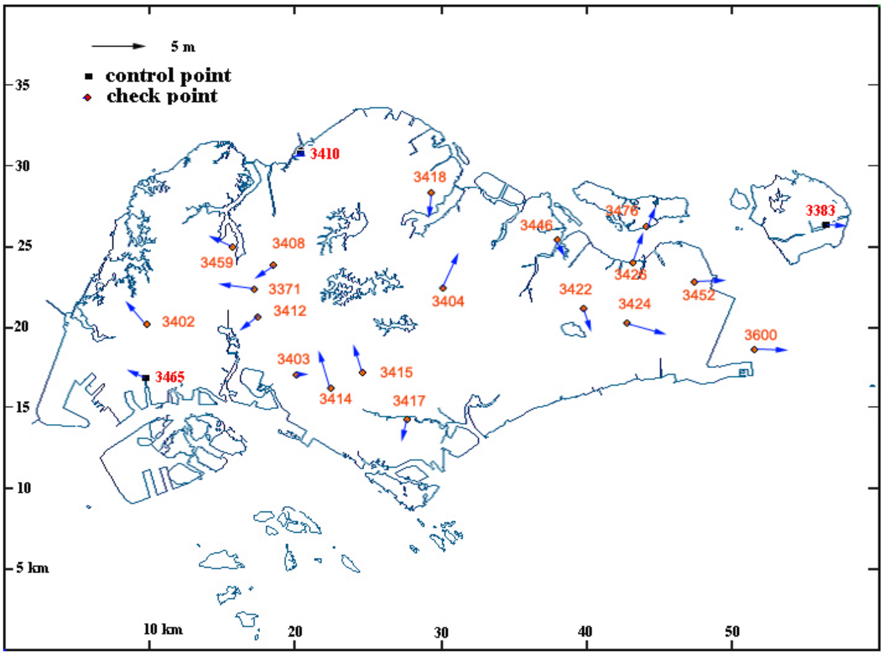

Fig.2 GCP residual error distributions on the image with 26.8^0 incidence angle

The figure 1 and 2 show the GCP residual error distributions on two images after the refinement of the camera model. From the figures, it can be seen that the residuals (after refining the 3 attitude parameters) were random, suggesting that there may be no systematic errors.

5. CONCLUSIONS

Our assessment confirms the location accuracy of SPOT5 imagery without use of GCPs is less than 50m. The accuracy (rms of check points) of about one pixel (2.5m) can be achieved with 3~ 4 GCPs by using only 3 parameters to correct the yaw, pitch and roll of the satellite.

It is also shown that SPOT5 imagery has good precision (relative accuracy).

6. REFERENCES

[1] SPOT IMAGE, 2002, “SPOT Satellite Geometry Handbook S-NT-73-12-SI”, Edition 1, Revision 0