3D Spatial Information Extraction from Stereo Combination of Two Different Satellite Images

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Abstract :

This paper describes the geometric accuracy testing of the IRS-1D and SPOT-4 images when combining together as stereo, over a test field in Zanjan province in the west part of Iran. For reconstruction of the image orientation we have used two different models: (i) a rigorous bundle adjustment program using an orbital parameters model and (ii) a generalized sensor model as rational function model. These models have already been tested for stereo SPOT Level 1A, Level 1B, IRS-1C, MOMS-02, as well as IKONOS. These mathematical models and analytical photogrammetric solution are first described in brief.
This is followed by the results of the various 3D geometric accuracy tests carried out with these images using different sets and combinations of control and check points. The GCPs for these tests are extracted from 1:25,000 scale topographic maps produced by National Cartographic Centre (NCC) of Iran using 1:40,000 scale aerial photographs. Finally an analysis of the results is given.

Introduction

These days the huge capability of satellite images, including their spatial, spectral, temporal and radiometric resolutions as well as their stereoscopic viewing, introduces them as a powerful source for Photogrammetry, Remote Sensing and GIS communities. To get more benefits from satellite images, one approach is to combine them together. Although there have been a lot of research on merging these images to obtain better radiometric and spectral information, the research on combining these images to extract 3D spatial information is less.
The purpose of this paper is to report on (i) an investigation into the mathematical modeling of IRS-1D and SPOT 4 images and differences between rigorous and generalized sensor models, and (ii) an evaluation of 3D spatial information extracted from the combination of these images.

Test Area and Materials

One SPOT-4 Level 1A stereo-pair images taken on 14 May and 21 June 2000, and one single IRS-1D Pan in superstructure format taken on 4 May 2003 covering a part of Zanjan Province in the west part of Iran, have been used in this research. The cross-track angles for the left and right images of SPOT stereo pair are +24 and -26.4 degrees respectively while for IRS-1D image it is just -1.8 degree.

For this project 30 Ground Control Points (GCPs) were extracted from 1:25,000 scale digital topographic maps of the area. These maps were produced by NCC using 1:40,000 scale aerial photographs. The accuracy of the contours where a 10m interval has been used is estimated to be ±3.5m. In total 32 well distributed GCPs have been selected and measured.

The Mathematical Models:

(i) A rigorous bundle adjustment program using an Orbital Parameters Model :

An orbital parameter model can be applied to the linear array stereo images such as SPOT-4 and IRS-1D in order to determine their exterior orientation parameters. The model adopted here is developed by the first author to deal with cross-track configuration of linear array images such as IRS-1D, along-track configuration such as (MOMS-02) as well as flexible pointing configuration such as IKONOS. The spacecraft is moving in a defined elliptical orbit. The position and attitude of the spacecraft are changing continually in a systematic way to keep the sensor pointing towards the centre of the Earth. An orbital resection method is developed to model these changes by finding the orbital parameters of the spacecraft during the period of its exposure of the stereo-pair. A bundle adjustment program based on the following collinearity equations has been developed to determine these parameters using GCPs:

$$\begin{pmatrix} x_i - x_0 \\ y_i - y_0 \\ -c \end{pmatrix} = S\ R \begin{pmatrix} X_i^g - X_0 \\ Y_i^g - Y_0 \\ Z_i^g - Z_0 \end{pmatrix}_{CT}$$

where

$$R = R_1(\alpha)R_2(\beta)R_3(\kappa)R_2(\varphi)R_1(\omega)$$

$$R_2((f+\omega_p)-\frac{\pi}{2})R_1(\frac{\pi}{2}-i)R_3(\Omega-\pi)$$

α : is the cross-track viewing angle,
β : is the along-track viewing angle,
κ, φ, ω : are additional undefined rotations of the spacecraft at the time of imaging,
f, i, ω_p, Ω : are the true anomaly, orbital inclination, argument of perigee, and right ascension of the ascending node respectively,
x_i , y_i : are the image coordinates of the image point i,
x_0 , y_0 : are the image coordinates of the principal point,
X_i^g , Y_i^g , Z_i^g : are the coordinates of the image point I in the Conventional Terrestrial (CT) coordinate system,
X_0 , Y_0 , Z_0 : are the coordinates of the position of the sensor's perspective centre in CT coordinate system,
c : is the principal distance,
R_j : defines the rotation around the j axis, where $j = 1, 2, or\ 3$.

Because of the dynamic geometry of linear array systems, the positional and attitude parameters of a linear array sensor are treated as being time dependent. This model has already been tested for SPOT Level 1A and 1B stereo pairs (Valadan and Petrie, 1998), MOMS-02 stereo images (Valadan, 1997), IRS-1C stereo pair (Valadan and Foumani, 1999), IKONOS image (Valadan and Sadeghian, 2003). For more information regarding the mathematical model the reader can refer to Valadan and Petrie, 1997.

(ii) A generalized sensor model as Rational Function Model:

One of the alternative sensor models for high resolution satellite imagery is rational function model. There are different solutions for this model. Direct solutions use rational function coefficients and sensor parameters information without any control points and refinement the original coefficients. Indirect solutions use ground control points for computing coefficients without using sensor parameters (Tao, Hu 2001). Some another ones use ground control points to refinement original value of coefficients and have got sub pixel results with only one control points (Hanley, Fraser 2003).Our solution is based on ground control points without any initial values of coefficients. First approximate values of parameters extract and then precise values compute with using ground control points. Rational Function Model with 20 parameters (Valadan, Sadeghiam 2002) is used in this paper as follow:

$$x=\frac{a_0+a_1\cdot X+a_2\cdot Y+a_3\cdot Z+a_4\cdot X\cdot Y+a_5\cdot X\cdot Z+a_6\cdot Y\cdot Z}{1+c_1\cdot X+c_2\cdot Y+c_3\cdot Z+c_4\cdot X\cdot Y+c_5\cdot X\cdot Z+c_6\cdot Y\cdot Z}$$

$$y=\frac{b_0+b_1\cdot X+b_2\cdot Y+b_3\cdot Z+b_4\cdot X\cdot Y+b_5\cdot X\cdot Z+b_6\cdot Y\cdot Z}{1+c_1\cdot X+c_2\cdot Y+c_3\cdot Z+c_4\cdot X\cdot Y+c_5\cdot X\cdot Z+c_6\cdot Y\cdot Z}$$

where
x, y : are the normalized row and column of pixel in image .
X, Y, Z : are the normalized coordinates of the image point in the Conventional Terrestrial (CT) coordinate system.
$a_0, a_1, ..., c_6$: Rational Function Coefficients (RFCs).

3D Geometric Accuracy Test of SPOT-4 and IRS-1D Imagery over the Test Area:

The one overlapping SPOT-4 image was available in Level 1A and formed the main reference stereo-pair. These images were acquired with mirror angles of L24 and R26.4 degrees. This results in an excellent base-to-height ratio of 0.94. Around 30 GCPs were extracted from 1:25,000 scale topographic maps covering the test area, so providing a good number of independent check points to assess the results.15 points of GCPs are in IRS-1D covering area. Because of RFM needs more GCPs three another points added to 15 points and 18 GCPs used in IRS-1D covering area.

(i) Results of Orbital Parameters Model :

The residual errors (ΔX, ΔY, ΔZ) at the 15 ground control points as well as 15 independent check points after the application of the bundle adjustment program for SPOT stereo pair are given as RMSE values and are summarized in Table I. As can be seen from this Table, good results have been achieved using this stereo image. The graphical analyses of these results using vector plots of the errors (FigureII) occurring at each individual GCP and independent check point show that the residual errors are random and free from systematic effects.

Figure II. Residuals Diagram for the SPOT-4 Level 1A stereo-pair covering the Zanjan project area

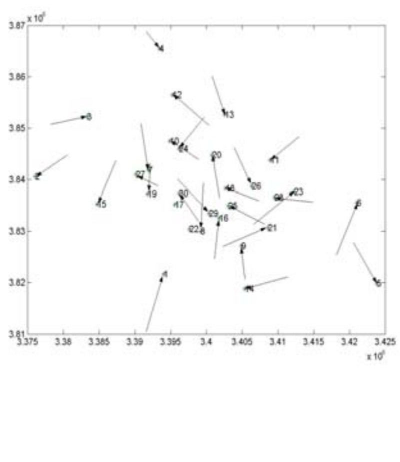


Table I. ΔX, ΔY, ΔZ residuals in WGS84 coordinates for the SPOT-4 Level 1A stereo-pair covering the Zanjan project area

Number of GCPs points	Number of Check points	RMSE in GCPs			RMSE in Check		
		ΔX (m)	**ΔY (m)**	**ΔZ (m)**	**ΔX (m)**	**ΔY (m)**	**ΔZ (m)**
10	20	3.299	4.741	3.079	11.272	16.406	10.105
15	15	6.017	7.792	5.440	7.551	8.301	6.496
20	10	8.132	11.441	8.211	7.491	6.439	5.674
30	0	9.617	11.288	8.267	-	-	-

Further tests have been carried out where one time the left image of SPOT-4 and the IRS-1D is considered as stereo pair and another time the right image of SPOT-4 and the IRS-1D is supposed to be stereo on the program. The resulting RMSE values in terms of their X, Y, and Z coordinates are shown in Table II and Table III.

Table II. ΔX, ΔY, ΔZ residuals in WGS84 coordinates for the SPOT-4 (left image) and IRS-1D (right image) stereo-pair

Number of GCPs points	Number of Check points	RMSE in GCPs			RMSE in Check		
		ΔX (m)	**ΔY (m)**	**ΔZ (m)**	**ΔX (m)**	**ΔY (m)**	**ΔZ (m)**
10	5	11.408	11.445	13.293	6.926	5.854	6.744
15	0	12.032	12.840	14.380	-	-	-

Table III. ΔX, ΔY, ΔZ residuals in WGS84 coordinates for the SPOT-4 (right image) and IRS-1D (left image) stereo-pair

Number of GCPs points	Number of Check points	RMSE in GCPs			RMSE in Check		
		ΔX (m)	**ΔY (m)**	**ΔZ (m)**	**ΔX (m)**	**ΔY (m)**	**ΔZ (m)**
10	5	8.720	14.310	11.287	11.239	7.671	4.282
15	0	13.559	16.882	12.208	-	-	-

The vector diagrams constructed from the residual values given in Table II and Table III (Figure III and Figure IV) show that the residual errors at he individual control and check points are completely random; no systematic component can be discovered in these vector plots.

Comparing the results in Tables II and III with the results of Table I show that the residual errors obtained from the original SPOT stereo pair is better than the results when combining SPOT and IRS-1D as stereo pair. This is obviously because of better base-to-height ratio for original SPOT stereo pair (nearly two times) comparing to those comprising of SPOT and IRS-1D images.

Figure III. Residuals Diagram for the SPOT-4 (left image) and IRS-1D (right image) stereo-pair

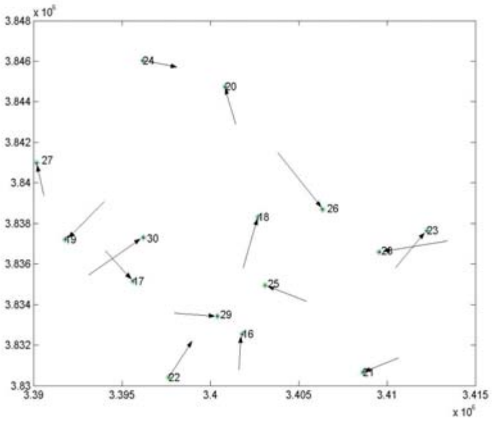
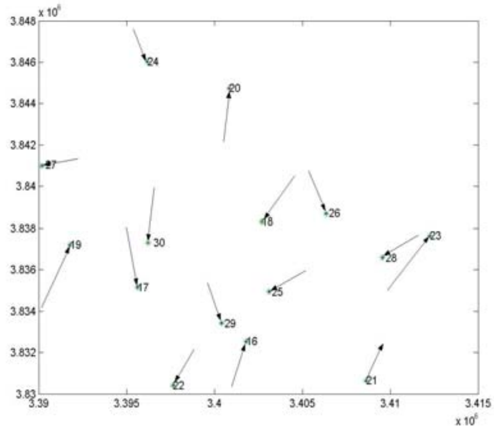


Figure IV. Residuals Diagram for the SPOT-4 (left image) and IRS-1D (right image) stereo-pair



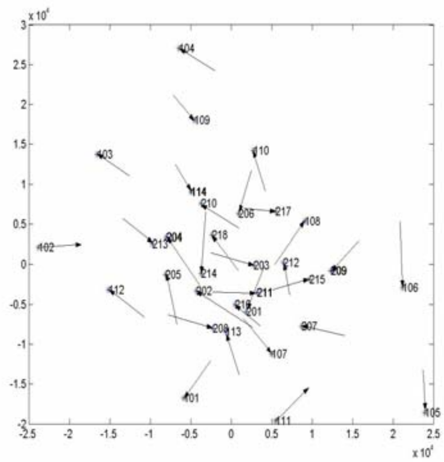
(ii) Results of Rational Function Model:

The residual errors (ΔX, ΔY, ΔZ) at the 14 ground control points as well as 18 independent check points after the application of the Rational Function Model for SPOT stereo pair are given as RMSE values and are summarized in Table IV. As can be seen from this Table, good results have been achieved using this stereo image. The graphical analyses of these results using vector plots of the errors (FigureV) occurring at each individual GCP and independent check point show that the residual errors are random and free from systematic effects.

Table IV. ΔX, ΔY, ΔZ residuals in WGS84 coordinates for the SPOT-4 Level 1A stereo-pair covering the Zanjan project area

Number of GCPs points	**Number of Check points**	**RMSE in GCPs**			**RMSE in Check**		
		ΔX (m)	**ΔY (m)**	**ΔZ (m)**	**ΔX (m)**	**ΔY (m)**	**ΔZ (m)**
32	0	9.213	12.198	8.609	-	-	-
14	18	4.261	5.810	3.484	10.804	11.533	9.770
12	6	4.012	4.440	2.656	12.844	20.360	11.775
18	0	6.682	6.725	4.934	-	-	-

Figure V. Residuals Diagram for the SPOT-4 Level 1A stereo-pair covering the Zanjan project area



Further tests have been carried out where one time the left image of SPOT-4 and the IRS-1D is considered as stereo pair and another time the right image of SPOT-4 and the IRS-1D is supposed to be stereo on the program. The resulting RMSE values in terms of their X, Y, and Z coordinates are shown in Table V and Table VI.

Table V. ΔX, ΔY, ΔZ residuals in WGS84 coordinates for the SPOT-4 (left image) and IRS-1D (right image) stereo-pair

Number of GCPs points	**Number of Check points**	**RMSE in GCPs**			**RMSE in Check**		
		ΔX (m)	**ΔY (m)**	**ΔZ (m)**	**ΔX (m)**	**ΔY (m)**	**ΔZ (m)**
14	18	-	-	-	16.418	14.889	15.119
18	0	8.592	6.999	8.061	-	-	-
12	6	2.523	3.955	5.157	40.250	15.631	43.533

Table VI. ΔX, ΔY, ΔZ residuals in WGS84 coordinates for the SPOT-4 (right image) and IRS-1D (left image) stereo-pair

Number of GCPs points	**Number of Check points**	**RMSE in GCPs**			**RMSE in Check**		
		ΔX (m)	**ΔY (m)**	**ΔZ (m)**	**ΔX (m)**	**ΔY (m)**	**ΔZ (m)**
14	18	-	-	-	16.665	29.876	20.171
18	0	7.050	8.446	5.822	-	-	-
12	6	4.027	2.039	4.783	18.225	43.596	13.625

The vector diagrams constructed from the residual values given in Table V and Table VI (Figure VI and Figure IVI) show that the residual errors at he individual control and check points are completely random; no systematic component can be discovered in these vector plots.

Comparing the results in Tables V and VI with the results of Table IV show that the residual errors obtained from the original SPOT stereo pair is better than the results when combining SPOT and IRS-1D as stereo pair. This is obviously because of better base-to-height ratio for original SPOT stereo pair (nearly two times) comparing to those comprising of SPOT and IRS-1D images.

Figure VI. Residuals Diagram for the SPOT-4 (left image) and IRS-1D (right image) stereo-pair

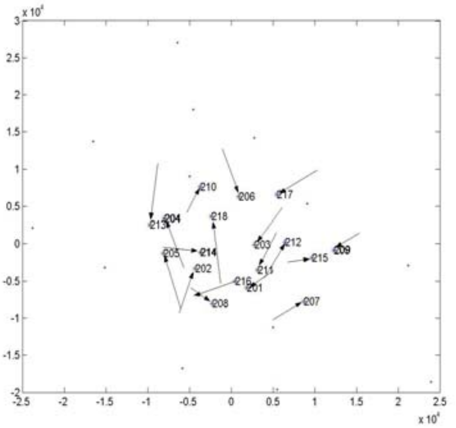
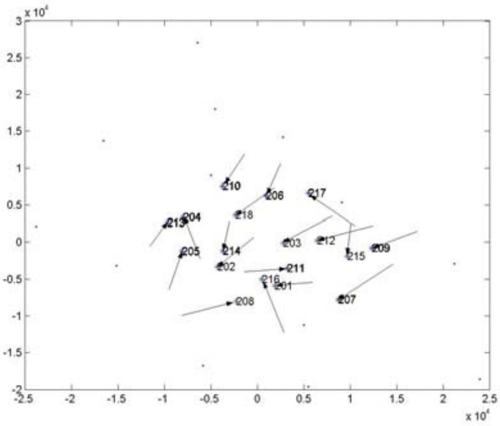


Figure IVI. Residuals Diagram for the SPOT-4 (left image) and IRS-1D (right image) stereo-pair



Conclusion

Geometric correction of a stereo-pair images consisting of SPOT-4 Level 1A and IRS-1D pan based on a simple orbital parameter model and also rational function model have been discussed in this paper. Different tests carried out using SPOT-4 stereo-pair and IRS-1D images show these images can be combined together as stereo in a mathematical model such as that used in this paper to extract 3D spatial information. Comparing between rational function model and orbital parameters model displays that RFM need more control points to increasing degree of freedom and extract precise results. It is obvious when only 12 points for solving 20 parameters. But with regarding rigorous orbital model and rational model with sufficient control points we can understand that stereo combination of these different satellite images has good results. But also we know decreasing base-to-height ratio (nearly two times) is one reason for lower accuracy.

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