

1:50000 SCALE TOPOGRAPHIC MAPPING IN WEST CHINA USING SPOT 5 DATA

Y. Qin^{a*}, M. Bernard^b, G. Wujun^a

^aChinese Academy of Surveying and Mapping(CASM), 16 Beitaping R., Beijing, 100039, China - yanqin@casm.ac.cn

^bSpot Image, 5 rue des Satellites, BP14359, 31030 Toulouse, France - marc.bernard@spotimage.fr

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ABSTRACT:

On the one hand, the successful launch of the SPOT 5 satellite in 2002 can be seen as a milestone for DEM extraction and mapping, because its payload includes HRS, a stereoscopic imaging instrument devoted to collection of large areas. Operating in panchromatic mode, the HRS instrument has two telescopes, one pointing forward and one aft of the satellite. HRS is thus able to cover an area of 600 km x 120 km in a single pass (ie 72 000 km² stereoscopic strips). Moreover, SPOT 5 is able to collect stereoscopic triplets, through a simultaneous activation of HRG sensors in vertical mode, which will overcome the difficulty of terrain shadow in DEM matching. Meanwhile the extremely precise ancillary metadata of SPOT 5 allows accurate geometric processing with sparse ground control points. Thus SPOT 5 stereoscopic imagery becomes one of main satellite data sources for accurate DEM extraction and quickly mapping large area. The current status and coverage of stereoscopic HRS imagery as well as the metadata of SPOT 5 will be briefly exposed. On the second hand, about 2 million km² in west China never has been covered by 1:50,000 scale topographic maps for several decades. The area contains the famous Qingzang plateau with average 5000m altitude and boundless Talimu basin desert. Mapping this area with traditional methods had unimaginable difficulties and was impossible to complete at all. With the high technology advancing, especially the great progresses in geomatics, it is the time to start to map the area with new geo-information technologies. So in 2006, China decided to initiate a large project, named 1:50,000 scale topographic mapping of west China (ab. west China topographic mapping project), in order to get the 1:50,000 scale topographic maps (DEM, DOM and DLG) of that area within next 5 years. As we know the weather is extremely atrocious and a lot of sites are out of reach in that area, mapping from aero-born and satellite remote sensing imagery with sparse ground control points was determined to be the main solution for the project. Within the several satellite remote sensing data used in the project, SPOT 5 data played an important role with its distinguished characteristics. The paper will present the methodology of mapping from SPOT 5 data developed and implemented by CASM. The methodology emphasizes to use as sparse ground control points as possible to facilitate the data processing. A simple general geometric RPC sensor model was established instead of the complex rigorous SPOT 5 sensor model. The model has been validated in several test sites using SPOT 5 HRS trips. The results proved that the model has the same accuracy as the rigorous model and just needs sparse ground control points to carry out the triangulation. Then, High precise matching algorithms considering feature points and feature lines were used to extract DEM from HRS stereo images or triplets. Comparing with some results get from other satellite images shows that the DEM has very fine textures. Contour lines were experimented to be interpolated automatically by DEM and DOM products were made finally. Sanjiangyuan block is one of the 8 mapping blocks of the project. It locates on the north of Qingzang plateau with average 4500m altitude and 120,000 km² area. In 2006, 250 sheets of maps of the block were produced using the methodology. Over 100 ground control points within 6 maps were accurately measured in field with GPS to assess the accuracy of DEM, DOM and DLG products. The presentation will detail the accuracy assessment results, and give some comparison results of contour lines obtained by automatic interpolation with DEM and by manual stereo measurements. In conclusion, the methodology of large area mapping with SPOT 5 data and sparse ground control points is successfully established in the west China mapping project. It was proved that the accuracy satisfied our standard demand of 1:50,000 scale map. Furthermore the west China mapping project can be an example for other mapping projects in difficult mapping areas considering weather, altitude and transport conditions, etc.

1. INTRODUCTION

West part of China is less developed area comparing to east part. The geographic condition is extremely bad, the weather is terribly atrocious and a lot of sites are out of reach in that area. In this part, about 2 million km² never has been covered by 1:50,000 scale topographic maps for several decades. The area contains the famous Qingzang plateau with average 5000m altitude and boundless Talimu basin desert. Mapping this area with traditional methods had unimaginable difficulties and was

impossible to complete at all. With the high technology advancing, especially the great progresses in geomatics, it is the time to start to map the area with new geo-information technologies. So in 2006, China decided to initiate a large project, named 1:50,000 scale topographic mapping of west China (ab. west China topographic mapping project), in order to get the 1:50,000 scale topographic maps (DEM, DOM and DLG) of that area within next 5 years.

* YAN Qin, Chinese Academy of Surveying and Mapping, tel: 01068219569, email: yanqin@casm.ac.cn

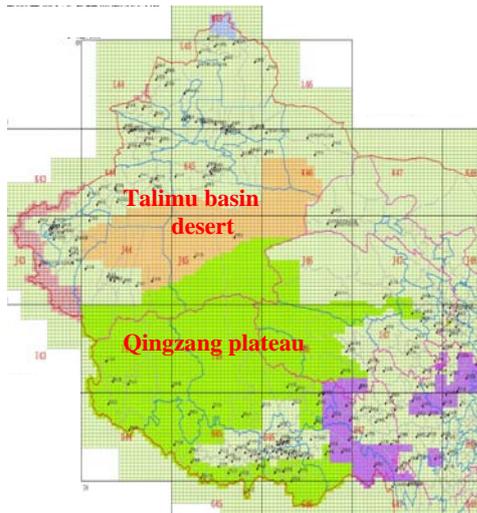


Figure 1. The location of West China Mapping Project

Within the remote sensing data sources, SPOT 5 imagery plays an important role in the project because that it has the distinguished characteristics suitable for large area mapping producing.

2. SPOT 5 HRS AND HRG IMAGERY

SPOT5 belongs to the latest generation of SPOT missions with significant improvements in terms of on-board instruments and autonomous system of positioning and attitude control that enables a high absolute location accuracy.

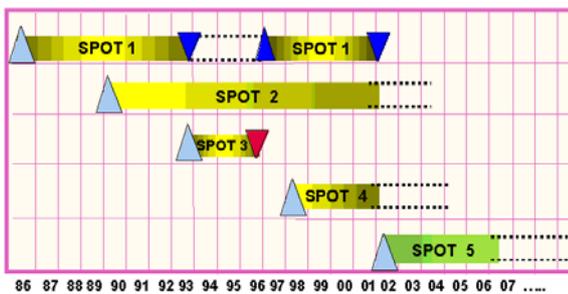


Figure 2. The series of SPOT satellites^[1]

The following table records the main characteristics of the instruments on-board the SPOT 5 satellite.

instrument	band name	sampling distance	CCD per line
HRG1 or HRG2	XS1	10 m	6000
	XS2	10 m	6000
	XS3	10 m	6000
	SWIR	20 m	3000
	HMA	5 m	12000
	HMB	5 m	12000
HRS	HRS1 (fore view)	10mx5m	12000
	HRS2 (aft view)	10mx5m	12000

Table 1. Instruments onboard the SPOT 5 satellite

Unlike the other 4 satellite, SPOT 5 has HRS instruments which are able to get stereo-images along the orbit. The following figure illustrates the HRS data acquirement.

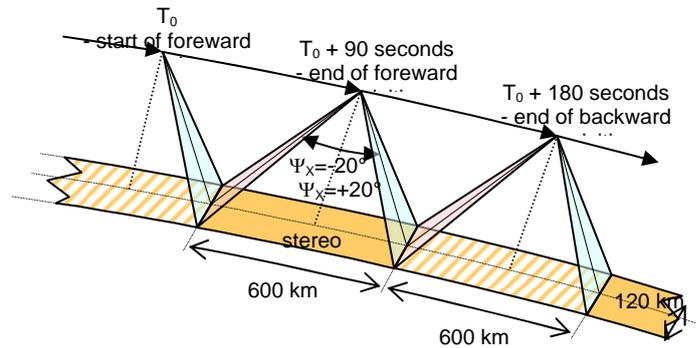


Figure 3. SPOT 5 HRS image acquirement

If HRS strip images combine the vertical HRG image, the triplets are formed which will facilitate the image matching especially in the high relief terrain area. Figure 4 demonstrates how the triplets come up.

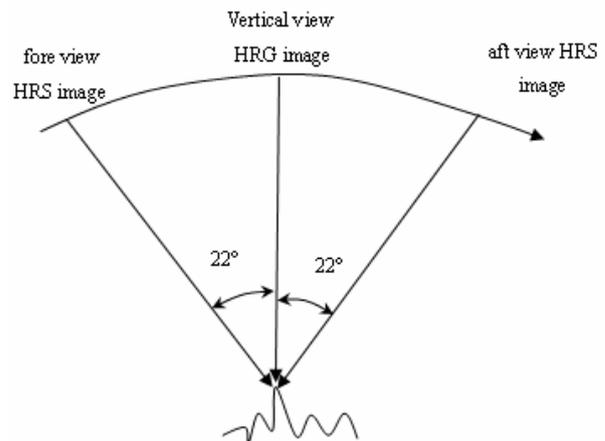


Figure 4. Triplets formation

3. PRODUCTION PROCESS

3.1 viewing geometry model by SPOTIMAGE

A viewing geometry model has been put forward by SPOTIMAGE^[1]. The viewing geometry model consists in establishing a relation between any pixel (l,p) of the level 1A image and the relative point (λ, φ) on a terrestrial reference system. In this relation, the altitude h of the point on the ground is supposed to be known. The model is computed performing a series of elementary transforms described as following:

(1)Line dating: set a relation between any pixel (l,p) of the image and the date t of its acquisition.

Date t of any line l is given with reference to the scene center date.

$$t = t_c + lsp \times (l - l_c) \quad (1)$$

Where t_c is the scene center date, l_c is the line containing the scene center, lsp is the line sampling period.

(2)Ephemeris interpolation: determinates the position $P(t)$ and velocity $V(t)$ of the satellite at the date t .

For SPOT5, ephemeris data are given every 30 seconds for the whole data strip including margins at the start and at the end of the data strip.

Let t being the time of the line l for which position $P(t)$ and velocity $V(t)$ shall be computed, select the four ephemeris samples at time t_1, t_2, t_3 and t_4 before t and the four samples at time t_5, t_6, t_7, t_8 after t ; all the time t_i being out of the acquisition range.

Position and velocity are given by the following formulae:

$$\vec{P}(t) = \sum_{j=1}^8 \frac{\vec{P}(t_j) \times \prod_{\substack{i=1 \\ i \neq j}}^8 (t - t_i)}{\prod_{\substack{i=1 \\ i \neq j}}^8 (t_j - t_i)} \quad (2)$$

$$\vec{V}(t) = \sum_{j=1}^8 \frac{\vec{V}(t_j) \times \prod_{\substack{i=1 \\ i \neq j}}^8 (t - t_i)}{\prod_{\substack{i=1 \\ i \neq j}}^8 (t_j - t_i)}$$

Where $P(t_i)$ are the satellite position coordinates, $V(t_i)$ are the satellite velocity coordinates, T_i are the universal times corresponding to the positions and velocities.

(3)Look direction in Navigation Reference Coordinate System: determinates the look direction within a reference system firmly attached to the satellite.

For SPOT5, look angles $[(\psi X)_i, (\psi Y)_i]$ are given for every detectors ($i=1..N$, where $N=3000, 6000$ or 12000) and all the bands. The look direction for pixel p is therefore immediately given by the value posted in auxiliary data:

$$\begin{aligned} \psi_X &= (\psi_X)_p \\ \psi_Y &= (\psi_Y)_p \end{aligned} \quad (3)$$

Where q is the number of the column ($p=1..N$), $(\psi X)_p$ is the along-track look angle for the CCD number p ($p=1..N$), $(\psi Y)_p$ is the across-track look angle for the CCD number p ($p=1..N$).

The look direction for any pixel p is given by the following formula:

$$\vec{u}'_1 = \begin{pmatrix} -tg(\psi_Y) \\ +tg(\psi_X) \\ 1 \end{pmatrix} \quad (4)$$

$$\vec{u}_1 = \frac{\vec{u}'_1}{\|\vec{u}'_1\|}$$

(4)Look direction in Orbital Coordinate System: express the look direction with a reference system integrating the navigation constraints, and in particular the attitude variations.

The Orbital Coordinate System ($O2, X2, Y2, Z2$) is centered on the satellite, and its orientation is based on the spacecraft position in space. The origin is the spacecraft center of mass $O2$, with the $Z2$ axis pointing from the Earth center of mass to the spacecraft center of mass. The $X2$ axis is the normalized cross product of the instantaneous velocity vector with $Z2$ axis. $Y2$ is the third unitary vector of the system.

$$\begin{aligned} \vec{Z}_2 &= \frac{\vec{P}(t)}{\|\vec{P}(t)\|} \\ \vec{X}_2 &= \frac{\vec{V}(t) \wedge \vec{Z}_2}{\|\vec{V}(t) \wedge \vec{Z}_2\|} \\ \vec{Y}_2 &= \vec{Z}_2 \wedge \vec{X}_2 \end{aligned} \quad (5)$$

Where $P(t)$ is the interpolated position of the satellite computed in eq.2, and $V(t)$ is the interpolated velocity of the satellite computed in eq.2

(5)Look direction in Terrestrial Coordinate System: determinates the look direction attached to the ITRF Earth reference system.

Because position $P(t)$ and velocity $V(t)$ are already expressed in ITRF, transformation from Orbital Coordinate System to Terrestrial Coordinate System is reduced to a simple base change.

$$\vec{u}_3 = \begin{bmatrix} (X_2)_X & (Y_2)_X & (Z_2)_X \\ (X_2)_Y & (Y_2)_Y & (Z_2)_Y \\ (X_2)_Z & (Y_2)_Z & (Z_2)_Z \end{bmatrix} \bullet \vec{u}_2 \quad (6)$$

Where u_2 is the look direction in Orbital Coordinate System, u_3 is the look direction in Terrestrial Coordinate System, X_2 is the pitch axis computed in eq.5, Y_2 is the roll axis computed in eq. 5, Z_2 is the yaw axis computed in eq. 5.

(6)Location on Earth model: computes the intersection of the line of sight with the Earth model (ellipsoid + DEM).

Let $M=(X,Y,Z)$ the geocentric coordinates to be found, point M is involved within the two following equations:

$$\vec{O_3M} = \vec{P}(t) + \mu \times \vec{u}_3 \Rightarrow \begin{cases} X = X_p + \mu \times (u_3)_X \\ Y = Y_p + \mu \times (u_3)_Y \\ Z = Z_p + \mu \times (u_3)_Z \end{cases}$$

(7)
And

$$\frac{X^2 + Y^2}{A^2} + \frac{Z^2}{B^2} = 1 \quad \text{with} \quad \begin{cases} A = a + h \\ B = b + h \end{cases}$$

Leading to solve the 2nd degree equation:

$$\begin{aligned} & \left[\frac{(u_3)_X^2}{A^2} + \frac{(u_3)_Y^2}{B^2} + \frac{(u_3)_Z^2}{B^2} \right] \times \mu^2 + 2 \times \\ & \left[\frac{X_p(u_3)_X}{A^2} + \frac{Y_p(u_3)_Y}{B^2} + \frac{Z_p(u_3)_Z}{B^2} \right] \times \mu + \\ & \left[\frac{X_p^2 + Y_p^2}{A^2} + \frac{Z_p^2}{B^2} \right] = 1 \end{aligned} \quad (8)$$

This equation has necessarily two distinct solutions (μ_1, μ_2). The smallest one (μ_{min}) shall be kept. Re-introducing this value within equation 7 gives the geocentric coordinates (X,Y,Z) of point M.

3.2 RFM model by CASM

RFM (Rational Function Model) is a kind of Rational Polynomial Coefficients model, which is rigorous transformed from the viewing geometric model of SPOT 5 satellite by CASM. The transform accuracy is strictly limited within 0.05pixel to guarantee the computation accuracy. The transform procedures mainly contain 2 stages:

(1) To establish ground control points grid

With the viewing geometric model of SPOT 5 satellite, the coordinates of ground control points are computed from image coordinates. If given several elevation values(h), several ground control points grid layers will be established. For each point, its ground coordinates(X, Y, Z) and image coordinates(x, y) are known.

(2)To solve the Coefficients of RFM
RFM model adopts the equations:

$$F_1 = l_n = \frac{NumL(U,V,W)}{DenL(U,V,W)} \quad (9)$$

$$F_2 = s_n = \frac{NumS(U,V,W)}{DenS(U,V,W)}$$

Where

$$\begin{aligned} NumL(U,V,W) = & a_1 + a_2V + a_3U + a_4W + a_5VU \\ & + a_6VW + a_7UW + a_8V^2 + a_9U^2 + a_{10}W^2 + a_{11}UVW \\ & + a_{12}V^3 + a_{13}VU^2 + a_{14}VW^2 + a_{15}V^2U + a_{16}U^3 + a_{17}UW^2 \\ & + a_{18}V^2U + a_{19}U^2W + a_{20}W^3 \end{aligned}$$

$$NenL(U,V,W) = b_1 + b_2V + \dots + b_{19}U^2W + b_{20}W^3$$

$$NumS(U,V,W) = c_1 + c_2V + \dots + c_{19}U^2W + c_{20}W^3$$

$$NenS(U,V,W) = c_1 + c_2V + \dots + c_{19}U^2W + c_{20}W^3$$

Using the ground control points' coordinates, the coefficients could be solved through the least square principle.

3.3 Production process and software developed in the mapping project

A production process methodology has been built up for topographic mapping from SPOT 5 HRG and HRS image. A software named ImageInfo™ has been developed by CASM. At least 5 provincial bureaus of surveying and mapping have adopted the process methodology and the software to establish themselves production chain in the west China Topographic Mapping Project. The success of the application of the software guaranteed the progress on schedule of the Project.

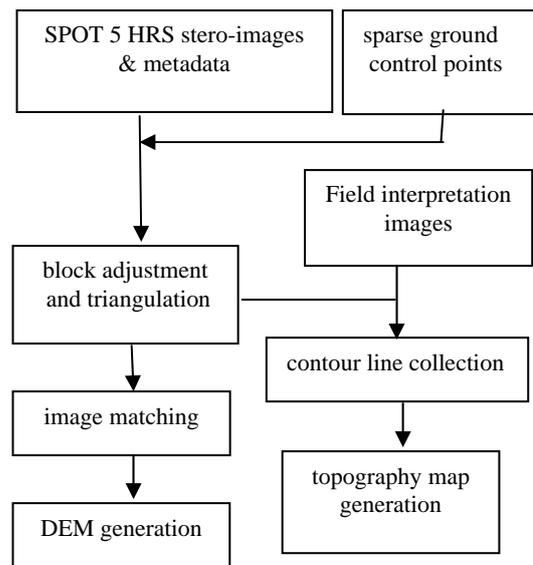


Figure 5. Production process

4. ACHIEVEMENTS

In 2006, about 250 sheets of 1:50000 scale topographic maps in the Three-river-origin area of Qingzang Plateau were produced by 3 provincial bureaus. 5 typical map sheets were selected to evaluate the accuracies with field measured GPS check points.

No.	relief	DEM		DOM		DLG	
		chk	rms	chk	rms	chk	rms
1	2	31	2.30	26	10.65	18	12.18
2	2	33	2.30	23	7.83	18	12.21
3	4	38	1.55	33	18.73	33	13.06
4	1	37	2.52	36	14.32	27	12.17
5	2	35	2.50	25	14.97	15	13.24

Note
 Relief: 1-plain, 2-hill, 3-mountain, 4-high mountain
 Chk-number of check points
 Rms unit: m

Table 2. The accuracy assessment of 5 maps

5. CONCLUSION

(1) A production process for mapping from SPOT 5 HRG and HRS imagery was built up in the project with many innovations, such as sparse control points requirement, large area mapping from satellite imagery, high precise and automatic image matching, etc. The maps produced in provincial bureaus of surveying and mapping satisfied the standards of 1:50000 mapping.

(2) SPOT 5 satellite has so many distinguished characteristics which determine it a real mapping satellite.

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