SPOT5 IN-FLIGHT COMMISSIONING : INNER ORIENTATION OF HRG AND HRS INSTRUMENTS

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ABSTRACT :

Launched on May 2002 the 3rd, SPOT5 is the latest of the SPOT series of satellites continuing and complementing the mission assigned to its predecessors in the field of Earth Observation and Mapping. In order to optimize the various improvements of the platform and of the payload the CNES has carried out, for the first time, an accurate determination of the inner orientation of the instruments. This paper details the method involved in this determinaation and the results obtained.

RESUME :

Lancé le 3 mai 2002, SPOT5 est le dernier né de la famille des satellites SPOT continuant et complétant la mission de ses prédécesseurs dans le domaine de l'Observation de la Terre et la Cartographie. Les multiples évolutions dans la définition de sa plateforme ainsi que de sa charge utile ont conduit le CNES à réaliser pour la première fois une détermination fine de l'orientation interne des instruments. Cet article présente la méthode mise en oeuvre et les résultats obtenus lors de cette détermination.

1 -INTRODUCTION

SPOT5 is the latest of the SPOT series of satellites continuing and complementing the mission assigned to its predecessors in the field of Earth Observation and Mapping. Launched on May 2002 the 3rd, its in-flight commissioning was led in two phases. The qualification phase permitted to hand over the satellite to Spot Image in july 2002 [Bouillon 2002,2003], [Breton 2002]. The second phase included fine tuning of its components and continued until early 2003 allowing to fully take advantage of the geometric improvements brought to SPOT5 compared to its elders :

- star tracker and improved steering mirror on HRG instruments for the localization,
- monolithic CCD array,
- resolution,
- along track stereoscopic instrument HRS.

Observations on the first SPOT 5 images showed imperfections in the CCD array and telescop alignments both on HRG and HRS instruments. An inner orientation of the instruments was therefore considered necessary, especially for the HRS stereoscopic instrument with an optical distorsion of several pixels. Following is a non exhaustive list of the outcomes expected from this inner orientation :

- assessed and refined look angle models provided by the satellite constructor ;
- optimized relative orientation between the forward and backward HRS stereoscopic instruments ;
- optimized relative orientation between the panchromatic and multispectral bands within each HRG instrument.

On previous SPOT satellites the geometric performance of the detectors has been assessed with relative methods [Valorge 2003] involving simultaneous acquisitions of the same scene with both instruments ; these methods never permitted to obtain an absolute measurement of the viewing directions [Gachet 1999]. The characteristics of SPOT5 instruments together with the objective of inner orientation made it necessary to implement another method based on absolute calibration using airborne images and elevation information from our « super site » in southeastern France.

Since March 2003, ancillary data provided in the « METADATA.DIM » file associated with SPOT5 images [Spot Image 2002] include the instruments look angles for each detector with an estimated RMS accuracy of 0.03 pixel.

2 -THE MANOSQUE SUPERSITE

2.1 The supersite characteristics

Since early 1999, CNES has worked on defining and equiping a supersite for its image quality assessment needs. Various criteria guided the definition of this supersite involving both the SPOT satellites characterictics and the image quality assessment methods.

2.1.1 Measurement quality through image matching : the accuracy that can be obtained using image matching technics depends on such parameters as

- the level of information to be matched, forbiding sites with radiometrically uniform areas
- the radiometric similarity between data to match (MTF, spectral bands, seasonal and long term diachrony, ...) . Hence the reference data must comply with the radiometric characteristics of the SPOT5 imagery, with a relatively slowly evoluting landuse, forbiding highly cultivated sites.

2.1.2 Geometric quality of the reference data : both planimetric and altimetric accuracy of reference data over the « supersite » must be controlled.

- Planimetry should be controlled through particularly

accurate aerotriangulation. AP coverages flown in the scope of IGN Topographic data base with a RMS error of 40 cm on the aerotriangulation are identified as a good candidate.

- Altimetry should be controlled through an elevation model (including superstructures) with an accuracy better than 1 m. No such data existing over France, the APs were preprocessed and the reference DTM provided by IGN was refined to produce a terrain model suited to our objectives. In order to minimize residual errors, the site should not have extreme slopes and stable superstructures, forbiding montainous as well as over urbanized areas.

2.1.3 Completeness of the measurement : In order to completely qualify and measure the SPOT 5 look angles, the reference data must cover the full swath which is, for HRG instruments, 60 km wide roughly in the east-west direction. The reference data, in effect, cover that swath but HRS images, twice as wide, could not be entirely covered once. Furthermore, when the HRGs improved steering mirrors allow to accurately overlap the reference site across track, no such device is available on HRS instruments reducing the opportunities to acquire the site during the in-flight commissioning.

2.1.4 Quality of the statistics : the final estimation of the inner orientation of the instruments is obtained through the average of several measurements, say 200 per km of image for the modes with best resolution. Therfore a set of reference data 5 km wide with 80% overlap ensures a redundancy of 1000 measurements per look angle.

2.1.5 Accessibility of the site : the relative shortness of the in-flight commissioning phase together with the need to minimize the diachrony between the reference data and the SPOT5 data implied the choice of a site with low cloud coverage statistics.

2.2 The initial reference site

A first attempt to apply an absolute method for inner orientation of SPOT images was led by L.FALALA and P. GIGORD in 1998 [Falala 1998]. The site of Yvetot in French Normandy region was selected without considering all the above characteristics and led to an unsatisfactory result although the main ideas of the method were implemented at that time. In order to improve the results, a site more suited was then looked for taking into account most of the constraints.

This drove to the choice of a site located in the South East of France between the Luberon chain and the Durance river, ensuring an acceptable meteorology. The landscape is mainly covered with scrubland and orchards and the topography is mostly made of gentle hills except in the eastern area.

Within the scope of the regular BDTopo ® , IGN has flown a 1/30000 scale APs coverage of the site in March 1997. From this coverage we acquired the 48 APs of a strip roughly 60 km wide spreading over the SPOT swath, the width of the strip being rougthly 8 km, together with the associated orientation models obtained through regular bundle adjustment ; these APs were scanned at a pixel size of 50 cm and further resampled to a 1.5 metre resolution.

Following is a sample of the 1.5 metre resolution data.

Along with the APs came a DTM from the IGN BDZ ; this DTM was improved to an estimated 1 metre RMS error over the site through the use of the scanned set of APs.

The following Figure shows the refined DTM over the whole swath of the dataset.

Digital Elevation Model

The method was then experimented on SPOT1images with this set of data.

2.3 The second generation site

The time lap between the reference data and the SPOT5 in-flight commissioning where most acquisitions occured in July 2002 introduced both seasonal and long term diachrony in the process. It was therefore decided to acquire a complete new set of high resolution aerial imagery with the new generation 4000x4000 digital camera PELICAN at a resolution of 50 cm and 80% overlap. The reference site is covered with 5 tracks of 200 images each, flown on July 2002.

Following is a sample of the PELICAN data

The inner orientation of the digital PELICAN images is ensured through a radial distorsion model provided by IGN. Further controls at CNES confirm the fitness of this model with RMS residuals of 0.2 pixel (ie 10 cm).

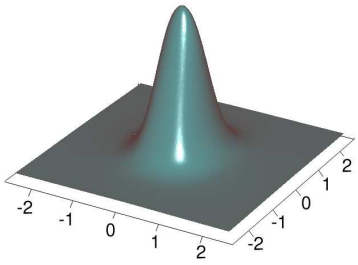
Instead of undertaking a costly and uncertain aerotriangulation on this block of 1000 low angle images, the exterior orientation parameters for each image have been computed through the optimization of image matching with the corresponding original set of APs using the refined digital elevation model available from the original reference data set. An average of 3000 points per image were used leading to a RMS error of 30 cm after 3 iterations. When landscape evolutions were too important for automatic processing (typically less than 1000 matching points unevenly distributed), hand adjustment was done.
For data management convenience, the aerial images were finally subsampled at a pixel resolution of 1.5 metre, compatible with the resolutions of SPOT5 data.
The evolution of the landscape between 1997 and 2002 did not justify to compute a specific DTM.

3 -THE METHOD

3.1 Description of the method

The method involved during the in-flight commissioning is based on the knowledge of the geometry of acquistion of both the reference data and the SPOT5 images . The reference data is associated with its conical inner and exterior orientations and an acurate digital elevation model. The SPOT5 images are geometrically described by their physical model except for the accurate viewing direction angles which are simply initialized with the values provided by the laboratory measurements ; estimated RMS accuracy of these measurements is estimated from about 0.3 pixel for HRG instruments to up to a few pixels for HRS instruments.

Finally the spatial resolutions of the SPOT5 instruments are described through their MTF models. Following is a representation of SPOT5 HRGs point spread function .



SPOT5 HRG point spread function

Given a SPOT5 image and its associated geometric physical and resolution models, each airborne picture of the reference dataset is projected in the SPOT5 focal plane thus simulating the conditions of acquisition of the actual HRG or HRS image.

For the given reference image let L_R be its associated geometric model : for each point (l_R,p_R) of the reference image the ground position of the point is given by $L_R(l_R,p_R)$.

Let then L_S be the initial geometric model of the SPOT image: $L_S(l_S,p_S)$ is the ground position of point (l_S,p_S) of the SPOT5 image. The simulation step then projects point (l_R,p_R) of the reference image at position $(l_S,p_S)=L_S^{-1}L_R(l_R,p_R)$ in the SPOT5 image while the actual position is (l,p).

The simulated and the real image are then compared to each other, using image matching tools.

3.2 Error budget

The objective of this paragraph is to analyze the budget errors leading to the measured difference

$$dm(l,p,Iref) = (ls,ps)-(l,p)+\varepsilon_{cor}(l,p)$$

where ε_{cor} stands for image matching errors. Image matching algorithms developped at CNES/QTIS and applied to this method give a RMS accuracy of 0.02 pixel for radiometrically similar looking images, which is the case here since diachronism as been avoided.,

and

$$(l_S,p_S)=(l,p)+\varepsilon_{REF}(Iref)+\varepsilon_{DEM}(l,p)+\varepsilon_{PSF}(l,p)+\varepsilon_{SPOT}(d)$$

where

ε_{REF}(Iref) stands for errors of the geometric models of the reference data sets; residuals in the bundle ajustment of the initial data set lead to a RMS error of 0.4 m. For a given image Iref of the reference data set, ε_{REF} (Iref) is considered a constant.

ε_{DEM}(l,p) stands for errors due to digital elevation model used to project the reference data into the SPOT5 geometry. Refined DEM accuracy is estimated to 1m ; it is increased to 2m to take into account the landscape changes during the 5 years period from original data set acquisition and SPOT5 data acquisition. SPOT5 data are all acquired with almost vertical viewing directions. The reference data set field of view is 20°, thus the RMS influence of DEM is estimated to :

$$\varepsilon_{DEM}(l,p) = \frac{1}{20°}\int_{0°}^{20°} \tan(x)\,dx \quad \text{x 2 m} = 0.3 \text{ m}$$

ε_{PSF}(l,p) stands for errors due to point spread function approximation ; the SPOT5 point spread function is very well known and its impact is considered less then a few hundredth of a pixel, RMS.

$\varepsilon_{SPOT}(d)$ accounts for geometric errors of the SPOT data, that is a geometric bias for the exterior orientation and the residuals of the inner ortientation :

$$\varepsilon_{SPOT}(d) = BIAS + \varepsilon_{INNER}(d)$$

BIAS is constant within a SPOT5 image

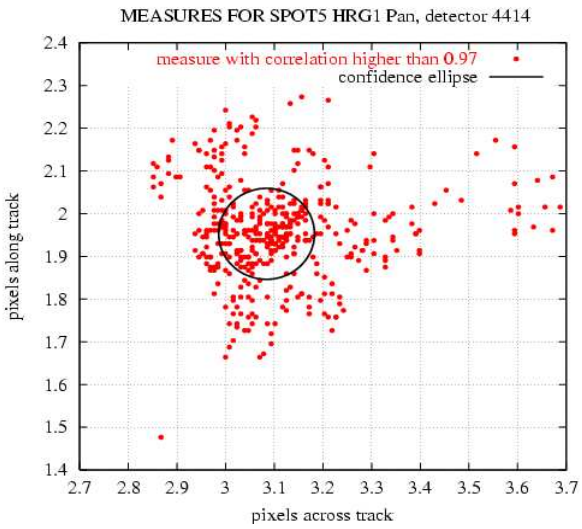
The inner orientation error $\varepsilon_{INNER}(d)$ only depends on the detector number d.

For each image matching measurement we have an estimation of $\varepsilon_{INNER}(d)$:

$$\varepsilon_{INNER}(d)(l,p,Iref) + BIAS = dm(l,p,Iref) - \varepsilon_{cor}(l,p) - \varepsilon_{REF}(Iref) - \varepsilon_{DEM}(l,p) - \varepsilon_{PSF}(l,p)$$

The same detector views a landscape 5 km wide (the width of our super site), that is 500 to 1000 rows depending on the mode to be processed, each pixel of the landscape being viewed in turn by 4 to 5 images of the reference data set. The image matching measurements was done with a density of one measurement every 5 rows.

Following is an example of the scattering of measures for a given HRG1 panchromatic detector ; in this example, 418 measures made over 20 different images of the reference dataset showed correlations better than 0.97. After filtering at 2 sigmas, the 1 sigma ellipse of confidence is a circle with radius 0.1 pixel.



4 -THE SPOT5 DATA

4.1 SPOT5 instruments

In this paragraph we briefly review the main geometric characteristics of SPOT5 payload.

SPOT5 high resolution payload is composed of 2 HRGs instruments, with 60 km wide swath, 5 meters resolution in panchromatic standard mode called HMA and 10 metres multispectral mode called XI. Since registration between spectral bands is measured with relative methods, it is not treated in this paper and for multispectral mode, only B2 mode (closest to panchromatic in radiometry) is concerned here.

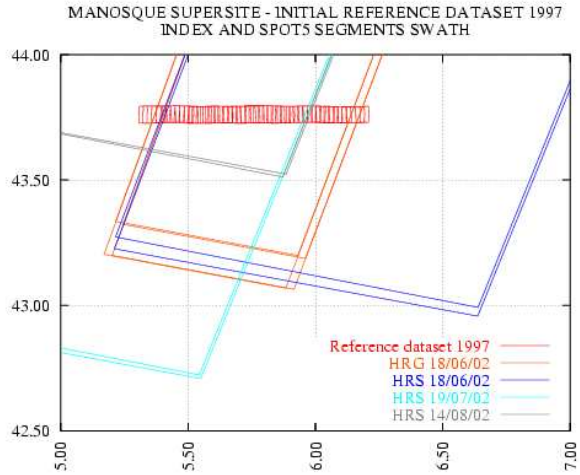
The payload is complemented with the stereoscopic HRS instrument built with 2 similar telescopes : forward and bakward HRS, with 120 km wide swath, 5 metres resolution along track and 10 m cross track looking 20° forward and backward [Baudoin 2004].

4.2 Data acquisition :

During the summer of 2002, the supersite has been imaged at least once with each instrument and in each of the modes described previously. The 120 km swath of HRS is covered in 2 steps using 2 tracks at 5 days interval. As far as it was possible, all the data were acquired with almost nadir viewing conditions.

The following table shows the data used for inner orientation of SPOT5 instruments. An assembly map completes the description of the data.

	HRG1 HMA	HRG1 XI	HRG2 HMA	HRG2 XI	HRS1	HRS2
28/05/02	x		x		x	
18/06/02	x	x	x	x	x	x
23/06/02			x		x	x
19/07/02			x		x	x
14/08/02					x	x



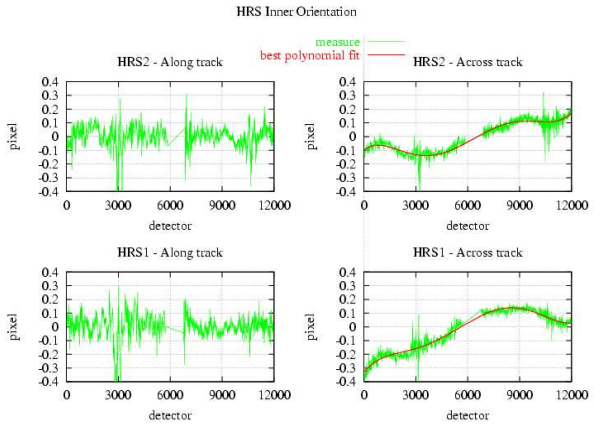
A control acquistion at one year interval was planed in july 03

5 -RESULTS

5.1 HRS Inner orientation

Along track, a major third degree polynomial distorsion with an amplitude of 5 pixels was observed with the reference dataset within the first month of in-flight commissioning on both HRS instruments and included into the ancillary data (so called PSTS), thus improving the quality of the geometric model.

The availability of the new dataset, allowed to observe the residual inner orientation. Following is a figure representing, in pixels, the residual inner orientation for both instruments along and across track.



Residuals across track show a small magnification error of 3.5×10^{-5} for HRS1 and 2.6×10^{-5} for HRS2 as well as fifth degree polynomial shape. After introducing these observations into the PSTS, residuals can be estimated for both intruments as follows :

Along track < 0.09 pixel RMS

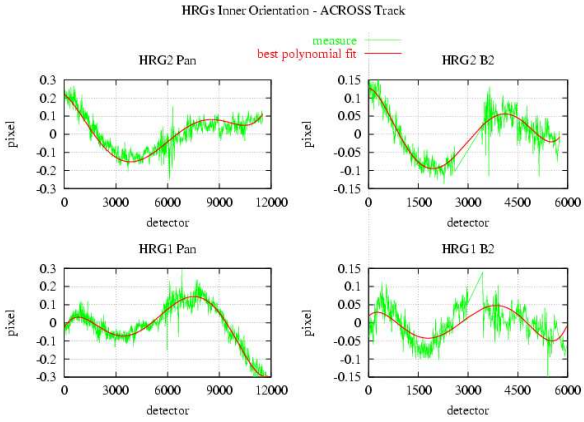
Across track < 0.05 pixel RMS

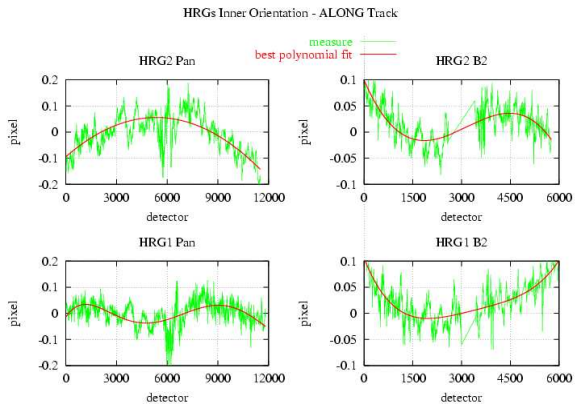
most of which being due to the accuracy of the reference data set as described in the error budget. This explains in particular the higher residuals along track were we have 20° looking angle, hence predominent effect of DEM.

5.2 HRG Inner orientation

Main inner orientation errors appear across track on both HRGs for panchromatic mode, with a total effect up to 0.5 pixel. After including fifth degree polynomials into the HRG PSTS, the remaining measures are within 0.04 pixel for HMA and 0.025 pixel for B2 modes.

The following figures represent the measures and associated polynomial models for HRGs instruments





CONCLUSION

The absolute method for inner orientation measurement of SPOT5 instruments implemented here is appropriate for objectives of inner orientation of the HRG and HRS instruments with an accuracy better than 0.1 pixel RMS.

However, the main limitations encountered are linked to the accuracy of the reference dataset : good enough for a 5 meter resolution instrument, it needs to be adapted for higher accuracy instruments.

This is the case of the Pleiades payload with its 0.70 meter resolution instrument for which we are now considering a new reference « super site » also located in South Eastern France, in the area of the Salon-en-Provence town.

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