THE SPOT1 IMAGE QUALITY : TWO YEARS OF EXPERIENCE

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1. INTRODUCTION - THE SPOT IMAGE QUALITY CHECK PROGRAM

SPOT has been designed as an operational and commercial remote sensing service (ref [1], [5]). This implies that the quality of the data supplied to the users must always be maintained within a set of precise specifications. Such a result can be reached by a sustained effort which can be divided in four major steps.

- During the project definition phase, mission analysis allows to take into account the future users needs and to convert them into mission specifications, which have to be broken into satellite and ground preprocessing system specifications.
- During the various steps of the development phase, image quality evaluations are periodically performed. They become more and more realistic as long as the satellite is assembled.
- Just after the launch, during the so-called in-flight assessment period, the quality of the raw data is controlled. This allows to optimize the ground preprocessing system parameters. When this operation is achieved, preprocessed data can be generated and checked so as to determine the actual image quality performances and compare them to the specifications (ref [3], [4], [6], [7]).
- Since aging evolutions may always occur in orbit, regular checks are undertaken during the operational SPOT life and a monthly synthesis is made. This can lead to update the performance evaluations, but also to modify some operational parameters (such as, for instance, the detector normalization coefficients).

This image quality check program allows us to precisely describe the initial status of the data quality, and how it has evolved for two years.

2. GEOMETRIC IMAGE QUALITY

The geometric image quality can be described by several items :
. localization and cartographic accuracy (external quality)
. length distortion, anisomorphism, local coherence (internal quality)
. multispectral and multidate registration (image to image quality)
. altitude measurement accuracy.

2.1. EXTERNAL GEOMETRIC QUALITY OF THE IMAGES

Before going any further into this paragraph, it may be useful to precise that the very good internal quality of SPOT images has allowed to create a new cartographic product using only a model of the imaging system (without any Ground Control Points).

Such a product, referred to as level 2A, is very useful for countries with a poor cartographic cover. Obviously, these images have the same localization accuracy as level 1B ones, but in term of cartographic accuracy they are similar to the previous level 2 products, now defined as level 2B products.

Each SPOT image is provided with the estimated geographical coordinates of some particular points. For the level 1B and 2A preprocessed images, this estimation is performed by modelling the orbit, the attitude of the satellite and the relative angular position of the instruments with respect to the satellite. Level 2B images are corrected with respect to maps, using both a model of the imaging system and GCPs.

2.1.1. Localization accuracy for level 1B and 2A products

The localization accuracy specification is 1500 m RMS for vertical viewing, and 1800 m RMS for oblique viewing.

A regular estimation of this parameter is performed taking GCPs over a statiscally significant number of images. Those images are chosen well distributed all over the world (USA-Europe-Japan-Brazil-Madagascar-Australia-New Zealand), in order to identify any local phenomena.

At the end of the in-flight assessment period, the estimated value, with 51 scenes, was 832 m.
The recurring checks carried out during the August 86/February 88 period have shown that the localization accuracy is between 150 m and 950 m, with a RMS value of 496 m (with 93 scenes).

2.1.2. Cartographic accuracy for level 2A and 2B products

On level 2B images, we can associate estimated geographical coordinates to each pixel of the image. It is specified that the RMS residual error between actual and estimated geographical coordinates for all the image points must be lower than 20 m (new specification). It must be understood that this error combines both GCPs pointing errors and residual internal distortion. The results of the different checks show that the performance is about 20 m.
Level 2A images can be superposed to a map by a translation. After applying this translation, the RMS residual localization error shall be lower than 80 m. The first acceptance tests on this product have shown that the specification is met.

2.2. INTERNAL GEOMETRIC QUALITY OF THE IMAGES

For vertical viewing (or flat landscapes), the internal image quality consists of three parameters :

- . the length distortion,
- . the anisomorphism,
- . the local coherence.

2.2.1. Length distortion

The length distortion is defined by the relative error between actual distances on ground and measured distances on the image (considering that the sampling pace is 10 m in panchromatic mode and 20 m in multispectral mode). It is specified to be lower than 10^{-2}.

This parameter is checked by using GCPs. The estimated value of the in-flight assessment was 1.5 10^{-3}, and further checks have proved the stability of this performance.

So, it appears that the length distortion requirement is very fairly met.

2.2.2. Anisomorphism

The anisomorphism is the amplitude of variation of the length distortion around a given point. In other words, it can be defined as the eccentricity of the ellipse obtained on the image when viewing a circle on ground. It is specified to be lower than 10^{-3}.

Measuring this parameter with such an accuracy is very difficult, that is why we use two different methods, providing two boundaries for this parameter.

The performance estimated during the in-flight assessment period was between 0.8 10^{-3} and 1.6 10^{-3}. Further checks have always confirmed these results.

So, it seems that the anisomorphism is at the limit of the specification, may be slightly above it.

2.2.3. Local coherence

While the previous parameters are related to the image quality from a global point of view, the local coherence refers to the behaviour of a pixel with respect to its neighbours. It specifies the relative difference between the theoretical sampling pace (10 m/20 m) and the actual local sampling pace along lines or columns. The specified value is 0.3 sampling pace.

In fact, since CCD linear arrays are used, defaults can only occur at the limit between two arrays (each image is generated by four arrays). The performance is checked using automatic correlation. All results obtained are lower than 0.1 sampling pace.

2.2.4. Conclusion

From these three results, it can be said that the internal geometry of the level 1B SPOT images is very good. This can be explained by the use of CCD arrays and the performances of the attitude control subsystem.

2.3. IMAGE TO IMAGE REGISTRATION

This paragraph deals with the registration of images viewed in the same geometric conditions : the three images of the multispectral mode, or two images with the same viewing parameters and processed at level S.
All tests undertaken to compute these performances use an automatic 2D correlation.

2.3.1. Multispectral registration

A good multispectral registration is mandatory in order that the concept of multispectral images makes sense.

The specification applies to the radius of the smallest circle including the three points on ground corresponding to the same pixel in the three spectral bands; such radius shall be lower than 0.3 sampling pace.

The in-flight assessment has given a value of 0.15 sampling pace for HRV1, and 0.10 for HRV2. Further checks have confirmed the stability of these performances.

2.3.2. Multidate registration

This specification applies to the standard level S product.
The two images must be viewed in the same geometric conditions (the difference of the viewing angles shall not exceed 1.8°), but panchromatic (Pa) and multispectral (Xs) modes may be mixed.

The RMS residual error of registration must be lower than 0.5 sampling pace.

All configurations have been checked, and the requirement is always met. As an example, Pa/Pa multidate registration is about 0.3 sampling pace.

2.4. EVALUATION OF THE STEREOSCOPIC ACCURACY

The paragraph 2.2 has shown that the internal geometric quality of SPOT images in vertical viewing allows a very good planimetric restitution. Our purpose, in this paragraph, is to present the results of the evaluation of the altitude restitution using a pair of stereoscopic SPOT images.

As specified, SPOT system must be able to achieve altimetric measurements with a RMS resolution of at least 10 m (panchromatic mode).

To validate this specification 14 pairs of images in -27°/+27° configuration, and 42 pairs in 0°/+27° configuration have been selected. The detailed analysis is presented in ref [9].

With the -27°/+27° stereopairs, a precision of 3.5 m can be achieved. With the 0°/+27° stereopairs the altimetric precision is 7 m. Obviously the actual accuracy depends on :
- the quality of the modelling,
- the errors commited in plotting the GCPs,

- the errors in determining the GCPs ground coordinates.

Several independent evaluations performed by other users have led to similar results. Some of them are presented in the same proceedings as ref[10].

This fulfills the cartographers expectation regarding SPOT, and gives some idea of the attractive applications that may be provided by SPOT stereoscopic capability.

3. RADIOMETRIC IMAGE QUALITY

The radiometric quality of the SPOT images is described by the following parameters :

- signal to noise ratio along the columns (detector noise),
- signal to noise ratio over the whole image (detector normalization),
- absolute calibration,
- MTF performance.

3.1. DETECTOR NOISE

As each line of SPOT images is generated by linear CCD arrays, the noise along a column is the noise generated by one detector and the associated electronics.
The specifications are expressed in terms of ground-based noise equivalent reflectance, $Ne\Delta\rho$.
The mission analyses have led to specify $Ne\Delta\rho \leq 0.5\ 10^{-2}$.

The translation from $Ne\Delta\rho$ to $Ne\Delta L$ (noise equivalent radiance), which is the actual significant quantity for the instrument, depends on :

- the angle between solar and vertical directions, θ,
- some atmospheric parameters.

Using the on-board calibration lamp, one can evaluate periodically the signal to noise ratio (SNR) of the system.
The following table shows the results of the in-flight assessment and the results after two years in orbit.

SNR	HRV1				HRV2			
	Pa	Xs1	Xs2	Xs3	Pa	Xs1	Xs2	Xs3
Specification	200	210	200	270	190	190	200	270
In-flight assessment results	203	359	248	412	114	331	254	385
Two years results	329	306	218	363	287	287	223	351

(The specifications differ from one HRV to the other one since the lamp radiances are different)

It can be noted that in multispectral bands the requirements has always been met. The noise has been stable over two years, but the signal has decreased (and so, the SNR) because of the aging of the instruments.

In panchromatic band, HRV2 was out of specification at the end of the in-flight assessment period, and HRV1 at the limit of the specification. For both instruments the noise has decreased and now the specification is fairly met. The periodic noise along lines noticed in HRV2 Pa images at the beginning of SPOT life (ref [6]) has now almost disappeared.

It is possible, using a standard atmosphere model, to compute the corresponding ground values in term of $Ne\Delta\rho$ for θ=15° and θ=60°.
The two years measurements have been so processed, and the results are presented in the following table. It can be clearly seen that $Ne\Delta\rho$ is function of the θ angle.

10^2 x $Ne\Delta\rho$	HRV1		HRV2	
	θ = 15°	θ = 60°	θ = 15°	θ = 60°
Pa	0.14	0.26	0.14	0.27
Xs1	0.14	0.26	0.15	0.29
Xs2	0.19	0.37	0.18	0.35
Xs3	0.14	----	0.14	----

(the results for θ=60° in Xs3 are not reported because the corresponding ρ value is out of the reasonable physical values)

The specification is very fairly met in the whole range of measurements. So, it can be acceptable to go beyond the limit angle =60° without any major radiometric defaults.

3.2. DETECTOR NORMALIZATION

A SPOT image is generated by 9000 (Xs mode) or 6000 (Pa mode) detectors. Each of them has its own radiometric behaviour, characterized by an offset (dark current) and a sensitivity coefficient.

The dark current is measured by preventing any light from reaching the detectors (using a specific position of the viewing mirror). The sensitivity differences between detectors are computed by some simple statistic methods using uniform images over large snowy fields. This calibration is performed every 3 or 4 months from Greenland or Antarctica images (according to the season).

The images are corrected thanks to those coefficients. The residual error of the detector normalization appears as a noise along the lines. The specification applies to the global noise which combined this normalization residual noise and the detector noise (see § 3.1). When computing this global noise over 10 x 10 pixels areas, the specificied value is :

$$Ne\Delta\rho \leqslant 0.7\ 10^{-2}$$

When computing it over the whole image, the specified value is :

$$Ne\Delta\rho \leqslant 0.85\ 10^{-2}.$$

The in-flight assessment period allowed to validate the normalization methods and to verify that the specified accuracy was actually met. Checks are made on a regular basis ; the following table shows the most recent results, computed over 10 x 10 pixels areas of uniform images :

10^{2} x $Ne\Delta\rho$	HRV1		HRV2	
	θ = 15°	θ = 60°	θ = 15°	θ = 60°
Pa	0.19	0.38	0.19	0.38
Xs1	0.14	0.29	0.14	0.29
Xs2	0.20	0.42	0.18	0.36
Xs3	0.15	0.31	0.15	0.31

(these results cannot be strictly compared to those of the previous paragraph since the date of the checks are not the same, and the radiances are slightly different)

This shows that the specification is quite met.

The specification over the whole image is more difficult to assess, but indirect verifications prove that it is also fairly met.

However some residuals problems should be reported :

. The in-flight assessment showed that a spurious effect appeared when a camera was used both in Pa and Xs mode. This effect appeared as a vertical periodic striping (7-pixels period).
This noise has been shown to be independent from the signal. So, it existed only because the dark current was measured on one channel keeping the second off.
We now measure the dark current in the two modes (second channel on and off) and correct the images generated in a given mode by the appropriate dark current. So, this spurious noise has disappeared. This correction is implented in the Ground Preprocessing Center and all images collected after november 1986 are processed using this method.

. On some very specific sites (mainly some deserts), a normalization default between CCD arrays can be noticed in Xs1 band (sometimes in Xs2 band). This default appears as four large vertical stripes with a slight difference of digital level. A specific software, implemented in Toulouse, is now available to correct this kind of defaults.

. For images with a low digital level and a low dynamic (water, forested region ...), a strong stretching could show the residual normalization striping. This is quite normal because of the signal is quantified. Checks have been performed on such images and the results have always proved that the noise was in the range of the $Ne\Delta\rho$ values given in the previous table.

3.3. ABSOLUTE CALIBRATION

The absolute calibration allows to determine the relationship between the digital output of the instrument and the corresponding radiance given in physical units.

Before SPOT launch, an absolute calibration of the instruments and the on-board calibration devices was performed.

During the in-flight assessment period this calibration and the characteristics of the on-board devices have been updated, taking into account :
- measurements made simultaneously with a satellite observation over a test site (White Sands desert - New Mexico USA), in cooperation with the University of Arizona (Prof. P.N. SLATER),
- statistical comparison of the two HRVs over the same areas in vertical viewing.

Regular checks that have been carried out since this period consist of:
- calibration using the on-board devices (calibration lamp, solar calibrator);
- new inter-HRV calibration;
- updated measurements over the test site of White Sands.

The analysis of the results, obtained by these different and complementary methods, leads to the following conclusions :

1) The accuracy of the inter-HRV calibration is 1% or 2%. That is important to assure of the radiometric coherence of the bi-HRV mode.

2) The stability of the calibration on-board devices is better than 2%. That is important for multidate studies. The losses of the imaging system, since SPOT launch, are estimated to be about 8% in panchromatic band, and about 15% in multispectral bands.

3) The initial measurements over the White Sands site were accurate for Pa, Xs1 and Xs2 bands, but 8% under estimated in Xs3 band. This has been rectified, and the absolute coefficients are now provided with a 6% estimated accuracy.

4) The accuracy of inter-bands calibration is very difficult to appreciate, it should be about 3%.

A complete analysis of these results and the best estimation of the absolute calibration coefficients can be found in ref [11].

3.4. MODULATION TRANSFER FUNCTION

The modulation transfer function (MTF) is specified at half the sampling frequency.

The in-flight evaluation of this parameter is performed according to methods which are detailed in ref [4].

First, we estimate the MTF for panchromatic band by comparison of actual SPOT images with simulated images generated with a series of MTF known values. This method, based on a visual criterion, is purely qualitative, but it allows to prove that the quality of the Pa band is better than specified for the HRV1 images, and is just as specified for the HRV2 images. Since no series of simulated images has been generated, the same method cannot be applied to multispectral bands.

A quantitative method has also been developed by observing the same ground area with the two instruments and by computing the MTF ratio of the corresponding CCD arrays of each HRV (at approximately 0.3 fe). That allows to characterize the homogeneity of the MTF over the whole image. In multispectral bands the two HRVs are more or less similar except in Xs2 band where two of the HRV2 CCD arrays are 20% worse than the other ones.

The detailed results are given in ref [6].

No significant evolution has been noticed during the two years SPOT life and so, no refocusing operation has been necessary.

4. CONCLUSION

The follow-up quality control program has allowed to refine the results we got during the in-flight assessment period, to define and operate any possible correction or improvement, and to monitor any possible aging effect.

The geometric image quality has been fairly good since the SPOT beginning of life.

The radiometric quality is also good; some improvements have been made in the system in order to correct the less satisfactory points, enlighted during the in-flight assessment period.

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