Effect of acquisition and image processing parameters on automatic correlation accuracy

P. Antonio, G. Bordes, E. Breton, G. Kuntz, C Latry, M. Pausader

CNES Toulouse France

ABSTRACT

The next generation of high-resolution SPOT satellites (Spot 5 & 6) will emphasise the acquisition of stereoscopic pairs. Along-track stereoscopy will enhance the quality of stereo pairs while easing their capture. The automatic matching of stereo pairs is currently used and will be more and more in order to produce digital terrain models in an operational way. The DTM extraction is a rather complex process encompassing several steps. The accuracy of the final product depends on a large number of parameters including:

- landscape parameters
- radiometric parameters
- geometric parameters
- ground processing methods

Some radiometric and geometric parameters as well as ground processing methods can be tuned up to increase the accuracy of the matching process. We studied the sensitivity of matching accuracy to correlation operator, interpolation function, instrument signal to noise ratio (SNR), modulation transfer function (MTF) value and spectral band. We simulated stereoscopic pair on different kinds of landscape with different high frequency content. A SPOT stereo pair is simulated from high resolution airborne images. In order to ease statistical estimation of performances, images of the pair are shifted images of a known fraction of SPOT pixel.

The shift is measured using different matching process on different images simulated with various characteristics of SPOT imagery.

Keywords: correlation accuracy – matching – interpolation – SNR – MTF – SPOT5

1. INTRODUCTION

SPOT1-4 system acquires stereo pairs on an operational base using off-nadir viewing capability from two different orbits. Viewing direction of each camera can be varied up to ±27° relative to the nadir. Using this capability, many stereo pairs are acquired in order to generate digital terrain model (DTM) [Cf Ref. 1,2]. Use of such pairs may be difficult if an important period separates the images acquisition: atmospheric differences (clouds, smog, sand wind...) and landscape change (vegetation growing stage, soil moisture, snow...) can occur and lead to image unlikelihood. Programmation complexity (area accessibility, B/H demand) and weather change in between the two orbit paths leads to extended waiting period.

SPOT5 will experiment a new stereoscopic mode which copes with such problems: along-track stereoscopy. Images will be acquired from the same orbit, by two instruments with different along-track viewing angles. Quasi-simultaneous acquisition (less than 2 minutes interval) simplifies programmation process and enhances images likelihood. With such stereo-pairs, DTM accuracy will mainly depend on the acquisition geometry (B/H [Ref. 3]) and correlation process.

The main objective of this study is the evaluation of automatic correlation performances according to instrumentation quality (SNR, MTF, sampling rate) processing method (matching operator, interpolation function) and landscape. We undertook such a study within SPOT5 preproject studies in order to tune up SPOT5 instruments specifications.

2. PARAMETERS AFFECTING DTM ACCURACY

DTM are produced through a complex process which includes image acquisition and processing. We can identify 4 important families of parameters which have an effect on DTM accuracy. A non exhaustive list follows:

1) observed landscape:
   altitude
   texture
   landscape variation with time
   atmospheric conditions
   artificial (houses) or natural (trees) superstructures

2) instrument: (Cf Ref. 5 & 6)
   ground sampling rate
   Modulation Transfer Function (MTF)
   Signal to Noise Ratio (SNR)
   compression methods and rates
   number of encoding bits
   spectral band

3) geometric acquisition conditions: (Cf Ref. 3)
   B/H
   unlikelihood due to viewing angle (stereo-radiometric effects)

4) Processing method
   correlation operator (function, mono or bi-dimensional computation, correlation window size)
   checking method
   interpolation function (for correlation maximum research)
   geometric viewing model
   "hole filling" method

Since we are interested in SPOT5 instruments design and processing limits, we focus on the evaluation of the impact of instruments parameters, and processing methods, on correlation performances. The impact of acquisition geometry on matching accuracy has ever been studied [Cf Ref. 3]. Such an analysis could not be done without considering landscape frequency content.

3. METHOD FOR MEASUREMENT OF PARAMETERS SENSITIVITY

Test images are simulations very close from assumed SPOT5 instrument images. Landscape is obtained from high resolution images, with a spatial resolution three times better than the one of SPOT. Such a ratio guarantees perfect MTF considering SPOT sampling frequency. Then, SPOT images are simulated by SPOT point spread function application and noise perturbations simulation on simulated landscape. The second image of the pair is simulated on the same way, with a shifted origin in the landscape image. A shift of several pixels in the airborne image is seen as a sub-pixel shift in the SPOT simulation.

The main characteristic of this pair is a constant parallax in the image which can be interpreted as a constant altitude on the area. Advantages of such a method are:

- choice and perfect knowledge of introduced parallax
- accurate measurement of results quality: it is possible to produce statistics on an important population of pixels since we measure many time the same parallax.
- use of wider correlation window: since all the pixels are shifted with the same parallax, parallax to be measured is constant in the whole correlation window; an increase of the correlation window size leads to correlator performance enhancement and measurement of the interpolation function true effect.
- images without disturbing parameters such as relief or landscape change.
- no need of image resampling in complex geometry (epipolar) to locate homologous pixel.

We have to keep in mind that the accuracy of our results will be quite ideal. If we can not expect such an accuracy on real images, the trends of our results will be representative of the one on real images. It was of great interest to define a method which allows to identify and weight the effect of each parameter handled separately.

Different kinds of landscapes have been observed.

- stochastic mono-dimensional signal of white spectrum
- high resolution images acquired by an airborne pushbroom which belongs to CNES. Spectral bands of this instrument are the ones of SPOT.
  Images named "AIX", "FORET" and "LANDES", have been acquired on various sites, respectively:
    peri-urban area (Aix en Provence)
    Forest (in Landes district)
    agricultural area (in Landes district)

During the simulation process, it is possible to modify:

Signal to Noise Ratio (SNR), quantization noise included

Modulation Transfer Function (MTF), through the change of its value for half the sampling frequency

sub-pixel translation value.

4. RESULTS

4.1 Sensitivity to processing parameters

4.1.1 Effect of the correlation function

The correlation operator allows location, for each pixel in one of the images, of the homologous pixel in the other image. It is a bidimensional problem which is usually reduced to a monodimensional one, in order to speed up the processing. Such a processing is named resampling of images in pseudo-epipolar geometry. [Cf Ref. 4]

For our study, by construction, images are in epipolar geometry (images are along line only translation dependent).

Many similarity functions are available in the literature [Cf Ref. 7, 8, 10]. We tested four of them:

– linear correlation coefficient:

$$CO3(x_p, y'_p) = \frac{1}{p}\sum_{i=0}^{i=p-1} \frac{(x_p(i) - \overline{x_p}) \cdot (y'_p(i) - \overline{y'_p})}{\sqrt{\sigma^2(x_p) \cdot \sigma^2(y'_p)}} =$$

$$\frac{\rho_{xy'}}{\sigma_x \sigma_{y'}} \qquad \rho_{xy'} = E[(x - \overline{x})(y' - \overline{y'})]$$

– sum of absolute difference:

$$CO1(x_p, y'_p) = \sum_{i=0}^{i=p-1} |x_p(i) - y'_p(i)|$$

This function is a measurement of norm, called L1, of the difference vector

– sum of square differences:

$$CO2(x_p, y'_p) = \sum_{i=0}^{i=p-1} (x_p(i) - y'_p(i))^2$$

This one measures quadratic norm of difference vector: L2 norm.

– Fourier transform correlator:

$$CO6(x_p(k), y_q(k))(j) = \sum_{i=0}^{i=p-1} |\overline{x_p(i)} \cdot y_q(i+j)|$$

where

x_p	correlation window composed of p pixels
$x_p(i)$	radiometry of pixel number i of x_p
y_q	research window number q in the "sister" image
y'_p	correlation window, extracted from the research window y_q, composed of p pixels.
$\overline{x_p}$	mean radiometry of the correlation window x_p
$\sigma(x_p)$	root mean square radiometry of correlation window x_p

We compare the performances of each of these correlator with regards to bias and RMS performances (Cf figure 7 & 8).

Bias: arithmetic difference between measured and true distance

RMS: quadratic distance between distance measured and mean distance measured.

All these correlators measure distance between homologous points with the same bias, except CO1 which is highly biased, and different RMS.

First we can see that smaller is the bias, greater is the RMS. So CO1 has the smaller RMS. CO3 and CO2 have almost same performances and CO6 is the worst. Since the linear coefficient CO3 has the interesting property of not being affected by linear radiometry changes between the images (such changes are expected if images have been acquired with different electronic gains). It is the one we select as the best correlator and we choose to realise our studies.

4.1.2 Effect of the interpolation function

The matching phase provides a discrete correlation function sampled at a pixel rate. The interpolation of this discrete function makes possible an accurate measurement of the parallax. At first, all the local maximum that such a discrete function may present are located. Then the most probable location of the absolute maximum is found out through checking criteria. Lastly, interpolation is performed on the selected candidate.

Validation is carried out through an elimination of discrete maxima of which correlation value remains below a given threshold or when measured parallax is different of more than half a pixel from the theoretical value.

Many interpolation functions, usually called interpolators, may be found in literature[Cf Ref. 9, 10, 11]. We tested some of them and proposed also a new one called "peak model":

- spline function
- Fourier series interpolator
- Lagrange polynomial
- peak model

The peak model is especially adapted to white spectrum "landscape" (with constant frequential component amplitudes); its shape is known as the one of the autocorrelation of simulated image derived from such landscape: $FT^{-1}(Constant^2.MTF^2)$ (when no noise is present in the simulated image, image spectrum is: Constant.MTF). This interpolator is the best for white signal (Cf figure 1) but, on real images, this interpolator was less efficient, since landscape spectrum is far from white. Nevertheless, for a white signal, such an interpolator allows a proper evaluation of accuracy degradation due to non optimum interpolator (Cf figure 1). On real images, the most interesting interpolator is Lagrange polynomial degree 4.

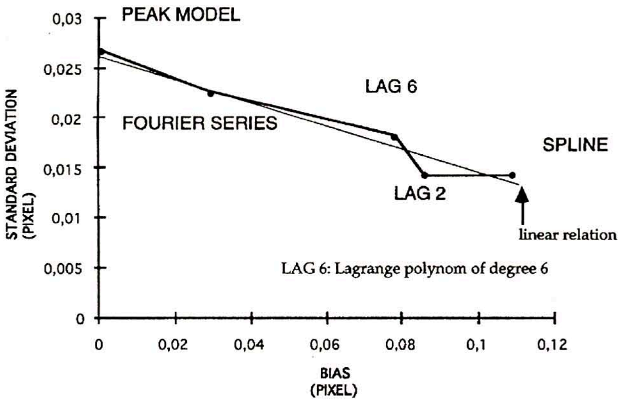

Figure 1 - Interpolators comparison on white spectrum landscape.

4.2 Effect of instrumental parameters

We tested parameters used to design the instrument:

- SNR
- MTF
- Spectral band

4.2.1 Sensitivity to SNR

Different instrumental noises have been simulated: quantization, electronic and detector noises. SNR values are given for the maximum dynamic of the image radiometry. We introduced noises for SNR from 10 to a maximum value corresponding only to the quantization noise. Variations of standard deviation versus SNR for studied landscapes are shown on figure 2. Related proportions of rejected correlations are in Table 1. We observe a decrease, followed by a stabilisation of standard deviation with SNR increase. The best behaviour is related to "AIX" with a stabilisation around SNR = 100 compared to a stabilisation around SNR = 150 for others landscapes. When stabilisation occurs, percentage of rejected pixels is becoming very low.

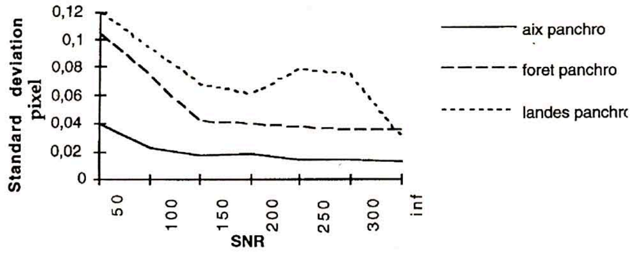

Figure 2 - Signal to Noise Ratio effect for three landscapes.

Table 1 - Wrong correlations percentages according to landscape and SNR

SNR	AIX	FORET	LANDES
10	13.7%	34.2%	96.9%
50	0	7.6%	36.4%
100	0	3%	20%
150	0	0	2.7%
200	0	0	9%
250 and over	0	0	0

Standard deviation value depends on the landscape and for the SNR close to the one foreseen for SPOT5 (SNR = 200), stabilisation is obtained whatever the landscape may be.

4.2.2 Sensitivity to MTF

MTF is applied on our landscape representation using an analytical model developed for SPOT. The shape of this analytical model depends on the value of MTF at half the sampling frequency (fs) of the satellite. Five MTF values have been tested:

0,64 (related to a perfect detector)

0,3 (specified for SPOT5)

0,15 and 0,05

We observe that MTF effect depends on the landscape and for each kind of landscape we determined the optimum MTF:

Image	**optimum MTF**
white signal	0,10
AIX	0,15
FORET	0,30
LANDES	0,64

This result finds its explanation in aliasing. The more high frequencies (> fs/2) are present in the image, the more high parasitic frequencies related to aliasing are present. From the observation of high resolution images spectrum we can see that high frequency amplitudes are of decreasing importance for "AIX", "FORET" and "LANDES" so aliasing is decreasing. As aliasing is decreasing higher MTF are providing more information without aliasing noise and the results are better.

Such an effect is confirmed by results achieved with images simulation without aliasing: we filtered the frequencies higher than half the sampling frequency for each landscape. Then standard deviation is getting better as MTF is increasing and error induced by aliasing can be evaluated (Figures 3 & 4).

4.2.3 Effect of the spectral band

Two of the SPOT5 spectral bands have been submitted to our test: panchromatic (B2) and near infra-red (B3). We observe that results depend on landscapes (Figures 5 and

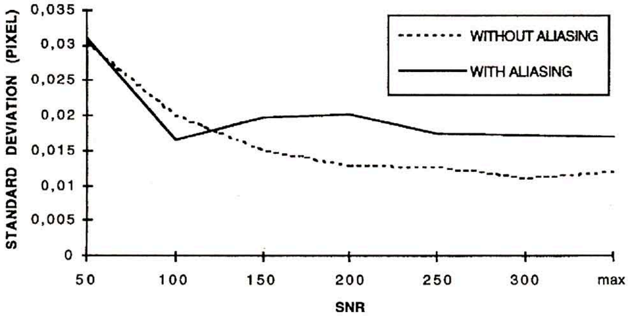

Figure 3 - Effect of spectral aliasing for "Aix" panchromatic; MTF = 0,64.

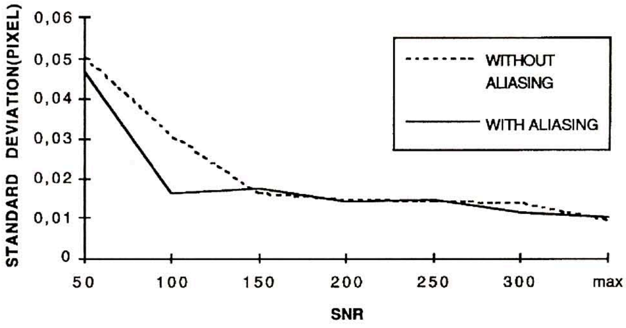

Figure 4 - Effect of spectral aliasing for "Aix" panchromatic; MTF = 0,15.

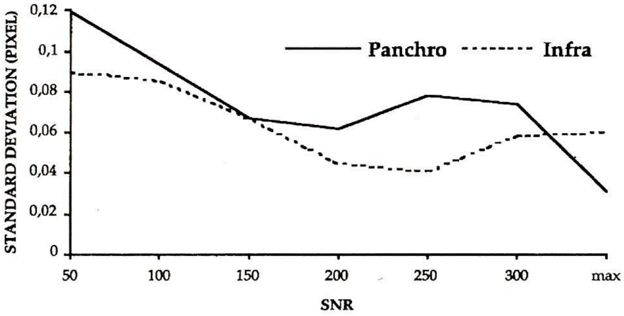

Figure 5 - Effect of spectral aliasing band for "Landes".

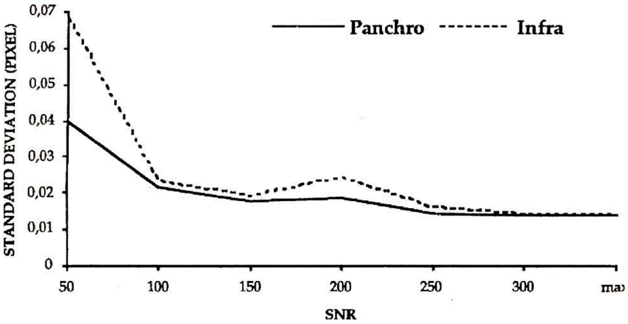

Figure 6 - Effect of spectral band for "Aix".

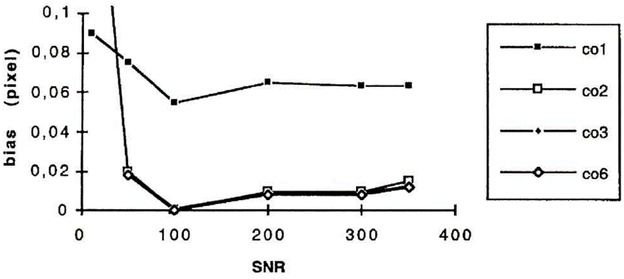

Figure 7 - Correlator performances on "white signal"; bias.

6). For landscapes as "FORET" and "LANDES", results are better in infra-red since infra-red is more sensitive to

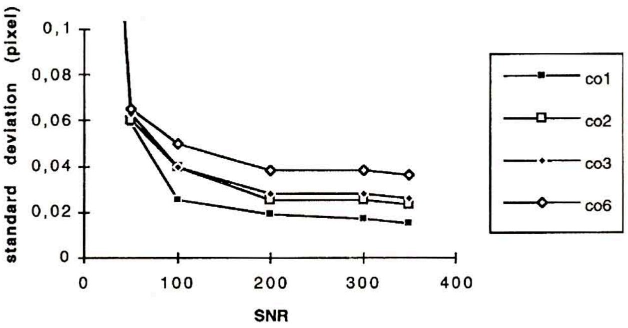

Figure 8 - Correlator performances on "white signal"; standard deviation.

vegetation coverage; for AIX results are better for panchromatic. Due to technical limitation, SPOT5's SNR level and MTF value will be better for panchromatic than for infra-red.

5. CONCLUSIONS

The developed method underscores effect of matching, interpolation and instruments parameters on automatic correlation performances. Performances are depending on the observed landscape but whatever the landscape may be, performances are optimal for SNR value greater than 200. For such a noise ratio, linear correlator and Lagrange polynomial interpolation are providing good results. Dealing with MTF, correlation performance is seen as a trade off between MTF value and landscape frequency content.

For SPOT 5, MTF of 0.3 and SNR of 200 have been specified for instrument design.

6. REFERENCES

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