

# PROCESS LINE FOR GEOMETRICAL IMAGE CORRECTION OF DISRUPTIVE MICROVIBRATIONS

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Commission VI, WG VI/4

**KEY WORDS:** Image processing, Correlation, Integration, Rectification

## ABSTRACT:

Since the beginning of earth observation satellites the dynamic disturbances have a strong impact on satellite design. During satellite conception and realisation, they are closely analysed, often with alarmist budgets. ... But so far most satellites have such a good stability that these disturbances are even difficult to characterised during in-flight commissioning.. However the recent needs to design smaller satellites, more compact and with higher sampling resolution make these dynamic perturbations more probable and critical. The correction of these disruptive vibrations thus becomes an important issue, and induces the establishment of a ground processing to improve the retrieved satellite attitude. . In this paper, we present a generic algorithm (an integration method) which allows us to estimate the disruptive signal from several differential observations derived from imagery. Applied to the PHR system in order to secure the budget of geometric stability, this innovative processing gives very accurate results (maximum error is 10% of a pixel). .

## 1. INTRODUCTION

Since the first in-flight commissioning of push broom earth observation satellite, the inter-retina images spatial matching has classically been used to calibrate the image static models, and more precisely the images viewing directions.

But in fact, because of the push broom system properties, the spatial matching which is done between two different times of acquisition of the same landscape line by the retina couple, produces a measurement of the temporal dynamic geometrical behaviour of the spatial images. This differential geometrical profile can be related to residues of attitude out of the dynamic model, and hence is of particular interest. Indeed, the on-board system AOCS estimates satellite attitude with cut-off frequencies in the range of 8 to 16Hz and thus cannot retrieve the exact image attitude which is subject to the effects of higher frequency vibrations on mirrors, focal plane etc...

The differential attitude residues estimated from the inter-retina images spatial matching are therefore measured in terms of specific image quality needs. By increasing the field of in-flight commissioning, and processing images of each product, it becomes possible to use this differential data residues of attitude to actually correct the images of disruptive microvibrations. The integration of these various differentials would allow us to restore the absolute disruptive signal.

But, as the differential measurements are coming from imagery, we have to keep in mind that we are restricted by the pixels time sampling, the record length along the satellite track, and

the high measurement noise coming from the spatial matching. The a posteriori correction will also not be effective on raw image quality budgets like local coherence (spatial local sampling) and will not allow us to correct the geometrical effects on Modulation Transfer Function (row and column desynchronization that affect the Basic radiometric information).

This line of sight attitude amelioration can be done under certain assumptions concerning the characteristics of the various retinas mounted in the focal plane, the sampling of images, and the disturbance signals that we want to correct. In fact, attitude differentials measurements are possible if inter-retina arrays are almost parallel and if the images produced by these retinas correlate sufficiently. In addition, the frequency range is reduced by the conditions of measurement of the inter-retinas images spatial matching : the disruptive signal is convoluted by a moving-average filter of size the number of lines of the picture window used for correlation, and constraints appear coming from the time lapse between the different retinas couples. Finally the integration process may differ from a viewing instrument to another, because the disruptive signal depends on the mechanical vibration source, equipment which may amplify these sources and therefore their signals signatures (frequencies law, magnitude law, the phases law).

We present an overview of the main concept of dynamic correction, starting with an application on SPOT5, and followed by a focus on the new ground processing line applied to image products for the restitution of microvibrations. This ground processing line has been prototyped during the years 2006/2007

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in order to secure the performance of in-flight image quality. This processing line will be implemented under the characteristics of the PHR system for an experimental in-flight commissioning checking, on a specific campaign which will amend by command the mechanical characteristics and generate vibrations.

First, an overview of data and background will be shown. Second, we will explain the principles of the new local integration method and its results. Third, the PHR system characteristics for this processing application are explained. And fourth we will give the performance of the algorithm on several cases of simulation for the PHR system, which is broadly satisfactory.

As it will be shown further, the new integration method is applicable to the restitution of harmonic or quasi-harmonic signals, in stationary or quasi-stationary state. It performs a local restitution of desired signal in temporal space, at each time step, using all together the different differentials measured around the processed time. Because signals are processed in the temporal space, the sampling of the measurements may be irregular or have some gaps. It is not necessary to observe all the signal : it is a local integration and hence it may be done in real time.

The processing will be detailed in order to show first, the measurements method by colocalisation and sub pixel level image matching, second, the algorithm which performs the line by line synthesis of all the measurements of each retinas couples correlations, allowed thanks to the supposed quasi-parallelism of couple arrays, third, the integration step. We will detailed also some further post-processes to this microvibrations restitution like filtering, plugging gaps and completion on the signal edges, eventually with correlation results between distant non-parallel retinas. These post-processes allow us to retrieve the most accurate signal over a maximum of time samples without extrapolation.

## 2. DATA AND BACKGROUND

This article is focused on the process of only one product of a pushbroom satellite. The available measurements are the results of the comparison between at least two images of the same product on the same landscape, viewed at different times with slightly different angles. In the following, we denote by "couple" one ensemble of 2 images leading to one time-dependant measurement of a differential of the disruptive signal. The comparison between the 2 images of a couple is made by correlation (similarity) taking into account the two images geometrical Models: Position of the satellite (Orbito), Line of sight Attitude (AOCS restitution Loop), detector viewing directions(DV) and terrain relief (Sensitivity depends on the B / H ratio). Calculated residues  $dc$  (pixel displacement in the swath) and  $dl$  (pixel displacement in time) from one image to another correspond to deviations from the assumptions of matching ("predicted shifts").

These differences have several origins:

- Attitude inaccuracy: lack of knowledge and instability
- Disregard Land (MNT / MNS) (effect of B / H ratio and the localization error)
- viewing directions model error
- correlation noise

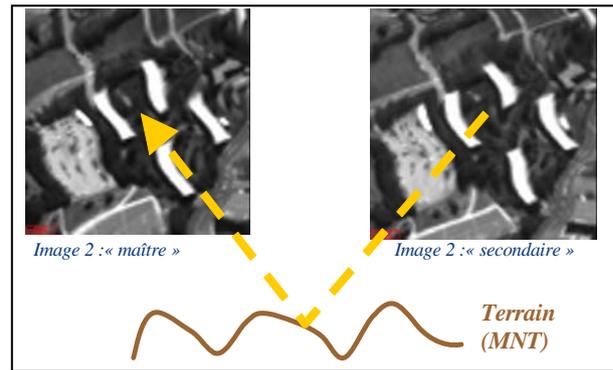


Figure 1. 2 images of the same product with disruptive vibrations

In the following, we state a very low B / H ratio (and thus an insensitivity to DTM) and a good accuracy of the geometric models returned. Taking account of the focal plane rigidity, we can thus make a physical interpretation of  $dc(t)$  displacements as a sensor roll differential and  $dl(t)$  displacements as a sensor pitch differential. But measurements by correlation are very noisy. It is a major error contributor that must be taken into account in algorithm design, indeed, standard deviation of correlation noise (supposedly Gaussian) may range from 10% to 20% of  $dc$  or  $dl$ .

In 2002-2004, on SPOT5, the correction of absorbed rocking of the line of sight corrector mirror on the image have been studied, because the tranquilisation time was chosen too short at the beginning of the in-flight commissioning.

First, A. Bouillon has analyzed and calibrated this instability phenomena by correlation between Pan HMA retina and HMB retina (Breton, 2003). She found a correction model corresponding to an extinguishing Sinus with a linear frequency drift. Secondly, J. Jouvray has created an image processing correction (for CNES during a training period in 2004) which computes correlation between PAN / XS with prediction of localisation (B / H ratio  $\sim 0,017$ ) and computes the correction by a global synthesis with least squares (on all points of measurement), modelling each shift with simple analytical formula of partial differential.

The geometric models has been then refined with 20 parameters: vibration roll with absorption, amplitude and chirp characteristic, attitude LF (polynomial degree 3), magnification and LF DTM errors.

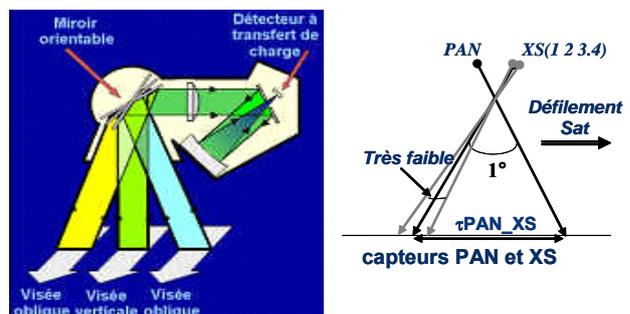


Figure 2. SPOT5 characteristics

Figure 3 shows the results of this method: the 2 images before correction and after and another image of the same landscape at an other day as reference. The results led to a good correction, allowing nice-looking images but not sufficiently accurate: with a sought signal amplitude of 3pixels , it remained a 0.1 pixel residual RMS error.

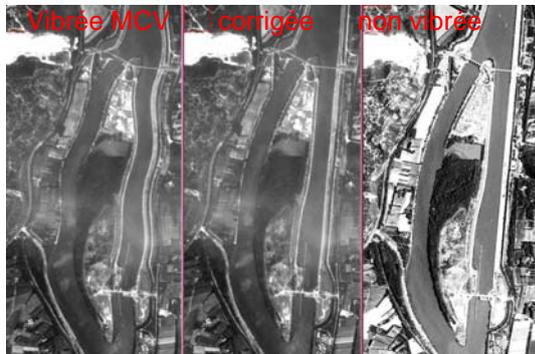


Figure 3. Image with instability on the left, corrected (middle) and another image without vibration

Moreover, this method based on a single image couple is inadequate for the following cases: when the disturbances model is unstable, when clouds are widely present, when there are inaccuracy on partial differential calculation and remaining ambiguities between DTM / Pitch / Line of sight error.

This results showed however that a similar process can be efficient using several differentials, low B/H ratio, another integration method, and without VLF errors correction but only MF, HF characterisation. That effort was continued in a research and development work with Astrium in 2003 and then a processing unit had been built by the CNES, which is presented in this paper.

### 3. METHODOLOGY

#### 3.1 Overall process

So the main issues related to attitude improvement on image processing are:

- to measure the geometric significant disruptive signal frequencies,
- to separate disruptive microvibrations effects from MNT effects and from correlation noise and errors,
- to calculate the absolute signal correction using several differentials inputs without using too much analytical modeling hypothesis
- to apply quickly and automatically the corrections on an image.

To reduce the measurements noise and errors, we avoided false correlation using a a-priori criterion, we then post-filtered results by synthesising them on each line of each image couple assuming a parallelism of retinas, The vibration is then obtained by synthesising at time t the attitude differentials of the various couples in relation to a "not rigid" vibrations model.. This need of filtering through a model is paramount, this model depends on the satellite and its disturbances.

However, these data pertain only geometric aspects observable on images. First, microvibration frequencies above the correlation cut-off sampling frequency can never be corrected (Shannon theorem) and aliasing effects are possible. Second, because the method is based on expected (calculated) shifts between two images, the bias, drift, and VLF signals perturbing the system flight cannot be retrieved, as we would not be able to estimate if these observed signals, for example estimated on very long record length, are real or are coming from the measurements method itself. Third, if the differentials are not independent some frequencies are blind or heavily depreciated.

The processing is generic and will be conducted in 4 stages as shown in Figure 4.

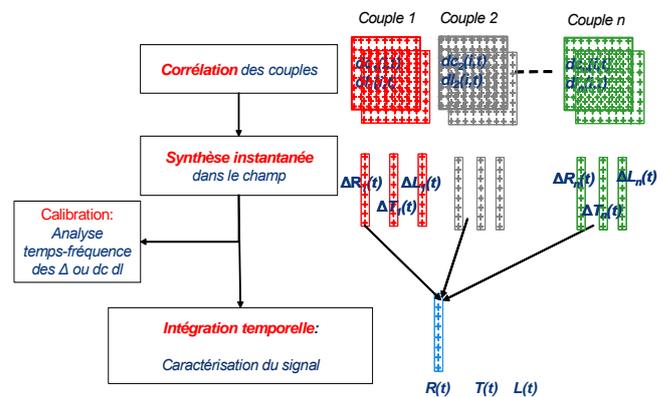


Figure 4. Algorithm flow for instability correction

The first step computes **co localisations** prediction (with or without MNT) and correlation masks to focus on the relevant points, then measures shift between images by **correlations**. It takes advantage of the various satellite retinas to increase the information at the same moment: it has several pairs of correlations. This first step gives, for each couple, n line-shift and n column-shift temporally sampled on each correlation line.

The following steps correspond to the heart of the system: the interpretation of these shift measurements and their transformation into attitude correction signals. First, the **instant synthesis** works on the shifts in the correlation line and obtains a roll and pitch differential  $\Delta R(t, \tau_j)$  &  $\Delta T(t, \tau_j)$  **in assumption that the two retina of couple are almost parallel and separate of  $\tau_j$** .

Second, the **temporal integration** of the attitude differentials estimates the absolute value of the disturbance at each correlation line. In the overall process, it is defined as a plug-in which depends on the satellite and available disturbances. Several methods are possible, they must be robust to inputs gaps and noise. A local innovative method has been developed with **assumptions** that the vibrations are PHR system-like: **quasi harmonic signals and almost stationary with homogeneity of differential (same convolution, spatial orientation...)**.

An iteration is possible in order to improve the accuracy of the results, taking into account the estimated vibration to refine the instant synthesis and compute again the correction signal.

The disturbances dynamic calibration is carried out systematically during in-flight commissioning and is monitored after. This calibration is not part of the chain but these results are used as parameters for the second step.

Complementary processes are possible but are largely specific: they consist in deducing the attitude correction signal for the other retinas from those calculated by local integration.

### 3.2 Method of local integration

The goal of this method is to compute correction attitude profiles  $\Delta x(t)$  from measurements of several differential attitude. It works independently on roll and pitch.

The mains issues are :

- ⇒ The differential are sampled with gaps and noise.
- ⇒ The sought signal is complex: for example with 4 noisy exciting frequencies, 2 noisy main harmonics and 6 secondary
- ⇒ Instability of the signal models: the exciting frequencies are slightly variable in time, and the drift is not linear.

So a local calculation, combining several differentials is very efficient to overcome this issues and to obtain accurate results.

#### 3.2.1 Principles of the method

##### On a stationary harmonic signal

At a time  $t$ , a signal composed of  $n$  harmonic stationary pulses can be expressed as a linear combination of  $2 \times n$  differential. Indeed the disruptive signal and the couple  $\tau_j$  differential can be written

$$\begin{aligned} x(t) &= \sum_{i=1}^n \frac{a_i}{2i} \left( e^{i(\omega_i t + \phi_i)} - e^{-i(\omega_i t + \phi_i)} \right) \\ &= \mathbf{a}^H \cdot \mathbf{v}(a, \boldsymbol{\omega}, \boldsymbol{\phi}, t) \end{aligned} \quad (2)$$

Where  $\sin(t) = \frac{1}{2i}(e^{it} - e^{-it})$ ,  $i^2 = -1$  et  $\mathbf{a}^H = (1 \dots 1)$

$$\mathbf{v}(a, \boldsymbol{\omega}, \boldsymbol{\phi}, t) = \begin{pmatrix} \frac{a_1}{2i} e^{i(\omega_1 \tau_1 + \phi_1)} \\ \vdots \\ \frac{a_n}{2i} e^{i(\omega_n \tau_n + \phi_n)} \\ -\frac{a_1}{2i} e^{-i(\omega_1 \tau_1 + \phi_1)} \\ \vdots \\ -\frac{a_n}{2i} e^{-i(\omega_n \tau_n + \phi_n)} \end{pmatrix}$$

$$\text{So } \Delta x(t, \tau_j) = \boldsymbol{\beta}(\boldsymbol{\omega}, \boldsymbol{\tau}_j)^H \cdot \mathbf{v}(a, \boldsymbol{\omega}, \boldsymbol{\phi}, t) \quad (3)$$

Because

$$= \sum_{i=1}^n \frac{a_i}{2i} \left[ \left( 1 - e^{-i\omega_i \tau_j} \right) e^{i(\omega_i t + \phi_i)} - \left( 1 - e^{i\omega_i \tau_j} \right) e^{-i(\omega_i t + \phi_i)} \right]$$

Also for several differentials, the linear formula between differential and sinus base is :

$$\begin{pmatrix} \Delta x(t, \tau_1) \\ \Delta x(t, \tau_2) \\ \vdots \\ \Delta x(t, \tau_m) \end{pmatrix} = \begin{pmatrix} \boldsymbol{\beta}(\boldsymbol{\omega}, \boldsymbol{\tau}_1)^H \\ \boldsymbol{\beta}(\boldsymbol{\omega}, \boldsymbol{\tau}_2)^H \\ \vdots \\ \boldsymbol{\beta}(\boldsymbol{\omega}, \boldsymbol{\tau}_m)^H \end{pmatrix} \cdot \mathbf{v}(a, \boldsymbol{\omega}, \boldsymbol{\phi}, t) = \mathbf{B}(\boldsymbol{\omega}, \boldsymbol{\tau}) \cdot \mathbf{v} \quad (4)$$

So if we have  $m$  differentials with  $m=2*n$  and  $\mathbf{B}$  invertible we obtain equation :  $|\det(\mathbf{B}(\boldsymbol{\omega}, \boldsymbol{\tau}))| \gg 0$

$$x(t) = \mathbf{a}^H \mathbf{v}(a, \boldsymbol{\omega}, \boldsymbol{\phi}, t) = \mathbf{a}^H \mathbf{B}(\boldsymbol{\omega}, \boldsymbol{\tau})^{-1} \begin{pmatrix} \Delta x(t, \tau_1) \\ \Delta x(t, \tau_2) \\ \vdots \\ \Delta x(t, \tau_m) \end{pmatrix}$$

$$x(t) = \mathbf{w}(\boldsymbol{\omega}, \boldsymbol{\tau})^H \cdot \Delta \mathbf{x}(t, \boldsymbol{\tau}) = \sum_{j=1}^{2 \times n} w_j \cdot \Delta x(t, \tau_j) \quad (5)$$

and the  $w_j$  coefficients depend on the frequency and time lags, not magnitudes nor phases.

##### On a quasi-stationary quasi-harmonic noisy signal

The methodology frees itself from previous assumptions by least squares approximation and regularization of the solution. First, we eliminate the secondary differentials according to weight values  $w_j$ , and secondly, we introduce into the simulation the knowledge of differential noise and all hidden variables (non-observable frequencies) and information on the harmonics noise, frequencies uncertainties, and on frequencies temporal variations. The sought signals may modeled following:

$$\hat{x}(t_k) = \sum_{i=1}^n (a_i + \varepsilon_a) \cdot \sin(\omega_i(t_k) \times t_k + \phi_i) \quad (6)$$

Where  $(a_i + \varepsilon_a)$  is the magnitude of the frequency  $\omega_i$ ,  $\varphi_i$  represents phase,  $\omega_i(t_k) = 2\pi \cdot (f_i + v_i(t_k) + \varepsilon_f)$ ,  $\Delta\hat{x}(t, \tau_j) = \Delta x(t, \tau_j) + \varepsilon_\Delta$ , where  $\varepsilon_a$ ,  $\varepsilon_f$  and  $\varepsilon_\Delta$  are random variables with zero mean and Gaussian distribution, with standard deviation  $\sigma_a$ ,  $\sigma_h$  and  $\sigma$  respectively, randomly chosen at each moment  $t_k$ , and where  $V_i(t_k)$  is the temporal drift of each frequency  $f_i$  and is not linear.

So we can compute the  $w_j$  coefficients by least squares:

$$\mathbf{w} = \mathbf{R}_{\Delta x}^{-1} \mathbf{r}_{\Delta x-dx} \quad (7)$$

with  $\mathbf{R}_{\Delta x} = E_t [\Delta\hat{x}(t, \tau) \cdot \Delta\hat{x}(t, \tau)^H]$  and  $\mathbf{r}_{\Delta x-dx} = E_t [\Delta\hat{x}(t, \tau) \cdot x(t)]$

The implemented method returns the main frequencies and takes into account the measurement noise. It does not require pre-processing of signals (such as Fourier transform). The sampling of the signal may be irregular or have some gaps but all the sampling differential must be synchronous.

It has no blind frequencies if independent differentials are combined. It requires, however, a pre-determination of the frequencies of disturbance, their maximum magnitudes, and an estimation of the differentials measurement noise. But this analysis is part of current assessments performed during in-flight commissioning. The accuracy can be increased using several sampling of the differential around the processed time step, like 2 or 3 for example. The results are better and more stable if the secondary differentials are removed from the equation 7 (according to the coefficients  $w_j$  weight).

### 3.2.2 Theoretical results

As example, with magnitudes of almost one pixel and the overlay of 8 disruptive harmonics signals of 4 stimulating very closed frequencies, with a non linear frequency drift (1%), with noises at 1 sigma of 1% on frequency and 1% on harmonics, 10% on amplitude, two main sought harmonics in the range of 50 to 78 Hz, with noise associated to the correlation of images, using three retina couples measurements sampled at 4 ms and only one local time sample, we get errors less than 0.064 pixel rms on the sought frequencies.

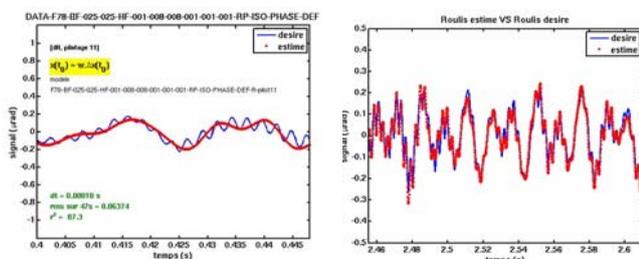


Figure 5. Example of results with MF sought on the left and HH on the right.

A lot of checking tests and sensibility analysis were conducted. The main results are very interesting. For a given set of  $w_j$  coefficients, bias on exciter frequency of 13% has no effect on performance. An error of + -33% on the values of harmonics has only little effect. The main characteristics of frequencies

can have random magnitudes, the process only restores magnitudes observed locally. Removing 3 exciter frequencies increases errors by a factor of 1.7. It is important to note that the noise is an important factor of the problem. The calibration coefficients  $w_j$  must take into account the measurement noise that are calculated for a minimum of 20 points per line correlation. The accuracy are decreased only with a factor of 1.16 on rms compared to a case without noise.

We can also increase the number of retrieved HF frequencies by decreasing the correlation step, like on Figure 5 right.

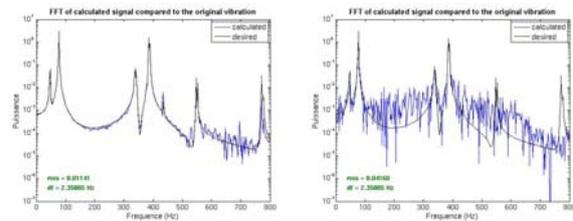


Figure 6. FFT on disturbance signal and retrieved signal only with three differentials and 7 local sampling, left: without measurement noise, right: with measurement noise.

With a sampling of 0.4 ms and only three differentials Figure 6 presents the sought signal and the retrieved signal after only one local integration. The local integration gives the signal with all the frequencies until 600 Hz.

### 3.2.3 Application to PHR data

In the PHR focal plane XS retina are not registered and almost parallel to each other and synchronized. The sampling time for XS retina is  $Te_{XS} = 0.4 \text{ ms}$  ( $f_{ech} = 2500 \text{ Hz}$ ). The XS maximum B/H ratio between B1 et B2 is 2.10-4 so DTM errors are under the correlation noise (altitude errors of 500m give displacement of about 0.1pixels  $Pan=0.025pXS$ ). The chosen couples for PHR is B2-B1, B0-B1, B2-B0, the most accurate for subpixel level image matching. This 3 couples give differential data about the 3 different delays, usable on PHR focal plane.

The Pan retina is a TDI detector with complex geometry, more distant from XS retina so the B/H ratio requires to use DTM for colocalisation and B2 is the better for image matching but not very efficient. So Pan is not useful for the correction computation heart.

The 4 gyroscopic actuators CMG are source of disruptive signals. The speed of AG will be adjusted to avoid resonating patterns of the satellite. But in-orbit before this adjustment, we will observe disruptive signals. They will be the sum of 8 harmonics (out of phase and noisy) of 4 excitatory frequencies, slightly variables over time. The PHR localisation budget is very accurate so the process have to correct the frequency between 16Hz and 110Hz. Figure 5 presents the disruptive simulated signal and the results.

As we see in chapter 4.1, the correlation cut-off sampling frequency is around 830 Hz (3 pixel XS). With a matching step of 1pixel XS the frequencies could be retrieved until this cut\_off frequency; with 3 pixel XS step, the retrieved frequencies are less than 410 Hz and with aliasing

(step=5pxXS =>f< 250). So we have to filter aliasing secondary frequencies.

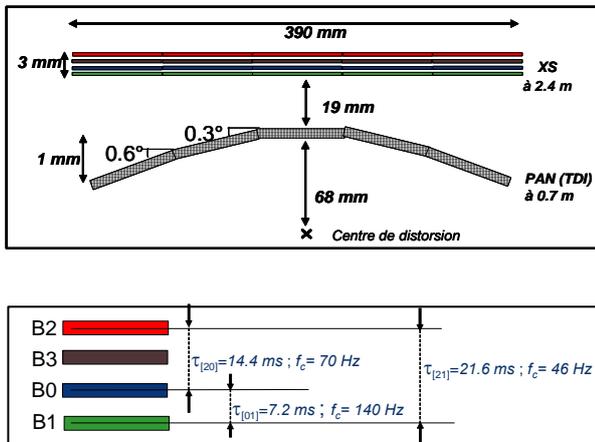


Figure 7: PHR focal Plane

The delays between the various couples aren't independent so there is some blind frequencies. We have the good luck that no harmonics are on this blind frequency and that the excitatory frequencies are variables over time.

### 3.3 Processing

#### 3.3.1 Colocalisation and correlation

On each retina couples, the processing computes colocalisation map (with an average altitude or with a DTM), and the effect of slight differences in roll and pitch to calculate the partial derivatives. Secondly it chooses the most relevant points for the correlation to avoid erroneous interpretations (sea and clouds) and to reduce the computing time, using a a-priori criterion built on HF radiometric local gradient (Delon, B.Rougé 2007). The need of the core process is 20 points for each line correlation of a couple. Then it computes the subpixel level image matching by similarity. For PHR we chose a correlation window of 3 pixels in line and 31 in column. For further processing correlation grids of different couples will be synchronous.

#### 3.3.2 Instant synthesis

First, displacements residues (filtered at 3 sigma) are computed with the best knowledge of attitude (eventually obtained by iteration with local integration). Second, on each correlation line and each couple, attitude errors differentials in the two directions (roll and pitch in the viewing referential) are fitted on residues by a weighted least-squares. These synthesis are performed in assumption that the two retina of couple are almost parallel and distant of  $\tau_j$

$$\left[ \begin{array}{l} dc(pt\_à\_t) = \frac{\partial c}{\partial R}(pt\_à\_t)\Delta R(t, \tau_j) + \frac{\partial c}{\partial T}(pt\_à\_t)\Delta T(t, \tau_j) \\ dl(pt\_à\_t) = \frac{\partial l}{\partial R}(pt\_à\_t)\Delta R(t, \tau_j) + \frac{\partial l}{\partial T}(pt\_à\_t)\Delta T(t, \tau_j) \end{array} \right]$$

An optional algorithm removes the TBF frequencies (less than 16 Hz) from this synthesis.

#### 3.3.3 Local integration

The goal is to calculate the correction attitude signal from several or one differentials. For PHR it implements the innovative approach (patent pending) of local integration by combining linear  $p \times k$  differential measurements ( $p$  couples shifts of the  $k$  samples around this time  $t_i$ ) for each moment  $t_i$ . So the inputs must be various differentials at the same instant of quasi harmonic signals and almost stationary.

Then the retrieved signal is interpolated and supplemented on areas where  $p$  couples lack information on the interval  $k$ . On the edges of holes we use the retrieved signal above and differential measures to avoid irrelevant extrapolation.

#### 3.3.4 Complementary Processing

This data processing is specific to PHR. The TDI PAN pixel date is the time of the last stage of integration and not of the middle. So the correction Pan signal must be out of phase with the correction XS signal.

In another hand, the PAN TDI retina is rather distant of the XS retina used by the correction calculation. A landscape hole viewed on XS retina at one time and an interesting landscape viewed on PAN retina can be simultaneous. And for this time no correction signal is available and the almost stationary disruptive signal does not allow extrapolation.

So the second step of this complementary process uses correlation between Pan and B2 retina (colocated on DTM) and the XS correction signal. It calculates by least square (like "Instant synthesis") the correction signal of the line image PAN, depending on the residue and correlation signal correction XS. This step is being developed.

## 4. RESULTS

A great number of simulation cases are checked, even on 2 different landscape and with various pilot conditions. The results are very accurate.

So taking the case of a disruptive signal with magnitudes of almost one pixel in each direction (roll & pitch) and the overlay of 8 disruptive signals which are composed of two main frequencies in the range of 50 to 80Hz, with a frequency drift of 0.2 to 1.1 %, a little frequency noise, a strong measurement noise associated to the correlation of images 0.17 pixels XS ( $\sigma$ ), using three retina couples measurements and six local time samples, with one iteration and a phase correction we get errors less than  $0.16 \mu rad = 0.04$  pixel XS on 99.7% of the time (0.013pixel XS rms) on the worse direction ( $r \oplus t$ )

This processing does not allow not only to find the principal harmonics but also a part of the secondary as we can see in Figure 6.

## 5. CONCLUSION

The development of this process line for improving the geometric model attitude HF on the image required an important work. The processing gave results of unexpected accuracy and enabled a great improvement over our previous work. This treatment will be used operationally during Pleiades in-flight commissioning because of its robust behaviour on slightly random signals disturbances and lack of correlation.

This processing can be reused for other satellites. It will efficiently secure the geometric stability performance.

For some satellites, this security enables to give more choice for dynamics adjustment during satellite development: we can choose to minimize the VHF disturbance (elementary effect) even not optimizing the geometrical stability.

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