PLEIADES-HR IMAGING SYSTEM: GROUND PROCESSING AND PRODUCTS PERFORMANCES, FEW MONTHS BEFORE LAUNCH

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ABSTRACT:

Pleiades-HR is the highest resolution civilian earth observing system ever developed in Europe. This optical imaging project is conducted by the French National Space Agency, CNES. It will operate two satellites designed to provide optical images to civilian and military users. The first satellite is ready for launch, the second 18 months later. It will allow, in Nadir acquisition conditions, to deliver image products 20 km wide, false or natural coloured scenes with a 50 cm ground sampling distance.
Imaging capabilities have been highly optimized in order to acquire, in the same pass, along-track mosaics, stereo pairs and triplets, and multi-targets. To fulfil the operational requirements and ensure quick access to information, ground processing has to automatically perform the radiometric and geometric corrections. Since ground processing capabilities have been taken into account very early in the mission development, it has been possible to relax some costly on-board components requirements, in order to achieve a cost effective on-board/ground compromise.
Starting from a Pleiades-HR system overview, this paper gives a quick description of the ground segment functional breakdown and focuses more precisely on the image processing and associated products. The geometric accuracy is evaluated and the excellent results obtained are presented.
Finally the paper presents the ground segment architecture that will handle this “heavy” processing in the different operational Centres.

1. 1. INTRODUCTION

Pleiades-HR, the high resolution optical earth observing mission developed for both civilian and military users, is under qualification tests in CNES and ASTRIUM premises. This project consists of two agile satellites that will provide high resolution images in Panchromatic (PA) and Multi-Spectral (XS) modes with a 50 cm ground sampling distance. This system, build up in a European context (partnerships with Spain, Sweden, Belgium, Austria and Italy), will be operated in a dual context with civilian and defence users.

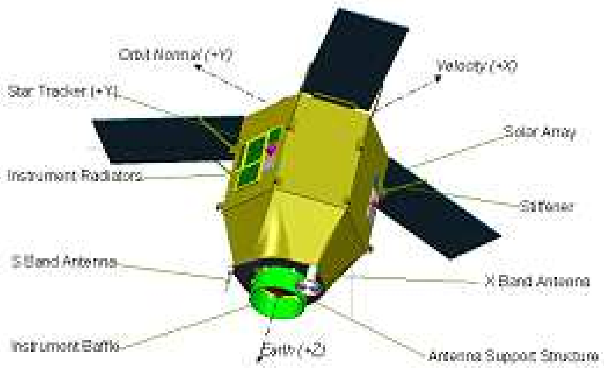

Figure 1: Pleiades-HR satellite

Imaging capabilities have been highly optimized in order to acquire several targets, in the same pass, allowing along-track image-mosaics, stereo pairs and triplets. To fulfil the operational requirements and ensure quick access to information, ground processing has to perform automatically radiometric and geometric corrections.
First, this paper offers an overview of the image processing system and the products definition. Then the main system products are detailed and their quality assessed. Finally, the image processing architecture is briefly presented.

2. FROM SYSTEM TO PRODUCTS DEFINITION

2.1 Overview

From a ground segment point of view, Pleiades-HR architecture is defined as a classical “image-mission” loop: the User Ground Centres (also called UGCs; there are 3 different UGCs: French and Spanish Defence UGCs and French Civilian UGC) gather the different users acquisition requests, optimizing the satellite resource, and prepare the dual work plan which is finally sent by the Control Centre to the satellite, 3 times per day. After sensing, the acquired data-strips are downlinked over the receiving stations (with respect to the work plans) and the image telemetry is automatically inventoried and archived in each UGC.
Then, each UGC manages the image production requests coming from authorized users and process accordingly the archived telemetry to generate the requested product. The delay between the end of the reception and the product delivery is less than one hour.
The ground processing has also been designed to be highly interoperable; to allow federations with other earth observation systems in the GMES context. Hence, data format (catalogued

data, final image product) and data access services (online catalogued data browsing, product ordering) definitions have been major issues (Baillarin 2006).
The UGCs, including the image processing algorithms, have successfully passed system tests and are now fully integrated and ready for operations.

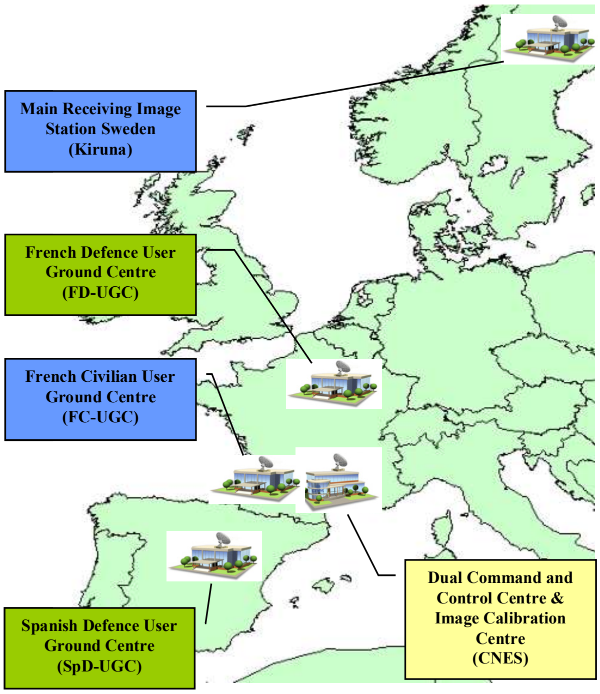

Figure 2: Pleiades-HR Ground Segment

A light version of the UGC, with image reception and production capabilities, is also available for any foreign users willing to receive and produce Pleiades-HR images (e.g. Kiruna Station).

2.2 Image products

Several types of products have been defined in order to fulfil the user needs considering that the remote sensing community is generally divided in two groups:
Users needing data for mapping purposes or using Geographic Information Systems (GIS), whatever the sensors characteristics. They usually use ortho-image products, which are resampled into cartographic projections and corrected from sensor and terrain distortions.
Users wanting to process "raw data" in order to deliver value-added products (such as 3D, geophysics data, …) using their own methods. They need comprehensive ancillary data to compute the geometric model. Because of the specific geometry of Pleiades-HR focal plane (Kubik 2005), a "Sensor Level" product has been defined making the geometric model simpler while preserving its accuracy.
Hence, two processing levels have been defined in addition to the classical raw levels. They are presented and assessed here after.

2.3 Sensor Level

The Sensor Level product corresponds to the image that would have been delivered by a perfect standard push-broom sensor. The product is only corrected from on-board radiometric and geometric distortions (viewing directions and high frequency attitude variations), but no ground projection is operated. All multispectral (XS) and panchromatic (PA) pixels are registered.
XS can be PAN-sharpened in the same processing flow to obtain a 0.50 m GSD 4-band colour image (blue, green, red, near infrared).
This product can be accurately located by rational functions: in addition to Pleiades-HR physical model, metadata contains direct and inverse location models that can be used by commercial software.

2.4 Ortho-image and Mosaic Level

The Pleiades-HR ortho-image is resampled into a cartographic projection and corrected from sensor and terrain distortions.
This product must be very precisely located to be used into geographic information systems (GIS). Product location is checked on an accurate DEM (Reference3D™, if available) with automatic GCPs (algorithm based on (Baillarin 2004)]). Users can also give their own DEM for ortho-rectification. The final product contains associated quality metadata.
Pleiades-HR ortho-images can also be PAN-sharpened to obtain a 0.50 m GSD 4-band colour image.
Mosaics products are larger size ortho-images, automatically processed as a seamless patchwork of individual strips. This is made possible thanks to the high agility and the precise pointing capability of the platform. The strips are all converted is same geometry, using automatically computed tie points and ground control points, then radiometrically homogenised, then joined together using computed stitching-line.

3. SIMPLIFYING THE FOCAL PLANE: THE "SENSOR" PRODUCT

The complexity of the Pleiades-HR focal plane makes the classical level 1 product difficult to use. A new product level called "Sensor Level" is proposed (De Lussy 2006).
This Sensor Level product consists in a basic product specially designed for the photogrammetric community and delivered with a physical model and a rational function model.

The purpose is to generate the image which would have been acquired by a simpler push-broom sensor (SPOT-like) in the same imaging conditions in order to be able to exploit the geometric characteristics of the image (such as DEM or 3D extraction) without having to take into account the complex geometry of the real sensor.

3.1 Perfect Sensor Geometry

Due to the complexity of the focal plane (mainly because of the detector layout composed of five slightly tilted TDI arrays for the PA and five CCD arrays for each XS band), the raw products should be considered as 25 different products with their own geometrical models.

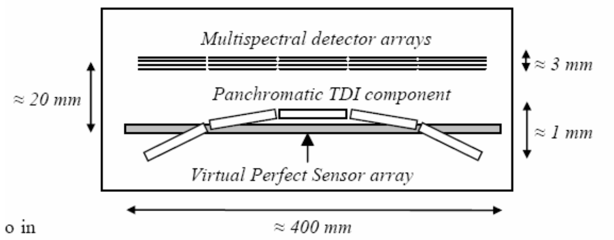

Figure 3: Focal plane layout and location of ideal array

In order to greatly simplify the use of sensor model, the Sensor Level product simulates the imaging geometry of a simple push-broom linear array, located very close to the PA TDI arrays. Besides, this ideal array is supposed to belong to a perfect instrument with no optical distortion and carried by a platform with no high attitude perturbations. This attitude jitter correction (made with a polynomial fitting) allows both for simple attitude modelling and more accurate representation of the imaging geometry by the rational functions sensor model (see further).

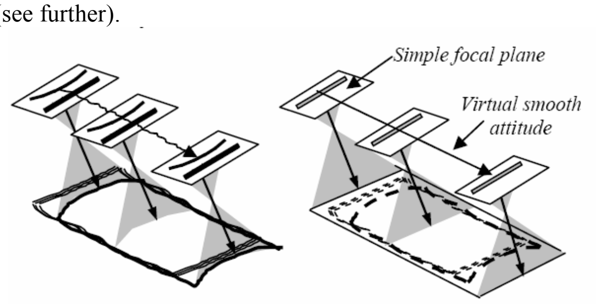

Figure 4: Perfect Sensor Geometry

3.2 Processing and image quality

The production of this ideal linear array imagery is made from the raw image and its rigorous sensor model.
The raw image is resampled into the Sensor Level geometry taking into account a DEM. The direct geolocation is made with an accurate Sensor Level geometric model. Thus, Sensor Level image and its geometric model are consistent. The impacts of the above processing on the geometric accuracy of the resulting products have to be significantly small (errors less than centimetres). These errors are due to:

- The quality of the resampling process,
- The accuracy of the DEM used (generally SRTM DTED1).

To obtain the best results:

- Resampling process is made with a highly accurate method (using spline interpolators (Unser 1999)),
- The DEM is pre-processed in order to minimize the relief artefacts due to errors and/or blunders.
- The geometric model differences between raw image and Sensor Level (especially attitude and detector model) are minimized to decrease the parallax and the altitude error effects.

Hence, the quality of a Sensor Level image is mainly linked with the quality of the corresponding raw image (the geometric budgets are detailed in (De Lussy, 2006)). The only remaining difference is due to the little parallax between Sensor Level model and Real sensor (less than 80µrad) combined to a uncertainty of the DEM. In term of location accuracy, the difference between Sensor Level images and real sensor images is less than 3.10-3 according to the SRTM 30m accuracy at 99.7%.

3.3 Accuracy of Sensor Level geometric model

The geometric modelling refers to the relationship between raw pixels in the image and geographic coordinates on ground. The Sensor Level product is delivered with two geometric models:

- a “rigorous sensor” model
- a rational function model

Users can choose either the rigorous sensor model, or the rational function sensor model: results are very comparable.
On one hand, the rigorous sensor model is defined from a complete set of parameters of the image acquisition:

- alignment and focal plane characteristics (linear array)
- image time stamp
- smoothed attitude and ephemeris time tagged

Such rigorous models are conventionally applied in photogrammetric processing because of the clear separation between various physical parameters and so, easier to use in block adjustments (refinement using GCP).
On the other hand, the Rational Function Model, RFM, is an approximation of the rigorous sensor model. It allows full three-dimensional sensor geolocation using a ratio of polynomials (Tao 2001), using a standardized and very simple relationship between raw pixels and geographic coordinates.
The RFM is able to achieve a very high accuracy with respect to the original rigorous sensor model. Accuracy assessment shows that RFMs yield a worst-case error below **0.02 pixel** compared with its rigorous sensor model under all possible acquisition conditions.

Therefore, when the RFM is used for imagery exploitation, the achievable accuracy is virtually equivalent to the accuracy of the original physical sensor model: the 0.02 pixel (1.4 cm) difference between the two models is an order of magnitude smaller than the planimetric accuracy and is therefore a negligible error. The RFM fully benefits from the pre-processing applied to generate the Sensor Level product (removing high frequency distortions) allowing rational functions to precisely represent this smooth geometric model. RFM can be used as a replacement sensor model for photogrammetric processing.

4. ORTHO-RECTIFIED PRODUCTS PERFORMANCES

The other set of products made available by the Pleiades-HR system are the ortho-images (and ortho-mosaic) products.
These products are ortho-rectified thanks to an accurate DEM (Reference3D™ if available, or a DTED1 System DEM by default). They are then easily usable with GIS as map products.
The ortho-rectification processing takes advantage of the high location accuracy of Pleiades-HR: 14 m probable (90% of the images) and up to 25 m maximum (99.7% of the images) of circular error.
For multi-temporal registration, it will also be possible to register the ortho-image to a reference image (Reference3D™ database). Even if this processing won’t increase the location accuracy, it shall guarantee a perfect multi temporal registration between images.
The method is detailed in (Baillarin 2004). It is composed of three independent steps:
1) Image and reference setup in the same geometry using a raw location model,
2) Image mis-registration measurements, using an automatic and generic process,

3) Location models improvement using a space-triangulation process and model parameters correction, including a possible DEM refining.

Moreover, thanks to the high agility and the precise pointing capability of the Pleiades-HR platform, it will be possible to acquire several successive adjacent strips within a unique pass over a targeted area.

Thus, the Pleiades-HR ortho-mosaic product will provide end-users with an image of larger size, as being the result of a seamless patchwork of individual strips. The output coverage may reach up to 10 000 km² and even more, according to the length of the neighbouring strips and the tolerated B/H ratio between acquisitions.

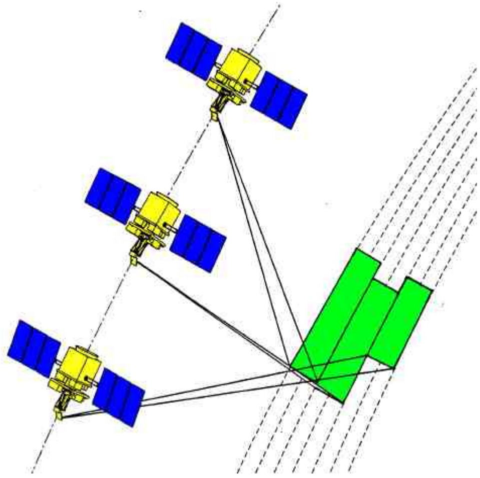

Figure 5: Pleiades-HR agility and mosaïcking capability

The automatic mosaicking process relies on two geometric refining phases (as described above). The same method is used for:
Phase 1: Absolute refining of each data strip location model using Reference3D™ data.
Phase 2: Relative and finer improvement of location models using overlapping areas of adjacent strips (350m to 3.5km) and Reference3D™ DEM. The evaluation has been done using aerial images simulating Pleiades-HR acquisitions and the results were excellent. Thanks to the first phase, the absolute accuracy is less than 2.5m (0.5 Reference3D™ pixels). The second phase refines the relative model with respect to the very high resolution of the acquisition (<0.5 pixels HR).
This product represents the successful realization of the Pleiades-HR mission since it takes advantage of the main characteristics of the system: agility and high location precision. The automatic mosaicking process relies on automatic tie point selection (Baillarin 2004) and geometric models refining phases followed by local radiometric homogenisation and stitching phases (seam-less line computation).

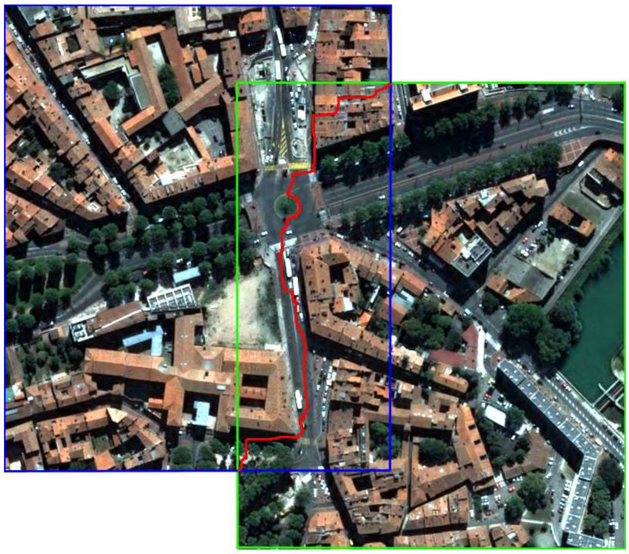

Figure 6: Pleiades-HR mosaic (and stitching line)

5. CONCLUSION AND OUTLOOK

The Pleiades-HR image processing is very complex (about 50 times more complex than SPOT5) and therefore time consuming, especially for geometric corrections. Nevertheless, a ground processing unit has been successfully developed to handle up to an average of 200 products a day for the main civilian UGC in Spot Image premises. Based on a multi-clusters architecture (IBM Blade Center™) linked by high speed Fibre Channel to a Storage Area Network, the Pleiades-HR infrastructure is highly scalable for the different centres needs (including local receiving stations). In particular, for emergency needs, pan-sharpened ortho-rectified products (20x20km²) are processed in less than 45mn and mosaic products (60x60km²) in less than 140mn.

The realization of the Pleiades-HR ground segment is once more the opportunity to demonstrate that a global optimization of the system from board to ground design must be considered in order to relax requirements of on-board architecture and lower the overall cost of the mission.

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