

PREPARING THE USE OF PLEIADES IMAGES FOR MAPPING PURPOSES: PRELIMINARY ASSESSMENTS AT IGN-FRANCE

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ABSTRACT

The Pleiades system, of which the first platform of the constellation shall be ready for launch in early 2009, is the new generation of high resolution optical sensor satellites developed by CNES, the French space agency. With its ability to provide photogrammetrists with instantaneous colour image stereo-pairs of 20km swath and 70cm resolution acquired with B/H ratios ranging from 0.15 to 2, the very agile and precisely pointing Pleiades platforms should open in many countries a new era for the updating of high scale maps, by probably avoiding heavy aerial survey campaigns in many cases. In the framework of a cooperation agreement between CNES and IGN-France (IGN-F), designed to prepare an operational use of these images, several experimentations and simulations are being carried out, in order to verify the ability of the system to fulfill the technical and operational requirements of the map-making processes, in comparison with those presently based on digital aerial photography. Among others, present studies particularly focus on :

- the geometric and radiometric quality assessment of the planned system products (sensor level, orthoimages and mosaics).
- the capacity assessment of the Pleiades constellation to meet the IGN-F cartographic mission needs in terms of image volume for the coverage of the national territory, whether in monoscopic or stereoscopic mode.
- the potential of stereo- and three-fold stereoscopic image simulations for the extraction of buildings in 3D, after adapting algorithms primarily dedicated to higher resolution aerial images.

After an overview of the main characteristics of the Pleiades system, the paper aims at presenting the first results of these studies, which will be of great importance, together with the economic side, in the decision process of IGN-F to transfer, or not, part of the supplying of fresh images from the aerial source to the satellite source.

1 INTRODUCTION

One of the missions of IGN-F, the French Mapping Agency, is to ensure an orthophotographic coverage of the whole national territory, according to a recurring rate of less than 5 years. In order to optimize public funding and to better answer growing demands for up-to-date geographic data, IGN-F is actually assessing the technical potential and the economic conditions for a dedicated use of submetric resolution satellite data, such as Pleiades imagery. In this respect, a comprehensive partnership with CNES, the French Space Agency, has been recently agreed to prepare the arrival of Pleiades images into IGN-F acquisition and production lines by 2009. In this article, after an overview of the Pleiades system products, we present results of two studies, one assessing the coverage capability of the satellites to cover France under various geographical and temporal constraints including cloud cover, viewing angle conditions and renewal hypothesis, the other assessing the 3D potential for semi-automatic retrieval of building roofs with the pre-operational 3D city models processing framework of IGN-F.

2 THE PLEIADES SYSTEM: A QUICK OVERVIEW

2.1 A system well suited for mapping purposes

The Pleiades system, designed by CNES, is developed by the French space industry with a contribution of several European countries. The first satellite shall be ready for launch by early 2009, a second one following one year later. Placed on the same sun-synchronous orbit at 694 km, these 2 satellites will acquire image strips of 20 km swath width, combining acquisitions in panchromatic band at 70 cm resolution (when nadir pointing) and in 3 visible (blue, red, green) and IR bands at 280 cm resolution, further merged into colour products. The very high agility of the satellite platform as a whole (see Fig. 1) makes possible various acquisition plans, such as a monoscopic cover up to 100x100 km or a stereoscopic instantaneous cover up to 60x60 km. Over the french metropolitan territory, this agility makes it possible, within a single pass of the satellite, to cover one or two administrative units of 5000 to 10000 km² each, or to cover several big cities in three-fold stereoscopic mode. Concerning the ground location

accuracy of the images, the specification has been set to 12 m for 90% of the images without Ground Control Points (GCP).

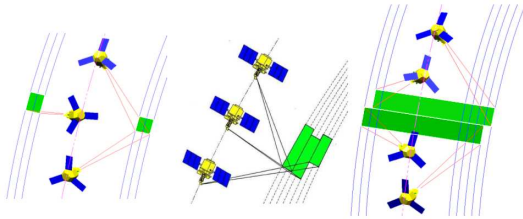


Figure 1: The very high agility of the satellite platform.

2.2 Product levels delivered by the system

The ground segment is being sized to produce daily up to 200 products, whether it be single images 20x20km or big mosaics. All products provided by the system to the users will be processed automatically, whether from panchromatic band or by merging original bands into the desired colour composition (natural colours or false colours). Panchromatic and colour merged products will be delivered at 50cm ground sampling distance. The 3 product levels are the following :

- a *sensor* level , resulting from the correction of on-board systematic distortions and attitude variations of the platform ; this product is specially dedicated to photogrammetric use ;
- an *orthoimage* level, resulting from the correction of terrain distortion with a standard DTM and geocoding of a single image strip into a geographic reference system ;
- an *orthomosaic* level, resulting from of seamless assembling of individual strips and geocoding as above.

Concerning the orthomosaic, the product specifications only concern a one-pass set of image strips, acquired under restricted angle conditions still to be confirmed by benchmarking :

- An off-the-shelves DSM (**Reference3D®** or improved **SRTM**) shall correct image distortions due to the topographic surface ;
- relative geometric distortions shall be less than 1 pixel along the connecting line ;
- local and global radiometric discrepancies should be minimized, keeping in mind that lightening conditions may produce non rectifiable effects on building facades.

To achieve the best possible radiometric and geometric quality, the main methods designed by CNES are the following :

- refining by space triangulation the initial *sensor models* therefore, an iterative matching process, helped by the local DSM data, shall select reliable homologous points inside the overlapping zones of each image pair ;
- refining local altimetric accuracy of the external DTM in overlaps ;
- determining radiometric look-up-tables grids in order to harmonize the radiometric rendering ;
- computing seam lines between the adjacent orthorectified strips

It should be noticed that several softwares or algorithms selected by CNES come out of aerial photo production lines operated and maintained by IGN-F on its own.

3 IGN-F EXPECTATIONS CONCERNING PLEIADES

The civilian mission assigned by CNES to Spot Image company, the pre-qualified image provider, is two-fold : meet the public sector requirements in France and Europe, under special rates covering merely operating charges, and the private sector needs in general, on a commercial rate basis. At present and on a long-term contract basis with IGN-F, the French state widely grant-aid both the aerial digital acquisition and the 50 cm sampled colour orthophoto layer production (**BD Ortho®**), thus considering the systematic image coverage of the national territory at 50 cm resolution as a patrimonial and general service of interest. Therefore, the charged rate per km² for a usage license is actually much lower than the commercial rate of the present US sub-metric image standards. In this context, the IGN-F choice to be or not one of the customers of Pleiades images by 2009 deadline widely depends both on their price and on a continuous and secure supplying capacity from Spot Image, the company in charge of image distribution. These questions are now being discussed in a joint team from CNES, Spot Image and IGN-F. Let's now focus on the technical assets of Pleiades for IGN-F future missions.

3.1 Assessment of Pleiades potential for the IGN-F missions

While achieving by 2007 its national mission to equip the French territory with an exhaustive and homogeneous digital cartographic reference (Référentiel à Grande Echelle = **RGE®**) at 1m location accuracy in XYZ , IGN-F is presently setting up working teams and information collecting processes for the updating of the various layers of the **RGE®** :

- renewal of the orthophotographic layer (**BD Ortho®**) every 5 years at least ;
- continuous updating of the topographic database (**BD Topo®**), with constraints to display all infrastructure and building features aged of more than a year.

In parallel, IGN-F is already thinking about how to answer emerging or insufficiently met needs from 2007 on, under economic constraints, such as a growing demand for always better renewed image covers or 3D urban models. At present, the Pleiades high revisit potential is seen as a complementary source of the IGN aerial photo task force ; indeed, the satellite data could make shorter in time the renewal of rapidly evolving areas (suburban) or environmentally sensitive areas (coastal, plains subject to floods). In this respect, Pleiades acquisitions might contribute to :

- the achievement of a renewal of the **BD Ortho®** layer on a 3 year basis, with constraints related to the season (summer preferable) and the trimming (administrative units)
- the *image monitoring* of specific areas (coasts, suburbs, flood plains) for early warning purposes
- the checking process of **BD Topo®** or **BD Alti®** releases, as a comprehensive and external data source.

3.2 Some technical and operational issues

In relation with above, the first issue concerns the Pleiades acquisition capacity that can be devoted to IGN annual cover needs over the national territory (see first results in the next section), in conjunction with other recurring needs such as crop monitoring or land use updating, which actually do not fall into IGN-F missions. However, since steady renewing of covers may contribute to several applications, compromises may be found somehow. An other issue is linked to the intrinsic image quality, in terms of information radiometric content : what can be seen in colour images at 70cm to 1 m resolution (30° off nadir) when the original colour information is acquired at four times lower resolution ? In this respect, the first simulations provided by CNES (on Fig. 2 50cm sampled pan-sharpened XS) show a quite compliance with the image quality of digital orthophoto acquired at 70cm for the **BD Ortho®** and seem even of better MTF than Pan-sharpened QuickBird images. Anyhow, IGN-F intends to inquire among a panel of present users of the **BD Ortho®** in order to confirm this point.



Figure 2: 50cm sampled pan-sharpened.

The intrinsic geometric coherence of images is also an acute issue. CNES has put an internal dispersion specification of

maximum 1 pixel for a 80 km long strip. This figure is actually compliant with **BD Topo®** and **BD Ortho®** geometric specifications. The absolute location accuracy without GCP, presently specified at 12m at 90%, could be improved in the facts to a much better figure, according to the first assessments. The actual planned performance shall highly simplify the space triangulation process in terms of computing time, since less GCP will be necessary. Finally, the potential of two-fold and three-fold stereoscopic acquisitions is also to be investigated. First results with aerial simulations over Toulouse and Amiens are shown in chapter 5.

4 ASSESSMENT OF THE ACQUISITION CAPABILITY OF PLEIADES OVER FRANCE : FIRST RESULTS

4.1 The CNES simulation tool for Pleiades image programming

CNES develops and maintains an image programming simulation tool. Programming demands can be put on specific geographic sites over a defined period of time. These demands, either monoscopic or stereoscopic, are analyzed according to orbit availability, swath, platform tilting capability. After a classification into individual mesh, a programming plan is elaborated according to meteorological forecast, surface to be covered, angular constraints and acquisition priority. Several plans can be merged, for instance put by a customer in mapping, a customer in agriculture, etc. Downloading constraints are also taken into account in the programming cycle. For our study, we got fully support from CNES for the implementation of the simulator.

4.2 Elaboration of scenarii for the RGE® image providing

We only present here two scenarii over France, both taking into account IGN needs and also estimated annual demands of other applications than topographic mapping, resulting from provisional investigations done by Spot Image for Pleiades thematic needs and kindly provided for our study, actually including mainly agricultural monitoring (multitemporal spots to be observed in spring-summer), coastal follow-up and response to natural hazard.

The first scenario aims at assessing the time delay required for the cover of the whole metropolitan territory with 2 satellites according to specifications close to the ones of the present **BD Ortho®** acquisitions, but without the constraint to cover administrative units at once, for which the satellite orbit configuration is not so appropriate as can be aerial photo dedicated flight plans. The territory, of approximately 540000 km², is divided into 216 mesh of 20x60 km, to be covered without clouds and according to 3 geometric conditions (see results in Fig. 3) :

- angles less than 30°
- angles less than 15°

- one pass 60 km² acquisition and angles less than 15°

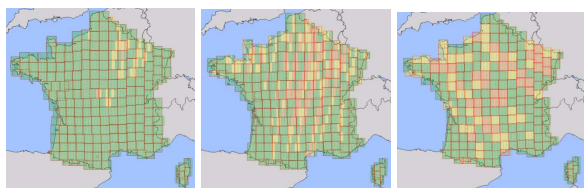


Figure 3: at left angles less than 30° IGN=95% SpotImage=35%, on center angles less than 15° IGN=68% SpotImage=37%, at right angles less than 15° one-pass IGN=62% SpotImage=41%.

A second scenario covering a 3 years period has been set up, based on the following an hypothesis for IGN-F image comprehensive needs over the national territory by the years 2010 (see Fig. 4) :

- the 60 cities of more than 100,000 inhabitants should be covered every year in monoscopic mode, as an one-pass 60 km² shot area ;
- the 90 towns or urban districts of more than 50,000 inhabitants should be covered once every 3 years in stereoscopic mode (30 towns per year), in order to help them update their own cartographic database ;
- the rest of the metropolitan territory should be covered within 3 years

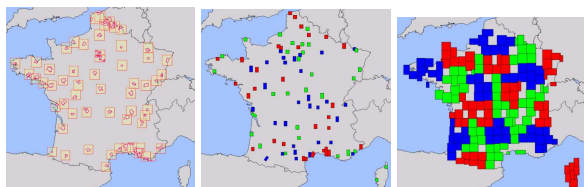


Figure 4: at left cities with more than 100,000 inhabitants, on center towns with more than 50,000 inhabitants, at right rest of the metropolitan territory

4.3 Results

In the first scenario, we only had at our disposal meteorological data on a statistical basis, i.e. data compiled from 10 years observations at low resolution (50 km). Let's call it climatic data. In the second scenario, we got the opportunity to retrieve recently acquired and archived data by Météo-France for the year 2004, consisting of real nebulosity data observed with a 7x11 km² resolution, of which we could select forecast cloud cover maps 27 hours and 3 hours before the satellite pass at 10 a.m. local time (see an example of 2 cloud cover forecast maps over Western Europe in Fig. 5). These two sets of data have been respectively used for the programming plan and the validation plan of the simulation process. We tried to do our best to optimize the 5 months duration of the study, but we could not play the first scenario with both meteorological data, but only the second one. Due to time constraints, we only

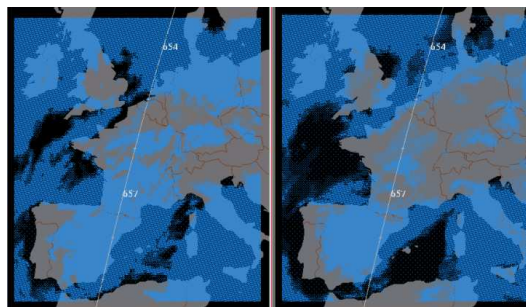


Figure 5: Forecast cloud cover data 27h and 3h before satellite pass

could play the second scenario with both meteorological data types (climatic and observed).

In the first scenario (see results in Fig. 3), we can state that within one year, 95% of the French territory can be covered with 2 satellites and a 30° maximum angle, whereas approximately 2/3 of the territory with a 15° maximum angle, whether it be according to a 20x60 km or 60x60 km mesh. An other point is that the Spot Image demands are filled up to approximately 40%, whatever the IGN-F angular hypothesis.

In the second scenario (see results in Fig. 6), the planned program for the first year of IGN demands (from January to December) is achieved at 98% when putting climatic data as input, at 100% when putting real observed cloud cover. And this planned programme is even finished on the 6th of July.

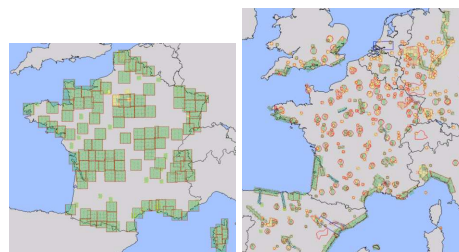


Figure 6: at left first year IGN demands (100% filled up), at right first year Spot Image demands (83 % filled up).

4.4 Conclusions and Perspectives

These results should be taken as a little optimistic, since the simulator tends to favour large covers (IGN-F demands) rather than the acquisition of small sites (agriculture monitoring). Furthermore, a one-shot success with 0% cloud cover is not realistic, a certain percentage of new acquisitions being necessary to fill up the hidden parts of the landscape. Anyhow, Pleiades seems to be a good candidate for the fulfillment of part of the foreseen acquisition requirements of IGN-F at mid-term. Further work should be done, in particular to tune up scenarii according to specific seasons, to extend the stereoscopic potential assessment to larger areas. The final objective of these studies is to evaluate the amount of IGN-F within the national comprehensive demand, in order to prepare a protocol for the sharing of the satellite resource over the country.

5 ASSESSMENT OF PLEIADES 3D POTENTIAL FOR BUILDING ROOFS RETRIEVING

The agility of the Pleiades system makes possible stereo and tri-stereo along the track acquisitions which is an essential feature for 3D image processing. This section presents the first results of a study on the 3D building reconstruction with Pleiades HR images. The potential of these stereoscopic images is evaluated with tests on tri-stereo image simulations with a 3D city models reconstruction framework designed by IGN-F. Two different areas have been used: one on Toulouse downtown and the other on Amiens downtown. These simulations have been processed from aerial images of the digital frame camera developed by IGN-F (Thom and Souchon, 2001). CNES-France has used the Modulation Transfer Functions (MTF) and the Signal to Noise Ratio (SNR) of the aerial images to calculate realistic radiometric simulations of images from the Pleiades system (see Fig. 8). On these two datasets a 3D city model has been produced in two contexts: with and without an initial 2D ground map (see Fig. 7). All these four 3D city models have been evaluated by comparison with 3D references.



Figure 7: 2D ground map on a building block



Figure 8: 80cm Pleiades simulation image (left) and 25cm aerial digital image (right)

5.1 Description of the fully reconstruction framework

The workflow of the platform is presented on Fig. 9. The DSM creation is the first step of the production line. The correlation process is presented in (Pierrot-Deseilligny and Paparoditis, 2006). Then a basic true orthophoto is processed. Afterwards the framework provides interactive tools to produce 3D city models. The operator can only edit the 2D ground footprints of buildings. Then from this 2D footprint all the 3D roof models are automatically produced through an automatic algorithm using a DSM. During this interactive process the operator can switch between the

DSM and a true orthoimage visualization to understand the scene.

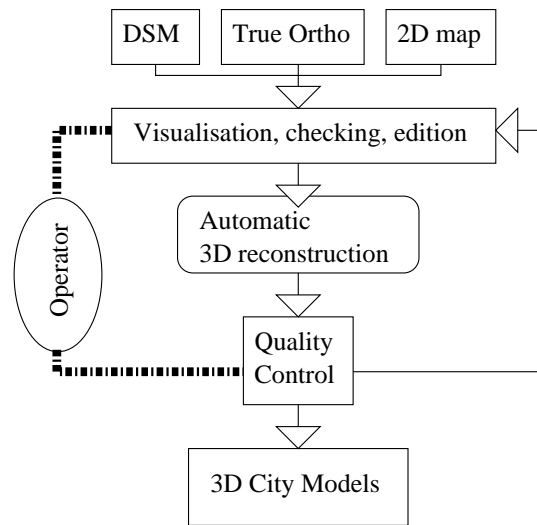


Figure 9: Reconstruction framework

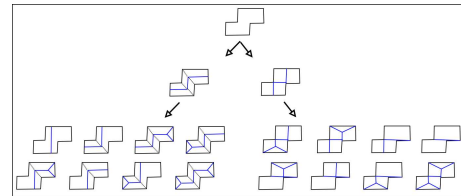


Figure 10: 3D roof shape hypotheses inferred from a 2D building footprint

The automatic 3D reconstruction is a model driven approach: for each building footprint several 3D roof shape hypotheses are inferred (Fig. 10). Each hypothesis is then fitted on the DSM, and the best scored solution is proposed to the user acceptance. More precisely, the hypotheses generation process is focused on flat roof, or building with a symmetric roof around a central ridge. Of course, it is a very restricted family of possible roof shapes, but with an appropriate 2D footprint preprocessing it is enough for precise and complete 3D city models (Fig. 12). Moreover, with this range of ground resolution (between 50cm and 1 m), it is necessary to use more constrained 3D building models to ensure a correct robustness. (Flamanc and Maillet, 2005) describes more precisely this reconstruction framework.

5.2 Results

Four quality indicators have been selected to evaluate 3D city models produced in the different contexts :

- Productivity: the time consuming cost per km²
- Exhaustiveness : estimated with the ratio of reference buildings surface covered in the reconstructed model
- Level of details : roughly estimated with the number of 3D roof facets per km²

Areas	Productivity h/km ²		Exhaustiveness %		Level of details 3D roof facets/km ²		Accuracy m (% of outlayers)	
	with 2D map	without 2D map	with 2D map	without 2D map	with 2D map	without 2D map	with 2D map	without 2D map
Amiens Centre Ville triplet 70 cm	8.7	12	90.1	80.4	7109	3940	0.9 (5)	1. (4.7)
ATS2B triplet (-6°,0,+6°) à 80cm	5.3	6.8	88.6	70.9	4690	2372	1.4 (3.3)	1.3 (3.)

Figure 11: Results on the two datasets with and without a 2D initial ground map.

- Accuracy: estimated with the RMS on the height differences between the produced 3D city models and the references after outlayers filtering with a 3xRMS threshold.

Results on the two datasets with and without an initial 2D ground map are presented in Fig. 11, and Fig. 12 show an overview of the 3D model on Amiens. The very first important point to notice is that these satellite tri-stereoscopic images can be used to produce metric 3D city models. Nevertheless, the two datasets are small and, as in all the interactive process, results depend on the operator who produces. So, global trends have to be considered rather than the exact values done by these indicators. The two main conclusions of this evaluation are: the height accuracy is metric, and the use of a 2D ground map improves a bit the productivity, but above all the exhaustiveness and the level of details.

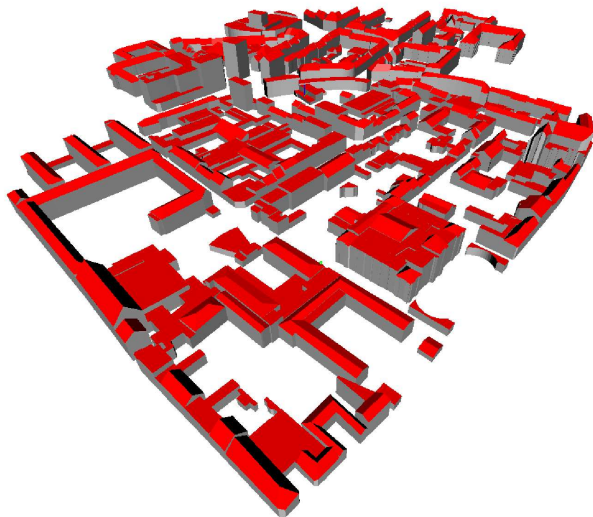


Figure 12: 3D Model from Pleiades tri-stereo simulations and a 2D map on Amiens.

6 CONCLUSION

We have presented in this paper how the french mapping agency (IGN-F) prepares the use of Pleiades images. The agility of the Pleiades system, its ground resolution and stereoscopic capabilities make it particularly well adapted

for mapping applications. Nevertheless, lots of economical and technical studies are necessary to find the most efficient way to use this system for the present and future missions of our mapping agency. These studies will be continued until, and even after, the launch of these two satellites. Especially, during the year 2006, they will be focused on:

- a test on a large area to confirm the potential of the system for building roofs retrieving
- using colour information to detect vegetation
- using some filtering for a DTM estimation from the digital surface model computed by correlation of stereoscopic images

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