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ABSTRACT

The PLEIADES program is a space Earth Observation system led by France, under the leadership of the French Space Agency (CNES). Since it was successfully launched on December 17th, 2011, Pleiades 1A high resolution optical satellite has been thoroughly tested and validated during the commissioning phase led by CNES. The whole system has been designed to deliver sub-metric optical images to users whose needs were taken into account very early in the design process. This satellite opens a new era in Europe since its off-nadir viewing capability delivers a worldwide 2-days access, and its great agility will make possible to image numerous targets, strips and stereo coverage from the same orbit. Its imaging capability of more than 450 images of 20 km x 20 km per day can fulfill a broad spectrum of applications for both civilian and defence users.

For an earth observing satellite with no on-board calibration source, the commissioning phase is a critical quest of well-characterized earth landscapes and ground patterns that have to be imaged by the camera in order to compute or fit the parameters of the viewing models. It may take a long time to get the required scenes with no cloud, whilst atmosphere corrections need simultaneous measurements that are not always possible.

The paper focuses on new in-flight calibration methods that were prepared before the launch in the framework of the PLEIADES program : they take advantage of the satellite agility that can deeply relax the operational constraints and may improve calibration accuracy. Many performances of the camera were assessed thanks to a dedicated innovative method that was successfully validated during the commissioning period : Modulation Transfer Function (MTF), refocusing, absolute calibration, line of sight stability were estimated on stars and on the Moon. Detectors normalization and radiometric noise were computed on specific pictures on Earth with a dedicated guidance profile. Geometric viewing frame was determined with a particular image acquisition combining different views of the same target.

All these new methods are expected to play a key role in the future when active optics will need sophisticated in-flight calibration strategy.

Keywords: Pleiades, calibration, agility, image quality

I. INTRODUCTION

A. The Pleiades Program

France, under the leadership of the French Space Agency (CNES), has set up a cooperative program with Austria, Belgium, Spain, Sweden, in order to develop a optical earth observation system. The Pleiades system is a dual-purpose optical observation system designed to complement the French military space observation system Helios 2 and the Spot satellites, in order to meet the needs of both defense and civilian users, institutional and also commercial. The system will operate two identical satellites that enable a world-wide daily access to high resolution imagery.

The purpose of Pleiades is to deliver optical images of sub-metric resolution to both civilian and defense users. Each kind of specific needs has been taken into account very early in the system architecture and the design process. For example, Defense authorities want a commitment in access priority (50 high priority images will be allocated each day) and confidentiality of requests, while civilian users express high requirements of acquisition capability and coverage. Many applications can benefit from Pleiades data : not only cartography and defense or security but also agriculture and forestry, geology and hydrology, marine applications, Earth science, resource management, land use, law enforcement and risk management according to scientific, institutional and commercial customers.
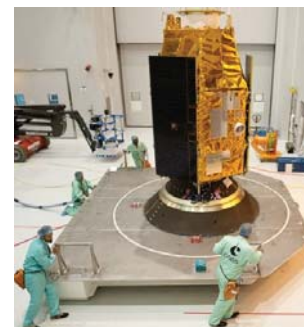

Figure 1 : Pleiades 1A a few days before launch in Kourou

B.   System overview and key mission performances

The Pleiades system operate two identical optical satellites positioned on a quasi-circular, Sun-synchronous orbit of 695 km altitude, at a local hour at descending node of 10h30. The first Pleiades satellite was launched by a Soyuz rocket on the night of 16 to 17 December 2011, from the European spaceport at Kourou in French Guiana. The second satellite will be launched about one year later [1].

The system is designed to provide images that are simultaneously acquired in Panchromatic (PA) and multispectral (XS) mode with four bands (Blue, Green, Red, Near Infrared), which delivers 20 km wide Earth images of a resolution equal to 0.70 m in PA and 2.80 m in XS for nadir viewing conditions. Coverage is almost world-wide with a revisit interval of less than 24 h for 2 satellites. Agility, which allows the satellite to acquire off-nadir scenes rapidly in a large flight envelope, enables to sequence numerous images and gives access to lateral multiband coverage (100x100 km^2) and virtually instantaneous stereoscopic pairs and triplets from the same orbit.

In order to be used in standard Geographic Information Systems (GISs), Pleiades image products have a very precise location accuracy better than 12 meters (circular error at 90%) without ground control points. This requirement is very demanding and mainly addresses the satellite performance in terms of attitude stability.

With its imaging capability of more than 450 images of 20 km x 20 km per day with one satellite, the Pleiades system is a major high resolution optical data provider : one can easily understand that the system availability is a key factor which has been considered very early in order to minimize the technological operations used for calibration.

C.   Satellite definition

Based on the system requirements, the satellite design has been fully optimized. Sizing the satellite is closely linked to a proper trade-off between on-board technological complexity and ground processing capabilities : some requirements which are often costly for the onboard segment (satellite/camera) can be relaxed if we are able to reproduce the performance at an acceptable level by an appropriate ground processing.

The key performances at system and thus at satellite level are : viewing capability, location accuracy, and Modulation Transfer Function (MTF) that measures the image resolution. MTF requirements chiefly determines the camera design and therefore the satellite size.

The Pleiades satellite body is very compact (around 2.20 meters by 3.50 meters) in order to maximize its ability to off-point rapidly around its axis (yaw, pitch, roll). Whereas older generations like SPOT used to accommodate their payload on top of the platform, the Pleiades instrument is partly embedded in a hexagonal shaped bus containing all equipment (Fig 2). Solar panels are rigid and fixed to the bus. The building of the two satellites was entrusted to EADS Astrium (satellite prime contractor) and Thales Alenia Space (high-resolution instrument prime contractor).
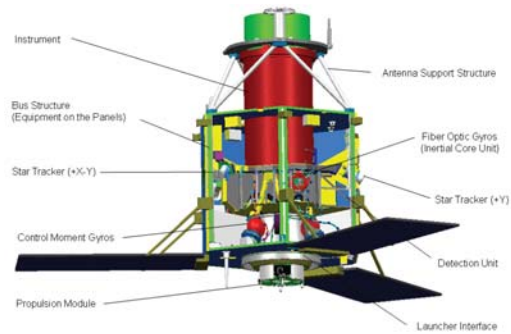

Figure 2 : Pleiades satellite architecture

The attitude control system uses for the first time in Europe a new generation of actuators called control moment gyros (CMG), with a very sophisticated on-board control software. The spin rate of the CMG wheels is tunable in a large range in order to minimize the high frequencies perturbations of the line of sight. The attitude estimation system uses 4 fiber-optic gyroscopes and 3 star trackers to provide attitude accuracy compatible with the system location specification of the products. The orbit navigation is performed by an autonomous navigator using the DORIS system.

D.   Instrument definition

The instrument design is mainly determined by the requirements for radiometric image quality in the panchromatic band which supplies the images with the sharpest resolution. One of the main trade-offs concerns the MTF requirement which is considered to be partly but not totally provided at satellite level since a ground processing is able to reach the final system level performance. That is why MTF requirement at satellite level is not so high : 0.08 at Nyquist frequency in PA band, and is restored up to 0.30 at system level. This requirement, in addition to the stability need for location accuracy, was the main guideline to define the camera, which uses a Korsch combination with an aperture D=65cm and a focal length f=12.90m, that has been highly compacted and optimized in order to lower its mass and volume.

The camera is based on a very stable design concept combining a carbon/carbon structure with Zerodur® mirrors. In order to optimize image sharpness during the satellite lifetime, the instrument includes an innovative thermal refocusing device which avoids the need for a complex mechanism [2].
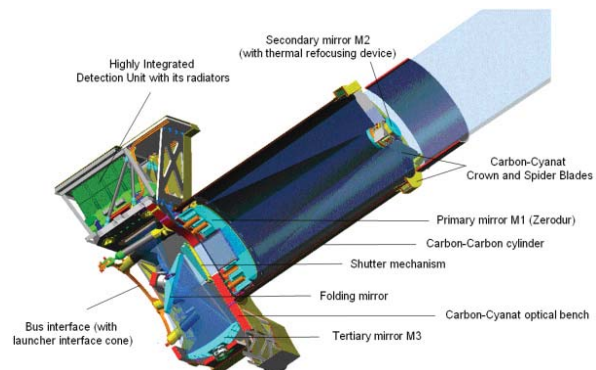

Figure 3 : Pleiades camera architecture

Image quality also requires a minimum signal to noise ratio that is achievable thanks to a Time Delay Integration (TDI) detection device for the PA band which allows to select between 7, 10, 13, 16 and 20 TDI lines. The standard tuning for flight is 13 TDI lines that deliver a SNR equal to 150 for PA band at medium radiance L2. The choice of TDI allows images to be performed without slow motion with a SNR that meets the specifications. The multispectral channels are detected by a four-color CCD with 52 µm square detectors. The blue, green, red and near infrared filters are positioned in front of each of the 4 retinas of this CCD. A four-color linear XS array has got 4 lines of 1500 detectors.

To acquire images over a field of view of 20 km, each line of sight is composed of 5 aligned linear arrays with 4 narrow overlapping areas; this generates images of 30000 columns in the PA channel and 7500 columns in the XS channel. The XS and PA viewing planes are approximately 1.5 mrad apart, i.e. 2 cm in the focal plane of the telescope. Among the 5 linear arrays of each retina, 2 operate by reflection and 3 by transmission around a beam-splitting mirror device which allows all the points in the field to be acquired almost simultaneously.

After quantization on 12 bits, the pictures are normalized on-board to correct inter-detectors response disparities. Then, they are compressed by a multiresolution JPEG2000 type algorithm that delivers 2.5 bits/pixel in PA, 2.8 bits/pixel in XS. The system can choose operational compression factors in a list of 5 values.

II. SPACE SYSTEMS CALIBRATION ISSUES

A. Performance assessment

Like others earth observing space systems, Pleiades has been designed to meet its performance requirements during all its lifetime. Performances compliance depends on a good knowledge of all parts of the system, from low-level equipment to global chains. This engineering knowledge is used to define useful physical models dedicated to image quality :

- The geometric model is used to compute the location on the Earth of any pixel. It takes into account a geometric modelization of the satellite : orbit determination, attitude estimation, datation, viewing frame determination, focal length adjustment, viewing directions of all detectors, and a ground reference frame.

- The radiometric model is used to convert raw digital counts to top-of-atmosphere radiance and to normalize the inter-detector sensitivities. It is suited to the push-broom acquisition principle since each elementary detector has its own sensitivity to input radiance and its own dark current.

- The resolution model is used to master how details are filtered by the imaging chain, and involves a convolution model by the point-spread function. This model can be handled easily in the Fourier domain where the Modulation Transfer Function (MTF) plays a major role.

Some contributors cannot be modelized and must be minimized by design, like sensors noises. But many parameters can be modelized and calibrated, either during on-ground validation tests or during in-flight operations.

B. On ground calibration

Before launch, the satellite manufacturer runs many tests in order to check the behavior of all the satellite components, and to demonstrate that the requirements are fully compliant. For example, the geometric model is built step by step by combining the different reference frames of the attitude control loop – including sensors and actuators - and the instrument line of sight model. In spite of very accurate measurements instruments like theodolites, this kind of model cannot reach the level of accuracy that is needed for the image location performance where one PA pixel defines an angle of one µrad . That is why a frame correction is scheduled at system or satellite level in order to compensate for all the uncertainties due to ground conditions or to launch .

Even if a ground sequence test can be considered accurate enough or very representative, the instrument behavior may change after the launch and throughout its lifetime on orbit : on-ground calibration has to be considered as the first characterization before launch. For example, detectors non-uniformity can be measured in front of a integrating sphere during on-ground tests, and the camera best focus can be determined using a collimator on an optical facility, but both of these parameters are expected to vary slightly in orbit and therefore must be updated after launch.

Ground tests are also mandatory to check the right signs of all the signed data : for example, the right sign of the TDI lines transfer is compared to the expected velocity of the scene due to the satellite motion.

C. In flight calibration

During the satellite development, the useful parameters of the three image quality models are identified and at least one dedicated calibration procedure has to be defined and validated before launch thanks to simulated images. A lot of experience has been gathered by CNES in the Earth observing systems domain and many calibration procedures rely on this basic principle : if you get an image of a well-known reference pattern, you are able to identify the unknown parameters of the model which links the input scene to the output image.

In radiometric image quality, in-flight normalization and signal-to-noise ratio are classically performed thanks to uniform expanses of snowy scenes, absolute calibration is computed on reference photometric sites with a simultaneous atmosphere characterization, MTF is measured on knife-edge ground patterns.

The geometric model parameters are estimated in two steps. First, image location bias are tuned thanks to location sites on which many ground control points (GCP) are available. As these landmarks give the true location of the line of sight, a block adjustment of several images is performed to determine the alignment bias that minimize the location error. Then, the viewing directions of each detector are computed with several

methods using inter-images correlation, either relatively between images given by different retinas, or absolutely between an image and a ground orthorectified reference equivalent to thousands of GCP.

All these calibration methods are very demanding in dedicated images of specific sites, because they may need a lot of images to make a accurate least-square estimation and because it is not easy to get cloud-free images over these sites. The project team can manage the resource sharing during the commissioning phase but the system unavailability during the operational mission must be strictly minimized. Looking for alternate methods that need less usage of ground references is therefore a issue of importance.

III. THE AGILE REVOLUTION

A. Enhancing the pointing capabilities

Pleiades is the first European satellite able to sequence very rapidly many images at various pointing angles. This capacity has been driven by the mission needs : multi-targets coverage, mosaics, stereo pairs and triplets.

Figure 4 : Example of Pleiades imaging capability
on a 1000x1000 km2 area

While guidance profiles were optimized by kinematics specialists in order to get the best trajectory of the line of sight at any viewing angle, the image quality team began to imagine other ways to take pictures than the classical push-broom principle.

Pleiades' ability to take pictures with any kind of attitude around its 3 axis is a revolution because it opened the door to a new territory that contains many efficient calibration solutions and has not been totally explored yet. We will see further that many new calibration methods have led to relax the operational constraints that used to penalize the system availability.

B. Looking from different points of view

The first new calibration method called AMETHIST has been defined to be able to compute the parameters of the radiometric model in case of non-linear behavior. An efficient way to bypass the quest of uniformity is to use the satellite agility in order to align the ground projection of the scanline on the ground velocity [3].
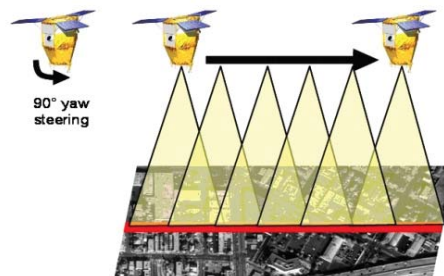
Figure 5 : AMETHIST guidance principle

This weird viewing principle allows all the detectors to view the same landscape. After a pre-processing that globally shifts each column of the raw image, we get an image that contains all needed information. This means that every row contains the set of detector responses to the same landscape. Thus, non-linear normalization coefficients can be computed by a histogram matching method.

Pleiades is not only able to be controlled at a specific 3D attitude, but also with a tunable rotation rate. This ability can be used to stop the scanline projection on the ground during the satellite overpass, so that each detector sees the same landscape during the image capture. : this is called steady-mode.
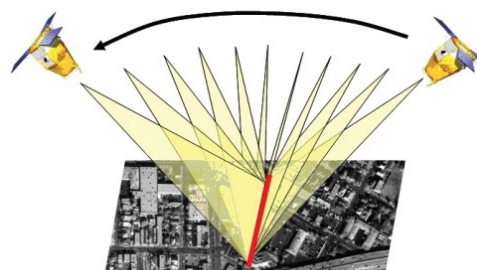
Figure 6 : Steady-mode guidance principle

This kind of image can be used to compute the SNR, and, combined with a single reference image in the same overpass, can deliver geometrical stability information [4].

The stereo and mosaics capability can be slightly adapted in order to get two or more images of the same landscape, with a adjustable offset along the scanline projection [5] :
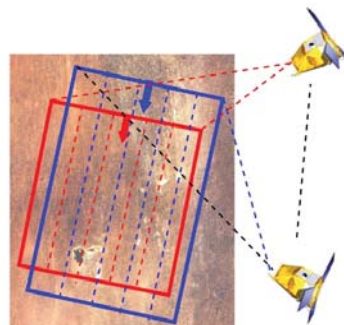
Figure 7 : Shifted stereo acquisition principle

This set of images can be used to compute the image quality variation along the scanline, which may be due to viewing directions, MTF, or focus.

The idea of viewing the same landscape from different points of view is very fruitful : it has been extended to calibration methods that will deliver accurate geometric parameters with no need of ground reference (GCP) [5], [6]. The first method, called auto-calibration, consists in viewing the same landscape at least twice from the same satellite overpass with two or more orthogonal ground trajectories.
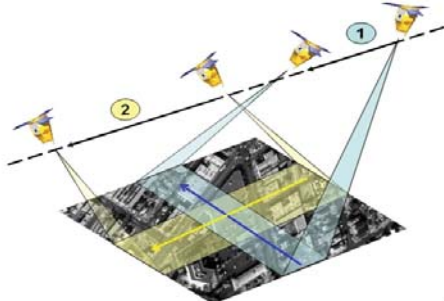
Figure 8 : Auto-Calibration guidance principle

In each image, the errors due to the viewing directions (along the scanline) and due to attitude residuals (along the columns) are transposed. After correlation and appropriate filtering of the attitude residuals, this method delivers the viewing directions.

The second extension is dedicated to the viewing frame bias determination: it uses a couple of images of the same landscape with a 180° difference of yaw. This method is called auto-reverse and needs a fine guidance to control the rotation speed on the spacecraft around pitch axis during the reverse imaging.
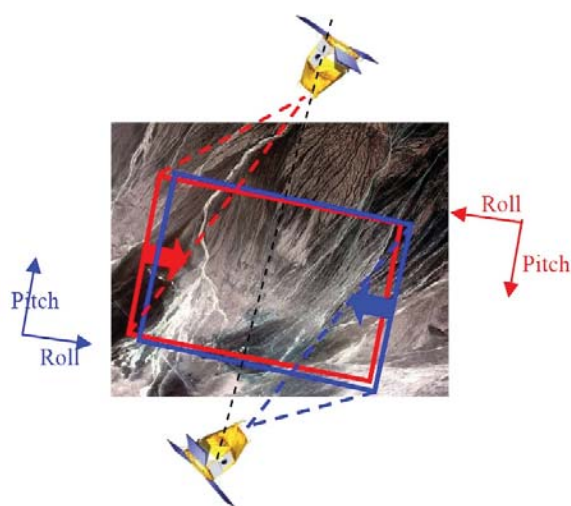
Figure 9 : Auto-Reverse acquisition principle

After correlation between the two images, the mean difference along the rows (resp. the columns) is due to the roll (respect. the pitch) bias.

C. Looking at new targets

The name of the Pleiades program was probably a hint that led us to look up above and force our imagination. First, it was decided to use the off-pointing capability to take pictures of the Moon, in order to follow the absolute calibration during the satellite lifetime without the constraints of ground sites, cloudiness, and atmosphere characterizations. A dedicated Astral viewing mode was set up in the programming chain, that allows to make an image of any planet on the celestial sphere with any kind of attitude rate.

This capability was extended in 2007 to stars : for the first time, the camera was able to image perfect source points without any atmosphere interference. Many applications have been derived for 5 years in all the image quality domains. The images taken at classical attitude rate give access to MTF, the best focus determination, absolute calibration, and the geometric model. From a geometric point of view, stars are the best GCP of the Universe, with a very well-known and stable position. With a dedicated very high slow-motion called StarAcq, they give access to the line-of-sight stability with an unrivalled accuracy [5],[8].
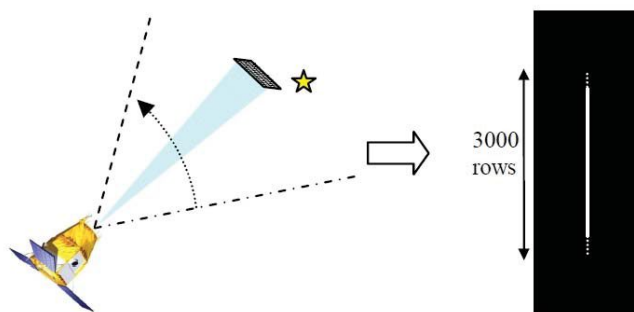
Figure 10 : StarAcq guidance principle

A star appears in the image during several rows, forming a « line » vibrating as the satellite. For each line, the position of the star in columns is computed, and this directly gives access to the profile of micro-vibration undergone by the satellite in roll axis. Whereas the tuning of the CMGs spin rate would have needed 15 days of intensive acquisition of urban sites on the Earth with cloudiness variability, the whole characterization was performed in 40 orbits thanks to stars images sequences.

IV. PLEIADES' NEW METHODS RESULTS

A. Detectors normalization

Several AMETHIST calibration campaigns were performed during the commissioning, over a large collection of landscapes that mix Earth, sees and clouds in order to get a large set of pixels at different radiance levels.
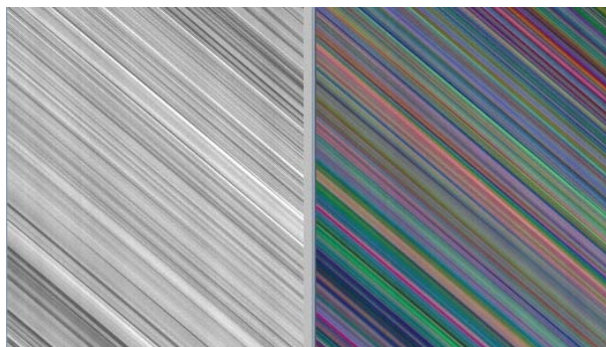
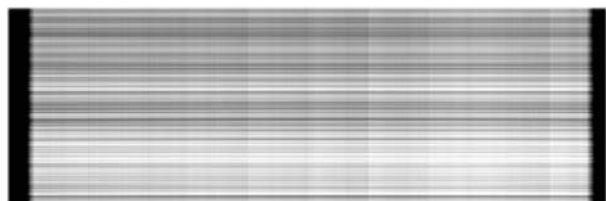Figure 11. Example of AMETHIST PA and XS images
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Figure 12. Example of rectified AMETHIST PA image
(central array, overlapped areas are visible on both sides)

The AMETHIST calibration method gives the same magnitude of residuals as the direct method that compute normalization parameters on uniform snowy expanses, with far less operational constraints [4]. Moreover, it allows a fine monitoring of the in-flight performance that can be compared to pre-flight expectations : up to now, the normalization monitoring confirms the need for an update of the parameters every 6 months, as expected on-ground.

B. Absolute calibration

In addition to images of well-characterized landscapes that have been used for years and continuously improved thanks to previous satellites commissioning, Pleiades has been taken many images of the Moon since the launch. In a nominal calibration mode, the moon is observed once a month during the descending phase in order to follow the stability of the absolute calibration of the different spectral bands [7].

The image below shows a lunar acquisition of PLEIADES with a phase of about -40°:

Figure 13 : Lunar acquisition of Pleiades with a phase angle of 40°
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As Pleiades have acquired stars regularly since the launch, it is planned to follow the temporal evolution of the absolute calibration of the instrument with these well-known and stable sources without any access conflict with the mission.

Some innovative studies are undertaken to study the sensitivity of the absolute calibration coefficient measurement with respect to the satellite viewing angle.
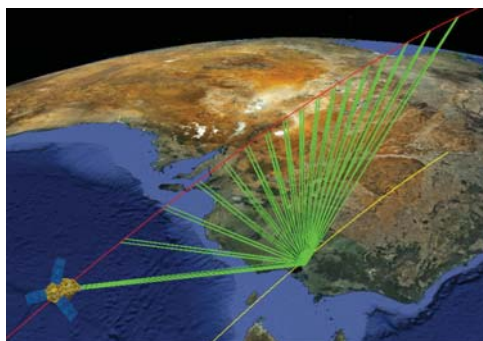

Figure 14 : Example of video-mode overpass on Melbourne

Pleiades ability to sequence several images of the same target with various viewing angle will allow to improve the analysis of directional effects over calibration sites.

All these methods demonstrate that Pleiades absolute calibration is fully compliant with the requirements : the accuracy is around 5% for all bands.

C. Signal-to-Noise

The radiometric noise behavior has been modelized for years : its variance is equal to an offset plus a linear function of the input radiance. The offset represents the variance of the noise in darkness and be directly computed on darkness images. The linear part can be computed by different calibration techniques. One of them is the steady-mode, that provides a full set of couples (radiance mean, radiance standard deviation) [4]:
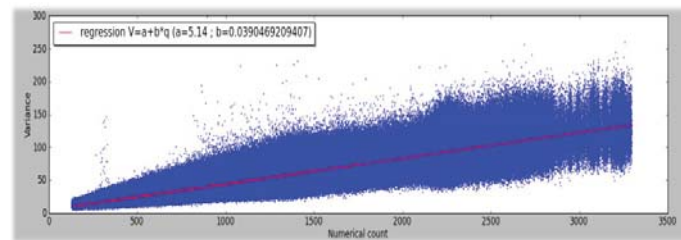

Figure 15 : Variance of the radiometric noise
computed on steady-mode image

The signal-to-noise performance is very good with respect to the requirement of 90 at medium-range radiance L2:

	PA	B0	B1	B2	B3
SNR	150	174	151	146	142

Table 1 : Pleiades in-flight SNR results at L2 radiance.

D. Modulation Transfer Function

Three days after the launch, the Pleiades satellite MTF was computed thanks to images of stars in the Pleiades constellation, as a sign of destiny. MTF is the Fourier Transform of the point-spread function, but the actual images of stars undergo aliasing effects because of the sampling and the high level of MTF, especially in XS bands. Therefore a preprocessing is applied on a large number of stars to interlace each elementary response to produce a well sampled one. This method delivers a very accurate MTF in two dimensions, whereas previous methods were able to measure the MTF only along one axis.
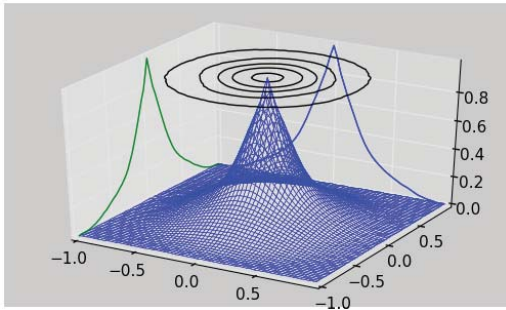

Figure 16 : 2D MTF for the PA band, up to 2 $f_{Nyquist}$

	X	Y
PAN	0.16	0.16
B0	0.33	0.28
B1	0.33	0.27
B2	0.33	0.25
B3	0.33	0.26

Table 2 : MTF at Nyquist frequency

These MTF values (of both XS and PA bands) have been taken into account in the Image Quality performance assessment methods, such as the restoration algorithm [10] or the noise measurement.

E. Refocusing

The best focus determination is a critical operation during the first days of the commissioning since the refocusing range and the available margin have to be validated after launch. Pleiades first images were sharp enough to make everybody comfortable with the defocus, but the best focus determination method [8] was fully run and validated five days after launch. The principle is to build a whole imaging sequence on stars with several states of defocus in a range that contains the best focus, and to compute the MTF including a decay model due to defocus for each set of stars.

This absolute calibration method was compared to a well-known method using neural network on earth landscapes and gave consistent results.

In addition, best focus has been monitored thanks to correlation between homologous PA pixels in overlapping zones as this offset is geometrically related to the defocusing. The three methods have demonstrate their consistency and their ability to monitor the focus position :
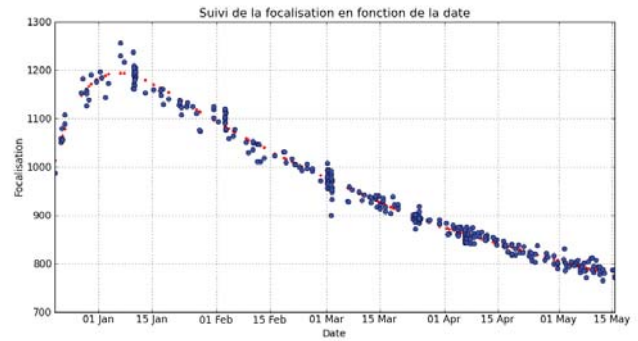

Figure 17 : Pleiades best focus monitoring since the launch

F. Viewing frame alignment

Several couples of auto-reverse images have been taken and processed in order to test this promising method. The results are very good and have been compared to the ones computed classically with GCP : the difference is less than 2 µrad [6].

The first alignment bias were equal to 160 µrad around roll and pitch axis, which demonstrates a good accuracy of ground measurements and a good stability during the launch [5], [9].

In addition, the commissioning results show that residual errors were mainly due to terrain elevation, because of the difference of viewing conditions between the two acquisitions. This error can be cancelled if the two images are viewed in the same conditions as after a period of time of one orbital cycle.

G. Viewing directions

The determination of the viewing directions is a very complex process that needs huge sets of image data. The auto-calibration method demonstrates very promising results without any need of external reference data except a sufficient terrain elevation knowledge [6]. This method gives also a good estimation of the yaw axis bias which is the slope of the relationship between the pitch bias and the detector index :
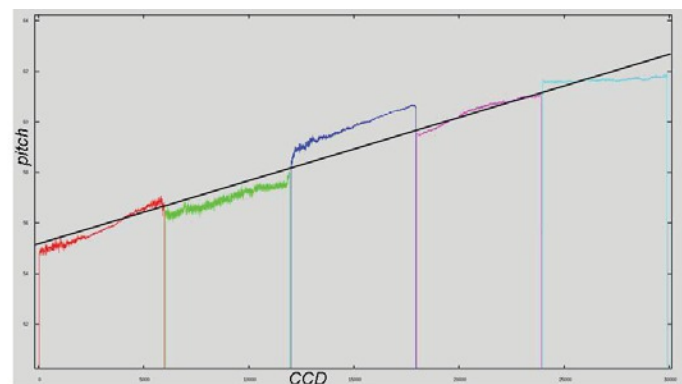

Figure 18 : yaw bias determination with auto-calibration

After proper filtering of the attitude residuals, the viewing directions are computed and show a accuracy of 0.03 pixel RMS, far less noisy than the results given by the classical method that uses a supersite ground reference.
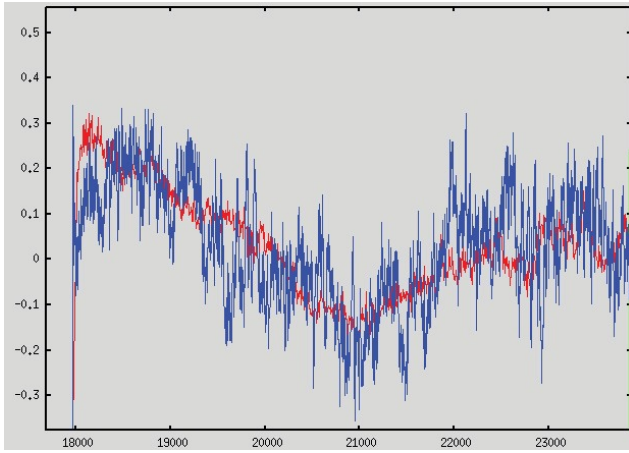
Figure 19 : viewing directions measurement using auto-calibration acquisition (red) and supersite (blue).

H. High frequency stability

During the first month on the commissioning a whole sequence of stars acquisitions was performed in order to get a good estimation of the spacecraft high-frequency stability. For each spin rate of the CMGs, varying from 70.9Hz to 78.4Hz, a dozen of acquisitions have been carried out, so as to measure the magnitude of the micro-vibrations with respect to the attitude maneuvers [8]. One single star acquisition would not be enough because the magnitude of the line-of-sight perturbation depends on how the different actuators positions are phased.
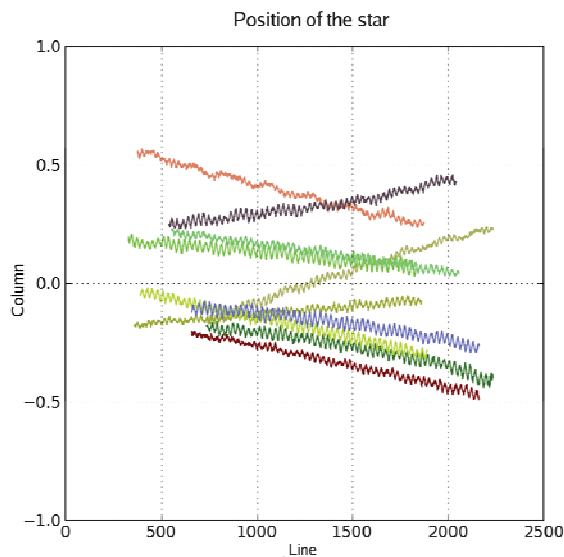

Figure 20 : Examples of temporal stability profiles observed on stars

For a given CMGS spin rate, these stability profiles can be analyzed by a Fourier Transform in order to see the main harmonics composing the signal of micro-vibration. Such kind of very high frequency decomposition helps a lot to improve the knowledge of the mechanical transfer functions that are used to assess the stability budgets before launch.
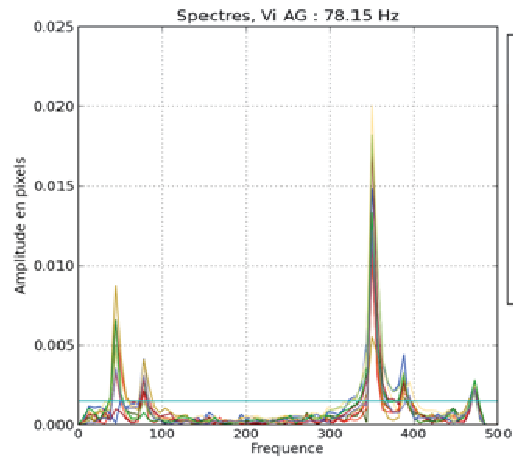

Figure 21 : Example of harmonics in the range [0, 500 Hz]

Pleiades line-of-sight stability is very good : no perturbation greater than the requirement of 0.1 pixel has been detected [6], [8].

V. FUTURE CALIBRATION NEEDS FOR ACTIVE OPTICS

A. Trend for high resolution satellites

The satellite architect of future very high resolution optical missions will have to face challenging issues. Considering the growing size of optics with the resolution improvement, large telescopes with a diameter from 1.5m to 2.5m will have to be accommodated on satellites. In order to define a affordable design mainly driven by the choice of the launcher, it is worth looking for the most compact architecture with lightened materials. Since spacecraft agility is a key performance in order to deliver quick access to very high resolution data, a compact design for the bus and the payload is mandatory and must be intimately coupled.

In order to limit the mass budget, optics and structures are going to be lighter and less rigid, so that the alignment stability in orbit will become a major issue. Global spacecraft design must therefore involve a dedicated correction loop that uses specific metrology and mechanical micro-actuators to maintain the image quality during the orbital lifetime.

Choosing a metrology is an issue of importance, depending on the kind of sources used to measure the misalignments or the wave front errors (WFE) and their availability. Using internal sources enables to use an autonomous active system, but may lead to critical reliability issues. On the contrary, using external sources, either extended or punctual, enables to simplify the instrument design but may not provide continuously the expected measurements.

Moreover, it may be more and more difficult for satellite and instrument manufacturers to run complete tests on ground, because of the gravity deformations of the large optics that cannot be corrected easily. A commitment to comply with the requirements without a final optical ground characterization is going to be an issue that has to be carried out with the active

optics validation. The question will no longer be to demonstrate that the instrument is in a fully compliant status on ground, but to validate before the launch that it will be fully compliant in orbit thanks to its active optics system.

B. Towards a complete in-flight alignment and calibration ?

Pleiades commissioning demonstrates the benefit for calibration of viewing new targets like stars. This first step has to be carried on in a wider extent, in order to imagine dedicated methods that calibrate most of the wave front errors after launch.

To propose a roadmap that uses Pleiades in-flight experience, we think it would be worth to define a calibration process in two steps. The first step starts after the launch and is fully dedicated to reach the coarse alignment of all optics in order to compensate for gravity and launch effects. During this phase, images of stars can be used to get not only focus estimation but higher order aberrations. Sensitivity to the thermal external conditions may also be monitored thanks to a dedicated guidance that varies the orientation of the satellite with respect to the Earth and the Sun. There is no operational constraint due to the mission during this commissioning phase.

Once the coarse alignments completed, fine calibration must be run : this second step starts during the commissioning, not only to calibrate the classical viewing parameters, but also to tune the active optics loop parameters that will be used the satellite lifetime. Images of stars could be used to fit a thermal model to WFE in order to relax the need of several optical measurements on each orbit. Operational constraints due to the mission will severely reduce the opportunity of stars acquisition, which makes this issue very challenging. Taking a few stars images on a useless part of each orbit may certainly help to design a efficient control loop that uses an hybridization between short-term thermal data and long-term optical data.

VI. CONCLUSION

Pleiades technological breakthrough has given the opportunity to imagine new methods in a way that serves not only the calibration accuracy but also the relaxation of operational constraints. These new calibration methods will reduce many time-consuming activities because they often provide a closer access to the final performance without external data. Pleiades commissioning has been an unforgettable experience of engineer enthusiasm : so many new ideas and concepts turned into reality. It is time now to keep on looking ahead and up above in order to face the next challenge of high resolution optics : the design and the calibration process of the next generation cameras with embedded active optics control loop.

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