3D Navigation over merged Panchromatic-Multispectral high resolution SPOT5 images

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ABSTRACT:

SPOT 5, the latest in the series of French optical remote sensing satellite, was launched on May 4, 2002 by an Ariane 4 rocket. Its characteristics, in terms of image resolution and swath, and the presence of a new instrument dedicated to Digital Terrain Models (DTM) generation, open a new field of applications, in particular 3D navigation over large geographical areas. The paper describes the new SPOT5 products (images and DTMs), the principles of multi-resolution spectral fusion (panchromatic and multispectral), and the satellite capabilities in terms of images and 3D navigation. It also presents an experimental application, consisting in generating a DTM directly from a panchromatic / multispectral image pair, leading to potential navigation over the whole merged image, without any need for external data.

RESUME:

Le satellite SPOT5, dernier né de la série des satellites d'observation optique français, a été lancé le 4 Avril 2002 par une fusée Ariane 4. Ses caractéristiques, en terme de résolution et de fauchée, et la présence d'un nouvel instrument dédié à la génération de Modèles de Terrain (DTM) ouvrent de nouvelles perspectives d'applications, en particulier celle de navigation 3D sur de larges zones géographiques. Ce papier décrit les nouveaux produits SPOT5 (images et MNTs), le principe de la fusion de canaux spectraux à différentes échelles (panchromatique et multispectral), et le potentiel de ce satellite en termes d'images et de navigation 3D. Il présente aussi une application expérimentale, consistant à générer un MNT directement à partir d'un couple panchromatique – multispectral, permettant une navigation 3D sans apport de donnée exogène.

1 SPOT SATELLITES PROGRAM OVERVIEW

The program consists in five satellites. The first three belong to the so-called first generation. The first four have a 10 m resolution in panchromatic, and 20 m in multispectral.

- **SPOT 1**: launched on February 22, 1986: still in operation, but on-board recorders are no longer operational.

- **SPOT 2**: launched on January 22, 1990: still in operation, but on-board recorders are no longer operational.

- **SPOT 3**: launched on September 26, 1993: lost in November 1996

- **SPOT 4** was launched on March 24, 1998. This satellite uses a new platform and its main instruments are provided with an additional spectral band in the mid infrared. Moreover, it is carrying a new Vegetation independent payload intended for global vegetation monitoring.

- **SPOT 5** was launched on May 4, 2002. Its two main instruments have an improved resolution of **5 m** and **2.5 m** in panchromatic mode, and **10 m** in multispectral mode. It carries a Vegetation 2 payload identical to that onboard SPOT 4 and a new payload for the operational generation of Digital Terrain Models (DTMs).

2 SPOT 5 SATELLITE INSTRUMENTS

SPOT 5 is on the same 832 km low earth orbit as its predecessors. Its nominal service life is 5 years. It has a solid state memory of 90 Gigabytes, or the equivalent of 550 images, and includes two transmission channels of 50 Mb/s each. It carries the following instruments:

2.1 High Geometrical Resolution (HGR) instrument

The two HGR instruments (identical and independent) are a considerably improved version of the HRV instruments of SPOT 1, 2 and 3 and the HRVIR of SPOT4 .

The 60-km swath (for an instrument) and the possibility of changing viewing direction by $\pm 27°$ perpendicular to ground track are identical to previous SPOT satellites.

Panchromatic data are sampled at 5 m, they use a quincunx detector which enables two 5 m images shifted by ½ pixel in line and column to be obtained simultaneously. As a result of a ground process specifically patented by the CNES (Ref. 1), the combination of these two images generates an image sampled at 2.5 m.

Multi-spectral data use the same bands as those of SPOT 4 but are sampled at 10 m (except in the mid infrared, which remains with a 20 m sampling).

2.2 High-resolution Stereoscopic (HRS) instrument

This is a totally new instrument. It is intended for the production of Digital Terrain Models (DTM).

It consists of two fixed cameras, which are inclined by ± 20° along the ground track. It takes images from the front and rear of the satellite's position (Figure 1). The stereoscopic B/H is 0.8, which means that a difference of altitude of 1 m will be measured as a shift of 0.8 m on the images, in the epipolar direction.
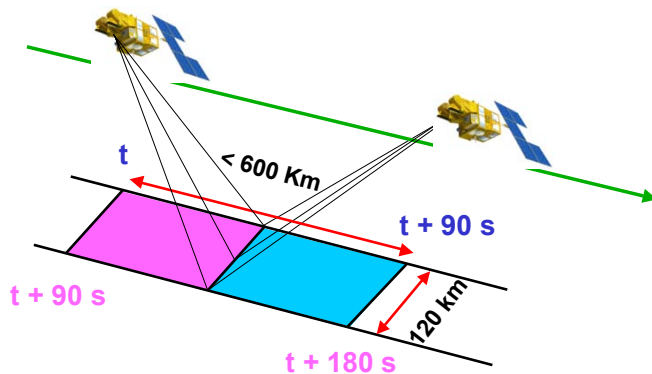

Figure 1: HRS principle

The HRS instrument operates in the panchromatic band with a swath of 120 km. Pixels ground size is 10m by 10m. Pixels are sampled every 10 m perpendicularly to the ground track, but every 5m in the along track direction (epipolar direction), in order to increase the altimetric accuracy.

Localization precision of an HRS image is about 25 m rms, the specification indicated 50 m rms. Localization precision of the DTM produced by HRS is 10m (after check using ground control points). Altimetric accuracy of DTM produced from a pair of images is 5 m rms.

2.3 Vegetation (VGT) instument

This instrument has been designed for the daily coverage of land. Image resolution is 1 km. Spectral bands are identical the the HGR ones, except that the green band of HGR is replaced by a blue one. Some advanced applications have been developed by CNES using this blue band, in particular for halieutic purposes above oceans in inter-tropical areas.

3 SPOT5 PRODUCTS

Automatically generated products are images and DTMs. Images are of level 1A (radiometric corrections only) or 1B (radiometric corrections + projection on a plan centered on the center of the scene) or 2A (radiometric correction + cartographic projection without ground control point using global DTM). When the project will be completed, at the end of 2003, the SPOT IMAGE production center will automatically provide high-resolution color ortho-images (5 m and 2.5 m).

3.1 Images

The following images are available through the distributor, SPOT IMAGE:

- **P** product(5 m): Panchromatic, 12000 x 12000 pixels

- **XI** product (10 m): 6000 x 6000 pixels x 4 spectral bands (Green, Red, Near Infrared, Mid Infrared)

- **THR** product: issued from the Supermode[®] CNES patent (Ref. 1), this is a panchromatic image with a 2.5 m resolution. Its size is 24000 x 24000 pixels. This product is built from 2 P 5m images taken by the quincunx detector of the same HGR combined on ground using a specific process.

- **Color HX (P + XI)** product: 5 m resolution, 12000 x 12000 pixels, 3 bands (B1,B2,B3)

- **Color THX (THR+XI)** product: 2.5 m resolution, 24000 x 24000 pixels, 3 bands (B1,B2,B3)

3.2 Digital Terrain Models

The DTMs produced by HRS are called Reference 3D™: All DTMs produced at SPOT IMAGE have a 30 m posting, and cover a 30'x 30' area. Smaller map frames are also available: 15'x15', and 7'30 x 7'30. But more than the DTM itself, this Reference 3D™ product contains a geo-referenced panchromatic HRS image of the same geographical area, which will be used for automatic production of ortho-images.

4 SPOT5 3D POTENTIAL

The large SPOT5 satellite swath and its high resolution are a unique compromise between resolution and covered geographical area: the standard images cover an area of 60 km x 60 km, and the best panchromatic resolution is 2.5m. Therefore, we can produce merged panchromatic and multispectral color images, obtaining 4 channels of 24000 x 24000 pixels.

On the other hand, the High Resolution Stereoscopic instrument produces very good quality DTMs. Although the DTMs may be used independently from the HGR images for many applications, such as defense, cartography or telecommunications, the HGR color images obviously represent an add-on value.

An application combining data from the two instruments, HGR and HRS, consists into warping the HGR high-resolution image (2.5 m) on the Digital Terrain Model produced from HRS images. To obtain better results, we have to go though two processing steps. First we produce high resolution color images from high resolution panchromatic image and lower resolution color ones. We call this merging step: "fusion". The second step consists in converting the SPOT5 "false colors" images into natural color ones. Both steps are explained hereafter.

Thanks to a specially developed tool, which handles this volume of data (DTM + 3 color channels of 24000 x 24000 pixels), and will be discussed further in this paper, we are

able to browse a 60 x 60 km image sampled at 2.5 m in 3D, in real time, and in relief.

This type of application is of high interest for defense, airport and territorial management, and communication.

Even without having a real time navigation tool, just mapping images on a DTM provides more information than just looking at them in 2D (Figure 2). DTMs provide add-on value to high resolution color images. On the other hand, given any DTM (from any source), warping an image on it allows to easily check its quality: defaults are highlighted, because human mind can easily recognize when the relief does not correctly correspond to the landscape (road, rivers, etc..).
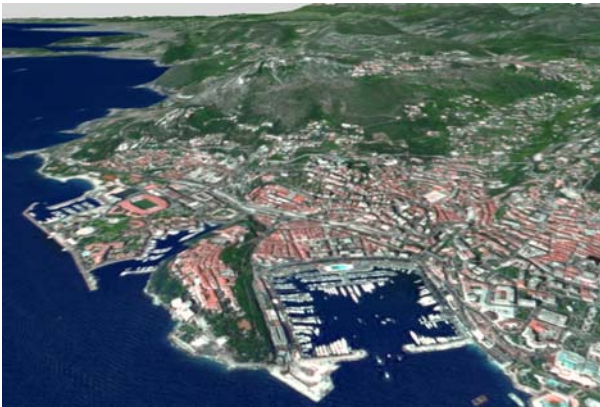

Figure 2: SPOT5 "3D" image: the Monaco harbor

Although we call it 3D, one must keep in mind that the texture provided by any satellite image will only be the one viewed in one direction: for example, in our SPOT5 examples, we will not have access to the vertical textures. On the other hand, even if we had some information on the vertical texture, the representation of DTMs, as regular grids of points, does not allow for vertical surface description. This is why the adequate term of what we presently produce with satellite images should preferably be 2.5D. But one should reckon that this terminology is not familiar to the public.

5   IMAGES PRE-PROCESSING

We have seen that two image processing steps are necessary, before navigation: fusion of the P (2.5 or 5m) and the XI (10m) images, and natural color transformation.

5.1   P+XI fusion

CNES has developed a fusion algorithm, as a result of R&D work. Last year, a comparison of this algorithm with other ones, issued from different European laboratories research, has been performed. The conclusion, coming from end users evaluation, is that, despite its simplicity, the CNES algorithm is considered as the best one (Ref. 2). Typical considered ratios of image resolution between multispectral and panchromatic images were ¼ and ½, which makes this study applicable for both SPOT5 and future Pleïades satellites. Following this comparison study, CNES does not expect to make changes in the near future to its fusion algorithm.

The algorithm principle is the following

- We create a panchromatic image, as close as possible, in the domain of spatial frequencies restitution, to the XI images, with the same resolution (10m for SPOT5)

- We correlate this band with the closest (radiometrically) XI band, which usually is the red one. This provides us with a precise knowledge of the geometrical distortions between the panchromatic and this multispectral band.

- We re-sampled the XI bands to make them superposable to the P band, with a 10m resolution, using the result of the previous step and the knowledge of the precise geometrical distortions between the XI bands (calibrated during the in-flight commissioning phase)

- We zoom all the re-sampled multispectral bands by a factor of 2 or 4 (depending if we have 5m or 2.5 m panchromatic images)

- We create an additional panchromatic band, called "blurred P", which has the same size as the original one, but which is filtered in order to only keep the spatial frequencies visible by the multispectral bands (which are frequencies lower than $1/2x10m$).

- Eventually, we compute the merged high resolution color image, the input being 5 images: the 3 multispectral (zoomed) ones, the P and the "blurred P". The principle is a IHS (Intensity, Hue, Saturation) transformation: the final hue and saturation are the ones of the zoomed color images. The final intensity is the intensity of the original P image, normalized by the intensity of the "blurred P" one.

The quality of the geometrical corrections is fundamental to insure a good quality of the fusion product. One must keep in mind that this operation has to be as precise as possible. CNES has developed a very precise correlation tool, which is now widely used in the Image Quality division. In the case of SPOT5 P+XI images, the P / XS geometrical distortions not only come from the data take geometrical characteristics, which might be modeled, but also from the local relief in the image, as will be shown later in the paper (advanced application). This is why a correlation step is mandatory.

5.2   Natural color transformation

The three SPOT5 spectral bands, sampled at 10m, extend from green to near infrared. The fourth spectral band, the mid infrared one (MIR) has a 20 m resolution. Although, for many applications, the lack of a blue band is not a problem, it becomes a drawback for navigation, because human is much troubled by false colors, in particular when the vegetation areas appear in red.

Therefore, for communication purposes (posters, photos, navigation), we have set up, with the help of SPOT IMAGE, a procedure to convert images into natural colors. The best results will always be achieved by a manual procedure, because the optimal parameters depend on the landscape, but we presently use a matrix transformation on the channels B1, B3 and B3, whose quality is considered as sufficient.

The only manual step is, if necessary, a final image contrast enhancement, which is sometimes necessary for navigation when the image dynamics is not large enough.

6   3D NAVIGATION TOOL

As an outcome of a R&D study, CNES participated to the development and the improvement of a tool called VirtualGeo. This tool has been developed by the CS-SI company. VirtualGeo main characteristics are:

- Available on a PC PIII or Athlon 1000 Mhz (or higher) with 256 Mo RAM, 10GB harddrive (SCSI preferred) and an fully compliant OpenGL 1.3 3D graphic card (Nvidia / GeForce for instance).

- Real-time 3D visualization software of massive textured terrain databases using satellite or raster images defined by GIS (Geographic Information System) software.

- Intuitive, 6 degrees of freedom navigation using keyboard, mouse or 3D control peripheral (joystick, Spacemouse©, Sensatrack©, FlockOfBird©, etc.).

- Visualization of lighting with cast shadow at a given time (rapid reconnaissance, radar zones,...)

- Sophisticated algorithm used to pre-compute DTM, that allows VirtualGeo to maintain terrain topology as well as 30 FPS (Frame Per Second) during visualization of the landscape (e.g. whole France at 80m resolution with scan 25000 at 40.000 meters visibility),

- A fine multi-resolution texture management,

- A very nice feature called "dynamic loading" coupled with a "pre-fetching" algorithm that allow VirtualGeo to load in main memory only data that it needs. The pre-fetching features avoid lag during data loading, because VirtualGeo is able to determine which area will be displayed the next 5 frames and check that data are in memory

- AVI export,

- Nice work dedicated features like 3D intervisibility, profile, ambiance (clouds, rain, snow, etc.), import/export NMEA (GPS like format) file, night vision google, etc.

Before performing the navigation, one must prepare the images and DTM. The only requirement is that DTM and image are in the same geometry (but they have neither to be at the same resolution, nor to have a correspondence between their first pixels). A tool has been developed, called "Terrain Designer" (CNES property), which thanks to a very simple menu prepares all data. The user only has to describe the image and DTM sizes and resolution, and one homologous point between them.

For the moment, only raw format is available for images (3 RGB raw channels). Recognized DTMs formats are raw, DTED and USGS.

7   ADVANCED APPLICATION

This still experimental application has been implemented by CNES and requires a very precise correlation tool. It consists into using the correlation results between P and XI, as exposed in the "fusion" paragraph, to compute a DTM. Taking advantage of the very small stereoscopic B/H (about 0.02) between the panchromatic viewing direction and the multispectral one, we can build a DTM by stereoscopy "inside" a P + XI image.

The expected advantages are that P and XI images will be in a very similar geometry because the viewpoint is very close (no hidden surfaces), and that the images will be taken almost at the same moment (+2s). On the other hand, the main drawback is that any uncertainty on either the instruments focal plane or the viewing direction and attitude parameters will have a large impact on the DTM. A B/H of 0.02 means that one pixel shift, at 10m resolution, represents a 500m altitude. Therefore, a 0.1 pixel error due to unmonitored attitude for example would lead to an error of 50m on the DTM… Another drawback is that the P and XI images are not radiometrically similar, and correlation is very sensitive to the radiometric resemblance.

In order to avoid these drawbacks, the method applied consists in computing a X1+X2 channel, which has proved to be very similar to the P one in terms of spectral sensitivity (The P band spectral sensitivity covers the X1 and the X2 ones). This simple operation leads to very good correlation coefficients, sign of very precise results in term of pixel shift. We have also used our most performing correlation algorithm, with very small bias and noise. Finally, we have tried to eliminate possible residual gradients, due to viewing directions uncertainties, and low frequency attitude residuals, due to a lack of knowledge of high frequency component of the attitude.

The digital terrain model obtained with this method has a final altimetric precision in the order of 10 to 15 m rms, and even better after filtering. Therefore, although this is not sufficient to consider the result as a quality DTM, it is very interesting for navigation purposes, mainly for the following reasons:

- It is available, as long as one has a P + XI image, because it is only built from those images. There is no need of any kind of external data.

- It covers, by construction, the whole area of the image. This is very interesting, because SPOT5 images are very large, and it is rare to get a DTM which covers to whole geographical extend of the image.

- There is no need for 'DTM' locking, which means setting of control points between image and DTM, and for DTM or image re-sampling to have them in the same geometry. This is because image and DTM are by construction superposable. This make the navigation preparation straightforward for the user.

This advanced application is built as a script which uses the standard software tools of the Image Quality division of CNES. It is not an operational tool, but it can be operated very simply. It is fully automated.

8   CONCLUSION

SPOT5 satellite paves the way to innovative applications, among which 3D navigation over high resolution color images. This application shows the interest of large swath images associated to high resolution. The experiment, based on SPOT5 images, consisting in generating a DTM directly from a panchromatic + multi-spectral image, proves that with an accurate correlation, it is possible to use very low B/H stereoscopy.

The Image Quality division of CNES is continuously developing and improving its tools, and in parallel performing advanced research, in order to promote new applications and prepare the future. Through 3D studies and parallel software tools development, CNES is preparing the next generation of very high resolution satellites (Pleïades), which will open the field of urban 3D with satellite images.

References

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