3D Capabilities of SPOT 6

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Abstract. On September 9th, 2012 a new optical satellite, SPOT 6, was successfully launched by ASTRIUM. SPOT 6 is the continuation of the SPOT series, operated since 1986. It will be followed in 2013 or early 2014 by SPOT 7 (twin). SPOT 6 provides 60km x 60km images at 1.5 meters.
This very agile acquisition system is able to relocate very rapidly and to scan the earth in any direction. The agility of the system offers the ability to acquire multi viewing angle images of the same area during the same orbit. This capacity, from a mere stereoscopic pair up to multiple viewing images, allows to automatically extracting 3D information over significant land areas.
The aim of the study is to validate and quantify the capacity of the SPOT 6 system to perform 3D extraction, and to derive elevation databases such as DEM or contour lines. The analysis will explore the advantages in terms of quality and automatism of using a triplet rather than 2 stereoscopic images.
In the last years, automatic 3D processing of digital images became more popular and efficient. Thanks to aerial images and very high resolution satellite images, new methodologies have been implemented to improve the quality and accuracy of the automatic 3D processing. We propose to experiment the same type of approaches using SPOT 6 images to produce 3D database, always taking care of the cost-vs-performance trend. Different ground-truth sites with very accurate 3D database are used to quantify the quality of the 3D performance from SPOT 6.
Our paper will briefly remind the basic characteristics of SPOT 6 imagery, and then expose the performance results we get from it, and the validation and verification methodology we derived from these tests.

Keywords: Photogrammetry, SPOT, Matching, DEM/DTM, Satellite, Accuracy, Stereoscopic

1. Introduction

Built by Astrium, a member of EADS, the SPOT 6 high-resolution Earth Observation satellite was successfully launched on September 9th 2012 from India. SPOT 6 keeps the 60-km swath that made the success of the SPOT series, while delivering products with a resolution down to 1.5m. Its twin SPOT 7 is scheduled for launch in January 2014. Together with Pléiades 1A and Pléiades 1B, they will form a complete operating constellation, ensuring continuity of optical Earth Observation services up to 2024. The constellation will allow a twice-daily revisit capability with an ingenious range of resolutions.

SPOT 6 ground and space segments were designed for improving the performances of the previous SPOT missions. In terms of resolution, the new 1.5-metre range meets the evolving needs of both state-owned mapping programs and commercial users, allowing better understanding of terrain features and easing the detection capability.

A much higher responsiveness of the systems -from acquisition ordering to image delivery- has been made possible thanks to the update of the mission plan every 4 hours, among other improvements, such as the capacity to integrate urgent acquisition requests up to 2 hours before the effective collection. The collection capacity is also increased with a daily coverage of 6 million km² (SPOT 6 and SPOT 7 together). Weather forecasts are updated 4 times per day and automatically integrated into the mission planning; this proves very efficient to increase the so-called “success rate”, ie the ratio of cloud-free imagery collected by the satellites.

In addition, SPOT 6-7 agility allows targeting of any point within a 1500km-wide across track corridor (45° viewing angle). This also opens the way to various acquisition scenarios matching different applications, e.g. the strip mapping mode to collect wide areas in a single pass. When nominal acquisition scheme for the SPOT 6-7 satellites is North to South, they may also be tasked to follow linear targets such as communication lines, rivers or coastlines. The SPOT 6-7 system also incorporates native tasking modes for stereo or tristereo acquisition, for 3D extraction purposes.

Pansharpened and orthorectified images are standard. The orthorectification process relies on Astrium Services’ elevation layer (Reference3D). The registration of SPOT images on Reference3D enables a perfect overlay for applications implying multi-source or multi-date data in a GIS environment, facilitating change detection processing, map revision, or complex projects.

2. Technical characteristics of SPOT 6-7

2.1. General figures

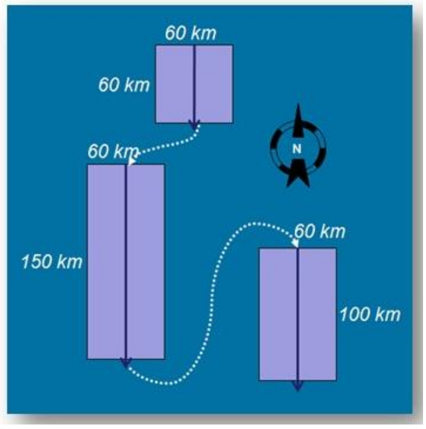
The main technical characteristics of SPOT 6 and SPOT 7 are summarized in the following table:

Number of satellites	2
Launch periods	SPOT 6: September 9th, 2012 / SPOT 7: planned Q1 2014
Design lifetime	10 years
Launch mass	712 kg
Orbit	Sun-synchronous; 694 km altitude; 98.79 minute period; 10:00 AM local time at descending node
Cycle	26 days
Revisit	• 1 day with SPOT 6 and SPOT 7 • between 1 and 3 days with only 1 satellite[1]
Pointing agility	Control Moment Gyroscopes provide quick maneuvers in all directions: 30° in 14s, including stabilization time
Acquisition capacity	Up to 6-7 million sq.km daily with 2 satellites
Nominal imaging mode	60 km swath; North-South strips up to 600km length

2.2. Monoscopic collection modes

The high agility of both satellites provides impressive collection capabilities particularly suitable to serve cartographic needs. SPOT 6-7 standard collection modes are illustrated below:

[1] Depends on the latitude of the area of interest



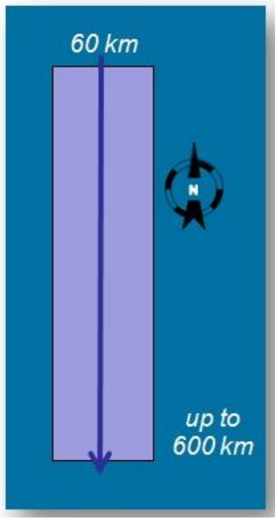


Figure 1a: Target mode

Figure 1b: Single strip mode

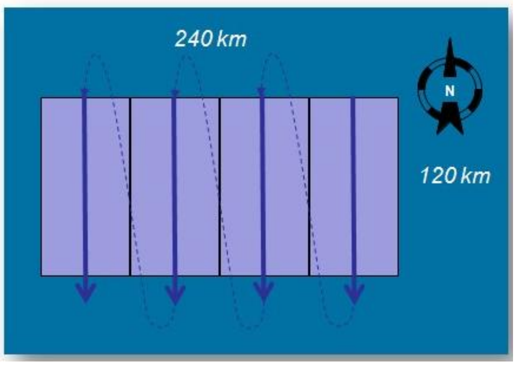


Figure 1c: Multistrip mode

The above standard modes are key to achieve homogenous coverage of large areas within a short period of time. This was demonstrated over Mali shortly after the launch of SPOT 6.

2.3. Monoscopic coverage: real-life example over Mali

On October 24th 2012, shortly after its launch, SPOT 6 was tasked to image the full territory of Mali, ie 1,240,000 km². The coverage was achieved within only 20 weeks, on March 12th 2013.

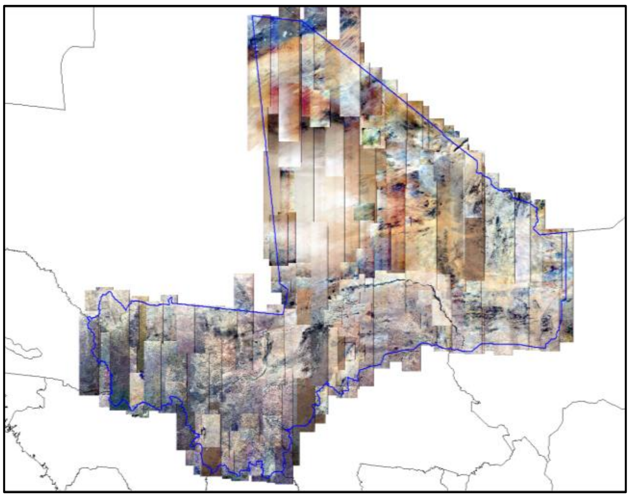


Figure 2: SPOT 6 monoscopic cloud-free coverage of Mali (Oct-March 2012/13)

The chart below illustrates the importance of the agility of SPOT 6 to achieve cloud-free coverage of large areas.

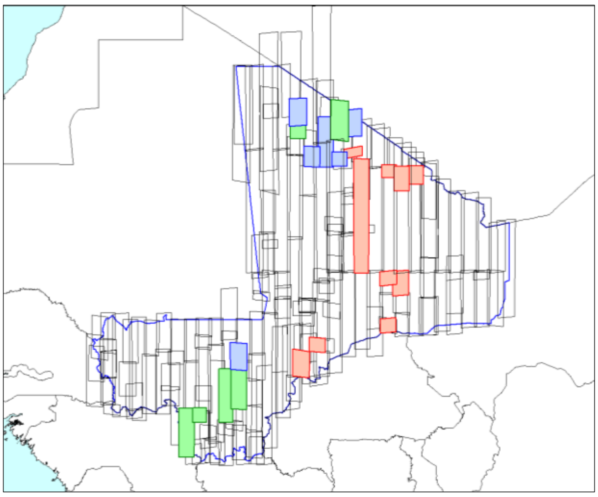


Figure 3: Single-day collections over Mali: December 12 & 14, Feb 18 (pink)

2.4. 3D collection modes

The agility provided by the CMG devices allows SPOT 6 & 7 to collect simultaneous multi-stereo imagery over large areas.

Several studies about DEM extraction showed that in most cases there is no benefit to accumulate more than 3 images, thus recommending the use of triplets as the optimum source for DEM extraction for difficult areas. Consequently, two standard modes were integrated into the SPOT 6 & 7 system for 3D applications: Stereo and Tristereo modes.

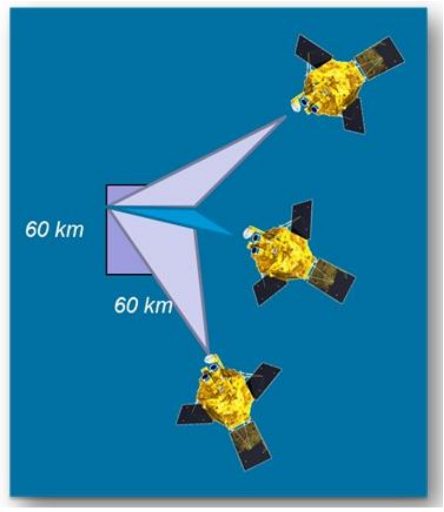


Figure 3: Tristereo capability of SPOT 6 & 7

The Stereo and Tristereo Modes are used for tailored tasking of SPOT 6. Here below we provide some figures considered for operational tasking (maximum allowed incidence angle is limited to 30°).

B/H	0.15	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Stereo	35	60	120	180	240	300	360	420	480	540
Tristereo	none	none	35	60	90	120	120	150	180	240

Table 1a: Maximum length of SPOT 6 stereo/tristereo strips, in km

	stereo	tristereo
Minimum B/H to cover a 111km x 111km area	> 0.3	> 0.6

Table 1b: Minimum B/H values to perform the stereo / tristereo coverage of a 1° x 1° geocell in one single SPOT 6 pass (30° max. incidence angle)

The values in Tables 1a and 1b above are indicative, as they result from simulations. In any case, the incidence angle was limited to 30°. The near future will help refining them from real-life collections. However, they can be used as rules of thumb to understand the potentialities of SPOT 6 for mapping.

3. DEM extraction from SPOT 6 stereo data

3.1. Test sites and source data

To assess SPOT 6 accuracy in elevation rendering, 3 test sites were chosen, where reliable ground truth were available:

- VIC: the Montagne Sainte Victoire area, near Aix-en-Provence (France, photogrammetric test site),
- MEL: the city of Melbourne, where terrain GCPs were collected some years ago for the need of another ASTRIUM project,
- HOB: an area encompassing the city of Hobart (Australia), where GCPs were kindly provided by Prof. Clive Fraser (Melbourne University).

The tests were performed using ASTRIUM's Pixel Factory software suite, applied to the following data:

	GCPs / Vertical Check	Area (km^2)	Images	Tested B/H
VIC	13 / 113	3,259	4	0.17/ 0.36/ 0.36/ 0.53 + 2 triplets
MEL	7 / 90-98	4,010	3	0.19 / 0.46 / 0.66 + 1 triplet
HOB	14 / 85	3,588	3	0.20 / 0.40 / 0.60 + 1 triplet

Table 2: Ground truth & SPOT 6 data used for the tests

The above zones show different landscape features, wrt DEM extraction. Melbourne is rather flat, with very tall buildings downtown, while both

Sainte Victoire and Hobart sites integrate steep slopes, including some cliffs (VIC), and water bodies (HOB).

It is important to mention that:

- cross-track angles show rather high values for MEL (17°, 19°, 26°) and VIC (20°, 21°, 23°, 27°), as opposed to HOB (6°, 8°, 11°).
- for all sites, along-track angles were programmed to compose near-symmetric configurations: MEL (18°,8°,-18°), HOB (18°, -4°, -16°), VIC (10°, 1°, -7°, -16°).
- SPOT 6 absolute horizontal accuracy, measured on VIC against 199 horizontal Check Points, was assessed to 1.20m CE90.

3.2. Global results: vertical accuracy of SPOT 6

DEMs with a 3m posting were extracted through a matching process using a few GCPs and many Check Points. The vertical results are the following:

Melbourne

	#Check	Mean*	Std dev*	Min*	Max*	LE90*	B/H
MEL 0	90	1.1	1.7	-2	12	2.3	0.66
MEL 1	96	0.5	2.3	-13	9	2.5	0.46
MEL 2	98	2.6	2.1	-3	10	4.9	0.19
1+2	97	0.9	1.9	-3	11	2.7	

Table 3: SPOT 6 elevation accuracy on Melbourne – *Values in meters

Hobart

	#Check	Mean*	Std dev*	Min*	Max*	LE90*	B/H
HOB 0	85	0.1	1.7	-9	6	2.3	0.60
HOB 1	85	0.1	1.7	-8	5	2.5	0.40
HOB 2	85	0.2	2.0	-6	4	3.2	0.20
1+2	85	-0.1	1.7	-9	5	2.4	

Table 4: SPOT 6 elevation accuracy on Hobart – *Values in meters

Montagne Sainte Victoire

	#Check	Mean*	Std dev*	Min*	Max*	LE90*	B/H
VIC 0	113	0.1	0.9	-2	4	1.3	0.53
VIC 1	113	0.2	1.1	-2	4	1.7	0.36
VIC 2	113	-0.2	1.2	-3	4	1.8	0.36
VIC 3	113	0.5	1.8	-5	6	3.1	0.17
2+3	113	0.0	1.2	-3	4	2.0	0.17+0.36
2 pairs	113	0.0	0.9	-3	4	1.4	0.36+0.36

Table 5: SPOT 6 elevation accuracy on Sainte Victoire – *Values in meters

3.3. Discussion – Lessons learnt

The above results suggest the following comments:

The best vertical accuracy is roughly pixel-size, and is achieved with the higher B/H, namely 0.5 and more (MEL 0, HOB 0, VIC 0). This is not really a surprise, but results most "comfortable" for the collection process, since the larger the B/H, the longer the possible stereo collection.

B/H ratio below 0.3 (MEL 2, HOB 2, VIC 3) provide poor results, even in downtown Melbourne.

The results introduced above by the mention "1+2" or "2+3" are obtained while considering 3 images (triplets), considered as 2 adjacent stereo pairs. Both DEMs are then merged through a process which aggregates neighboring measurements (least square estimation) after outliers filtering. The estimation could have been weighted according to the B/H ratio, but in that case the contribution of the small B/H pair would have been very low.

However, whatever their small B/H, the triplets allow in any case to reduce the voids (approximately by half) within elevation data. This can prove key for urban applications.

Finally, as a summary, we can draft the following recommendations :

1. SPOT 6 stereo collection should be tasked with a B/H of 0.5 or more, excepted may be under specific harsh constraints concerning the relief and ...the budget.

2. B/H ratios below 0.3 are not commendable, since they fail to provide optimized elevation accuracy.
3. To bring a real benefit to vertical accuracy, each and every B/H ratio within a triplet must be larger than 0.30. This suggests an “optimal” triplet configuration like *alpha/near-0°/-alpha*, with alpha standing between 15° and 20°, which was not encountered during these tests.

4. Conclusion

SPOT 6, launched in September 2012, proved extremely efficient at collecting the whole territory of Mali (1.2 M km^2) within less than 20 weeks. Studies performed to assess the accuracy of elevation extracted from stereoscopic acquisitions, both pair and triplet, showed a pixel-size horizontal and vertical accuracy (at CE90 and LE90 levels), suited for a contour line interval of 5m and above, according to the user’s need.

Finally, SPOT 6, a compromise between large swath and sharp product 1.5m image and accuracy, reveals as a perfect tool for middle- and large-scale mapping (Guérin et al. 2013).

References

Guérin K et al. (2013) Impact of Spot6 and 7 Data in the Constitution and Update of Spatial Data Infrastructures over Africa. ICA Dresden 2013