

**AUTOMATED SENSOR BLOCK ADJUSTMENT
AND LOCAL SATELLITE POSITIONNING
Benefits, and perspectives for mapping applications**

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ABSTRACT

Rigorous satellite and airborne sensor models are nowadays commonly used to set accurate mapping applications through accurate geodesy and ground cartography. Last decade improvement have enlightened the cartography community to the performance of such physical models to improve the map accuracy to a metric -or better- cartographic accuracy limit depending on the sensor type, math model robustness, ground control point quality and error dispersion control throughout the block adjustment of large image sets. Such operations allow to produce maps from high and very high resolutions sensors, optical and SAR in different contexts and for multiples applications such as urban mapping, rural land registration, precision farming... Nevertheless, this methodology still involves some limits in the case this is whether partly or not possible to obtain a reliable enough positional ground reference associated to the mapping project.

Various orbital and ground geodetic location systems are now commonly used among earth observation satellites, such as GPS and DORIS. Some recent experimental and operational works that use an original methodology still based on a rigorous sensor model and the support of a robust block adjustment have proven the ability to recombine series of sensor images on several orbits or flight paths. These tied together with the preservation of the sensor model, its refined earth position and support of a reliable digital elevation model, allow to georeference image blocks based on the internal airborne / spaceborne ground coordinates processed by the operator through the satellite positioning system. Such refined ground controls and a physical rigorous sensor model association now enables image block georeferencing to the ground with a final accuracy compatible enough with mapping standards even without reliable ground planimetric reference (GCP).

Several mapping tests controlled with various aerial, optical and SAR satellite sensors, such as Ikonos, Quickbird, Orbview-3, Envisat ASAR and SPOT 5, the Vexcel UltraCAM-D digital airborne camera along with IMU and GPS, as well as ground reference sources have proven that such methodology and resulting processed imagery makes possible the use of high and very high resolution satellite imagery for a much wider application field, such as marine cartography, accurately geo-positioned defense imagery recognition on remote or not accessible locations.

Our scope is precisely to determine which methodology used among those described sensors would apply to which case with error dispersion control capability or not, to validate such a mapping methodology and process, and finally foresee the possible applications field for the mapping industry.

Keywords: Rigorous Sensor Model, Block Adjustment, DORIS, GPS, Local Orbital reference system, Ground Reference system, Digital Elevation Model, Mapping, Geodesy.

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1 Three methodology experiments

Several methodological experiments were undertaken at Latitude Geosystems offices between 2004 and 2006. These test involved both optical VHR and HR, airborne and SAR sensors on the same PCI Geomatics Orthoengine image processing software. We will first relate a three step experiment involving successively image blocks from Ikonos, Vexcel's UltraCAM-D, Envisat ASAR combined with ASTER.

The three tests were performed in various geographical places in the world with common planimetric sources and altimetric external reference.

<i>Test</i>	<i>Location</i>	<i>Sensor / Model</i>	<i>Planimetric source</i>	<i>Altimetric source</i>
#1 Kauehi atoll	French Polynesia	Ikonos / Rigorous	Internal (GPS)	SRTM reprocessed
# 2 Amsterdam	The Netherlands	Vexcel UltraCam-D / Calibrated	GPS/INS	SRTM reprocessed
#3 Marseille	France	ASAR / ASTER Rigorous	DORIS	SRTM reprocessed

2 Experiment #1, Kauehi atoll

2.1 Experiment motivation

This experiment were originally motivated from location geography. Polynesian atolls have specific geographical features with emerged and submerged parts depending on recifal and coastal orientation. Most of atolls have a submerged part where coral reef remains only below the sea level or at most tidal area that is very temporary emerged – these areas are called « platières »- difficult to access to setup a fair GCP survey. However a 1:10000 map accuracy had to be reached to prepare an acceptable spacemap.

In the same time, a block adjustment of three 1 meter pansharpened Ikonos 16-bits color orbits were to be modelled in a common space triangulation block with a rigorous sensor model. Unlike Rational Polynomial Coefficients model, the rigorous model requires a minimum of well distributed and accurate ground controls to efficiently converge.

2.2 Ikonos on board planimetry ingest and block modelling

This motivated the use of internal GCPs supplied by the operator – GeoEye – A set of 5 internal GCPs were ingested per orbit. An exterior orientation and local orbital model determination were calculated on the fly trough PCI's EASI routines for each satellite path over the island. For each path a model orientation accuracy report was computed for 5 GCPs. In the same time, an external DEM was computed from SRTM 3 Sec/arc to a refined 1 sec/arc model including the lagoon area interpreted as a land surface. The DEM statistic indicated a 14 meter altimetric variation. Despite NASA gives a rough 16 meters coarse elevation accuracy, various observations on flat lands and coastal areas show fair elevation accuracy error compared with GPS and other altimetric sources.

Then, a block adjustment were performed with the help of modelled orbits, DEM ingest and automated tie elavation Tie point (ETP) calculation thanks to radiometric correlation of each orbit. Each of the three orbits were further automatically orthorectified and mosaicked after their pairing has been visually controlled.

2.3 Ikonos accuracy control materials and analysis

Some materials were therefore available to qualify triangulation quality:

- GCPs internal accuracy report during ingest and satellite model calculation for each path;
- ETPs planimetric accuracy during autocorrelation and X,Y planimetric error assessment;
- A 3D set of stereoplotted vectors from a 1:5000 vector database captured from an 1:15000 airphoto survey.

A performance analysis was conducted using both data reports analysis and vector overlay accuracy evaluation.

While Satellite modelling reports analysis revealed subpixel accuracy for all of the 3 orbits modelled, ETPs X and Y accuracy compensated was also evaluated with hereafter results.

<i>Orbit</i>	<i>X</i>	<i>Y</i>	<i>rms</i>
Orbit 1	0.08	0.14	0.16
Orbit 2	0.51	0.26	0.58
Orbit 3	0.27	0.84	0.88

Table 1: Orbit model calculation on 5 internal GCPs

<i>GCP (x,y)</i>	<i>CP(x,y)</i>	<i>ETP(x,y)</i>
N/A	N/A	0.24,0.30

Table 2: Bundle adjustment of modelled ikonos orbits

(meters)

A visual quality evaluation were also undertaken with stereo plotted 1:5000 3D vectors.



Illustration 1: Planimetric accuracy evaluation, Kauehi harbour

3 Experiment #2, Amsterdam vicinity – Vexcel Ultracam-D

3.1 Experiment motivation

The goal was to evaluate an automated orthophoto processing workflow without tedious and expansive GPS ground registration. Frame aerial large format digital sensors have a fair radiometric depth and signal to noise ratio good enough to allow automated correlation techniques that can significantly change time expanses while setting up aerial triangulation. This test session has were undertaken to verify Orthoengine's ability to automatically ingest UltraCam-D airphotos and process an orthophoto with a maximized computation scenario with support of an external DEM.

GPS and INS orientations were acquired along with a 20 cm 60% overlap digital aerial photo survey processed by *Aerodata Surveys b.v.* The sensor used is a vexcel UltraCam-D along with

a stabilized camera mount and an Applanix IMU attached to the sensor.

The Ultracam-D images were computed as pan sharpened 8-bits RGB and processed both with calibrated radiometric and geometric corrections removing sensor internal distortions. GPS frame centers were acquired and post processed with differential GPS techniques up to 1 pixel accuracy.

3.2 Ultracam-D on board orientation ingest and block adjustment

Both image block on one strip and associated GPS / INS data were ingested. GPS/INS were prepared and the UltraCam images oriented accordingly. An accuracy level was given to each orientation parameter for both $X_{gps}, Y_{gps}, Z_{gps}$ and exterior orientation values $\Delta\omega, \Delta\phi, \Delta\kappa$.

In the same time, an external DEM was computed from SRTM 3 Sec/arc to a refined 1 sec/arc model. The DEM altimetric variation is here negligible, while the area is close to the M.S.L, between 0 to 5 meters.

The application automatically oriented the image pairs, DEM ingest and automated tie elevation Tie point (ETP) were automatically correlated with the DEM support and the block adjustment was calculated on the fly. The test flight path was further orthorectified and automatically mosaicked after orthophoto pairing is visually controlled.

3.3 Ultracam-D Accuracy control materials and analysis

The same workflow were used for Amsterdam as the one used for kauehi even if the sensor has a totally different origin. Instead of internally calculated ephemeris coordinates we used post processed GPS/INS data. Given GPS postprocessing accuracy was 0,20m X,Y and we used 0,10° accuracy for the INS coefficients.

We observed the image layout in transparency, both in stereoscopic and monoscopic overlap. We concluded with a reliable enough image positioning on the Y dimension while we remarked a positional error in the X direction about 1 to 2 meters.

	$GCP(x,y)$	$CP(x,y)$	$ETP(x,y)$
Flightpath h	N/A	N/A	0.02, 0.19

Table3: Bundle adjustment of modelled UltraCam-D flight path (photo pixels)



Illustration 2: Ultracam orthorectified images overlay

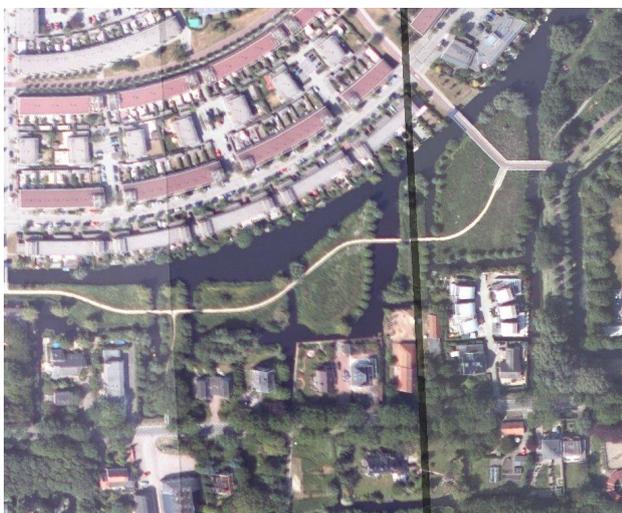


Illustration 3: Ultracam image pairing close-up on 10% overlap

A fast automatic mosaicking was then processed with PCI's algorithm that automatically seeks for minimal difference seamlines and automated LUT balance on the imagery.



Illustration 4: Ultracam automatic mosaic

The conclusion on this experiment is that we could test an instant block adjustment and orthomosaic processing of the UltraCAM into Orthoengine without any Ground controls thanks to a coarse DEM. Overall results were acceptable even if we remarked a X-parallax error probably generated due to the DEM poor vertical accuracy in comparison with the image scale given.

4 Experiment #3, ASTER / ASAR Doris geopositionning

This experiment was far more complicated to undertake and involved a real multisensor approach. The aim still remains the same: use a locally orbital coordinate system and the absolute positionnal accuracy instead of terrain controls.

4.1 Methodology

A space triangulation block from ASTER VNIR scenes laid over Marseille vicinity was

prepared as two approaches projects. We adopted a strategy that consists in :

- 1) – performing a block triangulation from standard ground controls acquired on a std mapping basis – e.g. IGN's maps and orthophoto given to be metric accurate.
- 2) - performing an automated Doris GCP ingested into an ASAR block modelling of 2 images collected into inverse pathes (descending and ascending), both test planimetry collection from radargrammetric ASAR modelled scenes (3D stereoplotted points) and orthorectified (2D monoscopic).

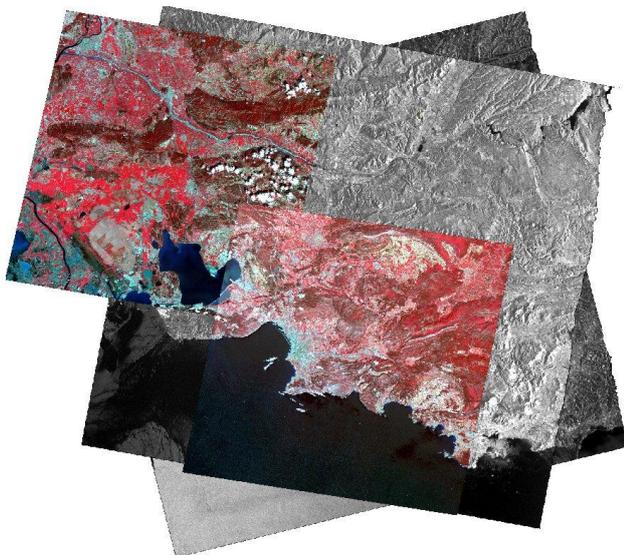


Illustration 5: ASAR/DORIS and ASTER orthorectified imagery over Marseille vicinity

4.2 Experiment execution

Doris GCPs were automatically ingested into modelled ASAR images thanks to a specific SAR satellite model available with PCI software. This model calculation was then compared by collecting checkpoints on metric IGN's orthophoto *bdortho* to evaluate an error dispersion:

	<i>GCP (x,y)</i>	<i>ICP (x,y)</i>	<i>ETP (x,y)</i>
<i>orbit 18856</i>	N/A	20.05 , 18,41	N/A
<i>orbit 16702</i>	N/A	18.92 , 22.71	N/A

GCPs were then collected from ASAR on a to triangulate the ASTER images block . In both cases a coarse SRTM DEM was prepared and refined to 1 arc second for further altimetric GCP and ETP collection as well as for orthorectification of ASTER and ASAR (2D) imagery.

The standard ASTER terrain collected bundle adjustment results gives the following results:

	<i>GCP (x,y)</i>	<i>CP (x,y)</i>	<i>ETP (x,y)</i>
<i>ASTER orbits</i>	13.97,6.88	20.27,15.37	0.10, 3.21

Table 4: Bundle adjustment of modelled ASTER orbits block (meters, from IGN mapping)

The ASAR / DORIS planimetry computed bundle adjustment results on the ASTER block gives the following results:

	<i>GCP (x,y)</i>	<i>CP (x,y)</i>	<i>ETP (x,y)</i>
<i>ASTER orbits</i>	16.39,11.89	17.55,9.31	0.46, 3.75

Table 5: Bundle adjustment of modelled ASTER orbits block (meters, from ASAR/DORIS geopositionning)

We observe on the tables above that the planimetric values are not varying significantly wether standard planimetry or Doris geopositionning is used. The results still remain around 1 pixel value for ASTER VNIR (15 meters resolution).

However we may add that on the last experiment we used a 2D planimetric GCP collection from automatically DORIS

orthorectified ASAR scenes and SRTM coarse altimetric values. Another method to get planimetry was also experimented, that consists in collecting 3D corrected points from stereoplotted ASAR inverse orbits. In this case, planimetric results were close with the 2D collection method while we observed a systematic significant Z error due to the SAR stereopair configuration.

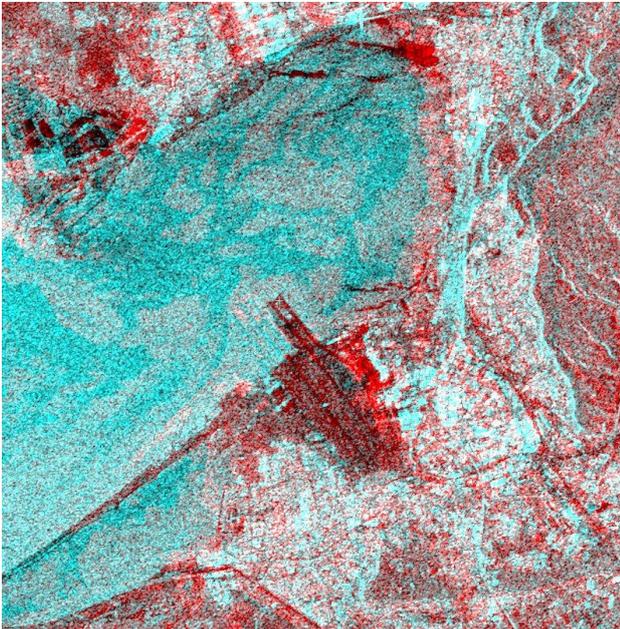


Illustration 6: Epipolar 3D planimetric collection –

4.3 Conclusion about DORIS ingest and use as planimetric 2D/3D base

The DORIS sensor exists on several satellite systems and in particular on earth observation spacecrafts that directly interests the cartographer.

We were given the opportunity to evaluate a common space triangulated scenario with standard ground collection or with a direct DORIS calculated GCP ingest from an external satellite data source, both approached by 3D stereoscopic and 2D orthorectified ways.

In both cases we concluded that:

- 1) the planimetric performance of the modelled ASTER block was around the pixel accuracy, while collectig GCPs from standard mapping source or from a 2D orthorectified ASAR planimetry;
- 2) Both cases involve a coarse resolution DEM that gives vertical measurements with an acceptable vertical error according to the image scale.
- 3) the planimetric performance from DORIS collected on ASAR modelled pair was not in excess of what concluded recent studies (Cheng, 2006), even collected from inverse orbit 3D stereopair on coastal and flat areas.

5 Common conclusions

During these 3 excercices we always were in the mind to solve block bundle adjustment with relevant planimetric and vertical sources that do not involve any ground control, neither from GPS collection on the field nor from available maps or any other geographical source.

Our scope was precisely to determine which methodology among the described sensors would best fit to control the block adjustment error dispersion with onboard control points, to validate such a mapping methodology and process.

On all cases, a common coarse resolution DEM is used as a standard elevation database, that may be enhanced depending on altimetric reference availability and quality assessment process, especially with very high resolution imagery and airborne digital imagery.

We have seen that we can follow the same methodolgy using either ephemeris and / or geodetic measurements acquired from GPS or DORIS networks, either from spaceborne and airborne sensors that use at the end close positioning and gyroscopic orientation devices.

Thus we also remark that basically the absolute ground positionnal accuracy remains a determinant factor in the success of such enterprise. We further foresee that a geodetic system refinement method is to be considered as a key issue within this concern.

These tests let finally foresee the use of high and very high resolution satellite and digital airborne imagery, even if the cartographer does not have access to a ground references such as reliable mapping, or a ground GPS survey. This methodology may apply for large scope of mapping applications such as marine cartography, accurately geo-positionned defense imagery recognition, mapping on remote or not accessible locations, and thus authorize new mapping possibilities that were given as not possible up to now.

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