BLOCK BUNDLE ADJUSTMENT OF IKONOS IN-TRACK IMAGES♥

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ABSTRACT

This letter presents a block bundle adjustment process applied to four IKONOS Geo in-track images with few ground control points (GCPs) over a high mountainous area of Venezuela. Various configurations of block bundle adjustment (1 to 4 images and different GCPs) were evaluated with independent check points. Whatever the number of images, the block bundle adjustment results were consistent with planimetric errors of about ±5 to ±7 m. Part of this error is due to the error of the ground data. The evaluation of the final ortho-mosaic with 1:1000 vector lines gives an approximation of relative and absolute errors to be ±2 m and ±3 to ±4 m with maximum errors of ±6 m and ±10 m, respectively.

1. INTRODUCTION

IKONOS, with 1 m spatial resolution in panchromatic mode, can provide the detailed information for assessing a natural disaster and its impact, such as the flooding which occurred on December 19, 2000 in Venezuela (Arismendi *et al.* 2000). However, due to the limited size of the images (around 10 km by 10 km), the projects require more than one image with partial overlap to cover the full study site. Instead of processing one image at a time, a well-known process named block bundle adjustment can be used to simultaneously compute the 3D parametric models of all images, resulting in a higher accuracy mosaic (Veillet 1991).

The objective of this letter is thus to apply a block bundle adjustment process based on the 3D parametric model developed for multi-sensor images and adapted for IKONOS images at the Canada Centre for Remote Sensing (CCRS) using four IKONOS in-track panchromatic images acquired over a mountainous site in Venezuela.

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2. EXPERIMENT

The study site, located in the Central Coast of Venezuela (10.5° S, 67.0° W) is characterised by a 2200 m elevation topography (Arismendi *et al.* 2000). To assess the damage due to flooding, the Venezuelan Government purchased four IKONOS panchromatic Geo-product images (15 km by 18 km) and metadata all acquired on December 30, 1999 from the same orbit (figure 1). The images display only partial overlap (generally 20% and 40% for the two Western images) in the East-West direction. Geo-product data were not corrected for terrain distortions and offer a low positioning accuracy of ±50 m with 90% level of confidence (Space Imaging 2002). Accuracy decreases to 300 m and 1000 m in the mountains due to the images being acquired with 15º to 30º off-nadir viewing angles.

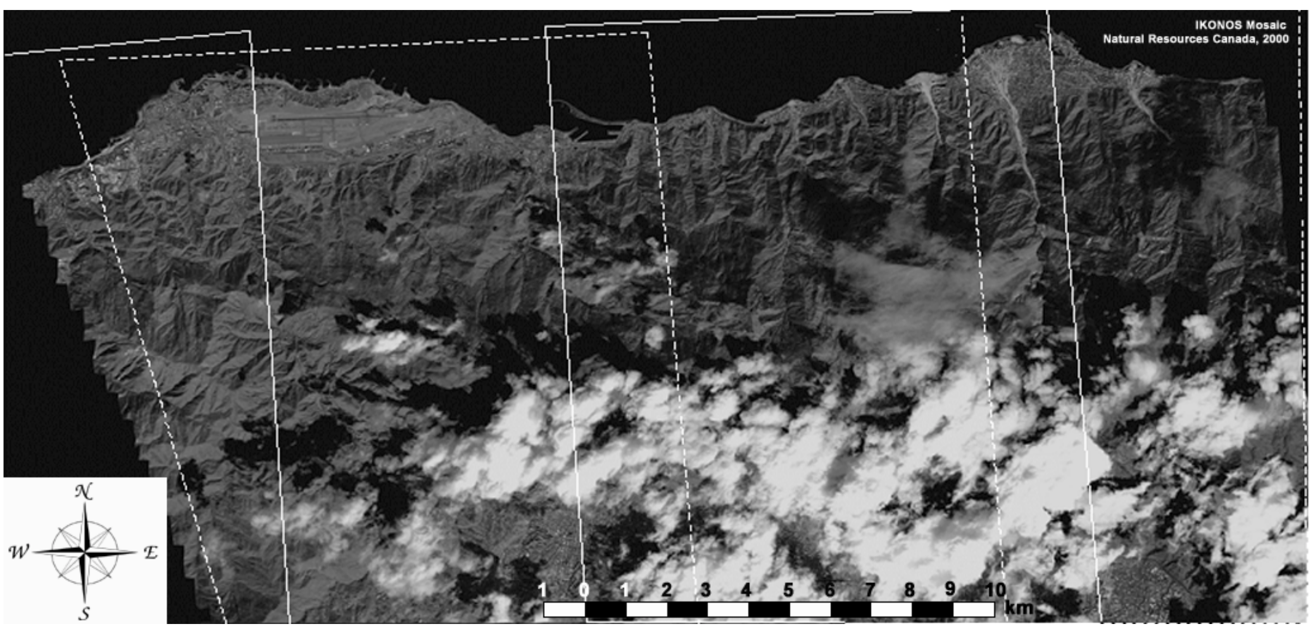

Figure 1. Ortho-mosaic of four panchromatic IKONOS images (1-m pixel spacing, 35 km by 18 km). IKONOS Images © Space Imaging LLC, 1999.

The cartographic data consisted of 2.5 m pixel spacing digital ortho-photos with ±5 m root mean square (rms) error, and a ±5 m rms error digital elevation model (DEM) with 5 m grid spacing. Furthermore, vector lines with ±1 m rms error from 1:1000 base maps were also available but only along the coastlines in the north (35 km by 4 km).

Even though detailed sensor information for the IKONOS satellite was not released, the integrated and unified 3D parametric model for multi-sensor images developed at CCRS (Toutin 1995) was adapted for IKONOS using basic information from the metadata and image files (Toutin 2001). Based on accurate GCPs, rms errors within one-third of a pixel were obtained for medium-resolution visible-and-infrared images, two pixels for high-resolution IKONOS images and one resolution cell for radar images. The block bundle adjustment was thus based on this 3D parametric model to compute all images together. There are four main processing steps to generate the ortho-mosaic with the block bundle adjustment process:

(1) Acquisition and pre-processing of the IKONOS images and metadata;
(2) Acquisition of ground points (image and cartographic coordinates) on each image and tie points (image and elevation coordinate) in the overlap areas;
(3) Computation and evaluation of the block bundle adjustment for 1 to 4 images;
(4) Generation of ortho-images with a DEM using the previously computed 3D parametric models and of the ortho-mosaic with evaluation of their accuracy.

Although six ±1 m rms error GCPs were enough to establish the spatial position and orientation of each IKONOS image, about 30 GCPs were acquired on each image to reduce the propagation of ortho-photo errors in the least-square block bundle adjustment, but also to perform accuracy tests with independent check points (ICPs). Since there is partial overlap between adjacent images (figure 1) 10 elevation tie points (ETP), as common features appearing in both images of the overlaps, were acquired to link these adjacent images. ETPs enable an increase in the relative accuracy between the images. The points (GCPs and ETPs) were weighted in the least-square adjustment as a function of their accuracy (cartographic and image coordinates).

3. ANALYSIS OF RESULTS

The first results are for the computation of the least-square block bundle adjustment using all GCPs for each individual image and for different block configurations with three images and four images. Table 1 gives the rms and minimum/maximum residuals on GCPs of the block bundle adjustment for these seven image configurations. The residuals reflect the modelling accuracy and represent *a priori* mapping error taking into account the original error of the input data. The results show a consistency and robustness in the adjustment whatever the image configuration (individual image or a block of three or four images):

- The rms *X* and *Y* residuals (±2.2 m to ±5.1 m) were around the ortho-photo rms errors (±5 m) due to the least-square block bundle adjustment with a large degree of freedom;
- The *X* and *Y* minimum/maximum residuals (around ±14 m) were generally around two and sometimes three times the rms residuals; and
- The larger rms residuals in Image 2 and Image 3 adjustment were generally reflected in the residuals of three or four image adjustments. In fact, the minimum residual in *X* (-13 m) in 3-4 image blocks is due to the same GCP minimum residual in *X* (-13 m) in Image 3 adjustment. Since the same GCP has about the same residual whatever the image configuration adjustment (1, 3 or 4 images), the *X*-*Y* residuals reflect the plotting quality of the point.

Table 1. Results of the block bundle adjustment with RMS, minimum/maximum residuals on GCPs for an individual image and for 3-image and 4-image block configurations

Image Configuration	**Number of GCPs**	**RMS Residuals**		**Min/max Residuals**	
		X	***Y***	***X***	***Y***
Image 1	27	2.7 m	3.4 m	-6/4 m	-6/7 m
Image 2	35	5.3 m	5.3 m	-11/12 m	-9/14 m
Image 3	38	5.1 m	2.2 m	-13/8 m	-4/4 m
Image 4	24	2.8 m	4.1 m	-5/5 m	-9/7 m
Images 1, 2, 3	100	5.1 m	5.0 m	-13/13 m	-11/14 m
Images 2, 3, 4	97	4.6 m	4.1 m	-13/10 m	-11/14 m
Images 1, 2, 3, 4	124	4.8 m	4.9 m	-13/13 m	-11/14 m

Different GCP/ICP configurations for the four images alone were realized to find the optimal number of GCPs in relation to the ±5 m error of the cartographic coordinates. It was noticed that more than 12 GCPs does not increase the accuracy, as soon as there is no extrapolation in planimetry but also in elevation. There is thus a ratio of 2.2 between the number of equations and of unknowns in the least-square adjustment. In order to keep the same ratio for the three and four image block bundle adjustment, 10 GCPs were then used for each outer image and 7-11 ETPs to link the inner images. Table 2 shows the errors over the ICPs for the same seven image configurations in table 1.

Table 2. Results of the block bundle adjustment with RMS, minimum/maximum errors over the ICPs for an individual image and for 3-image and 4-image block configurations

Image Configuration	**Number of GCP/ETP/ICP**	**Bias Errors**		**RMS Errors**		**Min/Max Errors**	
		X	***Y***	***X***	***Y***	***X***	***Y***
Image 1	12/0/15	0.9 m	0.9 m	2.9 m	3.9 m	-6/4 m	-6/7 m
Image 2	12/0/23	0.4 m	0.4 m	6.4 m	4.4 m	-11/12 m	-9/14 m
Image 3	12/0/26	0.9 m	0.4 m	6.9 m	4.4 m	-13/8 m	-4/4 m
Image 4	12/0/12	0.4 m	0.4 m	3.4 m	4.4 m	-5/5 m	-9/7 m
Images 1, 2, 3	20/18/80	0.7 m	0.7 m	6.0 m	4.8 m	-13/18 m	-8/20 m
Images 2, 3, 4	20/14/77	1.2 m	-1.2 m	6.8 m	5.2 m	-14/16 m	-15/8 m
Images 1, 2, 3, 4	20/25/104	-1.9 m	-0.5 m	7.1 m	5.0 m	-18/12 m	-12/14 m

Most of the patterns and explanations given for the GCP residuals in table 1 are also valid for explaining the ICP errors: ICP versus ortho-photo errors, rms versus minimum/maximum errors, rms errors of Image 2 and Image 4 adjustments versus three or four image adjustments. The bias, generally less than one pixel, is consistent and not significant. Consequently, the 3D parametric model properly describes the image and block geometry, is stable and robust for the full image block without generating local or systematic errors and the least-square adjustment with a large degree of freedom filters GCP errors. The input GCP error does not propagate through the rigorous 3D parametric model, but is reflected in the residual. As the ortho-photo error (±5 m) on the GCP/ICP results is included, the modelling and restitution accuracy should be greater than these error values of tables 1 and 2.

In addition to these quantitative results, qualitative and visual evaluations were performed:

- on the final ortho-mosaic (figure 1);
- on an image overlap area in the mountains (figure 2); and
- on a coastal area with the 1:1 000 vector lines overlaid (figure 3).

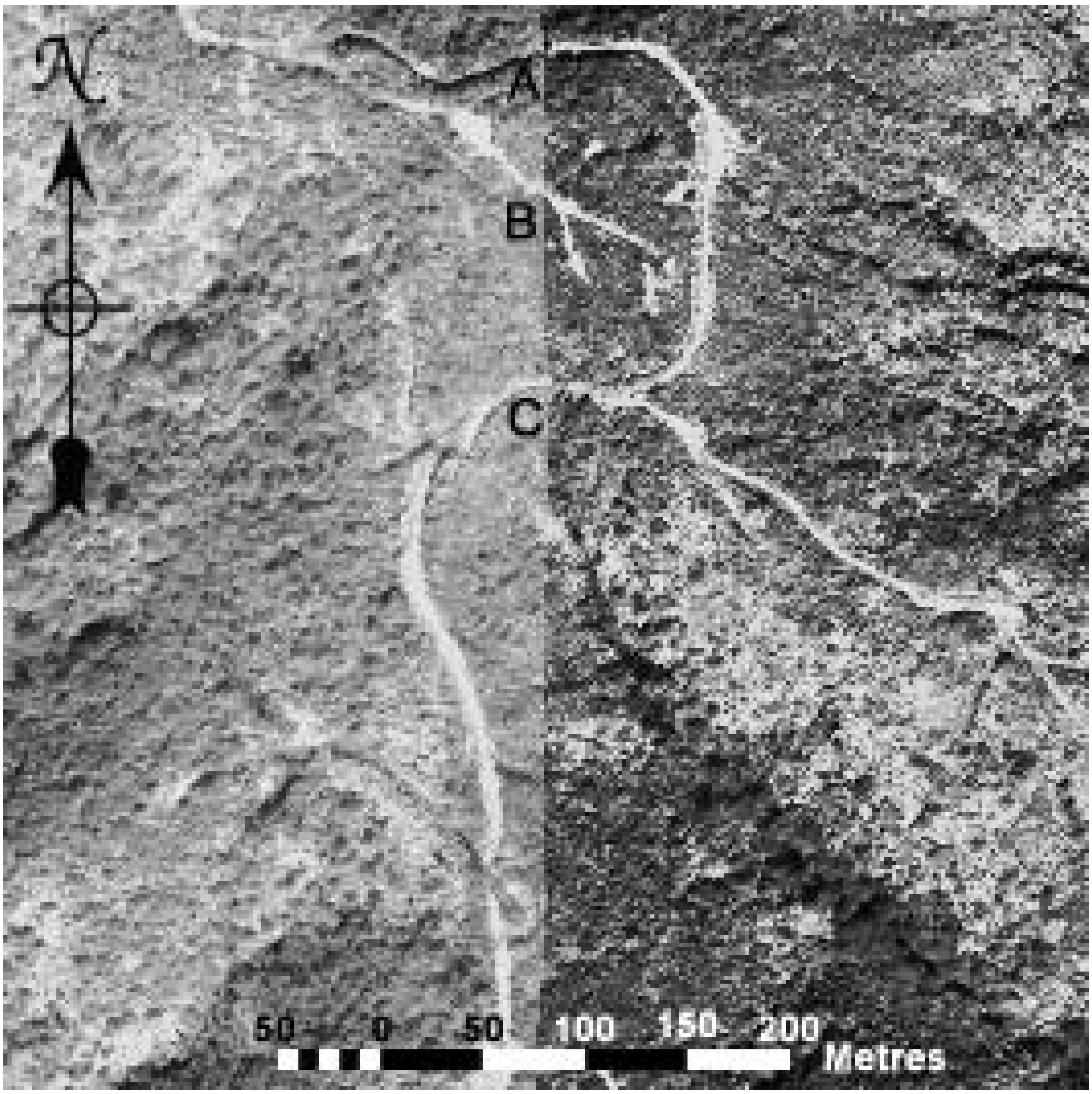

Figure 2.Sub-area (1-m pixel spacing, 512 pixel by 512 lines) of the IKONOS ortho-mosaic at the image overlap area in the mountains. Radiometric variations between the images were enhanced to show the seed. A, B and C are the roads where relative accuracy is evaluated. IKONOS Images © Space Imaging LLC, 1999.

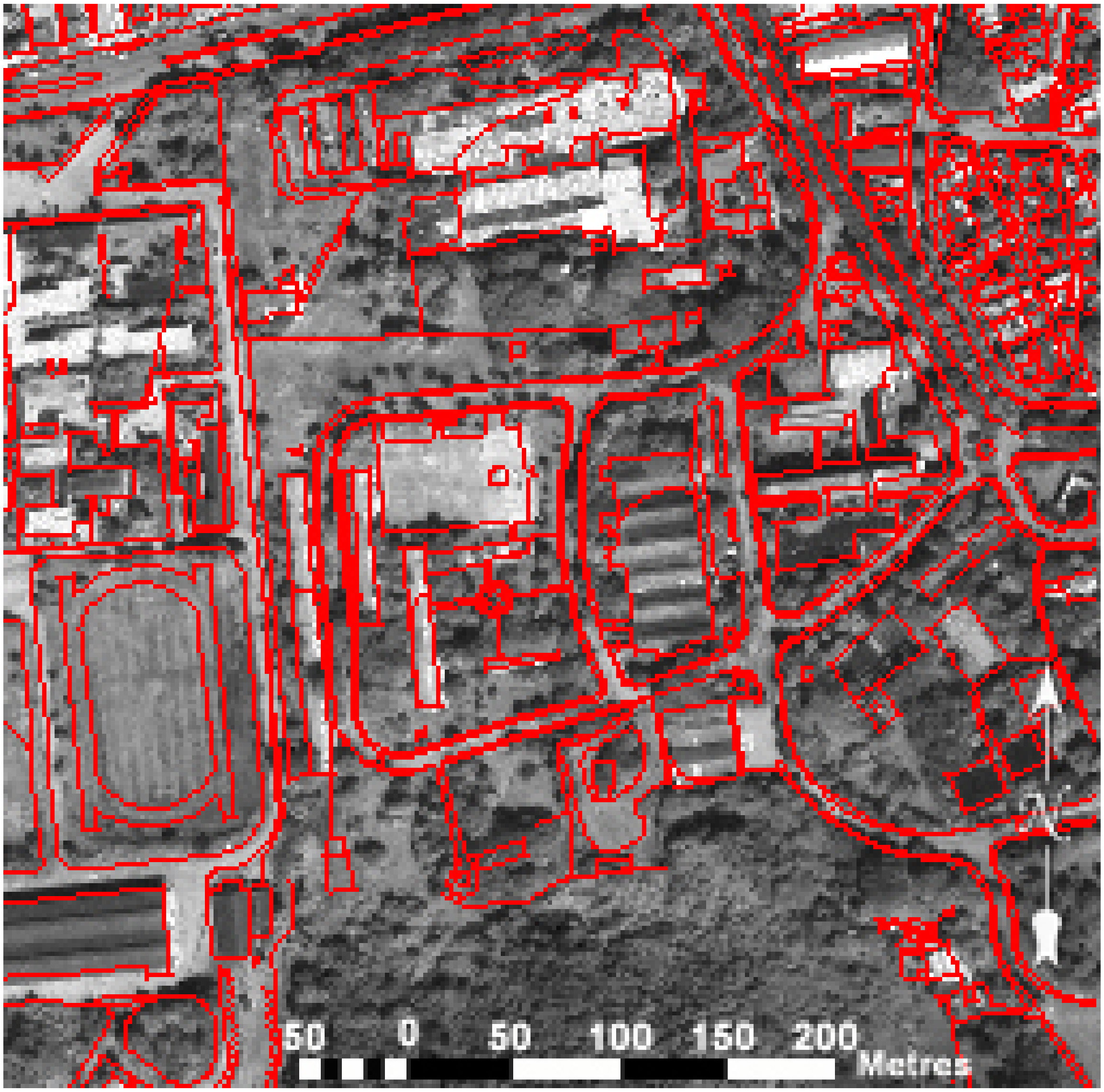

Figure 3. Sub-area (1-m pixel spacing, 512 pixel by 512 lines) of the IKONOS ortho-mosaic at the coastal area with the 1:1 000 vector lines overlaid.
IKONOS Images © Space Imaging LLC, 1999.

The radiometric variation between the two images (figure 2) was increased to show the seed in this area of the mosaic. The relative error between the images can thus be evaluated on three spots at the mountain road (A, B & C). It is in the order of ±2 m with a maximum error of 6 m for the lowest spot (C). Furthermore, Figure 3 shows that the absolute error is in the order of ±4 m with maximum error less than 10 m. Since these results are more accurate than the previous results on GCPs/ICPs they confirm that the ±5 m rms error of the ground data did not propagate in the 3D parametric model but was reflected in the residuals/errors. However, part of these relative and absolute mosaic errors is also due to the propagation of the ±5 m DEM error during the ortho-rectification of the images acquired with viewing angles of 15º to 30º.

4. CONCLUSION

This Letter has evaluated the use of a CCRS-developed 3D parametric model to geometrically process with a DEM four IKONOS panchromatic off-nadir viewing images in a spatio-triangulation method using a block bundle adjustment. Seven image configurations for the block bundle adjustment (using one, three or four images) were evaluated with different numbers of GCPs and ETPs. The consistent results on all tests (around ±5 to 7 m rms residuals and errors) confirm the applicability of the CCRS-developed 3D parametric model to IKONOS images and demonstrate its stability and robustness for the block bundle adjustment process. Ten GCPs in each outer image and 7-10 ETPs in each image overlap were enough to achieve these results. The visual evaluation of the resulting ortho-mosaic shows relative and absolute accuracies of about ±2 m and ±3-4 m (68% level of confidence) with maximum errors slightly less than 6 m and 10 m, respectively. It confirms that the ±5 m rms error of the ground data did not propagate into the 3D parametric model. Part of the mosaic error is due to the ±5 m rms error of the DEM in the ortho-rectification of 15º-to-30º viewing angle images.

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