Path Processing and Block Bundle Adjustment With RADARSAT-1 SAR Images♥

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***Abstract*- Spatio-triangulation process is applied to 15 RADARSAT-SAR fine mode images (5 paths by 3 rows). The paths were acquired over Rocky Mountains, Canada from different look angles (F1 and F4), creating a weak 6° intersection geometry. Precise geometric correction model and algorithms developed at CCRS were used. Results over 3-image paths and 5-path block gave errors of 20 m and 25-35 m, respectively. These final errors are mainly due to the weak 6°-intersection geometry, but also include the map errors. For better accuracy, the adjacent paths should have 8° minimum difference in the look angles.**

I. INTRODUCTION

As in photogrammetry where strips and blocks of aerial photos are processed together, the path and block adjustment can be applied to satellite images from same and/or adjacent orbits. The geometric processing is performed with a block bundle adjustment instead of a single image bundle adjustment. This block bundle adjustment process was first developed and tested with off-nadir viewing VIR images [1, 2]. Few results have been published with SAR images [3].

There are advantages to path and block bundle adjustment:

- It reduces the number of ground control points (GCPs);
- A better relative accuracy between the images is obtained;
- A more homogeneous and precise mosaic over large areas is achieved; and
- It generates a homogeneous GCP network for future geometric processing.

Path and block bundle adjustments use an iterative least-square adjustment with GCPs and orbit information to compute geometric-model parameters of all images together. With the block bundle adjustment, the same number of GCPs is theoretically needed to correct either a single image, an image path or a block: 6 GCPs are enough for RADARSAT [4]. However, in operational context, it is better to use more due to potential errors in GCP identification, plotting and maps. The least-square block bundle adjustment will thus reduce their error propagation.

This paper will present a method to generate and process image paths and block from RADARSAT-SAR images acquired over a challenging study site in the Canadian Rocky Mountains. Comparative results between the processing of a single image, image path(s) or block are presented to evaluate the accuracy of the system and its stability. The mathematical tool used is the multi-sensor 3D parametric correction model developed at the Canada Centre for Remote Sensing (CCRS) [5] and adapted to RADARSAT-SAR data [4].

II. STUDY SITE AND DATA SET

The study site is located in the south of the Canadian Rocky Mountains (49° N to 50° N; 121° W to 123° W) from Vancouver in the south-west to Okanagan Range in the south-east (Fig. 1). This challenging area is characterised by a rugged topography where elevation ranges from 300 m along lakes in valleys to 4000 m. The land cover consists mainly of a mixture of coniferous and deciduous trees with patches of agricultural land and clearcut areas, while the mountains over 2500 m are covered by snow and glaciers. The agricultural fields are found mostly along valleys, while the clearcut areas, linked by new logging roads, are distributed over the whole area. Roads are mainly loose or stabilised surface roads in the mountains, and hard surface roads in the valleys. Lakes and ponds are also found which are connected through a series of creeks flowing between steep cliffs.

15 RADARSAT-SAR fine mode images were acquired over the study site (Fig. 1 & Table I), and cover an area of 150 km by 200 km. They were alternatively acquired from beam 1 (Paths 2 & 4) and beam 4 (Paths 1, 3 & 5) from descending orbits, and processed in slant range oriented along the orbit path with 6.25-m pixel spacing. They generate a block with five paths and three rows with approximately 20% overlap between adjacent paths (Fig. 1). With same-side look angles adjacent paths have a weak intersection angle (6°) and geometry in the overlaps. All the paths have three images are acquired from the same physical orbit and at the same date. Consequently, the three images of the same orbit were processed together to generate 50x150-km image paths (about 8000 columns by 24,000-28,000 lines). This enabled different image/path/block bundle adjustments to be tested.

TABLE I
Description of RADARSAT-SAR Images and Paths

SAR Mode & Beam	Fine, beam 1	Fine, beam 4
Path numbers	2 & 4	1, 3 & 5
Orbit	Descending	Descending
Resolution	9.1 m x 8.4 m	8.1 m x 8.4 m
Look angles	36.8° - 39.9°	43.1° - 45.8°

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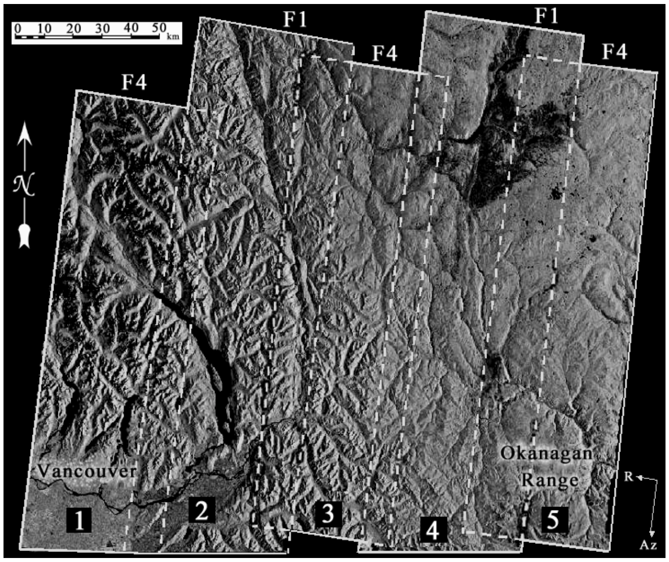

Fig. 1. RADARSAT-SAR fine mode image paths and block (200x150 km) over the Canadian Rocky Mountains study site

Cartographic data consisted of 42 topographic maps at 1:50 000 with 25-30 m accuracy. About 70 ground points per path (mainly lakes and rivers) were collected. The DEM for the final ortho-rectification was derived from digital 10-m contour lines of 1:50,000 maps with 20-m grid spacing and a 10-15-m vertical accuracy.

III. METHOD DESCRIPTION

The geometric model used for bundle adjustment to compute all images and/or paths together is based on the integrated and unified 3D parametric model for multi-sensor images developed at CCRS [5] and adapted for radar images [4]. This 3D parametric model has been applied with 3 to 6 GCPs to VIR data (Landsat 5 & 7, SPOT, IRS, ASTER, KOMPSAT, IKONOS and QuickBird), as well as radar data (ERS, JERS, SIR-C and RADARSAT). Based on accurate GCPs, errors within one-third of a pixel were obtained for medium-resolution images, two pixels for high-resolution images and one resolution cell for radar images.

As with the ortho-image rectification, there are four main processing steps to generate ortho-images and an ortho-mosaic with the path/block bundle-adjustment process [5]:

(1) Acquisition and pre-processing of the SAR images and their metadata;
(2) Acquisition of ground points (image and cartographic co-ordinates) on each image path and tie points (image and elevation co-ordinate) in the overlap areas;
(3) Computation and evaluation of the path/block bundle adjustment for 1 to 5 image paths together;
(4) Generation of ortho-images and of the ortho-mosaic with a DEM and the previously computed 3D parametric models.

Although six GCPs are enough to establish the exact spatial position and orientation of each SAR image or path, about 70 GCPs were individually acquired on each image path. A larger number of GCPs enables to reduce the propagation of ±25 m RMS map errors in the least-square block bundle adjustment computation of the 3D parametric models, and also were used to perform accuracy tests with Independent Check Points (ICPs). Since there is overlaps between adjacent images (Fig. 1) elevation tie points (ETPs) (i.e., features present in both images) were acquired to link adjacent image paths with the terrain. ETPs increase the relative accuracy between images. The points (GCPs and ETPs) are weighted in the least square adjustment as a function of their accuracy (cartographic and image co-ordinates).

Four sets of block bundle adjustments were performed with this data set by varying the distribution and number of GCPs used in the adjustment and the number of images and paths in the block:

A. All points are used as GCPs for one single image (as reference), for 3-image paths and for the whole block;
B. Path processing with a limited number of points;
C. All GCPs on the outer images and ETPs in the overlaps for the three, four and five image paths; and
D. GCPs every two image paths and ETPs in each overlap for the full (5 paths) block (“*checkerboard*”).

III. RESULTS AND ANALYSIS

A. All Points Are Used

The first results are with the computation of the least square block/bundle adjustment using all GCPs for one image (as reference), for all 3-image paths and for the 5-path block. Table II gives the RMS residuals on GCPs for the path/block bundle adjustment with these seven configurations. The residuals reflect the modelling accuracy and represent *a priori* mapping error taking into account the original error of the input data.

TABLE II
RMS Residuals of Different Image/Path Block Adjustments

Image/Path Block Configuration	Number of GCPs	RMS Residuals X (m)	RMS Residuals Y (m)
Reference Image[a]	27	18	16
Path 1	54	17	17
Path 2	80	25	19
Path 3	75	25	19
Path 4	72	19	19
Path 5	62	19	18
5-Path Block	343	21	18

[a] Being the mean of the 15 images computed separately

The results show a consistency and robustness in the adjustment whatever the image configuration (reference image, paths or block). All the tests for path/block configurations give similar results to reference test with one image, 17-25 m in both axes. In relation with the accuracy of the input data (25-30 m) the RMS residuals reflect this accuracy and are consistent with previous results [4].

B. Path Processing

The path processing corresponds to the processing of long strips of images (path) acquired from the same orbit and processed without GCP in the path centre. Consequently, 10-12 GCPs at the North and South end of each path were used for the separate least-square adjustment of each 3-image path. The results were checked using the remaining ICPs in the centres of paths. The RMS errors on ICPs are about the same for all image paths: 20-25 m in both axes, which correspond to the map errors, with maximum/minimum errors less than three times the RMS errors. These errors are also consistent with previous results of the geometric processing of SAR images [4, 5]. Consequently, it proves that the 3D parametric model is well adapted and accurate for path processing.

C. All GCPs on the Outer Paths

All GCPs were used for the two outer paths with ETPs to link the inner paths. The adjustment results are checked on the remaining ICPs in the inner paths. Table III gives the RMS residuals/errors (RMS-R/RMS-E) of the GCPs/ICPs, respectively for the block adjustments of different number of paths (3, 4 and 5). The errors reflect the final accuracy taking into account the original error of the input data (25 m).

When there is only one inner path without GCP (3-path block) the results are good and of the same magnitude as the previous results (25 m in both axes, Table II). However, the results, mainly RMS-E in X, quickly degrade as soon as the number of inner paths increases. It is important to note that the X-direction mainly corresponds to the elevation distortion. Consequently, the weak intersection geometry (6° angle) between the inner adjacent paths (3 and 4 for 4-path and 5-path block, respectively) does not correctly “transfer” the information from outer paths to inner paths. GCPs every two paths (“*checkerboard*”) are then needed with a **weak** intersection geometry.

D. GCPs every two Paths (“Checkerboard”)

Different GCP numbers are tested in the outer paths (1, 5) and middle path (3): (i) 54, 62, 75; (ii) 25, 25, 25; (iii) 25, 25, 6, respectively (Table IV). These tests evaluate the system robustness and its stability in an operational environment.

TABLE III

RMS Residuals/Errors for Block Adjustments with 3-5 Paths

Block Configuration	RMS-R X (m)	RMS-R Y (m)	RMS-E X (m)	RMS-E Y (m)
3-Path Block	22	17	26	24
4-Path Block	23	19	65	23
5-Path Block	19	17	271	43

TABLE IV

RMS Residuals/Errors for *Checkerboard* Block Adjustments

Number of GCPs For Paths 1, 3, 5	RMSR X (m)	RMSR Y (m)	RMSE X (m)	RMSE Y (m)
54, 75, 62	19	17	36	26
25, 25, 25	19	15	35	27
25, 6, 25	17	15	36	26

Al results are consistent with a slight degradation in the X-direction. However, the 25-m map errors are included in these final errors and a better accuracy can thus be expected, mainly with a better intersection geometry. It should be noted that only 56 GCPs are use in the full block (200 km x 150 km) over a rugged and challenging topography.

CONCLUSIONS

The CCRS-developed 3D parametric model and algorithms were successfully applied for path and block adjustment processing of 15 RADARSAT-SAR images (5 paths by 3 rows) acquired over a mountainous study site. Path processing of 3-image paths was applied without GCPs in the centre, and 20-25 m errors were achieved. The full block adjustment was performed with 56 GCPs (50 in the outer paths and 6 in the middle path), and 25-35 m errors were achieved. These errors result from a weak 6°-intersection geometry between adjacent paths and from 25-m map errors.

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