Multi Sensor Block Adjustment

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***Abstract*- Spatio-triangulation process, based on a multi-sensor block adjustment, is applied to 40 different VIR and SAR images: Landsat-7 ETM$^+$, panchromatic SPOT-4 HRV, multi-band ASTER, RADARSAT (fine, standard, wide modes) and ERS-1. The images were acquired over Rocky Mountains, Canada from different view/look angles (nadir, across- and in-track) creating various intersection geometries in the overlap areas. Only 1:50,000 paper maps were available for this area. A physical multi-sensor geometric correction model and algorithms developed at the Canada Centre for Remote Sensing were used for the processing. Preliminary results of block formed with all images gave positional errors of around 20-26 m. These errors result from medium-resolution sensors (ERS-1, RADARSAT standard/wide modes, Landsat-7 ETM$^+$), from weak intersection geometry between some images, but these errors also include the 1:50,000 map errors (25-30 m).**

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 thus performed with a block bundle adjustment instead of a single image bundle adjustment. The different advantages to path and block bundle adjustment are:

- The number of ground control points (GCPs) can be largely reduced;
- All image/path geometric model are computed together;
- A better relative accuracy between the images can be obtained;
- A more homogeneous and accurate ortho-mosaic over large areas can be achieved; and
- A homogeneous GCP network for future geometric processing can be generated.

To simultaneously compute the image/path geometric model parameters, path and block bundle adjustments generally apply an iterative least-square adjustment with GCPs and orbit information to compute geometric-model parameters of all images together. With the block adjustment, the same number of GCPs is theoretically needed to correct either a single image, or an image path or a block. In addition, tie points in the overlap areas should be used to generate a relative link between the images. The number of GCPs (1 to 6) depends on the type of image, the physical model and the experimentation conditions. However, in an operational context, it is recommended to use more GCPs than the theoretical number due to errors in GCP identification, image pointing and maps in order to take full advantages of the least-square adjustment. The least-square block bundle adjustment will thus reduce their error propagation.

The block bundle adjustment process was first developed and tested with single sensors: French SPOT-HRV across-track stereo images [1], German MOMS along-track stereo images [2], Landsat-7 ETM$^+$ nadir images [3], ERS-1 SAR images [4], RADARSAT-1 SAR images [5, 6]. However, no experiment has been realized with multi-sensor image block.

This paper will present a method to process image paths and block from multi-sensor images (VIR and SAR) 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 physical geometric correction model developed at the Canada Centre for Remote Sensing (CCRS), Natural Resources Canada [7].

II. STUDY SITE AND DATA SET

The study site is located in the south of the Canadian Rocky Mountains (49° N to 53° N; 116° W to 122° 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. 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.

Different images (VIR and SAR) were acquired over the study site (Fig. 1). Their characteristics are summarized in Table I. The larger block (600 km by 500 km) is covered by 15 Landsat-7 ETM$^+$ (15-m pixel spacing) from five paths and three rows. 40% overlaps in the East-West direction generate weak intersection angles of 7-8°. Only the three western paths were used in this experiment. Same-date images were stitched together to create continuous paths of 2-3 images.

A first smaller block (150 km by 200 km) is covered by five panchromatic SPOT-4 HRV raw level-1A data (10-m pixel). They generate a block with two paths of two-to-three rows with approximately 10% overlap between paths. Left and right paths were acquired with -3° and 11° viewing angles. Since the paths were acquired from the same physical orbit and at the same date, the images of the same orbit were

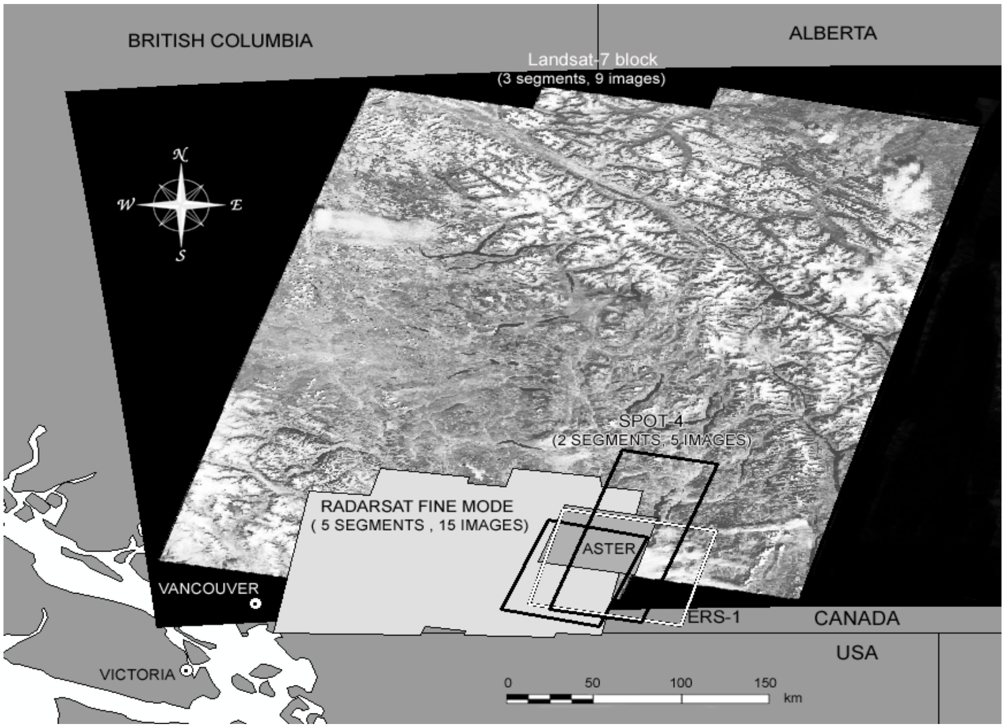

Fig. 1. RADARSAT-SAR fine mode image paths and block (200x150 km) over the Canadian Rocky Mountains study site

stitched together to generate 2-3 image paths.

An ASTER image with the VNIR subsystem from a descending orbit, cover approximately an area of 60 km by 60 km. The Level 1A raw data (4100 pixels by 4200 lines) are reconstructed unprocessed instrument digital counts with a ground resolution of 15 m. Only the near-infrared 26° backward and nadir images (3B and 3N) are used.

TABLE I
Description of VIR/SAR Images and Paths

Satellite, Sensor	Nb. Images, Path & Row	Viewing Angles
Landsat-7, ETM$^+$	9, 3 & 3	±7.5°
SPOT-4, HRV	5, 2 & 2-3	-3° & 11°
Terra, ASTER	2, 1 & 2	0° & 26° back
RADARSAT, SAR	15, 5 & 3	36.8° - 45.8°
ERS-1, SAR	1	-23°

A second smaller block is covered by 15 SGF RADARSAT-1 SAR fine mode images. The fine mode images generate a block with five paths and three rows with approximately 20% overlap between adjacent paths. They were alternatively acquired from beam 1 (37°-40°) and beam 4 (43°-46°) on descending orbits. With same-side look angles adjacent paths have a weak intersection angle (6°) in the overlaps. Since the images of the same path were acquired from the same physical orbit and at the same date, the images were stitched together to generate 3-image paths.

An ERS-1 SAR images was also available from a descending path with 23º viewing angle spacing (bottom-center in Fig. 1). The SGF-product image is generated in ground range projection with 12.5-m pixel.

Cartographic data consisted of 42 topographic maps at 1:50 000 with 25-30 m accuracy. 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 block bundle adjustment is based on the integrated and unified 3D physical model for multi-sensor images developed at CCRS [5]. This 3D physical model has been applied with 3 to 6 GCPs to VIR data (Landsat 5 & 7, SPOT-1/5, 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, one pixel for high-resolution images and one resolution cell for radar images.

Before the ortho-image rectification, there are three 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 VIR/SAR images and their respective metadata;
(2) Acquisition of ground points (image and cartographic co-ordinates) on each image path and tie points (ETPs) (image and elevation co-ordinates) in all overlap areas;
(3) Computation and evaluation of the block bundle adjustment for different block types.

70-90 ground points were acquired on each image or path for a total of 1357 points (mainly roads, lakes, rivers depending of the image content) with a positional accuracy of 25-30 m. Most of the points will be used as Independent Check Points (ICPs) to perform accuracy tests. In all image overlaps, ETPs (i.e., features present in both images) were acquired to link adjacent image paths with the terrain. Three sets of block bundle adjustments were performed:

A. The block adjustment is independently computed for each sensor using their respective GCPs;
B. The block adjustment is simultaneously computed for all sensors with all GCPs;
C. The block adjustment is simultaneously computed for all images and paths with a reduced number of GCPs.

III. RESULTS AND ANALYSIS

A. Block independently computed for each sensor

The first results are with the computation of the least square block adjustment independently for each separate block sensor: e.g., the Landsat-7 ETM$^+$, SPOT-4 HRV, ASTER VNIR and RADARSAT-1 SAR. The results are also given for the least square adjustment of the single ERS-1 SAR image. Table II (first 5th lines) gives the root mean square (RMS) residuals on GCPs for the block adjustments.

TABLE II
RMS Residuals (in meters) of Different Block Adjustments

Image Block	Number of GCPs	RMS Residuals X (m)	RMS Residuals Y (m)
Landsat-7 ETM$^+$	803	22.6	21.2
SPOT-4 HRV	259	16.4	18.2
ASTER VNIR	81	20.1	20.7
RADARSAT-1 SAR	426	21.4	19.6
ERS-1 SAR	64	29.1	23.0
All image blocks	1357	21.4	20.2

The results show consistency and robustness in adjustments regardless of the image sensor (rotating or push-broom scanner, across-or in-track, SAR) and of the resolution (8-30 m). RMS residuals (17-29 m) are mainly due to the map error (25-30 m), which is the predominant error in the error budget.

B. Block simultaneously computed for all sensors

Table II (last line) gives the RMS residuals on GCPs for the simultaneous block adjustment of all images. Results are equivalent than for independent block: around 20 m, which is in the order of the cartographic error. Since RMS residuals reflect this error, the internal accuracy of blocks is thus better than the RMS residuals [3, 6, 7].

C. Block simultaneously computed with reduced GCPs

The last test is performed with a reduced number of GCPs: 15-20 for each image or path, except for the Landsat ETM$^+$ and RADARSAT-SAR, where GCPs were used every second paths ("checkerboard") [3, 6]. The 500 other GCPs are used as ICPs. In addition, around 50 ETPs were used between each overlap area. Most of ETPs were common to 3-5 images creating a relative link between them. RMS errors of 24 m with 4-m bias were obtained over 500 ICPs, demonstrating consistency with the two previous results. More results will be presented at the Symposium.

CONCLUSIONS

The CCRS-developed 3D parametric model and algorithms were successfully applied for block adjustment processing of multi-sensor images acquired over a mountainous study site. Consistent results were achieved regardless the type of VIR/SAR image block and the number of GCPs. With a reduced number of GCPs, 24-m RMS errors with 4-m over 500 ICPs were achieved. These errors result from medium-resolution sensors, weak intersection geometry between adjacent paths and include the 25-m map errors.

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