GEOMETRIC VALIDATION OF ALOS/PRISM IMAGES

Armin Gruen, Sultan Kocaman, Kirsten Wolff

ETH Zurich
Institute of Geodesy and Photogrammetry , CH-8092 Zurich, Switzerland
<agruen><skocaman><wolff>@geod.baug.ethz.ch

Abstract
The photogrammetric processing of ALOS/PRISM imagery has special requirements due to the Linear Array CCD sensor structure. A set of algorithms for processing of high resolution satellite imagery has been developed by our group at ETH Zurich and realized in a software suite called SAT-PP, which has already been tested successfully for different sensors.
We have implemented new algorithms for the geometric processing of the PRISM images, in particular for the interior orientation and self-calibration. In addition we have refined our sensor models according to the multiple camera head structure of the sensor.
We have tested our methods of georeferencing and DSM generation for four different testfields. The rigorous sensor model performs well and results in sub-pixel accuracy of 0.48-0.35 pixels in planimetry and height for georeferencing and point determination. The height RMS error of the DSM generation is around two pixels over all. Locally, the accuracy depends strongly on the topography, land use characteristics and image quality.

Keywords: PRISM images, high resolution, sensor modelling, calibration, validation, DSM generation

1. INTRODUCTION

High resolution satellite images have been widely used in recent years to acquire panchromatic and multispectral images in pushbroom mode for photogrammetric and remote sensing applications. Most of these sensors use Linear Array CCD technology for image sensing and are equipped with high quality orbital position and attitude determination devices like GPS, IMU systems and/or star-trackers. The ALOS/PRISM sensor is also operating in the pushbroom mode, and has Linear Array CCD pixels with 2.5 meter ground resolution. It provides along-track quasi-simultaneous overlapping triplet imagery with three different viewing angles. This leads to a reduction of problems for image matching, mainly caused by occlusions, multiple solutions, surface discontinuities, and results in a higher accuracy.
We have developed a full suite of new algorithms and the software package SAT-PP (Satellite Image Precision Processing) for the precision processing of high-resolution satellite image data. The software can accommodate images from IKONOS, QuickBird, SPOT5 HRG/HRS, Cartosat-1 and sensors of similar types to be expected in the future.
For the georeferencing of aerial Linear Array sensor imagery, we have implemented a modified bundle adjustment algorithm with the possibility of using three different trajectory models [1]. Two of those models, the DGR and the PPM are modified for the special requirements of the PRISM sensor and extended with additional parameters (APs) for self-calibration, to possibly improve the camera's interior orientation parameters and to model other systematic errors. The self-calibration model currently includes a total of 30 additional parameters for all 3 cameras.
The matching algorithm for the DSM generation is based on a multi-image least-squares matching for feature points, grid points and lines and is applicable for linear array and single frame sensors [2].
The results of our work for processing ALOS/PRISM imagery are presented in this paper. Although the images have particular radiometric quality problems leading to image artifacts, partially to fixed pattern noise, the sensor orientation and matching results are at a good level of accuracy. The reasons for those deficiencies are problems with black reference calibration (resulting in striping), jpeg-compression (resulting in blocking), saturation effects (mainly related to only 8-bit radiometric depth collection), and others [4]. Lately, JAXA proposed a new processed version of the early ALOS/PRISM imagery with less striping. The reduction of the striping doesn't has an influence for georeferencing and only a local influence on the DSM generation, but not on the height RMSE over all.

2. METHODS

2.1 ALOS/PRISM Rigorous Sensor Model

We have developed a modified bundle adjustment procedure for the rigorous sensor modelling of ALOS/PRISM imagery. The original model has been developed for the georeferencing of airborne Three-

Line-Scanner (TLS) imagery [1]. The method employs the collinearity equation and allows the use of different trajectory models. Three models have been implemented and tested within the TLS Project. Two of them, the Direct Georeferencing (DGR) Model and the Piecewise Polynomial Model (PPM) have been extended for the georeferencing of PRISM imagery. The specifications of the PRISM interior and exterior geometries have been taken into account in the models.
The sensor platform trajectory values are provided in the image supplementary files of PRISM images. The attitude and position estimates are based on star tracker and GPS receiver data [3]. The given trajectory values are used as stochastic unknowns (observed values) in the adjustment.
Self-calibration is an efficient and powerful technique used for the calibration of photogrammetric imaging systems. It is an alternative and supplementary method to the laboratory and testfield calibration. The method can use the laboratory calibration data as stochastic input in the adjustment. For the self-calibration of the PRISM imagery, we have initially defined 30 additional parameters (APs) for the 3 cameras. The parameters are described in accordance with the physical structure of the PRISM imaging sensors [4] [5]. The AP set of each image includes:
+ scale effect in *y* direction (per image),
+ CCD line bending parameter (per image),
+ displacements of the centres of the CCD chips from the principal point of the relevant camera.

2.2 DSM Generation using SAT-PP

The powerful software package SAT-PP was tested effectually for different images from sensors like IKONOS, QuickBird, SPOT5 HRG/HRS and Cartosat-1. The image matching approach of SAT-PP for automatic DSM generation from multiple images acquired by linear array sensors has the ability to provide dense, precise, and reliable results. The approach uses a coarse-to-fine hierarchical solution with an effective combination of several image matching algorithms for multiple views, feature points, grid points and lines and automatic quality control [2] [6] [7] [8]. To improve the matching results image pre-processing with the Wallis filter is realized. To avoid the negative influence on the matching results in water and cloud areas we defined them as dead areas without any height information.

3. EMPIRICAL TESTS

As a Member of JAXA's Calibration/Validation Team we have so far processed data over 4 testfields: Piemont, Italy, Saitama and Okazaki, Japan and Bern/Thun, Switzerland. The DGR model and the PPM are used for the georeferencing tests. The self-calibration is applied in all tests.

3.1 Saitama Testfield, Japan

The Saitama testfield is located in the north-east of Tokyo, Japan. The PRISM images have been acquired in April, 2006. There are 203 ground control points measured on the images. The image measurements of the GCPs have been performed by JAXA. The tie points were measured manually at our Institute. A brief overview of the accuracy results is given in Table 1. The results are in meters.

Table 1. The DGR and the PPM results of Saitama tests with self-calibration and different GCP configurations

GCP no.	*5*	*5*	*9*	*9*	*25*	*25*
Model	*DGR*	*PPM-2*	*DGR*	*PPM-2*	*DGR*	*PPM-2*
$RMSE_{XY}$	1.38	2.10	1.24	1.25	1.24	1.34
$RMSE_Z$	2.46	2.77	2.13	2.33	2.00	2.30
σ_{XY}	0.79	1.52	0.74	0.86	0.71	0.70
σ_Z	2.10	2.76	1.98	2.18	1.92	1.89

The image triplet of Saitama contains many small clouds. We do not have any reference DSM for this area, therefore we generated the DSM without defining any dead area to see the influence of the clouds.
The bigger clouds could be matched reasonably between the three images and they are the highest areas of the DSM. The smaller clouds could not be matched correctly. The matcher found for the images of the clouds false matches (usually buildings with light image signatures). So each small cloud produces up to three blunders in the DSM, lined up in flight direction.

3.2 Bern/Thun Testfield, Switzerland

The Bern/Thun testfield is the area between the two Swiss cities Bern and Thun. The area contains beside the two cities different terrain types like a mountainous region in the southern part, smooth hilly regions, open areas, forests, two rivers and the Lake of Thun. The testfield in its current form and the GCP field was set up by our group under a contract with JAXA. The coordinates of the GCPs were determined by GPS.
The results of triangulation are given in Table 2. The results are in meters. The accuracy both in planimetry and height, as evidenced by $RMSE_{XY}$ and $RMSE_Z$, is below 1 pixel in all DGR tests. The PPM is instable with a small number (5) of GCPs.

Table 2. The DGR and PPM results of Bern/Thun tests with self-calibration and different GCP configurations

GCP no.	*5*	*5*	*9*	*9*	*25*	*25*
Model	*DGR*	*PPM-2*	*DGR*	*PPM-2*	*DGR*	*PPM-2*
$RMSE_{XY}$	2.23	4.35	1.97	3.47	1.80	1.93
$RMSE_Z$	1.77	5.24	1.57	3.30	1.46	3.21
σ_{XY}	0.82	2.52	0.75	0.99	0.89	1.01
σ_Z	2.09	6.51	2.01	2.62	2.43	2.77

Table 3. DSM accuracy evaluation results of the three testareas Thun, SW (SouthWest) and Bern and for different sub-areas (O- Open areas, C – City areas, T – Tree areas, A – Alpine areas).

TF	*# points*	*RMSE [m]*	*Mean [m]*	*Min [m]*	*Max [m]*	*<5m*	*5m-12.5m*	*12.5m-25m*	*>25m*
Thun	**3508099**	**5.5**	**1.2**	**-41.6**	**63.4**	**75.6%**	**20.4%**	**3.7%**	**0.3%**
- O1	202704	4.7	1.1	-30.3	35.4	84.8%	12.2%	2.9%	<0.1%
- A2	291284	7.2	2.6	-33.8	61.3	74.7%	17.1%	7.2%	1.0%
SW	**2752822**	**6.6**	**0.55**	**-76.9**	**84.5**	**70.7%**	**23.6%**	**4.8%**	**0.9%**
- A1	815265	6.7	2.2	-46.4	80.0	74.0%	20.9%	4.6%	0.5%
- T1	80033	12.8	-1.8	-74.5	64.2	45.8%	32.4%	15.4%	6.4%
Bern	**4340836**	**5.7**	**-1.3**	**-60.0**	**50.0**	**70.8%**	**25.4%**	**3.5%**	**0.3%**
- C1	123954	5.6	-3.1	-74.6	70.9	97.2%	2.4%	0.3%	<0.1%
- C2	174464	5.0	-2.7	-28.5	27.8	98.0%	1.9%	0.1%	~0% (2)
- T2	126727	7.9	-2.9	-42.4	34.4	34.4	91.4%	7.4%	1.1%

For the validation of the sensor model of PRISM we used the whole area, for the validation of the DSM generation we used three smaller parts. The three reference DSMs where generated with aerial images and our software package SAT-PP. We defined the rivers and bigger lakes as dead areas without any given height. The expected accuracy of the DSMs is in the range of 0.5 m to 2.5 m and is therefore by a factor 5 better than the expected PRISM matching results [9].
The reference and the generated DSM were given at the same grid points. Therefore the comparison of the two DSMs could be realized by a calculation of the vertical difference between them.
We evaluated the DSM accuracy for each testfield separately and also for different sub-areas with special topographic or land use features: one open area O1, city areas C1 and C2, tree areas T1 and T2 and alpine areas A1 and A2. Table 2 gives the DSM accuracy evaluation results. The overall height RMSEs for all three test areas are better than three pixels (5.5 m – 6.6 m). As we expected, we get the best accuracy for open areas (O1, 4.7 m). The worst results were obtained for a tree area next to a river, although a fairly wide area around the river was defined as dead area (forest area T1). There are still some blunders left in the data (up to 85 m), as can be seen from the histogram values of Table 3. This blunders results mainly from shadows.
For this testfield we had also the new version of the images with less striping. There was no influence on the overall height RMSEs of the DSM generation, only a local influence could be detected.

3.3 Piemont Testfield, Italy

The Piemont testfield is located in the north western part of Italy. Most of it is very mountainous, so it is difficulty to get a good distribution of GCPs. The testfield was set up by GAEL, France. The coordinates of 29 GCPs were determined by GPS.
The DGR model and the PPM have been tested with two different GCP configurations and the results are given in Table 4. The accuracy values are at sub-pixel level for all models. The DGR model performs again better than the PPM in the 5 GCPs configuration.

Table 4. The DGR and the PPM results of Piemont tests with self-calibration and different GCP configurations

GCP no.	*5*	*5*	*9*	*9*
Model	*DGR*	*PPM-2*	*DGR*	*PPM-2*
$RMSE_{XY}$ (m)	2.34	2.58	2.22	2.20
$RMSE_Z$ (m)	1.05	2.36	1.03	1.20
σ_{XY} (m)	0.58	2.37	0.59	0.68
σ_Z (m)	1.60	4.10	1.64	1.82

3.4 Okazaki Testfield, Japan

The last testfield has been generated by JAXA and is located in the area of Okazaki, Japan. 51 GCPs are used in the adjustment. A given reference DSM (6 x 6 km^2) in the southern part of the testfield consists mostly of forest and has been generated by using aerial images. The DGR results with 5, 9, and 25 GCP configurations and the PPM results with 25 GCPs are presented in Table 5.

Table 5. The DGR and the PPM results of Okazaki tests with self-calibration and different GCP configurations

GCP no.	*5*	*9*	*25*	*25*
Model	*DGR*	*DGR*	*DGR*	*PPM-1*
$RMSE_{XY}$ (m)	2.0	1.9	1.9	2.0
$RMSE_Z$ (m)	3.2	2.4	1.8	1.8
σ_{XY} (m)	1.2	1	0.9	0.9
σ_Z (m)	3.0	2.6	2.5	2.5

Table 6 gives an overview of the DSM accuracy evaluation results. The sub area with the reference DSM contains nearly 400 000 points. The height RMSE is better than three pixels (6.3 m).

Table 6. DSM evaluation results of testfield Okazak.

# points	*$RMSE_Z$ [m]*	*Mean [m]*	*Min [m]*	*Max [m]*
388710	6.3	2.4	-102.4	99.6
Z -Z_{Ref} <5m	*Z -Z_{Ref} 5-12.5m*	*Z_G -Z_{Ref} 12.5-25m*	*Z_G -Z_{Ref} >25m*	
64.9%	31.0%	3.5%	0.6%	

4. CONCLUSIONS

We have calibrated and validated early ALOS/PRISM images over 4 testfields: Piemont, Italy, Saitama and Okazaki, Japan, and Bern/Thun, Switzerland. We calibrated the PRISM system using the technique of self-calibration. In all cases we used PRISM image triplets. Validation is a system approach, it includes the sensor performance, but also the quality of both the data processing algorithms and the reference data.

The validations of our georeferencing procedures could be performed in all 4 testfields. For georeferencing we applied both our sensor/trajectory models DGR and PPM and found that DGR had the better performance in case of very few GCPs. Under the given sensor configurations the PPM method turned out to be a bit instable with 5 GCPs, but with 9 and more GCPs both methods performed equally well overall.

If we only consider the DGR results here we achieved over all 4 testfields the following average values:

+ Planimetric accuracy: RMSE(X,Y) = 1.2 - 2.3 m
Sigma (X,Y) = 0.58 - 0.94 m

+ Height accuracy: RMSE(Z) = 1.0 - 2.5 m
Sigma (Z) = 1.6 – 2.6 m

+ Estimated accuracy of image coordinates Sigma0 = 0.27 – 0.54 pixel

We note that in some cases the empirical height accuracy values (RMSE(Z)) are better than the corresponding theoretical precision values (Sigma(Z)).

Over all 4 testfields we achieved with our empirical accuracy values quite consistent results: We stay in all cases in the sub-pixel domain, in the best cases we achieved about half pixel accuracy.

The performance of PRISM imagery in connection with our multi-image matcher of SAT-PP was tested by calculation the height RMSE for three sub-areas of the Bern/Thun testfield (mixed areas) and one in Okazaki (forest area).

The height RMSE over all is 5 – 7 m for the raw matching results without any post-processing for blunder removal. Additionally, we defined within the sub-areas of Bern/Thun, areas of specific and homogeneous topographic/land use characteristics (open space, city, forest and alpine) in order to test the DSM generation quality in dependence of these parameters. The height RMSE values ranged from 4.7 m (open areas) to 12.8 m (forest). This corresponds to a height accuracy of 2 – 5 pixels.

For the Bern/Thun testfield we had also a new version of the image data with less striping. We detected only a local influence on the DSM generation. The height RMSE over all did not changed.

If we compare these georeferencing results with those which were obtained with other satellite sensors of similar type (SPOT-5, IKONOS, Quickbird) we note that the accuracy (expressed in pixels) is about the same.

A critical point for future research has to be the detection and/or avoidance of blunders.

5. REFERENCES

[1] A. Gruen, L. Zhang, “Sensor Modeling for Aerial Triangulation with Three-Line-Scanner (TLS) Imagery”, Journal of Photogrammetrie, Fernerkundung, Geoinformation (PFG), 2/2003, pp. 85-98.

[2] A. Gruen, L. Zhang, H. Eisenbeiss, “3D Precision Processing Of High Resolution Satellite Imagery”, ASPRS 2005 Annual Conference, Baltimore, Maryland, USA, March 7-11, on CD-ROM.

[3] T. Iwata, “Precision Geolocation Determination and Pointing Management for the Advanced Land Observing Satellite (ALOS)”, IEEE/IGARSS 2003, July 21-25, Toulouse, France.

[4] A. Gruen, S. Kocaman, K. Wolff, “Calibration and Validation of Early ALOS/PRISM Images”, The Journal of the Japan Society of Photogrammetry and Remote Sensing, Vol 46, No. 1, 2007, pp. 24-38.

[5] S. Kocaman, A. Gruen, “Orientation and Calibration of ALOS/PRISM Imagery”, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVI, Part I/W51, 2007.

[6] L. Zhang, “Automatic Digital Surface Model (DSM) Generation from Linear Array Images”, Ph. D. Dissertation, Report No. 88, Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland, 2005, 206 p.

[7] L. Zhang, A. Gruen, “Automatic DSM Generation from Linear Array Imagery Data”, International Archives of Photogrammetry and Remote Sensing, 35(B3), 2004, pp. 128-133.

[8] L. Zhang, A. Gruen, “Multi-image matching for DSM generation from IKONOS imagery”, ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 60, No. 3, May 2006, pp.195-211.

[9] A. Gruen, H. Eisenbeiss, T. Hanusch, M. Sauerbier, K. Wolff, “Documentation of the reference DSMs of the ALOS testfield Bern/Thun”, Report to JAXA, 2006.

ACKNOWLEDGEMENTS

The authors would like to thank JAXA, Japan and GAEL, France for providing the reference data for the Saitama and Piemont testfields and acknowledge their continuous support throughout this study.