UP TO DATE DSM GENERATION USING HIGH RESOLUTION SATELLITE IMAGE DATA

K. Wolff*, A. Gruen

Institute of Geodesy and Photogrammetry, ETH Zurich
Wolfgang-Pauli-Str. 15, CH-8093 Zurich, Switzerland – (wolff, gruen@geod.baug.ethz.ch)

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ABSTRACT:

Due to the increasing costs of high resolution satellite image data with stereo capabilities, products like accurate DSMs are becoming attractive for more and more users and applications. The Japanese optical sensor ALOS/PRISM which was launched in January 2006 has stereo capabilities by providing a simultaneous acquired image triplet. We have published several results of our evaluation of the potential of ALOS/PRISM image data together with our powerful software packages SAT-PP (Satellite Image Precision Processing) for DSM generation. Here, we focus on a new aspect, namely on the potential of the use of the image triplet in comparison to the use of just a stereo image pair, e.g. the combination of FN and FB. As we will see improves the use of a third image the results of the DSM generation especially for the combination of FB, but also for the combination FN. Additionally we will present the evaluation results of a new testfield, the volcano Sakurajima in Japan. The special characteristics of the volcano surface are very difficulty conditions for the image matching and DSM generation.

1. INTRODUCTION

Due to the increasing costs of high resolution satellite image data with stereo capabilities, products like accurate DSMs are becoming attractive for more and more users and applications. Satellites with just one lens capture stereo images with a time delay, e.g. Ikonos and WordView-1. Satellites with two or more lenses can capture quasi simultaneously stereo images, e.g. Cartosat-1 with a forward and an aft view or ALOS/PRISM with the triplet forward (F), nadir (N) and backward (B).

As a member of the validation and calibration team for ALOS/PRISM we focused among other topics on the DSM generation and its evaluation. We have published several results of our evaluation of the potential of ALOS/PRISM image data together with our powerful software packages SAT-PP (Satellite Image Precision Processing) for DSM generation. For details about the testareas and the evaluation results see Gruen et al. (2006), (2007) and (2008) and Wolff and Gruen (2007). The software has been tested successfully for processing of a number of high resolution satellite sensors, such as IKONOS, QuickBird, ALOS/PRISM, and SPOT-5 HRS/HRG and is meanwhile close to operation. Detailed information on the SAT-PP and its functionalities can be found in Zang and Gruen (2004), Zang (2005) and Gruen et al. (2005).

Here, we focus on one hand on the potential of the use of the image triplet in comparison to the use of just a stereo image pair, e.g. the combination of FN and FB. As we will see improves the use of a third image the results of the DSM generation especially for the combination of FB, but also for the combination FN.

Additionally we will present the evaluation results of a new testfield, the volcano Sakurajima in Japan. The special characteristics of the volcano surface are very difficulty conditions for the image matching and DSM generation. Therefore the results of the DSM generation are less good as the results of other testareas.

2. IMAGE DATA

Radiometric problems of ALOS/PRISM image data like black reference calibration (resulting in striping), jpeg-compression (resulting in blocking), saturation effects (mainly related to only 8-bit radiometric depth collection), and others were already discussed. For details about the radiometric problems see Gruen et al. (2007).

JAXA proposed a new processed version of the early ALOS/PRISM imagery with less striping. The use of these new processed images is beneficial for visualization purposes. However, the reduction of the striping does not has any significant influence on georeferencing and only a local influence on the DSM generation, but not on the height RMSE over all.

The three views of ALOS/PRISM which we will use in different combinations do have the following viewing angels: -23.8°, 0°, 23.8°.

3. DSM GENERATION

The main component of our powerful software package SAT-PP is the matching algorithm for the DSM generation. The procedure is based on a multi-image Least-Squares Matching (LSM) for image features like points and lines. The image matching approach uses a coarse-to-fine hierarchical solution with an effective combination of several image matching methods and automatic quality indication. In addition to the multi-image processing of Linear Array CCD images, the approach is also applicable to single frame aerial photos (analog and digital).

To improve the matching results, the software pre-processes the images using a combination of an adaptive smoothing filter and the Wallis filter. The first filter reduces the noise level, while sharpening edges and preserves even fine details such as corners and line end-points. The Wallis filter is used to strongly enhance the already existing texture patterns. After pre-processing and production of the image pyramids, the matches of three kinds of features, here feature points, grid points and edges, on the original resolution images are found progressively starting from the low-density features on the images with the low resolution. Matching with edges and feature points alone may provide under certain conditions very sparse matching results. Therefore, SAT-PP uses also uniformly distributed grid points for matching. This force for a “must match” and a possible resulting blunder can be avoided by using only the feature points and lines. To get an analysis for the whole area, we used both features and the grid points.

After determine the 3D coordinates of the features and grid points, a TIN is reconstructed using the constrained Delauney triangulation method. Therefore the evaluation of the DSM quality contains also the interpolation error.

Optionally a least squares matching can be used as a modified MultiPhoto Geometrically Constrained (MPGC) matching method for point matching while a Least Squares B-Spline Snakes (LSB-Snakes) is used for matching edges, which are represented by parametric linear B-Splines in object space. For ALOS7PRISM images with a GSD of 2.5 meters and the radiometric problems mentioned above, we got no significant improvement using the time consuming MPGC. Therefore we have chosen here a less complex modified cross-correlation matching.

Water areas like wide rivers and lakes can be defined in SAT-PP as so-called dead areas. Also, disturbing objects like clouds or image artifacts can be defined likewise and excluded from matching.

4. RESULTS

4.1 Testfield Bern/Thun – comparison of the results of stereo pairs (FN, FB) and the image triplet (FNB)

For the comparison of the use of all three available views FNB or just a combination of two of them, we came back to an already used testfield Bern/Thun which 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. For the orientation of the image triplet we measured GCPs all over the covered area. For the validation of the DSM generation we generated three sub areas as reference data by using aerial images of scale 1:25 000 to 1:34 000 and our software package SAT-PP. We have the following three sub areas:

- *Bern:* city and tree area, max. height difference 400m,
- *SW* (south west): mountainous and tree area, max. height difference 1500m,
- *Thun*: city, open and tree area, max. height difference 1000m.

We excluded rivers and significant lakes as dead areas without any given height and they were not used for the evaluation procedure. The expected accuracy of the reference 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 (see Gruen et al., 2006).

For the generation of the DSM with SAT-PP we first determined the parameters of the rigorous sensor model and in a second step we used these parameters to generate Relational Polynom Coefficients (RPCs). The Root Mean Square Error (RMSE) of the triangulation is in planimetry and height below one pixel for the Direct Georeferencing Model (DGR) and by this sufficient for a DSM generation with a grid size of 5m.

For the comparison of the results of stereo pairs combination FN and FB with the image triplet FNB we determined the 2.5D RMSE of the height for each sub area and for the three combinations.
Table 1 gives an overview of the DSM accuracy evaluation results. The histogram of the results for the FNB DSM of Bern in **Figure 1** shows the normal distribution of the residuals and that we do not have any systematic errors. The other residuals have the same characteristics.

Each sub area contains more than 2.7 million points. The overall RMS height errors for all three test areas for the FNB combination are better than three pixels (5.5 m – 6.6 m). As we expected, we get a less good accuracy for the FN combination with 6.4m – 7.5m and for the BF combination even 6.6m – 9.3m. The worst results were obtained for the sub area SouthWest with an alpine area.

PRISM View Combination	*Number of points*	*2.5D RMSE-Z*	*Mean / Min / Max*
Bern FNB	4340836	5.7	-1.3 / -60.6 / 50.0
NB		6.4	-1.1 / -59.8 / 74.8
FB		6.6	-1.5 / -62.5 / 77.2
SW FNB	2752822	6.6	0.6 / -76.9 / 84.5
NB		7.5	1.1 / -79.0 / 91.1
FB		9.3	0.0/ -103.2 / 220.0
Thun FNB	3508099	5.5	1.2 / -41.6 / 63.4
NB		6.4	2.8 / -68.7 / 96.0
FB		8.1	1.2 / -109.6 / 135.2

Table 1. DSM accuracy evaluation results of the three test areas for the three different view combination FNB, FN and FB. Bern: city and tree area, maximally height difference 400m, SW (south west): mountainous and tree area, maximally height difference 1500m, Thun: city, open and tree area, maximally height difference 1000m.

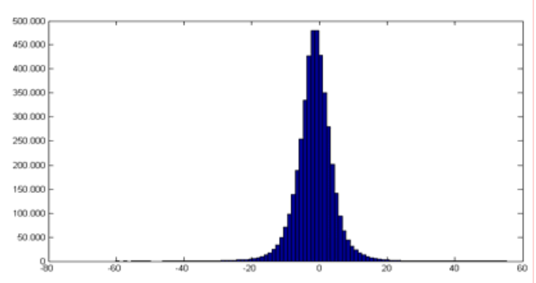

Figure 1 Histogram of the residuals of the FNB DSM for the sub area Bern.

For a visual evaluation of the differences we have chosen three examples. The shaded visualizations of the three different DSMs are shown in **Figure2,Figure3 and Figure 4** The first example is the city of Bern. The FNB DSM contains the main structure of the roads and houses in the city. The NF DSM has no significant errors. With the FB combination we lost most of the structure and we have now also small peaks in the DSM which are blunders. Also the structure of the valley in **Figure 3** got lost nearly totally. This applies also for the mountainous area shown in **Figure4** where the details of the mountains are still visible in the FN DSM, but not in the FNB DSM.

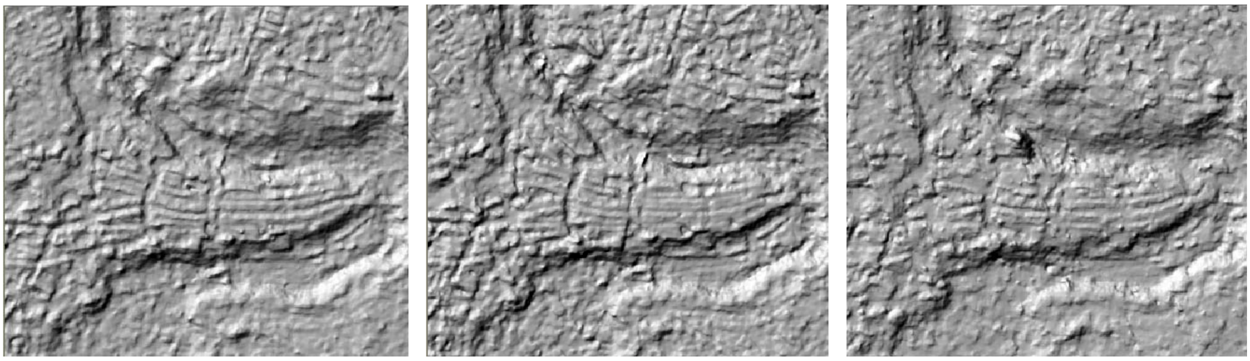

Figure 2 Urban area: Shaded visualization of the FNB DSM (left), the FN DSM (middle) and the FB DSM (right).

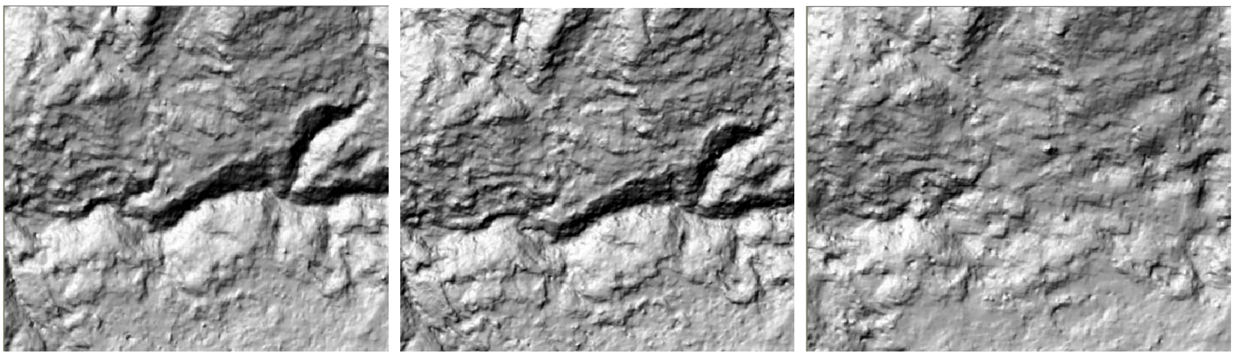

Figure 3 Valley area: Shaded visualization of the FNB DSM (left), the FN DSM (middle) and the FB DSM (right).

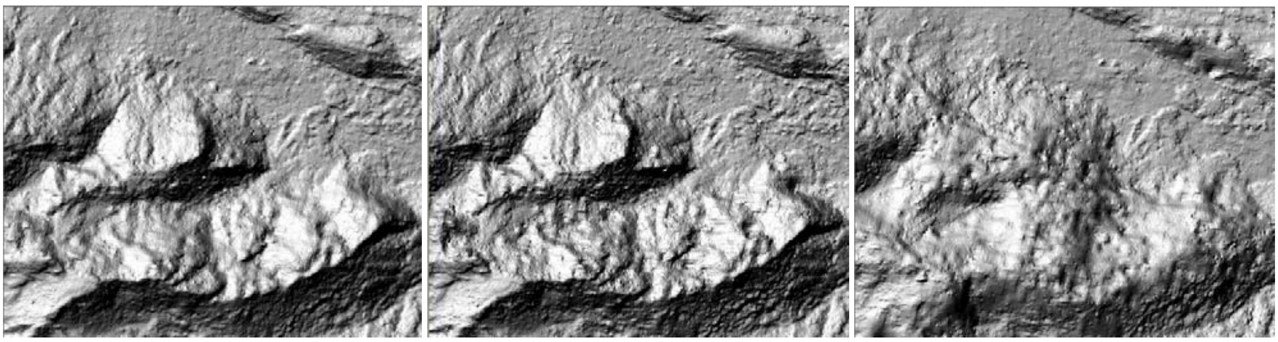

Figure 4 Alpines area: Shaded visualization of the FNB DSM (left), the FN DSM (middle) and the FB DSM (right).

4.2 Testfield Sakurajima, Japan

The Sakurajima testfield for DSM generation is a steep volcano area. A small part of the volcano Sakurajima is given as a laser scanner reference dataset provided by Kokusai Kogyo Co. Ltd. with a resolution of 5 m. Figure 5 shows the orthophoto together with the extension of the reference area. The main characteristics of the volcanic area results in the following matching conditions: a large part of the area of interest is covered by heavy shadows without any useful grey value information and a large part has also no sufficient texture (e.g. the caldera). Good texture suitable for image matching is only available along the edges of the shadows.
In the PRISM triplet, the larger one of the two craters is covered by clouds. This area was defined as a dead area, no height values where determined for this areas and by this it was excluded from the evaluation.

The Root Mean Square Error (RMSE) of the triangulation is in planimetry and height below one pixel for the Direct Georeferencing Model (DGR) see Kocaman and Gruen (2008).

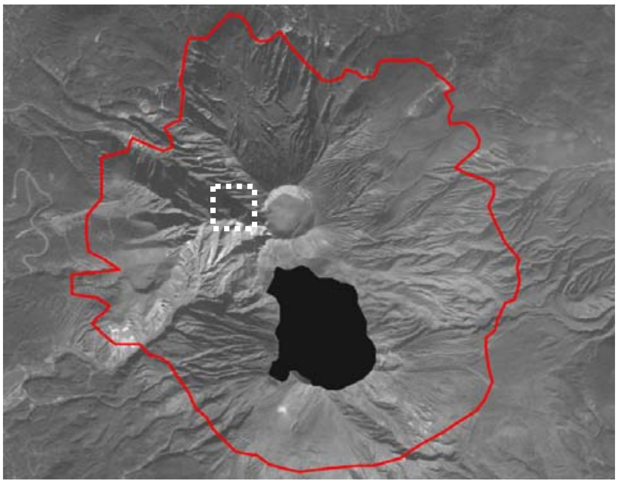

Figure 5. Sakurajima: Orthophoto (Nadir) and the extension of the reference area. The black area is a cloud area which was excluded from the evaluation.

# points	*RMSE-Z*	*Mean*	*Min*	*Max*
394828	10.8 m	-0.71 m	-111 m	60 m

Table 2. DSM accuracy evaluation results of the test area of the volcano Sakurajima.

Figure 6 shows the color coded DSM of the mountain area around the volcano. Table 2 summarizes the evaluation values of the DSM generation. The height RMSE is better than 5 pixels (10.8 m). The quality of this DSM generation is mainly influenced by the large part of shadow areas without sufficient grey value information for a suitable image matching. In these areas we have blunders up to 100 m. To visualize this influence
Figure 7

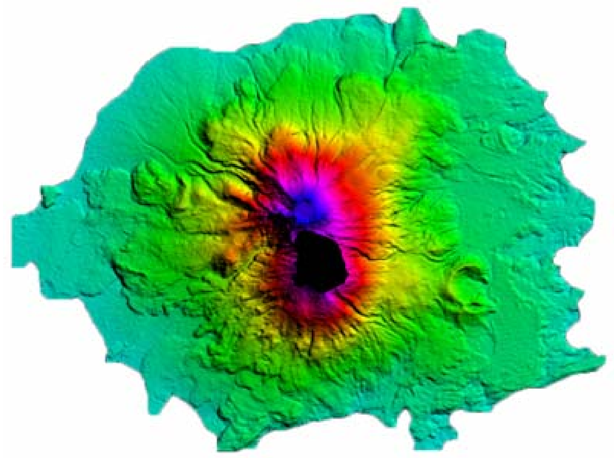

Figure 6. Shaded and color coded visualization of the generated DSM of the volcano. The black area is a cloud defined as dead area without any height information.

Figure 7 shows the analysis of the DSMs for a shadow area marked in Figure 5 (green square).

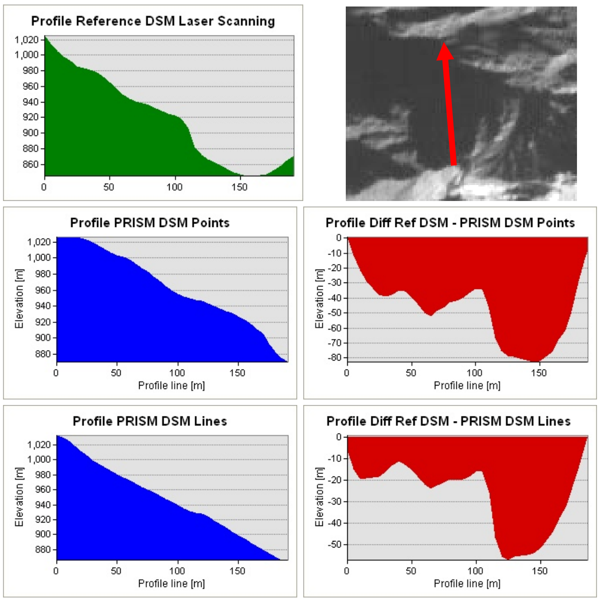

Figure 7. Profiles of the DSMs for the same area and their evaluation results.

On the left side we have first of all the profile of the reference DSM with small structures of the volcano surface. The second profile on the left side is generated for a DSM_{points} generated by using only feature and grid points. The third one results out of the DSM_{lines}, when only lines were used for the DSM reconstruction. The first image on the left side is the original nadir image of the shadow area
with the position of the profile line. The last two images on the right sight show the profiles of the height errors (reference DSM – generated DSM) for DSM_{points} for DSM_{lines}. There are big blunder areas up to - 80 m in case of DSM_{points} and up to - 57 m in case of DSM_{lines}. For the reconstruction of DSM_{points}, mismatched points were found inside the shadow area. In case of $DSM_{lines,}$ lines were matched only at

the edges of the shadow area. For the other shadow areas we found similar effects.

5. DISCUSSION AND CONCLUSIONS

We have validated DSM generation using ALOS/PRISM image data over two testfields. For the Bern/Thun testfield we focused on the comparison of using the image triplet in comparison to the use of just two views (here FN and FB). With the testfield Sakurajima we gave new results of our work as a member of the validation and calibration team for ALOS/PRISM.

The results of our first test confirm what we expected: in comparison to the RMSE of the FNB combination of we got instead of a 5.5 m – 6.6 m a less good accuracy for the FN combination with 6.4m – 7.5m and for the BF combination even 6.6m – 9.3m. The worst results were obtained for the sub area SouthWest with an alpine area included. Over all is the RMSE less than 4 pixels. For a detailed analysis we visualized three example areas with their shaded DSM. It was shown that valleys disappear using the FB combination and mountains loose their structure.

The performance of PRISM imagery in connection with our multi-image matcher of SAT-PP was tested for the new volcanic testfield Sakurajima (largely open volcanic terrain). The height RMSEs for the testfields are all between 2 to 5 pixels for the raw matching results without any post-processing for blunder removal. These results are in the range of what we can expect from high resolution satellite image data. 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. Although these values look quite good, we must note that there are still too many blunders in the data, which are not acceptable for mapping tasks. These blunders appear mainly in shadow areas what we analyzed for one example in detail.

For the Bern/Thun testfield we had also a new version of the image data with less striping. We detected only a small local influence on the DSM generation which will be analyzed in detail in the future. The height RMSE did not change overall. However, for visualization purposes the image quality of the new images is improved.

If we compare these results of DSM generation 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 in the automatically generated DSM.

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REFERENCES

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

Gruen A., Kocaman S., Wolff K., 2007. "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.

Gruen, A., Murai, S., Baltsavias, E., Kocaman, S., Wolff, K., Hanusch, T., 2008. „Investigations on the ALOS/PRISM and AVNIR-2 Sensor Models and Products2". Interim PI Report for JAXA.

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

Wolff K., Gruen, A., 2007. "DSM Generation from early ALOS/PRISM data using SAT-PP". High-Resolution Earth Imaging for Geospatial Information, Proceedings of ISPRS Hanover Workshop.

Zhang, L., 2005 "Automatic Digital Surface Model (DSM) Generation from Linear Array Images", Ph. D. Dissertation, Report No. 88, Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland.

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

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