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TERRASAR-X STEREO DIGITAL ELEVATION MODELS FOR COMPLEX TERRAIN CONDITIONS IN ALPINE REGIONS AND ITS SUITABILITY FOR ORTHORECTIFICATION PURPOSES OF OPTICAL AND SAR IMAGERY

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ABSTRACT:

The technology of interferometry is already well established for the generation of digital surface models (DSM). However, the short wavelength of the TerraSAR-X satellite causes temporal incoherence for repeat pass interferometry, thus, the satellite's data is not well suited to derive reliable surface models in many regions of the world using interferometry. However, it is possible to generate reliable surface models with TerraSAR-X data simply by taking advantage of the possibility to acquire data at different incidence angles. The technology used is based on photogrammetry methodologies the so-called radargrammetry. The technology for radargrammetric or stereo DSM processing is already implemented as part of Infoterra GmbH's infrastructure and enables the generation of DSMs with a vertical height accuracy of 5 to 10 meters (LE 90) for slopes smaller than 20° based on StripMap mode data (3 m spatial resolution). In the frame of Infoterra's global DEM verification campaign, a development project focusing on the refinement of the radargrammetric processing methodologies and the verification of results for an area with complex terrain conditions was conducted. The test site is the Juneau Icefield (Alaska, USA), which provides difficult terrain conditions for DEM generation as the area is mainly covered by snow and ice and is characterized by very high slopes. In order to emerge the best acquisition scenarios for DEM generation, several data sets were acquired in different TerraSAR-X modes with varying incidence angle combinations in different seasons. The verification results for the different test cases with respect to height accuracy as well as suitability for orthorectification purposes of SAR and optical (RapidEye) data will be presented. The statistical analysis shows that the vertical accuracies are strongly dependent on the disparity angle of the input scenes. They vary between a vertical error of 16.2 meters (LE90) for small (9°) and 6.5 meters for larger disparity angles (20°) and better.

1. INTRODUCTION

For TerraSAR-X data the usage of repeat pass interferometry for Digital Elevation Model (DEM) processing is limited due to temporal incoherence caused by the short wavelength of the system and a repeat pass of 11 days. In order to overcome this limitation, a technology based on methods from photogrammetry, the so-called radargrammetry, is used. For radargrammetry two SAR images (stereo pair), which cover the same area and are acquired at different incidence angles, are used for DEM processing.

Infoterra GmbH has developed and thoroughly evaluated the capacity of generating digital elevation models from TerraSAR-X data using radargrammetric processing. The development resulted in a product launch of the TerraSAR-X ELEVATION product end of Mai 2010 [1, 5]. During the development of this product, Infoterra performed a global DEM verification campaign for which several test sites with different land cover and relief conditions were selected all over the globe and a detailed statistical and visual inspection on DEM quality was performed. For one of these test sites, a research project with focus on the refinement of the radargrammetric processing methodologies and verification of results for an area with complex terrain conditions was conducted. The test site is the Juneau Icefield (Alaska, USA), which provides difficult terrain conditions for DEM generation. The results of the project are presented in the following.

2. RADARGRAMMETRY FOR COMPLEX TERRAIN CONDITIONS

2.1 Test site: Juneau Icefield, Alaska, USA

The test site covers the main part of the Juneau Icefield which is located northwest of the capital of the state of Alaska: Juneau. The Juneau Icefield covers an area of approx. 8000km², half of the area being covered by a system of glaciers. The area shows quite demanding conditions for DEM processing: The terrain consists of very steep slopes, i.e. the elevation rises from sea level up to 1700 meters within 22 km horizontal distance. Further, nearly the entire area is covered by ice and snow. Ice and snow coverage mostly shows little features in SAR images and is very sensitive to weather changes. Thus, for stereo matching it is a complex case.

In July and August 2009, DGPS measurements were acquired in the area during a field campaign by participants of the Juneau Icefield Research Program. These measurements were made available as reference data.

2.2 Test Scenarios and DEM processing

The test scenarios are mainly based on different acquisition scenarios. The input to radargrammetric processing is at least two stereo pairs. TerraSAR-X data can be acquired with different incidence angles over one area. However, the acquirable incidence angle range is limited to between 20 and 45 degrees for TerraSAR-X StripMap mode. The quality of data acquired with incidence angles in this range, which is called "full performance range", fulfils the specification for TerraSAR-X image products [2]. In order to have more options for the

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combination of stereo pairs, data acquired outside the full performance range (15 to 60 degrees) were also used in the project.

The following acquisition scenarios were used for testing:

- Acquisition with StripMap mode, single polarized data (HH)
- Acquisitions in both orbit directions (in order to avoid layover and shadow effects where no stereo matching is possible)
- Acquisition at incidence angles of ~25°, ~35°, ~45°, ~58° in ascending orbit direction
- Acquisition at incidence angles of ~29°, ~45°, ~56° in descending orbit direction
- Two acquisition campaigns: one in July / August 2009 (in parallel to the field campaign), a second one in October 2009

With help of the different acquisition scenarios, stereo pairs with different disparity ranges were composed and used for digital surface model (DSM) calculation by the automated radargrammetry processor integrated into Infoterra's production infrastructure.

2.3 DEM Evaluation

During the development phase of the TerraSAR-X ELEVATION product, Infoterra followed a strict validation approach, which was also applied to the results of this development project.

The evaluation was performed on the results of the different test scenarios:

- Verification based on the raw DSM product for each orbit direction, i.e. DSM product without any filtering, interpolation of smaller gaps or filling of larger gaps with an external DSM source
- Verification of the raw DSM merged from both orbit directions, i.e. no filtering, but gaps are reduced due to availability of height information from the alternate orbit directions.
- Verification of the edited DSM, i.e. TerraSAR-X ELEVATION DSM product, which is produced with the best suited acquisition scenario. It includes outlier removal, filtering, interpolation of smaller gaps, filling of larger gaps with an external DSM source and edited water bodies [1].
- Verification of the edited and calibrated DSM.

2.3.1   Verification methods: The following verification methods are applied to the data:

Visual inspection
Visual inspection is performed on a shaded relief representation of the DSM. This step helps to identify structural irregularities in the data processing, deviations in comparison to other DSM datasets, systematic artifacts, and outliers inside the elevation model.

Additionally a linear profile plot with the available DEM sources is drawn and visually analyzed [3]. A regular shift and irregular undulations in the DEM can easily be identified with this method.

Statistical analysis
In addition to the visual inspection of a DEM, the statistical analysis is the most important step of the validation process. The statistical calculations are based on a 90 % linear error (LE90) for the vertical accuracy [4]. In this project, input to the

statistical calculations was the DGPS measurements acquired during a campaign in July and August 2009. A total of 739 points was available.

For point based data like DGPS measurements a difference between the DSM and the height values from the reference data is calculated. Generally, all reference points are taken into account for statistical analysis independent of slope and sensor dependency. No selection of reference points according to selection criteria was carried out and only data of inconsistency is excluded from the process.

In the standard DEM evaluation procedure a classification of different slope and land cover classes is accomplished if a large number of points with a regular distribution over the entire area are available. In case of the Juneau Icefield, all available reference points were acquired over the glacier, thus falling into the same slope and land cover class. Consequently, no differentiation of classes was possible.
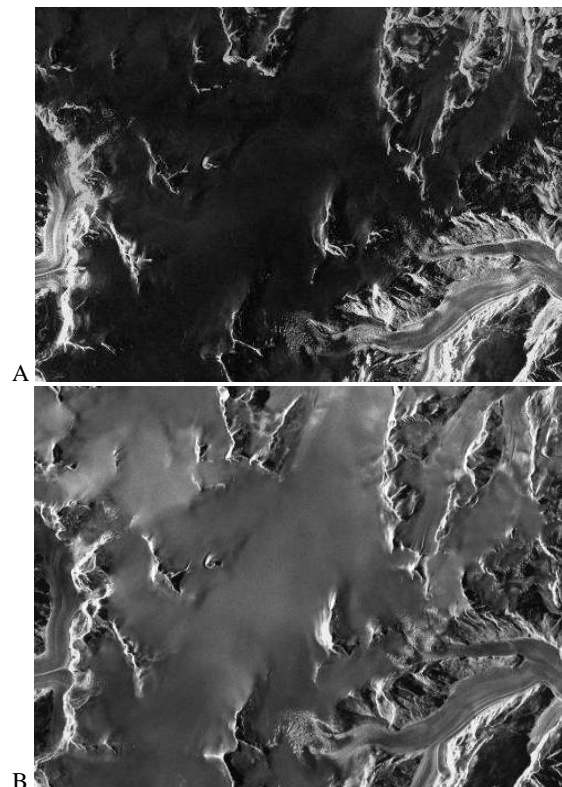

Figure 1. TerraSAR-X StripMap images over the Juneau Icefield: A: Acquired in July 2009, B: Acquired in October 2009

2.3.2   DEM evaluation results: During the visual inspection of the input scenes it was noted that the backscatter of the areas covered by snow and ice was very low for the acquisition performed in the summer season (July / August) due to the warm weather conditions and wet snow and ice (see Figure 1, A). Therefore, it was assumed that the DSM produced with these scenes might have some quality deficiencies in comparison to the DSM calculated on basis on the scenes acquired in autumn (October) (see Figure 1, B). The visual inspection of the DSM confirmed these assumptions. The DSM calculated with the scenes acquired during the summer season show more noise whereas the results received from the autumn scenes looks homogenous (see Figure 2).
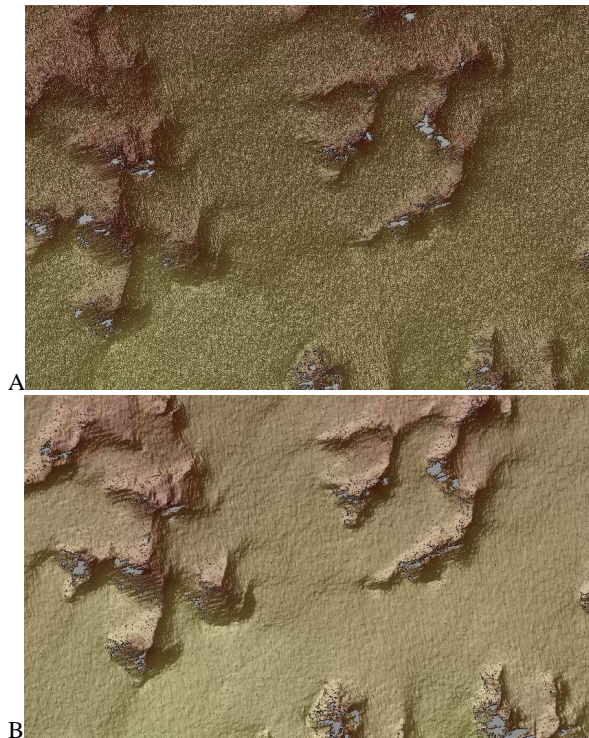
Figure 2. Results of the radargrammetric stereo processing for the summer acquisitions (A) and autumn acquisitions (B)

Furthermore, the acquisitions acquired with an incidence angle of more than 56° were not used for DSM calculation due to strong ambiguities in the images.

The visual inspection of the test results achieved with different disparity angle settings showed the following:

- DSMs calculated with stereo pairs with a small disparity angle (9°) show strong artifacts and noise.
- The artifacts and noise reduces with an increasing disparity angle.
- The results achieved with a disparity angle of ~20° showed visually the best results.
- Areas with invalids caused by layover and shadow artifacts (no matching possible) increase with a larger disparity angle.

Scenario	LE 90 [m]	No Points	Mean
Ascending summer (20°), raw	5.8	634	-2.4
Descending summer (20°), raw	6.4	634	-2.0
Descending October (20°), raw	6.7	473	-1.9
Ascending October (9°), raw	16.2	458	-4.2
Ascending October (11°), raw	8.9	453	-2.9
Ascending October (20°), raw	6.5	452	-2.6
Asc / Desc Oct. (20°), raw	5.1	616	-2.2
Asc / Desc Oct. (20°) edited	4.7	616	-2.2
Asc / Desc Oct. (20°) edited (cal.)	3.1	616	-0.2

Table 1. Statistical analysis for test scenarios using different orbit directions and disparity angles (raw = unedited DSM, cal. = calibrated)

In a next step, the statistical analysis was performed. The distribution of the DGPS points in combination with the evaluation result for the DSM calculated for the October scenes (disparity angle ~20°, combination of ascending and descending

orbit) is depicted in Figure 3. Table 1 shows the statistical analysis for some representative test results.

In contrast to the visual impression, the statistical analysis show better results for the DSM calculated with the summer acquisitions compared to the DSM of the October acquisitions. A reason might be that the reference points were acquired in parallel to the summer acquisitions.

However, the statistics confirm that the quality improves with a larger disparity angle. The accuracy could further be improved by combining of ascending and descending orbit direction, which also reduces the number of invalid pixels. Moreover, the editing (smoothing, outlier removal) improves the visual impression and the statistical result. In a last step, the DSM was calibrated, improving the statistical results even more.
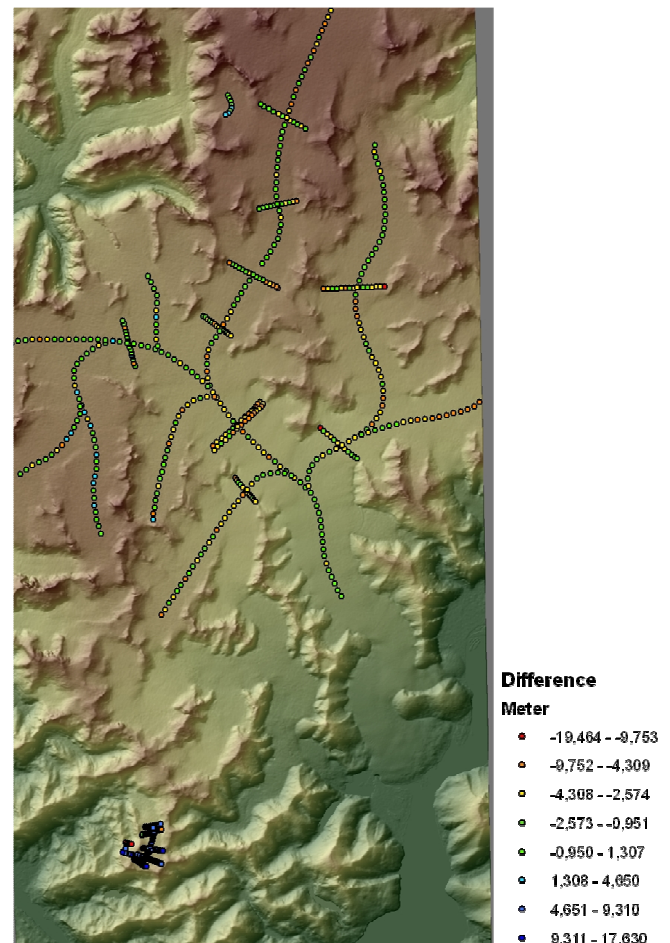

Difference
Meter
- -19.464 - -9.753
- -9.752 - -4.309
- -4.308 - -2.574
- -2.573 - -0.951
- -0.950 - 1.307
- 1.308 - 4.650
- 4.651 - 9.310
- 9.311 - 17.630

Figure 3. Evaluation result for the DSM (based on October scenes, disparity angle ~20°, combination of ascending and descending orbit)

2.3.3 Orthorectification: Based on the edited DSM from the October acquisitions, an orthorectification of the TerraSAR-X images was performed with Infoterra's in-house orthorectification processor. For a part of the test site street vector data was available. The overlay of the street vectors and the orthorectified images showed a very good match of 1 to 2 pixels (2.5 meter spacing).

In the frame of the research project, the DSM and the orthorectified TerraSAR-X images were provided to RapidEye AG, where both data sets were used for co-registration and orthorectification of RapidEye data. The achieved geo-location

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for the orthorectified RapidEye data was within one pixel (5m spacing) compared to the TerraSAR-X data.

3. CONCLUSION

In the frame of the research project tests considering different acquisition scenarios for radargrammetric processing of TerraSAR-X StripMap data were performed. It was shown that the generation of Digital Surface Models based on TerraSAR-X data using radargrammetry techniques is possible even for very complex terrain conditions. The combination of DSMs derived from ascending and descending orbit helps to minimise significantly void areas from shadow and layover. The results also confirmed theoretical considerations with respect to the acquisition scenarios best suited for radargrammetric processing. All the results were included into the development process of the TerraSAR-X ELEVATION product and processor [1, 5].

Furthermore, it was demonstrated that the resulting TerraSAR-X ELEVATION DSM is very well suited for orthorectification of both optical and SAR satellite data.

ACKNOWLEDGEMENTS

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