# Accuracy Assessment of 3D Point Retrieval from TerraSAR-X Data Sets

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## Abstract

Based on high-resolution TerraSAR-X (TSX) stereo pairs, an investigation was launched addressing the retrieval of 3D point information from such data sets. The objectives were to determine 3D accuracies on the one hand, and to conclude on the best suitable image acquisition scenarios on the other hand. Related investigations using TerraSAR-X Spotlight as well as Stripmap multi-image data sets have shown that attractive 3D point quality can be achieved from such data sets. Thus, this approach of 3D point extraction could be reasonably utilized to establish control point data bases, particularly in poorly mapped areas.

## 1 Introduction

Since its launch in June 2007 the German TerraSAR-X-mission provides spaceborne SAR images in different acquisition modes. Among them, the Stripmap and the Spotlight imaging mode provide high resolution images in the order of about 3 and 1 meter, respectively [1]. Furthermore, image data can be acquired at various imaging beams. Thus, several images may be acquired for a certain area at different off-nadir viewing angles (beams) in the full TerraSAR-X performance range, which is 20 to 55 degrees for the Spotlight mode and 20 to 45 degrees for the Stripmap mode. Additional acquisitions are feasible outside the full performance range.

Along with the image data, detailed and very precise metadata are provided. For instance, the accuracy of the so-called science orbit is said to be in the range of several centimetres, and the geo-location accuracy inherent to TerraSAR-X Spotlight imagery is reported to be in the order of less than 1 meter [2].

These circumstances stimulate the utilization of TerraSAR-X data for stereo mapping purposes, aiming at the extraction of 3D ground information, like selected points in the present context. The overall objective of this work is to investigate, whether 3D points can be reliably retrieved from stereo or multiple TSX Spotlight or Stripmap data sets. Follow-on utilization of the retrieved points is to establish a control point data base, particularly in poorly mapped areas, where such information is not available or insufficiently accurate. A comprehensive quality analysis therefore is further to be made in order to investigate the best suitable data acquisition scenarios and to definitely assess the accuracy of retrieved 3D point coordinates. Here the focus is put on the results achieved from TerraSAR-X Spotlight products.

## 2 Image and Reference Data

A first test site to be investigated in this context was selected in the south-west of the city of Graz in Austria, covering urban/sub-urban as well as rural areas. According to the data acquisition scenario schematically shown in Figure 1, the following TerraSAR-X data sets were acquired:

- 4 Spotlight images each in ascending and descending mode (SL_asc* and SL_dsc*). The nominal GSD is 0.75 meters, except SL_asc1 (1.5 meters) and SL_dsc1 (1.0 meters).
- 4 Stripmap images each in ascending and descending mode (SM_asc* and SM_dsc*). The nominal GSD is 1.25 meters, except SM_asc1 (1.5 meters)

The centre incidence angles are indicated in the figure as well as those scenes, which were acquired outside the full performance range with their naming given in red colour.

Control points had to be measured for the intended investigation. Therefore, a Lidar DSM with a pixel size of 1 meter, derived from Lidar point clouds showing a point density of 4 points per square meter, was used as reference data set. Natural targets like road intersections, traffic circles, flat roofs and the like had to be used. As realized in previous work on high-resolution TerraSAR-X data [3, 4], the identification and measurement uncertainty of such targets in the high resolution image data is in the order of 1-2 pixels anyway. Moreover, point measurement sometimes is not precisely and homogeneously possible in all images due to different illumination effects caused by incidence angle as well as illumination direction. Figure 2 shows an example of a control point as measured in the Lidar DSM as well as the 8 Spotlight scenes. In total 19 control points were finally measured in all images of this data set.

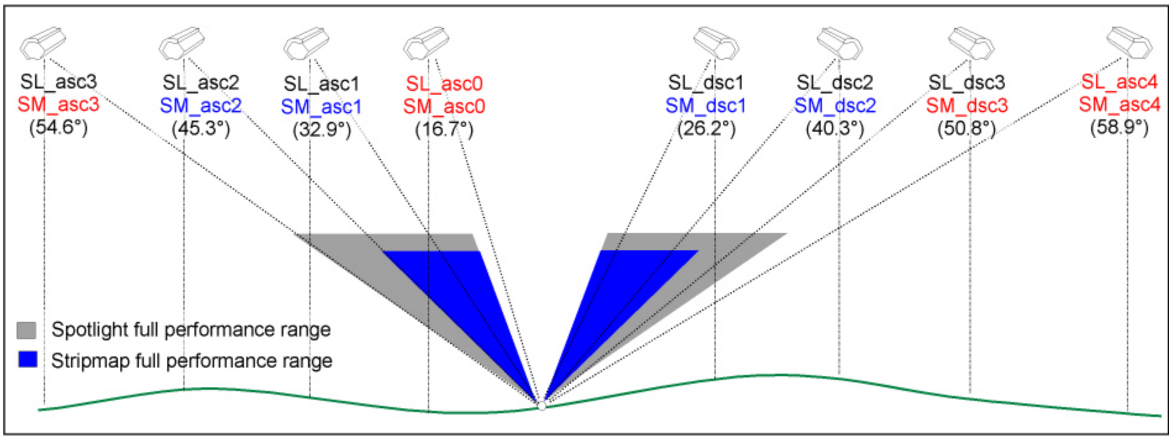


**Figure 1:** TerraSAR-X multi-beam imaging capability

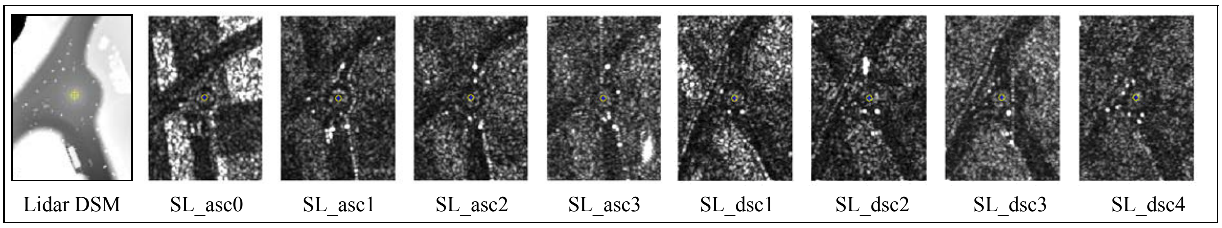


**Figure 2:** Example of point measurement (center point of traffic circle)

## 3 Assessment of 2D Geo-location Accuracy

In order to assess the geo-location accuracy of the present test data, backward point transformation of ground coordinates of the GCPs into the SAR image geometry was made and point residuals were calculated in azimuth and range as the differences between resulting and measured image pixel coordinates.

The root mean square (RMS) values as well as the mean values of the resulting point residuals are summarized in Table 1 for the individual Spotlight and Stripmap images. The scenes which were acquired outside the full performance range are indicated by the shaded entries. The following can be noticed:

- The RMS residuals in azimuth and range are in the order of 1 – 2 pixels, while the RMS residual length is in the order of 2 pixels. This corresponds to the estimated point identification and measurement accuracy.
- A minor bias in the sub-pixel range is indicated for some images by mean residual values deviating distinctly from zero.
- Images acquired outside the full performance range do not show an abnormal behaviour, except the Stripmap image "SM_asc0", showing a major range bias of about 5 pixels in range.

| Mode | Image | RMS | | Mean | |
|---|---|---|---|---|---|
| | | Az | Rg | Az | Rg |
| Spotlight | SL_asc0 | 1.06 | 1.71 | -0.24 | 0.83 |
| | SL_asc1 | 1.54 | 1.85 | -0.81 | 0.87 |
| | SL_asc2 | 1.08 | 1.36 | -0.37 | 0.39 |
| | SL_asc3 | 1.25 | 1.16 | 0.22 | 0.00 |
| | SL_dsc1 | 1.00 | 1.88 | -0.44 | 0.02 |
| | SL_dsc2 | 1.30 | 1.93 | -0.25 | 0.46 |
| | SL_dsc3 | 1.23 | 1.55 | -0.40 | 0.29 |
| | SL_dsc4 | 1.39 | 1.60 | 0.01 | -0.54 |
| Stripmap | SM_asc0 | 2.03 | 7.13 | 0.03 | 5.17 |
| | SM_asc1 | 1.26 | 1.50 | -0.22 | -0.29 |
| | SM_asc2 | 1.05 | 1.03 | -0.07 | 0.19 |
| | SM_asc3 | 1.78 | 1.51 | -0.88 | 0.23 |
| | SM_dsc1 | 1.15 | 2.32 | 0.30 | 0.18 |
| | SM_dsc2 | 1.32 | 1.88 | -0.40 | -0.13 |
| | SM_dsc3 | 1.28 | 1.70 | 0.40 | 0.36 |
| | SM_dsc4 | 1.57 | 1.38 | -0.45 | -0.60 |

**Table 1:** 2D geo-location accuracy of Spotlight and Stripmap products, given in pixels

# 4 Assessment of 3D Point Retrieval Accuracy

## 4.1 Same-side Spotlight Dispositions

First, various stereo pairs were composed from the Spotlight image data sets in order to assess the accuracy of 3D point coordinates being retrieved there from, like

- any combination of 2 ascending or descending images;
- additional multi-image dispositions comprising 3 or 4 images.

The 3D accuracy analysis is based on spatial point intersection of control points being measured in the individual images of the model or image block. "Intersected" ground coordinates are then achieved, and comparison to the measured ground coordinates yields 3D point residuals on ground. The RMS values of the point residuals in East (E), North (N) and height (H) as well as of the length (L) of the individual residuals are summarized in Table 2.

The figures of the table show, that the 3D accuracy is strongly driven by the stereo intersection angle (Δθ), i.e. the difference of the centre incidence angles of the involved images. The robustness of the point intersection increases with increasing incidence angle. Hence, the worst results are achieved for the stereo pairs with smallest stereo intersection angle (e.g. asc2-asc3, dsc3-dsc4). 3D RMS residuals in the order of less than 2 meters and RMS residual lengths close to 2 meters are feasible.

| Model/Block | Δθ | E | N | H | L |
|---|---|---|---|---|---|
| asc0 – asc1 | 16.2° | 1.45 | 0.98 | 0.97 | 2.00 |
| asc1 – asc2 | 12.4° | 1.81 | 0.94 | 1.61 | 2.60 |
| asc2 – asc3 | 9.3° | 3.29 | 0.99 | 3.95 | 5.23 |
| asc0 – asc2 | 28.6° | 1.05 | 0.90 | 0.82 | 1.60 |
| asc1 – asc3 | 21.7° | 1.60 | 0.92 | 1.62 | 2.46 |
| asc0 – asc3 | 37.9° | 1.25 | 0.91 | 1.02 | 1.85 |
| asc012 | 28.6° | 1.70 | 0.95 | 1.58 | 2.51 |
| asc123 | 21.7° | 1.36 | 0.85 | 1.53 | 2.22 |
| asc0123 | 37.9° | 1.07 | 0.83 | 1.15 | 1.78 |
| dsc1 – dsc2 | 14.1° | 3.03 | 0.99 | 1.96 | 3.74 |
| dsc2 – dsc3 | 10.5° | 3.19 | 0.95 | 3.34 | 4.71 |
| dsc3 – dsc4 | 8.1° | 3.93 | 0.93 | 5.28 | 6.65 |
| dsc1 – dsc3 | 24.6° | 1.52 | 0.90 | 1.22 | 2.15 |
| dsc2 – dsc4 | 18.6° | 2.82 | 0.86 | 3.20 | 4.35 |
| dsc1 – dsc4 | 32.7° | 1.61 | 0.82 | 1.32 | 2.23 |
| dsc123 | 24.6° | 1.57 | 0.82 | 1.24 | 2.16 |
| dsc234 | 18.6° | 2.75 | 0.85 | 3.15 | 4.27 |
| dsc1234 | 32.7° | 1.35 | 0.74 | 1.27 | 2.00 |

**Table 2:** 3D geo-location accuracy (meters) achieved from Spotlight stereo dispositions

The largest stereo intersection angles (asc0-asc3, dsc1-dsc4) not always yield best results, obviously due to radiometric and geometric image dissimilarities which degrade the GCP measurement and point intersection quality.

## 4.2 Opposite-side Dispositions

Apart from same-side data acquisition dispositions, more robust acquisition scenarios are given by opposite side arrangements, comprising one or more acquisitions from ascending as well as descending orbit. Using the Spotlight data set, various such stereo models or image blocks were established, and adequate 3D accuracy analysis made. Selected arrangements are shown in Table 3 along with achieved RMS residuals. As could be anticipated, distinctly higher accuracies are achieved from opposite-side scenarios. RMS residuals of individual coordinates are in the sub-meter range, while RMS residual lengths are in the range between 1 and 1.5 meters. In general, the accuracy may be increased by using a larger number of images. However, to keep involved image data low, a scenario utilizing 2 ascending as well as 2 descending images (e.g. the one indicated by asc13&dsc13) seems to be a reasonable compromise.

| Model/Block | Δθ | E | N | H | L |
|---|---|---|---|---|---|
| asc1&dsc1 | 32.9°&26.2° | 0.84 | 0.94 | 0.80 | 1.49 |
| asc2&dsc2 | 45.3°&40.3° | 0.70 | 0.65 | 0.93 | 1.33 |
| asc3&dsc3 | 54.6°&50.8° | 0.79 | 0.79 | 0.78 | 1.36 |
| asc13&dsc13 | 54.6°&50.8° | 0.70 | 0.72 | 0.73 | 1.24 |
| asc123&dsc123 | 54.6°&50.8° | 0.58 | 0.66 | 0.76 | 1.16 |
| asc&dsc (all) | 54.6°&58.9° | 0.59 | 0.64 | 0.71 | 1.13 |

**Table 3:** 3D geo-location accuracy (meters) achieved from ascending/descending Spotlight image dispositions

# 5 Detection of Unreliable Points

When using multi-image data sets, the benefit may be twofold:

1. In the course of the least squares point intersection the impact of erroneous point measurements may be reduced due to the increased over-determination.
2. Erroneous/unreliable point measurements may be identified by residual feedback of the least squares point intersection, and such points then be rejected.

An example of inaccurate, i.e. inconsistent point measurements is shown in Table 4 for various acquisition arrangements. The table on the one hand shows image residuals in azimuth and range as achieved from backward transformation of the ground coordinates resulting from the spatial point intersection, and on the other hand the length of point displacement (dL) on ground.

With respect to example 1, the azimuth and range residuals of the "asc13" model are small and do not indicate 3D inaccuracy of almost 4 meters. For the "asc1&dsc1" model, the 2D residuals get larger and indicate inconsistency of the measurements, but on the other hand the 3D inaccuracy is decreased to about 2.5 meters due to the more robust opposite-side arrangement. The inconsistency of point measurements becomes obvious in the multi-image arrangement "asc13&dsc13", yielding several pixels of 2D residuals. The 3D accuracy of about 3 meters is poor but not extremely bad, again due to over-determination and robust opposite-side arrangement. Nevertheless, such 2D residuals should be considered as an indicator to reject the respective point.

| Model/Block | Image | Az | Rg | dL |
|---|---|---|---|---|
| asc13 | asc1 | 0.41 | -0.01 | 3.89 |
| | asc3 | -0.41 | 0.03 | |
| asc1&dsc1 | asc1 | -1.69 | -0.37 | 2.54 |
| | dsc1 | -1.70 | 0.33 | |
| asc13&dsc13 | asc1 | -1.28 | -1.45 | 3.04 |
| | asc3 | -1.66 | 4.66 | |
| | dsc1 | -2.41 | -2.40 | |
| | dsc3 | 0.37 | 6.55 | |

**Table 4:** Identification of inconsistent point measurements

## 6 Conclusion

The investigation has shown that a fairly high accuracy is feasible with respect to 3D point extraction from TerraSAR-X image data. In order to achieve optimum accuracy, opposite side acquisition arrangements should be considered, being composed by one or more ascending and descending acquisitions.

For such arrangements, Spotlight pairs may yield a geo-location accuracy of retrieved 3D points in a range between 1 and 1.5 meters. This is also shown in Figure 3, illustrating plots of residual lengths of the measured control points – sorted in decreasing order - for some selected acquisition arrangements. Over-determination, i.e. utilization of more than 2 images, may help (a) to get more robust results from spatial point intersection, (b) thereby to reduce the number of erroneously retrieved points and (c) to identify and reject unreliable points.

The investigation was carried out in an adequate manner for Stripmap stereo and multi-image arrangements. For the more favourable arrangements as recommended above RMS residual errors close to 1 meter for individual coordinates as well as an RMS residual length close to 2 meters were achieved (see also Figure 3). Images acquired outside the full performance range occasionally may be useful, but should rather not be included to retrieve reliable and accurate 3D information.

## References


[1] DLR, 2008. TerraSAR Ground Segment – Basic Product Specification Document, Doc. TX-GS-DD-3302, issue 1.5, 103 pages.

[2] Fritz T., H. Breit, and M. Eineder, 2008. TerraSAR-X Products – Tips and Tricks. 3rd TerraSAR-X workshop, Oberpfaffenhofen, Germany, 25th – 26th November, 2008. Published at http://sss.terrasar-x.dlr.de/

[3] Raggam H., R. Perko, and K.H. Gutjahr, 2009. Investigation of the Stereo-Radargrammetric Mapping Potential of TerraSAR-X. 29th Annual EARSeL Symposium, Chania, Greece, 15th – 18th June, 2009.

[4] Raggam H., K.H. Gutjahr, R. Perko, M. Schardt, 2009. Assessment of the Stereo-Radargrammetric Mapping Potential of TerraSAR-X Multi-Beam Spotlight Data. IEEE-TGRS, Special Issue on TerraSAR-X: Mission, Calibration, and First Results, Volume 48, No. 2, pp. 971-977, February 2010.


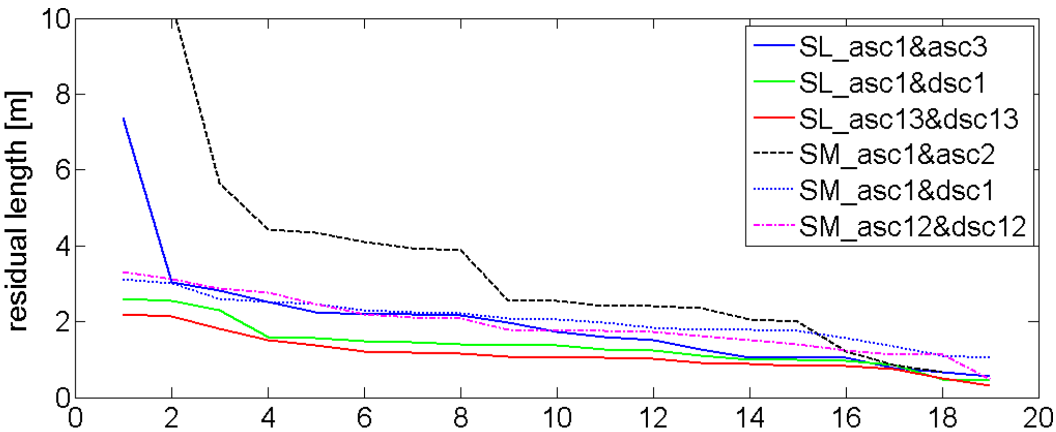


**Figure 3:** Plot of point residual lengths for selected acquisition arrangements