Two Years of TanDEM-X Relative Navigation

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Outline

- Introduction to the TanDEM-X Mission
- Relative Navigation Accuracy Requirements
- Filter for Relative Navigation of Spacecraft (FRNS)
- Baseline Calibration and Combination
- Conclusions
The TanDEM-X Mission

- TSX satellite launched in June 2007, TDX in June 2010
- Mission Objective: global DEM within 3 years
- Orbit height ca. 515 km
- Close helix formation (<500m)
- Main Payload: SAR instrument
- IGOR GPS receiver for navigation
Navigation Hardware

- Provided by GFZ

- Dual-frequency GPS receiver (IGOR)
  - 16 channels
  - 12 for POD
  - 4 for radio-occultations

- Laser Retro-Reflector
  - Orbit validation
  - Backup for POD
Requirements for Baseline Accuracy

Mission Objective: 10m abs. / 2m rel. DEM accuracy @ 12m x 12m

\[ \Delta h = \frac{h_{amb}}{\lambda} \Delta B_{LOS} \]

-1mm Baseline error in LOS => ~ 1 m DEM error
-1mm Baseline error => tilt of 0.0002°
-tilt and height error cause displacement of the DEM
-displacement larger than half a pixel cause wrong matching

Requirement for Baseline accuracy: 1 mm (1D - RMS)

-Baseline computed by GFZ & DLR with 3 independent software packages
-Baseline calibration and combination process installed
Filter for Relative Navigation of Spacecraft (FRNS)

- Absolute Navigation accuracy < 5 cm (3D-RMS)
- Double-differences for ambiguity resolution & error elimination
- Low influence of differential ionosphere
- Extended Kalman Filter
- ~48 states estimated
- Single-frequency solution possible (~25 states)
Available Data

- Daily average of observed satellites is stable
- TSX: Ø 8.5 Satellites
- TDX: Ø 8.5 Satellites
- common: Ø 8.1 Sat.
Phase Center Calibration

Results – GPS Residuals

Dual-frequency (0.2 m, 0.7-1.1 mm)  

Single-frequency (0.3 m, 3.3 mm)
Results – Single-Frequency vs Dual-Frequency

<table>
<thead>
<tr>
<th></th>
<th>Radial [mm]</th>
<th>Tangential [mm]</th>
<th>Normal [mm]</th>
<th>3D-RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>wide formation ~20 km</td>
<td>0.1 +/- 1.0</td>
<td>2.1 +/- 1.6</td>
<td>1.5 +/- 0.9</td>
<td>3.5</td>
</tr>
<tr>
<td>close formation &lt; 1km</td>
<td>0.0 +/- 0.7</td>
<td>1.0 +/- 0.8</td>
<td>1.2 +/- 0.7</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Baseline Calibration and Combination

- Software was developed using GRACE data
- Inter-agency comparisons showed bias of several mm
- 3 independent operational solutions
  - EPOS by GFZ
  - Bernese by GFZ
  - FRNS by DLR
- Dedicated baseline calibration data-takes over well known areas
  - Height offset proportional to Baseline offset in LOS
  - Different incident angles allow separation in components
Baseline-Calibration

BL-Calibration Test-Sites

“NRT” Stations

Std. Std.

HiPrio HiPrio

Standard DEM Production with calibrated Baseline

ITP SAR Processor

CalRawDEM

MCP DEM Offset

DEM Offsets (LOS)

Baseline Calibrations Processor GFZ

CALB BL

EPOS

Bernese

FRNS
Baseline Calibration Results

- Radial bias: $1.9 \text{ mm} \pm 1.1 \text{ mm}$

- Normal bias: $-1.9 \text{ mm} \pm 1.3 \text{ mm}$
Baseline Combination

![Graphs showing baseline combination trends](image-url)

FRNS - Bernese

[DLR Link]
Baseline Combination

- Offsets in normal direction < 2 mm
- Offsets in radial direction < 0.2 mm
- Tangential errors of EPOS larger -> reprocessing
- 3 solutions: noise reduction & outlier detection

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<td>FRNS – EPOS</td>
<td>+0.1 ± 1.1</td>
<td>+1.8 ± 0.9</td>
<td>+1.8 ± 3.4</td>
</tr>
<tr>
<td>EPOS – Bernese</td>
<td>+0.1 ± 1.0</td>
<td>-1.2 ± 0.8</td>
<td>-2.8 ± 3.4</td>
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<td>+0.6 ± 0.7</td>
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Conclusions

- GPS data quality remains constant
- Systematic biases of at most 2 mm in cross-track
- Baseline combination reduces noise
- Still not possible to quantify absolute accuracy
- Baseline calibration leads to error reduction