Investigations on the Influence of Antenna Near-Field Effects and Satellite Obstruction on the Accuracy of GNSS-based Distance Measurements

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Motivation

Site-dependent effects - one of the accuracy limiting factors in GNSS-based distance measurements
Motivation

- **Signals blocked/obstructed** by e.g. buildings leads to a deteriorated satellite geometry
- **Signals reflected and diffracted** leads to short-periodic errors
- **Offset** of the phase center to the antenna reference point (PCO)
- **direction dependent variations** of the mean phase center (PCV)
- **Influence of the first 50cm...**
  - can change the antenna phase center characteristics
  - leads to long-periodic multipath

**satellite obstruction / multipath**

**PCO/PCV**

**near-field effects**
Idea

Analyzing the influence by...

- Variation of antenna set-ups in "optimum" GNSS-Environment
- Comparison to reference values with superior accuracy
- Numerical simulation on basis of "optimum" datasets

near-field effects

satellite obstruction
**EDM calibration baseline site Munich (University of Armed Forces)**

- **excellent GNSS capabilities**
  - weak multipath environment
  - nearly free horizon

- **usage of calibrated antennas**
  - phase centre offset (PCO)
  - phase centre variations (PCV)
Measurement campaign

- 7 pillars used
- **individually calibrated antennas used**
  - Trimble Zephyr Geodetic
  - Trimble Zephyr 2
  - Leica AT504GG Choke Ring
- **different antenna-spacers used**
  (0,20,40,60cm)
- **observation duration at least 4 hours**

**dataset of 162 baselines**
- 38 baselines with identical set-up
- 124 baselines with different set-up
Data Processing with Leica Geo Office:

- GPS L1+L2, Hopfield troposphere model, standard ionosphere model
- Baselines separated into distance and height component
- Comparison to reference values with superior accuracy ($\sigma < 0.1\text{mm}$)

First outcome:

- Significant deviations in baselines were 60cm, spacers are used
- Remaining uncertainties from levelling and centering
- Setup unstable

Exclusion from further investigations
Antenna Near-Field - Results

**Equal set-ups**
- very high accuracy level in both components
- completely similar set-up
  - same antenna- / spacer type
  - identical cable routing

**Different set-ups**
- decreasing accuracy level
- bigger influence on height component
  - nearly factor of 2
- different set-up
  - different antenna- / spacer type
  - different cable routing
Different set-ups:
- decreasing accuracy level
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Equal set-ups:
- very high accuracy level in both components
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Lower accuracy level results from different near-field situations!

Similar antenna set-up enables minimization of near-field effect during double-differencing process!

Accuracy of <0.5mm possible for both baseline components!
Satellite Obstructions
Satellite Obstruction - Scenarios

Boundaries of shadowing areas are defined by azimuth and elevation values.
Satellite Obstruction - Results

Baselines with equal antenna set-up used as data basis

Mean differences to reference values [mm]

Mean DOP values

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>H</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref</td>
<td>1.3</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Wall</td>
<td>2.1</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Tree</td>
<td>1.5</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Mining</td>
<td>3.4</td>
<td>1.6</td>
<td>3.0</td>
</tr>
<tr>
<td>Canyon</td>
<td>4.2</td>
<td>2.2</td>
<td>3.5</td>
</tr>
</tbody>
</table>

- no significant impact in distance component
- height component of scenarios Mining and Canyon slightly affected

Compensation of obstructions by observation time?
Satellite Obstruction - Results

Shortened observation duration:

- no impact on accuracy of distance component visible
- slightly decreasing accuracy level of height component

1 hour observation duration

\[ \bar{\Delta d} < 0.25\text{mm}, \sigma_d < 0.5\text{mm} \]
\[ \bar{\Delta h} < 0.5\text{mm}, \sigma_h < 1.0\text{mm} \]
Satellite Obstruction - Conclusions

Estimation of position accuracy by

\[
\sigma_{\text{pos}} = \sigma_{\text{meas}} \cdot PDOP
\]

satellite geometry

measurement accuracy

a poor geometry (high PDOP) amplifies the range error

**reality**

Obstructions are accompanied by:
- multipath effects
- deterioration of signal quality

**simulation**

- mere changing of satellite geometry
- high signal quality remains
Hypothesis 1: Measurement accuracy seems to be higher than indicated in the common literature.

\[ \sigma_{pos} = \sigma_{meas} \cdot PDOP \]

Hypothesis 2: Multipath and signal distortions are more critical than a deteriorated satellite geometry.

Accompanied effects (multipath, signal distortion, …)
Summary / Outlook

[Image of satellite dish + Image of cityscape]
can be minimized during the double-differencing process in case of a completely identical antenna set-up (antenna type, mounting, cable routing, etc.)

prerequisite for achieving highest accuracies!

• based on the results it can be assumed that a deteriorated satellite geometry is less critical than expected
• the correlation between satellite obstructions and multipath effects has to be analyzed in detail
Satellite Obstruction vs. Multipath

Step 1: measurements with artificial reflector
- multipath, signal distortion, signal shadowing

Step 2: determination of reflector dimensions
- transform object into GPS coordinate system

Step 3: measurements without artificial reflector
- same satellite constellation

Step 4: simulation of reflector
- no multipath and signal distortion
- only signal shadowing

Separation of the influence of multipath and satellite obstruction
Thank you for your attention!
### DOP values for one session at pillar 3

#### Mean differences and DOP values

<table>
<thead>
<tr>
<th>Site</th>
<th>Distance component [mm]</th>
<th>Height component [mm]</th>
<th>Mean DOP values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ref</strong></td>
<td>0.14 (x) 0.31 (σ)</td>
<td>0.02 (x) 0.46 (σ)</td>
<td>P: 1.3 H: 0.8 V: 1.0</td>
</tr>
<tr>
<td><strong>Wall</strong></td>
<td>0.23 (x) 0.41 (σ)</td>
<td>0.09 (x) 0.46 (σ)</td>
<td>P: 2.1 H: 1.4 V: 1.6</td>
</tr>
<tr>
<td><strong>Tree</strong></td>
<td>0.07 (x) 0.38 (σ)</td>
<td>0.07 (x) 0.46 (σ)</td>
<td>P: 1.5 H: 1.0 V: 1.1</td>
</tr>
<tr>
<td><strong>Mining</strong></td>
<td>0.15 (x) 0.38 (σ)</td>
<td>0.32 (x) 0.87 (σ)</td>
<td>P: 3.4 H: 1.6 V: 3.0</td>
</tr>
<tr>
<td><strong>Canyon</strong></td>
<td>0.21 (x) 0.40 (σ)</td>
<td>0.13 (x) 0.60 (σ)</td>
<td>P: 4.2 H: 2.2 V: 3.5</td>
</tr>
</tbody>
</table>

Note: The table above provides the mean values (x) and standard deviations (σ) for both the distance and height components, along with the mean DOP values (P, H, V) for each category.