Introduction

For high accuracy GNSS applications phase center corrections (PCC), which include corrections for the phase center offset (PCO) and the phase center variations (PCV), are mandatory. These corrections are provided by different institutions & methods. At the moment only L1 & L2 frequencies for GPS are GLONASS are published by the IGS. However, partly chamber calibrations for the newer signals (Galileo and GPS L5) are available in the EPN. In this contribution, the PCC estimation approach of the Institut für Erdmessung (IfE) is presented. The estimated pattern are presented and validated with a common-clock set up at the Physikalisch-Technische Bundesanstalt (PTB). Moreover, the impact of the receiver on the estimation process is shown.

Methodology

As an IGS accepted calibration facility, IfE calibrates antennas using the method of absolute field calibration with a robot. The PCC are estimated post processed in the so called Hannover approach.

Data acquisition

- Setup: short baseline (≈ 8 m) and common clock.
- Defined sequence of movements for the robot.
- Tilting and rotating of antenna under test (AUT) around fixed point in space.
- Logging of raw GNSS data for each station and movements of robot with timestamps (orientation parameters).

Data analysis

- Finding corresponding observations on both stations where robot was not moving.
- Building of time-differented single differences (ΔSD); Most errors are cancelled out due to short baseline and short time period.
- Phase-wind-up and robot pose is modelled.

PCC estimation

- Parametrisation of PCC by spherical harmonics (SH) with degree m = 8 and order n = 8
- PCC (x, y, z) = \sum_{m=0}^{8} \sum_{n=0}^{m} \sum_{t=0}^{2} a_{mn} \cos(n \phi) + b_{mn} \sin(n \phi)

- SH analysis to estimate unknown coefficients a_{mn} and b_{mn},
- Coefficients with an odd index sum are restricted to zero.
- SH synthesis with estimated coefficients to calculate PCC grid.

Least-squares adjustment to calculate PCO and PCV from PCC grid.

Repeatability of estimated pattern

- Several calibrations with different antennas/antenna types typical for IGS stations in February and August 2019 (Tab. 1).
- Analysing of repeatability by calculating RMS of difference pattern. Results show an overall good repeatability (RMS ≤ 1 mm) except for GLSX (less transmitting satellites). Biggest differences occur at low elevations (Fig. 2).
- Frequency dependency of PCC can be clearly seen, especially for LEIA20 (Fig. 4).
- PCC are similar for LEIA25 and LEIA20 and range up to 15 cm.

Validation of estimated PCC

- Experimental setup at the PTB (Fig. 5): common-clock short baseline (≈ 5 m) configuration is used to calculate receiver-to-receiver single differences (SD) (Tab. 2).
- GNSS measurements (GPS, Galileo, GLONASS) from February 4th to 7th 2018 (DOY35 - DOY38).
- Precise coordinates are calculated relative to reference station PTB1 with sub-millimeter accuracy.
- Estimated pattern of NOV031GGR can be found in [1] and [2]. As there are no chamber calibrations available for this antenna, the similar PCC of LEIAX120GG are used instead.
- IfE’s PCC fit very good into SD and decreases its RMS up to 3.5 mm for ELSX.

Impact of different receiver on estimated PCC

To analyse the impact of different receivers on the estimated PCC (as the combination of antenna and receiver affect the PVT result) a zero baseline is set up.

- Two receivers are connected to the antennas on both stations (Tab. 3).
- AUT is LEIA25 R3 LEIT (S/N: 08340000), estimation process equal to the one described in section Methodology.
- Tracking loop parameters, calibration time & robot pose are identical for all four receivers.

- Differences in PCC pattern between estimated PCC using Javad or Septentrio receivers on DOY 239 for following frequencies: GL1C, GL5X, EL1X and EL5X (Tab. 4).
- Coefficients with sub-millimeter accuracy.
- As there are no chamber PCC available for this antenna, the similar PCC of LEIA25 are used instead.
- Expected noise of the zero baseline configuration for GL1C.

Conclusion & Outlook

- IfE is ready to estimate PCC for several GNSS signals using the Hannover approach.
- A good repeatability (RMS < 1 mm, except for GLSX) is reached. Differences in repeatability can occur due to different robot movements and different calibration times (different satellite geometry).
- Calibration of further signals like GL2L, EL7Q and EL8Q is possible with Septentrio receiver.
- Further analysing of the antenna-receiver impact on the estimation procedure, especially regarding the repeatability and the validation.

References and Acknowledgement

[4] The authors would like to thank the PTB, especially A. Bauch, for their support and commitment during the practical measurement on the grounds of the PTB in Braunschweig.

Figure 5: Experimental setup at the PTB. The used Antennas are indicated by a red circle.

Table 1: Antenna and antenna types which were calibrated with the Hannover approach.

<table>
<thead>
<tr>
<th>Station</th>
<th>Antenna</th>
<th>DOY</th>
<th>RMS [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEIA25 R3 LEIT</td>
<td>GL1C GL5X EL1X EL5X</td>
<td>08340000</td>
<td>0.23 1.36 0.61 0.79</td>
</tr>
<tr>
<td>LEIA25 R3 LEIT</td>
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Figure 6: Difference pattern between estimated PCC using Javad or Septentrio receivers on DOY 239 for following frequencies: GL1C, GL5X, EL1X and EL5X (Tab. 4).

Table 2: Hardware setup at the PTB.

<table>
<thead>
<tr>
<th>Station</th>
<th>Antenna</th>
<th>Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROBO LEIA25 R3 LEIT</td>
<td>08340000</td>
<td>JAVAD DELTA TREGST</td>
</tr>
<tr>
<td>ROBO LEIA25 R3 LEIT</td>
<td>08340000</td>
<td>SEPT PolaRa4TR</td>
</tr>
<tr>
<td>MDS8 LEIA25 R3 LEIT</td>
<td>09330000</td>
<td>SEPT PolaRa4TR</td>
</tr>
</tbody>
</table>

Table 3: Hardware setup for zero baseline configuration at IfE.

<table>
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<tr>
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<th>Receiver</th>
</tr>
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</tr>
</tbody>
</table>

Figure 7: Difference pattern between estimated PCC using Javad or Septentrio receivers on DOY 239 for following frequencies: GL1C, GL5X, EL1X, EL5X (Tab. 4).

Table 4: RMS and Spread [3] for the difference pattern (estimation with Septentrio or Javad receiver).

<table>
<thead>
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<th>DOY</th>
<th>Receiver</th>
</tr>
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<td>ROBO LEIA25 R3 LEIT</td>
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Figure 8: Expected noise of the zero baseline configuration for GL1C.