Analysis of the Impact of Rotating GNSS Antennae in Kinematic Terrestrial Applications

TS04E - Laser Scanners, Friday, 20 May 2011

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FIG Working Week – Bridging the Gap Between Cultures
Marrakech, Morocco, May 18-22, 2011
Transformation of local, sensor defined coordinates to absolute or global coordinates

- Typical task in terrestrial laser scanning applications
- Transformation parameters: translation and rotations (at least the azimuthal orientation) required
- Observation of transformation parameters (with additional sensors) is worthwhile

→ Most suitable is the use of GNSS equipment

Current realisation of the combination of laser scanner and GNSS equipment at the Geodetic Institute
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**GNSS equipment to determine position and orientation in kinematic applications**

- *Alternating orientation of an eccentrically mounted GNSS antenna*

⇒ Systematic effects:
  - Polarisation of the satellite signal (Phase wind up effect)
  - Phase centre corrections (offsets and associated variations)
Contents

1 Brief overview about errors related to rotating GNSS antennae

2 Experimental studies
   • Location and used equipment
   • Pre-investigations - measurements with a non-rotating antenna
   • Kinematic measurements with an eccentrically rotating antenna

3 Analysis and interpretation of the results
   • Observation domain
   • Coordinate domain
   • Different mathematical approaches within the GNSS analysis

4 Conclusions and Outlook
Errors related to rotating GNSS antennae

Phase wind up (PWU) effect

- Up to one full cycle due to the signal polarisation
- PWU effect is linear in time and identical for all satellites visible in the topo-centre assuming an antenna horizontally rotating with constant velocity
- Single-differences on a short baseline
  - Constant net effect for all satellites
  ⇒ Absorbed by the receiver clock error

Phase centre corrections (PCC)
Errors related to rotating GNSS antennae

Phase wind up (PWU) effect

Phase centre corrections (PCC)
- Measurements related to electrical phase centre
- Modelling of observations in adjustment often w.r.t. antenna reference point (ARP)
- PCC described by phase centre offset (PCO) and associated elevation and azimuth depending phase centre variations (PCV) close the gap

Sketch of PCC for an eccentrically (and horizontally) rotating antenna

\[ \Delta \phi_{\text{ant}}(\alpha,e) = [\text{PCO}\| e] + \Delta \phi(\alpha,e=\pi/2,z) \]
Location and GNSS equipment

Location: Geodetic network with 9 pillars at the roof of the building of the GIH

 GNSS equipment

Reference station (MSD08)
Antenna: LEIAR25 LEIT
Receiver: JAVAD TRE_G3T DELTA

Antenna under test (MSD06)
Antenna: JAV_Grant-G3T
Receiver: JAVAD TRE_G3T DELTA
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Analysis of Rotating GNSS Antennae
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Brief overview about errors related to rotating GNSS antennae

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Location and used equipment
Measurements with non-rotating antenna
Measurements with ecc. rotating antenna

Analysis & interpretation of the results
Conclusions & Outlook

PCV pattern L1: *Javad Grant G3T* antenna

Investigation strategy

In the following study we used:

• Wa1 software using single-differences between receivers to eliminate
• Orbit errors,
• Satellite clock errors and
• Errors due to propagation delays in the atmosphere

• A small baseline of about 14 m ⇒ eliminates all atmospheric effects
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GNSS equipment – investigation strategy

PCV pattern L1: Javad Grant G3T antenna

Investigation strategy
- Simultaneous acquisition of GNSS and reference trajectories
- Creation of reference trajectories
  (1) Theoretic one: Computed based on the known geometry of the GNSS antenna mount on top of the laser scanner
  (2) Experimental one: Tracking of a Leica GRZ122 360° prism with a Leica TS30 tacheometer
- Data analysis in observation and coordinate domain
PCV pattern L1: *Javad Grant G3T* antenna

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**Location and used equipment**

Measurements with non-rotating antenna and measurements with eccentric rotating antenna.
Performance of the used antenna for estimating coordinates with non-rotating antenna

- Similar combination of antenna, 360° prism and height above pillar
- DOY049: Standard tripod on pillar 6
- DOY041: Additional use of the wing adaption for mounting on a laser scanner
- $\Delta T$ for DOY049 and 041 corresponds to difference of sidereal and solar day length

Get a rough idea about the influence of the wing adaption

Antenna setup without wing adaption

![Image of antenna setup without wing adaption]
Pre-investigations - measurements with a non-rotating antenna (DOY049 and 041)

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Skyplot DOY049 – 09:50:38 - 11:25:38
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Kinematic measurements with an eccentrically rotating antenna (DOY025)

Analyse the impact of rotating GNSS antennae in kinematic terrestrial applications

- Measurements with a laser scanner rotating about its vertical axis (duration for full circle $\approx 13$ min, vertical rotation speed $\approx 12.5$ Hz)
- $\Delta T$ for DOY025, 049 and 041 corresponds to diff. of sidereal and solar day length
- Weight compensation for GNSS antenna and prism
- Laser scanner is oriented to the direction of gravity; for observation of remaining spatial residuals inclinometer were used
- All observations (GNSS and tacheometer) are synchronised by an external computer

Used equipment
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![Image of a laser scanner and GNSS antenna setup]
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Used equipment and sample trajectory in local geodetic coordinates
For every epoch a new set of PCC for an eccentrically rotated antenna is calculated and projected into the line of sight to the individual satellites:

\[ PCO_c = f(PCO, \alpha_0, r, \Delta \alpha) \]

\[ PCV_c = f(PCV, \alpha_0, r, \Delta \alpha) \]

\[ \Phi_{ci}^j = \Phi_{ci}^j - PWU_{ci}^j + PCO_{ci}^j - PCV_{ci}^j \]

mit:

- \( i := \) Frequenz L1/L2
- \( j := \) Satellit No.

- Initial azimuth of antenna orientation
- Well known geometric parameters (radius and angle inc. between 2 rotation steps)
- PWU effect already treated by analysis software Wa1

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1. Personal correspondence with L. Wanninger
Analysis of the impact of the PCC by calculation of range corrections

For every epoch a new set of PCC for an eccentrically rotated antenna is calculated and projected into the line of sight to the individual satellites

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\begin{itemize}
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\[\Rightarrow\text{ Re-processing of modified observations and further analysis in the coordinate domain}\]
Original PCC minus rotated PCC

Original PCC minus rotated PCC for GPS L1 signals; DOY025, run15
Original PCC minus rotated PCC for GPS L1 signals; DOY025, run15

Intermediate result

⇒ For GPS L1 magnitudes of up to 5 mm occur at low elevations
NEU coordinates of non-rotating antenna in different scenarios

Differences (to ITRF05 coordinate of pillar 6); 1 Hz data rate and 10° cut-off angle

Intermediate results: Kinematic coordinate estimation potential of the used GNSS antenna
NEU coordinates of non-rotating antenna in different scenarios

Differences (to ITRF05 coordinate of pillar 6); 1 Hz data rate and 10° cut-off angle

Intermediate results: Kinematic coordinate estimation potential of the used GNSS antenna

- Maximum range of 1 cm for northing, easting and up to 2 cm for the up component
- NO significant influence due to the wing adaption
NEU coordinates of rotating antenna (GPS)

Computed differences between experimental reference trajectory and rotated PCC pattern as well as original PCC pattern

- North [m]
- East [m]
- Up [m]
NEU coordinates of rotating antenna (GPS)

Difference between GNSS trajectories with original and rotated PCC applied

Intermediate results: PCC effect for rotating GNSS antenna
Intermediate results: PCC effect for rotating GNSS antenna

Magnitude from 0 \text{ mm} to 4 \text{ mm} for northing and the other way round easting as well as range of discrepancy of 0.4 \text{ mm} for the up component
Difference of NEU coordinates of epoch-wise solution vs. filter-based solution

Differences between experimental trajectory and filter-based solution (GNSMART\(^2\), green circles) as well as epoch-wise solution (Wa1, red bullets)

\(^2\) GNSMART by Geo++

Special thanks go to Nico Lindenthal for the support with the kinematic GNSS analysis with GNSMART.
Conclusions and sum up of the results

Observation domain

- Double differences analysis shows no significant impact of the used wing adaption in the direct vicinity (see paper)
- PWU effect is constant $\implies$ treated like receiver clock offset in the adjustment
- Effect of up to $5 \text{ mm}$ for rotated PCC against original PCC $\implies$ corresponds to horizontal offset component

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Coordinate domain
- Also indicates an effect of up to $5\ mm$
- PCC effect is dominated by the PCO components
- Noise range of epoch-wise GNSS analysis is larger than rotated PCC effect

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Outlook
- Further investigations of filter-based GNSS analysis
- Analysis of the impact of the rotated PCC on the derived transformation parameters
Conclusions and Outlook

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Thank your for your attention!

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