Analysis and mitigation of site-dependent effects in static and kinematic GNSS applications

Analyse und Minimierung stationsspezifischer Abweichungen bei statischen und kinematischen GNSS-Anwendungen

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PhD Defense
02 September 2019
Positioning with GNSS

$X, Y, Z?$
Absolute positioning with GNSS

‘navigation solution’ using code observations

true position

median = 3.53m

www.tim-online-nrw.de
Static and kinematic GNSS applications

...where the accuracy requirements are substantially higher:

**CORS-networks**

www.sapos.nrw.de

www.bafg.de

**cadastral or engineering surveying**

www.stadt-muenster.de

www.businesskorea.co.kr
Static and kinematic GNSS applications

mobile multisensor systems / autonomous navigation

www.phenorob.de

www.dji.com
To achieve accuracies at the millimeter to centimeter level:

**a) relative positioning is performed**

- observations of **two antennas** are used
- **baseline vector** between rover and master is determined

If the baseline is short, **systematic errors can be eliminated or minimized** by forming observation differences!
To achieve accuracies at the millimeter to centimeter level:

b) carrier-phase observations are used

- phase difference $\Delta \lambda$ observed
- carrier-phase ambiguities $N$ need to be solved
Positioning with GNSS

- relative positioning using carrier-phase observations

- accuracies in the mm to cm range achievable

...in case of short baselines and fixed ambiguities
Relative positioning with GNSS

‘baseline solution’ using phase observations

true position

median = 0.84m

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Site-dependent GNSS effects

I. Satellite geometry
II. Far-field multipath
III. Signal diffraction
IV. NLOS reception
V. Antenna near-field

...differ at master and rover antenna (usually)
...cannot be reduced by double-differencing
...remain as dominant influence on the positional accuracy
Site-dependent GNSS effect - 1

- no obstructions
- satellites are evenly distributed across the sky

quality of the satellite geometry is high
Site-dependent GNSS effect - I

- obstructions block signals
- satellites are not evenly distributed across the sky

quality of the satellite geometry deteriorated

negative impact on positional accuracy expected
Site-dependent GNSS effect - II

- signal reaches antenna on multiple paths
- interference of direct and reflected signals
- negative influence on receiver internal correlation process

for carrier-phase observations

effect limited to $\lambda/4$

($\approx 5cm$ for GPS-L1)
Site-dependent GNSS effect - III

- Direct signal path is blocked
- Signal is ‘bended’ into shadowing zone
- Range error equals additional signal path

Error usually in the range of several centimeters to decimeters

τ can reach values up to 10°...20°
Site-dependent GNSS effect - IV

- direct signal path is blocked
- only reflected signal reaches antenna
- range error equals additional signal path

error typically in the range of several tens of meters
occurs less frequently than diffraction
objects in the immediate surrounding of the antenna (tribrachs, adapters, cables,...) can lead to long-periodic and non-zero mean multipath effects and change the antenna phase center characteristics.
Subject to scientific research for decades
Numerous methods and mitigation techniques have already been developed

Hardware-based

Receiver-Design
- Different correlator spacing
- Multipath-Estimating-Delay-Lock-Loop
- ...
- *Good overview given in*  
  *Irsigler (2008), Smyrnaios (2016)*

Antenna-Design
- Pin-Wheel antennas, *Kunysz et al. (2000)*
- Choke-Ring antennas, *Bedford et al. (2009)*
- ...

Data-driven

- Sidereal filtering, *Bock (1991)*
- MPSM, *Fuhrmann et al. (2015)*
- Dynamic elevation masks from SNR,  
  *Kersten and Schön (2017)*
- Temporal correlations,  
  *Zhang and Schwieger (2019)*
- ...

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...so why further research?

- increase the understanding of the different effects
- enlarge the amount of available mitigation techniques

contribute to a holistic solution

Currently...

- preferably every observation, whether affected or not, shall be used
- (majority of) available mitigation techniques try minimize the influence of affected signals on the position estimation
Analysis and mitigation of site-dependent effects in static and kinematic GNSS applications

detection and exclusion of affected signals

**IGG-rooftop, 2nd September 2019, 13pm**

utilization of antenna environment models

**Campus Poppelsdorf**

GPS only: #14  Multi-GNSS: #46

3D city model  TLS point cloud

www.gnssplanning.com
Site-dependent effects in GNSS applications

- antenna near-field
- satellite geometry
- NLOS reception
- signal diffraction
- far-field multipath

Publication A
Publication B
Publication C
Publication D
Publication E
Site-dependent effects in GNSS applications

- antenna near-field
- satellite geometry
- NLOS reception
- signal diffraction
- far-field multipath

Publication A
Publication B
Publication C
Publication D
Publication E
Main aspects of talk

1. Mitigation of NLOS reception and signal diffraction using Obstruction Adaptive Elevation Masks (OAEM)

2. Far-field multipath analysis using the Fresnel zone concept
...to detect signals affected by NLOS reception or signal diffraction!
Obstruction Adaptive Elevation Mask

A priori given:
- initial antenna position
- georeferenced point cloud of antenna environment

- determination of highest elevation angles for azimuthal directions

- adjustment with respect to positional uncertainty
Obstruction Adaptive Elevation Mask

I

II

III

House A

House B

I

II

III

House A

House B

0

15

30

45

60

75

90

120

150

180

210

240

270

300

330

0
Field tests

static

kinematic

GPS antenna

GPS track

≈ 31m

≈ 21m

www.tim-online-nrw.de

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Results from static field test

[Diagram with various graphs and data sets showing comparisons between original and OAEM applied results]

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Results from kinematic field test

(Video in original talk)

ambiguities
- ...fixed
- ...float

88% 12%

OAEM

55% 45%

[Graph showing data points and north-east coordinates]
NLOS reception and signal diffraction can be mitigated by Obstruction Adaptive Elevation Masks derived from TLS point clouds leading to higher positional accuracy in static and kinematic GNSS applications.
1. Mitigation of NLOS reception and signal diffraction using Obstruction Adaptive Elevation Masks (OAEM)

2. Far-field multipath analysis using the Fresnel zone concept
Satellite selection for far-field multipath?

- Geometrical visibility check not applicable
- Different approach for detecting potentially influenced signals needed
Far-field multipath and SNR

- trend in time-series represents direct signal component
- oscillations on top of trend represents multipath signal
Far-field multipath occurrence

- assumption of pointwise reflection process not valid

- active scattering regions exist called **Fresnel zones**

- size of Fresnel zone depends on antenna height, elevation angle and signal wavelength

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**Theoretical prerequisites for far-field multipath occurrence are related to Fresnel zones**

**#1:** reflecting surface inside the Fresnel zone needs to be smooth enough

**#2:** Fresnel zone should completely be located on reflecting surface
Prerequisite #2 for multipath occurrence

Fresnel zone should completely be located on reflecting surface
Prerequisite #2 for multipath occurrence

Fresnel zone should completely be located on reflecting surface

...what happens if not?
Field test on spatially limited reflector

- End of track
- Start of track

GPS antenna

North [m]

East [m]
Simulation of far-field multipath

\[ A_C = A_D \sqrt{1 + 2\alpha \cos(\Delta \Phi_M)} + \alpha^2 \]

amplitude of compound signal

amplitude of direct signal

attenuation factor \( \alpha \):

\[ \alpha = \frac{A_M}{A_D} \]

\( A_M \) … amplitude of reflected signal

\( A_D \) … amplitude of direct signal

multipath relative phase \( \Delta \Phi_M \):

\[ \Delta \Phi_M = \frac{2\pi}{\lambda} 2h \sin \theta \]

\( h \) … antenna height

\( \lambda \) … signal wavelength

\( \theta \) … satellite elevation
Fresnel zone vs. far-field multipath

$P_{FZ} = 100\%$

$50\% \leq P_{FZ} < 100\%$

$P_{FZ} < 50\%$
Fresnel zone vs. far-field multipath

- good agreement/high correlations below 30° elevation
  - still good agreement between simulation and observation
  - small correlations
  - variation of observed SNR of random nature

- multipath clearly occurs

$P_{FZ} = 100\%$

- multipath effect already occurs!

$50\% \leq P_{FZ} < 100\%$

- no multipath occurs

$P_{FZ} < 50\%$

- multipath clearly occurs
Fresnel zones applied to multipath analysis
- 50% overlap with reflector sufficient for occurrence
- deepens the understanding of the effect
- forms the basis for detection and exclusion algorithm

Obstruction Adaptive Elevation Masks
- detection and exclusion algorithm based on point clouds
- can substantially improve the positional accuracy
- applicable in static and kinematic applications
Conclusion

- analysis of influence on positional accuracy by simulation of generic obstruction scenarios
- influence marginable compared to concomitant effects

- mitigation by optimized measurement strategy
- identical antenna set-up enables mitigation during double differencing process
advanced measurement strategy for mitigating site-dependent effects in

high-precision applications
(e.g. CORS networks, engineering geodesy tasks)
\( \sigma_{\text{POS}} \leq 2 \ldots 3\text{mm} \)

medium-precision applications
(e.g. cadastral surveying)
\( \sigma_{\text{POS}} \leq 2 \ldots 4\text{cm} \)
Outlook

Multi-GNSS

Advanced satellite selection strategy

- LOD models
- OAEMs from moving platforms
- Real-time camera images
- Selection based on Fresnel zones
- Arbitrary reflectors

...
Peer-review publications


Further publications

Peer-reviewed publications:


Guidelines:


Non peer-reviewed publications:


Thank you!