Improved algorithms for precise positioning with GNSS in a near real-time mode

Kinga Wezka
Technische Universitat Berlin
Department for Geodesy and Geoinformation Sciences

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Supervised by
Prof. Dr. Roman Galas
Outline of the presentation

The main goal and theoretical introduction:
- GNSS observation equations;
- Ionospheric influences on the GNSS observables.

Selected numerical examples:
- Post-processing of the LCK1 data recorded in the static mode;
- Processing of the static data in kinematic mode;

Methodology and conclusion:
- Investigation of various ionospheric models;
- System’s performance parameters;
Main goal

Improvement of performance of the GNSS data processing algorithms for:

- Precise Point Positioning (PPP);
- Long-Baseline Relative Positioning.

Requirements:

- Algorithms based on zero-difference observables;
- Near-real- and real-time approaches;
- Algorithms for mitigation of strong ionospheric disturbances
Motivation and methodology

Motivations:

- **Ionospheric irregularities** are the most critical phenomena affecting the quality of the GNSS positioning especially in a real-time, because their nature and occurrence are very difficult to predict and reduce;

- Influence of the **higher order ionospheric terms** have to be investigated, because according to (Elsobeiey & El-Rabbany 2011) applying of it can improve accuracy of the PPP 3D real-time positioning solution by about 3 mm, and the **convergence time** of the estimated parameters can be **shorted by 15%**.

Metodology:

- An investigation of the operational applicability of various ionospheric models will be done and they performance will be measured and examined using:
  - system’s performance parameters;
**GNSS observation equations**

\[ r_{rs}(t) = \rho_{rs}(t) + c(\delta t_r - \delta t_s) + \delta_{\text{ion}} + \beta_r - \beta_s + \delta_{\text{trop}} + \delta_{\text{rel}} + \delta_{\text{mult}} + \epsilon_{rs} \]

\[ L_{rs}(t) = \rho_{rs}(t) + c(\delta t_r - \delta t_s) - \delta_{\text{ion}} + \lambda(N + \alpha_r - \alpha_s) + \delta_{\text{trop}} + \delta_{\text{rel}} + \delta_{\text{mult}} + \epsilon_{rs} \]

- \( \rho \) - geometrical distance between satellite and receiver;

- \( \delta t_r \) and \( \delta t_s \) - receiver and satellite clock corrections

- \( \beta_r \) and \( \beta_s \) - code signal delays in the hardware of the receiver and satellite;

- \( \alpha_r \) and \( \alpha_s \) - carrier phase signal delays in the hardware of the receiver and satellite;

- \( \lambda \) - carrier wavelength;

- \( N \) - carrier phase ambiguity;

- \( \delta_{\text{ion}} \) - influence of the ionosphere;

- \( \delta_{\text{trop}} \) - influence of the troposphere;

- \( \delta_{\text{rel}} \) - relativistic corrections;

- \( \delta_{\text{mult}} \) - multipath effects;
Ionospheric influences on GNSS observables

- Ionospheric group refractive index:
  \[ n_{gr} = 1 + \frac{\mathcal{I}_1}{f_2} + \frac{\mathcal{I}_2}{f_3} + \frac{\mathcal{I}_3}{f_4} + \ldots \]

- Ionospheric phase refractive index:
  \[ n_{ph} = 1 - \frac{\mathcal{I}_1}{f_2} - \frac{\mathcal{I}_2}{2f_3} - \frac{\mathcal{I}_3}{3f_4} - \ldots \]

where:
- First-order:
  \[ \mathcal{I}_1 = 40.309 \int r \hat{s} \cdot Ne \, ds \]
- Second-order:
  \[ \mathcal{I}_2 = 1.128410 \int r \hat{s} \cdot NeB\cos\theta \, ds \]
- Third-order:
  \[ \mathcal{I}_2 = 3812.4210 \int r \hat{s} \cdot Ne\hat{r}_2 \, ds \]
One of the useful methods for monitoring the changes of the density of ions is continuous analysis of the time derivative of TEC:

- **ROT** - Rate of change of the TEC:
  \[ ROT = \frac{\text{TEC}_{t+s} - \text{TEC}_{t-1}}{t+s - t - 1} \]

- **ROTI** - Rate of change of the TEC index:
  \[ ROTI = \sqrt{\langle TEC^2 \rangle} - \langle TEC \rangle \]
Scintillations
Ionospheric scintillations are fast and random fluctuations of radio Frequency (RF) signal amplitude and phase

Scintillation phenomena can not only limit the accuracy of GNSS positioning, but even result in a loss of carrier lock and intermittent the receiver operation.

Traveling Ionospheric Disturbances (TIDs)
Traveling ionospheric disturbances (TID) are understood as plasma density fluctuations that propagate through the ionosphere at an open range of velocities and frequencies
An initial investigation was conducted in order to evaluate the influences of ionospheric disturbances onto GNSS precise positioning.

This step has been performed using 1Hz GNSS data collected at the high latitude station LCK1 (Kiruna, Sweden).

Static GNSS observations in the RINEX format, for the time period from January 1, 2012 until July 30, 2012 were provided by the German Aerospace Centre (DLR) in the frame of cooperation within the TRANSMIT project.

The analysis of ionospheric influences was done with help of ROTI maps (available on the SeSolstrom website developed by the Norwegian Mapping Authority September, 2012) to identify time periods within which unusual ionospheric disturbances were present.

Temporal resolution of those ROTI maps is equal to 5 minutes.

Norwegian Mapping Authority (September 2012). www.sesolstorm.kartverket.no
Post-processing of the LCK1 data recorded in the static mode:

- LCK1 (Kiruna, Sweden) – (1Hz data were sampled to 30 s)
- reference stations: KIR0 and KIRU
- Software: GAMIT/GLOBK - based on double-difference

1st Approach: L3 linear combination was used for mitigation of the first order ionospheric influences

2nd Approach: Correction to observations using the CODE ionospheric model distributed by Center for Orbit Determination in Europe (first-, second- and third-order terms) were applied.
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- Kinematic receiver: LCK1 (Kiruna, Sweden) – (1Hz data were sampled to 30 s);
- Reference receiver: KIR0 (Kiruna, Sweden)
- Baseline length: 30 km;
- Software: GAMIT/GLOBK module TRACK (based on double-difference relative positioning)
- **extra Wide-Lane** linear combination (also called ionospheric phase) to fix carrier-phase ambiguities regardless the baseline length (Herring et al. 2010a) ;
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Carrier Phase Residuals per Satellite, DOY 022
An investigation of the operational applicability of various ionospheric models will be done and their performance will be measured and examined;

Evaluation of the quality and robustness of novel approaches and models:

- Parameters describing the quality of raw observations.
- Parameters estimating quality and robustness of the navigation solution and performance.
Parameters describing the quality of raw observations:

- Number of cycle slips detected;
- Number of not-correctable cycle slips;
- Number of loss of locks of signal;
- Number of single epoch gaps;
- Length of connected carrier phase arcs.
Parameters estimating quality and robustness of the navigation solution and performance:

- Precision and accuracy;
- Integrity;
- Availability;
- Confidence level and significance level;
- Convergence time
Summary and conclusion

The above numerical examples show that the suggested parameters can help to describe performance of the GNSS processing approaches for mitigation of the ionospheric threats.

Continuous monitoring of 1Hz time series of the GNSS coordinates can help to allow an assessment of the risks caused by ionospheric disturbances.

In order to improve the system performance all performance parameters listed here should be evaluated and issued in real-time applications.
Summary and conclusion

This above numerical examples shows some influences of the ionospheric disturbances on accuracy and precision of the GNSS positioning.

In order to confirm the usability of the suggested performance parameters our numerical analysis will be continued.

In the further investigations various ionospheric models will be applied, among them products of the IPDM services.

The second-order ionospheric term have to be investigated for real-time appli
Thank you for your attention

Kinga Wezka
kinga.wezka@tu-berlin.de
Bibliography


Currently

- Operation of continuous ultra high rate GNSS monitoring reference station at TUB
- Will be used, for example for evaluation of performance of the available services

Data streaming in real-time
- High-Rate (1 Hz)
- Very- and Ultra-High-Rate
- RT Quality Control
Network approach

**Observation Space Representation (OSR)**
- **distance dependent state** parameters are derived and combined with reference station observation;
- OSR describes **lump sum** of GNSS errors;
- Example: **Real Time Kinematic (RTK)**
  - rover use observations of reference station(s) and RTK network corrections (e.g. VRS, PRS, MAC)

**State Space Representation (SSR)**
- provides all GNSS errors for direct use functional and optional stochastic state description
- SSR describes **each individual GNSS biases**
- Example:
  - observations of single GNSS receiver
  - rover uses state space information (e.g. IGS products)

[Wubbena et al., 2005]
The proposed PPP-RTK is synthesis of the positive characteristic of both, PPP and RTK networking concept.

[Wubbena et al, 2005]

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