Precise Point Positioning
Performances under Ionospheric Scintillations

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NGI, The University of Nottingham
Handling

Project

Softwares

Geometry

Stochasticity
We installed two Septentrio receivers in the Geophysical Center of Dourbes (RMI)

SWANS Project
Geophysical Center of Dourbes (RMI)
Septentrio PolaRx3eG
Very Short Baseline
GioveA and GioveB (E1 – E5)
GPS 01/25 (L1 – L5)
1-year data set
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SWANS Project
Geophysical Center of Dourbes (RMI)
Septentrio PolaRx3eG
Very Short Baseline
GioveA and GioveB (E1 – E5)
GPS 01/25 (L1 – L5)
1-year data set
We designed a preprocessing method based on this new data set
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The PPP is a performant technique
The PPP suffers from several weaknesses
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Ionospheric Scintillations involve physical effects on GNSS signals

- Cycle slips
- Ambiguity resolution processes
- Additional convergence time
- Measurement noise
- Signal power fluctuations
- Lost signals
- Geometry troubles
- Signal delay

\[ \sigma_{POS} = DOP \times \sigma_P \]
PPP performances under Ionospheric Scintillations can be improved by using several strategies

WP0 - GNSS Tools

WP1 - Signals

WP2 - Geometry

WP3 - Stochasticity

WP4 - Model

WP5 - Ambiguity
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gLAB is a free and open source multipurpose GNSS data processing and analysis software.
AgLAB is a MATLAB software which exploits gLAB to process large network data sets.

- Automatic downloading
- Processing (SPP/PPP)
- Output Data Format
- Report Files
- Errors Detection
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- Galileo?
- Rinex v3.0?
- Triple Frequency Data?
- Simulated Data Processing?
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Ionospheric Scintillations reduce the number of tracked satellites
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\[ \sigma_{POS} = DOP \times \sigma_P \]
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Ionospheric Scintillations reduce the satellite geometry quality
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The geometric effect of Ionospheric Scintillations is a major effect for satellite positioning.
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Ionospheric Scintillations produce unbalanced satellite geometry
High DOP values are not only due to a small number of tracked satellites

\[
T_1 = 2.36 \quad DOP = 13.78
\]

DOP = 2.36

DOP = 13.78
High DOP values are correlated to a normal matrix close to a singular state

\[ |N| = 3.47 \]

\[ |N| = 0.04 \]
A conical satellite geometry drives the DOP to infinite values

$$\left| N \right| = 0$$

$$Q_{\hat{x}} = N^{-1} = (A^T A)^{-1}$$

$$A = \begin{bmatrix}
- \cos \eta^1 \sin \chi^1 & - \cos \eta^1 \cos \chi^1 & - \sin \eta^1 & 1 \\
- \cos \eta^2 \sin \chi^2 & - \cos \eta^2 \cos \chi^2 & - \sin \eta^2 & 1 \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
- \cos \eta^n \sin \chi^n & - \cos \eta^n \cos \chi^n & - \sin \eta^n & 1
\end{bmatrix}$$

Any linear dependence?
High DOP values are not only due to a small number of tracked satellites.
A nearly conical satellite geometry drives the DOP to critical values

- T₁
  - DOP = 2.36

- T₂
  - DOP = 13.78
A nearly conical satellite geometry deteriorates the satellite geometry quality.

**$T_1$**

- DOP = 2.36

**$T_2$**

- DOP = 13.78
Ionospheric Scintillations increase the probability to encounter conical satellite geometries.
Coherent Observation Weigthing Scheme is essential to correctly combine observations.
The combined use of GPS and Galileo satellites improves the satellite geometry quality
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Quantify the improvement of PPP’s performances involved by the expanded GPS-Galileo satellite geometry

- Precision
- Time convergence
- Reliability

Ionospheric Scintillations
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Ionospheric Scintillations degrade satellite signal quality

Signal amplitude fluctuations
Ionospheric Scintillations degrade receiver measurement precision

\[ \sigma_{POS} = DOP \times \sigma_p \]
The PPP stochastic model considers receiver measures to be independent/uncorrelated

\[ \Sigma = \begin{pmatrix}
\sigma_1^2 & \sigma_{12} & \ldots & \sigma_{1n} \\
\sigma_{21} & \sigma_2^2 & \ldots & \sigma_{2n} \\
\ldots & \ldots & \ldots & \ldots \\
\sigma_{n1} & \sigma_{n2} & \ldots & \sigma_n^2
\end{pmatrix} \]
The PPP stochastic model considers receiver measures to be independent/uncorrelated.

\[
\Sigma = \begin{pmatrix}
\sigma_1^2 & 0 & \ldots & 0 \\
0 & \sigma_2^2 & \ldots & 0 \\
\ldots & \ldots & \ldots & \ldots \\
0 & 0 & \ldots & \sigma_n^2
\end{pmatrix}
\]
First law of Geography...

“Everything is related to everything else, but near things are more related than distant things.”

Waldo Tobler
Satellite Signals are affected differently by Ionospheric Scintillations
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Spatial Auto-Correlation (SAC) can be exploited to generate a new PPP stochastic model.
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Spatial Auto-Correlation (SAC) is measured by computing SAC indices on satellite geometries.

\[
I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (v_i - \bar{v})(v_j - \bar{v})}{\sum_i (v_i - \bar{v})^2}
\]

\[
v_i = S1C_i
\]

\[
w_{ij} = \frac{1}{d_{ij}}
\]

\[-SAC \quad \text{random} \quad +SAC\]

-1 \quad 0 \quad 1
Spatial Auto-Correlation (SAC) is measured by computing SAC indices on satellite geometries.

\[ I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (v_i - \bar{v})(v_j - \bar{v})}{\sum_i (v_i - \bar{v})^2} \]

\[ v_i = S1C_i \]

\[ w_{ij} = \frac{1}{d_{ij}} \]
Spatial Auto-Correlation (SAC) is fluctuating in time.
Perspective 1: several SAC indices exist with their own specificities

- Moran’s I
- Geary’s C
- Mantel’s $\Gamma$
- Getis and Ord’s index
- LISA tests
Perspective 2: a Least Square Adjustment to fit a polynomial surface on satellite geometries

\[ S = f(\chi, \eta) \]
Perspective 3: a Principal Components Analysis (PCA) to study the correlation between variables.
Perspective 4: a SAC detection based on other observables

Signal Strength (S1C)

Tracking error (Conker model)

\( S_4 \)

\( \sigma_\phi \)

...
Perspective 5: more realistic simulations with potentially more tracked satellites
Perspective 6: a Correlation in Time?
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