Partial Ambiguity Resolution (PAR) for Reliable GPS/Galileo Positioning

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Outline

1 Introduction and Motivation
   Our Proposal

2 Methodology
   Real Time Kinematic (RTK)
   Partial Ambiguity Resolution (PAR)

3 Test and Results

4 Outlook and Future Work

source: https://phys.org/news/2017-12-space-technology-autonomous-ships.html
Introduction

High demand for accurate navigation for safety-critical applications

- Automated landing
- Driverless cars
- Autonomous shipping

Precise positioning also in geodesy

- Geodynamic phenomena (tectonic plate movement, water level, …)
Challenges of Precise Navigation

- Influence of ionospheric and tropospheric delays
- Ephemeris and satellite clock offset errors
- Mitigate the effect of “wrong” observations

- Accurate positioning → use of carrier phase
  - Very low noise
  - Ambiguous by certain number of cycles
Challenges of Precise Navigation

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Accurate positioning → use of carrier phase
  - Very low noise
  - Ambiguous by certain number of cycles

DISCLAIMER:
Radio navigation cares about ionosphere… About how to remove it!
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What is Real Time Kinematic – RTK?

- **Relative positioning method:**
  - A base station of known position required
  - Challenge on correction data link
  - Elimination of satellite- and atmospheric-related errors

Diagram:

- GNSS i SATELLITE
- PIVOT SATELLITE
- BASE STATION
- $\rho_B, \Phi_B$
- $\rho_R, \Phi_R$
- $\rho_i, \Phi_i$
- $\rho_r, \Phi_r$
- $p_B, b, p_R$

Equations:

$$\rho_B, \Phi_B$$
$$\rho_R, \Phi_R$$
$$\rho_i, \Phi_i$$
$$\rho_r, \Phi_r$$

**Note:**
- Elimination of satellite- and atmospheric-related errors

**Chart:**
- DLR.de
- Chart 7
- IWGI 2019
- Daniel Medina
- Partial Ambiguity Resolution for GPS/Galileo Positioning
RTK Positioning Model

\[ \Phi^i_R = \|p^i - p_R\| \quad \Phi^i_B = \|p^i - p_B\| \]

\[ \Phi^r_R = \|p^r - p_R\| \quad \Phi^r_B = \|p^r - p_B\| \]

\[ \begin{align*}
DD \Phi^i &= - (u^i - u^r)^T b + \lambda a^i + \varepsilon^{ir} \\
DD \rho^i &= - (u^i - u^r)^T b + \varepsilon^{ir}
\end{align*} \]
RTK Positioning Model

\[
\Phi^i_R = \| p^i - p_R \| \quad - I^i + T^i + c (- dt^i + dt_R) + \lambda N^i_R + \varepsilon^i_R
\]

\[
(-) \quad \Phi^i_B = \| p^i - p_B \| \quad - I^i + T^i + c (- dt^i + dt_B) + \lambda N^i_B + \varepsilon^i_B
\]

\[
\Phi^r_R = \| p^r - p_R \| \quad - I^r + T^r + c (- dt^r + dt_R) + \lambda N^r_R + \varepsilon^r_R
\]

\[
(-) \quad \Phi^r_B = \| p^r - p_B \| \quad - I^r + T^r + c (- dt^r + dt_B) + \lambda N^r_B + \varepsilon^r_B
\]

RTK functional model

\[
y = \begin{bmatrix} DD\Phi \\ DD\rho \end{bmatrix},
\]

\[
E(y) = Aa + Bb, \quad D(y) = Q_y
\]
Solving RTK

\[ \{a, b\} = \arg \min_{a \in \mathbb{Z}^n, b \in \mathbb{R}^3} \|y - Aa - Bb\|_{Q_y}^2 \]
Solving RTK

\[
\{a, b\} = \arg\min_{a \in \mathbb{Z}^n, \ b \in \mathbb{R}^3} \left\| y - Aa - Bb \right\|^2_{Q_y} = \left\| \hat{e} \right\|^2_{Q_y} + \left\| \hat{a} - a \right\|^2_{Q_{\hat{a}}} + \left\| \tilde{b}(a) - b \right\|^2_{Q_{\tilde{b}(a)}}
\]
Integer Ambiguity Resolution (IAR)

IAR → process of resolving the unknown carrier ambiguities as integer numbers

- It constitutes a n-hyperdimensional ellipsoidal search
- The success of the process depends on:
  - Quality of the observation model
  - Number of observations

The integer phase → enhance the positioning estimation

RTK Positioning: short baseline

San Fernando IGS stations
2019, DOY 001, 00:00 – 23:59
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Motivation for PAR

- Based on the baseline separation, ionospheric and tropospheric effects are to be considered

- Dual frequency combination is a bad idea → no IAR

Partial Ambiguity Resolution (PAR)

- Regular Full Ambiguity Resolution (FAR) finds (or not) a solution for all satellites
- The more observations → the more challenging IAR becomes

- PAR aims at:
  - Provision of a centimeter-level accuracy
  - Increase the availability of the solution
PAR – Original

- PAR decorrelates the ambiguities and sorts them in decreasing noise levels.
- Ambiguities are sequentially discarded until a probability of success is fulfilled.

Simple implementation

Decorrelation method is affected by biased / contaminated observations.
PAR by Levels

- Objective function reformulated based on accuracy needed

\[
\min \| \tilde{a} - \hat{a} \|^2_{Q_\alpha}, \quad \text{s.t.} \quad \begin{bmatrix} \sigma_E \\ \sigma_N \\ \sigma_U \end{bmatrix} \leq \begin{bmatrix} 3\text{cm} \\ 3\text{cm} \\ 5\text{cm} \end{bmatrix}
\]

- Set of observations sorted by their Ambiguity Dilution of Precision (ADOP)
- A valid candidate must fulfills:
  - Probability of successful ambiguity fixing
  - Minimal (projected) accuracy

DLR.de • Chart 18 • IWGI 2019 • Daniel Medina • Partial Ambiguity Resolution for GPS/Galileo Positioning
PAR by Levels

Level 1

Level 2

Level 3

Level 4

Best ADOP

Worst ADOP
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Source: https://phys.org/news/2017-12-space-technology-autonomous-ships.html
Test and Results: Medium Baseline

Koblenz – Montabaur Sapos stations (~30 km)
2019, DOY 001, 00:00 – 23:59

<table>
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<tr>
<th>Method</th>
<th>Availability [%]</th>
<th>Mean Error [cm]</th>
<th>RMSD [cm]</th>
<th>95% CDF [cm]</th>
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<tr>
<td>Float Solution</td>
<td>-</td>
<td>28.17</td>
<td>16.56</td>
<td>62.95</td>
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<tr>
<td>ILS</td>
<td>24.96</td>
<td>7.54</td>
<td>1.12</td>
<td>9.59</td>
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<tr>
<td>PAR – original</td>
<td>30.12</td>
<td>7.94</td>
<td>1.12</td>
<td>11.32</td>
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<td>PAR by Levels</td>
<td>78.14</td>
<td>5.9</td>
<td>2.6</td>
<td>9.58</td>
</tr>
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Outlook and Future Work

- Introduction to the basics of RTK, the effects of ionosphere in medium/long baselines

- A new PAR methodology is presented, minimal computation for a desired accuracy

- Realize experimentation for long (and very long) baselines

- Is it worth it the addition of ionosphere model to assist on long-baseline RTK?
Thank you for your attention!

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