Improving Kinematic accuracy by means of multi-constellation PPP-RTK

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- Estimation of Uncalibrated Hardware Delays for Galileo
- Multi-constellation PPP-RTK in a maritime dynamic environment
## PPP vs RTK

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<td>- Relative positioning</td>
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<td>- Differential carrier-phase observations rover-base station</td>
<td>- Undifferenced observations from single station</td>
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<td>- GNSS errors are largely cancelled by double-differencing</td>
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<td>- Integer resolution of double-differenced carrier-phase ambiguities</td>
<td>- No ambiguity resolution (float ambiguities)</td>
<td>- Possible to fix ambiguities at single-station PPP</td>
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<td>- Position accuracy depends on distance to reference stations</td>
<td>- Homogeneous accuracy</td>
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<td>- Dense network needed</td>
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**Absolute positioning**
- Requires precise modeling of GNSS errors (orbits, clocks, troposphere, etc…)
- Possible to fix ambiguities at single-station PPP
- Better than float PPP
- Sparse network required

**Relative positioning**
- Differential carrier-phase observations rover-base station
- GNSS errors are largely cancelled by double-differencing
- Integer resolution of double-differenced carrier-phase ambiguities
- Position accuracy depends on distance to reference stations
- Dense network needed
Fixing ambiguities in PPP

- Traditional ionosphere-free float-PPP does not allow integer ambiguity resolution due to the presence of satellite and receiver delays
  - Uncalibrated Hardware Delays (UHDs)

- PPP-RTK is based on the estimation of these UHDs in order to resolve carrier-phase ambiguities

- Several approaches have been developed in recent years for GPS:
  - Single Difference Approach (GFZ)
  - Decoupled Clock Model (NRcan)
  - Integer Clock Method (CNES)

- Extension of the method to Galileo
Galileo sats 5-6

- Galileo IOV data has been used in this study
  - First 4 satellites E11 E12 E19 E20

- Galileo FOC satellites 5&6 were injected into wrong orbit due to an anomaly in the Soyuz upper-stage
  - Navigation payload not active yet
Galileo data tracking

- For Galileo orbit and clock estimation, observation data from the IGS Multi-GNSS Experiment (MGEX) is used
  - Ionosphere-free linear combination of E1 and E5a frequencies
Galileo orbit accuracy

- Day boundary differences for central 24 hours of 3-day orbit arcs
Compatibility of receiver types for Galileo PPP-RTK

- Need to verify the compatibility of receiver types for Galileo ambiguity-fixing
- Observation data collected by the University of New Brunswick (Canada)
  - UNB3: Trimble NETR9
  - UNBD: Javad Delta G3T
  - UNBS: Septentrio PolaRx4
Compatibility of receiver types for Galileo PPP-RTK

- Single-differences E11-E19 for May 5\textsuperscript{th}, 2014
Compatibility of receiver types for Galileo PPP-RTK

- Melbourne-Wübbena measurements used to derive WL ambiguity
  - Higher noise observed for the Javad receiver UNBD
Network UHD-estimation

- It is challenging to estimate UHDs for Galileo with few satellites available.
- In order to improve satellite observability, a network densification was performed using data from the European Permanent Network (EPN).
- Mix of receiver types for UHD estimation.
UHDs for Galileo

- Single difference UHDs (E20 is the reference satellite)
UHD residual

- Ambiguity-residuals after applying UHDs

Wide-Lane

Narrow-Lane
UHD residual

- Comparison between GPS and Galileo

![Graphs showing comparison between GPS and Galileo for Wide-Lane and Narrow-Lane UHD residuals.](image-url)
PPP-RTK tests with Galileo

Trimble NETR9
Septentrio PolarRX4
Javad Delta G3T
PPP-RTK tests with Galileo

Horizontal PPP results

Position Error RMS (cm)

GPS (float) + Galileo (float)
GPS (float) + Galileo (fixed)
GPS (fixed) + Galileo (fixed)
PPP-RTK tests with Galileo

Vertical PPP results

Position Error RMS (cm)

- GPS (float) + Galileo (float)
- GPS (float) + Galileo (fixed)
- GPS (fixed) + Galileo (fixed)
Multi-constellation PPP in a dynamic environment

- ‘Baronen’ passenger ferry navigating in Oslo fjord
- 2 Fugro 9205 Multi-GNSS receivers installed on board
Antenna locations

- Vessel equipped with 2 Trimble GA810 antenna, separated about 15 meters away
Vessel’s trajectory
Satellite visibility from Oslo

- Galileo satellites visible few hours per day
- Continuous BeiDou tracking
- BeiDou GEO G05 visible from Oslo at low elevation (12 degrees)
PPP results in dynamic environment

- Multi-constellation PPP solutions computed independently for each antenna on-board
  - Computed difference between epoch-wise positions
  - 'True' baseline is 15.69 m
  - Reduced baseline noise when using multi-constellation PPP
PPP-RTK results in dynamic environment

- UHDs generated from a reference station in Fugro premises in Oslo:
  - UHDs for GPS, Galileo and BeiDou
  - Used to fix ambiguities in the moving vessel

- PPP and PPP-RTK solutions compared for different multi-constellations configurations
Conclusions

- **Galileo PPP-RTK**
  - Demonstrated the feasibility of fixing Galileo ambiguities in PPP
  - Promising results in the estimation of the UHDs
  - Contribution in the position domain still limited by:
    - Number of satellites available
    - Satellite modelling for precise orbit/clock estimation

- **Multi-constellation PPP in a maritime dynamic environment**
  - Small position improvement when adding Galileo and BeiDou
  - Best accuracy obtained when using all 4 GNSS in PPP-RTK mode
  - Significant increase in robustness and availability when using multi-constellation
    - Specially in difficult tracking conditions (scintillation, interference, etc)