GNSS Modernisation and Its Effect on Surveying

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The Motivation

- Short range GNSS phase-based positioning is limited by multipath
  - Other errors spatially correlated
- This limits some RTK type applications
- GNSS phase multipath mitigation is extremely difficult today
  - Especially from very close reflectors
- GPS modernization and the new European GNSS – Galileo will provide reliable multiple signals for GNSS phase data processing
Galileo possible frequency combinations and services

<table>
<thead>
<tr>
<th>Frequency Combinations</th>
<th>Services (Types of Data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 E5a</td>
<td>OS/CS/SOL</td>
</tr>
<tr>
<td>L1 E5b</td>
<td>OS/CS/SOL</td>
</tr>
<tr>
<td>L1 E6</td>
<td>OS/CS/SOL + CS/PRS</td>
</tr>
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- GPS modernization and the new European GNSS – Galileo will provide reliable multiple signals for GNSS phase data processing
  - Most current solutions are effectively GPS L1 only
  - Multipath error is frequency-dependent

Most multiple frequency studies concentrate on ambiguity determination and ionospheric modelling
The Questions

- How can the new signals be used to mitigate multipath?
- Will short range phase GNSS be more precise after GPS modernization and Galileo in FOC?

The Route to The Answers

- Simulate multiple frequency GNSS data
  - No real data available today
- Process combinations
  - GPS: L1, L1+L2, L1+L2+L5
  - Galileo: L1+E5a+E5b
  - GPS+Galileo: L1+L2+L5+L1+E5a+E5b
- Compare with GPS L1 ONLY
  - Assess impact of ‘averaging’
Multipath Modelling

- Inputs
  - Reflector Positions (coordinates of four corners)
  - Relative Permittivity (RP)
  - Antenna Gain Pattern (AGP)
  - Phase Centre Variation (PCV)

- Computations
  - Reflection coefficient (from geometry, RP)
  - Phase shift of reflected signal (from geometry)
  - Polarization efficiency (from geometry, RP)
  - Gain ratio (from geometry, AGP)
  - Damping factor (from RC, PE, GR)
  - Correlation function (from chipping rate)
  - Phase error (from DF, CF, geometry)


Validation of Simulator (1)

Real and simulated L1 DD residuals
Validation of Simulator (2)

Double difference residual (mm)

Real and simulated L2 DD residuals

Simulated Multipath in Validation

Double difference residual (mm)

GPS L1 (red) and L2 (blue)

It shows that phase multipath is frequency-dependent
Validation of Simulator

- Good agreements of simulated multipath data with real multipath data
- Multipath errors in the future GPS and Galileo multiple-frequency data

GNSS Data Processor

- Standard double difference model
  - Atmospheric models not turned on
- Separate equations for each frequency
  - No frequency weighting
  - Assume multiple frequency data will have similar noise
- Single epoch ambiguity solutions
- Standard least squares solutions
  - No rejection of data
  - Leads to positions and residuals
### Summary: Statistical results

<table>
<thead>
<tr>
<th>System</th>
<th>3D pos. error</th>
<th>95% 3D pos. error</th>
<th>Max. 3D pos. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS Single</td>
<td>4.3</td>
<td>2.5</td>
<td>9.1</td>
</tr>
<tr>
<td>GPS Dual</td>
<td>3.1</td>
<td>1.9</td>
<td>6.8</td>
</tr>
<tr>
<td>GPS Three</td>
<td>2.5</td>
<td>1.4</td>
<td>5.2</td>
</tr>
<tr>
<td>Galileo Three</td>
<td>1.8</td>
<td>1.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Galileo+GPS</td>
<td>1.3</td>
<td>0.6</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Unit: mm

### Conclusions

- **Realistic multipath simulator**
- **GPS**: Use of multiple frequency data leads to significant averaging of the multipath error in least-squares estimation
  - Dual is about 28% better than single
  - Triple is about 19% better than modernized dual
- **GPS + Galileo**: About **70%** improvement when compared with GPS single-frequency data
- **Robust solution for RTK multipath**