Evaluation and Calibration of Receiver Inter-channel Biases for RTK-GPS/GLONASS

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Outline

• Background and Objective
• Inter-channel Bias Calibration
• RTK-GPS/GLONASS with Calibrated Biases
• Use of GLONASS Float Ambiguity
• Summary and Conclusions
Mobile RTK Positioning

Instantaneous RTK (Real Time Kinematic) is precise positioning with epoch by epoch carrier-phase ambiguity resolution (AR).
Results of Mobile RTK Positioning

NovAtel - NovAtel

<table>
<thead>
<tr>
<th>Solution</th>
<th>Fix</th>
<th>Float</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>43 %</td>
<td>57 %</td>
</tr>
</tbody>
</table>

NovAtel - JAVAD

<table>
<thead>
<tr>
<th>Solution</th>
<th>Fix</th>
<th>Float</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 %</td>
<td>99 %</td>
</tr>
</tbody>
</table>

We aim to improve GLONASS positioning performance in RTK-GPS/GLONASS between different types of receivers.

GPS + GLONASS L1 + L2
Results of Static RTK Positioning

**NovAtel - NovAtel**

- **Fixed solution**: 99.0%
- **Float solution**: 1.0%

**NovAtel - JAVAD**

- **Fixed solution**: 29.5%
- **Float solution**: 70.5%

**GPS + GLONASS L1 + L2 instantaneous AR**

Base length = 300 m
Background and Objective

What is main source of observation errors to prevent GLONASS ambiguity from being fixed?

Inter-channel bias

- The RF hardware design of a receiver will introduce frequency-dependent biases. These biases are known as an inter-channel bias.

- These biases can **not be canceled** out with double differencing between different types of receivers in GLONASS, except for GPS.
Background and Objective

- Estimates of GLONASS inter-channel bias for several receivers are obtained in short baseline [Wanninger, L., et al, ION GNSS 2007].

- Narrow band loop filter smoothes SD residual to get on line code bias [Kozlov, D., et al, ION GNSS 2000].

- In this study, we try to improve the positioning performance of instantaneous RTK with off line tables of GLONASS inter-channel bias at various receivers calibrated in only zero baseline measurements.
In the zero baseline, double-difference (DD) of code measurements can cancel out terms of orbital errors, clock errors, atmospheric delays and multipath, and remain DD of receiver noises and inter-channel biases.
## Inter-channel Bias Calibration

### Experimental Environment

<table>
<thead>
<tr>
<th></th>
<th>JAVAD</th>
<th>NovAtel</th>
<th>Topcon</th>
<th>Trimble</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver type</td>
<td>Legacy</td>
<td>OEMV</td>
<td>NET-G3</td>
<td>R7GNSS</td>
</tr>
<tr>
<td>Antenna</td>
<td></td>
<td></td>
<td></td>
<td>Trimble (Zephyr 2 )</td>
</tr>
<tr>
<td>Site</td>
<td></td>
<td></td>
<td>Roof of our university (Open sky)</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td></td>
<td>2009/12/23</td>
<td></td>
</tr>
<tr>
<td>Total/interval</td>
<td>24 hours/30 s</td>
<td>20 hours/30 s</td>
<td>24 hours/30 s</td>
<td>24 hours/30 s</td>
</tr>
</tbody>
</table>
Calibrated L1 Inter-channel Code Biases
Tables of bias with slot 21

![Graph showing DD of L1 inter-channel code biases (m) vs. GLONASS frequency number for different combinations of GNSS receivers: NovAtel-NovAtel, NovAtel-Trimble, NovAtel-Topcon, NovAtel-Javad, Javad-Javad.]
Calibrated L2 Inter-channel Code Biases
Tables of bias with slot 21
RTK-GPS/GLONASS with Calibrated Biases

1. GLONASS double difference equation

\[ \Phi_{rb}^{ij} \equiv \lambda_i \left( \phi_i^r - \phi_b^i \right) - \lambda_j \left( \phi_j^r - \phi_b^j \right) \]

\[ = \rho_{rb}^{ij} + N_{rb}^{ij} + d(\phi)_{rb}^{ij} + mp(\phi)_{rb}^{ij} + \epsilon(\phi)_{rb}^{ij} \]

\[ P_{rb}^{ij} \equiv (p_r^i - p_b^i) - (p_r^j - p_b^j) \]

\[ = \rho_{rb}^{ij} + d(P)_{rb}^{ij} + mp(P)_{rb}^{ij} + \epsilon(P)_{rb}^{ij} \]

d(P) : inter-channel code bias, d \( \phi \) : inter-channel carrier bias

Assumption on d(P) = d(\( \phi \))

2. Compensation by tables of biases

\[ d_{rb}^{ij} = -d_{rb}^{si} + d_{rb}^{sj} \]
We evaluate positioning accuracy and fix rate of RTK-GPS/GLONASS in order to improve the GLONASS positioning performance by tables of bias.

**RTK Processing Options**

- **AR mode**: Instantaneous AR (epoch by epoch)
- **AR method**: LAMBDA, ratio-test (threshold : 3)
- **Base length**: 300 m
  *(Rover: NovAtel, Javad. Base: NovAtel, Javad, Trimble, Topcon)*
- **Date**: 2009/12/23 24 h (epoch intervals 30 s)
- **Elevation mask angle**: 15 deg
Positioning Results of RTK with GLONASS ambiguity fix solution

RTK-GPS/GLONASS L1 + L2
Baseline : NovAtel - Trimble

No correction

Correction with tables of biases

No improvement
Considerations

Why can not we fix GLONASS ambiguity by tables of inter-channel code bias?

1. Estimation of \( d(\rho) \) has poor accuracy. 2. Assumption on \( d(\rho) = d(\phi) \) might not be true.

→ Estimation of \( d\rho \) is produced by code measurements.

\[
\Phi_{rb}^{ij} \equiv \lambda_i (\phi_r^i - \phi_b^i) - \lambda_j (\phi_r^j - \phi_b^j) \\
= \rho_{rb}^{ij} + N_{rb}^{ij} + d(P)_{rb}^{ij} + mp(\phi)_{rb}^{ij} + \epsilon(\phi)_{rb}^{ij}
\]

\[
P_{rb}^{ij} \equiv (p_r^i - p_b^i) - (p_r^j - p_b^j) \\
= \rho_{rb}^{ij} + d(P)_{rb}^{ij} + mp(P)_{rb}^{ij} + \epsilon(P)_{rb}^{ij}
\]

The variation of inter-channel code and carrier biases (slot 23 - slot 7)

Inter-channel carrier bias can be obtained by subtracting the GLONASS integer ambiguity fixed in static mode from DD of carrier-phase measurement.

From the next slide, we try to evaluate the positioning performance of RTK-GPS/GLONASS with GLONASS ambiguity float solution.
Use of GLONASS Float Ambiguity

Accuracy of float solution has an effect on the performance of ambiguity fixing.

We use GLONASS float ambiguity as the aid of GPS ambiguity resolution.

Float Solution

**Only GPS**

<table>
<thead>
<tr>
<th>East (m)</th>
<th>North (m)</th>
<th>Up (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.27</td>
<td>0.42</td>
<td>1.02</td>
</tr>
</tbody>
</table>

**GPS + GLONASS**

<table>
<thead>
<tr>
<th>East (m)</th>
<th>North (m)</th>
<th>Up (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.29</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Positioning Results of RTK with GLONASS ambiguity float solution

RTK-GPS/GLONASS L1
Baseline: NovAtel - Trimble

No correction

Correction with tables of bias

Improved by 20%
Positioning Results of RTK with GLONASS ambiguity float solution

RTK-GPS/GLONASS L1 + L2
Baseline : NovAtel - Trimble

No correction
Fix rate : 96.7 %
E/N/U (m) : 0.01 /0.01/0.02

Correction with tables of bias
Fix rate : 99.0 %
E/N/U (m) : 0.01/0.01/0.02
### Accuracy of RTK positioning with L1 measurements

<table>
<thead>
<tr>
<th>Baseline 300 m</th>
<th>Only GPS</th>
<th>GPS + GLONASS (GLONASS float)</th>
<th>GPS + GLONASS (GLONASS float + bias)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fix rate</td>
<td>Fix rate</td>
<td>Fix rate</td>
</tr>
<tr>
<td></td>
<td>E/N/U (m)</td>
<td>E/N/U (m)</td>
<td>E/N/U (m)</td>
</tr>
<tr>
<td>NovAtel - Trimble</td>
<td>49.5 %</td>
<td>31.9 %</td>
<td>52.1 %</td>
</tr>
<tr>
<td></td>
<td>0.07/0.09/0.25</td>
<td>0.11/0.17/0.31</td>
<td>0.05/0.07/0.11</td>
</tr>
<tr>
<td>NovAtel - Topcon</td>
<td>45.5 %</td>
<td>41.5 %</td>
<td>47.0 %</td>
</tr>
<tr>
<td></td>
<td>0.09/0.17/0.39</td>
<td>0.10/0.16/0.27</td>
<td>0.07/0.09/0.15</td>
</tr>
<tr>
<td>NovAtel - JAVAD</td>
<td>29.9 %</td>
<td>31.9 %</td>
<td>33.8 %</td>
</tr>
<tr>
<td></td>
<td>0.13/0.21/0.54</td>
<td>0.12/0.17/0.40</td>
<td>0.11/0.18/0.35</td>
</tr>
<tr>
<td>JAVAD - Trimble</td>
<td>35.8 %</td>
<td>21.9 %</td>
<td>36.5 %</td>
</tr>
<tr>
<td></td>
<td>0.12/0.14/0.32</td>
<td>0.17/0.23/0.53</td>
<td>0.10/0.11/0.30</td>
</tr>
<tr>
<td>JAVAD - Topcon</td>
<td>41.0 %</td>
<td>68.7 %</td>
<td>68.8 %</td>
</tr>
<tr>
<td></td>
<td>0.09/0.11/0.32</td>
<td>0.04/0.06/0.14</td>
<td>0.04/0.06/0.14</td>
</tr>
</tbody>
</table>
## Accuracy of RTK positioning with L1 + L2 measurements

<table>
<thead>
<tr>
<th>Baseline 300 m</th>
<th>Only GPS</th>
<th>GPS + GLONASS (GLONASS float)</th>
<th>GPS + GLONASS (GLONASS float + bias)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fix rate</td>
<td>Fix rate</td>
<td>Fix rate</td>
</tr>
<tr>
<td></td>
<td>E/N/U (m)</td>
<td>E/N/U (m)</td>
<td>E/N/U (m)</td>
</tr>
<tr>
<td>NovAtel - Trimble</td>
<td>98.9%</td>
<td>96.7%</td>
<td>99.0%</td>
</tr>
<tr>
<td></td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
</tr>
<tr>
<td>NovAtel - Topcon</td>
<td>98.9%</td>
<td>96.4%</td>
<td>98.9%</td>
</tr>
<tr>
<td></td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
</tr>
<tr>
<td>NovAtel - JAVAD</td>
<td>98.2%</td>
<td>98.0%</td>
<td>98.5%</td>
</tr>
<tr>
<td></td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
</tr>
<tr>
<td>JAVAD - Trimble</td>
<td>98.1%</td>
<td>95.3%</td>
<td>97.0%</td>
</tr>
<tr>
<td></td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
</tr>
<tr>
<td>JAVAD - Topcon</td>
<td>98.2%</td>
<td>98.0%</td>
<td>98.0%</td>
</tr>
<tr>
<td></td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
<td>0.01/0.01/0.02</td>
</tr>
</tbody>
</table>
Summary and Conclusions

- We analysis and improve the performance degradation on GLONASS AR epoch by epoch.
- We can obtain tables of inter-channel biases with zero baseline test.
- Tables of inter-channel biases are effective in GLONASS ambiguity float solution.
- More precise calibration method of the biases is required for GLONASS Fixed ambiguity.
Future work

• Complete tables of inter-channel carrier bias as well as more precise code bias calibration
• Evaluate the difference between carrier and code bias