Receiver positioning with zero-difference integer ambiguity fixing

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Antarctic 2007 campaign

Data from project CRACICE et NIVMER (Benoit Legresy, Laurent Testut, CNRS/LEGOS)
GPS measurements on Mertz glacier in November 2007

Reference IGS stations:

dav1, mcm4, mac1, hob2, yar2
distances 2500-3200 km

User receivers:

dum1 (Dumont d'Urville)
and two receivers on the glacier
cra4, cra5 (distance 3.4 km)
240 km from dum1

Kinematic positioning of cra4, cra5 with zero difference ambiguity fixing
The three equations

Emitter j, receiver i, dual frequency observables P1,P2,L1,L2

Widelane:

\[ L_2 - L_1 + f(P_1, P_2) = -N_w + \mu_i(t) - \mu^j \]

\[ N_w = N_2 - N_1 \]

Phase iono-free:

\[ Q_c = D_c + \lambda_c d_{windup} + h_i(t) - h^i(t) - \frac{\lambda_2 N_w}{1 - \gamma} - \lambda_c N_1 \]

\[ \lambda_c \sim 10.7 \text{cm} \]

Pseudo-range iono-free:

\[ P_c = D_c + h_{p,i}(t) - h^j_p(t) \]

Measured quantities on the left, model and unknowns on the right

\[ N_w, N_1 \] integer ambiguities, constant during a pass

\[ \mu_i(t), \mu^j \] widelane biases, stable for the emitter, each epoch for the receiver

\[ h_i(t), h^i(t) \] phase clocks, each epoch (in meters)

\[ h_{p,i}(t), h^j_p(t) \] pseudo-range clocks, each epoch

remark: \[ h^i(t) - h^j_p(t) \] is stable enough and can be aligned to be \[ \frac{\lambda_c}{2} \]
Similar to double difference processing:

- **Widelane equation**
  - integer \( N_w \)
  - emitter and receiver widelane biases

- **Phase equations**
  - integer \( N_1 \)
  - emitter and receiver phase clocks
  - (emitter and receiver pseudo-range clocks)
  - model parameters

Remark: standard positioning solutions (floating ambiguities)

- **Phase equations**
  - real valued ambiguity
  - emitter and receiver clocks
  - (same clocks are used for phase and pseudo-range)
  - model parameters

- **Pseudo-range equations**
Application to PPP and Kinematic positioning

Network solution (using igs ephemeris) integer ambiguity fixing:

Satellite data
- widelane biases
- phase clocks
- pseudo-range clocks

PPP or kinematic

- receiver widelane ambiguities, integer Nw (using satellite widelane biases)
- adjusted parameters (x,y,z ...) with integer N1
Antarctic 2007, network solution

Data from project CRACICE et NIVMER (Benoit Legresy, Laurent Testut, CNRS/LEGOS)
GPS measurements on Mertz glacier in November 2007

Reference IGS stations:
dav1, mcm4, mac1, hob2, yar2
distances 2500-3200 km

Network solution
GPS satellite bias and clocks data
when in visibility
PPP and kinematic positioning

Using the network solution:

**dum1** PPP and kinematic positioning with ambiguity fixing:

- validation of the approach
- expected performance

**cra4, cra5** kinematic positioning with ambiguity fixing:

- independent trajectories
- comparison with short baseline solution
  - single frequency
  - dual frequency
Solution of:
- x, y, z, t for each 30 s epoch
- troposphere (1 hour segments, with evolution constraints)
- N1

Floating or integer N1

<table>
<thead>
<tr>
<th>dum1</th>
<th>(flo)</th>
<th>(int)</th>
</tr>
</thead>
<tbody>
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<td>East</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>North</td>
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<td>9</td>
</tr>
<tr>
<td>Vert.</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

Remark: no correlations between epochs for positions and clock (this explains the noise ~ 1 cm rms)
Common linear evolution removed for horizontal data:

East

North

Vertical

two days
cra4 and cra5 comparison

comparison with short baseline relative solution, all solutions with integer ambiguity fixing:
distance between the receivers for
L1 and Lc single baseline
Lc zero-difference (from previous slide)

Absolute positioning allows same performance as the short baseline solution (dual frequency)
Two hours solutions, 30 s, 1 tropo value comparison with reference for float./int. N1

<table>
<thead>
<tr>
<th></th>
<th>Cra4 (flo)</th>
<th>(int)</th>
<th>Cra5 (flo)</th>
<th>(int)</th>
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<td>22</td>
<td>1</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>North</td>
<td>16</td>
<td>2</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>Vert.</td>
<td>32</td>
<td>10</td>
<td>36</td>
<td>16</td>
</tr>
</tbody>
</table>

millimeters rms (without ref. solution noise)

ambiguity fixing was not successful (50 %)

it is important to have a maximum number of GPS in visibility
Conclusion

An application of PPP and Kinematic positioning with integer ambiguity fixing is demonstrated here over a wide area in Antarctic (more than 1000 km).

Algorithms for integer phase clock solutions

over a local or global network
for single receiver positioning applications

Reference network phase clocks with ambiguity fixing produce very good standard solutions (floating ambiguities for the receiver)

Ambiguity fixing stabilises/improves the solutions for the receiver

limited improvement for long durations w.r.t. floating solution (~one day)
significative improvement for shorter durations (~ two hours)

Other areas (Jason 1 orbits, time transfer, real time) ....

PPP and Kinematic positioning solutions with integer ambiguity fixing are now possible and efficient
Other results

Jason 1 orbits with ambiguity fixing

very efficient (all receiver passes are very short (below one hour))
common views with complete constellation are much longer than common views with a ground station

ION 2008

Integer Phase clocks and time transfer

continuous GPS time transfer, no drift (known problem in the floating solutions)
connection of overlapping clocks solutions without error

International Journal of Navigation and Observation, special issue, selected papers from TimeNav 2007

Real Time solutions

adjustment of GPS orbits and clocks in real time, improved performance on real time positioning

ION 2009
Thank you for your attention
Summary

Some definitions for zero difference ambiguities

Properties of the solutions
  zeros difference widelane properties
  integer phase clocks
  independent receiver positioning with ambiguity fixing

Example
  Kinematic positioning
    with ambiguity fixing for LEGOS 2007 Antarctic campaign

Conclusion
Initial observation equations

GPS satellites and receiver biases referenced to ionosphere free combinations

\[ \Delta h : \text{clocks terms (in meters), one value per epoch} \]
\[ \Delta h, \Delta h_p, \Delta \tau, \Delta \tau_p : \text{biases, 'slow' variations} \]

\[
P_1 = D_1 + e + \Delta h_p + \Delta \tau_p
\]
\[
P_2 = D_2 + \gamma e + \Delta h_p + \gamma \Delta \tau_p
\]
\[
\lambda_1 L_1 = D_1 + \lambda_1 d_{\text{windup}} - e + \Delta h + \Delta \tau - \lambda_1 N_1
\]
\[
\lambda_2 L_2 = D_2 + \lambda_2 d_{\text{windup}} - \gamma e + \Delta h + \gamma \Delta \tau - \lambda_2 N_2
\]

Clock
(ionosphere-free pseudo-range
one value per epoch)

tgd

observables

pseudo
range

phase

wavelength

models

ionosphere

integer
ambiguities

\[ \Delta h = h_i - h^j \]

EGU Vienna 2009 – F. Mercier
Reduced equations

Use of three ionosphere free combinations:

\[ \frac{\gamma P_1 - P_2}{\gamma - 1} = D_c + \left( h_{p,i}(t) - h_p(t) \right) \]

Pseudo-range ‘ionosphere free’

Wideland integer ambiguity

\[ L_2 - L_1 + f(P_1, P_2) \approx - (N_2 - N_1) + \mu_i(t) - \mu^j \]

Wideland ‘ionosphere free’ ‘geometry free’

Receiver widelane bias (each epoch) Emitter wide lane bias (stable)

\[ N_w = N_2 - N_1 \text{ fixed} \]

Phase ‘ionosphere free’

\[ \frac{\gamma \lambda_1 L_1 - \lambda_2 (L_2 + N_w)}{\gamma - 1} = D_c + \lambda_c d_{windup} + \left( h_i(t) - h^j(t) \right) - \lambda_c N_1 \]

\[ \lambda_c \sim 10.7\,cm \]
Reference network solution

WideLANE:
- Identification of satellite and receiver wideLANE biases, using only the RINEX files (no model)
- Satellite biases: stable over few days
- Receiver biases: may vary, depending on the receiver environment (thermal effects)
- Production of a set of fixed wideLANE ambiguities, for each pass

Pseudo-range and Phase equations: network solution
- Adjusted parameters
  - Models if necessary (here, use of IGS precise ephemeris and ITRF stations)
  - N1 integer ambiguity per pass
  - Emitter and receiver clocks (integer phase clocks)

Satellite wideLANE biases (typically daily values)
Satellite clocks at each epoch
  - Allowing N1 ambiguity fixing
Positioning solution with ambiguity fixing

**Integer PPP**
User receiver

**Wide lane:**

\[
L_2 - L_1 + f(P_1, P_2) + \mu^j = -N_w + \mu_i(t)
\]

Pseudo-range and phase equations: PPP or Kinematic solution
input: satellite ephemeris and integer phase clocks
adjusted parameters
- models (coordinates, troposphere)
- N1 integer ambiguity per pass
- receiver clock

\[
\frac{\gamma p_1 - p_2}{\gamma - 1} + h^j(t) = D_c + h_i(t)
\]

\[
\frac{\gamma \lambda_1 L_1 - \lambda_2 (L_2 + N_w)}{\gamma - 1} + h^j(t) = D_c + \lambda_c d_{winup} + h_i(t) - \lambda_c N_1
\]

Remarks: same equations as for standard PPP but N1 can be fixed to an integer value
code-phase biases have been neglected here
(below 10 cm with these definitions)