Advances in GNSS Equipment

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With Input From:
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2010 IGS Workshop, Newcastle Upon Tyne
Q: What advances in GNSS receiver technology can the IGS exploit to improve its network and products?
Outline

- Review conclusions from Miami 2008
- A look at commercial receiver state-of-the-art
- Advances in software receiver technology
  - DFE: The final front-end
  - The CASES receiver
  - The IFEN/UFAF SX-NSR receiver: Performance evaluation
- Not all observables are created equal
- Summary
Conclusions from Miami 2008

- Many excellent commercial RXs to choose from
- All major manufacturers have road maps toward all-in-view capability
- Pseudorange and phase measurement error statistics are heterogeneous and ill-defined, impairing IGS products
- Software receivers show promise but have not been vetted
The Super Receiver

- Tracks all open signals, all satellites
- Tracks encrypted signals where possible
- Well-defined, publicly disclosed measurement characteristics (phase, pseudorange, C/No)
- RINEX 3.00 compliant
- Completely user reconfigurable, from correlations to tracking loops to navigation solution
- Internal cycle slip mitigation/detection
- Up to 50 Hz measurements
- Internet ready; signal processing strategy reconfigurable via internet
- Low cost
The Ultra Receiver

Digital Storage Rx

RF Front-End
ADC
Mass Storag

Software Post-Processing

FFT-based Acquisition
Tracking Loops, Data Decoding, Observables Calculations

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Referenc e Oscillator
Sample Clock
Commercial Receiver Offerings (2008)

- Septentrio PolaRx3
- Trimble NetRS/NetR5
- Leica GRX1200
- Topcon NET-G3
Commercial Receiver Offerings (2010)

- Septentrio GeNeRx1
- Trimble NetRS/NetR5/NetR8
- Javad G3T
- Leica GRX1200+GNSS
- Topcon NET-G3
Approaching the Super Receiver

Example Commercial Receiver: Javad G3T

- Tracks all open signals, all satellites
- Tracks encrypted signals where possible
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- Completely user reconfigurable, from correlations to tracking loops to navigation solution
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- Up to 50 Hz measurements
- Internet ready; signal processing strategy reconfigurable via internet
- Low cost
- ~$8k

Except E5B, 216 channels

Loop BW, update rate configurable

Only one G3T in IGS network (BOGI, Poland)

Performance appears good
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Recall: The Ultra Receiver

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Software Correlators

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The ARL:UT Digitizing Front End

Variable Gain: 23 to 53 dB
Single anti-aliasing bandpass filter
* 6dB passband: 1110 to 1630 MHz

8-bit samples at up to 3GHz

CIC and FIR filters
* 30 MHz passband
Decimate by 48

Reconfigurable on reccompilation

Amplify And Filter → Digitize

Tuning → Filter And Decimate

Filter And Decimate

2 bit complex I and Q
40.912 MSPS

FPGA
The ARL:UT Digitizing Front End

(Fig. 1 of Wallner et al., “Interference Computations Between GPS and Galileo,” Proc. ION GNSS 2005)
The ARL:UT Digitizing Front End

- 500 MHz bandwidth
- Single RF signal path and ADC substantially eliminates inter-signal instrument biases
- Temperature-stabilized signal conditioning chain
- Open-source design, as with GPSTk
- Debut at ION GNSS 2010
UT/Cornell/ASTRA CASES SwRx
UT/Cornell/ASTRA CASES SwRx

- Dual-frequency narrowband
- Completely software reconfigurable
- Antarctic deployment 2010
- Space deployment 2012 (as occultation sensor)
CASES Multi-System Receiver Bank

- Data Buffer: $q_1, q_2, \ldots, q_n$ buffer
- Channel:
  - PLL
  - FLL
  - DLL
  - Estimated State
  - Carrier Generator
  - Code Generator
- Observables:
  - Time of measurements
  - Pseudorange Vector
  - Carrier Phase Vector
- Configuration Object
- Nav. and Timing Fusion Module:
  - Position
  - Velocity
  - $\delta t_{RX}$
Approaching the Ultra Receiver

Digital Storage Rx

RF Front-End
ADC
Mass Storage

Software Post-Processing

FFT-based Acquisition
Tracking Loops, Data Decoding, Observables Calculations

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8-bit samples at up to 3GHz

Tuning
Filter and Decimate
FPGA

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40.912 MSPS

Reconfigurable on recompilation

Data Buffer
$q_1$ buffer
$q_n$ buffer

Bank

Observables
Time of measurements
Pseudorange Vector
Carrier Phase Vector
Configuration Object

Channel
PLL
FLL
DLL
Estimated State
Carrier Generator
Code Generator

Nav. and Timing Fusion Module
Position
Velocity
$\delta t_{RX}$
$\delta t_{RX}$

Mass Storage
Multicore GNSS Processing

- **Signal-type level**
  - Low comm/sync overhead
  - Poor load balancing

- **Channel level**
  - Low comm/sync overhead
  - Good load balancing
  - Favors shared memory architecture

- **Correlation level**
  - Higher comm/sync overhead
  - Good load balancing

- **Sub-correlation level**
  - Very high comm/sync overhead
  - Good load balancing

- **Demonstrated 3.4x speedup on 4-core machine with OpenMP**
- **CASES post-processing now 25x real-time**
- **Bodes well for reanalysis**
UFAF SwRx Evaluation (Carsten Stroeber)

<table>
<thead>
<tr>
<th>Running since</th>
<th>End 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Signals</td>
<td>GPS L1 C/A, L2C (CM+CL), L5 Giove A+B SBAS</td>
</tr>
<tr>
<td>Frontend</td>
<td>Fraunhofer, (IFEN possible)</td>
</tr>
<tr>
<td>Longest running time without external reset</td>
<td>&gt;10 days</td>
</tr>
<tr>
<td>Longest running time with external reset</td>
<td>&gt;1 month</td>
</tr>
</tbody>
</table>

Annotations:
- External reset denotes automatic restart of the receiver via script program
- Reference station was on a productive system simultaneously employing monitoring algorithms -> priority was not only given to long time stability
- Currently Glonass is in test mode
- Dedicated software receiver reference station (GPS L1, L2 only) intended for long run stability is in test phase

Advantages

- Extensive data analysis possible at measurement time
  - e.g. instantaneous monitoring for signal distortions with access to “low” level measurements i.e. signal sample data
- Software receiver is “independent” from utilized hardware

http://www.unibw.de/lrt9_3
Horizontal scatter plot of final PDGPS adjustment at highest temporal resolution with bounding box (upward: north; right: eastward).

<table>
<thead>
<tr>
<th>Date</th>
<th>DoY 170, Year 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis Software</td>
<td>PrePos GNSS Suite</td>
</tr>
<tr>
<td>Measurements</td>
<td>GPS L1</td>
</tr>
<tr>
<td>Number observations</td>
<td>128614</td>
</tr>
<tr>
<td>(double differences)</td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td>405 min</td>
</tr>
<tr>
<td>Data deleted due to</td>
<td>2%</td>
</tr>
<tr>
<td>cycle slips</td>
<td>(for OEM 4 receiver 1%)</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>X 5.2mm</td>
</tr>
<tr>
<td>position</td>
<td>Y 3.7mm</td>
</tr>
<tr>
<td></td>
<td>Z 6.1mm</td>
</tr>
</tbody>
</table>
Operational performance comparable to NovAtel OEM 4

Coordinate time series of final PDGPS adjustment. Software receiver at top, OEM IV at bottom.
UFAF SwRx Evaluation

Drawbacks, suggested directions

• Complex interaction between PC hardware, working system, additional applications and software receiver e.g.:
  – USB access is controlled by working system (drivers ...) -> buffering needed
  – Additional applications starts unmeant, process time consuming action e.g. disk defrag -> additional applications must be deleted or configured too

• Short-time internal processing load peaks due to frequently simultaneous execution of extensive tasks -> 2 strategies:
  – For reference station no “real” real-time needed -> use already existing buffering
  – Adapt configuration to PC hardware and use high power hardware

• Free configurability leads to a big error source given by non optimal or wrong configuration -> in reference station mode this is relaxed due to fixed configuration
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Implementing a Pseudorange Reading Standard with the SX-NSR

Thomas Pany, Bernhard Riedl

IFEN GmbH
Toward a Standardized Carrier Phase and Pseudorange Measurement Technique

- Different receiver manufacturers use proprietary (code/cARRIER) measurement definitions
- Standard proposed by L. Young at last IGS workshop based on the US patent no. 4,821,294 (Thomas, Jr., Caltech)
- Goal: to have stochastically independent code/cARRIER observations with a well understood observation principle
- Use SX-NSR software receivers API for a prototype implementation
Illustration (Carrier Phase)

- ‘Verification’ that correlator based observations are truly independent
- Download: C++ source code and exemplary data (GPS L1, Galileo E1/E5a) at www.ifen.com
Illustration (Pseudorange)

GPS C/A PRN13
Week 1570, sec ~ 234179, NavPort-2
Frontend with OCXO
Evaluating the Example

- Code minus carrier analysis shows that data is statistically independent.
- Discriminators cancel time correlation caused by the low bandwidth (0.1 -0.25 Hz) tracking loops.
- Phase discriminator unwrapping together with FLL tracking gives valid carrier ranges.
Summary

Q: What advances in GNSS receiver technology can the IGS exploit to improve its network and products?

A1: Commercial receivers are approaching the “Super Receiver”: nearing all-GNSS-signals tracking, reconfigurable, low-cost

A2: 500-MHz digitizing open-design front-end captures all current and planned GNSS signals, substantially eliminates inter-signal RX biases

A3: 500-MHz front-end + Multi-system SwRx + Multi-core processing + data buffering → Ultra Receiver

A4: SwRx performance comparable to commercial geodetic RXs (but not yet as reliable)

A5: Receiver APIs offer path for measurement standardization (e.g., IFEN SX-NSR)