How Multi-GNSS Brings Benefits to SEA

A Technical Point of View

ICTP Workshop on the use of Global Navigation Satellite Systems for the Scientific Applications

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The mission of Navis is to boost the R&D of satellite navigation technology, especially the European Galileo System, in South-East Asia.

http://navis.hust.edu.vn
Work Motivation

- South East Asia (SEA) region is covered by:
  - All 4 GNSSes (GPS, Galileo, GLONASS, Beidou); and
  - 1 RNSS (QZSS).
- Now: GPS-standalone solution still dominates, but
- Future is multi-GNSS + RNSS;

Verification of the advantages of Multi-GNSS over stand-alone solutions in SEA by real data collected from all system constellations.
Content

1. Multi-GNSS Environment
   – Challenges of Multi-GNSS Environment
   – Advantages of Multi-GNSS Environment

2. Multi-GNSS Signal Processing Chain
   – Experiment Result

3. QZSS augmentation services:
   – Centimeter class: L6-LEX.

4. Conclusions
Content

- **Multi-GNSS Environment**
  - Challenges of Multi-GNSS Environment
  - Advantages of Multi-GNSS Environment

- **Multi-GNSS Signal Processing Chain**
  - Experiment Result

- **QZSS augmentation services:**
  - Sub-meter class: L1-SAIF;
  - Centimeter class: L6-LEX.

- **Conclusions**
Multi-GNSS Environment
Global Navigation Satellite Systems (GNSS)

- GPS: 1995 (32)
- GLONASS: 2011 (28)
- Galileo: 2019 (6/30)
- Beidou: 2020 (14/35)

Regional NSS

- QZSS: 2018 (1/4)
- IRNSS: 2016 (3/7)

Augmentation Systems

2020: ~140 satellites for navigation purposes
Multi-GNSS Environment
Challenges of Multi-GNSS Environment

- Inter-system interference: GNSSes broadcast navigation signals in overlapped frequency bands → Inter-system interference.

- Complexity increase:
  - Analog part: operate with multiple systems, multiple frequency bands at larger signal bandwidths → Increase complexity and receiver cost.
  - Digital part: More advanced and complex algorithms, more channels for more satellites → Increase the computational complexity, the resource capability requirements and receiver cost.

- Different Coordinate Reference System: each GNSS uses its own coordinate reference systems

<table>
<thead>
<tr>
<th>System</th>
<th>GPS</th>
<th>GLONASS</th>
<th>Galileo</th>
<th>Beidou</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate reference system</td>
<td>WGS-84</td>
<td>PZ-90.02</td>
<td>GTRF</td>
<td>CGCS2000</td>
</tr>
</tbody>
</table>
Advantages of Multi-GNSS environment

- More signals, more services => more options

Source: qzs.jp
• Increase in availability and coverage:
• More robust and reliable services:
  – Reliable services: Integrity information is provided by SBAS or GNSSes;
  – Robustness positioning:
    – New advanced signals
    – The redundancy of multi-systems and multi-bands; => more difficult to be jammed and spoofed;
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GNSS Signal Processing Chain

- Conditioning and digitizing the analog signals
- Signal synchronization: Acquisition, Tracking
- Data demodulation
- PVT computation
- Satellite position, pseudo-range and position computations;
- Carrier wipe-off; and spreading code wipe-off
• Signals in concerns: open and free signals of the 5 systems, namely:

<table>
<thead>
<tr>
<th>Signals</th>
<th>Carrier (MHz)</th>
<th>PRN code</th>
<th>Code Length</th>
<th>Code rate</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS L1-C/A</td>
<td>1575.42</td>
<td>Gold</td>
<td>1023</td>
<td>1.023</td>
<td>50</td>
</tr>
<tr>
<td>Galileo E1</td>
<td>1575.42</td>
<td>Memory</td>
<td>4092</td>
<td>1.023</td>
<td>250</td>
</tr>
<tr>
<td>Beidou B1</td>
<td>1561.098</td>
<td>Gold</td>
<td>2046</td>
<td>2.046</td>
<td></td>
</tr>
<tr>
<td>Glonass L1-OF</td>
<td>1602+ k×0.5625</td>
<td>Minimal length</td>
<td>511</td>
<td>0.511</td>
<td>50</td>
</tr>
</tbody>
</table>

Note: GLONASS L1-OF is the only FDMA signal; the others are CDMA ones
Adaptations to Multi-GNSS:

Analog parts (1/2): (Antenna & Front-end)

• Antenna requirements:
  – Capable of receiving all 4 signals;
  – Aero Antenna Choke Ring AT1675-120: [1525 ÷ 1615] MHz
Adaptations to Multi-GNSS:

Analog parts (2/2): (Antenna & Front-end)

• Front-end:
  – Functionalities: conditioning and digitizing analog signals
  – Chosen front-end: MAX2769

<table>
<thead>
<tr>
<th>Table 1: MAX 2769 front-end configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sampling frequency</strong></td>
</tr>
</tbody>
</table>
| **Intermediate frequency** | $F_{IF1} = 4.092$ MHz (for L1-C/A, E1 and B1)  
                          $F_{IF2} = -16$ kHz (for L1-OF) |
| **Bandwidth** | $B_{w1} = 4.2$ MHz (for L1-C/A, E1 and B1)  
                           $B_{w2} = 8$ MHz (for L1-OF) |
| **Number of quantization bits** | 2 bits |
Result Analyses: Acquisition

GLONASS PRN 1

Beidou PRN 5

Galileo PRN 20

GPS PRN 22
Result Analyses: Tracking

GLONASS PRN 1

Beidou PRN 5

Galileo PRN 20

GPS PRN 22
Result Analyses: Data demodulation

- Sky-plot (satellite positions): 26 satellites-in-view of 5 systems, namely:
  - 8 GPS;
  - 4 Galileo;
  - 5 GLONASS;
  - 8 Beidou;
  - 1 QZSS.
Result Analyses: Stand-alone Positioning (1/3)

GLONASS

Beidou
Result Analyses: Stand-alone Positioning (2/3)
### Result Analyses: Stand-alone Positioning (2/3)

- **Accuracy of GNSSes at the campaign**

#### Horizontal Errors

<table>
<thead>
<tr>
<th>System</th>
<th>$\delta_{\text{East}}$ (m)</th>
<th>$\delta_{\text{North}}$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glonass</td>
<td>3.2584</td>
<td>8.1746</td>
</tr>
<tr>
<td>Beidou</td>
<td>3.7629</td>
<td>13.4952</td>
</tr>
<tr>
<td>Galileo</td>
<td>4.0887</td>
<td>12.8882</td>
</tr>
<tr>
<td>GPS</td>
<td>2.9859</td>
<td>6.3924</td>
</tr>
</tbody>
</table>

#### Dilutions of Precision

![Dilutions of Precision Chart]

- **GPS**
- **GLONASS**
- **Galileo**
- **BeiDou**
Result Analyses: Multi-GNSS Positioning

GPS+Galileo

\[ \delta_{\text{East}} = 2.4029 \text{ m} \quad \delta_{\text{North}} = 5.8056 \text{ m} \]

- GPS L1 C/A and Galileo BOC(1,1) are two interoperability signals with a common carrier frequency
Result Analyses: Multi-GNSS Positioning

3 GPS + 2 Beidou

\[ \delta_{\text{East}} = 5.4983 \text{ m} \quad \delta_{\text{North}} = 8.0544 \text{ m} \]

- Geostationary SVs of Beidou always visible at high elevation in SEA
Result Analyses: Multi-GNSS Positioning
All GNSSes + QZSS

- GPS/GLONASS/Galileo/Beidou/QZSS: 26 satellites are involved
- Better accuracy in comparison with any stand-alone
- But complexity increase

\[ \delta_{\text{East}} = 1.7582 \text{ m} \quad \delta_{\text{North}} = 3.7840 \text{ m} \]
Among 50 first users of the Galileo system
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Overview of QZSS

- The Quasi-Zenith Satellite System (QZSS) is a RNSS of Japan.

- Functional Capability:
  - GNSS Complementary
  - GNSS Augmentation:
    - Sub-meter class
    - Centimeter class
  - Messaging Service

- Signals:
  - L1C/A, L1C, L2C and L5
  - L1S (L1-SAIF)
  - L6 (LEX)

- 2018: provide services by 4 SVs
• Elevation and Azimuth of the 1\textsuperscript{st} SV: Michibiki

Elevation and Azimuthal angles for each city (Observation EPOCH = 2009/Dec/26/12:00 UTC)
• Coverage: East Asia and Pacific Region

Ground Track of a QZSS satellite
QZSS – LEX: Centimeter Service

• Based on Precise Point Positioning (PPP) Technology:
  • With single receiver (no reference station)
  • Conventionally post-processing
  • With recent services such as: IGS Realtime, QZSS LEX it is possible to have realtime PPP

• Need satellite orbit and clock
  • Post-processing (IGS final) or real-time (IGS RT, QZSS LEX)
  • Require observation data of tracking stations world-wide
  • Vietnam does not have any IGS station, NAVIS is the first one in MGA

• Data format:
  • SP3 for orbit (ECEF positions of satellite mass center)
  • CLK for clock biases
Precise Point Positioning – IGS Products

Sample IGS Realtime services: products.igs-ip.net, mountpoint IGS01-03, IGC01-03

GLOBAL DATA CENTER (CDDIS, IGN, ...)

DATA ANALYSIS CENTER (CODE, MIT, NOAA, ...)

PRODUCTS (FINAL, RAPID, ULTRA RAPID, REALTIME)

IGS Station Network
• LEX Realtime positioning is possible (almost as good as IGS Rapid product)
• Convergence time is still a problem (30-60 minutes to reach decimeter level in kinematic mode)
Conclusions

• Multi-GNSS environment increases: availability, reliability and accuracy of the navigation services

• South-East Asia is covered by the largest number of systems (GNSSes + RNSSes) => interesting region for GNSS research

• Multi-GNSS positioning solutions are validated in South-East Asia, with results showing the advantages of multi-GNSS solutions

• QZSS-LEX is a good solution for precise positioning (no local infrastructure required, good performance…)

• … but just the beginning, exhaustive research on “smart” combinations of G(R)NSSes (with complexity & cost concerns) must be done.
Thank you very much for your attention!

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