Multi-GNSS and deeply-coupled integration of sensors for interference mitigation

Dr Laura Ruotsalainen
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Finnish Geospatial Research Institute (FGI)
National Land Survey
**Expertise areas of the Dept. of Navigation and Positioning**

**Satellite navigation**
- GPS, GLONASS, BeiDou, Galileo, IRNSS
- EGNOS
- Interference detection and mitigation
- Receiver techniques
- Precise navigation

**Indoor navigation**
- Sensor integration
- Indoor positioning
- Visual and DTV positioning
- Optical sensors

**LBS and contextual thinking**
- Mobile LBS
- Context awareness
- Positioning in ITS
- Positioning for maritime safety
Multi-GNSS for interference mitigation
### Current Status of Multi-GNSS

<table>
<thead>
<tr>
<th></th>
<th>GPS</th>
<th>GALILEO</th>
<th>GLONASS</th>
<th>BeiDou</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of planned satellites</td>
<td>30</td>
<td>30</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>Current Status</td>
<td>31 operational, 1 under maintenance</td>
<td>8 operational, 2 under maintenance</td>
<td>23 operational, 2 in preparation, 2 in flight tests phase</td>
<td>16 operational satellites, 4 under commissioning</td>
</tr>
<tr>
<td>Orbital planes</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Access Scheme</td>
<td>CDMA</td>
<td>CDMA</td>
<td>FDMA/CDMA</td>
<td>CDMA</td>
</tr>
</tbody>
</table>

- SBAS: 3 WAAS, 3 EGNOS, 3 SDCM, **4 IRNSS (7 planned)**, 1 QZSS (7 planned)
FGI-GSRx software-defined Receiver

FGI-GSRx

Galileo
   E1
GPS
   L1
BeiDou
   B1 and B2
Glonass
   L1
IRNSS

✓ MATLAB implementation for postprocessing
✓ Dual-frequency code-phase based positioning
✓ Multi-GNSS performance analysis, Jamming detection, Tightly-coupled INS + GNSS etc.
Data collection with multi-GNSS Front-ends and L1 jammer

- Multi-GNSS Repeater
- L1 Jammer
- Multi-GNSS Antenna
- NSL Stereo v2 front-ends
Analyzed jammer

Covert GPS L1 jammer: with special permission from the Finnish Communications Regulatory Authority, restricted to -30 dBm (nominal 13 dBm)

Instantaneous frequency

Signal spectrum at L1
Jamming Detection

- A Running Digital Sum (RDS) –based jamming detection method
- Computes the level changing rate of RDS of the digitized raw data bins

## Multi-GNSS performance

<table>
<thead>
<tr>
<th>Normal</th>
<th>Jamming L1</th>
<th>GPS</th>
<th>GLONASS</th>
<th>BDS B1</th>
<th>BDS B2</th>
<th>Multi-GNSS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.8</td>
<td>6.7</td>
<td>14.3</td>
<td>8.1</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>375</td>
<td>73.7</td>
<td>16.9</td>
<td>7.2</td>
<td>145</td>
</tr>
</tbody>
</table>

### RMSE$_{3D}$ [m]
- Multi-GNSS constellations switched to a single constellation BeiDou B2, when a jamming signal is detected

- $\text{RMSE}_{3D} 6.5$ m
Benefits and challenges of multi-GNSS

Implementation complexity vs. expected performance

- Dual/triple built-in front-ends targeted for different frequencies
- Some tens of channels need to be continuously tracked => processing power
- High bandwidth signals => high sampling rates => will drain out the receiver power

- Improved accuracy, availability, reliability, integrity
- Interference mitigation
Deeply coupled GNSS, INS and visual sensor integration
Deeply coupled GNSS/INS

- Software GNSS receiver
- Corrected replicas
- DLL, FLL Discriminator
- NCO
- Clock
- Deeply coupled Kalman filter
- Inertial Navigation System
- IMU corrections
- P, V, A
Visual sensors

- Motion of features in consecutive images provide motion information
- Heading and translation
  - Visual gyroscope and visual odometer
  - Translation a challenge when monocular camera used
    - Ruotsalainen, Doctoral dissertation 2013
- Used for correcting INS measurements for improved deeply-coupled processing

Data Collection

• Jamming scenario:
  • GPS data was collected, jamming was started at 48 seconds, ended at 80 seconds
  • Static scenario

• Data was analyzed using:
  • GPS signals only
  • GPS + INS deeply coupled
  • GPS + INS + visual sensor deeply coupled
  • INS: XSens MTi-G-700 MEMS IMU
  • Images for visual processing obtained using a GoPro Hero3 camera
Deeply-coupled Results

- **GNSS only, C/N\(_0\) s below the line, no pv solution**
- **Jamming started**
- **GNSS+INS+Visual**
  - Max errors
    - Position: 80m
    - Velocity: 2 m/s
    - Attitude: 3 deg
- **GNSS+INS**
  - Max errors
    - Position: 300m
    - Velocity: 7 m/2
    - Attitude: 5 deg
Publications 1/2


Publications 2/2


European Navigation Conference 2016

Helsinki, Finland, 30th May – 2nd June 2016

IMPORTANT DEADLINES

Full-paper submission: 15th January, 2016
(Scientific Track)

Abstract Submission: 15th January, 2016
(Industry Track)

Acceptance Notification: 31st March, 2016

Early Registration: 15th April, 2016