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

Dr Laura Ruotsalainen
ICG EXPERTS MEETING, 17. December, 2015

Finnish Geospatial Research Institute (FGI)
National Land Survey

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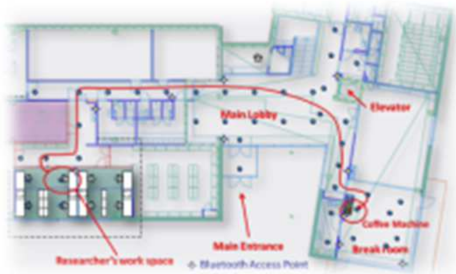
# Expertise areas of the Dept. of Navigation and Positioning

## Satellite navigation

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

## LBS and contextual thinking

- Mobile LBS
- Context awareness
- Positioning in ITS
- Positioning for maritime safety




## Indoor navigation

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

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# Multi-GNSS for interference mitigation

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# Current Status of Multi-GNSS

| | GPS | GALILEO | GLONASS | BeiDou |
|---|---|---|---|---|
| First launch | 1978 | 2011 | 1982 | 2007 |
| Full Operational Capability (FOC) | 1995 | 2018~2020 | 2011 | 2020 |
| Number of planned satellites | 30 | 30 | 24 | 35 |
| Current Status | **31** operational, 1 under maintenance | **8** operational, 2 under maintenance | **23** operational, 2 in preparation, 2 in flight tests phase | **16** operational satellites, 4 under commissioning |
| Orbital planes | 6 | 3 | 3 | 3 |
| Access Scheme | CDMA | CDMA | FDMA/CDMA | CDMA |

- SBAS: 3 WAAS, 3 EGNOS, 3 SDCM, **4** IRNSS (7 planned), 1 QZSS (7 planned)

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# FGI-GSRx software-defined Receiver

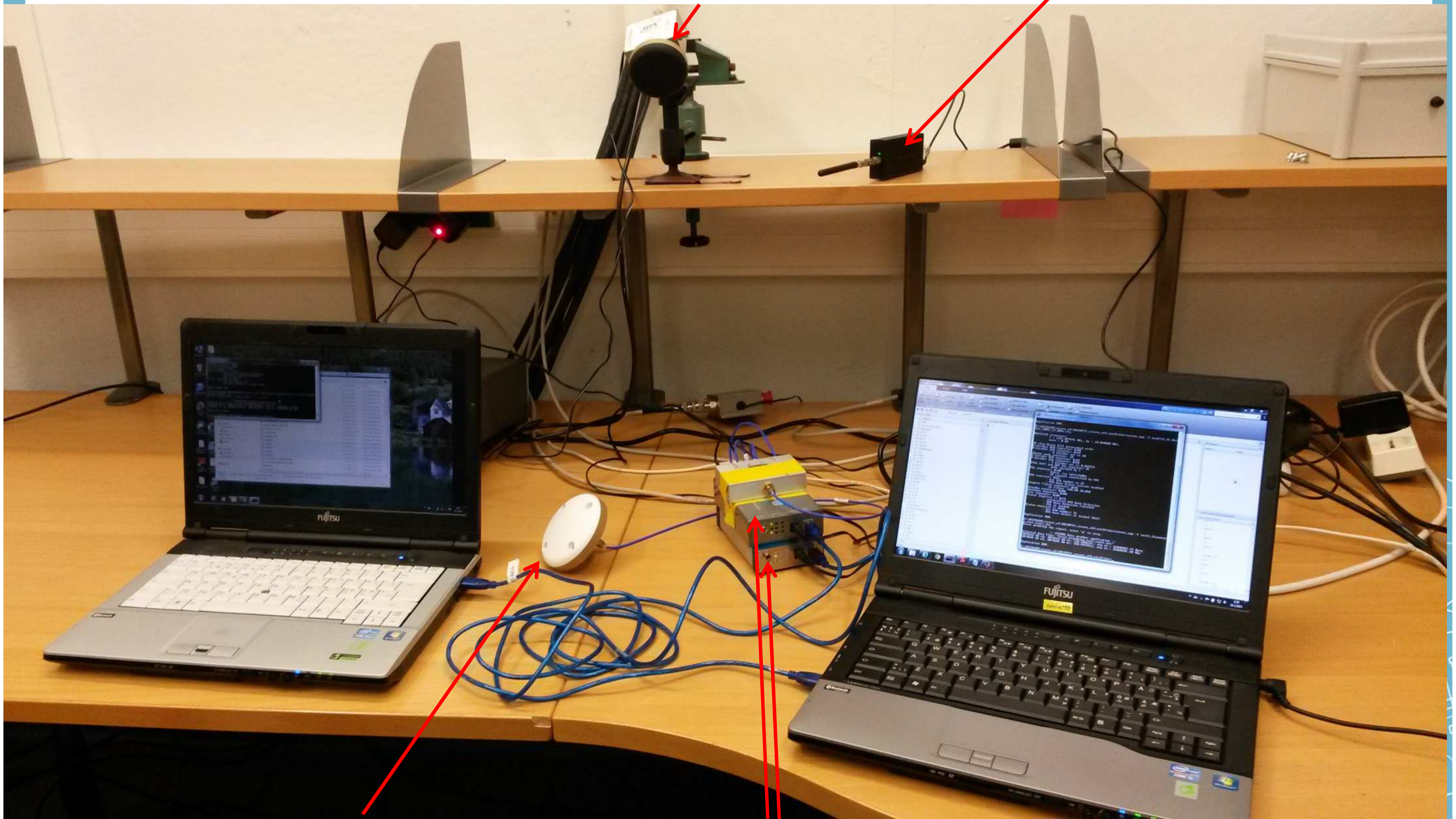
**FGI-GSRx**

| Galileo | GPS | BeiDou | Glonass | IRNSS |
|---|---|---|---|---|
| E1 | L1 | B1 and B2 | L1 | |

- ✓ MATLAB implementation for postprocessing
- ✓ Dual-frequency code-phase based positioning
- ✓ Multi-GNSS performance analysis, Jamming detection, Tightly-coupled INS + GNSS etc.

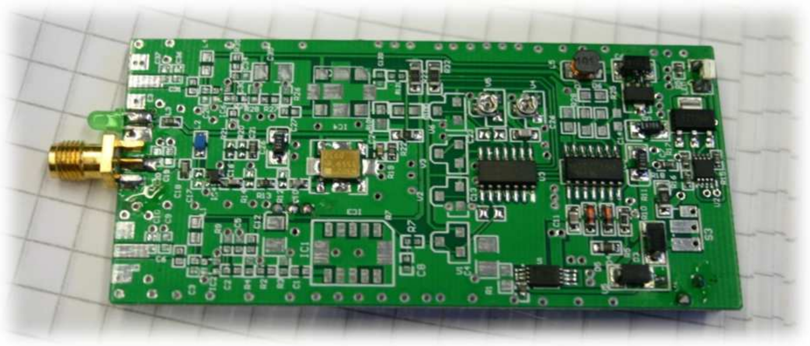
# Data collection with multi-GNSS Front-ends and L1 jammer

Multi-GNSS Repeater L1 Jammer

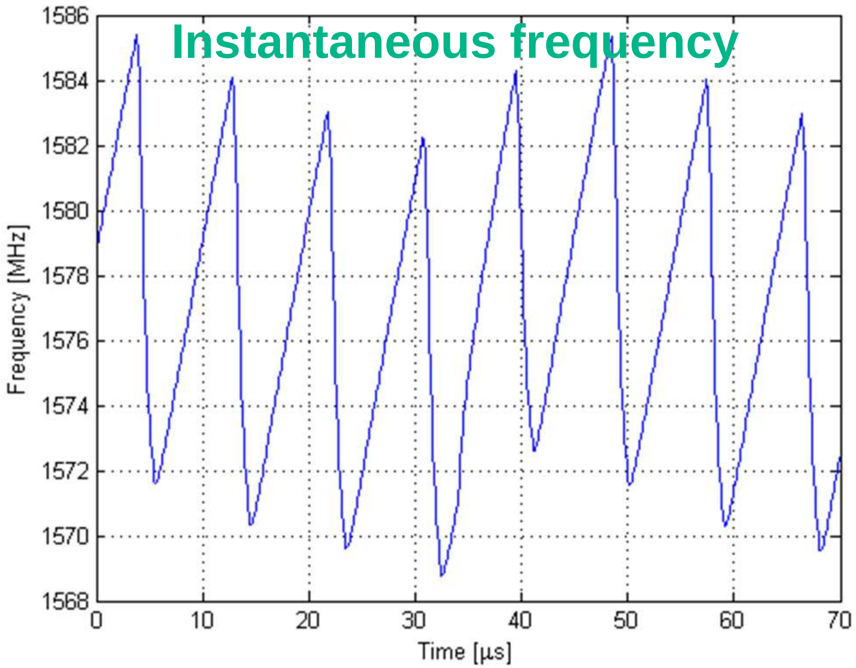


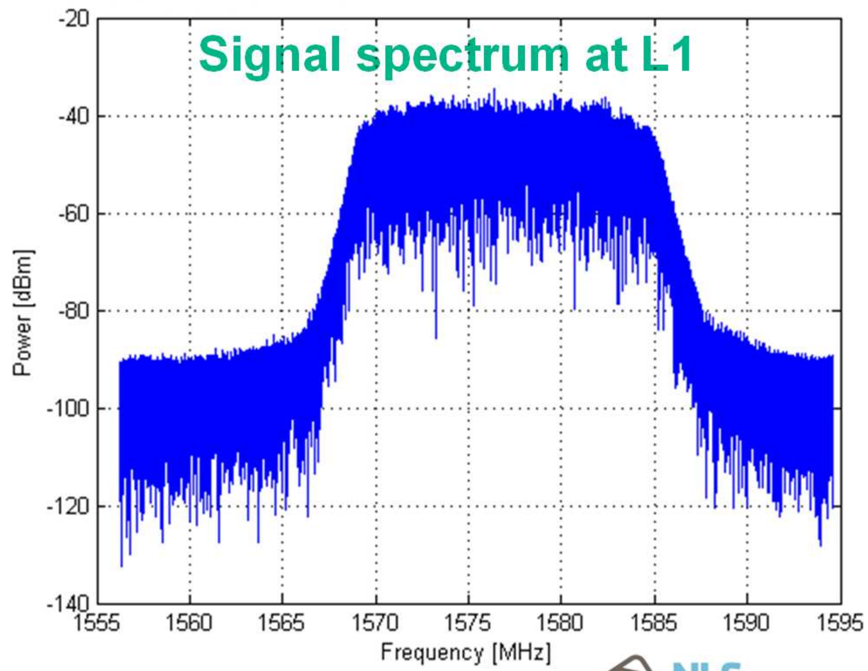
Multi-GNSS Antenna NSL Stereo v2 front-ends

# Analyzed jammer



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

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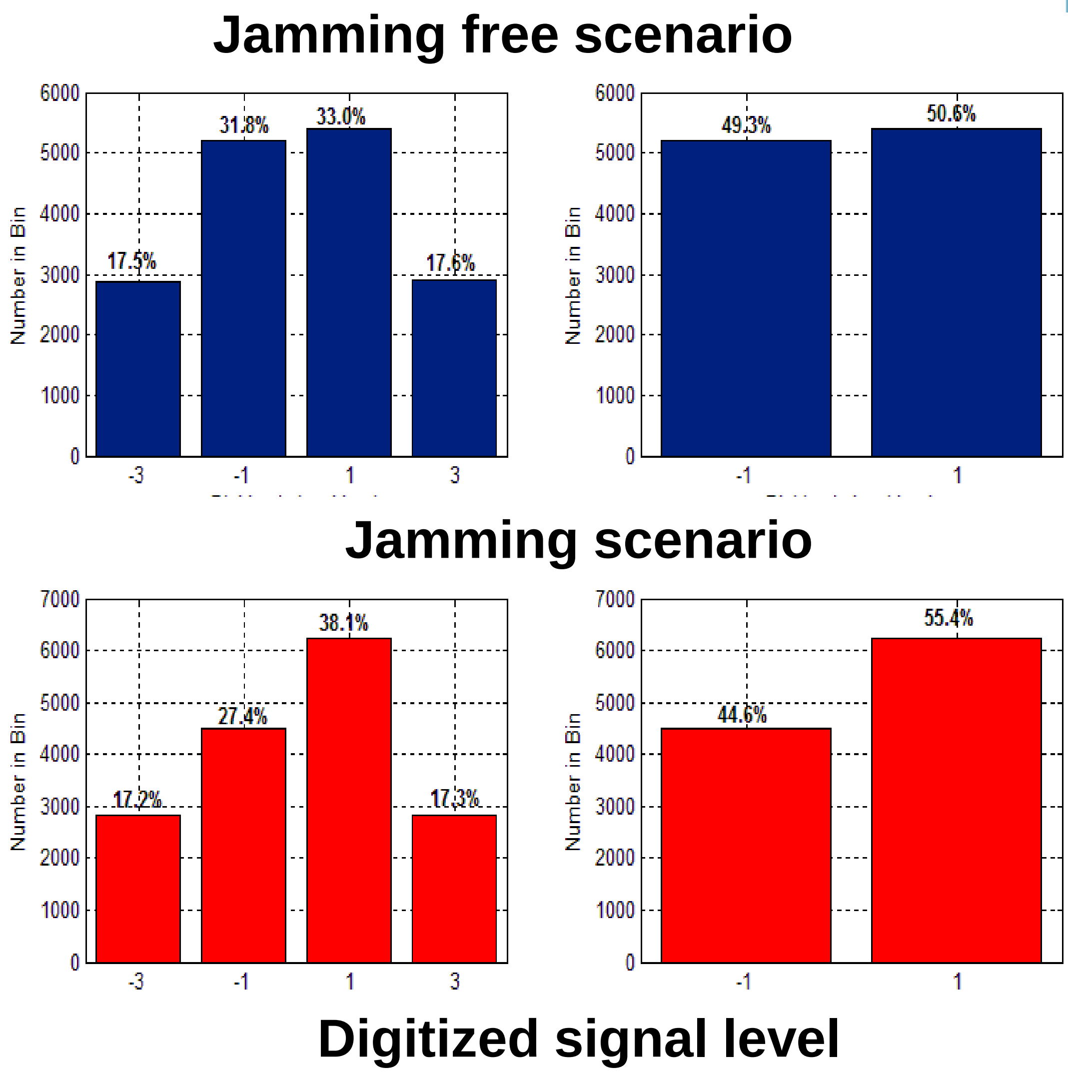
# Jamming Detection

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




* M. Z. H. Bhuiyan, H. Kuusniemi, S. Söderholm and E. Airos (2014) “The Impact of Interference on GNSS Receiver Observables – A Running Digital Sum Based Simple Jammer Detector,” Radioengineering journal, Vol. 23, No. 3, pp. 898-906.

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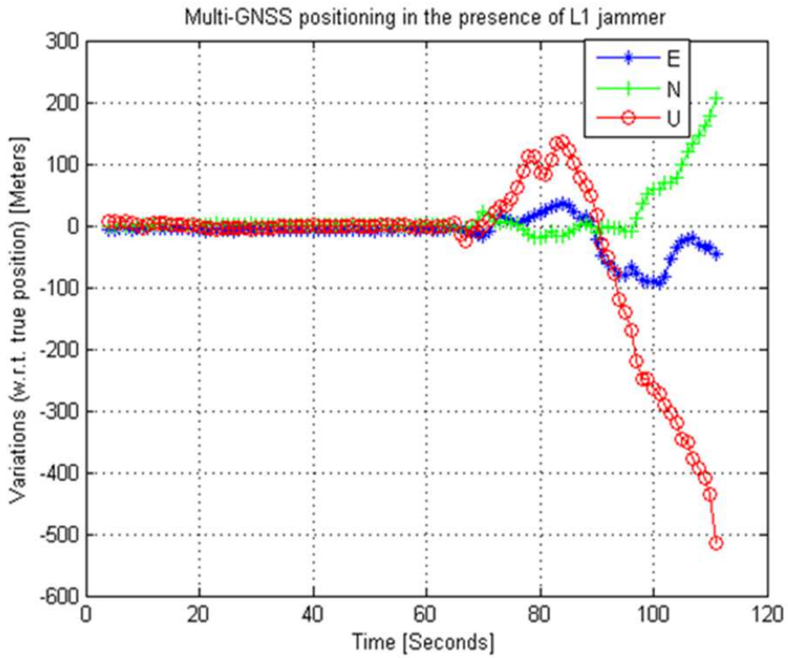
# Multi-GNSS performance

| | GPS | GLONASS | BDS B1 | BDS B2 | Multi-GNSS |
|---|---|---|---|---|---|
| Normal | **2.8** | **6.7** | **14.3** | **8.1** | **7.0** |
| Jamming L1 | **375** | **73.7** | **16.9** | **7.2** | **145** |

**RMSE$_{3D}$ [m]**




- Multi-GNSS constellations switched to a single constellation BeiDouB2, when a jamming signal is detected
  - ➢RMSE$_{3D}$ **6.5** m

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# 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

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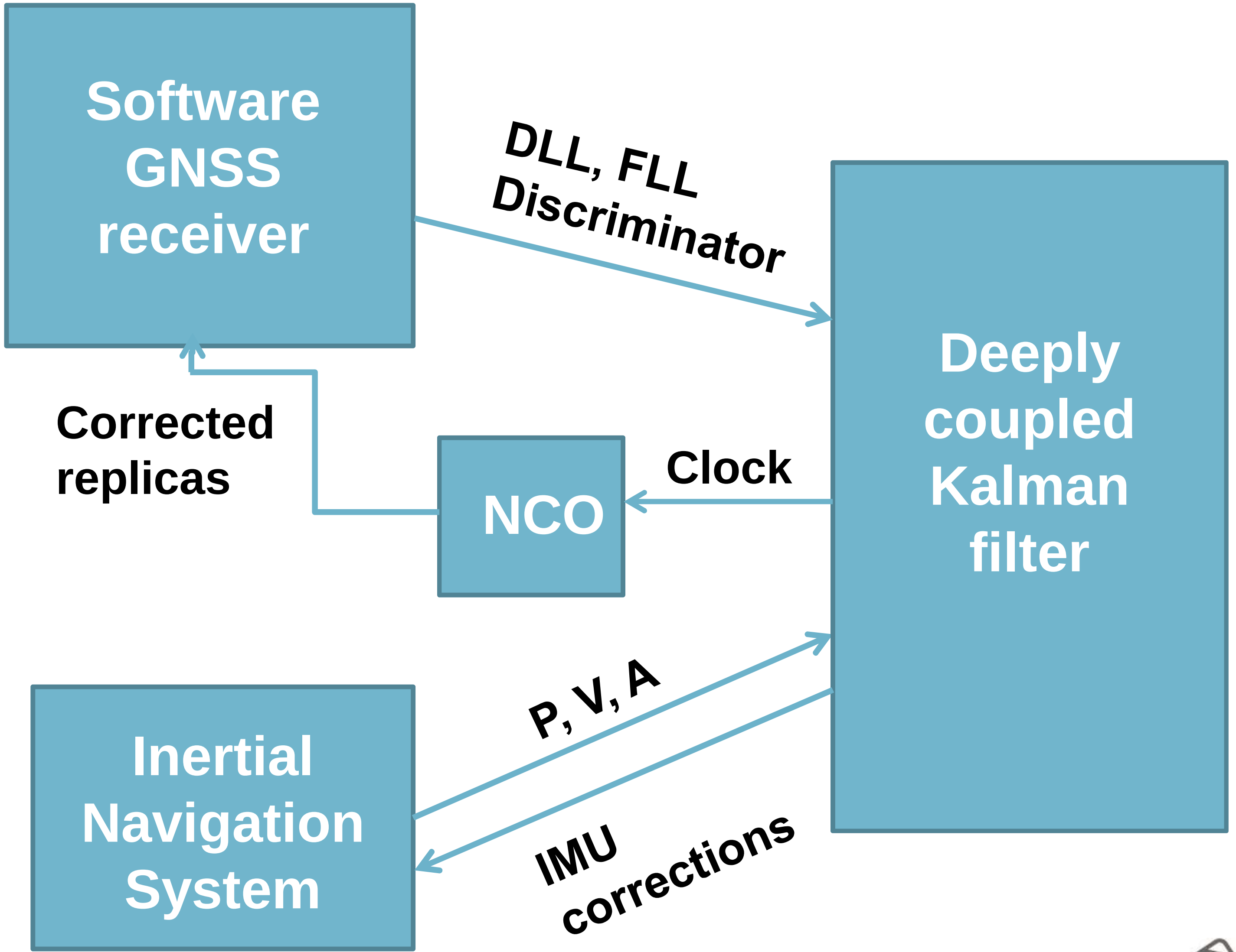
# Deeply coupled GNSS/INS

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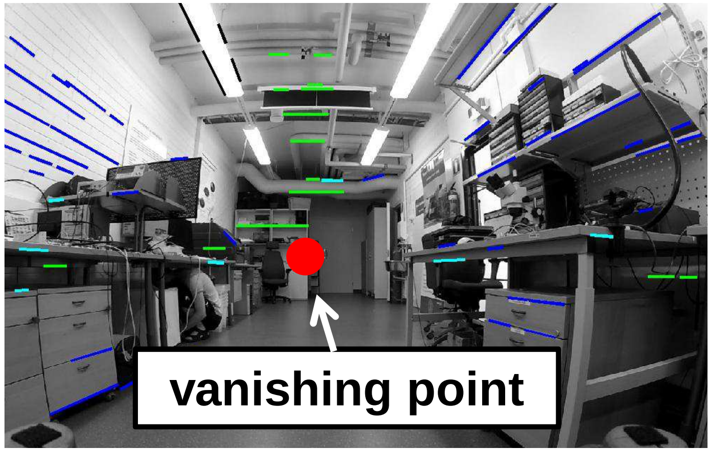
# Visual sensors

- 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




**Visual Gyroscope**

Ruotsalainen L., Vision-Aided Pedestrian Navigation for Challenging GNSS Environments, Doctoral dissertation, 2013

# 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



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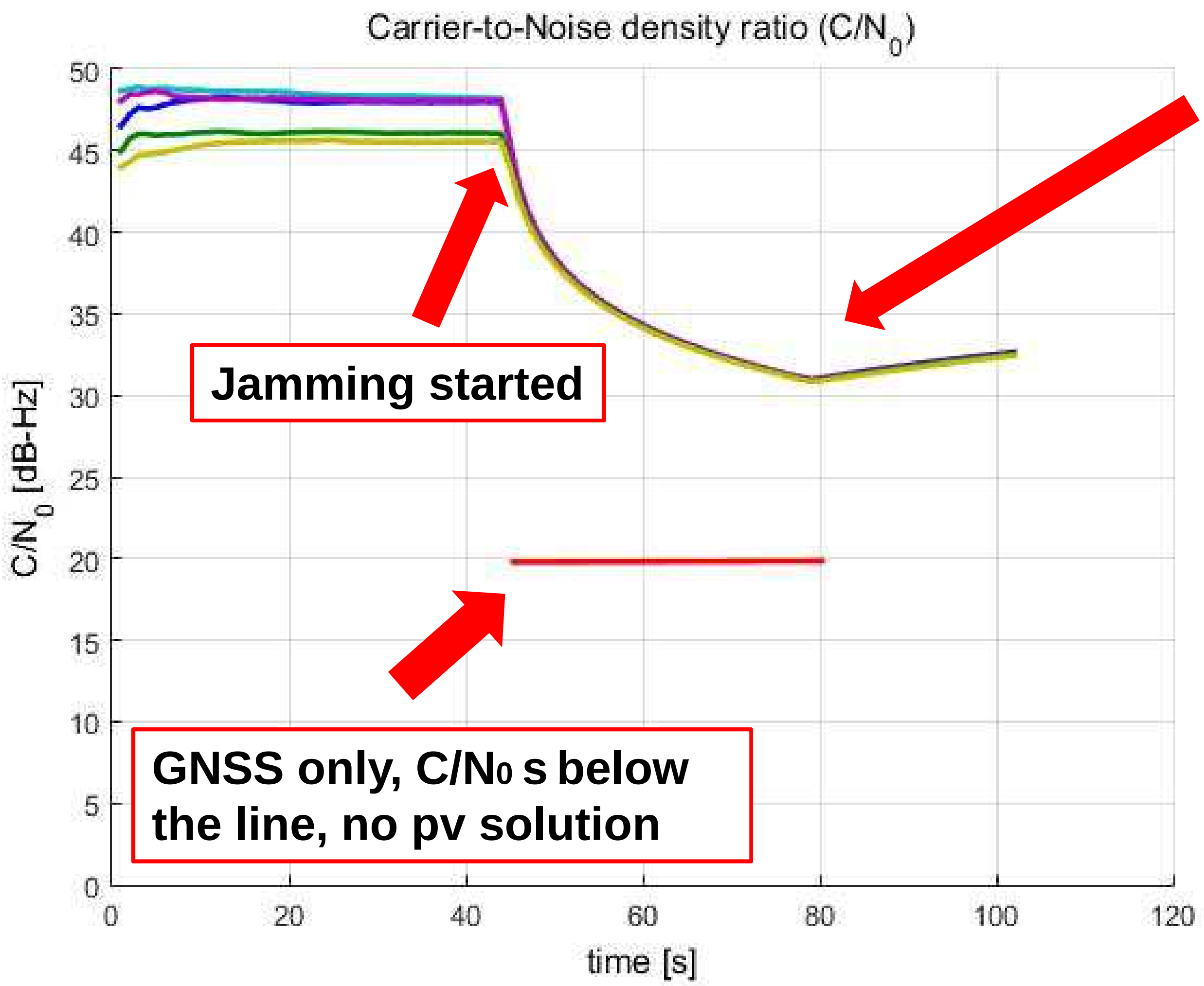
# Deeply-coupled Results




**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


- Bhuiyan, M. Z. H., Honkala, S., Söderholm, S. and H. Kuusniemi, 2015. Performance Analysis of a Mul-ti-GNSS receiver in the Presence of a Commercial Jammer. International Association of Institutes of Navigation World Congress 2015, 20-23 October, 2015, Prague, Czech Republic.
- Bhuiyan, M. Z. H., Söderholm, S., Kuusniemi, H., Thombre, S., and L. Ruotsalainen, 2015. Utilization of a Novel Channel Quality Index for Improved Multi-GNSS Positioning in GNSS-denied Environ-ments. 5th Int. Galileo Science Colloquium, 27-29 October, Braunschweig, Germany.
- Bhuiyan, M.Z.H., Söderholm, S., Thombre, S., Ruotsalainen L. and H. Kuusniemi (2014). Overcoming the Challenges of BeiDou Receiver Implementation, Sensors, MPDI.
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- Bhuiyan, M.Z.H., Söderholm, S., Thombre, S., Ruotsalainen, L., and Kuusniemi, H. (2014). First Studies of BeiDou in Finland, Poster presentation, ICL-GNSS 2014, Helsinki, Finland, June 2014.
- Bhuiyan M.H.Z., Kuusniemi H., Söderholm, S., Thombre, S., Ruotsalainen L. (2014).Tracking the BeiDou Satellites with a Software-defined Receiver, Geospatial World - the Geospatial Industry Magazine, 21 April, Magazine.
- Bhuiyan M.H.Z., Söderholm, S., Thombre, S., Ruotsalainen L. and H. Kuusniemi (2014). Implementation of a Software-defined BeiDou Receiver, Lecture Notes in Electrical Engineering (ISSN: 1876-1100).
- Bhuiyan M.Z.H., Söderholm, S., Thombre, S., Ruotsalainen L., Kirkko-Jaakkola M. and H. Kuusniemi (2014) Performance Evaluation of Carrier-to-Noise Density Ratio Estimation Techniques for BeiDou B1, in Proceedings of UPINLBS 2014.
- Kirkko-Jaakkola M.,Ruotsalainen L., Bhuiyan, M.H.Z., Söderholm, S., Thombre S., Kuusniemi, H. (2014). Performance of a MEMS IMU Deeply Coupled with a GNSS Receiver under Jamming, in Proceedings of UPINLBS 2014
- Kuusniemi, H., Airos, E., Bhuiyan, M.Z.H., Kröger, T. (2012a). Effects of GNSS Jammers on Consumer Grade Satellite Navigation Receivers. European Navigation Conference (ENC) 2012, Gdansk, Poland, 25-27 April, 2012.

# Publications 2/2


- Kuusniemi, H., Airos, E., Bhuiyan, M.Z.H., Kröger, T. (2012b) “GNSS jammers: how vulnerable are consumer grade satellite navigation receivers?,” European Journal of Navigation 08/2012; 10(2):14-21.
- Kuusniemi, H. and Bhuiyan, M.Z.H. (2012c). “Signal Barred“, Geospatial World, The Geospatial Industry Magazine, November 2012: 31-33.
- Kuusniemi, H, Bhuiyan, M.Z.H. and Kröger, T. (2013a) “Signal Quality Indicators and Reliability Testing for Spoof-Resistant GNSS Receivers,” European Journal of Navigation 08/2013; 11(2):12-19.
- Kuusniemi, H, Bhuiyan, M.Z.H., Liu, J., Ruotsalainen, L. and Honkala, S. (2013b) “Tracking the First Satellites of the European Galileo and the Chinese BeiDou Systems,” Finnish National Committee on Space Research Conference 2013, Metla, Vantaa, August 29-30, 2013
- Ruotsalainen L., Bhuiyan M.Z.H., Thombre S., Söderholm S., Kuusniemi H. (2014a). Impact of cheap commercial jammer on BeiDou signals, In proceedings of ENC, 14-16 April, Rotterdam.
- Ruotsalainen L., Kirkko-Jaakkola, M., Bhuiyan, M. Z. H., Söderholm, S., and Thombre, S., and H. Kuusniemi (2014b). Deeply-coupled GNSS, INS and visual sensor integration for interference mitigation, Proceedings of ION GNSS.
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- Söderholm, S., Bhuiyan, M. Z. H., Thombre, S., Ruotsalainen L. and H. Kuusniemi (2014). An L1 CDMA multi-GNSS software receiver, GPS Solutions, Springer, in press
- Thombre, S., Bhuiyan, M.Z.H., Söderholm, S., Kirkko-Jaakkola, M., Ruotsalainen L. and H. Kuusinemi 2015. A Software Multi-GNSS Receiver Implementation for the Indian Regional Navigation Satellite System. IETE Journal of Research, Oct 2015. http://www.tandfonline.com/doi/full/10.1080/03772063.2015.1093968
- S. Thombre, M. Z. H. Bhuiyan, S. Söderholm, M. Kirkko-Jaakkola, L. Ruotsalainen, H. Kuusniemi (2014). 'Tracking IRNSS Satellites for Multi-GNSS Positioning in Finland', InsideGNSS, Nov/Dec


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# ENC 2016

***www.enc2016.eu***

## European Navigation Conference 2016



## Helsinki, Finland, 30$^{th}$ May – 2nd June 2016

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**IMPORTANT DEADLINES**

| | |
|---|---|
| Full-paper submission: (Scientific Track) | 15$^{th}$ January, 2016 |
| Abstract Submission: (Industry Track) | 15$^{th}$ January, 2016 |
| Acceptance Notification: | 31$^{th}$ March, 2016 |
| Early Registration: | 15$^{th}$ April, 2016 |

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