GNSS Technology Innovation –
Day 2: Galileo for Railways and Transport

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Presentation Overview

1. Thematic areas of Railway
2. GNSS in Railway and its challenges
3. ESA activities, research and development
   a. Potential for technology transfer to railway
4. ESA programmes and how they contribute
5. Conclusion
1. **Broadband to passengers**
   a. **Opportunities**: On board internet and entertainment in case of lack of terrestrial coverage in rural areas complemented by terrestrial networks
   b. **Activities**: Broadband to Trains, SAET, INDRA, EOMST

2. **Signalling**
   a. **Opportunities**: Low cost signalling using GNSS, SatCom and bearer-independent telecommunications solutions; innovative solutions at level crossing.
   b. **Activities**: 3InSat, SBSRailS, SatCom Rail, EMUSER, INLU, RailSafe, LeCross, Saferail

3. **Railway Infrastructure monitoring**
   a. **Opportunities**: Railway stability and subsidence analysis, landslides and rock fall prevention
   b. **Activities**: MATIST, LIVE LAND

4. **Tracking**
   a. **Opportunities**: Railway asset monitoring for safety and operational effectiveness
   b. **Activities**: SAMOLOSA, IRISS
GNSS IN RAILWAY AND ITS CHALLENGES
Satellite-based functions (including use of GNSS for virtual balise detection) have been identified as **key new capabilities of the next evolution** of the European Rail Traffic Management System (ERTMS).

Source: ERA and UNIFE

European Union Agency for Railways, ERTMS Control Command and Railway Communication Conference (CCRCC) in Lille, 22nd September 2015
GNSS System Evolutions

Safety of Life Overlay Systems

- GPS
- GLONASS
- GALILEO
- BEIDOU
- QZSS
- IRNSS
GNSS Signals

- Multi-frequency/Multi-signal
- Ionosphere removal
- Wideband signals
- Interference rejection
- Multipath rejection
- Frequency diversity
- High accuracy

SBAS today
PNT User Technology Evolutions
GNSS Challenges (Local Environment)

- **AIRBUS Beluga (10) (SBAS/EGNOS CMC)**

- **DLR Aeronautical channel**

- **DLR Land mobile car channel (LMC)**

- **Airframe multipath budget**

  - Multipath observed in railway environment
GNSS Challenges (Intentional Interference)

1. Resilience in the presence of...
   a. Jamming
      i. Unavailability caused by GPS jammers
         1) E.g. in vehicles parallel to the railway line
   b. Spoofing
      i. Need to understand risk and possible attack scenarios
System failures

2014 GLONASS anomaly case

For 11 hours worldwide GLONASS equipped GNSS receiver were exposed to a failure

2016 GPS anomaly case

Satellite failure caused global GPS timing anomaly

Created 13 microsecond error.

A time spike in the global positioning system which rippled through the world yesterday was caused by a satellite launched in 1990 failing and triggering a software bug, United States officials have confirmed.
Impact on ETCS operations with virtual balise detection using GNSS

Impact on positioning performance (e.g. availability, accuracy), cost, complexity, certification, etc.
What is needed to meet THR? (e.g. RAIM, hybridisation, track map, multi-frequency, multi-constellation, etc.)

Performance of augmentation systems
Are performances of existing systems translatable / applicable to railway?

Magnitude of risk reduction required to meet THR

Residual risk of misleading information

Barriers against local feared events

Barriers against system feared events
Achievable risk reduction with augmentation (e.g. SBAS, GBAS, etc.)

Feared events leading to misleading information hazard

GANSS in ERTMS (Safety of Life)
Potential for Technology Transfer to Railway

ESA ACTIVITIES, RESEARCH AND DEVELOPMENT
**ESA Activities Supporting Virtual Balise Concept**

**3InSat**

Integrated Signalling System
- 2 GNSS reference stations
- Vital Safety Server implementing RBC and Track-area LDS functions (installed in Cagliari control centre)
- Train equipped with ERTMS EVC and LDS on-board (shadow mode)

**INTEGRAIL - GNSS-1 RAIL USER NAVIGATION EQUIPMENT**

Status date: 01 June 2004
The aim of INTEGRAIL is to open the way for profitable use of the EGNOS signal in safety-critical railway traffic management and control.

**LOCOLOC**

Status date: 25 January 2004
The main objective of LOCOLOC is the development and demonstration of a complete very low cost fail-safe train navigation and integrity system based on the Global Navigation Satellite System (GNSS), focusing on speed and acceleration, as well as a service centre to complement LOCOPROL, a related project launched by the European Commission.
ESA Activities Supporting Virtual Balise Concept

SBS RAILS
Feasibility study
- determine the technical feasibility and economic viability of “satellite add-ons”
- (SATNAV and SATCOM with terrestrial comms)

1. Proof of Concept in SBS RAILS project
   a. GNSS multipath and interference modelling
   b. Simulation with RF signal generation equipment
Integrity for Navigation of Land Users (INLU) TRP Project

1. Railway Work Package
   a. Railway Channel Model
   b. Map-aided Solution Separation ARAIM (Odometry & track map)
Integrity for Navigation of Land Users (INLU) – Trackers, PVT and Integrity Analysis Tool

**GNSS baseband samples / Analytic correlation results**

**Tracking Techniques**
- Early-minus-Late
- Bump Jumping
- Double Estimator
- Astrium Correlator
- BPKS-like Tracker
- Multipath Estimating DLL
- Vision Correlator
- EKF/UKF Multicorrelator
- ...

**Analysis Tools**
- Performance Statistics
- Protection Levels
- Integrity Risk Assessment

**Integrity Monitoring**
- Classical WSSE RAIM
- Multi-Hyp. Solution Separation
- GNSS/INS Filter Bank Approaches
- ...

**PVT**
- Snapshot WLS
- Kalman Filter
- GNSS/INS Loosely Coupled
- GNSS/INS Tightly Coupled
- GNSS/INS Ultra-Tightly Coupled
- GNSS/z-Gyro/Odometry
- ...

**Aiding Sensors**
Modelling Multipath – LMM File production

**LOS Visibility**

**SimGEN Scenario**

- Orbit settings
- Vehicles settings
- Antennas settings
- General settings
- Deterministic LMM Files

**Possible incoming rays**

SE-NAV masks can be imported in SPIRENT SimGen® (LMM format)

**3D Synthetic Environments**
GAUPSS – Spoofing Testbed

1. In-the-loop testing of receivers against spoofing threats
   a. Aligns live signals with spoofing signals
   b. Generates defined signal and message level attacks
   c. Monitors the development of an attack
   d. Generates GNSS/INS hybridized measurements
Interference Mitigation Based on Novel Signal Processing Cancellation and RF Front End (TERMINATE)

1. Future GNSS receiver design offering **superior interference detection and rejection capability** compared to typical state-of-the-art commercial GNSS receivers

2. RF Front End features:
   a. ADC maximum dynamic range for interference, ADC agility, out-of-band signal rejection

Digital enabling algorithms based on:
- Pulse Blanking
- Statistical Tests
- FIR and IIR filter (for time-stationary “standard” and time-varying “adaptive”)
- Fourier Transform (FT)
- Fractional Fourier Transform (FrFT)
- Wavelet Transform (WT)
Design and Development of Advanced Antenna & Receiver for GNSS Reference Stations

Design and development of Advanced Antenna and Receiver for Ground Stations (DADAR)
- Funded by European GNSS Evolution Program (EGEP)
Industry Roadmap, ESA Programmes and how they Contribute...

ESA PROGRAMMES
Space4Rail is an ESA initiative to support the railway community by raising awareness of the added value that space-based assets can bring to railway applications.

The initiative identifies ESA funding programmes that can support potential opportunities for the exploitation of space-based assets such as telecommunication, navigation and earth observation satellites to meet today’s challenges and needs in railway operations.

The ESA programmes included in the Space4Rail initiative are:

- Advanced Research in Telecommunications Systems (ARTES)
- Navigation Innovation and Support Programme (NAVISP)
- General Support Technology Programme (GSTP)
- Technology Research Programme (TRP)
- General Studies Programme (GSP)

http://space4rail.esa.int
What we do in Railway... (Navigation-related activities)

TELECOMS

NAVIGATION (GNSS)

Inter-directorate WG on Railways

RAILSOL

TIA

TEC

NAV

http://space4rail.esa.int

ARTES
Advanced Technology

ARTES
Competitiveness & Growth

ARTES
IAP

NAVISP

GSP

TRP

GSTP 6.1

GSTP 6.2

EGEP

DADAR

INLU

RAILSAFE

TERMINATE
GAUPSS
OKTAL SE
ESA Role

Support GNSS and Rail stakeholders in coordination with GSA in the field of:

- user requirements, architecture and system concept design,
- and laboratory testing; especially in connection with receiver development

GSA Role

Support UNISIG & S2R activities from GNSS perspective through H2020, consultancy and involvement of experts and institutions from GNSS fields

Coordination and agreed role between agencies

GSA/ESA Railway Activities Coordination Committee

https://www.gsa.europa.eu/node/41278
ESA Activities Workflow (ERTMS Virtual Balise)

**General Support Technology Programme (GSTP-6)**

**Element 1**

- **GT16-xxxES**
  - Definition of MP and EMI scenarios and models for GNSS in railway environments
  - Modelling of Intentional Interference
  - Datasets for testing conformance

**Technology Research Programme (TRP)**

- **TRP AO/1-8830**
  - Simulation Testbed 1

**Simulation Testbed**

- **Gxxxx-xxxES**
  - Simulation Testbed 2
- **GT16-001ES**
  - GNSS Receiver Chain & Integrity Techniques (SFSC, DFMC)
- **Gxxxx-xxxES**
  - Virtual balise reader platform for ERTMS (DFMC-ready)
- **Gxxxx-xxxES**
  - Resilience Against Intentional Interference & Spoofing

**Technology Support Activities**

- **GT16-xxxES**
  - Consolidaion of Safety & RAM Requirements

**Consolidation**

- **NAVISP EL1-003**
  - System Suitability Study for Train Positioning using GNSS in ERTMS (time frme 2020)
  - EGNOS/V2 (GPSL)

**Navigation Innovation and Support Programme (NAVISP)**

**Element 1**

- **NAVISP EL1-xxx**
  - System study (time frame post-2020) – broader PNT solutions (SBAS/GBAS/hybrid/ARAIM)
  - EGNOS/V3 (DFMC, GPS+GALILEO)

**Laboratory Tools**

- **Modelling Railway Environment**
  - **Gxxx-xxxES**
    - Hardware-In-the-Loop Testbed

**Certification Laboratories**

- **Prototype ERTMS Virtual Balise Reader (Shift2Rail)**

**Receiver Development (GSA Fundamental Elements)**

**Industry Initiated Activities**

- Approved
- To be proposed 2017/18

**ESA Initiated Activities in line with industry roadmap (ESA/ESA/ERA)**

- To be proposed 2017/18

**Enabling activities to support industry roadmap**

- Approved
- To be proposed 2017/18
- To be proposed in future
Industry Proposed Initiatives

**Industry proposed initiatives**

a. Activities industry believes should be brought to higher TRL for commercial exploitation

b. Provides support for co-funded activities that are:
   
i. Proposed by industry
   
ii. Outside the coordinated work plan of activities proposed in previous slides (i.e. development and standardisation activities for the evolution of ERTMS)

**Possible Programmes:**

1. NAVISP Element 2
   
   • Priorities under consolidation

2. GSTP 6.2 – competitiveness element
   
   • Focused on user technology activities

3. Integrated Applications Promotion (IAP)
   
   • Demonstration towards commercialisation / market uptake
Conclusions

- Usage of satellite based technology in support of railway applications can offer important enhancement and cost saving opportunities

- In particular, the use of GNSS for virtual balise detection is considered a GAME changer for ERTMS evolution by ERA and UNIFE, and is included in the roadmap of the enhancements to be pursued

- On the one hand the tremendous capabilities offered by present and planned GNSS systems, including augmentations and overlays, and supported by similar enhancements on the user technology side, can be used to enable the enhancements to ERTMS using GNSS

- On the other hand the challenges for the provision of the very stringent safety of life services need to be addressed by dedicated technological developments. Gaps exist and need to be filled

- A few examples of ESA activities addressing those challenges have been presented

- ESA programs and coordinated strategy in support of railway developments have been also described offering industry and research institution R&D opportunities to cover or complement the identified technology roadmaps
Thank you
Integrity for Navigation of Land Users (INLU) - PIPE Tool

Positioning and Integrity Performance Evaluator

Aiding Sensors

IMU

Channel Model

Scenario Generator

RFCS

Positioning and Integrity Performance Evaluator

GNSS Baseband Samples

RF Front-End & Sampler

Trajectory, Ephemeris,...
Multipath Models and SimGEN Integration

SimGEN + SE-NAV module

- Orbit settings
- Vehicles settings
- Antennas settings
- General settings
- Deterministic LMM Files

SimGEN Scenario

3D Synthetic Environments

SimGEN + SE-NAV module

SimGEN Scenario

Orbit settings

Vehicles settings

Antennas settings

General settings

Deterministic LMM Files

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