ON GNSS AUGMENTATION SERVICES FOR THE ERTMS TRAIN CONTROL AND CONNECTED CAR APPLICATIONS: TECHNICAL SYNERGIES AND OPPORTUNITIES

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Rail and Road transport systems are evolving toward **Autonomous Driving**.

**GNSS-based** high integrity and accuracy vehicle positioning is needed to comply with the required levels of safety.

Standardizable, interoperable and economically sustainable **augmentation system solutions are needed that** leverage:

- Reuse of existing and planned SBAS
- Services tailored to specific applications
- Local elements to enhance performance
- Proximity of rails and roads to share costs
ERTMS / ETCS (European Rail Traffic Management System – European Train Control System) developed in Europe for high-speed lines is the de facto railway standard train control system being adopted in most new lines and major upgrades.

ERTMS has been designed to replace the different railway signalling systems in Europe with a single system:

- Interoperable
- Standard
- Certifiable

with harmonised procedures and improved safety

- Railways Supported: **120,000 km**
- In operation by **2005 in Italy @ 300 km/hr, 2 train operators, and 5 minutes headway**
In ordinary ERTMS/ETCS, train localization is based on the combination of:

- **ABSOLUTE POSITIONING**: based on the detection of the passage over RF transponders (*Balises*) deployed along the railway
- **RELATIVE POSITIONING**: travelled distance from the last detected transponder provided by odometry
The GNSS Location Determination System generates the same signals produced by a Balise Reader detecting a physical Balise, through the same logical and physical interface, then emulating Balise reader behavior with respect to the train equipment. In this way, the On Board ERTMS/ETCS location determination functions do not need to be changed.
**WHY INTRODUCE GNSS IN ERTMS**

GNSS is one of the *Game-Changing* innovations for ERTMS

- **Cost reduction**
- **Interoperability**
- **Additional revenues**
- **Applicability**

**virtual balises**

the system is detected in the same way worldwide; certifiable for safety with a harmonised approach

**physical balises will disappear**

higher accuracy to increase line capacity

**broadening of use, including regional and local lines**

**MAIN CHALLENGE:**

- **FULFILL THE SAFETY INTEGRITY LEVEL SIL-4 REQUIREMENTS**
Exploitation of synergies between rail and road applications can transform the independent operations of roads and railways into a coordinated economically-sustainable ecosystem – a priority of Europe.

**Major synergies**

- Sharing telecoms and GNSS augmentation networks (rails and roads are close to each other and share the same EM environment and similar requirements)
- **Assimilation** of technologies and safety and certification processes
- Leveraging auto market potential to develop cost-effective multi-sensor solutions beyond the capability of the stand-alone rail marketplace
BACKGROUND: THE HELMET PROJECT

High Integrity EGNSS Layer for Multimodal Eco-friendly Transportation

Co-funded by the Horizon H2020 Programme of the European Union

- **UNIFIED MULTI-MODAL AUGMENTATION** and **INTEGRITY MONITORING PLATFORM** supporting High Integrity, High Accuracy Positioning services for Rail, Roads and UAVs, exploiting synergies among them
- **SAFETY** framework for **ROAD** vehicles harmonized with avionics and railways best practices
- **HELMET MULTISENSOR** On Board Unit with advanced Integrity Monitoring Capabilities
- **TIGHTER INTEGRITY BOUNDS** incorporating (Statistical) Knowledge about LOCAL HAZARDS as part of the augmentation data
- **EXPLOITATION** of **EGNSS DIFFERENTIATORS** to fight back against common hazards in land-mobile scenarios
- Contribution to the standardization activities (RTCM SC 134)
RAILWAY REQUIREMENTS (ERTMS/ETCS)

- ERTMS/ETCS only uses relative positions in relation to (physical/virtual) balise groups placed in the track.
- Longitudinal position error is safety-related but not safety-critical, because margins are added by supervision functions.
- Large margins, however, may impact performance and capacity, as trains could stop or reduce speed too early.

### Use case

<table>
<thead>
<tr>
<th>Use case</th>
<th>Integrity</th>
<th>Accuracy (95%)</th>
<th>Alert Limit</th>
<th>Time to alert</th>
<th>Availability</th>
<th>Security</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odometry Calibration (virtual balise)</td>
<td>&lt; 1e-9/h</td>
<td>0.70 m</td>
<td>1.7 m</td>
<td>&lt; 1 s</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>Cold Movement Detection</td>
<td>&lt; 1e-9/h</td>
<td>2 m</td>
<td>5 m</td>
<td>&lt; 10 s</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>Track Identification</td>
<td>&lt; 1e-9/h</td>
<td>0.70 m</td>
<td>1.7 m</td>
<td>10 s – 30 s</td>
<td>High</td>
<td>Very High</td>
</tr>
</tbody>
</table>

### Additional Requirements

**Train orientation with respect to track**
No specific performance and safety requirements have been specified for the train orientation.
It can be assumed that they are similar to the track selectivity requirements.

**Direction of train movement along the track**
No specific performance and safety requirements have been specified for the train direction of movement.
It can be assumed that they are similar to the track selectivity requirements.

**Missing a balise**
ERTMS/ETCS currently specifies a failure rate for a balise information point to become undetectable equal to $10^{-9}$ dangerous failures/hour, while the failure rate of the on-board to be able to detect the transmission of an information point equal to $10^{-7}$ dangerous failures/hour.

**Erroneous reporting of a balise**
According to Subset-036, Section 4.4.4, the balise reader should not erroneously report the detection of a balise more than $10^{-3}$ times/hr.
AUTOMOTIVE REQUIREMENTS

Longitudinal Alert Limit is mainly related to the longitudinal vehicle control.

Lateral Alert Limit is essentially determined by:
- Vehicle side clearance, minimum passage distance, precision docking
- Cross-coupling between longitudinal and lateral accuracy increases as far as lane width and/or curvature decrease.

Altitude accuracy requirements depend on the distance between overlapping lanes.

In addition to position and velocity, Attitude is required.

### ELECTRONIC HORIZON

**Vehicles and Road users**
- Position, speed
- Acceleration
- Direction (heading)
- Yaw rate

**Static obstacles**
- Position

**Infrastructure**
- High Accuracy Digital map

**From other sources**
- Traffic
- Weather information

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Integrity</th>
<th>Accuracy 95%</th>
<th>Alert Limit</th>
<th>Time to Alert</th>
<th>Availability</th>
<th>Continuity</th>
<th>Security</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated Driving on Highway</td>
<td>&lt;1e-6/h</td>
<td>0.27 m</td>
<td>4.50 m</td>
<td>0.5°</td>
<td>0.67 m</td>
<td>11 m</td>
<td>1.5°</td>
</tr>
<tr>
<td>Automated Driving on Local Roads</td>
<td>&lt;1e-6/h</td>
<td>0.17 m</td>
<td>0.40 m</td>
<td>0.5°</td>
<td>0.42 m</td>
<td>1 m</td>
<td>1.5°</td>
</tr>
<tr>
<td>Automated Driving on Narrow and Winding Roads</td>
<td>&lt;1e-6/h</td>
<td>0.07 m</td>
<td>0.11 m</td>
<td>0.5°</td>
<td>0.17 m</td>
<td>0.30 m</td>
<td>1.5°</td>
</tr>
<tr>
<td>Service Id</td>
<td>Description</td>
<td>Achievable Accuracy (95%*)</td>
<td>Integrity</td>
<td>Time To Alert</td>
<td>Availability</td>
<td>Application</td>
<td></td>
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<tr>
<td>SL 1</td>
<td>GNSS Single/Multi-Constellation Single-Frequency DGNSS /GBAS like, SBAS</td>
<td>2 m AT</td>
<td>THR &lt; 1e-6/hr&lt;br&gt;THR &lt; 1e-9/hr&lt;br&gt;AL &lt; 5 m</td>
<td>TTA &lt; 10 s</td>
<td>High</td>
<td>RAIL Cold Movement Detection</td>
<td></td>
</tr>
<tr>
<td>SL 2</td>
<td>GNSS Multi-Constellation Single/Multi-Frequency RTK Float + GBAS (Galileo HAS****)</td>
<td>&lt; 0.6 m AT/CT</td>
<td>THR &lt; 1e-6/hr&lt;br&gt;THR &lt; 1e-9/hr&lt;br&gt;AL &lt; 1.8 m&lt;br&gt;AL &lt; 1.7 m</td>
<td>TTA &lt; 10 s&lt;br&gt;TTA &lt; 1 s***</td>
<td>High</td>
<td>RAIL Track Identification &amp; Odometer Calibration</td>
<td></td>
</tr>
<tr>
<td>SL 3</td>
<td>GNSS Multi-Constellation Multi-Frequency RTK Fixed/Float + NRTK (Galileo HAS****)</td>
<td>&lt; 50 cm AT&lt;br&gt; &lt; 35 cm CT</td>
<td>THR &lt; 1e-5/hr&lt;br&gt;THR &lt; 1e-8/hr&lt;br&gt;AL &lt; 75 cm&lt;br&gt;AL &lt; 1.4 m</td>
<td>TTA &lt; 1 s</td>
<td>High</td>
<td>AUTOMOTIVE Autonomous driving on highway</td>
<td></td>
</tr>
<tr>
<td>SL 4</td>
<td>GNSS Multi-Constellation Multi-Frequency RTK Fixed + NRTK + IMU + other sensors (odometer, camera, LIDAR)</td>
<td>&lt; 25 cm AT (LR)&lt;br&gt; &lt; 20 cm CT (LR)&lt;br&gt; &lt; 10 cm AT (NCR)&lt;br&gt; &lt; 10 cm CT (NCR)**</td>
<td>THR &lt; 1e-5/hr&lt;br&gt;THR &lt; 1e-8/hr&lt;br&gt;AL &lt; 45 cm&lt;br&gt;AL &lt; 65 cm&lt;br&gt;AL &lt; 20 cm&lt;br&gt;AL &lt; 30 cm</td>
<td>TTA &lt; 1 s</td>
<td>High</td>
<td>AUTOMOTIVE Autonomous driving on local roads (LR) &amp; Autonomous driving on narrow and curved roads (NCR)</td>
<td></td>
</tr>
</tbody>
</table>

*: accuracy 95% for AT (along-track or longitudinal) and CT (cross-track or lateral)

**: LR stands for Local Roads scenario, NCR stands for Narrow & Curved Roads scenario

***: TI stands for Track Identification scenario, OC stands for Odometer Calibration scenario

****: Currently Galileo HAS is not available and GNSS receivers are not able to decode and apply relevant correction; it is anyway assumed that when available, such Service Level can be met through Galileo HAS if convergence time is suitable
On June 2018 RTCM (Radio Technical Commission for Maritime Services), the international organisation working for decades into the field of High Accuracy GNSS System standardization, founded a new Committee SC-134 entitled “Integrity for High Accuracy GNSS-Based Applications”.

The main scope of this Committee is to study and develop standards for emerging applications needing both High Integrity and High Accuracy navigation.

Four Working Groups have been created for this scope:
- WG 1: Automotive
- WG 2: Rail
- WG 3: Maritime and Other Applications
- WG 4: Harmonization of Requirements and Metrics.

In this work, RTCM includes the relevant heritage coming from RTCM SC-104 standards on Differential GNSS that define the standards and protocols currently used for Real-Time Kinematic (RTK), Network RTK, and Precise Point Positioning (PPP) system developments.

The intention of the Committee is, starting from a completed critical detailed review of relevant Requirements, Standards and Safety Analysis for each application domain, to proceed with the definition of relevant Augmentation Messages for High Accuracy and High Integrity System implementations.

Safety concepts and metrics (e.g. tolerable hazard rate [THR] vs. aviation integrity risk [Pr(MI)]) are integrated into the WGs work for meeting Transport Requirements.

In order to guarantee backward compatibility with historical developments in the High Accuracy application sector, SC-134 Augmentation Messages will be integrated within the long-standing and consolidated RTCM SC-104 message format structure and protocol – i.e., Networked Transport of RTCM via Internet Protocol (NTRIP).
Rail and Road On Board GNSS receivers are prone to:

- **GLOBAL HAZARDS**: error sources with sufficiently high spatial correlation that Augmentation Techniques are effective
  - Ephemeris and satellite clock errors, Ionospheric and tropospheric delays, Inter-frequency biases, wind-up effects, solid tides, ...

- **LOCAL HAZARDS**: error sources with very low spatial correlation like shadowing, multipath, and RF interference
  - For these, HELMET provides a statistical, space varying, description of their behavior
### Features

- Augmentation messages (e.g. Reference stations raw data for RTK, precise orbit and SVs clock corrections)
- Integrity parameters coordinated with specific user applications
- Use of EGNOS, Minimum and Extended Integrity Messages (e.g. Satellite, Constellation and Reference Station Health Status flags, following 2-Tiers approach and RTCM SC-134 draft proposals) to provide integrity functions.
- Certifiability with respect to CENELEC norms.
- Use of a private, secure, and high QoS communication network to connect the local network.
- Processing of advanced corrections algorithms and standard corrections data formats (RTCM SC-134 Extended messages and overbounding parameters)
Features
- Multiple service classes: DGNSS, RTK, NRTK, PPP, SSR
- On-demand services: Possibility to switch among services on the fly
- I/F compliance to international standards for High Accuracy, High Integrity

RTCM Messages (SC-104, SC-134,...)
NMEA GGA Pressure, humidity, temperature

Communications Front-End
DGNSS/RTK/NRTK/SSR Implementation Message Calculation & Formatting
ZTD Cadastrial RP
Ancillary Data
Cadastral Reference Points

Reference Station Operating Center
Reference Station Data Gateway (NTRIP Client)
SIS & RS Fault Detection & Exclusion
Reference Framework Definition

GNSS AUGMENTATION (1st Tier)
SBAS Ground Services
GPS & GALILEO Ground Services
The HELMET On Board Unit reference architecture has been designed to meet today’s requirements (e.g., Virtual Balise support) but with enough growth capability to support future needs (e.g., Enhanced Odometry as well as full integration of hybrid navigation solutions into fully Automated Vehicle Control).

GNSS + IMU + Mechanical Odometer + Video + Lidar + … are processed by the navigation subsystem along with the data provided by the augmentation network.

The integrity monitoring procedure excludes faulty measurements, estimates Protection Levels, and ensures integrity for each application.

A communication subsystem (e.g. FRMCS) ensures secure interaction between the ground segment and the on-board unit.
To emulate realistic GNSS-based train positioning that exploits a track constraint by using a road vehicle, a track digital map has been built by integrating a digital map with lane centerlines obtained by RTK post processing of GNSS data acquired by a vehicle equipped with lane keeping and imaging recording facilities.

**Scheduling of activities**

- First acquisition campaign for trackDB creation (April 7)
- Second acquisition campaign for post processing analysis on the PVT calculated by the OBU (April 12)
- Field test campaign for real-time processing of GNSS data + Sogei augmentation (April 12)

During the tests, environmental data from on-board cameras were collected for in-depth post processing analysis.
EXPERIMENTAL SETUP

**TEST EQUIPMENT**

**Mobile Unit**: GNSS receiver (Multi-Frequency GPS + GALILEO) + cameras (GoPro + 360°)

**RTK Network** (for track DB generation): HxGN SmartNet

**AIMN Network** (real time): Sogei augmentation network.
EXPERIMENTAL RESULTS
HELMET combines multiple GNSS augmentation technologies to provide a coordinated solution for multiple user platforms and accuracy/integrity demands.

GNSS positioning with high integrity for land mobile applications is challenging compared to aviation:

- Liability mechanism (PNT vs Pseudorange)
- Liability sharing (between service provider and application system integrator)
- User interface: MOPS vs. SC-134 (certified receivers vs COTS)
- Coverage (regional vs global)

Existing and planned SBAS infrastructures are key to building robust GNSS service provisioning:

- HELMET 2-tier architecture for rail and connected car applications reusing SBAS:
- Multi-modal approach to address a larger customer base sharing similar requirements
- Different service levels – less-demanding ones are installed/tested/certified first
- Local augmentation is scalable and deployable as a function of user demand

Ongoing and future work

- Integrity validation by demonstration of comprehensive threat mitigation
- Development of certification plan and safety case for appropriate authorities
Backup slides follow...
ASSUMPTIONS:

- Use EGNOS V2 (V3 when available) and build on top of it a local augmentation system
- Costs to deploy local elements shared between rail and roads infrastructure owners
- Service provider to sell Au data to Infrastructure managers who will broadcast to trains and cars
- Service provider funded at 100% (as for aviation) or at 50% are viable options to avoid direct public investment

Cost and revenue for a service provisioning including OBU – funding 100% of investment

Cost and revenue for an augmentation service – funding 50% of investment