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GRAIL-2: Enhanced Odometry based on GNSS

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Abstract

Following the introduction of the Satellite Navigation technology (GNSS) in the railway domain started with past European initiatives, the objective of GRAIL-2 is to define, develop and validate a GNSS application in high-speed railway lines, focusing at a concrete market and aiming at offering a product close to the customers within the European Rail Traffic Management System framework (ERTMS) paradigm. The proposed system is based on Enhanced Odometry. In the frame of the 7th Framework Programme, 2nd Call, the GRAIL-2 consortium has been granted with European funds to start rolling out the strategy, defined in the precedent project, GRAIL, for a smooth integration of GNSS into control and command applications and particularly within the European Train Control Systems (ETCS) framework. The GRAIL-2 Consortium is composed of 10 participants from 8 EC countries.
A prototype has been developed and it will be tested to demonstrate the concept in a real environment. Details on the concept, activities performed and first results are presented in this paper.
The GRAIL-2 project is managed by the European GNSS Agency (GSA) in the name of the European Commission.

Keywords: GNSS; odometry; ERTMS; ETCS.

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1. Introduction

The European Rail Traffic Management System (ERTMS) is an initiative backed by the European Union to enhance cross-border interoperability and signalling procurement by creating a single European-wide standard for train control and command systems. The two main components of ERTMS are the European Train Control System (ETCS), a standard for onboard train control, and GSM-R, the GSM mobile communications standard for railway operations. In this framework, there have been several initiatives to introduce the mature, but still underexploited, technology of Satellite Navigation (GNSS) in rail applications throughout Europe.

The introduction of GNSS in the railway domain in Europe, despite the established technological basis, has followed different paths. This has prevented from using a common approach that allows interoperability of the technical solutions at different system levels in similar applications, and the reusability of products for different purposes; a common approach would let actual compatibility and low cost figures in the deployment of GNSS on railroads. The GRAIL project (GNSS introduction in the Rail sector) proposed a strategy, consistent with the current deployment process of ERTMS/ETCS in Europe, for a smooth integration of GNSS into control and command applications, and particularly in signalling. As a sequel of this project, the current GRAIL-2 project focuses in one of these applications, ‘enhanced odometry’ in the scope of high-speed railway lines, to get to a final product close to the market.

The aim of the GNSS ‘enhanced odometry’ subsystem is to support the odometry function (speed measurement) with accurate location information. This subsystem aims at replacing conventional sensors such as Doppler radars, which have shown to cause some operational problems under some conditions and whose maintenance costs are high, enabling at the same time a cost-effective way to implement this function and paving the way for the introduction of other ERTMS functions which may rely also on the GNSS signals.

In this paper, the GRAIL-2 project, a 7th Framework Programme (FP7) initiative, will be presented, highlighting the progress in the development and the envisaged plan to carry out the remaining project activities.

Nomenclature

<table>
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<tr>
<th>Acronym</th>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<tr>
<td>Enhanced Odometry</td>
<td>Odometry is the use of data from moving sensors to estimate change in position over time. The ‘enhanced odometry’ concept refers in this paper to the use of sensors based on novel technologies, such as GNSS, in the estimation of train speed.</td>
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<tr>
<td>ERTMS</td>
<td>European Rail Traffic Management System</td>
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<td>ETCS</td>
<td>European Traffic Control System</td>
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<td>FP</td>
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<td>GSM-R</td>
<td>Global System for Mobile Communications - Railway</td>
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<td>OBU</td>
<td>On-board Unit</td>
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<td>UT</td>
<td>User Terminal</td>
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2. Project description

2.1. Motivation of GRAIL-2

Current odometry systems rely on on-board sensors, such as Doppler radars, tachometers or inertial units and trackside equipment (balises). Maintenance of the trackside equipment is expensive, which induces the search of alternatives. Furthermore, under-performance of the Doppler radar-based odometry is common on slab track or in winter conditions (snow on the track); this fact could have safety implications, as an under-estimation of the train speed could be a significant hazard in the event of emergency braking of the train. In a less extreme scenario, these under-performance events could originate major delays in passenger services, leading to significant commercial losses for the train operator.

With this scenario in mind, and taking into account that GNSS is an inexpensive means to achieve good positioning performances, use of this technology in the railway domain is an ongoing trend, in particular in odometry applications. However, GNSS alone cannot achieve the stringent performances needed to assure the required safety levels in passenger or cargo rail transport: obscuration, loss of sight of the satellites (during transit of tunnels or trenches), multipath and interference are local effects which must be overcome by means of other techniques.

2.2. Satellite navigation systems

The project will prove, in a particular case, the benefits of the introduction of GNSS, especially EGNOS, in the railway environment.

The core GNSS constellation to be used is the American GPS. GPS consists currently of 31 satellites which provide an equipped user with accurate positioning and time information, in all-weather conditions and at any point in the Earth with unobstructed view of a sufficient number of ranging sources. This system is being extensively used in many applications all over the world: road, aviation, agriculture, leisure, etc.

EGNOS, the European ‘satellite-based augmentation system’, supplements the capabilities of GPS in terrestrial, maritime and aviation applications with built-in features that ensure better accuracy and guarantee of service, which enhances safety.

EGNOS is the precursor of Galileo, the European core GNSS constellation. Galileo will be composed of 30 satellites in its final configuration and will be fully operative by this decade’s end. It will provide enhanced navigation capabilities with respect to GPS, managed independently from Europe and under civilian control. In practice, GPS and Galileo will be used together by the users; this joint use would enable services that are currently unavailable at some places, due to the lack of enough visible satellites from a single constellation.

In railways, the benefits that GNSS bring include specifically:

- Enhancement of existing safety-relevant systems, e.g. odometry units.
- Cost-effective railway traffic management.
- Access to enhanced functionalities related to absolute positioning.
• Rationalisation of signalling equipment costs.
• Savings in insurance expenses.
• Less CO$_2$ emissions due to a more efficient traffic management.

2.3. The European Rail Traffic Management System

The European Rail Traffic Management System (ERTMS) initiative aims to provide a new generation of train control and signalling capabilities (ETCS- European Train Control System), which includes automatic train protection by continuously supervising train speed and braking. As a complement of the ETCS, ERTMS uses the GSM-R radio system standard for signalling data transmission.

The ERTMS technology has different levels of capacity and performance:

• Level 0 is when an ETCS vehicle is used on a non-ETCS route. The trainborne equipment computes the maximum train speed and the train driver must monitor the trackside signals.
• In Level 1, ‘Eurobalise’ radio beacons transmit trackside signals as a movement authority to the trainborne equipment. There, the maximum speed and braking curve are obtained and automatic train protection is ensured with these data.
• In Level 2, it is possible to remove trackside equipment, as the trains automatically report, on a regular basis, their navigation data to a Radio Block Centre, which transmits back the next movement authority.

ERTMS will intervene if the train over-speeds, to bring it back to safe levels. The system stops a train safely to prevent it from exceeding its movement authority. Precise knowledge of the train speed, thus, is a central topic in the ERTMS developments.

2.4. Scope of GRAIL-2

In GRAIL-2, a prototype of GNSS ‘user terminal’ (UT) will be integrated together with a piece of ETCS equipment (EuroCab or ‘on-board unit’ –‘OBU’) in such a way that the determination of speed (odometry function) is supported by the satellite navigation technology. The interface between both the user terminal and the on-board unit has been developed according to a standard agreed previously by different railway stakeholders in the FP6 ‘GRAIL’ project. Specifically, the Profibus standard is being used, which has been widely adopted in other ERTMS applications.

The particular scenario to which the GRAIL-2 enhanced odometry function is being applied is the case of high-speed lines. In such a scenario, requirements against local effects are even more demanding, so it is a must to duly characterise the railway environment, to cope with the limitations imposed by the terrain and to assure adequate service levels to the odometry macro-function. Therefore, an activity to measure the levels of multipath, interference and other effects has been launched within the project, whose results are being used to fine-tune the user terminal algorithms.

Prior to the development of the equipment, a set of user and system requirements have been identified and reviewed by different railway stakeholders. Based upon this requirement baseline and the experience gathered in previous projects, a development process has been carried out, on both the UT and OBU sides, to build a prototype as close as possible to the industrialisation phase.
In parallel, comprehensive safety studies are being performed, whose goal within GRAIL-2 is to demonstrate that the safety requirements for the application can be fulfilled, according to current rail standards and procedures. First, it was analysed if the original development concept would meet the safety requirements imposed on the odometry functionality. Then, a second iteration was performed to assess what parts of the design should be revised so that the adequate level of safety is reached for the application. Finally, in parallel to the collection of evidences for the completion of the application safety case, an independent safety analysis started, with the aim of ensuring the correct use of the methodology set out by European norms to demonstrate safety.

The developed prototype will be tested, first in factory and then in a live environment (high-speed line and train), and the results will be compared against the identified requirements. A demonstration campaign is also scheduled to show, in real time, the benefits of this kind of technology to key stakeholders.

In addition to these technical activities, a work package is devoted to devise a certification roadmap, to establish the activities and measurements needed towards the implementation of the GRAIL-2 application in high-speed lines, demonstrating the feasibility of GRAIL-2 prototype to become a commercial product in a short-medium term. Finally, dissemination activities have been planned to raise awareness on the benefits of GNSS in the rail domain, and specifically to present the outcomes of this project. One of these activities has consisted of the design and launch of a project website (see the References section).

2.5. The GRAIL-2 Consortium

To carry out the project activities, a Consortium has been set up, composed of 9 participants from 8 countries (Belgium, the Czech Republic, France, Germany, Italy, Portugal, Spain and the United Kingdom). This consortium is the result of a thorough selection process from European organisations based on their skills and engagement in innovative applications in the railway sector or in the Galileo Programme. The most appropriate experts in each participating organisation have been involved, therefore the key expertise fields for this type of project are fully covered (rail signalling, GNSS and information technologies, consultants and railway infrastructure managers). The involved companies in the GRAIL-2 project are the following:

- Ineco (ES): Consultancy firm, acting as project coordinator and in charge of the requirements, safety, certification and dissemination work packages.
- Ansaldo STS (FR): Signalling systems company, in charge of the OBU development and the validation work package
- Thales Alenia Space – Italy (IT): Space systems developers, responsible for the UT subsystem.
- ADIF (ES): Infrastructure manager, participating in the critical review of the outputs.
- NSL (UK): Application developers, in charge of the environment characterisation campaign.
- Alstom (BE): Signalling systems company, participating in the critical review of outputs and the validation.
- iQST (D): Quality, safety and transport consultancy firm, in charge of analogous tasks within the project.
- REFER (PT): Infrastructure manager, participating in the critical review of the outputs.
The GRAIL-2 project is managed by the European GNSS Agency (GSA) in the name of the European Commission. This project runs under a grant agreement within the 7th Framework Programme of the European Union, and is expected to end in the first quarter of 2013.

3. The GRAIL-2 prototype

Based on an existing development made in GRAIL, the core activities of the GRAIL-2 sequel consist of making the necessary evolutions in such a prototype so that a resulting odometry function is as much as possible consistent with the safety requirements imposed on a commercial system of these characteristics. These requirements can be grouped in a single requirement: a Safety Integrity Level of four (SIL-4), which means that a systematic failure in the full function, originating fatal consequences, must have a probability less than $10^{-8}$ per hour.

The first safety iteration in the project consisted of analysing the SIL level achievable by the GNSS User Terminal (which included an inertial unit), legacy from GRAIL. As the SIL level of the outputs that such sensor would inject to the OBU resulted not to be SIL-4, the original aim of replacing all conventional sensor types by the UT alone was abandoned and a more pragmatic approach was decided: the odometer architecture would retain some conventional sensors, but remove the Doppler radars, whose maintenance costs and some reported availability problems were the first motivation for choosing this application.

Therefore, a second safety iteration was launched with the architecture which was to be replicated in the commercial product (see Fig. 1).

Fig. 1. Schematic diagram for the GRAIL-2 prototype.
Fig. 2. Simplified diagram showing the architecture of the GRAIL-2 User Terminal.

There will be product elements in the industrialisation phase which are missing in the prototype, and the same for the safety processes performed in the project. For instance, the setting up of an independent safety team in charge of the analysis and the execution of a thorough validation phase to achieve certification. In any case, all missing elements are being identified so that resuming the activities would be straightforward.

The User Terminal architecture consists of a GNSS front-end, an inertial measurement unit (IMU), a data-fusion element and the GIRASOLE algorithmic modules in charge of the provision of the position, velocity and time data feeding the Eurocab (see Fig. 2).

EGNOS navigation is being obtained from this unit, hybridised with the inertial inputs coming from the IMU. For the adequate characterisation of these inputs, a number of tests have been scheduled with the IMU installed in the train, providing parameters of the train dynamics (e.g. vibration) which would otherwise impact the accuracy of the navigation solution. The sense of having an inertial unit along with the GNSS sensor consists, roughly, of complementing the zones lacking satellite output (for instance, during tunnel transits) with the coasting solution provided from past, well-estimated positions in the track. Two bi-frequency antennas were installed on the train roof, well apart one another, to capture the GNSS signal and also determine the train direction.

Fig. 3. ‘SENCA’ test train, used to carry out the environment and IMU characterisation campaigns, and planned to be employed in the GRAIL-2 validation tests.
Another input to the UT algorithms is the set of parameters which characterise the signal environment. As mentioned above, a data acquisition campaign was scheduled, to capture as much measurements as possible in order to describe, in the target line, the signal quality and its noise and multipath contributions. A study was planned for tracing the retrieved data to the different environment scenarios along the track (open air, foliage, trenches, urban, etc) and for getting useful statistics. For that purpose, a receiver + data logger module (the TITAN unit) built by NSL was installed in the test train ‘SENECA’ from Adif (see Fig. 3), which was the same train to be used for the inertial characterisation campaign and the prototype validation tests. Data has been regularly recorded, mostly in the target Valencia-Madrid line, but also in other sections of the Spanish rail infrastructure where the train was needed to perform other kind of tests. The installation layout was made in such a way that the antenna used by the TITAN unit was shared by the UT equipment.

All the GNSS-related equipment, apart from the antennas, is fitted in a 19’ rack in the SENECA train. The User Terminal is connected via a Profibus interface with the ERTMS equipment (which is installed in the locomotive), as Fig. 4 shows.

![Diagram of the equipment layout](image)

Fig. 4. Distribution of the equipment in the test train.

### 4. Next steps

After the laboratory tests of the prototype, next step will be the thorough validation, in real conditions, of the equipment onboard the target train. The objective of the tests is not only to verify that the function performs well, but also to provide the sufficient evidences in the safety case of the application to determine that the function can be validated according to the applicable requirements.

Preparation of certification activities is another important task to be carried out in the project. As displayed repeatedly by key railway actors, certification is a must for safety-critical applications to reach the market. However, a set of appropriate standards must be defined first and the roles and responsibilities of the certification bodies must be clear. A certification roadmap will be conceived for this specific application, paving the way for the certification of a future GNSS-enabled odometry commercial product and other GNSS applications.

Besides, a live demonstration is planned to be done, along with a users’ workshop, to close the project. This demonstration is aimed at showing on-site, and in real time, the benefits of this solution to the railway community. The organisation of both test campaign and workshop must be carefully planned so that, on one hand, no flaws can be left for the demonstration, and, on the other hand, all relevant stakeholders are represented.
5. Conclusion

The GRAIL-2 project aims at demonstrating the benefits of GNSS technologies in the railway domain, focusing on a particular application, ‘enhanced odometry’ for high-speed lines. Challenges for this technology are significant (terrain, multipath), but the economical and, remarkably, safety benefits are expected to be high.

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References

GRAIL-2 website: http://grail2.ineco.es