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GNSS-based performance and Railway operating rules

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Abstract. Railway environment produces local effects for GNSS use for train localisation. This technological context is discussed with regard to the state of the art. Then, the daily management of disturbances and parametric variation by railway driver is shortly presented in order to share a vision concerning the potential industrial use of the considered technology.

Keywords: Operating rules; railway safety, localisation, GNSS

1 Introduction

GNSS (Global Navigation Satellite System) is now identified as a realistic and serious game changer for the future of the ERTMS (European Rail Traffic Management System). But the the environmental conditions of track and surroundings configuration, i.e, tunnels, dense urban areas or vegetation. often degrade positioning performance and thus its efficiency and safety. For its part, an experimented driver will extract from environmental conditions some predictions to adapt its driver's behaviour. This knowledge is part of the driver skills. As an example, after the theoretical training, the French process of a new driver's qualification ends with a supervised period with an experimented driver who advises the young driver. The experimented driver has the responsibility to decide when the young one is able to operate on the line, when he is efficient enough and when he acquired the needed specific knowledge of the line.

In this context, we investigate how the use of a GNSS-based train positioning device can be integrated in the global needed knowledge of a specific line. If the on-board GNSS is used to eliminate track devices, GNSS information becomes safety critical. But if tailored actions can preserve the global safety, these actions just have to be added to the set of needed knowledge. This paper discusses how the variable positioning performance knowledge can be integrated into an efficient operational railway system as a whole.

2 GNSS-based localisation in a railway environment

All GNSS users have already experienced loss of accuracy or availability when travelling in dense urban cities or inside tunnels. This will also be the case for

a GNSS-based train locator. Indeed GNSS-based positioning solutions can be seriously impacted by the track surroundings as they can generate multi-path, NLOS (Non-Line-Of-Sight) and interferences inducing inaccuracy, unavailability and lack of integrity.

2.1 GNSS principles in presence of local effects

Satellite-based positioning techniques rely on Time-Of-Arrival measurements. Each of the worldwide GNSS constellations (GPS, Galileo, GLONASS and BeiDou) are composed of non-geostationary satellites that broadcast continuous signals, that are received, decoded and used by the receiver to estimate their propagation time. These times multiplied by the speed of the signal (i.e., the speed of light for GNSS) will represent the emitter-to-receiver distances, called pseudo-ranges. The reception of n (at least four) satellites will allow the receiver to benefit of n observations to solve the system of n equations where the unknowns are $(x,y,z,\delta t)$; (x,y,z) being the antenna position and δt the clock bias coming from the user and satellite clock offsets. The system resolution is classically performed with a Least Square (LS) estimator or a Kalman Filter. The different GNSS can be used independently and with interoperability but whatever the constellation used, their positioning performances are strongly related to measurement accuracy, as well as to the satellite distribution around the reception antenna. The straighter the path of the signal between the satellite and the receiver is, the more accurate will be the satellite-receiver distance estimation. Unfortunately, for land transportation users, measuring the propagation time of the direct signal can be a challenge because of obstacles that can reflect or block satellite signal reception and then degrade the measurement accuracy. These local effects are called multi-path and non-line of sight (NLOS). Multi-path refers to the phenomenon that a signal reaches the receiver after reflections or diffractions that are combined with the Line-Of-Sight (LOS) signal. Each received path is called an echo. Its delay and phase depends on the surface characteristics and geometry of the scene. Multi-path will distort the shape of the correlation used by the receiver to extract the pseudo-range information. Its impact on the position will depend on the distortion of the correlation. The NLOS label is used when the direct signal cannot be received because of the presence of a masking obstacle. Then, the correlation output is always characterised by a delay on the pseudo-range estimation caused by the absence of the direct path that will induce positioning error in the estimation step. These phenomena can vary very quickly along the train path depending on the its speed and on the topology of the track.

2.2 State of the art of GNSS-based solution for rail

When addressing safety-critical applications, GNSS-based solutions must prove their performances in terms of availability, accuracy and integrity and their compatibility with RAMS [1]. Integrity, in the GNSS domain, is defined as the measure of trust that can be placed in the correctness of the information supplied

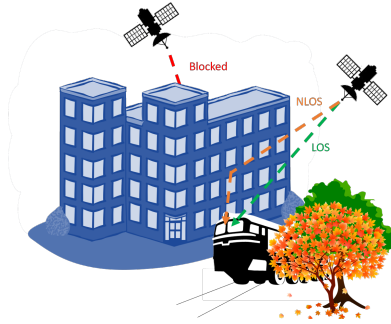


Fig. 1. Environment impact on GNSS signal reception

by a navigation system. It includes the ability of the system to provide timely warnings to users when some system anomaly results in unacceptable navigation accuracy.

The on-going developments of GNSS-based localisation units anticipate the consequences of these harsh conditions of reception and will rely on a series of barriers aiming to prevent or mitigate them when possible. A first objective is to develop a solution that will reach the railway requirements in terms of accuracy and availability. Most promising solutions will rely on hybrid solution embedding GNSS and an IMU (Inertial Measurement Unit) [2] at least, completed with fault detection and exclusion (FDE) processes [3]. But some residual or unexpected errors will remain. The FDE is developed with some integrity monitoring concepts that intend to bound errors and avoid critical errors of the system. Some solutions are today in a development phase such as in the TRENI project [4] that intends to embed most of the latest technologies. Predictive studies may also help to anticipate dynamic losses of GNSS-based solution performance, that can be based on track characterization as proposed in [5] in the ERSAT-GGC project, multipath error mapping [6] or in a statistical basis as well as with training methods [7].

On the other hand, and independently, meteorological conditions are also environmental conditions impacting the train operation on the line. The presence of leaves on rails or snow on track for example will request the driver to modify the train speed and its driving behaviour.

3 GNSS integration and railway operating rules

3.1 Safety rules, principles

Scientific literature dealing with building and managing safety rules is not very extensive [8]. One of the most relevant contributions concerning the way of making rules is constituted by Hale's publication in 2003: "Management of safety rules: the use of railways" [9]. However, this publication itself mentions the few

existing works available in the literature of this area. A rule is based on collective knowledge to define safe behaviours and equipment and implement them [10]. If the knowledge is collective, it is then appropriate to collaborate with the different holders of a piece of this knowledge for building and validating a rule. Indeed, a rule is based on the perception and representation of the system of the rule maker. Therefore the matching between the system and its conceptual model is critical, assuming that a model is an abstraction of the real system. This abstraction is built using a specific point of view, allowing to skip many non-needed details [11].

3.2 Contextual actions

A security rule is a set of actions to be implemented to bring all operations to an acceptable level of security. Let us present it as a triple:

- a context of application (place, time, type of intervention, nature of agents),
- conditions and constraints validating the application of the rule,
- a list of actions to implement.

Rules can be built, based on preliminary risk analysis or based on gap analysis using a Common safety method comparing with a reference system (CSM-2, see [12]). Fundamentally, the idea is that it is not possible to wait for the occurrence of accidents to integrate them into a common knowledge: it must be therefore anticipated in order to avoid operating with a base of rules whose relevance is proven for a system which no longer exists [13]. There is therefore a need for a predictive approach [14]. This last consideration brings up a new challenge. Indeed, a declarative text naturally describes knowledge, but the predictive approach relies on logical or functional links whose textual representation is much more delicate. There is therefore a need to structure this knowledge since it must be interpreted to make a prediction.

3.3 Barriers and protections:

Let us consider two types of security rules:

- The first ones apply a measure intended to prevent the occurrence of an accident: this is the concept of the barrier.
- The second ones promote the non-occurrence of accidents (for example staff training), or reduce the severity (for example lower speed). This is a protection strategy.

Preventing hazard occurrences seem to be the most definitive strategy. However, building a barrier can be not achievable:

- preventing that infrastructure will disturb GNSS signal reception is not realistic,
- change of meteorological conditions are also environmental conditions impacting the train, but they can not be prevented.

Concerning the protection function, the latter being integrated into a general process aiming at achieving a satisfactory level of safety, it is sometimes triggered during a transient mode specific to a failure. The question is then: who will certify that changing the type of a rule does not degrade the overall security of the system. A general study at the highest level of responsibility is a satisfactory response from a functional point of view. Nevertheless, it is more efficient to only validate the subsystem that is directly impacted by the modification.

3.4 Driver operating rules

In the framework of the TCraill project [15], some expert drivers have been interviewed in order to check if the delay introduced by a remote operation may have a severe safety impact. As a matter of fact, train drivers daily managed with rain, smoggy weather, obscurity, leaf in autumns, etc.. Most of this common variations impacting safety do not appear in the driving reference book [16]. They are handled locally, as behavioural local adaptation on a given railway line. A driver must know his line, and this required knowledge includes anticipation of smog on a bridge over a river, leaf inducing sliding during Autumn, and probably future satellite disturbances at a given point of the infrastructure.

Let's consider braking performance as an example. Braking performances are completely modified when the rail is wet compared to nominal behaviour. It is then susceptible to evolve all along a run, as GNSS performance may do. We can then wonder if GNSS disturbances will impact driving conditions more than braking performance diversity that freight drivers manage everyday. For braking, the use of mathematical models of context-based disturbances allows to anticipate the evolution of the knowledge of the system. Inspired by such models, future investigations will then concern context-based models for GNSS performances to be integrated in the global system knowledge.

4 Conclusion and perspectives

This paper develops a pragmatic analysis of future GNSS exploitation challenges in future of railway signalling, integrating main railway environmental constraints and local effects producing GNSS disturbances. These considerations are explained and discussed with regard to the state of the art. In a second step, the daily management of disturbances and parametric variations by the railway driver are shortly presented to share a vision concerning the potential operational use of GNSS. Future work will discuss the level of management to be involved to manage future GNSS disturbances, regarding potential system impacts.

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