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### ► To cite this version:

David Bétaille, Miguel Ortiz, Gorka Velez, Oihana Otaegui. Paper ID EU-TP1411 : Standardization issues related to hybrid GNSS positioning. 25th ITS World Congress, ITS Asia-Pacific and ITS America and strongly supported by the European Commission, Sep 2018, Copenhagen, Denmark. hal-04486256

**HAL Id: hal-04486256**

**<https://univ-eiffel.hal.science/hal-04486256v1>**

Submitted on 1 Mar 2024

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Paper ID EU-TP1411

**Standardization issues related to hybrid GNSS positioning**

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**Abstract**

GNSS, for many very good reasons among which continuity, is hybridized for land positioning. Indeed, GNSS outages remain frequent in the core of modern cities, despite satellite multi-constellation inter-operating today. Urban positioning is known as a difficult problem, in which satellite measurements, if not occulted, suffer from multipath caused by the receiver local building environment. In Intelligent Transportation Systems and mobility in general, many solutions, applications, innovations rely on satellite positioning. Hybridization with inertial measurements, but also other proprioceptive sensors like odometer/podometer, as well as exteroceptive devices such as cameras, lidars, radars... enable advantages and drawbacks to complement each other leading to improved performances. In the automotive sector, where one's location as well as that of many surrounding objects (infrastructure, other vehicles, pedestrians...) is a key technical component, standardization efforts have been initiated. This article will give an overview of which standards have been produced so far in terms of positioning performance, and will outline the specific issues raised by the performance assessment of hybridized GNSS positioning devices.

**Keywords:**

Positioning, Standardization, Automotive sector, Hybrid GNSS

**Introduction**

Human drivers are constantly trying to know where they are driving so they can orient themselves and estimate the remaining time to destination. However, this is a very challenging task when you are not familiarised with the area where you are driving. The first attempt to overcome this, using modern technology, was the development of Portable Navigation Devices based on Global Navigation Satellite System (GNSS) technology. The main objective of these devices is to assist the driver, giving guidance. These devices can achieve road-level accuracy; however, this accuracy is degraded a lot in certain situations like in urban canyons or tunnels, and the GNSS signal can even get lost. The accuracy obtained with these pure GNSS devices is sufficient for the basic navigation applications but it is not enough for the next-generation applications, such as lane level positioning in Advanced Driver Assistance Systems (ADAS), hyper-specific location-based services and self-driving cars.

## Standardization issues related to hybrid GNSS positioning

The solution for this problem is the combination of a GNSS receiver with other sensors. By fusing the data received from the different sensors, one can enhance the positioning accuracy and make it more robust to environmental changes. In the automotive sector, sensors such as Inertial Measurements Units (IMUs), cameras and LiDAR are being studied for their combination with GNSS. Cameras are particularly appealing as they are cost effective and they can recognise objects or elements from the driving environment and use those as visual cues to enhance the positioning. For example, lane markings could be compared with the ones stored in a High Definition map to help locating the vehicle in a specific lane. In addition, Visual Odometry and Visual Simultaneous Localization And Mapping (Visual SLAM) are two well-known techniques in Computer Vision that can enhance the positioning estimation provided by the GNSS receiver and work well in situations where the GNSS signal is not reliable.

The hybridisation of GNSS with camera and IMU outputs is still a matter of research and most of the automotive products that target this are still on a prototype stage. The biggest challenges to increase the Technology Readiness Level and obtain a market-ready product based on such a hybrid approach are the validation and certification. This is particularly true in the Advanced Driver Assistance Systems sector, where usually, more time is spent in testing and validation than developing the algorithms [1]. The localisation systems based only on GNSS use a mature technology and the standardisation bodies have had much more time to address the corresponding certification issues. Each sensor has its own testing limitations and distinctive features that need to be considered. The validation and certification of a hybrid positioning system is therefore a much more complex task and standardization plays an important role here.

The objective of this article is to review the current standards that deal with positioning performance and highlight the specific issues raised by the performance assessment of hybridized GNSS positioning devices.

This article is organized as follows:

- First summarize the initiatives related to the standardization activities in GNSS-based positioning for ITS, which are currently undergoing by several SDOs in Europe with CEN, ETSI and in the world with ISO;
- Second deliver a state of the art related to field, lab and “record and replay” tests for GNSS only;
- Third address which problems are specifically raised by IMU and perception in hybrid systems for their performance testing.

### Status of the standardization activity

Standardization activities are currently on-going at CEN, ETSI and ISO in the field of GNSS-based land positioning. No standard exists for land domain so far, actually only for civil aviation. For that purpose, the SaPPART COST action, 2013-2017, Satellite Positioning Performance Assessment for Road Transport [2], initiated and conducted studies about performance assessment methodology.

*From CEN*

Standardization about GNSS-based Positioning Terminal (GBPT) is addressed by CEN/CENELEC Technical Committee 5 “Space” Working Group 1 (TC5-WG1). CEN-TC5-WG1 is working on EN16803 that is named “Use of GNSS-based positioning for road Intelligent Transport Systems (ITS)”. In this field, 3 different parts have been defined:

- Part 1: Definitions and system engineering procedures for the establishment and assessment of performances [3];
- Part 2: Assessment field tests for basic performances of GNSS-based positioning terminals;
- Part 3: Assessment field tests for security performances of GNSS-based positioning terminals.

**Table 1: CEN-TC5-WG1 roadmap for EN16803**

Ref	Title of CEN/CENELEC deliverables	Start Date	Draft	Standard
WI1	<b>Revision of EN 16803-1 / Part 1: Definitions and system engineering procedures for the establishment and assessment of performances.</b>	<b>2017-09-06</b>	<b>2018-10-15</b>	<b>2020-02-28</b>
WI2	TR1 : Metrics and performance levels detailed definition / Field tests definition for basic performances	Mid 2018	End 2018	End 2019
WI3	TR2 : Error models development	Mid 2018	End 2018	End 2019
WI4	<b>EN 16803-2 / Part 2: Assessment of basic performances of GNSS-based positioning terminals</b>	<b>2017-03-06</b>	<b>2018-04-15</b>	<b>2019-08-29</b>
WI5	TR3 : Security attacks definition	Mid 2018	End 2018	End 2019
WI6	TR4 : Test procedures for assessment of robustness to security attacks	Mid 2018	End 2018	End 2019
WI7	<b>EN 16803-3 / Part 3: Assessment of security performances of GNSS-based positioning terminals</b>	<b>2017-03-06</b>	<b>2018-04-15</b>	<b>2019-08-29</b>
WI8	<b>EN 16803-4 / Part 4: Definitions and system engineering procedures for record and replay design and validation (TBC)</b>	<b>TBD</b>	<b>TBD</b>	<b>TBD</b>

## Standardization issues related to hybrid GNSS positioning

As described in Table 1, 4 Technical Reports (TRs) are also under preparation, on the key technical topics that are necessary to investigate for the drafting of the ENs themselves. These TRs will be provided by a specific project called GP-START, funded by EC through CEN. 2 TRs have been released for EN16803-2 and 2 others for EN16803-3. A new part, Part 4, dedicated to Record&Replay, is still to be confirmed and defined.

The strategy adopted by CEN is to cover all the metrics assessment by field test or Record&Replay tests. The domain addressed by the CEN norms is Road ITS. Four families of performance features have been identified:

- Accuracy: refers to position error, velocity error or speed error
- Integrity: refers to protection level and its associated integrity risk
- Availability: refers to the percentage of time during which the output of the dut is available
- Timing: refers to timestamp resolution, output latency and Time To first Fix.

Most of these families could be broke down into several components: 3D, Horizontal, East, North, Along track, Cross track, Vertical (ie Horizontal Position Accuracy, or North Position Protected Level). The metrics proposed by CEN to assess these performance features, are 3 key values of the cumulative distribution function (CDF): 50%, 75% and 95%.

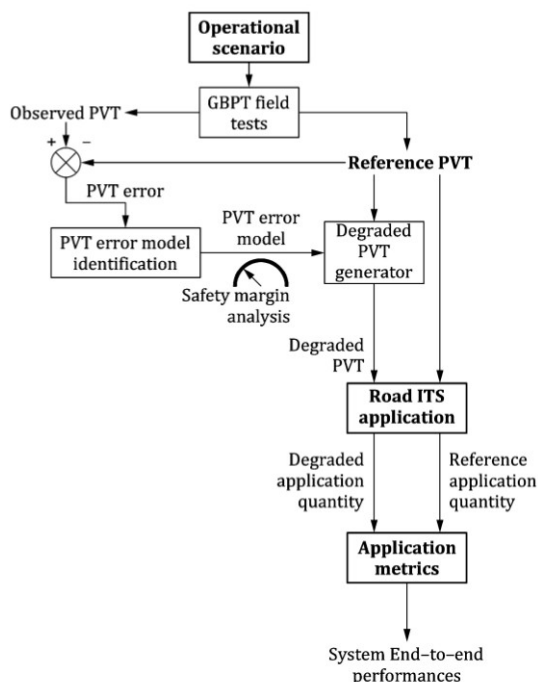
Up to 6 environments are defined in EN16803-1:

- “Flat Rural”, or “clear sky”: rural roads in a flat countryside with masking angles smaller than 10°, no mountains nor high hills;
- “Tree-lined Rural”: rural roads, with lines of trees with foliage on each side and a significant effect on signal reception due to the foliage;
- “Mountainous”: roads with sharp curves and high mountains around, generally on one side of a valley, with numerous tunnels and sometimes trees, masking angles between 10° and 80°;
- “European Peri-urban”: suburb or medium cities ring roads, with relatively large streets and small to medium height buildings, masking angles up to 30°;
- “European Urban”: standard European “old” big cities with relatively narrow streets, but sometimes large avenues or ring roads, with buildings from medium height to tall, masking angles up to 60° generating frequent multipath and Non-Line-Of-Sight (NLOS) phenomena;
- “Modern Urban Canyon”: business centres with very high modern sky scrapers, large avenue, tunnel, masking angles often greater than 60° generating frequent NLOS phenomena.

These environments are very important, because a dedicated GPBT will have different performances and probably a different performance class based on the environment in which assessment has been done. We can imagine that a geodetic GNSS receiver could be “Class1” in a clear sky environment, but only “Class2” in an urban scenario.

Standardization issues related to hybrid GNSS positioning

EN16803 addresses also sensitivity analysis concerning Road ITS application. Basically, the idea is to assess End to End (E2E) performances. For instance, in a road user charging application, one needs to have a very low rate of false detection (ie a taxation on a road whereas it should not). These E2E performances could be: less than 1 over 1 million (1E-6) of false detection. Testing this feature needs simulation: this is the method proposed EN16803-1:



**Figure 1: sensitivity analysis general principle (according to EN16803-1)**

*From ETSI*

Standardization about GNSS-based Location Systems (GBLS) is addressed by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

ETSI SES has produced the 5 following technical specifications:

- Part 1 named 103 246-1: Functional requirements
- Part 2 named 103 246-2: Reference Architecture
- Part 3 named 103 246-3: Performance requirements
- Part 4 named 103 246-4: Requirements for location data exchange protocols
- Part 5 named 103 246-5: Performance test specification

The GBLS architecture is quite aligned with the Positioning System architecture as defined in CEN.

The strategy adopted by ETSI is to cover all the metrics assessments by simulation. To assess these metrics, different scenarios are composed with the following target operational environments: open

Standardization issues related to hybrid GNSS positioning

area / urban / asymmetric area, and for both moving / static motion types. By doing so, each performance feature can be evaluated in an exhaustive way.

What is called “area” is a kind of sky plot allowing the GNSS simulator to generate appropriate GNSS signals:

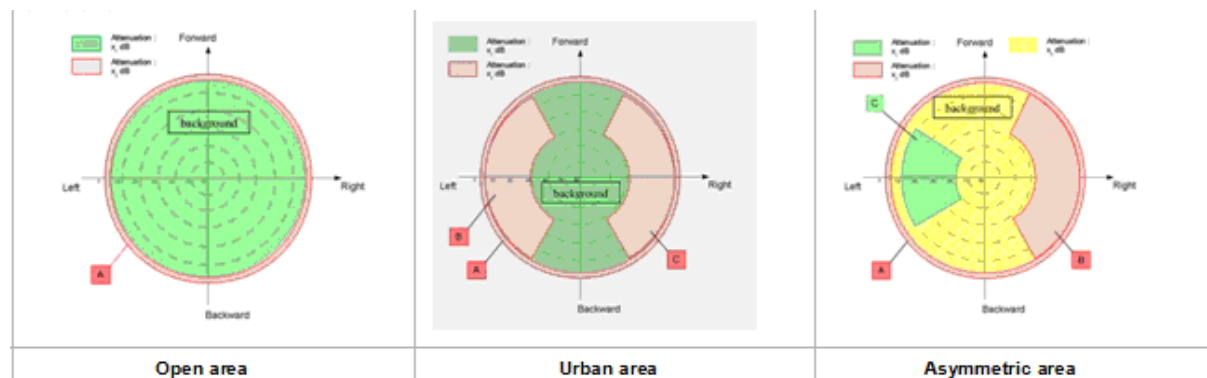


Figure 2: skyplots characterizing areas (according to ETSI)

*From ISO*

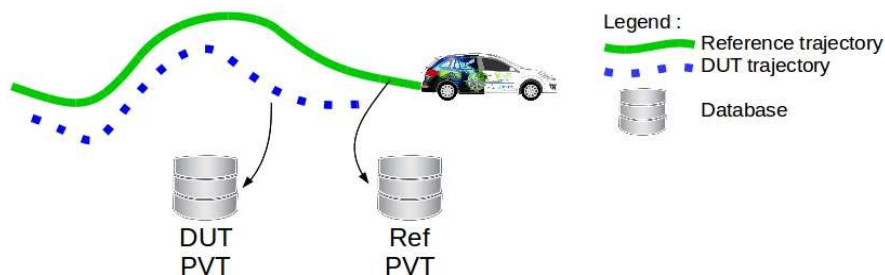
A new Technical Specification (TS n°21176) has been proposed in 2017 under the name “Position, velocity and time functionality in ITS stations” (i.e. On-Board Units or Road-Side-Units). According to the preliminary exchanges between CEN and ISO about this subject, the architecture proposed by CEN will be able to fit in the ISO standard. The main objectives of this TS-21176 are to provide interfaces (input / output) that are enough generic to cover needs of ITS-S. CEN has already started to give elements that could help the definition of this TS. The work is still on-going.

### Field, lab and R&R tests for GNSS only: an overview of what is done

In order to simplify explanations, the following section will only deal with horizontal accuracy (or 2D error). But the principle is also valid for every other performance feature described before.

*Field tests*

An experimental vehicle, e.g. the VERT (Vehicule Experimental de Reference des Trajectoires) from Ifsttar [4], that provides a reference trajectory, and embeds a Device Under Test (DUT) and computers is needed. Field tests consist in logging at the same time the reference trajectory (or at least every data needed to post-process it) and the output of the DUT. This output should contain at least position and time (e.g. GGA or RMC sentences, according to the NMEA protocol).



**Figure 3: device under test and reference trajectories**

Reference trajectory has to be understood as the expected trajectory that the DUT should have if it was perfect. That means lever arms (between ground truth antenna and DUT antenna) should be taken into account.

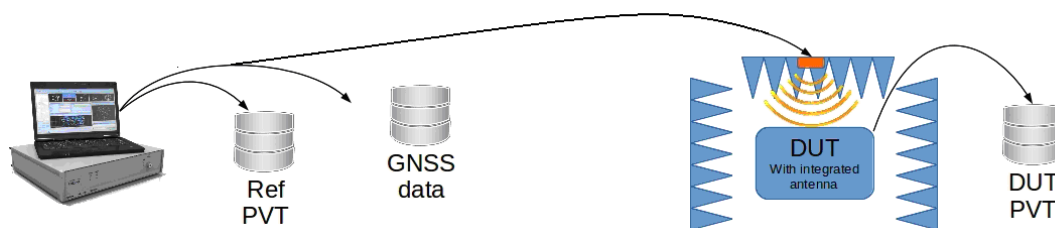
Moreover, the reference trajectory has to be at least 10 Hz sampled, considering the dynamics of the vehicle, and it will be interpolated to the exact time delivered by the DUT.

*Lab tests*

For these tests, one has to build from scratch simulated GNSS signal. Dedicated tools already exist. Such tools allow building multipath condition by ray-tracing in a 3D city model. The reference trajectory is also built at this step.

The GNSS simulator allows injection of GNSS signal; and so the DUT can be spoofed.

RF signal are then conducted in the DUT by using a cable, if the DUT has an external antenna connector. If it is not the case, then one shall use an anechoic room and broadcast RF in the air.



**Figure 4: computer designed GNSS data, RF broadcasted (or cable-conducted) to the DUT**

*Record and replay tests*

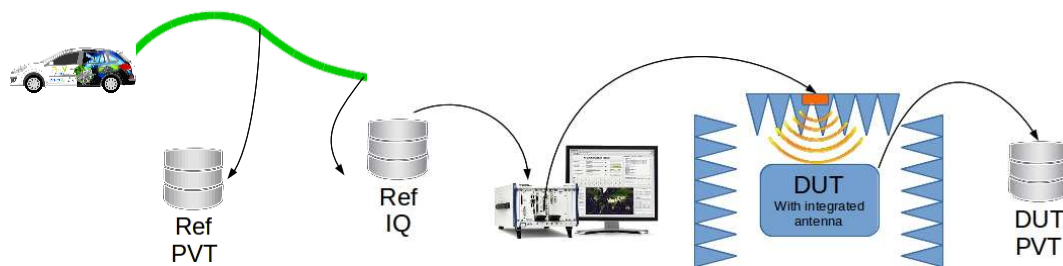
Record first: An experimental vehicle that provides a reference trajectory, and embeds a system being able to record numerical GNSS signals (I/Q) and computers is needed. Field tests consist in logging at the same time the reference trajectory and the I/Q reference database.

Digitalizing GNSS signals in I/Q data allows rebuilding a radio-frequency (RF) signal. With a



## Standardization issues related to hybrid GNSS positioning

dedicated system, one replays (possibly N times...) the GNSS signal as it was logged during the record process; and so the DUT can be spoofed: RF is cable-conducted or broadcasted to the DUT.



**Figure 5: field tests GNSS IQ data, RF broadcasted (or conducted) to the DUT**

Last, but not least, and for all 3 different test cases, the final offline analysis is the same. The reference position shall be computed for each output from the DUT and each “error” (i.e. time to time difference) can then be computed and analysed in a deep process: cross/along track error, cumulative distribution function (CDF), histogram...



**Figure 6: time to time position difference between DUT and the interpolated reference**

### Hybrid GNSS testing specificity

The testing of a positioning system for certification purpose, using test standards, can be done with 3 different approaches:

- Pure field tests,
- Pure lab tests,
- Record&Replay tests.

Table 2 summarizes the pros and cons of each approach. And, for the obvious reason of not being able to accelerate the DUT on a bench, neither reproducing visual road scene with sufficient realism, IMU and perception hybridized GNSS devices cannot be tested so far in lab conditions. Note that the rotations (heading and tilt) of the vehicle body, as well as the rotation of the wheels, are possible on a bench, but not the acceleration.

**Table 2: Advantages and drawbacks of each testing approach**

APPROACH	Cost	Realism	Complexity	Repeatability	Valid for hybrid
Field tests	High	High	High	Low	Yes
Lab tests	Low	Low	Medium	High	No
R&R tests	Medium	High	Medium	High	No

Pure field tests are the most representative and apparently easier, but suffer from drawbacks in terms of repeatability and cost effectiveness.

Pure lab tests are cheaper and repetitive but need synthetic signals. Synthetic GNSS signals can be produced, by constellation simulators, but the real physical phenomena around the obstacles cannot be reproduced with a high degree of realism. The possibility to produce synthetic (and synchronised) signals from IMU and video cameras to feed the hybridized systems still seem very challenging and at the level of research today. Additionally, standardized lab tests on hybrid systems in the lab would need open and standardized interfaces to inject these synthetic signals into the system under test, which cannot be considered anymore as a black box, but more as a “grey box”, in analogy with something in between black box and fully open white box.

R&R tests can offer the best compromise and the possibility to use a digital data base of standardized test scenarios. In this case, the signals used in the lab will not be synthetic signals but recorded signals, replayed in the lab. This is already feasible with GNSS signals but it is still challenging, although not as much as for synthetic signals, for IMU and video signals. The ultimate solution would be a kind of driving simulator with the projection of the real scene on a screen and the mechanical simulation of the vehicle movements. In this kind of facility, the hybridized system can be tested as a black box. An intermediate solution would be to replay GNSS signals and to inject the recorded video and IMU signals into the system. But here again the system should be a kind of “grey box”, with standardized interfaces to inject these signals. This approach is the one chosen by inLane [5] for the validation tests of the prototype.

inLane is an innovation project funded by the European GNSS Agency (GSA) inside the European Union’s Horizon 2020 research and innovation programme. inLane’s main technical objective is to fuse GNSS and computer vision to obtain an enhanced positioning accuracy to be used on lane-level navigation and crowdsourced map updates. inLane promotes the standardization of the interfaces of the intermediate “grey box” solution. However, until the “grey box” approach is standardized, this option does not seem suitable for certification tests that will be applied on black boxes only.

It is also important to note a well-known issue in the replaying approach: that of data synchronisation. Each sensor has its own data format and frequency, so the data fusion algorithm needs to cope with this heterogeneity. A common solution is to use a middleware that assigns a timestamp to each raw data sample using the same time reference system. The recordings contain not only the raw data but also the associated timestamps so all the data can be replayed in a synchronised way.

## **Conclusions**

The validation and certification of a hybrid positioning system suppose big challenges. Such a system can be tested with Record & Replay tests as a white box. This is useful for validating functionalities but it cannot be used for certification as you are exposing your software modules. Currently, only field tests are available for certification. However, field tests are very expensive and have a low repeatability. Moreover, the reliability of the reference (i.e. detection and exclusion of outliers in local urban spots in space and in time) where/when its error is not bounded still deserves research interest.

The solution presented here and promoted in the inLane project, is to study the feasibility of a semi-open architecture offering some standardized interfaces to execute R&R tests and to propose some recorded signals potentially standardizable. This way you are not exposing your software architecture but you are using some standardized interfaces that everybody should use. A third party, like a certification organization, could then plug in to your system and monitor the corresponding signals to check that everything is working as expected. From the authors' perspective, this important issue needs to be addressed as soon as possible by the standardization bodies. This would potentially lead to a reduction in time and costs of the certification of hybrid positioning systems.

## **Acknowledgments**

This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687458 (project inLane).

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