New Test Facilities for GNSS Testing and Dynamic Calibration

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***Abstract*—With Galileo, the European GNSS (Global Navigation Satellite System) starting early services in 2015, open-area-testing of applications which use the new positioning system gets more and more important. This contribution gives an overview on existing test sites like railGATE, automotiveGATE and seaGATE, it highlights the latest addition for dynamic calibration with geodetic precision and finally describes the testing regime of the BONUS project ANCHOR, where multiple test sites are used for maximum benefit in a maritime application.**

***Index Terms*—Galileo, GPS, GNSS, Galil-EU, Geodetic Receivers, Dynamic Calibration, ANCHOR, Pilot Assist, ADAS**

I. Introduction

Today, for most people satellite navigation is synonymous to using GPS. However, this is not the only Global Satellite Navigation System (GNSS) available. Russia is pushing hard its GLONASS system, while the European Union already operates EGNOS and currently establishes the first civilian GNSS: Galileo. Advantages of Galileo are numerous. As a system under civil control which offers integrity information and which currently evaluates the introduction of an authenticated signal, Galileo is the only GNSS which can be used in safety related applications. With higher inclination and more modern technology, it will offer a better visibility and a higher accuracy than, e.g., GPS.

The new functionality is backed from EU with strong efforts, to introduce initial applications in time with Galileo early services. The development of these applications is facilitated by instruments such as Horizon 2020, where a considerable amount of the initial calls addresses use of Galileo in different disciplines, but it is also supported through the installation of dedicated test beds (Galileo Test Beds, GATEs) and complementary incubation or science-2-business centres (e.g. the Automotive & Rail Innovation Center Aachen.

II. Galileo Test Beds

To be able to already investigate and develop innovative receiver technologies and applications a variety of test facilities where set up, all located in Germany. These test beds where funded by DLR with aid of the German Federal Ministry of Economics and Technology and by the European Commission DG Enterprise and Industry within the frame of Competitiveness and Innovation Framework Programme (CIP).

The test beds focussing on land based traffic, automotiveGATE and railGATE, have been installed in the project Galileo above under leadership of the Institute of Automatic Control (IRT) of RWTH Aachen University. The IRT conducts research in the whole variety of automation and control applications, in particular with a focus on Automotive, Combustion, Galileo, Industry, Energy and Medical. In those fields the IRT uses its expertise in Rapid Control Prototyping, Modelling and Simulation of Dynamic Systems and Sensor Fusion to implement advanced control methods like Model-based Predictive Control (MPC) and Robust Control, to name a few.

In these test beds so called pseudolites (pseudo satellites) are spread in an area around a testing site. The pseudolites are terrestrial transmitting stations which emit Galileo conform signals. This way it is possible to already receive Galileo signals in the GATEs, independent from the number of launched Galileo satellites. Signals can be received in the Galileo E1 and E5a/b bands. Besides the pseudolites, which are mounted on up to 60 m height masts, a reference station to survey the systems state and provide additional information belongs to each GATE.

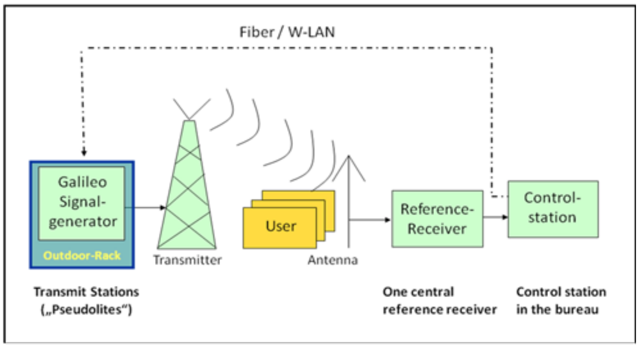

***Figure 1:** Galileo Test Bed Control Loop*

The test beds have been introduced, e.g., in [7] and [8].

A. Automotive

The automotiveGATE is located at the Aldenhoven Testing Center (ATC). The ATC offers a variety of test cases. There is an oval circuit of 2 km length having two banked corners that allow a lateral force free cornering speed up to 120 km/h. It also

***Figure 2:** ATC Aldenhoven with automotiveGATE*

offers a handling track of 1.5 km length including a 1 g dip. On the rough road segment and the braking test track different road conditions and surfaces can be experienced. A huge vehicle dynamics area, with a diameter of 210 m and separated approach and return lanes enabling an approach length of up to 500 m, completes the ATC. Suitable for motorcycles, cars and trucks, it is an ideal proving ground for Galileo in the automotive sector and for other fields of applications.

B. Rail

The railGATE on the other hand is located at the Siemens Test- and Validationcenter Wegberg-Wildenrath (PCW). On 5 different test tracks with meter and standard gauge railway operations can be realistically simulated. This contains traveling through curves or on slopes, braking distance measurements, and acoustic tests on all together 28 km of tracks. The railGATE optimal suits the requirements of the railway sector, but also delivers big advantages in other sectors as well. So for instance the rail tracks lead to reproducible trajectories which are known in beforehand. This is a big advantage in the development process of Galileo applications and used for dynamic calibration also for other areas like Marine (see Section III)

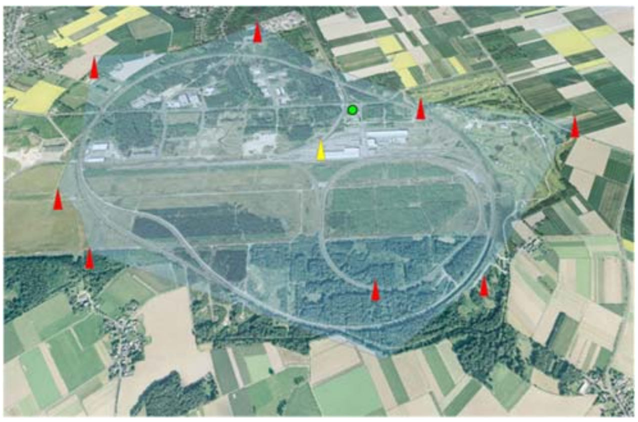

***Figure 3:** PCW Wegberg Wildenrath with railGATE*

C. Marine

A similar test bed targeting the maritime sector is seaGATE in Rostock. seaGATE was the first of the test beds for Galileo based applications to be completed in Germany. It is operational since May 2008 in the harbour of Rostock.

Within the scope of seaGATE, Rostock harbour has been equipped with pseudolites mounted on high buildings and towers. These cover the areas of the harbour entrance, the sea-channel and the docking and transfer sites.

Rostock harbour is an ideal location for the test site, since the tide is very small and, thus, vertical movements are limited. In addition, there is very good visibility of the area and a direct line-of-sight to the pseudolites is given at most times.

As a first continuous user of Galileo, the ferry Mecklenburg-Vorpommern has been equipped with a receiver. Here, the precision of Galileo helps to make a turn within the limited space of the harbor.

***Figure 4**: seaGATE at Rostock Harbor. Photo courtesy of EADS RST Rostock System-Technik GmbH*

D. Further Areas

Further Galileo test environments in Germany are aviationGATE in Braunschweig to test airborne applications and GATE in Berchtesgaden to verify receiver capability with a virtual satellite mode.

III. DYNAMIC CALIBRATION AT RAILGATE

Following the installation of the Galileo test beds, the EU-project Galil-EU currently establishes roadmaps to push the use and acceptance of Galileo in Europe. At first workshops are being organized where surveyors, automotive- and rail engineers as well as GNSS specialists are teaming up and sharing their experiences as well as their requirements on position based systems and measurements. The outcome and the superposition of these results define the requirements for appropriate measurement tools, testing procedures, specifications and environment. In a brighter view the synergies found by the multi-disciple teams will be leading to new processes, services and products.

As a part of this effort also a reference track is being established. A dedicated track terminal loop with a length of about 550 m has been selected inside the railGATE facility. A high precision geodetic network forms the basis for all measurements to be done on the track. The network consists of six observation poles (Figure 5), which are being set up along the tracks. The relative geometry of the network is located in the sub-millimetre range (Figure 6).

Different geodetic instruments like total stations, laser scanners, digital levels and GNSS receivers can be mounted to

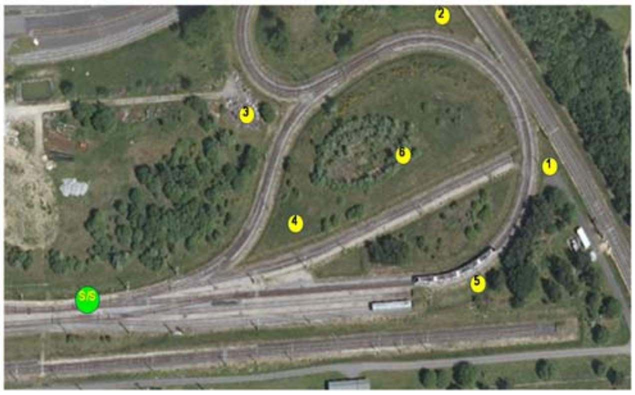

Figure 5: *Reference Test Track and Positions of Poles*

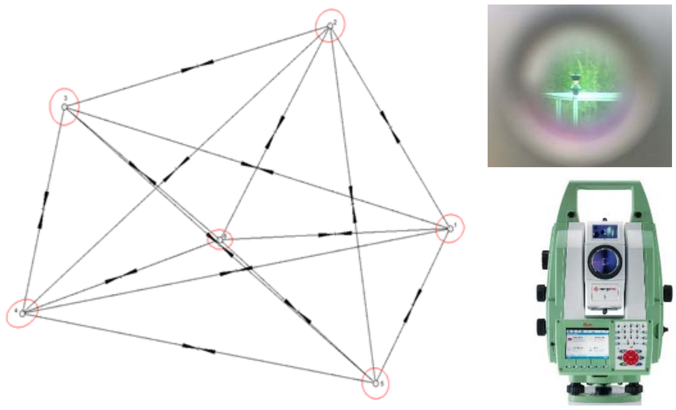

Figure 6: *(Left) Estimated Relative Accuracy of Reference Network and (right) Observation of Gang Car*

the observation poles to perform any kind of geodetic observations concerning the stability of the network and the 3D track, as well as the driving characteristics of the vehicle. Therefore a special designed electrically driven rail vehicle (gang car) is being built to serve as a transportation platform to carry the measurement equipment as well as the devices under test (DUT). While the vehicle is driving along the geodetically surveyed tracks the entire system forms a quasi 3D invariant in space.

With this reference configuration any kind of positioning unit like GNSS receivers etc. can be tested even dynamically at an adjustable constant speed up to 25 km/h or even under accelerations. Beside of being part of the 3D-reference system, the vehicle will also be integrated into the well-defined environment of the railGATE facility by using the Galileo pseudolite system. Finally inertial (gyros, accelerometers) and tilt sensors are also mounted on the vehicle. So, all angular rates, accelerations and bank angles can be measured at any time in any direction with precise time- and position-stamps along the test drive.

All raw data will be recorded during the tests and evaluated in the post processing. This concerns the GNSS data as well as the reference measurements done by the total stations and other sensors included. After the test drives the measured results of the DUT can be compared to the data of the highly accurate reference track and INS. The results can be used either to test and evaluate the DUT, or to calibrate it.

IV. Initial Application Projects Rail & Road

In order to gain scientific knowledge even while the test fields where still under construction, and in order to ensure the correct performance of the GATEs, it was decided to run initial projects and to establish a science-2-business center in parallel with the construction phase of Galileo above.

With the objective to reduce the number of vehicle-to-vehicle collisions (which represent 50 percent of all accidents according to studies [2]) and mitigate their consequences, the automotive initial project was about developing a collision avoidance system (CAS) designed to detect an approaching vehicle heading for a collision. The system is to intervene autonomously if the driver fails to react in a timely and appropriate manner. It is designed to recognize both moving and standing vehicles [1]. The System was successfully tested at the automotiveGATE.

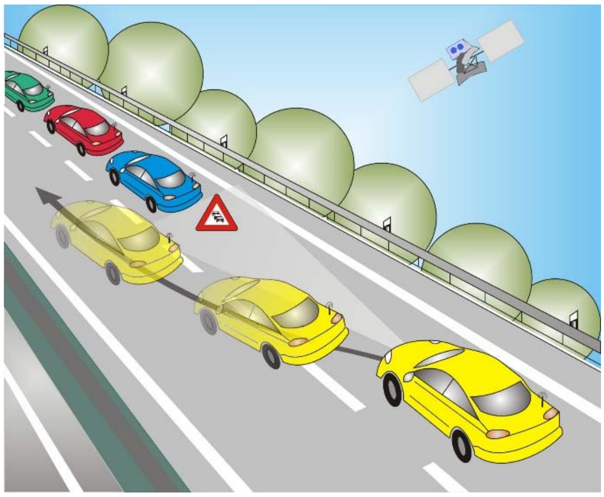

Figure 7: *Galileo Collision Avoidance System*

The core functionality of the initial rail project was controlling a shunting locomotive to perform target braking which consists of a defined approach and a precise halt towards an object, namely a wagon. Optimal target braking is a multiple trade-off between fast approach versus high safety margins, close halt versus avoidance of contact bump as well as fast movement versus low energy consumption and low machine wear. In order to precisely halt at the required location, the shunting locomotive receives the coordinates of the target location in geodetic coordinates. Comparing this target position with its own GNSS-based location, the locomotive can perform target braking what was tested in the railGATE.

In another project this basic functionality was extended to create an assistant system to use automation for the process of train formation and handling in flat marshalling yards that can be located at the site of shippers/receivers of goods. The system aims to increase efficiency and safety of train formation and therefore encourage more freight onto trains. Central element of the assistance system is GNSS-based position information. The precise and reliable position information is fundamental for the system which commands an automated shunting locomotive through a marshalling yard and moves freight wagons. [3]

Besides those initial projects other projects have been realized in the GATEs. For instance the SiPoS-Rail project, where the underlying approach is a tightly coupled navigation

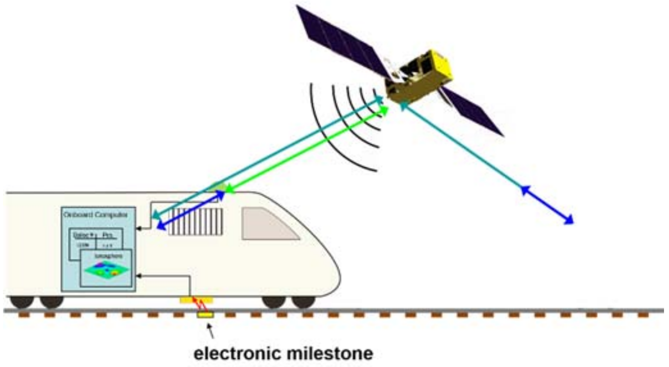

Figure 8: *Functionality of SiPoS-Rail*

system supported by a differential GNSS. The aim of differential GNSS is to reduce the position error by determining the combined error in ephemeris, ionosphere and satellite clock using a reference station at a known position. In a classical differential GNSS the correction values calculated by the reference station are transmitted to the user and are there applied to the measured pseudoranges. [4]

Due to the requirements of rail transport and the lack of certification of existing wide area differential GNSS like EGNOS, the train calculates pseudorange correction values independent of existing systems. This avoids integration of other systems that are beyond the control of the rail operator. To calculate pseudorange correction values, the system uses electronic beacons along the track as landmarks. The positioning system takes the calculated pseudorange corrections, the GNSS measurements and additional sensor data and combines them in the navigation filter. [5, 6].

To ensure sustainability of the investments made, the Automotive & Rail Innovation Center (ARIC) has been founded as a science-2-business center for applying Galileo. ARIC is a partner for testing in several projects and a direct link between industry and science. Testing of the GPS Jammer detection in the FP7 project DETECTOR (see [10…16]), e.g., has been carried out by ARIC in automotiveGATE, the testing for ANCHOR [17] as described below is coordinated by ARIC using railGATE and seaGATE.

V. Application to the Maritime Sector: Testing for ANCHOR

The railGATE and its dynamic calibration site will also be used as test environment in the ANCHOR project, where a captain assistant system is to be developed. While the ANCHOR project itself is described in more detail in other contributions to

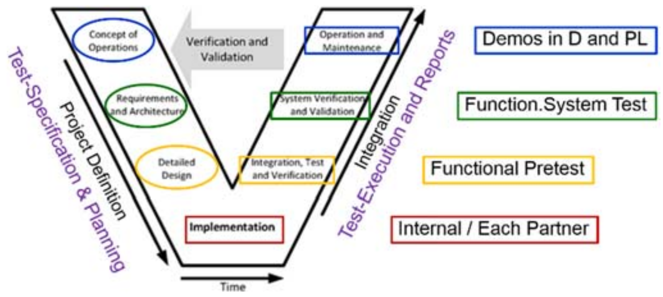

Figure 9: *The V-model of Development & Testing*

NAVSUP [17], here, the testing regime shall be highlighted. To the ingenuous reader at first it might seem strange, tat maritime applications should be tested in a rail facility. Yet, regarding the positioning module within an application, it is much more straight-forward to verify and to repeatedly pass a position on a railway track, which is more or less a fixed trajectory, than on an ocean. Thus, testing in ANCHOR, which follows the common V-model as depicted in Figure 9, is carried out in four main categories.

A. Functional Pretests

These are the first functional tests in the middle of project, when the software and hardware works are almost finished. Each part of the Anchor system (software and hardware) will be tested and feedback given. The pretests allow for an early warning, in case parts of the system prove to be non-feasible.

The functional pretests will include verification in the Galil-EU dynamic calibration environment and railGATE. These test sites have been chosen for

- Easy handling
- Offering positions which can be verified
- The location in a forest, which is a dedicatedly hard case for communications
- Repeatability of trajectories on the fixed tracks.

B. Functional Tests

Here, the functionality of each part of the system is to be checked after the system as a whole is operational for the first time. During these tests possible upgrades may be done so that after the tests the system will be ready for presentation to the potential end-users. The functional tests in ANCHOR are split between railGATE in Germany and Gdansk harbor in Poland.

C. System Demonstration and Verification at seaGATE

The third stage incorporates validation tests with potential end-users. These tests will be done in SeaGATE and prove the potential of the system and its adoptability for global use. Test scenarios derived within ANCHOR will be executed in Rostock to show the complete system functionality.

D. Final Demonstration in Gdansk

Finally, there will be a demonstration of ANCHOR capabilities with potential end-users in a Polish harbor, preferably the container harbor of Gdansk. The demonstration tests consist of a complete docking procedures of a ship with assistance of the Anchor system in real conditions. This final test is organized by the Polish Naval academy AMW.

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