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1 Introduction

1.1 Context

Up to now within SaPPART actions, position models have been matched to experimental series of GNSS position errors. This was performed with the aim of testing the performances of GNSS hardware for specific performance levels of ITS applications thanks to the generation of a large diversity of perturbed trajectories. Record and replay solutions of GNSS raw data, which were recorded during road tests, have been studied to test different GNSS positioning systems and assist the writing of testing guidelines. Finally positioning errors distributions have been estimated with experimental data and led to the definition of three different performances classes. These classes are used to assess the positioning performances of satellites based positioning systems by classifying them.

With an increased offer of combined GNSS and Inertial Mobile Unit and the growth of vision based navigation systems embedded in future automated cars, it is interesting to address positioning performance assessment of “hybrid receiver”. It is the topic of this report with the aim of extending existing SaPPART work on Satellite Positioning Performance Assessment for ITS applications to hybrid receiver testing.

1.2 Workplan

The work plan starts with a survey of state-of-the-art equipment/software dedicated to the simulation of inertial navigation systems data (possibly Record & Replay tests) with a focus on the analysis of the capacities and possibilities to playback GNSS data with additional inertial data. A test-setup to collect relevant data for assessing the challenges arising in ITS navigation with hybrid receiver is then presented. Tests were carried out in winter conditions and outcomes of the data processing are presented. Additional analysis on vision-aiding system and wheel speed sensors is still undergoing.

2 State of the art on hybrid receiver testing systems

2.3 Main testing strategies

There exist three main strategies to test positioning systems including hybrid receivers.

- “Lab” or “Simulation and Replay” tests where GNSS signals and complementary signals (inertial, visual, etc.) are generated from scratch using simulation tools.
- “Record and Replay” tests where real GNSS signals and complementary data are recorded during experimental data collections. They are then re-broadcast and replayed using broadcasting systems and diverse hardware (turntables, video projectors, etc.)
- “Field” tests correspond to road testing with a dedicated vehicle that provides also a reference solution for comparison purposes.

2.4 Signals of interest of ITS applications

Facing the fast development of new positioning sensors and their integration in car’s body, a question raises: what are the data of interest for hybrid positioning systems in the context of ITS applications?

GNSS receiver is the primary hardware for positioning but it signals are often coupled with other measurements recorded by additional sensors integrated in the car’s body.

They are inertial mobile unit, speedometer, odometer, single axis gyro, camera, radars lidar, ultrasonic sensor, etc. Figure 1 illustrates the sensors commonly integrated in vehicles nowadays or in the future with the advent of self-driving vehicles. The Google car is only chosen for illustration purposes.

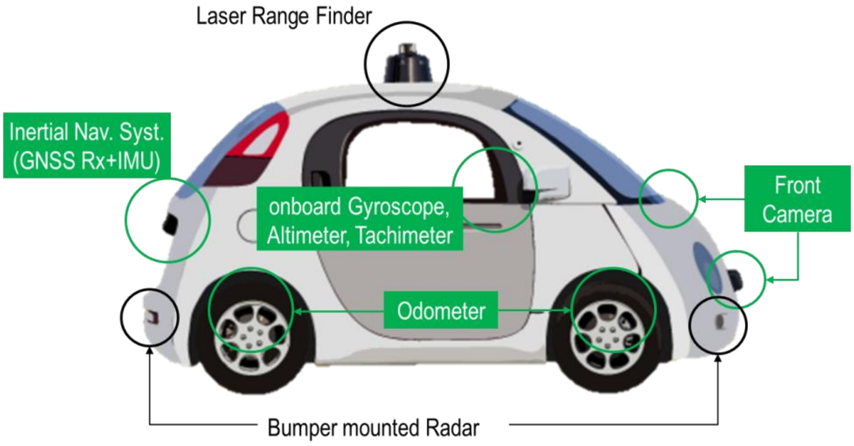

Figure 1. Sensors embedded in cars useful for positioning, in green those considered as the most easily accessible. The Google car is only used for illustration purposes.

<u>Sensors to control the vehicle</u>

Although all these sensors could theoretically contribute to positioning, some of these sensors are dedicated to other tasks: monitoring and controlling the vehicle (Advanced Driver Assistance Systems, etc.). Radars mounted on the car´s front and rear bumpers are principally used to detect surrounding vehicles and obstacles.

<u>Sensors useful for positioning</u>

Some off the shelf and low cost sensors are now widely used to enhance satellites based positioning systems. Odometers are mounted on the wheels to count wheels' rotation changes and derive the vehicle's speed. Heading changes can be measured either using a vertical axis gyroscope located in the car or a differential odometer system mounted on two wheels of the same axle. Video frames recorded by cameras, mounted on the windshield, are processed to estimate the changes in the vehicle's dynamics (heading changes) from road features detection and tracking (lane markers). Structure from motion or simultaneous localization and mapping algorithms are applied to track the vehicle's position using only visual data or in combination with other sensor data.

Lidar are principally used for research and development on self-driving vehicles. Lidar is also integrated in high-end professional vehicle (industrial/agriculture applications). It is the heart of Google self-driving car but it is very expensive equipment and the associated processing algorithms are complex. It is not considered in the rest of this report.

<u>Focus on wheel speedometer and inertial mobile unit</u>

Wheel counts provide better measurements than accelerometer integration for estimating the speed of the vehicle. Once, the speed estimate is fed to the filter, pitch and roll angles can be estimated accurately.

Inertial Mobile Unit is principally used to estimate yaw changes of the vehicle. Accelerometers are used to correct pitch and roll of the vehicle. Indeed heading output from one vertical gyroscope would suffer from large scale factor errors.

A dead reckoning process is then applied to estimate 3D or 2D coordinates.

Let us note that wheel count outputs will be biased when side slip and sliding occurs (snow conditions) whereas they could be estimated with accelerometers.

2.5 Existing testing solutions of hydrid receivers

2.5.1 Lab Tests

Several research facilities have been developed for EMC testing of vehicles. Why not using the later for testing hybrid positioning systems? These facilities often comprise sophisticated turntables that could be used to assist the replay phase of “record and replay” tests. Inertial data could be used to drive the turntable and satellite signals could be broadcasted in the facilities. Completed by wide screens, these facilities could even be used to test vision-aiding systems in hybrid receivers.

One example of such facilities is the large test hall that was designed for EMC testing of vehicles with a turntable and a four-wheel chassis dynamometer at the Research Institutes of Sweden (RISE) and whose use is now extended to automotive wireless test [1]. A physical limitation of Lab Tests is the impossibility to generate vehicle’s accelerations.

2.5.2 Experimental Testing

Hybrid receiver can be mounted on specific instrumented test vehicles for real road tests [2]. The testing procedure is the same as the one for satellites based only positioning system. A very accurate reference trajectory is computed using the instrumented vehicle records and compared to the trajectory estimated by the hybrid receiver.

2.5.3 Record and Replay

The SimAUTO toolbox [3] from Spirent SimGEN software suite enables to simulate vehicles Dead Reckoning data (heading and wheel count sensor outputs, single-axis rate table drive) with a user defined vehicle geometry synchronized with GNSS RF signals.

Hunerbein et al. developped a 6 kg Record and Replay system for multi sensor vehicle testing including bus CAN inertial sensors data, GNSS receivers signals and videos from 3 cameras [4]. GNSS signals are recorded with the Spirent GSS6425 (GPS, GLONASS, Beidou, Galileo and Augmentation Systems WAAS, EGNOS, MSAT and QZSS, and the SBAS based on Inmarsat). This system is also used to store videos. A Gryphon S4 CAN bus interface stores the vehicle´s data. A 2-D axis rate table is embedded to capture heading and pitch changes. A high end inertial navigation system is used to get ”true” position, veolicty and orientation estimates.

LabSat proposes an hybrid navigation system testing solution that comprises a GNSS simulator, a video data logger, turntable, yaw rate sensor and wheel speed generation unit [5]. The system records experimental GPS and GLONASS L1 signals and synchronised vehicle data from the CAN. WAAS/EGNOSS can also be recorded. A turntable is then used to replay the data in the simulation phase. The turntable rotates based on the recorded vehicle data simulating the yaw rate of the car. The system is also able to replay synchornized video files (VBOX video) for visual validation purposes of the hybrid position estimates.

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Figure 2. LabSat Turntable System and visual assessment of the position performances based on recorded vehicle's data [5]

3 Experimental assessment of a low cost GNSS/INS "Hybrid receiver" in snow conditions

3.1 Description of the experimental test

A 25 minutes road data collection was conducted with a Novatel span system [6] and a MTi-G-700 GNSS/INS hybrid receiver from XSens [7] in snow conditions on main roads and in the forest. A GoPro Hero 3 camera was installed behind the windshield. Figure 3 shows the hardware setup. The hybrid receiver and the span reference system were rigidly attached together located behind the passenger seat. The same GNSS antenna, located on the top of the car roof, was used by both systems. Figure 4 shows the snow conditions on the main roads and in the forest, where the roads were slippery. On top of sliding effects, multipath and fading effects deteriorated the satellite based positioning solution in the forest.

Figure 3. Road data collection setup

(a) (b)

Figure 4. Photos extracted from the GoPro Hero 3 video illustrating main road (a) and forest (b) snow conditions.

3.2 Hybrid receiver accuracy metric

3.2.1 Trajectory estimates

Novatel span data were post-processed with Inertial Explorer software in a differential mode to compute a centimetre level accurate trajectory. The hybrid receiver trajectory was extracted from the proprietary *.mtb file from xsens. The left part of Figure 5 shows the reference and hybrid receiver trajectories, respectively in green and red, for the entire data collection. The right part of the same figure zooms on the yellow mark in the forest. A degradation of hybrid receiver positioning accuracy is observed in this part. The degradation of the satellite signals propagation in the forest degrades the hybrid trajectory. It can be seen with the two red lines of the return drive that nearly overlap.

Figure 5. Reference (green) and hybrid receiver (red) trajectories with a zoom (yellow) in the forest.

3.2.2 Horizontal Positioning Error (HPE) Computation

The Horizontal Positioning Error (HPE) is computed by comparing the horizontal coordinates of the hybrid receiver with those of the high accurate reference solution at the same epochs. Time stamps of both systems are used to associate corresponding position estimates. Whereas with a satellite based only positioning system, time stamps are natively based on GPS time, other time references can be used to timestamp hybrid receiver's data. Indeed, a hybrid receiver is collecting data from different devices, which may have different clocks. For example, the inertial mobile unit can have one clock and the camera another one. A specific synchronization strategy must be adopted for hybrid receivers.

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3.2.3 Timestamp issues with the collected experimental data

Timestamping issues were observed in the output of MTi hybrid receiver. This is illustrated in Figure 6 with the first derivative of successive time stamps. Globally a mean 0.0025 second time interval, corresponding to the 400 Hz IMU sampling rate, is observed between consecutive samples but many outliers are present. At sample 18 in Figure 6, the time interval between two samples is above 3 seconds (out of the y-axis range in the figure) implying a possible data loss. In this case, it becomes challenging to compute the HPE using the time stamps of the position estimates to match the reference path and the hybrid receiver path. Another strategy must be adopted.

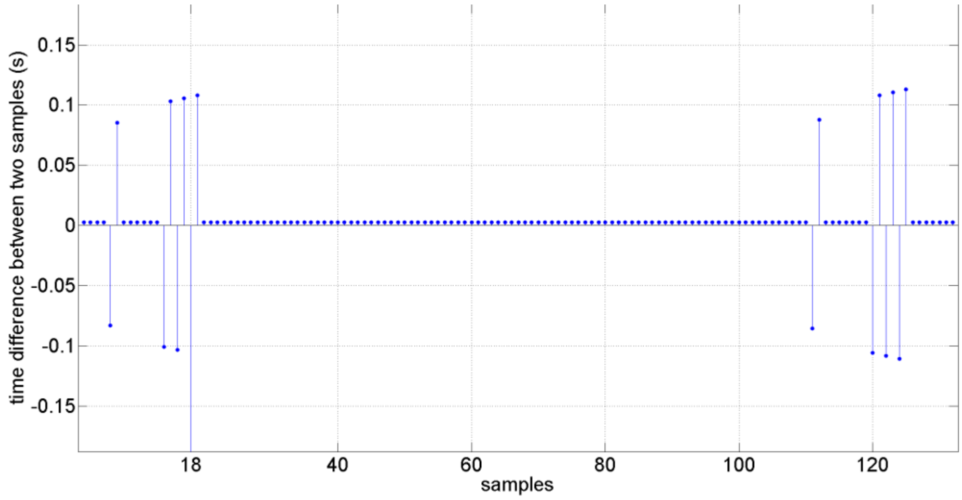
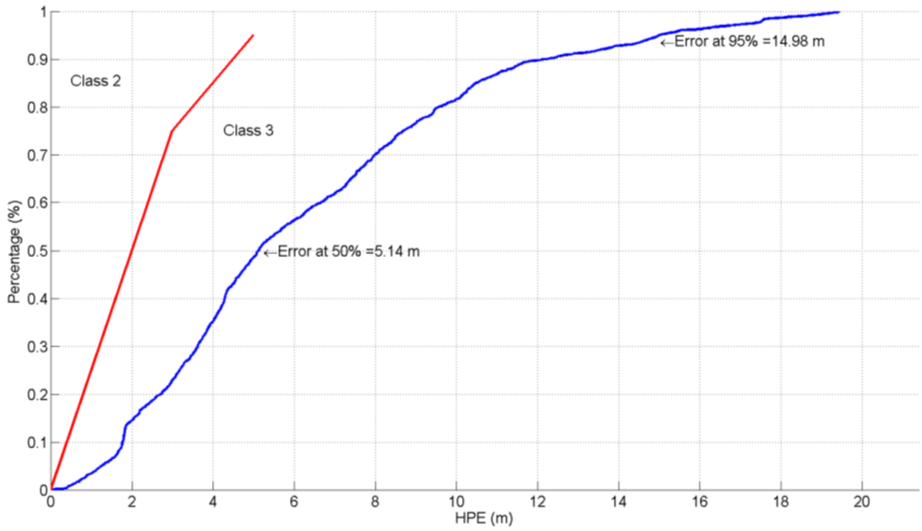


Figure 6. Time interval between two consecutive time stamps of the hybrid receiver MTi position estimates.

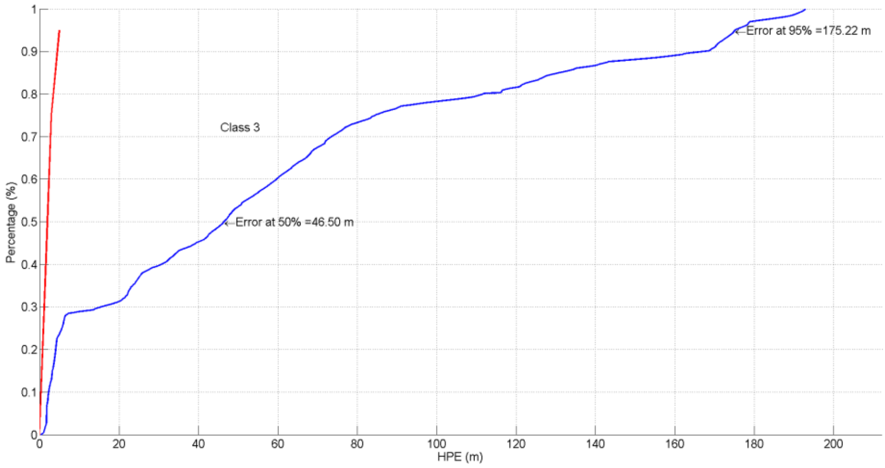
Modeling the clock drift and bias is a possible solution but it cannot be applied to the collected experimental data due to the chaotic nature of the time distortion. A matching strategy between the reference geographic coordinates (Lat, Lon) and the hybrid receiver geographic coordinates has been adopted instead.

3.2.4 HPE with and without timestamping correction

Figure 7 shows the cumulative distribution for the HPE with and without timestamping correction.



(a)



(b)

Figure 7. Cumulative distribution of the hybrid receiver HPE with (a) and without (b) correcting the timestamps.

It is observed that both curves fall into class 3 of the horizontal position accuracy performance classes defined in SaPPART guidelines. Class 3 is defined by performances located on the right side of the red curves in Figure 7. It is also observed that the result in Figure 7(b) is completely out of the range of normal positioning system performances. In this experiment, timestamping issues are really large leading to outlying result. But smaller clock issues could result smaller HPE differences with a wrong accuracy performance classification of the receiver under test. This suggests that possible timestamping issues should be considered in the testing procedure of the positioning performances of hybrid receivers.

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