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Kinematic Performances Comparisons Between Galileo, GPS And Glonass Satellite Positioning Systems

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Abstract

The initial Galileo satellite positioning services, starting from the 15 December 2016, became available with a formal announcement of the European Commission. This was the first step toward the Galileo system Full Operational Capability (FOC) and allowed many researchers to test the new system. The aim of this paper is to show some results of kinematic tests involving a GNSS multi-constellation receiver able to acquire the Galileo Open Service (OS) signal.

The acquired data were compared with the outputs obtained by a Mobile Mapping System (MMS) implementing integrated high-performance GPS/INS measurements. Using GrafNav software version 8.80 all the possible operative combinations were tested and analyzed. The results, referred to the performed experimental test, show that the new European system is characterized by better planimetric performance with respect to the other systems whereas, from an altimetric point of view, the GPS and Glonass systems perform better.

Keywords: Kinematic; Galileo; GPS; Glonass; Mobile Mapping System; GrafNav

Abbreviations: USA: United States of America; FOC: Full Operational Capability; OS: Open Service; MMS: Mobile Mapping System; PCS: POS Computer System; GAMS: GPS Azimuth Measurement Subsystem; POSPac™: Position and Orientation System Post-Processing Package; MMS™: Mobile Mapping Suite; IOV: In Orbit Validation

Introduction

Galileo navigation satellite system is the global positioning European program designed to be completely interoperable with the analogues GPS and GLONASS positioning systems produced by the United States of America (USA) and by the Russian Federation. With Galileo, the European Union aims at owning and providing an independent positioning/navigation service under the civil control [1].

Galileo program is constituted by two macro-phases: in Orbit Validation (IOV) phase and the Full Operational Capability (FOC) phase (whose conclusion is planned for 2020). Specifically, during the IOV the Galileo system robustness was tested by mean of two satellites (GIOVE-A and GIOVE-B) and, subsequently, with a reduced constellation of only four satellites (and the related ground infrastructure) with the aim to synchronize the satellites onboard atomic clocks and to perform a precise orbit tracking. Further details related to the IOV phase can be found within the works of Simsky et al. & Steigenberger et al. [2-5] and in [6,7].

The first step toward the FOC phase has been constituted by the European Commission formal announcement of the starting the Galileo initial services (15 December 2016). When the FOC phase will be concluded the constellation will rely on 24 satellites (and 2 back-up satellites for each orbital plane). In this phase, each satellite will take 14 hours to complete its orbit at the altitude of 23222 Km [8]. The whole system is designed to guarantee the visibility of at least 4 satellites in each point of the Earth. Indeed 24 satellites will be equally distributed on three different orbital planes at 56° with respect to the equatorial plane [9]. Further details related to the preliminary analysis of the FOC phase can be found in the novel work of Zaminpardaz S & Teunissen PJG [10] whereas a detailed review of the project status (up to 5 July 2016) can be found in [11].

The Galileo system is designed to provide different services. In this paper was considered the Galileo Open Service (OS) [8]. The Galileo OS is freely available for mass applications of synchronization and positioning. This service does not require any authorization and can be used by any user equipped with an adequate receiver. The OS provides up four carrier frequencies: E1 (1575.42MHz), E5a (1176.45MHz), E5b (1207.14MHz) and E6 (1278.75MHz). Galileo signal-to-noise ratio density is higher than the GPS one and that Galileo signals are characterized by smaller multipath and noise than the GPS ones.

As far the authors know, there are no examples of kinematic comparisons of the Galileo positioning performance, against GPS and Glonass positioning systems, by using as benchmark the acquisition of a precise Mobile Mapping System (MMS). In a previous paper [12], a preliminary single frequency kinematic performance assessment of Galileo, GPS and, Glonass data referred to a trajectory estimated with MMS equipped with a POS/LV (Position and Orientation System for Land Vehicles) produced by the Applanix corporation, has been presented. The Applanix system features a filtering system capable of integrating GNSS measurements with an IMU (inertial measurement unit) with the aim to guarantee a stable, reliable and repeatable positioning solution for land-based vehicle applications [12] and to guarantee better positioning performance with regard to GNSS only measurements (complementary and surpassing property [13]). The performed comparisons were produced in such a way to consider, for the three positioning systems, all the possible combinations (with 4, 5 and 6 satellites for each considered constellation), thus by simulating a reduced operability for the GPS and the Glonass constellations. All the positioning solutions were derived by mean of the GrafNav software It supports:

a) standard and precise positioning algorithms with GPS, Glonass, Galileo, QZSS, BeiDou and SBAS;

b) Single, DGPS/DGNSS, Kinematic, Static, Moving-Baseline, Fixed, PPP-Kinematic, PPP-Static and PPP-Fixed positioning modes with GNSS for both real-time and post-processing (further details can be found in [14]).

The final results were statistically assessed and showed, for the performed experiment, a better Galileo planimetric performance whereas, from an altimetric point of view, the GPS and Glonass systems performed better.

Materials and Methods

Experiment location and MMS POS/LV description and configuration

The kinematic tests were carried out in the Karst plateau over Trieste municipality at a mean altitude of 375m above sea level, Italy and along a path inside Trieste urban area. The researchers drove the MMS vehicle at constant speed along different paths in urban and extra-urban contexts. The urban areas were chosen in order to analyze the Galileo performances also under sever satellite visibility conditions (Figure 1).

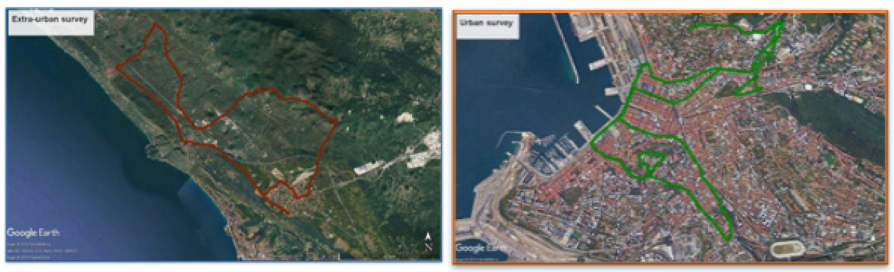

Figure 1: The extra-urban (on the left) and urban (on the right) surveys superimposed on the Google Maps satellite images.

Figure 2: The MMS of the GeoSNav Lab, University of Trieste, and the Applanix Corporation POS LV© system components mounted on board the vehicle.

For the absolute positioning, the Mobile Mapping System uses the POS LV System of Applanix Corporation, a fully integrated, position and orientation system, using GNSS positioning integrated by inertial technology to generate stable, reliable and repeatable positioning solutions for land-based vehicle applications (Figure 2). Designed to operate under the most difficult GNSS conditions in urban and extra-urban environments, it enables accurate positioning for road geometry, pavement inspection, GIS database and asset management, road surveying and vehicle dynamics (e.g. [15]). The integrated GNSS/INS (Global Navigation Satellite System/Inertial System) system is able to give, instant by instant, the position and attitude of the vehicle. Besides two geodetic GNSS receivers and the Inertial System, an odometer mounted on the back-left wheel of the vehicle, is present, measuring the travelled distance.

The inertial system integrates GPS in case of satellite signal lacking, due to obstacles like bridges, trees, buildings, giving positioning accuracies comparable to the ones obtainable using differential techniques. A Kalman filter, allowing gaining in any instant the best solution, performs the integration of each sensor data. GNSS data has a 1Hz acquisition rate, while the odometer and the inertial system send data to the System CPU at a 200Hz rate.

In the present research, for the planned comparisons, the output point for the MMS positioning data was set on the PolaNt-x MF [15] antenna phase center.

The PCS (POS Computer System) is the central element of the system: it acquires and processes the data coming from the different sensors, giving the vehicle positioning and attitude parameters in real-time and stores them for subsequent post-processing. The integrated inertial system is a Litton LN-200 fiber optic gyro IMU with three accelerometers and three fiber optic laser gyros. DMI (Distance Measuring Indicator) is mounted on the vehicle left back wheel and contains an optical sensor generating 1024 pulses per revolution; its function is to estimate the run distance and above all to determine when the vehicle is stopped (ZUPD – Zero velocity UPDate). Two geodetic GPS receivers give the data to PCS for positioning and direction determination, this last one using the GAMS (GPS Azimuth Measurement Subsystem) software module [16-23].

Survey experimental design

Data were acquired during different sessions, in November 2018, March 2019, July 2019 and August 2019. For each session two different survey environment were used: urban and extra-urban, in order to analyze the system performances. Indeed, the location and the acquisition time were chosen to always guarantee the visibility of at least 4 Galileo satellites with a cut-off of 10° and of 6 Galileo satellites for the major part of the time. With regard to the other constellations, a peak of 11 satellites (GPS) and 9 satellites (Glonass) were respectively available for the survey (Figure 3).

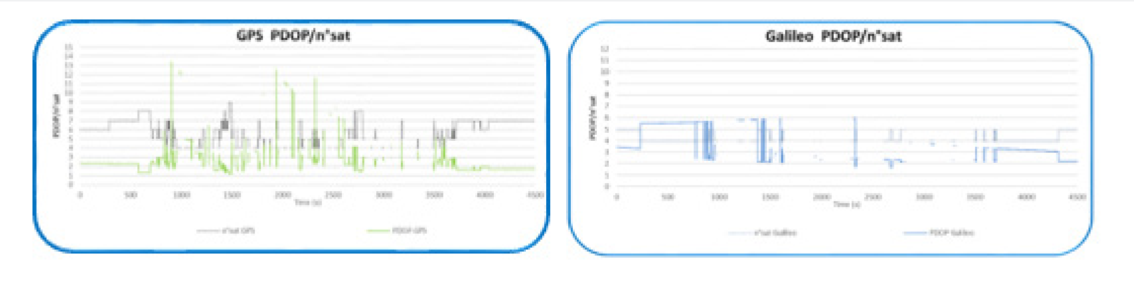

Figure 3: Satellite GDOP (geometric dilution of precision) and number of available satellites during the survey.

Figure 3 shows the number of satellites and the PDOP for one of the surveying sessions and clearly depicts the difference between the status of operability of GPS and Galileo positioning systems. The spikes in PDOP plot are generally due to cycle-slips or temporary loss of tracking of one or more satellites. From this point on view the GPS constellation feature the best configuration.

The full acquisition, made with both the Septentrio AsteRx-U receiver and the MMS, took almost one hour per survey at a sampling rate of 1 Hz. Septentrio AsteRx-U receiver acquired E1, E5a, E5b, E6 signals from the Galileo constellation. Before the beginning of each survey, a static session was executed to initialize the fixing of the phase ambiguities before the beginning of the next trip. This was also necessary to fulfill the aim of testing all the possible signal acquisition conditions during the survey (further details can be found in the next section). Lastly, the data of the Marussi GNSS network were downloaded to perform the subsequent differential post-processed position computation.

Data Processing and comparison method

The data process chain, implemented in this paper, can be summarized in three macro-phases:

a) Septentrio AsteRx receiver data differential position computation for the three considered constellations and for all the possible combinations;

b) MMS output computation;

c) Data filtering and comparisons.

As stated in the Introduction section all the comparisons were performed under the hypothesis that the MMS solution was more precise than the single differenced constellation solution. The single constellation differential solution was achieved by means of the GrafNav v.8.80 Novatel software.

Differential position computations

The aim of the differential position computations was to produce differential solutions for the whole set of Septentrio AsteRx acquired epochs and to perform the subsequent comparisons. Each computation was performed by using GrafNav v.8.80 Novatel software and using the selected permanent station data.

The most important solution data for the selected configuration file, are characterized for each epoch by: latitude, longitude

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and ellipsoidal height; a quality flag (in this case 1 for a fixed solution and 2 for a float solution), the number of used satellites, all the variance and covariances related to the 3D solution uncertainties. Lastly, all the geographic coordinates were projected in the UTM ETRS reference system using a specific software capability. This was made since we found more convenient to assess the comparison dealing with plane coordinates.

MMS output computation

POS LV system gives in output more than fifty data fields; the first one contains the main navigational data, computed in real-time and referred to the origin of the vehicle reference system.

Among the computed data: positioning parameters (latitude, longitude, and ellipsoidal height), run distance, vehicle attitude (roll, pitch and yaw angles), speed respect to North, East and z-axes, accelerations (in the vehicle reference system), angular speeds, measurements rms.

POS/LV system is built to integrate the data acquired from the different sensors, monitoring their health, isolating the sensors showing degraded performances and re-configuring, conveniently weighting data inputs, so to give in any case the best positioning and attitude values. Sensor errors are estimated on a continuous base using a Kalman filtering technique.

The system is calibrated thanks to the lever arms computing, to give the positioning data of any point of the vehicle. In order to compute the level arms and the reciprocal positions of the GPS antennas, a reflector-less total station has been used.

The reference trajectory was computed by post-processing the integrated GPS/INS data surveyed by the MMS. For this aim, the Position and Orientation System Post-Processing Package (POSPac™) Mobile Mapping Suite (MMS™) was used [24]. POSPac MMS with IN-Fusion™ technology (that provides a deep level of sensor integration and error modeling) provides multiple processing modes to handle different combinations of rover and reference GNSS data. IN-Fusion uses a centralized filter approach to combine the GNSS receiver's pseudo range and phase observables with the IMU data. As a result, Applanix IN-Fusion technology has continual access to all GNSS aiding information even if the GNSS receiver is tracking fewer than four satellites. Lastly, the provided geographic coordinates were projected in the UTM ETRS reference system.

The MMS output 3D trajectory computed using all the available satellites, was used as reference for the subsequent data filtering and comparisons.

Data filtering and comparisons

The comparisons were executed calculating epoch by epoch the differences between the computed solutions and the reference trajectory. Then, the Galileo results considered for the combinations of 4, 5, and 6 satellites were compared and statistically assessed with the analogous results of the GPS and the Glonass systems. From the POSPac™ solution (Figure 2) and using the ZUPD feature the kinematic epochs of the survey were identified. These epochs were used to extract the related kinematic part of the solutions both for the MMS system and for all the previously filtered solutions [25].

Results

MMS trajectory and GrafNav results

The differential solutions computed using Novatel GrafNav v. 8.80 software were achieved with a reference station close to the surveyed areas and belonging to the Marussi Friuli Venezia Giulia Region GNSS network. The reference station data (free of charge) used for the MMS solution already include Galileo acquisitions. The mean distance between the reference station and the vehicle, mounting both the MMS POS/LV system and the GS14 receiver, was less than 11,4km.

Moreover, a clear difference between the Galileo system, and the Glonass and GPS ones, relies on the cut-off angles associated to the best solution for each considered combination. This could be related to the increasing number of Galileo cycles slips (or loss of satellite tracking) occurred at lower elevation angles, whereas the opposite occurred for the other two constellations since the availability of many combinations with satellites characterized by high elevation angles. Moreover, the experimental results show for the GPS and Glonass constellations a high occurrence of good solutions achieved with the "fix and hold" method.

With regard the MMS solution, as the distance from the survey area and the nearest reference station (named "Trieste" and belonging to the "Antonio Marussi" network, managed by "Regione Friuli Venezia Giulia" [26]) was in the order of 11km, not requiring a network solution, the "IN-Fusion Single Base Station Processing" mode was chosen, reaching centimetric rms both in planimetric and altimetric positioning.

Comparisons results

The comparisons were performed in terms of and in terms of continuity discrepancy with respect the MMS solution considered as the reference. Precisely, the comparisons were executed only if for the same epoch, for the same type of solution (phase fixed solutions were separated from float solutions), and for the considered parameter (ΔE, ΔN, ΔH) were contemporary available at least one value for the Galileo solutions and at least one value for GPS or Glonass solutions.

The tests involved a huge amount data, produced to consider and compare the average behavior of all possible operative condition.

Table 1 shows, for the performed kinematic test, a strong evidence of the better performance of the Galileo system, both for the planimetric and altimetric components. This experimental evidence becomes even stronger with the increasing of satellite numbers, regardless of the considered constellation. In particular, in the Galileo and GPS comparisons and Galileo and Glonass comparisons, the GPS system performed slightly better than the Glonass system. Another important finding is the number of fixed solutions produced by the Galileo combinations. In fact, the reduced number of Galileo available satellites can lead to a very small available number of satellites combinations.

Table 1: Comparisons in terms of ΔE (m), ΔN (m) and ΔH (m) between the Septentrio AsteRx-U and MMS trajectories for GPS, Galileo, GPS/GLONASS, GPS/Galileo and GPS/GLONASS/Galileo in the urban context.

ΔN(m)					
	GPS L1 L2	**Gal E1 E5b**	**GPS L1 L2 GLO G1 G2**	**GPS L1 L2 Gal E1 E5b**	**GPS GLO Gal**
MAX	16.48	14.55	5.94	15.77	20.83
MIN	-5.62	-13.84	-6.04	-11.42	-11.81
MEAN	0.172	-0.089	0.175	0.033	0.114
STD DEV	1.216	1.061	0.652	1.233	0.829
epochs	3045	2435	3569	3589	3792
95% Accuracy	0.043	0.042	0.021	0.04	0.026
ΔE(m)					
	GPS L1 L2	**Gal E1 E5b**	**GPS L1 L2 GLO G1 G2**	**GPS L1 L2 Gal E1 E5b**	**GPS GLO Gal**
MAX	13.24	1.04	8.74	13.29	3.54
MIN	-3.13	-8.24	-6.27	-10.5	-10.23
MEAN	0.142	-0.151	0.17	0.043	0.054
STD DEV	1.042	1.131	0.764	0.847	0.508
epochs	3045	2435	3569	3569	3792
95% Accuracy	0.037	0.045	0.025	0.028	0.016
ΔH(m)					
	GPS L1 L2	**Gal E1 E5b**	**GPS L1 L2 GLO G1 G2**	**GPS L1 L2 Gal E1 E5b**	**GPS GLO Gal**
MAX	24.95	13.67	24.06	17.51	23.01
MIN	-2.26	-6.77	-3.55	-27.03	-25.96
MEAN	0.375	0.072	0.361	0.483	0.268
STD DEV	1.986	1.447	1.804	1.936	1.471
epochs	3045	2435	3569	3589	3792
95% Accuracy	0.071	0.057	0.059	0.063	0.047

Comparing the obtained solutions, we have strong evidence of the better Galileo performance characterized by planimetric solutions closer to the MMS trajectory.

From the altimetric point of view, the proposed scenario shows also a better performance of the Galileo system to respect to GPS and Glonass systems. This is more evident in the extra-urban environment than in the urban one, thanks to a higher number of acquired satellites.

Table 1 Comparisons in terms of ΔE, ΔN and ΔH between the Septentrio AsteRx-U and MMS trajectories for GPS, Galileo, GPS/GLONASS, GPS/Galileo and GPS/GLONASS/Galileo in the urban context

Discussion

In this study, the comparison between the novel Galileo satellite positioning system and the GPS and Glonass systems is proposed for an urban kinematic survey. The GNSS data were acquired with a Septentrio AsteRx GNSS receiver and compared with the output obtained by a Mobile Mapping System (MMS) implementing an integrated high-performance GPS/INS measurement. In particular, as far as the authors know, this is the first work that implements a precise MMS for the assessment of the kinematic performances of the Galileo system.

All the differential solutions were produced with the GrafNav v.8.80 Novatel software. Planimetric and altimetric results are very encouraging and should be considered, as stated by other authors (e.g. [3-5,10]), related also to the strong S/N ratios of the Galileo signals. The Authors, both as far as regards the planimetric and altimetric performances, have noticed an increasing performance correlated to the increasing number of satellites, compared to the previous tests and showed in Table 1.

Conclusion

In this study, a big computational effort was produced to analyze different kinematic surveys carried out using multi-frequency and multi-constellation Septentrio GNSS receiver. The acquired data include a contemporary acquisition with an MMS equipped with a POS/LV produced by the Applanix corporation. The MMS acquisition was used as reference trajectory and the robustness of its solution is the most important hypothesis for the results shown in this study. In particular, this hypothesis can be considered always valid for this study since it was found by coupling the GNSS technology with precise inertial instruments.

Moreover, thanks to the GNSS acquisitions of reference stations close to the surveyed areas was possible to implement post-processed differential solutions using GrafNav v.8.80 Novatel software. The performed comparisons were also analyzed by means of a statistical test. The results show a clear better, and statistically significant, planimetric and altimetric performance of the Galileo positioning system. From the showed results, it is possible to conclude that the novel system is very promising also alone, and in a disadvantaged comparison, was able to produce better planimetric and altimetric accuracies, in a kinematic survey, than the GPS and Glonass positioning systems. Future development of this work can include other kinematic inter-constellation comparisons, the evaluation of the robustness of velocity and acceleration estimation with the Galileo constellation and attitude estimations.

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References

1. (2017) ESA: Galileo Fact Sheet.
2. Steigenberger P, Hugentobler U, Montenbruck O (2013) First demonstration of Galileo-only positioning. GPS World 24: 14-15.
3. Simsky A, Mertens D, Sleewaegen JM, Hollreiser M, Crisci M (2008) Experimental results for the multipath performance of Galileo signals transmitted by GIOVE-A satellite. Int J Navig Obs 416380: 13.
4. Simsky A, Mertens D, Sleewaegen JM, De Wilde W, Hollreiser M, et al. (2008) Multipath and tracking performance of Galileo ranging signals transmitted by GIOVE-B. In Proceedings of ION GNSS, pp. 1525-1536.
5. Simsky A, Sleewaegen JM, Hollreiser M, Crisci M (2006) Performance assessment of Galileo ranging signals transmitted by GSTB-V2 satellites. In ION GNSS, pp. 1547-1559.
6. Hellemans A, A simple plumbing problem sent Galileo satellites into wrong orbits.
7. Langley RB, ESA discusses Galileo satellite power loss, upcoming launch.
8. European Union (2016) Galileo open service, signal in space interface control document (OS SIS ICD); European space agency/European GNSS supervisory authority.
9. ESA: Galileo: a constellation of navigation satellites.
10. Zaminpardaz S, Teunissen PJ (2017) Analysis of Galileo IOV+ FOC signals and E5 RTK performance. GPS Solut 21: 1855-1870.v
11. Steigenberger P, Montenbruck O (2017) Galileo status: orbits, clocks, and positioning. GPS Solut 21(2): 319-331.v
12. Tarantino E, Novelli A, Cefalo R, Sluga T, Tommasi A (2018) Single-Frequency Kinematic Performance Comparison between Galileo, GPS, and GLONASS Satellite Positioning Systems Using an MMS-Generated Trajectory as a Reference: Preliminary Results In ISPRS Int J Geo-Inf 7(3): 122.
13. Takasu T (2011) RTKLIB ver. 2.4. 2 Manual. Last Checked 2011, 9, 2011.
14. Caroti G, Piemonte A (2010) Measurement of cross-slope of roads: evaluations, algorithms and accuracy analysis. Surv Rev 42: 92-104.
15. Septentrio AsteRx-U.
16. Barzaghi R, Betti B, Biagi L, Pinto L, Visconti MG (2016) Estimating the Baseline between CERN Target and LNGS Reference Points. J Surv Eng 142: 04016012.
17. Leica Geosystems SmartNet ItalPoS.
18. Takasu T (2011) RTKLIB: An open source program package for GNSS positioning.
19. Subprocess — Subprocess management — Python 2.7.14 documentation.
20. Multiprocessing — Process-based “threading” interface — Python 2.7.14 documentation.
21. Novelli A, Aguilar MA, Aguilar FJ, Nemmaoui A, Tarantino EC (2017) AssesSeg Concurrent Computing Version of AssesSeg: A Benchmark Between the New and Previous Version. In: Springer, pp. 45–56.
22. Pyproj 1.9.5.1: Python Package Index.
23. Conversione Coordinate IGM.
24. Applanix Corporation, PUBS-MAN-001768- POSPacTM MMSTM GNSS-Inertial Tools Software Version 7.2, Revision 12 - User Guide, 2016.
25. Montgomery DC, Runger GC (2010) Applied statistics and probability for engineers; John Wiley & Sons, USA.
26. Regione Autonoma Friuli Venezia Giulia - Rete GNSS.

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