Assessing Galileo Positioning Using a Smartphone in an Airborne Platform

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Abstract

GNSS positioning and navigation capabilities using smartphones have seen a great development in recent years, allowing today a level of accuracy that was only achieved before using standard GNSS receivers. This is possible due to the fact that modern smartphones allow access to raw GNSS code and carrier-phase measurements, in particular to the Galileo and GPS multi-frequency signals.

This work presents results related with the performance of a Galileo enabled smartphone used in an aerial environment. The Xiaomi Mi8 smartphone, capable of recording dual frequency Galileo and GPS measurements, was mounted in an aircraft used in the scope of the aerial campaigns realized in the frame of the GRC-MS project (Galileo Reference Center - Member States). A Septentrio geodetic receiver, centimeter capabilities, was also installed in the aircraft to be used as reference in the comparison. Galileo-only, GPS-only and Galileo+GPS smartphone solutions, were computed using code and carrier-phase measurements in differential, as well as in standalone modes. Results show that, even with the non-optimal conditions for smartphone signal acquisition in these campaigns, the Galileo-only solutions reached the sub-meter level for the horizontal component and the combined Galileo+ GPS was at the sub-meter level, both in the horizontal and vertical components.

Keywords 1

Smartphone, Galileo, raw phase measurements, airborne

1. Introduction

Terrestrial navigation with GNSS enabled smartphones has definitely entered in everyday life of the common citizen around the world. Code based positioning is the core of the navigation applications that support many smartphone´s Apps. The introduction on the market, in 2016, of a new generation of smartphones allowing the users to access not only the pseudo-ranges, but also the Doppler and carrier-phase measurements, opened new prospects for PNT (Positioning, Navigation and Timing) based applications. As already demonstrated by several authors, (Elmezayen & El-Rabbany, [1]; Paziewski, Marco Fortunato, Mazzoni & Odolinski, [2]; Critchley-Marrows, Fortunato & Roberts, [3]; Uradziński & Bakuła [4] and Heßelbarth & Wanninger [5]) these paved the way for the achievement of centimeter level accuracy in static positioning, which, until then, could only be achieved with the more expensive and high performance GNSS geodetic receivers.

In its “White Paper on using GNSS Raw Measurements on Android devices” [6], the European GNSS Agency (GSA), responsible for promoting the use of the Galileo system, and also the exploitation of the smartphones potential for high accuracy positioning for the mass market applications, showed that a single frequency smartphone, with access to raw data, allows the user to achieve accuracies at the few decimeters level. In fact, results of 0.90 m and 0.62 m, respectively, for the horizontal and vertical

ICL-GNSS 2021 WiP Proceedings, June 01–03, 2021, Tampere, Finland
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components, with a 68% confidence level (one-sigma) are reported, using a combination of GPS and Galileo measurements in PPP (Precise Point Positioning) positioning mode, demonstrating the sub-meter potential in kinematic.

Proven the potential of smartphones for terrestrial navigation, we decided to assess the performance of a Galileo enabled smartphone, for aerial classical navigation and, also, for geodetic navigation, where the main goal is a posteriori determination of the position of a platform, equipped with geodetic sensors, along pre-defined profiles.

This paper presents the results obtained in 2 aerial campaigns that took place during 2019 and 2020. The smartphone used in our tests was a Xiaomi Mi8 equipped with a Broadcom BCM47755 chipset [7] with access, among others, to dual frequency Galileo and GPS signals (E1/L1, E5a/L5). The main goal of the tests was to analyze and process the Galileo and GPS raw measurements to assess the quality of the respective solutions through the comparison with a reference solution. The other GNSS systems, namely GLONASS and BeiDou, were not analyzed, mainly because the double frequency measurements for these two systems were not available. Our results show that, even today, with a still incomplete Galileo constellation, it is possible to achieve Galileo only solutions with decimeter accuracy using the differential positioning mode and processing the measurements with the double-differences model to eliminate common errors, provided that we have a good satellite geometry. For the standalone SPP single frequency solutions, errors are generally below 4 and 6 meters, respectively in the horizontal and the vertical components. This allows us to advance that, with Galileo entering its Full Operational Capability (FOC), a smartphone Galileo enabled, with access to raw measurements in two frequencies, has the potential for being used as a low-cost device for geodetic, where the main goal is a posteriori determination of the position of a platform, equipped with geodetic sensors. As well as for classical aerial navigation this can be quite useful for small aircrafts, especially those used for leisure, as a complement to the Visual Flight Rules (VFR). It is already common to use code-only GNSS low-cost devices, or smartphones, with single frequency, to navigate with small aircrafts. This is actually the case with the CESSNA C210 used in our tests, where there is no GNSS based navigation system incorporated in the airplane.

2. Fields campaigns

In the scope of the GRC-MS (Galileo Reference Center – Member States) Project, funded by GSA (European GNSS Agency), which aims at assessing Galileo performance in its different aspects, the group from the FCUP (Faculty of Sciences University of Porto) is responsible for assessing the Galileo performance for aircraft positioning and navigation. Several aerial campaigns (4/year) have been realized since Fall 2018 until present. An article was recently submitted to Inside GNSS which includes results from 4 additional campaigns.

Profiting from the availability of the aircraft, the group from FCUP decided to take onboard the aircraft also a smartphone with capability to collect GNSS raw measurements, in particular Galileo and GPS, aiming at assessing its potential to be used as a low-cost device for aerial navigation and georeferencing.

A Xiaomi Mi8 smartphone was then mounted in the back top window of a CESSNA C210 airplane as shown in Figure 1. Xiaomi can receive measurements in multiple frequencies (L1, L5, E1, E5a)

Figure 1: CESSNA C21A airplane (left), Xiaomi Mi8 and AeroAntenna positioning (right)

In the aircraft, a multi-frequency PolaRx5 Septentrio receiver [8], with a dedicated multi-frequency AeroAntenna, which allows the acquisition of multi-constellation, multi-frequency signals (L1, L2, L5, E1, E5a, E5b, E6, G1, G2, B1, B2, B3) from all GNSS systems available today, was also mounted for the purposes of the GRC_MS project. The Xiaomi antenna located in the upper left corner of the smartphone´s screen was aligned with the Septentrio antenna by the fuselage rivets and the leverarm was obtained using a tape. To refer the smartphone and Septentrio coordinates to the same reference point the following values were used: x=1.10 m; y=0.00 m; z=0.30 m, as shown in Figure 2.

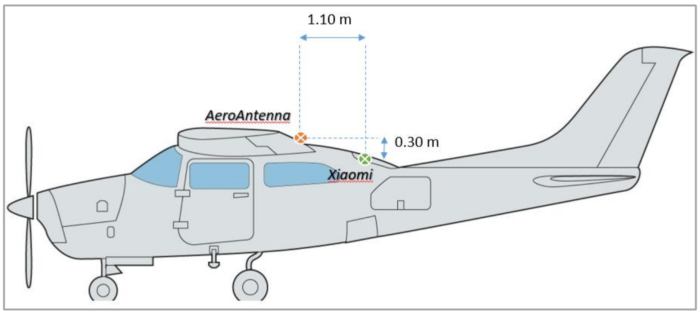


Figure 2: Leverarm between smartphone antenna and the AeroAntenna

The GNSS raw data from the Mi8 was collected using the Geo++ RINEX Logger App at 1 Hz [9], which generates files in RINEX format 3.03. The Septentrio receiver was also set to collect data at 1 Hz. The data analyzed in this work was collected in two of the GRC-MS aero campaigns, whose trajectories are shown in Figure 3. One campaign took place in October 7, 2019 and the other in June 10, 2020. For the relative positioning a permanent reference station, equipped with a multi-frequency Trimble Alloy receiver and a Zephyr GNSS Geodetic II antenna, located at the AOUP (Astronomical Observatory of the University of Porto) facilities was used. Coordinates were computed in the ITRF2014 frame at the observations epoch.

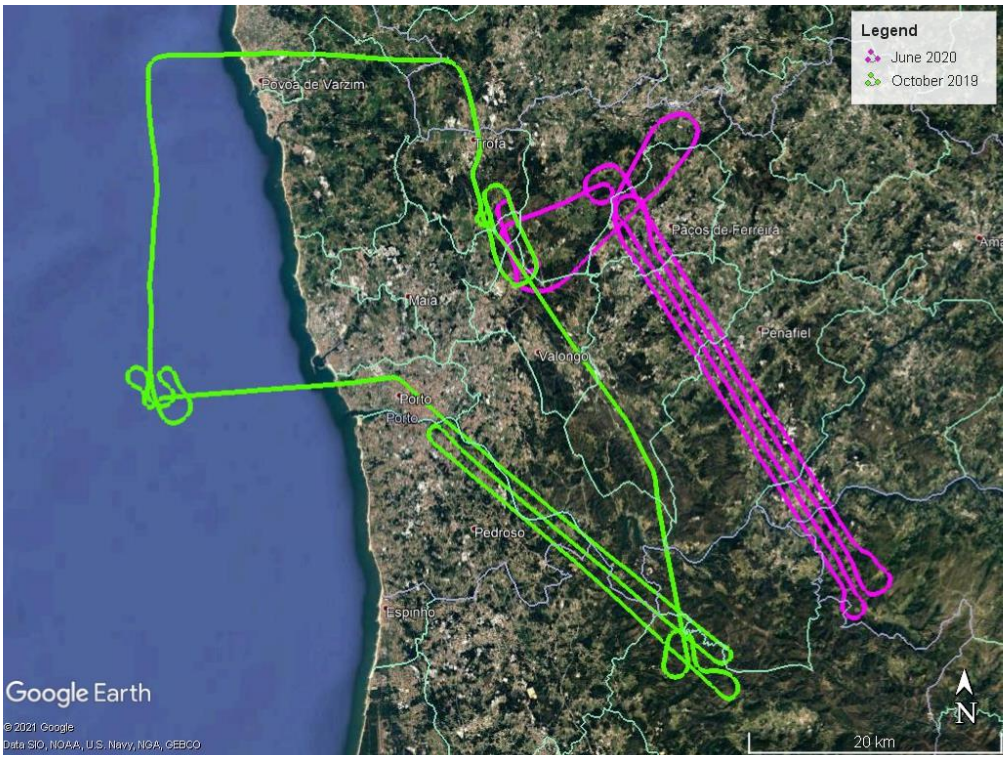


Figure 3: Trajectories followed during the two GRC-MS aero campaigns used in this analysis

3. Data analysis and processing results

PVT (Position, Velocity and Time) solutions were calculated in post-processing using the RTKLIB Demo5 [10] software, based on the RTKLIB [11]. Double frequency (DF) differential solutions, for Galileo-only, GPS-only and Galileo+GPS combined observations, were obtained using code and carrier-phase measurements.

Figure 4 shows the Galileo and GPS skyplots during the two campaigns.

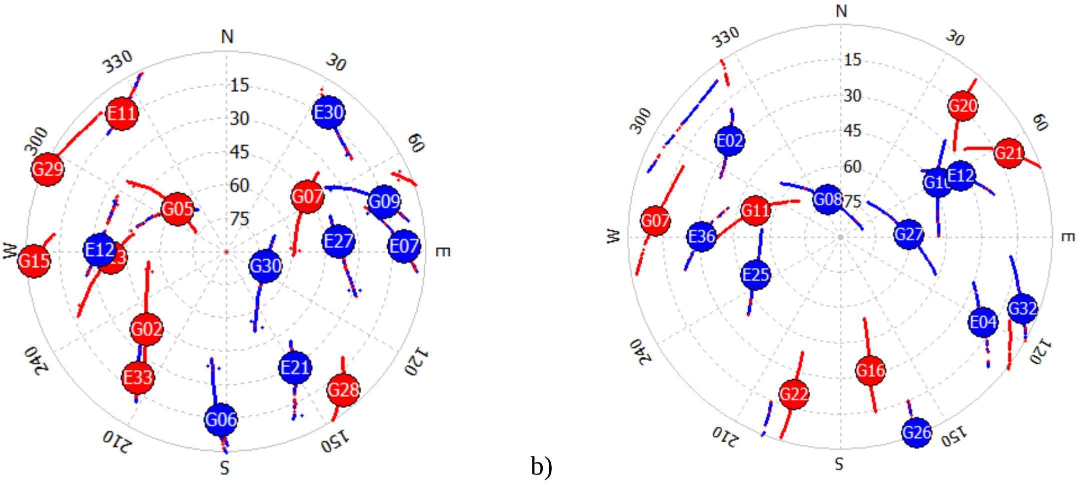
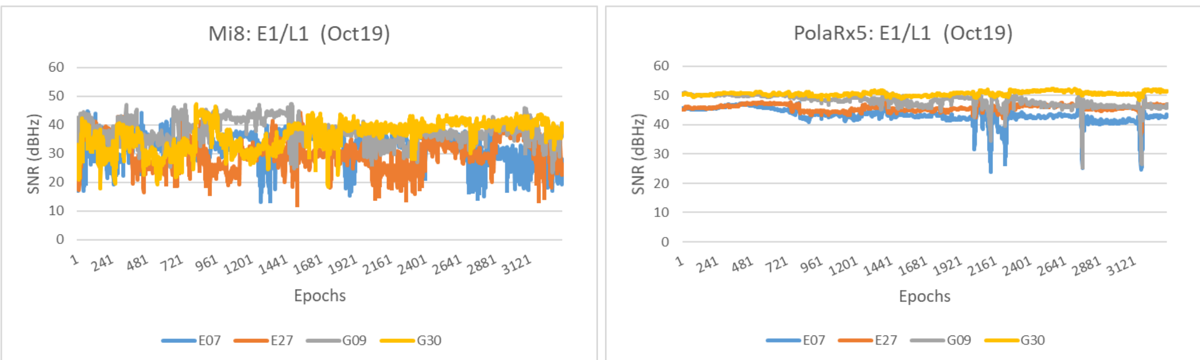


Figure 4: Skyplot for October 2019 (a) and June 2020 (b) campaigns. **E** stands for Galileo satellites and **G** for GPS satellites

The SNR (Signal-Noise-Ratio) of the Galileo E1/E5a and the GPS L1/L5 signals, acquired by the Xiaomi Mi8 smartphone and the Septentrio PolaRx5 receiver are shown in figure 5 only for some of the satellites in order to facilitate the readability. Two low and two high Galileo and GPS satellites were chosen. As we can see from the skyplot in figure 4, the low satellites shown for the October 2019 campaign were the E07 and G09 and for the June 2020 campaign the E04 and the G32. The high satellites shown were the E27 and G30 for October 2019 campaign and the E25 and G08, for June 2020 campaign.



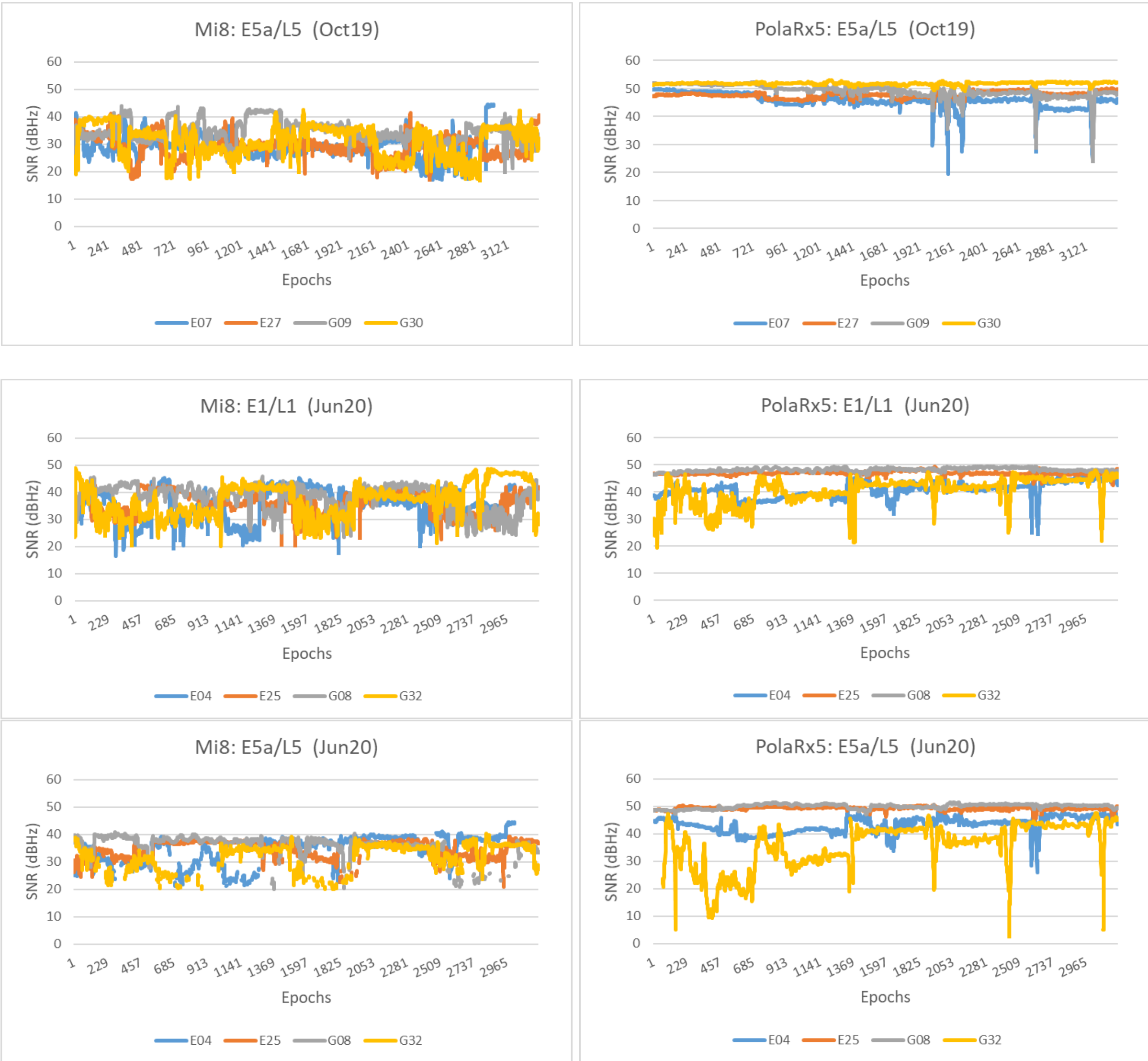
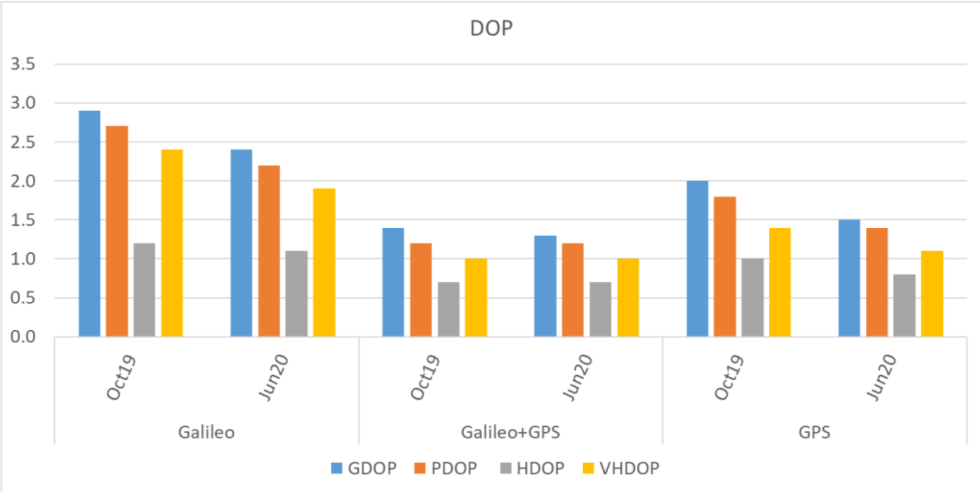


Figure 5: SNR for the Xiaomi Mi8 smartphone (left) and the Septentrio PolaRx5 (right) measurements for two Galileo and two GPS satellites for the E1/L1 and E5a/L5 bands

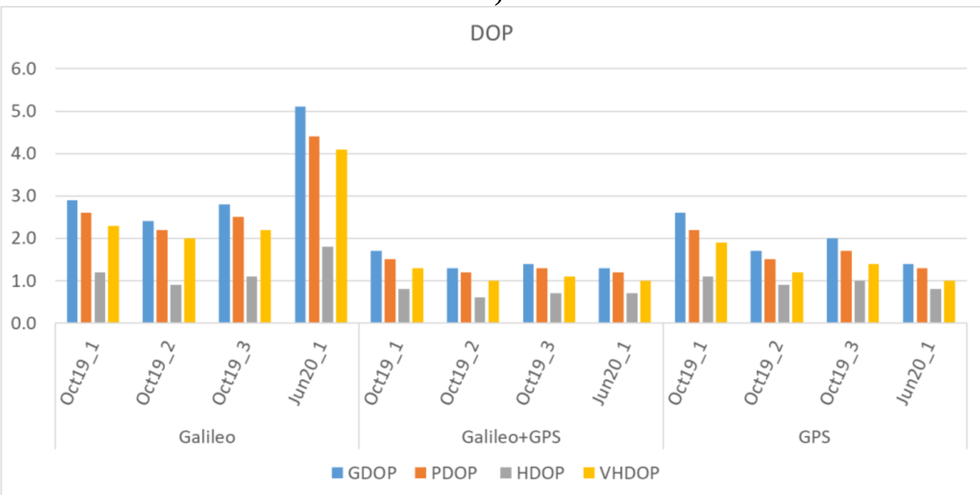
As expected, the SNR from the Mi8 is lower than that of the PolaRx5, due to the limitations of the Planar Inverted-F Antenna (PIFA) type of antenna. The lower SNR is most noticed for the E5a/L5 signals. Due to the airplane maneuvers the signal from the low satellite G32 shows significant oscillations for the PolaRx5. This is not seen in the Mi8 signals, because the Mi8 loses more times the signals and therefore those spikes are no present. As, due to some constrains, the smartphone was positioned in a less adequate location (inside the rear window of the aircraft), this can be an additional reason for the attenuation of the signals.

Having in mind the assessment of the smartphone solutions for classical aerial navigation, SPP solutions for the full flight trajectories were computed. For assessing the ability of the smartphone for geodetic navigation some profiles were selected in each aerial campaign. Unfortunately, the flight maneuvers caused a lot of signal loss and a good differential solution was not always possible. Therefore, our analysis has been restricted to a few profiles.

Four flight profiles (discarding maneuvers parts) were chosen in the two campaigns to compute kinematic differential solutions. Three of these profiles were flown during the October 2019 campaign and one during the June 2020 campaign. Figures 6 and 7 show the average DOP (Dilution of Precision) and number of satellites for each profile analyzed.

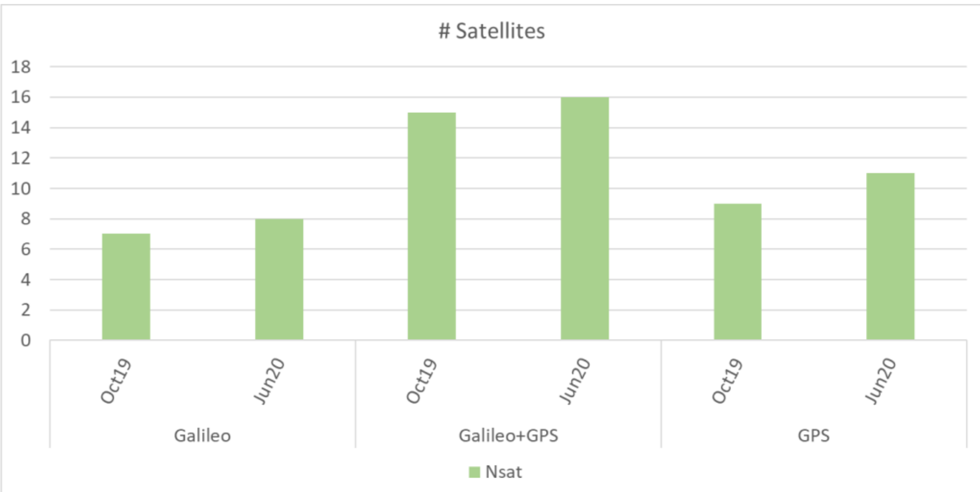


a)

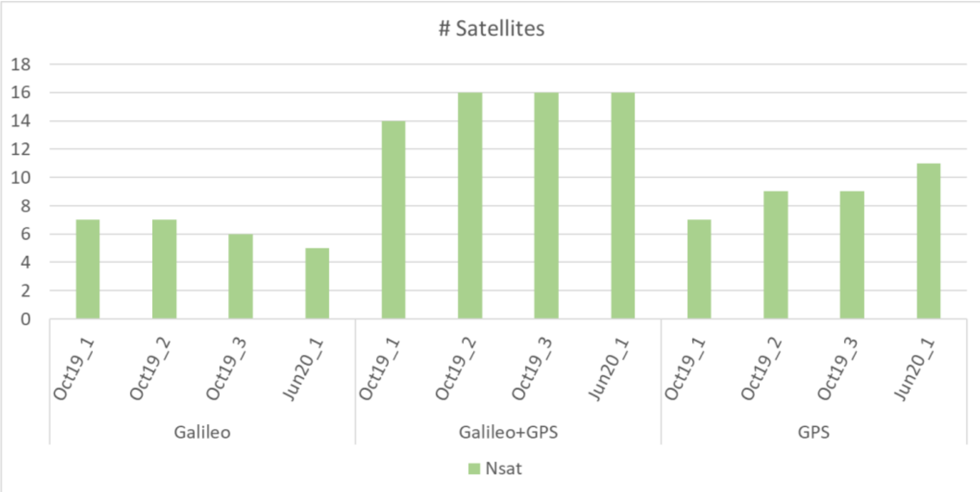


b)

Figure 6: Dilution of Precision for the full campaign (a) and during each flown profile (b)



a)



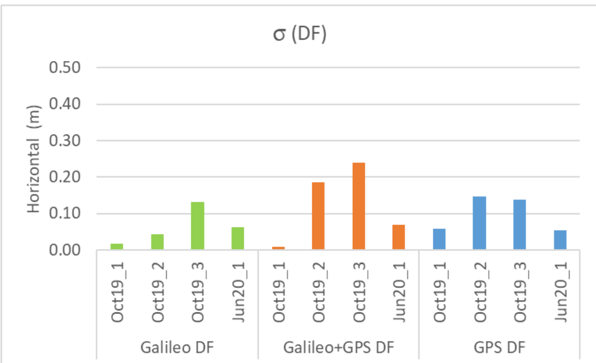
b)

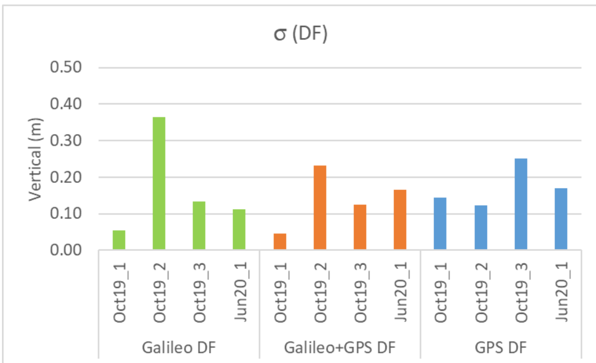
Figure 7: Average number of satellites for the full campaign (a) and during each flown profile (b)

Absolute single frequency SPP (Single Point Positioning) code solutions were also computed using the E1E5a/L1L5 frequencies from Galileo/GPS and broadcast ephemerides. A 10º elevation mask was considered and the Klobuchar [12] model was used in the Galileo and GPS solutions for ionosphere corrections, as well as the Saastamoinen [13] model for the tropospheric corrections.

For the reference trajectory differential triple frequency (TF) solutions, obtained with the combined Galileo+GPS measurements from the Septentrio PolaRx5 receiver, using the E1/L1, E5a/L5 and E5b/L2 frequencies, were computed using RTKLIB with the same settings referred above. Over the all GRC campaigns, the solutions precision obtained with the PolaRx5 receiver when compared with independent GNSS/IMU and GPS/GLONASS PPP has shown values of less than 5 cm in the horizontal component for 95% of the times, while the vertical component values vary between 13 -25 cm.

Figures 8 and 9 show the statistics for the dual frequency (DF) differential solutions and the SPP (Single Point Positioning) solutions. The standard σ, mean and 95% confidence interval, obtained from the comparison between the Mi8 smartphone solutions and the Septentrio PolaRx5 Galileo+GPS triple frequency (E1/l1, E5a/L5, E5b/L2) solutions, used as reference, are shown.
Figure 8 shows the statistics for the differential solutions.





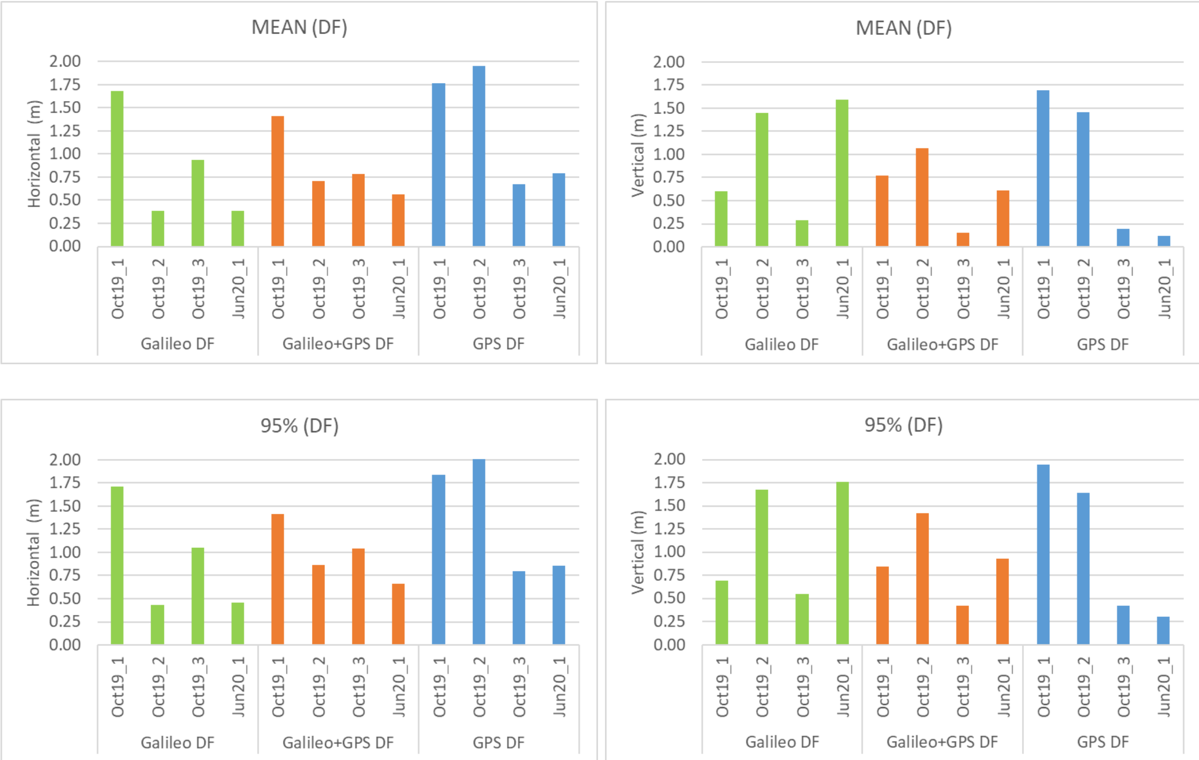
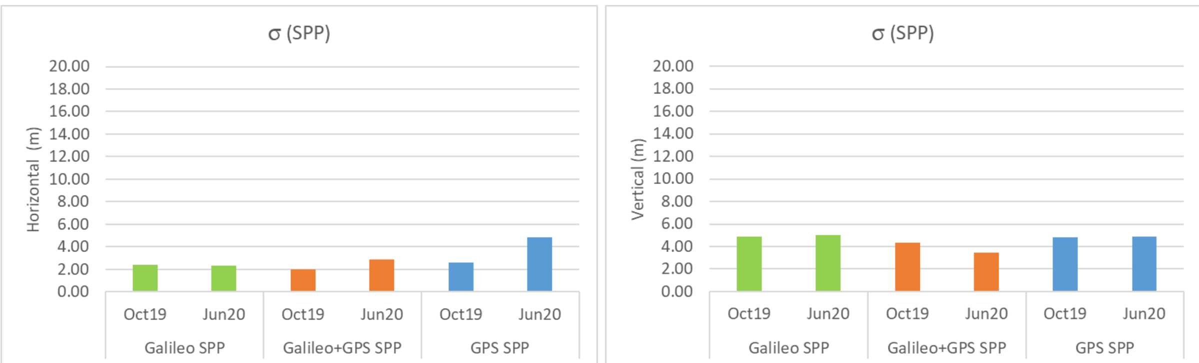


Figure 8: Differential solutions statistical analysis

From the figure we can see that the Galileo horizontal solutions have σ with values generally below 0.20 m. For the vertical, results are worst, but still below 0.40 m. Looking at the 95% confidence interval for all profiles, values reach the 1.75 m. However, for two of the profiles, values are under the 0.50 m for the horizontal and under 0.75 m for the vertical.

For the DF results, Xiaomi Galileo only results are of better or identical quality as the GPS only results. Taking into account that the geometry for the GPS constellation is generally better, and with more visible satellites (see figures 6 and 7 above), than the Galileo constellation, the Galileo only results seem quite good.

As mentioned before, SPP results were also computed. Figure 9 shows the statistics for these SPP solutions.



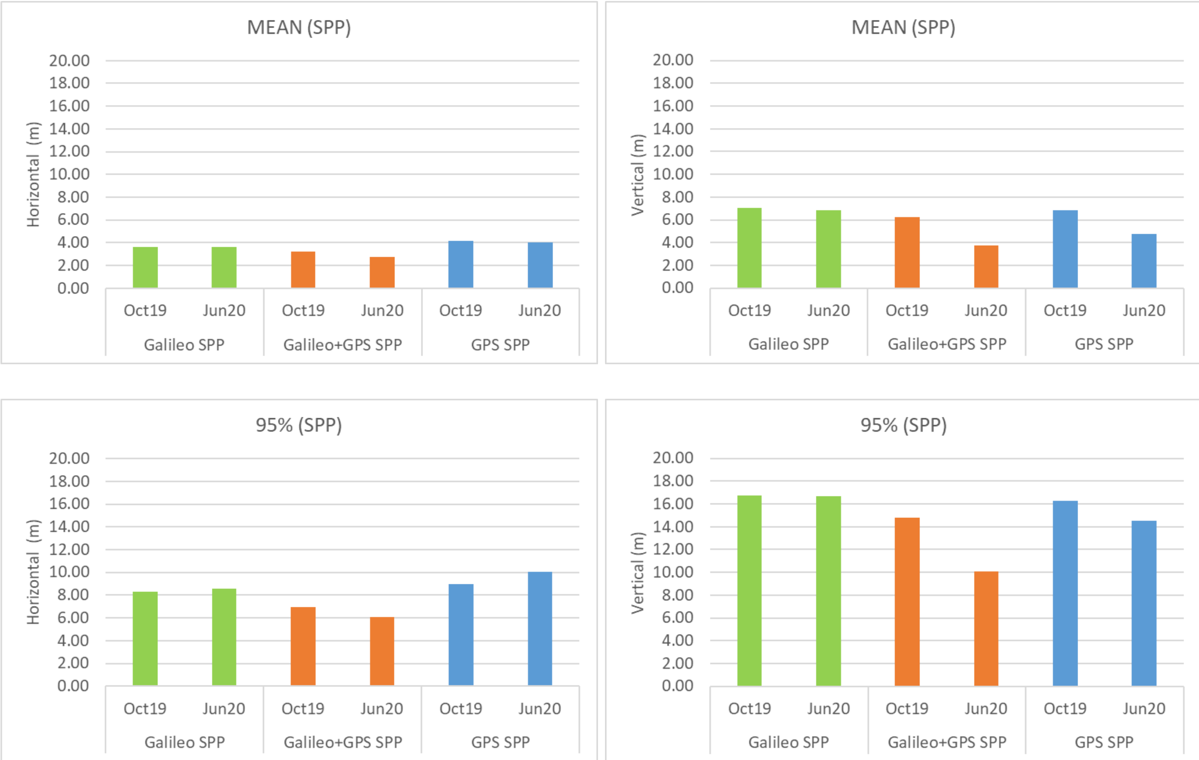


Figure 9: SPP solutions statistics analysis

The standard deviations of the Galileo only SPP solutions, computed for the full trajectory (including maneuvers) reached 2 m in the horizontal and 5 m in the vertical. Looking at the 95% confidence interval we can see that values are near the 8 m for the horizontal and 16 m for the vertical. These high values are mainly due to loss of signal during maneuvers, (when errors grow substantially), that are most felt by the Xiaomi due also to its unfavorable location at the rear window. Nevertheless, also for the Xiaomi SPP solutions, Galileo also delivers better solutions than GPS.

4. Conclusions

The results obtained show that a GNSS enabled smartphone, with access to dual frequency signals, can be explored to obtain sub-meter precision, in differential mode, in a kinematic aerial survey.

Looking to the accuracy of the SPP results we can see that, at this point, they do not comply with the requirements for performance based aerial navigation indicated in the GSA GNSS Market Report [15] for the Instrument Flight Rules (IFR) operations. In fact, while for the horizontal component, the accuracy is well below the required 16 m for 95% of the time, for the vertical the values are well above the required 4 m for 95% of the time.

Some improvements can still be made, like installing the smartphone in a more convenient location in the airplane and turn the duty cycle off [16], which was not done in the two campaigns presented.

Nevertheless, and in spite of the fact that satellite coverage still presents periods with few satellites and poor geometry, we can conclude that Galileo-only can deliver results of better or identical quality than GPS-only both in differential and SPP modes.

This is very interesting as one can expect that with the Galileo FOC, the potential of smartphones to deliver geodetic quality results will be confirmed, as well as its capacity to fulfill the accuracy requirements for aerial navigation, being a valuable tool for en-route navigation as a complement to the use of Visual Flight Rules (VFR).

Furthermore, with the conclusion of GPS modernization, we can foresee that the improvement of the combined Galileo+GPS solutions will foster new smartphone based applications and a change in paradigm in navigation and mapping.

5. Acknowledgements

We acknowledge the support of the GRC-MS (Galileo Reference Center – Member States) Project, funded by GSA (European GNSS Agency), for the aerial field campaigns.

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