State of the Art of the Agriculture Professional GNSS Receivers

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Abstract

The aim of this paper is to present the outcomes of the agriculture testing campaign performed by Thales Alenia Space Italia in the implementation of a contract signed with the European GNSS Agency (GSA) and financed by the European Union under the Galileo Programme budget. The main objective of the test campaign is to evaluate the performance of a set of professional GNSS receivers, highlighting the added value of using the Galileo system in the GNSS market segment of agriculture Machine Guidance, in particular from the end user point of view. This paper will present anonymized performance of eight agriculture receivers, tested in parallel under the same live conditions, considering different configurations and augmentation modes. More specifically, GNSS Single Point Positioning (with both single frequency (SF) and multi-frequency (MF) approach), Satellite Based Augmentation System, Precise Point Positioning and Real Time Kinematic modes have been tested with single-constellation and multi-constellation (MC) configurations, considering GPS, Galileo and GLONASS. The most relevant Key Performance Indicators (KPIs) for agriculture-related applications, such as cross-track accuracy and repeatability have been assessed per each test case. The results have shown that Galileo standalone configuration provides similar or even better performance than GPS standalone, despite the lower number of available satellites with respect to GPS. Moreover, it is also confirmed that its use in a multi-constellation configuration, especially for standalone positioning, enhances the performance for both positioning accuracy and availability.

Keywords 1

GNSS, Galileo, Agriculture Market Segment.

1. Introduction

In recent years, an increasing number of applications started to rely on Global Navigation Satellite Systems (GNSS) to provide improved services to their users, thanks to the possibility to get accurate Position, Navigation and Timing (PNT) solutions with cost-effective devices.

Among the other GNSSs, the satellites and ground infrastructure of the European navigation system Galileo were declared operationally ready on December 2016. In that moment, the Galileo Initial Services started to be offered worldwide. The performances and limitations of the Galileo Initial Services, together with the system configuration, are described in [1]. Galileo offers a highly accurate service but, for the time being, the system is not yet in Full Operational Capability (FOC), therefore the performance will further increase when the full constellation will be available. Information related to the Galileo satellites available for Position, Velocity and Time (PVT) computation can be found in [2].

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In the last years, encouraged especially by the benefits provided by the use of multi-constellation systems, GNSS receiver manufacturers have started to provide to their users the possibility to exploit also Galileo signals. For this reason, the European GNSS Agency (GSA) decided to carry out dedicated testing campaigns to check the status of the Galileo implementation in professional receivers. In 2018, a first testing campaign was performed to support the Geographic Information System (GIS) community. Interesting results have been derived from that, considering also the limited number of satellites available for the PVT computation, [3]. Due to these encouraging results and the increasing interest of Precision Agriculture on GNSS-enabled solutions, on July 2020, a second campaign has been carried out, this time addressing the agriculture market segment. The data collection has been performed with a number of twenty-two active Galileo satellites.

In order to provide information regarding the state of the art of the GNSS in the agriculture market segment, in this work the performance of eight professional GNSS receivers has been evaluated and compared.

Similarly to the testing activities performed in [3], the main objectives of this campaign were:

1. to support the professional receiver's manufacturers in fine-tuning the implementation of Galileo within their receivers and pointing out the benefits on its use;
2. to highlight the added value of using the Galileo system in the GNSS market segment of agriculture Machine Guidance, in particular from the end user point of view;
3. to assess the added value of Galileo in multi-constellation receivers, including an assessment of where today Galileo is with respect to the other GNSSs.

It is important to remark that the scope of this activity was not the validation of the Galileo system, but the assessment of the benefits on using Galileo by end users whom will use agriculture receivers currently available in the market.

Since each agriculture application requires a specific level of accuracy, as described in [4], different positioning modes have been tested in this testing campaign:

- Single Point Positioning (SPP, also referred to as Standalone Positioning);
- Satellite Based Augmentation System (SBAS);
- Precise Point Positioning (PPP);
- Real Time Kinematic (RTK).

In addition, multi-frequency and multi-constellation configurations have been also tested, in order to evaluate the increase of the accuracy and availability of the PVT solution. In particular, for MF test-cases all the available frequencies supported by the receivers have been enabled for the PVT estimation:

- GPS: L1/L2/L5;
- Galileo: E1/E5a/E5b/E5AltBOC
- GLONASS: L1/L2/L3

The paper is organized as follows. In Section 2, the set-up of the testing campaign has been described together with the main KPIs relevant for the agriculture market segment. The main results of the testing campaign have been presented in Section 3, through the comparison of the performance of the tested receiver, the demonstration of the Galileo added values and the summary of the agriculture receiver status. Finally, the conclusions of this work are drawn in Section 4.

2. Agriculture test campaign set-up and KPIs

The test set-up has been organized in a way so that only the performance of the GNSS receivers were tested and evaluated. IMU and other sensors or also processing on machine guidance device/software side thus have not been considered.

One of the main objectives of the testing campaign is to assess the added value of Galileo in multi-constellation receivers, including an assessment of where today Galileo is with respect to the other

GNSS, in particular GPS and GLONASS. The testing campaign envisaged different test-cases in Open Sky conditions, which is the most relevant scenario for agriculture market segment, with the duration of three hours per each, testing different configurations and augmentation services.

To obtain comparable results under the same conditions and to ensure the repeatability of the test as well as an easy controllability of the same, a rail track and a carriage were used to perform the test, instead of real tractors able to be automatically driven by a configurable GNSS receiver. In particular, tests were performed in parallel by connecting all the Receivers Under Test (RUTs) to the carriage on the rail track. During each test-case, the carriage performed several working lines, from point A to point B, as shown in Figure 1.

Figure 1 Testing Campaign Working Line

After reaching point B, the carriage was driven on reverse mode up to the point A, in the following line, stop and then continue forwards the rail track towards to the point B. This job lasts approximately 2 minutes, depending on the carriage speed (nominally 7 km/h). It shall be noticed that the rail track ensures a smooth trajectory, without the typical deviations and vibrations of real agriculture applications, due to the field irregularities.

For each test case, the following agriculture-related KPIs have been assessed:

- **Trajectory Error** is the variation between the actual tilling trajectory with respect to the reference one. As it is often used in Precision Agriculture applications, the trajectory error will be provided in terms of **cross-track accuracy**.
- **Repeatability** (or year-to-year) is generally understood to mean the ability of a GNSS receiver or GNSS guidance system to bring the user back to the exact same spot in the field reliably each time the tractor drives into the field, from year to year. It is worth mentioning that ‘year-to-year’ is a term used in agriculture community and it is generally used to mean absolute accuracy.

In Figure 2, the methodologies for the calculation of these KPIs are presented, having considered also [6] and [7]. In particular, the cross-track error has been calculated as the difference between the instantaneous estimated position with respect to the “true trajectory” in the transversal direction to the corresponding rail track, while for this testing campaign the repeatability has been calculated as the 95th percentile of the absolute horizontal accuracy provided by the receiver on two fixed points, indicated as A and B in Figure 2. With regards to the latter point, the reader should interpret the repeatability as absolute horizontal accuracy for comparison purposes with other testing campaigns.

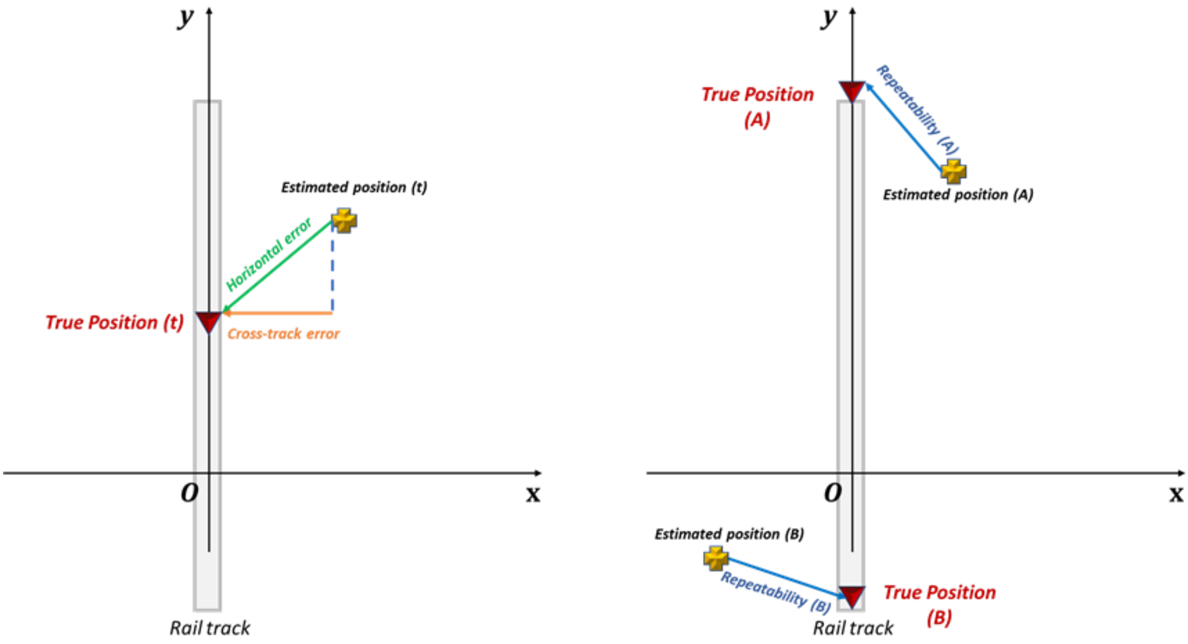

Figure 2: Agriculture-related KPIs: cross-track error (on the left) and repeatability (on the right).

Six RUTs over eight are smart antennas, while the other two receivers were connected to a single shared external antenna. It is worth mentioning that the Test Site was equipped also with a Single Base Station, able to stream RTCM (Radio Technical Commission for Maritime Services) corrections to the RUTs, in order to perform RTK test cases.

For each test case, the reference "true" trajectory has been estimated by exploiting a commercial third-party post-processing tool, that is able to provide kinematics solution by using the rover and base station's observables, reaching cm-level 3D accuracy. This is used to benchmark RUTs performance by using an external tool that is not dependent on the receivers' proprietary algorithms.

The performance has been evaluated with real-time positions computed by the receivers and, consequently, by using NMEA (National Marine Electronics Association) messages.

Considering the main objectives of the testing campaign, a test duration of 3 hours is a fair trade-off between the high number of test cases to be executed and the quality of the results obtained. Furthermore, 3 hours of data collection are able to provide a relevant number of samples for performance estimation, as the scenario of interest is Open Sky.

3. Agriculture test campaign results

The main results of the agriculture testing campaign are derived through the evaluation of the performance achieved by the tested receivers in terms of cross-track accuracy and repeatability.

3.1. Receivers Performance Comparison

The performance of the tested receivers has been compared considering different positioning modes. More specifically, as introduced in Section 1, both the configuration without corrections (SPP) and the results achieved by applying augmentation strategies (SBAS, PPP and RTK) have been analyzed.

The comparison of the performance achieved by the different receivers for the cross-track accuracy and the repeatability is shown in Figure 3 and Figure 4, respectively, where histograms representing the 95th percentile of the related errors are displayed for each positioning mode.

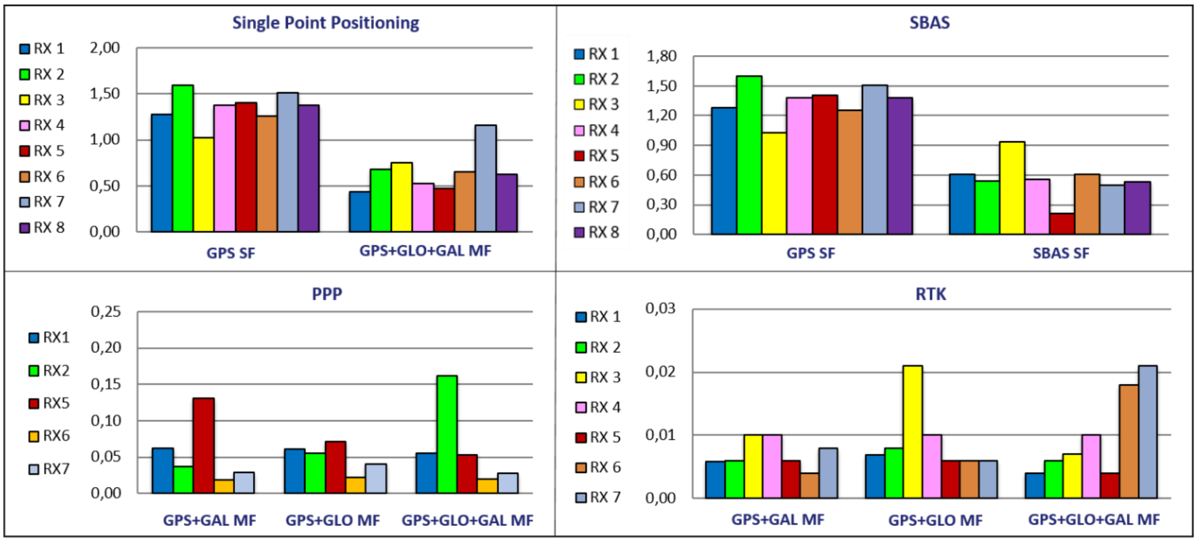

Figure 3: Cross-track Accuracy Histogram [m].

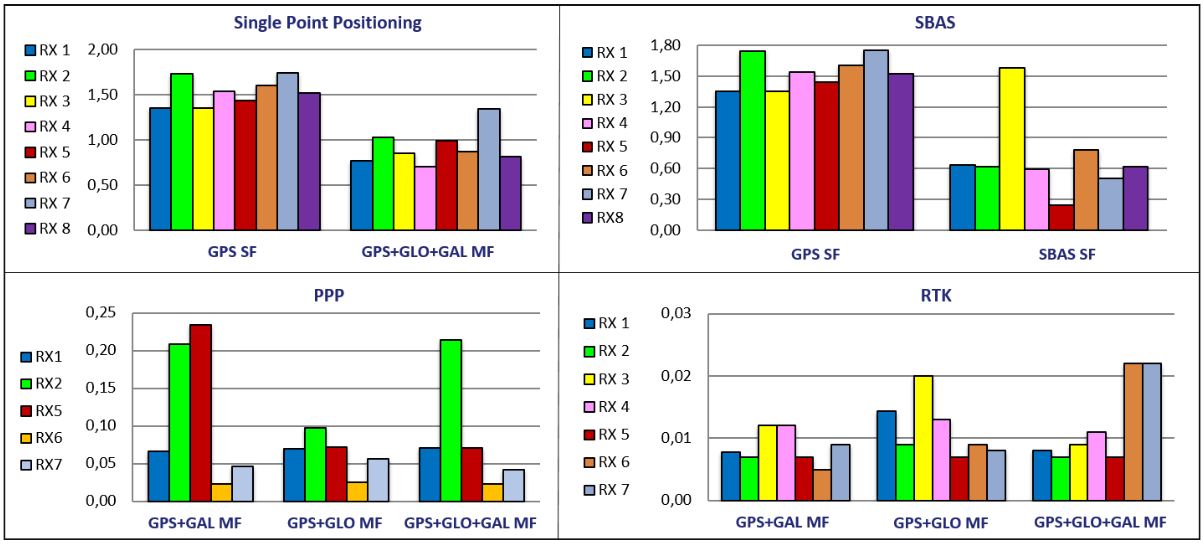

Figure 4: Repeatability Histogram [m].

A selection of the most relevant results among all the tested configurations is shown in these figures. In particular, from Figure 3 and Figure 4, it is possible to notice that the exploitation of enhanced configurations, such as the MC-MF approach, with GPS, Galileo and GLONASS constellations and all their frequencies enabled, provides a significant improvement in performance in terms of cross-track accuracy and repeatability with respect to the standalone GPS in SF mode for all the tested receivers. This is mainly due to the fact that the multi-constellation configurations provide better HDOP, as the number of satellites available for the PVT computation increases.

The SBAS-aided positioning performances are compared only with GPS SF (L1 band), as at the time of writing this is the only configuration supported by EGNOS. As expected, the application of SBAS corrections on GPS L1 noticeably improves the positioning performances over the standalone GPS SF configuration, reaching cross-track accuracy down to 60 cm for almost all the tested receivers.

For PPP and RTK positioning modes, only MC configurations with all frequencies enabled have been tested, as they represent the situation closest to the end user's needs.

From Figure 3 and Figure 4, it is apparent that not all the receivers could perform PPP test-cases. However, all the tested configurations provide excellent performance in line with expectations [5] for almost all the RUTs that support PPP, thus representing a suitable choice for applications requiring dm-level accuracy, such as Machine Guidance. On average, triple-constellation configuration provides better performance, especially in terms of cross-track accuracy, with respect to double-constellation configurations, except from one receiver that probably does not properly manage the three different constellations.

Finally, when RTK mode is used, all the receivers achieve cross-track accuracy and repeatability at cm-level, being able to meet the stringent requirements of the most demanding applications such as Automatic Steering and Variable Rate Application (VRA), as defined in [4].

3.2. Galileo Added Value

As previously mentioned, one of the objectives of this work is to evaluate the performance of Galileo and assess it versus other GNSS. The results of this testing campaign have shown that in most of the tested configurations, Galileo brings an added value in terms of cross-track accuracy and repeatability. Indeed, although the Galileo constellation was not yet fully deployed, it is recorded that Galileo provides better positioning accuracy performance than GPS, in terms of cross-track accuracy and repeatability, reaching sub-meter level in Open-Sky scenario.

An example of results showing the added value of Galileo is reported in Figure 5, where the Galileo SPP and GPS SPP, both with all frequencies enabled, are compared through the Cumulative Distribution Functions (CDFs) of the cross-track accuracy (on the left) and the repeatability (on the right) for one of the tested receivers.

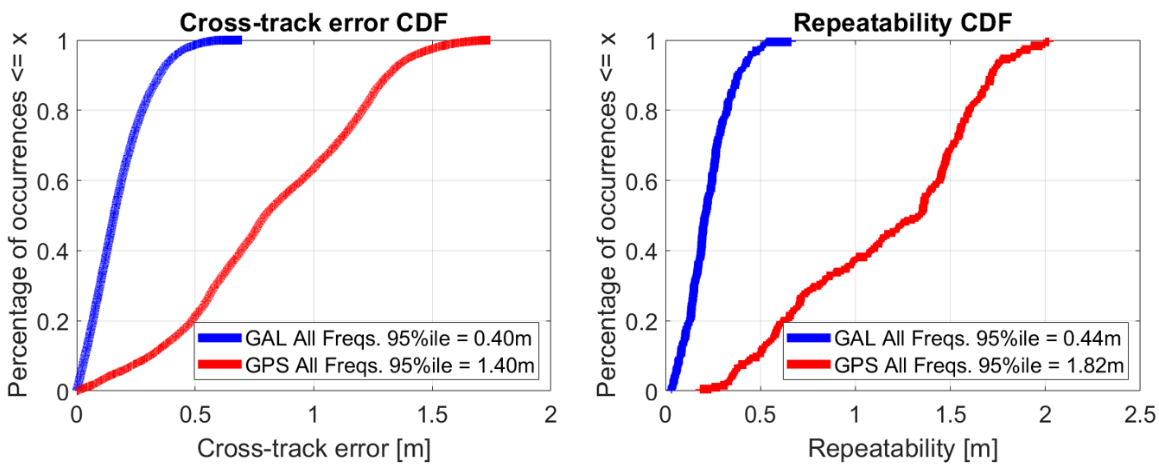

Figure 5: Galileo vs GPS agriculture performance: CDF of cross-track accuracy (left) and CDF of Repeatability (right).

Aiming at showing the overall comparison of GPS and Galileo in SPP mode, in Figure 6, the performance achieved by all the considered RUTs are shown for different combinations of frequencies and constellations. On average, Galileo provides very similar or even better cross-track accuracy with respect to GPS (despite a higher HDOP due to the low number of satellites). It also provides better repeatability with respect to GPS for almost all the receivers. Moreover, it is important to underline that the results have shown an availability always at 100% for all the tested receivers when Galileo signals are exploited, except from one receiver that is not able to perform PVT when less than 5 usable satellites are present. On the other hand, it is worth to highlight that some of the tested receivers do not support Galileo only positioning mode, so a full comparison was not possible for all the receivers, as it is evident in Figure 6.

The Galileo added value can be also seen in multi-constellation configurations, that is reported in Figure 6 for comparison. This aspect is apparent also observing the results shown in Figure 3 and Figure 4, where we have already underlined that the exploitation of more GNSSs leads to an improvement in performance with respect to those achieved by GPS standalone positioning mode, especially thanks to the better HDOP provided by a higher number of satellites available for the PVT estimation.

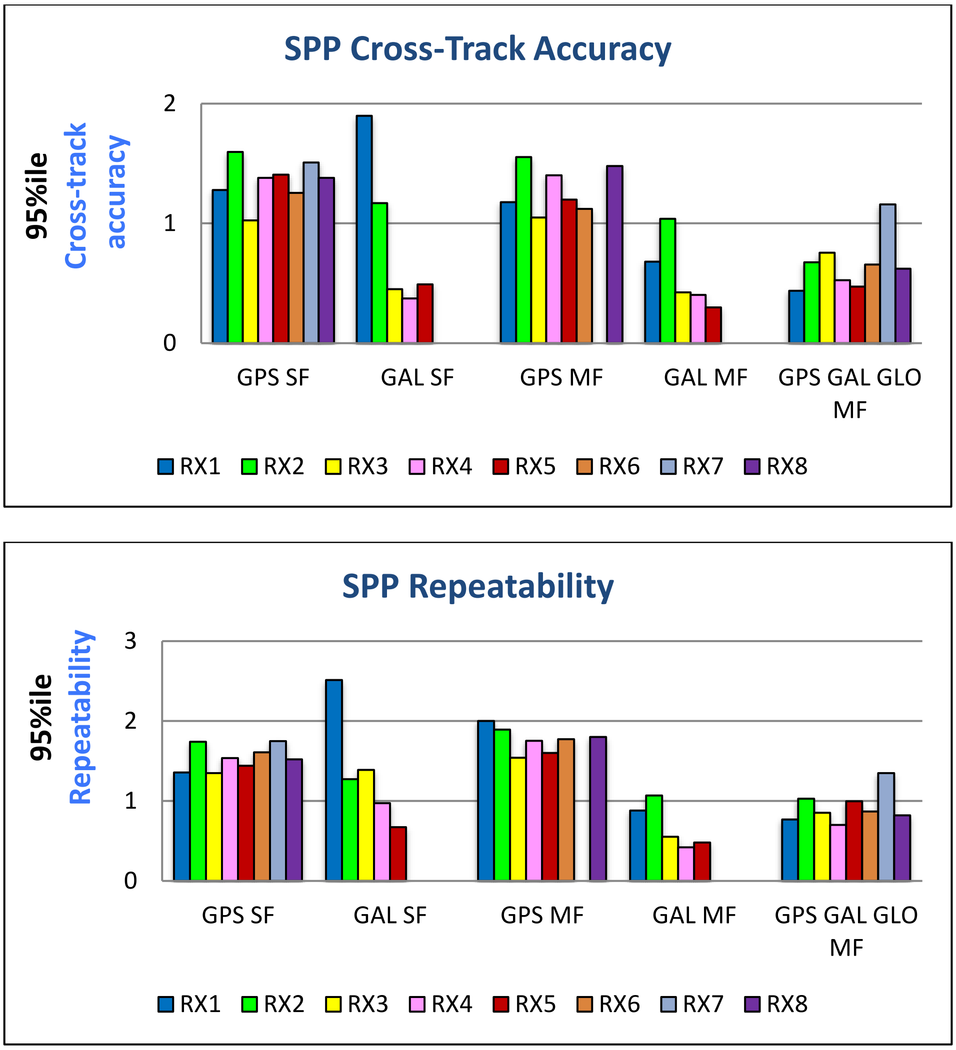

Figure 6: SPP results with different combinations of constellations and frequencies: cross-track accuracy and repeatability

3.3. Agriculture receiver status

In this section, the state of the art of agriculture professional receivers is shown through the comparison between the performance achieved by the receivers used in this testing campaign and the accuracy values expected for agriculture applications. More specifically, in Figure 7 the average performance of all the receivers for all the analyzed positioning modes has been benchmarked with respect to agriculture user needs and requirements of different applications, which are presented in [4]. By observing this figure, it can be seen at a glance that on average the tested receivers provide performance in line with expectations for almost all the analyzed positioning modes and configurations, while the need of improvements has been highlighted for Galileo only standalone mode (both single-frequency and multi-frequency) set for some RUTs for the first time and only for the purpose of this particular testing, as it can be noticed from Figure 6 (i.e. Galileo SF for Receiver 1). It has to be noted that it is highly improbable mode as most of the users want all what is available, that is multi-constellation mode in which Galileo brings indisputable added value to all RUTs.

Positioning Mode	Constellation	Application Type (required cross-track accuracy)	Average performance
SBAS	GPS + EGNOS	Type B/C – sub-metre	✓
RTK	GPS + GLONASS	Type D – down to 2.5 cm	✓
RTK	GPS + GLONASS + GALILEO	Type D – down to 2.5 cm	✓
RTK	GPS + GALILEO	Type D – down to 2.5 cm	✓
PPP	GPS + GLONASS	Type D – 2.5 – 10 cm	✓
PPP	GPS + GLONASS + GALILEO	Type D – 2.5 – 10 cm	✓
PPP	GPS + GALILEO	Type D – 2.5 – 10 cm	✓
Standalone	GPS + GLONASS + GALILEO	Type B/C – meter-sub-metre	✓
Standalone	GALILEO	Type B/C – meter-sub-metre	⚠ Some RUTs does not implement properly Galileo Standalone mode
Standalone	GPS	Type A – meter-level	✓
Standalone	GALILEO (SF)	Type B/C – meter-sub-metre	⚠ Some RUTs does not implement properly Galileo Standalone mode
Standalone	GPS (SF)	Type A – meter-level	✓

Legend
Type A - meter-level of accuracy (*Livestock tracking and virtual fencing, Geotraceability*)
Type B - meter-level/sub-metre (*Soil Sampling, Farm machinery monitoring and asset management*)
Type C - sub-metre (*Harvest/Yield Monitoring, Biomass Monitoring, Precision viticulture, Precision Forestry, Field delineation*)
Type D - cm-level (*Farm Machinery Guidance, Automatic Steering, VRA-Low, VRA-High*)
✓ In line with expectations ⚠ Improvements needed

Figure 7: Average performance highlighted by the testing campaign. Required cross-track accuracy is defined in [4].

4. Conclusions

In this paper, the Galileo added value in the agriculture market segment and the assessment of the status on its implementation in the specific professional receivers have been addressed. The evaluation has been performed through the analysis of the results obtained on the data acquired in the agriculture testing campaign held in July 2020 and performed by Thales Alenia Space Italia in the implementation of a contract signed with the European GNSS Agency (GSA) and financed by the European Union under the Galileo Programme budget.

The results presented in this paper show that, although the Galileo system is not yet in Full Operational Capability, with not fully deployed infrastructure (mainly in terms of available satellites) there are several benefits that the users experience already today. The analyses on the standalone positioning mode confirms that Galileo standalone configuration provides similar or even better performance than GPS standalone, despite the lower number of available satellites with respect to GPS. In addition, it is also confirmed that their joint use brings an increase in performance in terms of both positioning accuracy and availability. Finally, the results on the test cases with augmentation methods (SBAS, PPP and RTK) have shown that the performance is in line with expectations for almost all configurations, confirming that the tested receivers are able to meet also the needs of the most demanding applications.

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