D4.2-TN7: EGNSS functional test report

DELIVERABLE DETAILS			
Deliverable Nr	**Lead Beneficiary**	**Dissemination Level**	**Status**
D4.2	WAY4WARD	PU	CONTROLLED
Edition	**Revision**	**Issue**	**Document Code**
00	0	01.00	D4.2_01.00
File Name	D4.2 - TN7 EGNSS functional test report_1.0.docx		
Ref. Template	D0.0-Certiflight Document Template_01.00.dotx		

DOCUMENT HISTORY					
Issue	**Date**	**Status**	**Author**	**Partner**	**Change Description**
00.01	26/07/2024	DRAFT	Joseph Locantore	W4W	First version
00.02	30/07/2024	DRAFT	Francesco Russo	TOP	Review of first draft
00.03	30/10/2024	DRAFT	Joseph Locantore	W4W	Final version of the document with all its test completed
01.00	31/10/2024	CONTROLLED	Francesco Russo A.Mennella	TOP	Formal review

APPLICABLE DOCUMENTS		
Ref.	**File Name**	**Description**
AD 1	Grant Agreement-101082484-CERTIFLIGHT	Project Grant Agreement
AD 2	D2.6-CONOPS and System Requirements	CERTIFLIGHT System Requirements and CONOPS specification.
AD 3	D4.1-CERTIFLIGHT solution verification plan	Verification plan to fulfil the system requirements defined in the System Requirements document
AD 4	TN5: DKF and Spoofing detection SW library documentation	Technical specification SW library of GNSS Algorithms for Spoofing detection for Certiflight platform.
AD 5	D1.2 - Project Management Plan v2.0	Project Management Plan document v2.0 with updated Risk Matrix
AD 6	TN2 – UTM Box dataset analysis	The purpose of the note is to collect the comments, and the analysis related to the dataset to be injected in the APP software library.

REFERENCE DOCUMENTS		
Ref.	**File Name**	**Description**
RD 1	-	-

This document is part of a project that has received funding from the EUSPA under grant agreement No 101082484 under European Union's Horizon Europe programme, funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or European Union Agency for the Space Programme ('granting authority'). Neither the European Union nor the granting authority can be held responsible for them.

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Abstract

This document represents the contractual deliverable (Technical note) D4.2-TN7: EGNSS functional test report. The document includes tests to verify the functionality and performance of the APP and GSD algorithms, along with their respective results

Status of the tests		
Test name	Status	Notes
TEST_ EGNSS.00010 APP/GSD Input Verification	Completed	-
TEST_ EGNSS.00020 APP Performance Verification	Completed	
TEST_ EGNSS.00030 GNSS Outages Verification	Completed	
TEST_ EGNSS.00040 GSD Performance Verification	Completed	-

1 Scope of the document

The scope of the document is to report the results of test case described in section 4 of the verification plan (D4.1). In particular, this technical note reports the results of test codes TEST_EGNSS_00XX.

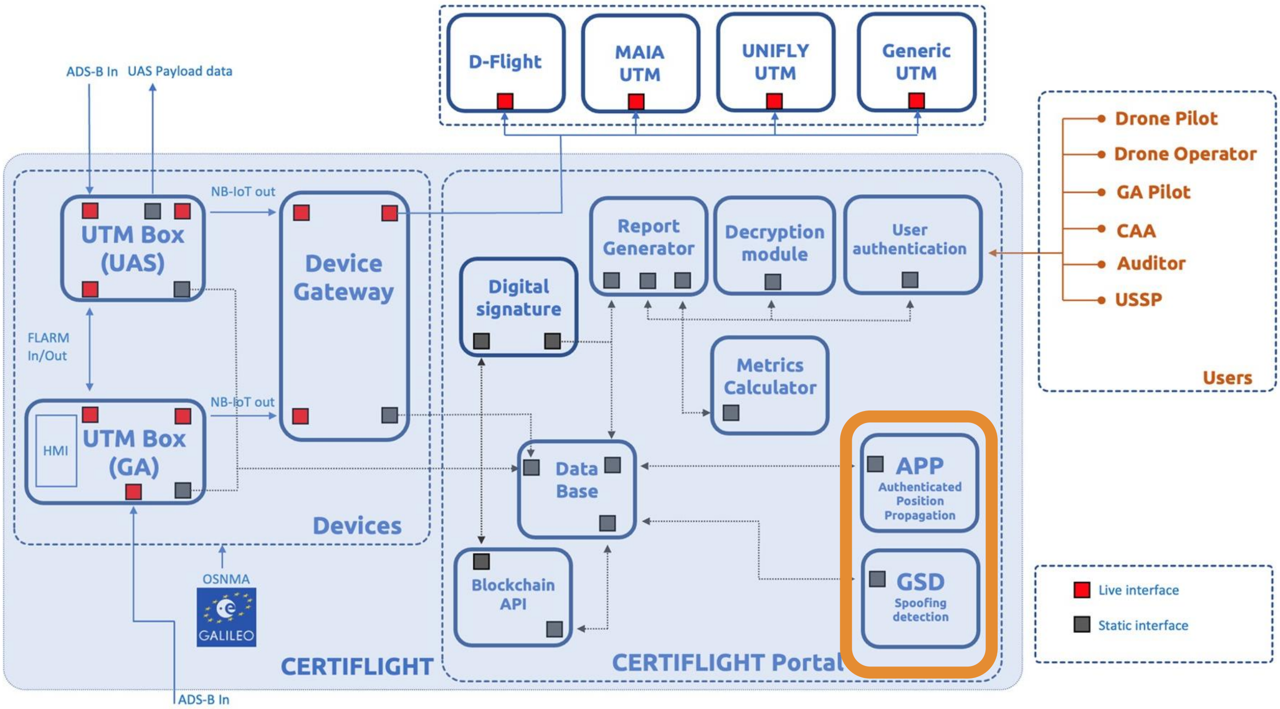

Figure 1-1 System architecture

To facilitate the reading, the Architecture of Certiflight is reproposed in the Figure 1-1, with a brief explanation of modules tested in this document.

This document describes the tests of APP and GSD modules, both part of the Certiflight Portal:

- **Authenticated Position Propagation (APP) Module:** The APP function outcomes will be integrated in the “Full report”. The input to APP algorithm, specified in the requirement CFT-SYS-0950 of D2.6 document allows the algorithm to provide the following information, in post-flight, to be included in the full report:
  - a trustable position information starting from an authenticated position
  - computation of the propagated position to reinforce the authenticity of the PVT solution and the UAS trajectory in post flight phase.
  - authenticated UAS trajectory.
  - protection of the solution from potential spoofing attacks aimed to manipulate the true position
- **Spoofing detection Module (GSD):** The GSD function outcomes will be integrated in the full report. The input to GSD algorithm is specified in the requirement CFT-SYS-0990 of D2.6 document. The purpose of the GSD algorithm is:
  - to guarantee the authenticity of data generated by the UTM Box, providing indications whether the authenticated PVT solution is genuine (Spoofing / Meaconing free).

- To be able to indicate the level of confidence/trust of the authenticated position during all flight, providing indicators/metrics in correspondence to significant events (i.e. no OSNMA satellites present in the solution, values below threshold of defined indicator).

1.1 Acronyms

Acronyms	Description
APP	Authenticated Position Propagation
CSV	Comma-separated values
EGNSS	European Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GSD	GNSS Spoofing Detection
IMU	Inertial Measurement Unit
OSNMA	Open Service Navigation Message Authentication
SBF	Septentrio Binary Format
TBC	To be confirmed
TN	Technical Note
UTM	Unmanned Traffic Management

Table 1-1 Acronyms list

2 Test Procedure

CERTIFLIGHT test procedures are built according to the following identification format: PROC_EGNSS. <NNNNx>, where <NNNN> is the progressive number (E.g. PROC_EGNSS.0010) and x identifies the substeps of each test. The structure of the test procedure is described in the table below.

PROC_EGNSS.NNNNx. Procedure Title			
Step	**Activity description**	**Expected Result**	**Notes**
S_NN	<Step Title> Procedure description	Test explaining what it is expected for each step of the procedure	Notes for further explanation

3 EGNSS Requirement Verification Matrix

ReqID	ReqTitle	ReqText	Type	Verification	D,A,I Justification (Only for A,I,RoD verification)	Status of compliance	Close-out Status
CFT-SYS-0380	APP function	The APP function shall be able to propagate the authenticated drone's position to the next authenticated position in post processing, through the integration of the GNSS and IMU measurements	Functional	T	-	C	CLOSED
CFT-SYS-0390	APP function state vector	The APP function shall deliver a navigation state vector composed at least of the following elements: - Geodetic drone's position (Lat, Long, altitude) - Drone's velocity magnitude	Functional	T	-	C	CLOSED

		Drone's Heading					
CFT-SYS-0400	GNSS raw measurements database	The UTM box shall be able to recover from the GNSS receiver and store in the Database the following raw measurements in order to allow post-processing: - GNSS time (GPS or GAL) - control parameter which identifies the GNSS constellation - control parameter which identifies the GNSS signal frequency band - control parameters which identify a GAL authenticated satellite message - GNSS satellite PRN (sat ID) - Lock time - Pseudorange - Doppler - Full Carrier Phase - C/N0 - GNSS measurements variance (Pseudorange, carrier, Doppler)	Functional	T	-	C	CLOSED
CFT-SYS-0410	CFT-SYS-0410	The UTM box shall be able to recover from the GNSS receiver and store in the Database the following data in order to allow post-processing: - GNSS time (GPS or GAL) - Position - Velocity - Receiver clock bias - Receiver clock drift	Functional	T	-	C	CLOSED

		- DOPs (GDOP, PDOP, HDOP, VDOP and TDOP) - Number of Satellites					
CFT-SYS-0420	GNSS Aiding database	The UTM box shall be able to recover from the GNSS receiver and store in the Database the following data in order to allow post-processing: - GNSS satellites ephemerides - the interconstellation clock bias between GPS and Galileo (GGTO) broadcasted by the Galileo navigation message. - code multipath correction - carrier multipath correction	Functional	T	-	C	CLOSED
CFT-SYS-0430	IMU raw measurements database	The UTM box shall be able to recover from the Inertial Measurement Unit (IMU) and store in the Database the following data in order to allow post-processing: - Time - Calibrated Accelerometers measurements - Calibrated Gyroscopes measurements - Calibrated Magnetometers measurements - Accelerometers, Gyroscope, Magnetometers measurements variance - Accelerometers, Gyroscopes, Magnetometer deterministic errors (bias, scale factor or equivalent)	Functional	T	-	PC	OPEN The UTM box was not capable to provide noise information related to the IMU. The IMU measurement show frequent spikes and outliers that cannot be mitigated during the pre-processing and cannot be used by the APP without high degradation in performance. The APP.

CFT-SYS-0440	GNSS data frequency	The GNSS Data shall be stored in the database at minimum 1Hz frequency	Functional	T	-	C	CLOSED
CFT-SYS-0450	IMU data frequency	The IMU data shall be stored in the database at minimum 10Hz frequency	Functional	T	-	PC	OPEN Frequency of logging is not stable and sometimes shows values lower than 10hz. The time in the datasets presents sudden jumps, where the Unix time is not logged correctly and presents invalid values. This problem is caused by the high computational loads for the UTM box micro-controller to sign the data for authentication that affected the IMU data collection
CFT-SYS-0460	APP solution frequency	The APP solution, under nominal conditions, shall be delivered in output at minimum frequency of 1 Hz	Functional	T	-	C	CLOSED

CFT-SYS-0470	APP function with GNSS outages	In absence of trackable GNSS satellites, the APP function shall be able to deliver the solution based only on the IMU sensors	Functional	T	-	C	CLOSED
CFT-SYS-0570	APP function Horizontal position accuracy	The expected horizontal position accuracy shall be better than 1.5 m (1 sigma confidence level) under the following nominal conditions: - At least 4 GAL authenticated satellites' messages - PDOP lower than 6	Performance	T	-	PC	OPEN Tested in not complete nominal condition, the APP shows slightly higher errors
CFT-SYS-0580	APP function Vertical Position accuracy	The expected vertical position accuracy shall be better than 1.5 m (1 sigma confidence level) under the following nominal conditions: - At least 4 GAL authenticated satellites' messages PDOP lower than 6	Performance	T	-	C	CLOSED
CFT-SYS-0590	APP function Velocity accuracy	The expected velocity accuracy shall be better than 0.2 m/s (1 sigma confidence level) under the following nominal conditions: - At least 4 GAL authenticated satellites' messages - PDOP lower than 6			-	C	CLOSED
CFT-SYS-0600	APP function heading accuracy	The expected Heading accuracy shall be better than 2 degrees (1sigma confidence level) under the following nominal conditions: - At least 4 GAL authenticated satellites' messages PDOP lower than 6	Performance	T	-	C	CLOSED

CFT-SYS-0950	APP required input parameters	The APP function, in order to provide the nominal performance, shall receive, as input from the Data Base, the following parameters: - Initial GNSS receiver navigation solution (position, velocity, clock bias, clock drift) - the following GNSS raw data, in dual frequency (L1/L5, E1/E5a) and multiconstellation (at least GAL+GPS): GNSS time (GPS or GAL), Pseudorange, Pseudorange rate (Doppler), C/N0, GGTO, GNSS measurements' variance - control parameters which identify the GNSS constellation and signal band frequency - control parameters which identify a GAL authenticated satellite message - GNSS satellite PRN (Sat ID) - GNSS satellites updated ephemeris - Calibrated IMU measurements in body reference frame (accelerometer, gyroscope, magnetometer) - IMU deterministic error (bias, scale factor or equivalent) - Accelerometers, Gyroscope, Magnetometers measurements' variance	Functional	T	-	C	CLOSED
CFT-SYS-0990	GSD required input parameters	The GSD, in order to provide the nominal performance, shall receive from the Data Base, at least the following parameters: - GNSS time (GPS or GAL) - lock time,	Functional	T	-	C	CLOSED

		- GNSS satellite PRN (sat ID) - control parameter which identifies the GNSS constellation - control parameter which identifies the GNSS measurement frequency band - C/N0 - pseudorange - carrier doppler frequency - full carrier phase - code multipath correction - code variance - carrier variance - carrier multipath correction - receiver clock bias receiver clock drift					
CTF-SYS-480	GSD function	The GSD function shall be able to discriminate between altered (spoofed) and authentic GNSS signals in post-processing using Machine learning models	Functional	T	-	C	CLOSED
CTF-SYS-490	CFT-SYS-0490	The GSD solution shall be time tagged with the time tag of GNSS measurements	Functional	T	-	C	CLOSED
CTF-SYS-610	GSD spoofing detection capability	The GSD shall be able to detect a spoofing attack with a probability of at least 80% (TBC, 1 sigma confidence interval) when at least 6 satellites are tracked. Note: the probability is TBC because the technique is completely new and there are neither reference performance available nor detailed user requirements for this function.	Performance	T	-	C	CLOSED

4 Test Report

CERTIFLIGHT test reports are built according to the following identification format: REP_EGNSS.<NNNN>, where <NNNN> is the progressive number (E.g. REP_ EGNSS.0010).
Each test report presents one or more procedures and below of those are discussed the specific results.
The EGNSS subset of tests has been led by W4W, and the results in the following sections. These tests are aimed to prove the compliance of the EGNSS Algorithms (GSD/APP) according to the functionalities and the performance envisioned in the specific System Requirements and in the D3.6 Technical Note [AD 4]. TopView has been involved in the test activities for the generation of flight data through the UTM Box and for UAS Operations. Due to issues related to the logging capabilities of the UTM box the tests were performed adopting the MARLIN T0 device as better explained in the following sections.

4.1 REP_ EGNSS.0010 APP/GSD Input Verification

This paragraph reports the test of the APP/GSD input verification functionality.
This test has been performed following the steps in the table below.

PROC_EGNSS.0010 APP/GSD Input Verification			
Step	**Activity description**	**Expected Result**	**Notes**
S_01	The Septentrio receiver is configured in order to log all the packages required in the document D3.6. A twenty minutes long record will be performed in order to collect IMU and GNSS datasets. The IMU dataset is verified to be compliant for the APP. The “APP_lib” is run and the output of “Data Parsing and Organization” module is checked	The APP_lib shall not raise error in the processing of dataset	
S_02	The Septentrio receiver is configured in order to **not log** all the packages required in the document D3.6. A twenty minutes long record will be performed in order to collect IMU and GNSS datasets. The IMU dataset will be modified to not be compliant for the APP. The “APP_lib” is run and the output of “Data Parsing and Organization” module” is checked	The APP_lib shall raise error in the processing of dataset	
S_03	S_01 and S_02 are repeated for “GSD_lib” without the IMU dataset	GSD shows a correct behaviour	

4.1.1 Test execution and results

S_01: APP Input Verification in Nominal conditions.

The Septentrio receiver is configured in order to log all the packages required in the document D3.6 as depicted in the configuration file (Figure 4-1).

```
setSatelliteTracking,GPS+GALILEO
setSignalUsage, GPSL1CA+GPSL5+GALL1BC+GALE5a, GPSL1CA+GPSL5+GALL1BC+GALE5a
setGalOSNMAUsage, loose,E5530A33D5CB60C95016B8AEC74593DBCDF2711D399EA24869173CA229379A15
setGalOSNMAPublicKeys, Key1,
'MFkwEwYHKoZIzj0CAQYIKoZIzj0DAQcDQgAEl+tDeJqg9tBSpjhGjs9SeOb234Rl7LjYuEuMejUB9zvjp/2XMkWQ4yFXM4NY97drQnKC49BGztwlhmTW+9m3aw=='
setSBFOutput,Stream1,USB1,MeasEpoch+MeasExtra+GPSNav+PVTCartesian+PVTGeodetic+GPSAlm+GPSIon+GPSUtc+GALAlm+GALNav+GALIon+GALUtc+GALGstGps+PosCovCartesian+PosCovGeodetic+VelCovCartesian+VelCovGeodetic+DOP+AttEuler+ReceiverTime+SatVisibility+GALAuthStatus,sec1
```

Figure 4-1 – Septentrio Nominal Configuration

Twenty minutes long record is performed in order to collect IMU and GNSS datasets ("GNSS_dataset.sbf" and "IMU_dataset.csv").

The IMU dataset is verified to be compliant for the APP, in particular it shall satisfy the following features:

- The dataset shall be delivered and formatted as comma separated value "IMU_dataset.csv" file format.
- The dataset shall present a correct header and to allow the library to properly parse the variables as presented in Figure 4-2
- The IMU dataset shall be logged at minimum 10Hz stable without time holes

```
unix_time,lat,lon,msl,Acc_x_m_s2,Acc_y_m_s2,Acc_z_m_s2,Gyro_x_deg_s,Gyro_y_deg_s
,Gyro_z_deg_s,Mag_x_g,Mag_y_g,Mag_z_g
```

Figure 4-2 – IMU dataset nominal header

The "APP_lib" is run in Matlab Environment and the output of "Data Parsing and Organization" module" is checked showing no triggered alarms.

```
Command Window
>> APP_Lib
APP_lib is running...
Data Organization and Parsing Completed!
fx >>
```

Figure 4-3 – APP_lib nominal response

S_02: APP Input Verification in altered conditions.

Step 1 is repeated introducing the following modifications firstly on the GNSS dataset and checking the output:

1. The name of the GNSS file is changed in "GNSS_dataset_wrong.sbf". The algorithm triggers correctly the *Error Code 100: File not found* (Figure 4-5)

2. The file format of the GNSS file is changed in “GNSS_dataset.txt”. The algorithm triggers correctly the *Error Code 101: Unsupported File format (*Figure 4-6*)*
3. The “csv” files provided by the sbf parser are modified to present anomalies in data formats in order to not be compliant to comma separated value. The csv files are reformatted as tables, this triggers correctly the *Error Code 200: Invalid Data (*Figure 4-7*)*
4. The configuration file (Figure 4-4 – Septentrio Altered Configuration
5.) is modified removing an essential package from the logging, the GALAuthStatus which includes information on the GAL satellites with authenticated signals. The algorithm triggers correctly the *Error Code 201: Missing Data (*Figure 4-8*)*

```
setSatelliteTracking,GPS+GALILEO
setSignalUsage, GPSL1CA+GPSL5+GALL1BC+GALE5a, GPSL1CA+GPSL5+GALL1BC+GALE5a
setGalOSNMAUsage, loose,E5530A33D5CB60C95016B8AEC74593DBCDF2711D399EA24869173CA229379A15
setGalOSNMAPublicKeys, Key1,
'MFkwEwYHKoZIzj0CAQYIKoZIzj0DAQcDQgAEl+tDeJqg9tBSpjhGjs9SeOb234Rl7LjYuEuMejUB9zvjp/2XMkWQ4yFXM4NY97drQnKC49BGztwlhmTW+9m3aw=='
setSBFOutput,Stream1,USB1,MeasEpoch+MeasExtra+GPSNav+PVTCartesian+PVTGeodetic+GPSAlm+GPSIon+GPSUtc+GALAlm+GALNav+GALIon+GALUtc+GALGstGps+Pos
CovCartesian+PosCovGeodetic+VelCovCartesian+VelCovGeodetic+DOP+AttEuler+ReceiverTime+SatVisibility,sec1
```

Figure 4-4 – Septentrio Altered Configuration

6. The “csv” files provided by the sbf parser are modified to include incorrect data types (i.e. NaN), this triggers correctly the *Error Code 300: Data Analysis Error (*Figure 4-9*)*

A similar procedure is repeated for the IMU dataset without touching the GNSS data:
The name of the IMU file is changed in “IMU_dataset_wrong.csv”. The algorithm triggers correctly the *Error Code 100: File not found* (Figure 4-5)
The file format of the GNSS file is changed in “IMU_dataset_wrong.xls”. The algorithm triggers correctly the *Error Code 101: Unsupported File format (*Figure 4-6*)*
The header of the “csv” files is modified to present anomalies with respect Figure 4-2 this triggers correctly the *Error Code 200: Invalid Data (*Figure 4-7*)*
A column of the csv file is removed simulating an error in the logging and writing of the file from the logging, causing the absence of a IMU sensor (i.e. gyroscope). The algorithm triggers correctly the *Error Code 201: Missing Data (*Figure 4-8*)*
The “csv” is modified to include simulate a not compliant logging rate as showed in Figure 4-10. The dataset shows a not stable logging rate with the number of IMU measurement mostly equal at 8 with instant reach values lower than 5. This triggers correctly the *Error Code 300: Data Analysis Error (*Figure 4-9*)*

```
Command Window
  APP_lib is running...
  Error Code 100: File not found!
fx >>
```

Figure 4-5 – App_lib Error 100

```
Command Window
 APP_lib is running...
 Error Code 101: Unsupported File format!
fx >>
```

Figure 4-6 - App_lib Error 101

```
Command Window
 APP_lib is running...
 Error Code 200: Invalid Data!
fx >>
```

Figure 4-7 - App_lib Error 200

```
Command Window
 APP_lib is running...
 Error Code 201: Missing Data!
fx >>
```

Figure 4-8 - App_lib Error 201

```
Command Window
 APP_lib is running...
 Error Code 300: Data Analysis Error!
fx >>
```

Figure 4-9 - App_lib Error 300

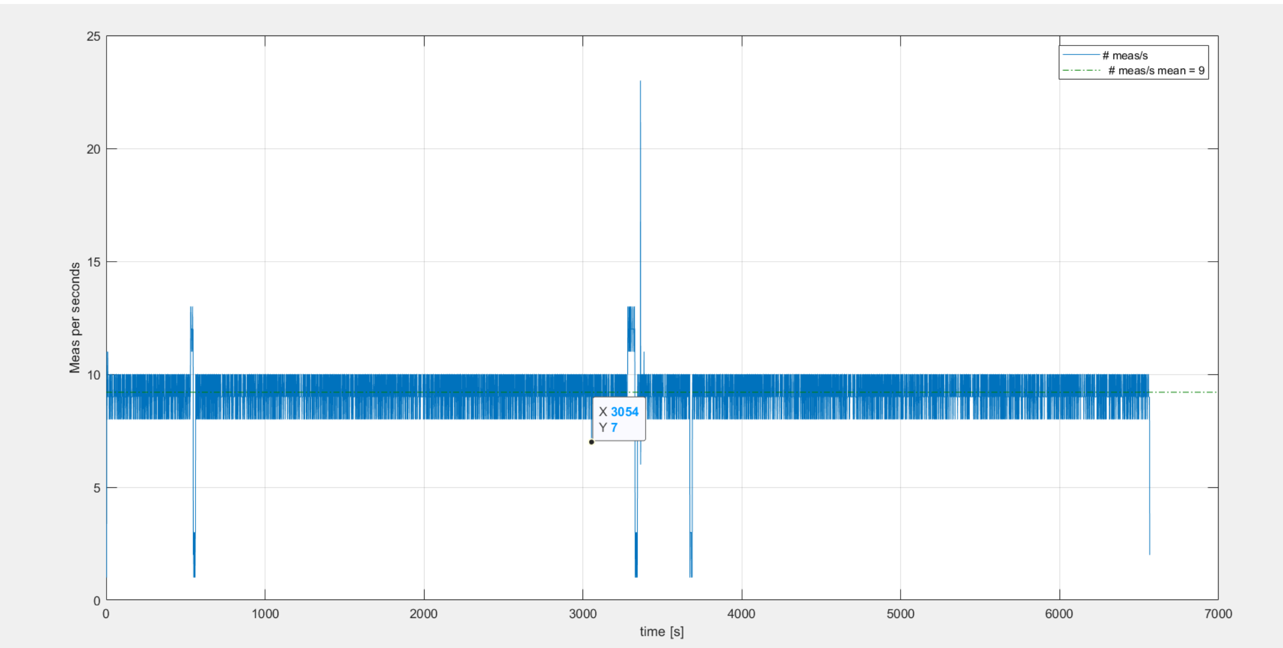

Figure 4-10 – Altered IMU dataset

S_03: GSD Input Verification in nominal and altered conditions.

The steps 1 and 2 are repeated for “GSD_lib” in Python Environment considering only the GNSS dataset and checking the behaviour of the library which responded correctly (Figure 4-11, Figure 4-12).

Figure 4-11 – GSD_lib response in altered condition

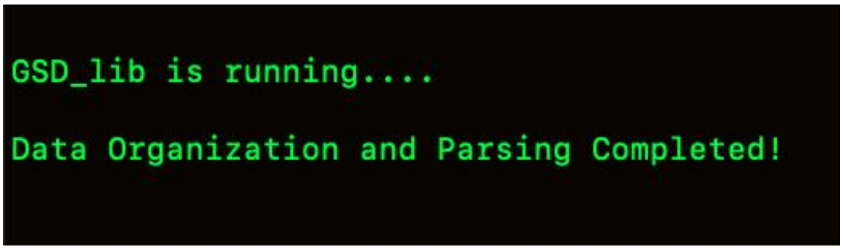

Figure 4-12 – GSD_lib response in nominal condition

4.2 REP_ EGNSS.0020 APP Performance Verification

This paragraph reports the test of the APP performance verification functionality.
This test will be performed following the steps in the table below.

PROC_EGNSS.0020 APP Performance verification			
Step	Activity description	Expected Result	Notes
S_01	A preliminary free flight of 20 minutes with drone equipped with UTM box shall be performed in order to let the onboard receiver to download the full navigation	Data collected satisfy the test condition: • At least 4 GAL authenticated during the flight	For free flight is meant a flight without a predefined path, to allow the correct initialization

	message for GPS and Galileo satellites. Once the drone is ready a test flight with has been performed, and the reference trajectory is recovered through RTK	• PDOP <6 • Stable IMU measurements • Reference trajectory with accuracy of 10cm in position	of the receiver
S_02	Verify the minimum requirements for APP position/velocity/heading accuracy	The APP shall satisfy the accuracy requirements included in AD 2	
S_03	Verify that APP provides a time-tagged solution in a CSV format	APP provides the output in the correct format	

4.2.1 Test execution and results

S_01 Data acquisition campaign

Some data acquisition campaigns were performed since the TRR together with TopView to test the capability of UTM box to correctly collect the GNSS and IMU data. After some iterations with a total of 12 datasets collected, W4W identified a limitation in the UTM sensor and/or microcontroller to provide stable IMU data, the faced issues were included and described AD 6. In order to cope with the problem and performed a new data collection W4W proposed the adoption of MARLIN T0 device internally developed in partnership with the twin company GEA Space s.r.o and rapidly configured for drone's application.

The MARLIN T0 has the following main characteristics:

- GNSS Receiver Multi Constellation,
  Triple Frequency is Septentrio Mosaic X5
- IMU è iNEMO Inertial Sensor
- Magnetometer è IIS2MDC
- Barometer
- Ubuntu based Microprocessor
- Data storage up to 256GB
- Battery with > 1h of autonomy without direct power supply
- Dimensions: 19.4 cm x 10.8 cm x 4.4 cm

Figure 4-13 – MARLIN T0 Device

A new test campaign was performed at the end of June (26-27th) near Caserta together with TopView. The MARLIN T0 was mounted on a DJI M300 drone (Figure 4-14) and different trajectory were performed and collected (i.e.Figure 4-15), the IMU of the MARLIN T0 was configured at 10Hz. This type of approach allowed the W4W to finalize and validate the Data parsing and Feeder of the APP library (see Section 4.1), which took half month in line with the plan presented during the TRR.
Unfortunately, even if W4W tried to shrink the activities, the APP activities are currently in the "Tuning and configuration" phase and was not possible to configure completely the APP to grant a stable solution for the past issue of this Document.
New iterations with TopView were performed to tackle some issues related the complete acquisition of reference information from the Drone's log in particular velocity data and attitude to properly perform the performance verification, and eventually a new test campaign will be expected.
Another test campaign was conducted in September 4-5-11th in order to solve the faced problems.
In both scenarios, synchronization issues persisted between the APP solution and the reference RTK due to limitations in the RTK time definition, which lacks millisecond precision. This limitation hinders accurate time alignment, preventing precise performance comparisons. Consequently, these synchronization challenges degraded filter performance and limited the fine-tuning of the internal filter.

Figure 4-14 – MARLIN T0 Test Setup mounted on DJI M300

Figure 4-15 – Example of Test trajectory

S_02 Performance Verification

For test verification, the flight conducted on June 27th was selected, as the IMU configuration at 10Hz was expected to better align with the expected behaviour of the UTM box. Reference data was extracted and parsed from the drone's internal binary file. The test, however, did not consistently meet nominal conditions, displaying variability in the number of authenticated GALILEO satellites, with moments where fewer than four satellites were authenticated, as illustrated in the Figure 4-16.

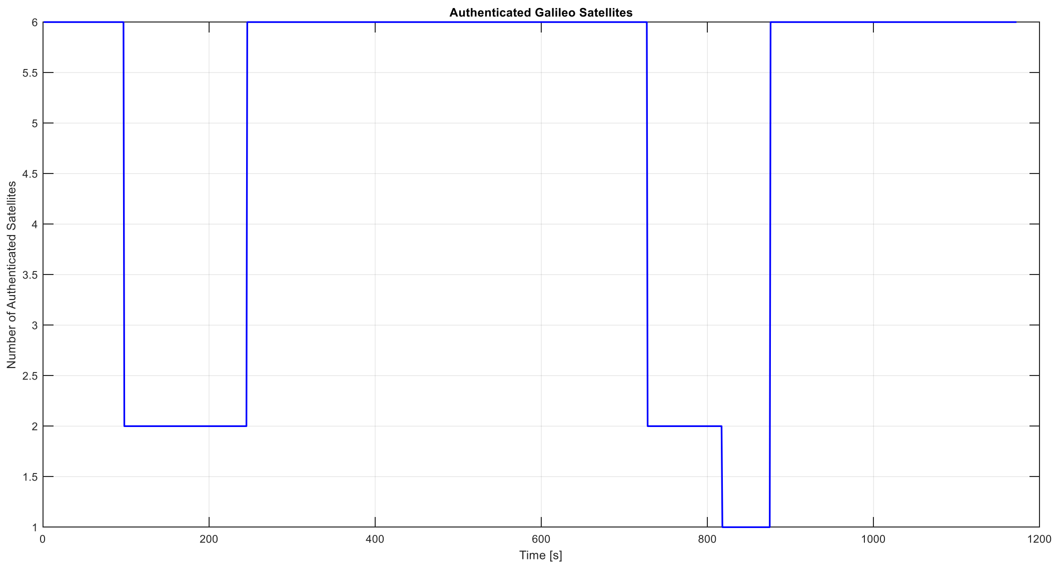

Figure 4-16 – Nr of GAL Authenticated Satellites

Under these conditions, the APP algorithm demonstrated good performance in terms of accuracy, achieving a horizontal accuracy of **2.21m**, slightly below the required threshold of **1.5m**, and a vertical accuracy of **0.36m**, significantly better than the required performance, as illustrated in the Figure 4-18. Velocity accuracy also met requirements, with an error of **0.04m/s**, surpassing the expected performance level (Figure 4-19). Heading accuracy remained within acceptable limits, though some instability was observed, likely due to rapid shifts in drone heading between +180 and -180 degrees. Excluding these instability points, where error values reached ±360 due to angle definition ambiguities, the average heading error stabilized at **0.22degrees**, as seen in the Figure 4-22. The Figure 4-20 and Figure 4-21 also illustrate respectively the heading behaviour of RTK versus APP solution, and the error including the ambiguity values.

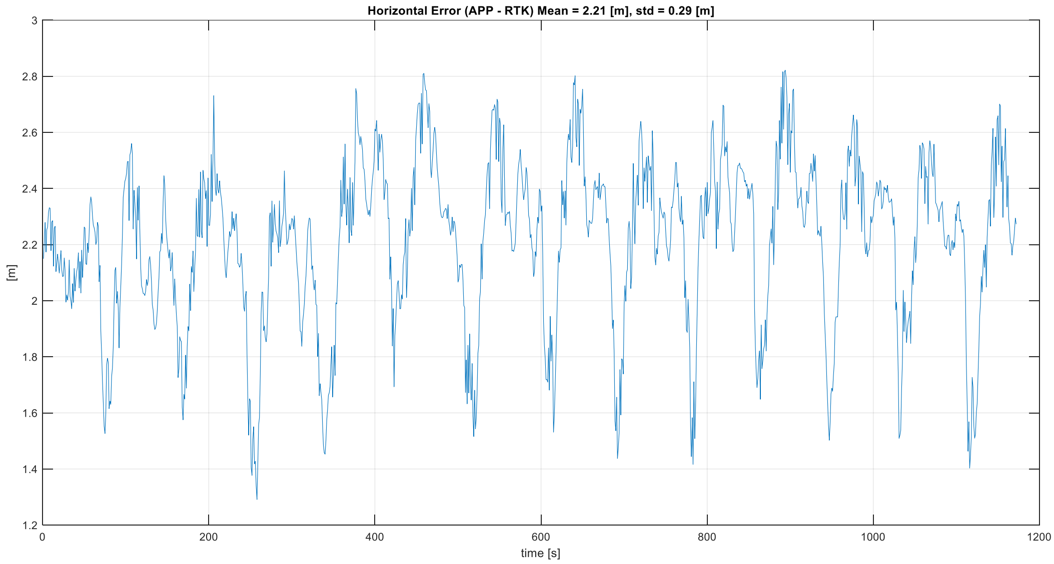

Figure 4-17 – Horizontal Error Accuracy

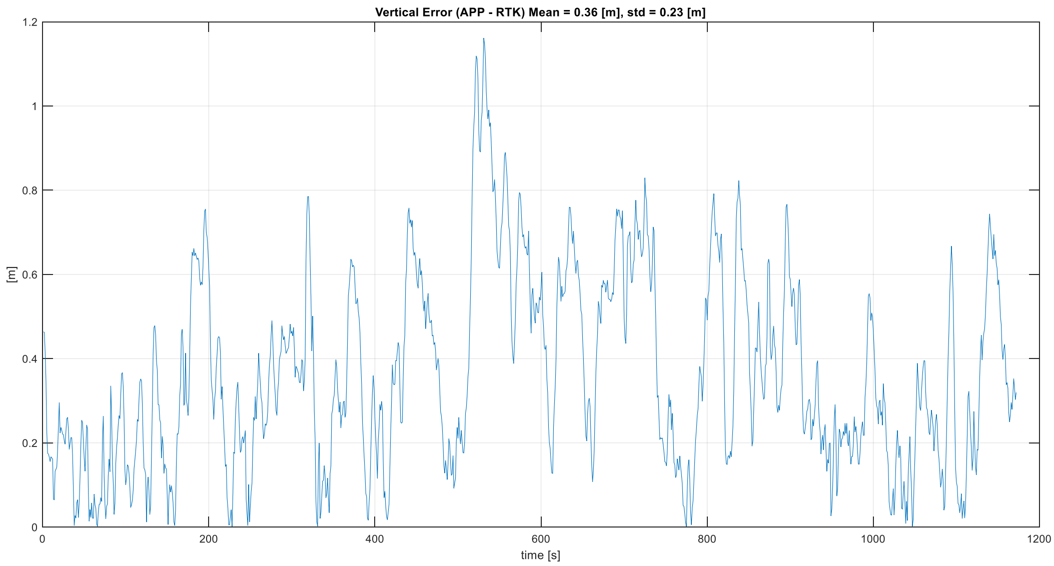

Figure 4-18 – Vertical Error Accuracy

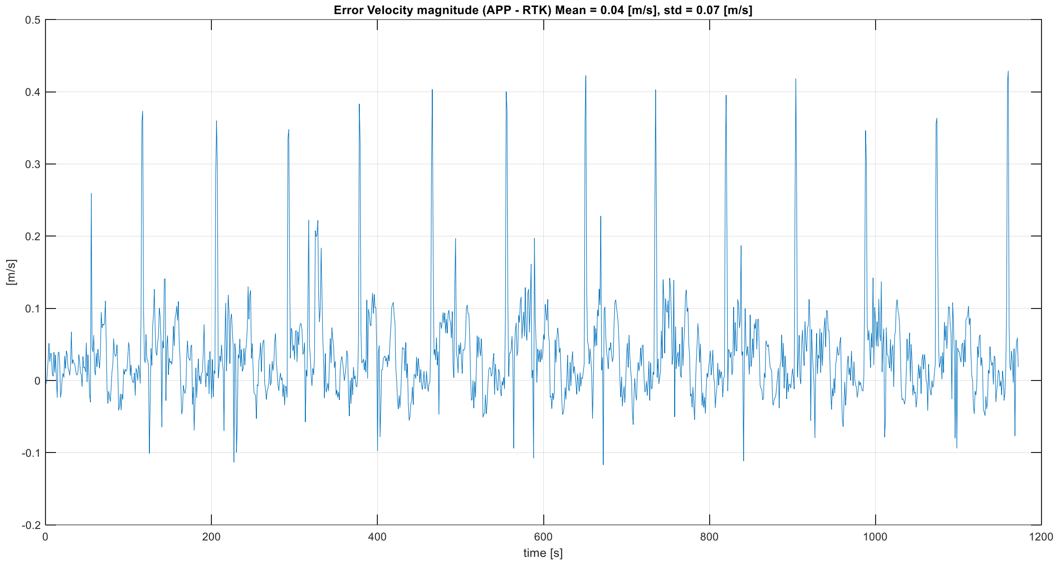

Figure 4-19 – Velocity Error Accuracy

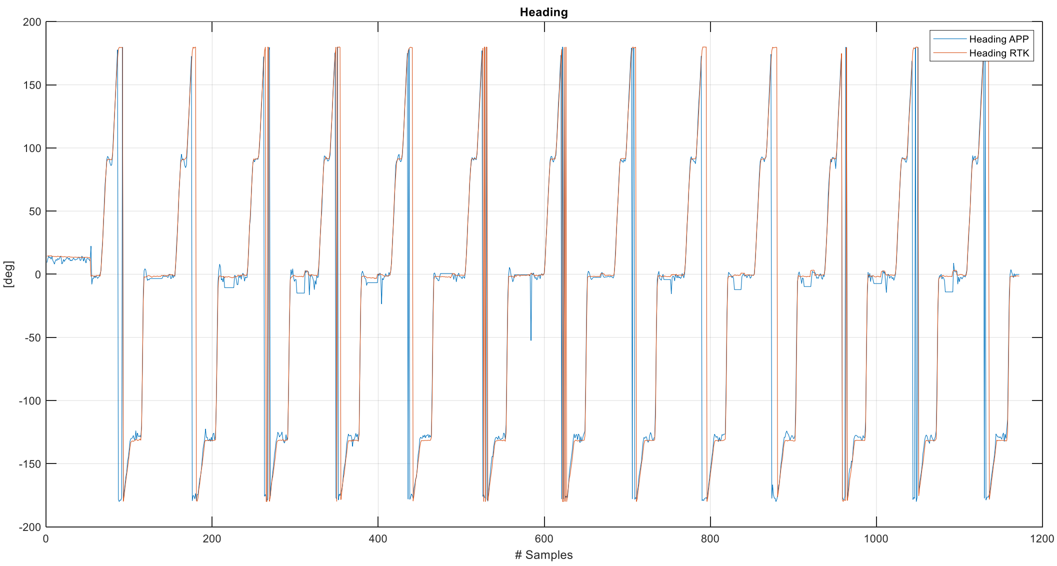

Figure 4-20 – APP vs RTK Heading solution

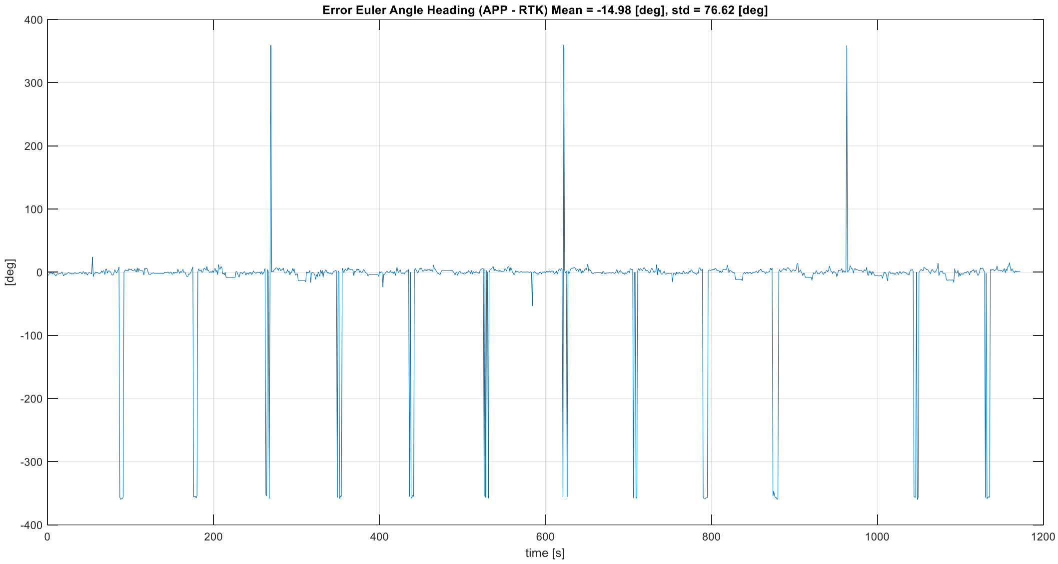

Figure 4-21 – Heading Error Accuracy with ambiguity points

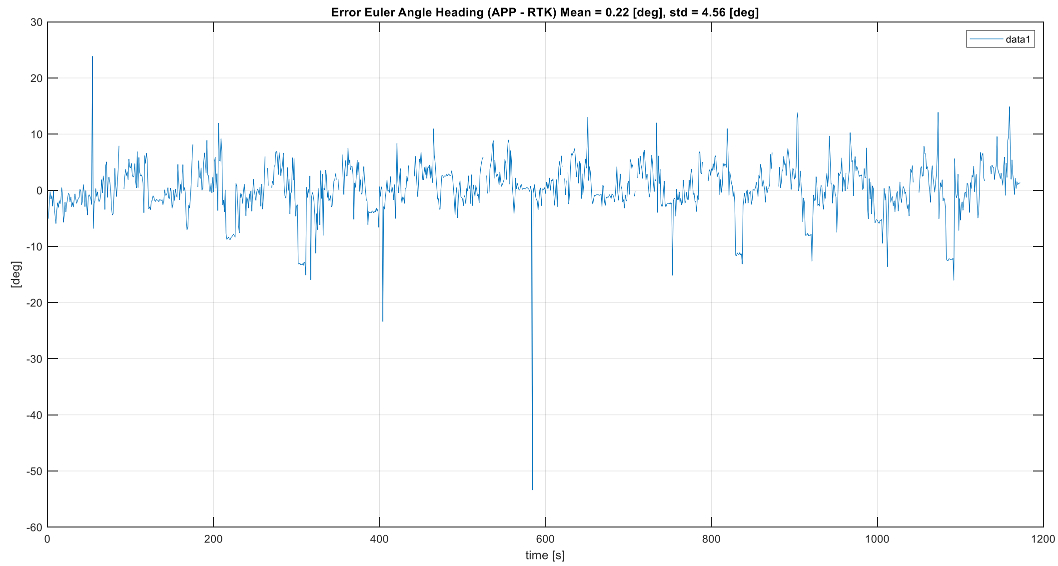

Figure 4-22 – Heading Error Accuracy without ambiguity points

S_03 Verify that APP provides a time-tagged solution in a CSV format

The APP algorithm during the test was capable to provide the time tagged solution in a CSV format as shown a small sample in the following Figure

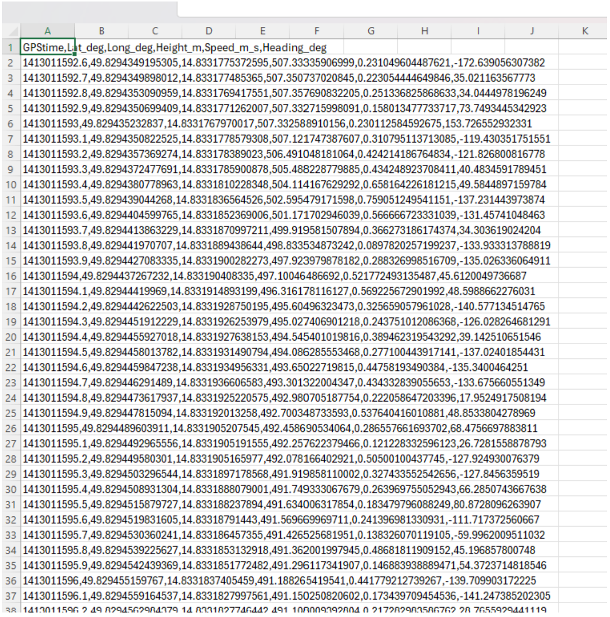
GPStime,Lat_deg,Long_deg,Height_m,Speed_m_s,Heading_deg
1413011592.6,49.8294349195305,14.8331775372595,507.33335906999,0.231049604487621,-172.639056307382
1413011592.7,49.8294349898012,14.833177485365,507.350737020845,0.223054444649846,35.021163567773
1413011592.8,49.8294353090959,14.8331769417551,507.357690832205,0.251336825868633,34.0444978196249
1413011592.9,49.8294350699409,14.8331771262007,507.332715998091,0.158013477733717,73.7493445342923
1413011593,49.829435232837,14.8331767970017,507.332588910156,0.230112584592675,153.72655293231
1413011593.1,49.8294350822525,14.8331778579308,507.121747387607,0.310795113713085,-119.430351751551
1413011593.2,49.8294357369274,14.833178389023,506.491048181064,0.424214186764834,-121.826800816778
1413011593.3,49.8294372477691,14.8331785900878,505.488228779885,0.434248923708411,40.4834591789451
1413011593.4,49.8294380778963,14.8331810228348,504.114167629292,0.658164226181215,49.5844897159784
1413011593.5,49.829439044268,14.8331836564526,502.595479171598,0.759051249541151,-137.231443973874
1413011593.6,49.8294404599765,14.8331852369006,501.171702946039,0.566666723331039,-131.45741048463
1413011593.7,49.8294413863229,14.8331870997211,499.919581507894,0.366273186174374,34.303619024204
1413011593.8,49.829441970707,14.8331889438644,498.833534873242,0.0897820257199237,-133.933313788819
1413011593.9,49.8294427083335,14.8331900282273,497.923979878182,0.288326998516709,-135.026336064911
1413011594,49.8294437267232,14.833190408335,497.10046486692,0.521772493135487,45.6120049736687
1413011594.1,49.82944419969,14.8331914893199,496.316178116127,0.569225672901992,48.5988662276031
1413011594.2,49.8294442622503,14.8331928750195,495.60496323473,0.325659057961028,-140.577134514765
1413011594.3,49.8294451912229,14.8331926253979,495.027406901218,0.243751012086368,-126.028264681291
1413011594.4,49.8294455927018,14.8331927638153,494.545401019816,0.389462319543292,39.142510651546
1413011594.5,49.8294458013782,14.8331931490794,494.086285553468,0.277100443917141,-137.02401854431
1413011594.6,49.8294459847238,14.8331934956331,493.65022719815,0.44758193490384,-135.3400464251
1413011594.7,49.829446291489,14.8331936606583,493.301322004347,0.434332839055653,-133.675660551349
1413011594.8,49.8294473617937,14.8331925220575,492.980705187754,0.222058647203396,17.9524917508194
1413011594.9,49.829447815094,14.833192013258,492.700348733593,0.537640416010881,48.8533804278969
1413011595,49.8294489603911,14.8331905207545,492.458690534064,0.286557661693702,68.4756697883811
1413011595.1,49.8294492965556,14.8331905191555,492.257622379466,0.121228332596123,26.7281558878793
1413011595.2,49.829449580301,14.8331905165977,492.078166402921,0.50500100437745,-127.924930076379
1413011595.3,49.8294503296544,14.8331897178568,491.919858110002,0.327433552542656,-127.8456359519
1413011595.4,49.8294508931304,14.8331888079001,491.749333067679,0.263969755052943,66.2850743667638
1413011595.5,49.8294515879727,14.833188237894,491.634006317854,0.183479796088249,80.8728096263907
1413011595.6,49.8294519831605,14.83318791443,491.569669969711,0.241396981330931,-111.717372560667
1413011595.7,49.8294530360241,14.833186457355,491.426525681951,0.138326070119105,-59.9962009511032
1413011595.8,49.8294539225627,14.8331853132918,491.362001997945,0.48681811909152,45.196857800748
1413011595.9,49.8294542439369,14.8331851772482,491.296117341907,0.146883938889471,54.3723714818546
1413011596,49.829455159767,14.8331837405459,491.188265419541,0.441779212739267,-139.709903172225
1413011596.1,49.8294559164537,14.8331827997561,491.150250820602,0.173439709454536,-141.247385202305

Figure 4-23 – APP Solution. csv sample

4.3 REP_ EGNSS.0030 GNSS Outages Verification

This paragraph reports the test of the APP behaviour during GNSS Outages.
This test will be performed following the steps in the table below.

PROC_EGNSS.0030 GNSS Outages verification			
Step	**Activity description**	**Expected Result**	**Notes**
S_01	The test data collected for EGNSS_0020 will be manually modified to simulate the absence of GNSS measurements for 10,30,60 seconds		
S_02	Verify the APP can deliver a solution in this operative condition and report the accuracy	The APP shall satisfy the requirements included in AD 2	
S_03	Verify that APP provides a time-tagged solution in a CSV format	APP provides the output in the correct format	

4.3.1 Test execution and results

S_01 Data acquisition campaign

See Section 4.2.1

S_02 Performance Verification

The EGNSS.0020 test scenario was used and manually modified to simulate GNSS signal loss for intervals of 10, 30, and 60 seconds. During these outages, the APP maintained its solution based solely on IMU data, resulting in different levels of accumulated error. Notably, the APP successfully recovered and reconverged to accurate position and velocity levels once GNSS visibility was restored, achieving accuracy consistent with the EGNSS.0020 baseline. The following figures illustrate the error variations in position and velocity over the simulated GNSS outage periods. The high levels of accumulated error can be caused by the sampling rate and noise of IMU measurements; increasing the sampling rate up to 100Hz a better dynamic of the drone can be represented by the IMU sensors and reduce the error. At the moment neither the UTM box and the MARLIN T0 devices are able to provide this sampling frequency but it's a good indication for the final product.

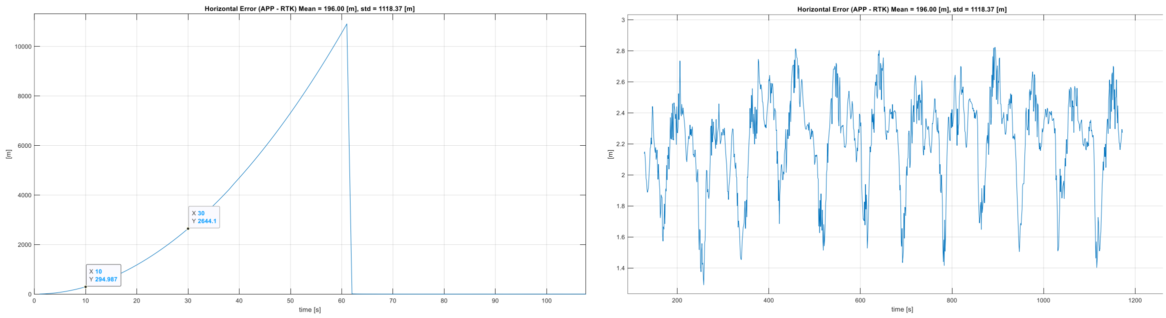

Figure 4-24 – Horizontal Error during GNSS Outages

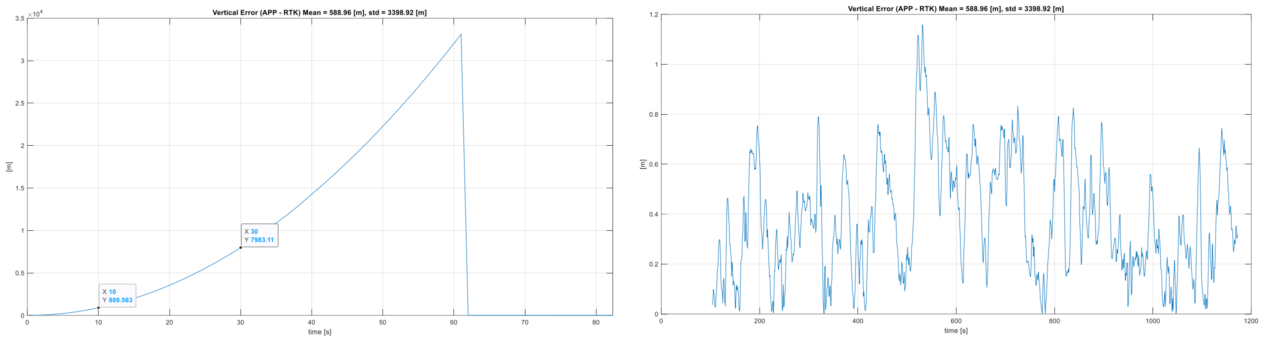

Figure 4-25 – Vertical Error during GNSS outages

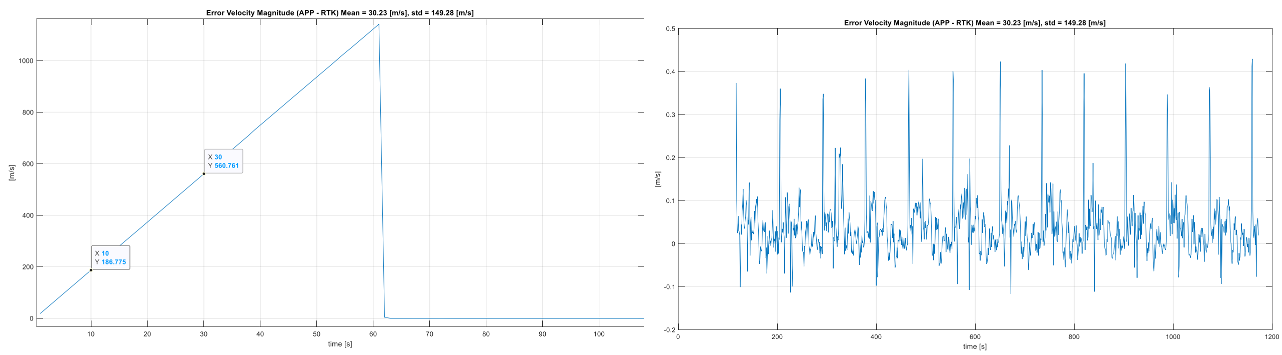

Figure 4-26 – Velocity Error during GNSS outages

S_03 Verify that APP provides a time-tagged solution in a CSV format

The APP algorithm during the test was capable to provide the time tagged solution in a CSV format as shown a small sample in the following Figure

```
GPStime,Lat_deg,Long_deg,Height_m,Speed_m_s,Heading_deg
1403514537,41.1798768947154,14.4461554013963,157.01673622895,19.1837305709508,-0.0201250698512886
1403514538,41.1799653177357,14.446153833455,130.239756468683,37.9577989060885,-1.19846185038336
1403514539,41.180106947837,14.4461488064561,85.6804039049894,56.7072716935129,-1.77989676136095
1403514540,41.1803021775304,14.4461403039864,23.3663579178974,75.4535583832026,-1.99017815934385
1403514541,41.1805509226514,14.4461282841568,-56.6706402720883,94.1880895646241,-2.14789776074328
1403514542,41.1808524598971,14.4461137896988,-154.480083410628,112.929881251434,-2.00430929477822
1403514543,41.1812068381471,14.4460978707937,-270.03724231571,131.626797889659,-1.89126279431382
1403514544,41.1816140383005,14.4460802419085,-403.328351151198,150.34042481638,-1.860487009883
1403514545,41.1820740017896,14.4460604422395,-554.361412962899,169.058659452366,-1.83313253829897
1403514546,41.1825862661053,14.4460395544475,-723.162659840658,187.782720192884,-1.71279617548131
1403514547,41.1831510791617,14.4460180097877,-909.697270693257,206.461759898625,-1.59797449207389
1403514548,41.1837690039307,14.4459961382471,-1113.92793284357,225.14207566699,-1.45510742275223
1403514549,41.184440474506,14.445974675825,-1335.82208033837,243.786067583688,-1.31602042228066
1403514550,41.1851659844633,14.4459538353626,-1575.31646820344,262.388023498251,-1.18183542386226
1403514551,41.185945580247,14.4459340657637,-1832.39756522514,281.010631198572,-1.02574300755481
1403514552,41.1867785769237,14.4459155122866,-2107.11918830313,299.673732040923,-0.909527973037608
1403514553,41.1876650819593,14.4458973955339,-2399.48923581559,318.306034687102,-0.860194975239947
1403514554,41.1886058670859,14.4458789064864,-2709.46029586997,336.924257497186,-0.810910389081888
1403514555,41.1896007059425,14.4458615275908,-3037.02621775214,355.545099338168,-0.713090835780861
1403514556,41.190648210081,14.4458450909372,-3382.29730260745,374.311660053348,-0.785570553047436
1403514557,41.1917434030144,14.4458223191047,-3745.61257399525,393.115774503035,-0.917010009858916
1403514558,41.1928897649673,14.4457987339324,-4126.76918803807,411.83176816229,-0.87406742551623
1403514559,41.1940892092087,14.4457748663095,-4525.63579046354,430.528447973487,-0.860532384529993
1403514560,41.1953412766703,14.4457498191252,-4942.260039513,449.265470635917,-0.866718203580055
1403514561,41.1966453818129,14.4457240349596,-5376.69538374059,468.016439494957,-0.836912940521625
1403514562,41.1980008310353,14.4456984778623,-5828.96323560178,486.785975944954,-0.798182579316842
1403514563,41.1994073616414,14.4456726533517,-6299.0967840096,505.532841369322,-0.805844749018776
1403514564,41.2008660365304,14.4456452922677,-6787.04861040693,524.288710470888,-0.821938452091075
1403514565,41.2023769140046,14.445616565618,-7292.80230409745,543.03278230594,-0.813666867065147
1403514566,41.2039398178783,14.4455874562759,-7816.34367984533,561.775642619367,-0.802316210990779
1403514567,41.2055542773076,14.4455575931129,-8357.74733422883,580.568338569023,-0.788284653511248
1403514568,41.2072200819018,14.4455276447192,-8917.01468542498,599.323230000375,-0.766298787422268
1403514569,41.2089366818256,14.4454980254495,-9494.16763747763,618.146453776295,-0.721608245316818
1403514570,41.2107032256655,14.4454704959021,-10089.3146982342,636.981601988189,-0.634234047373364
1403514571,41.2125206667213,14.4454451531445,-10702.384190686,655.779684551147,-0.579057259998288
1403514572,41.214389104721,14.4454206363403,-11333.3570040939,674.567222074234,-0.557394363207346
1403514573,41.2163091374356,14.4453967389269,-11982.2039476326,693.347240362067,-0.519994971453474
```

APP_solution

Figure 4-27 – APP Solution. csv sample with GNSS outages

4.4 REP_ EGNSS.0040 GSD Performance Verification

PROC_EGNSS.0040 GSD Performance verification			
Step	**Activity description**	**Expected Result**	**Notes**
S_01	Verify the minimum requirements for GSD spoofing detection probability (min. 80%, with 1 sigma confidence interval) when at least 6 satellites are tracked for each constellation	GSD spoofing detection probability is above 80% with 6 satellites tracked for each constellation	
S_02	Verify that GSD provides a time-tagged signal classification in a CSV format	GSD provides the output in the correct format	

4.4.1 Test execution and results

S_01: Verify the minimum requirements for GSD spoofing detection probability, when at least 6 satellites are tracked for each constellation.

The test set will be created using data from the JRC acquisition campaigns, incorporating unused data from the training phase. It will encompass six distinct scenarios, comprising authentic signals and five different types of spoofing cases, to be utilized in the verification protocol.
Namely, the test set will include one 30-minute acquisition (frequency=1 Hz) for each type of spoofing attack: meaconing (100 ms delay), meaconing (100 ns delay), advanced, synchronized, and SCER. Each acquisition will consist of 5 minutes of authentic signals followed by 25 minutes of attacks on both GPS (L1/L5 frequency bands) and Galileo (E1/E5 frequency bands) constellations (6+6 satellites). The data was stored in SBF format and contained all necessary features. The five datasets have been combined to be utilized in the verification plan.
For each epoch, the function, referred to as "GSD_lib", will acquire the input from the "Data Parsing and Organization" module and generates an output file named "GSD_solution.csv," which includes the time parameter (GPStime) and a binary flag (Spoofing_flag) indicating if a spoofing attack has been detected or not. Epochs containing spoofed/authentic signals will be labelled by the "Spoofing_flag" set respectively to 1 and 0. The function was required to achieve a minimum spoofing attack detection probability (Recall) of 80% within a 1 sigma confidence level. Results are shown in Figure 4-28, which represents the confusion matrix for the binary classification of the dataset discussed above.
Namely, the rows of the confusion matrix represent the true labels of the signals, indicating "0" if the signal is authentic and "1" if it has been spoofed, while the columns represent the predicted labels. For instance, the cell "00" indicates the number of epochs where an authentic signal (class 0) has been correctly predicted as authentic. In particular, the values reported inside the cells represent the count of epochs falling into each category.
In more detail, the four cells of the matrix, indicated as (a,b), where "a" and "b" refer respectively to row and column numbers, can be interpreted as follows:

- **Cell (0, 0) - TN (True negatives)**: An authentic signal (class 0) has been correctly predicted as authentic (0).
- **Cell (0, 1) - FP (False positives)**: An authentic signal (class 0) has been incorrectly predicted as spoofed (1).
- **Cell (1, 0) - FN (False negatives)**: A spoofed signal (class 1) has been incorrectly predicted as authentic (0).
- **Cell (1, 1) - TP (True positives)**: A spoofed signal (class 1) has been correctly predicted as spoofed (1).

From the values reported in the confusion matrix, it is also possible to derive two parameters summarizing the performance of the model: accuracy and recall. The *accuracy* is calculated as the proportion of correctly predicted instances (both authentic and spoofed) out of the total instances evaluated. Mathematically, it is expressed as:

$$Accuracy = (TP + TN)/(TP + FP + TN + FN)$$

On the other hand, the *recall,* also known as sensitivity or true positive rate, measures the proportion of actual spoofed signals that were correctly identified. It is calculated as:

$$Recall = TP/(TP + FN).$$

In our case, the values for the accuracy and recall obtained in this test amount respectively to 0.9333 (**93%**) and 0.976 (**98%**). For this reason, we consider the requirement for GSD of featuring a minimum spoofing attack detection probability (Recall) of **80%** fully met.

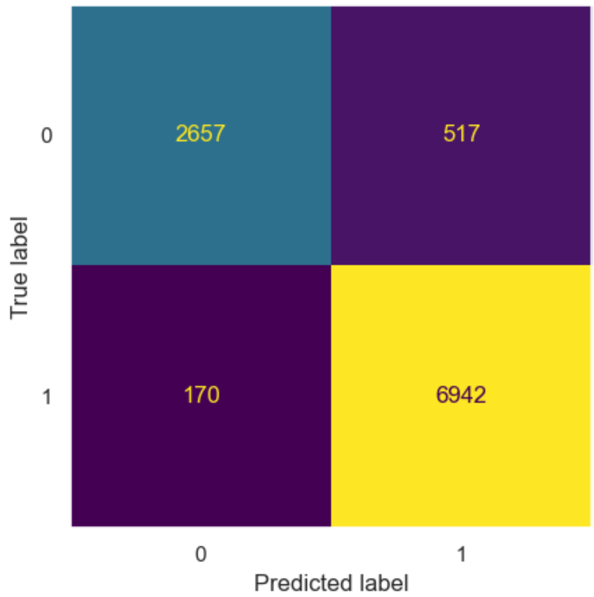

Figure 4-28 Confusion Matrix for the verification predictions of the GSD algorithm utilizing a single multi-attack dataset

To verify if the performance is robust within the 1 sigma confidence interval, we repeated the predictions for 10 test campaigns for each type of attack. All campaigns contained data which was not used during the training process and, as previously discussed, each campaign consisted of 30-minute acquisitions, where the first 5 minutes contained authentic signals and the remaining 25 minutes contained only spoofed ones. Our goal was to ensure that at least **68%** of these campaigns (7/10) met the performance benchmarks (Recall > 80%), which corresponds to achieving a performance level within the 1 sigma confidence interval. The results are presented in Table 4-1 demonstrating that all test campaigns (10/10) for each type of attack meet the requirement of achieving a spoofing detection probability (Recall) greater than 80%. As an example of the reliability of our spoofing detection capacity, we also provide the confusion matrix for a single test campaign (out of the 10 conducted) for the meaconing (100 ns delay) attack (Figure 4-29), from which the values for the accuracy and recall can be derived, amounting respectively to 0.981 (**98%**) and 0.977 (**98%**).

Type of attack	#Test campaigns featuring Recall > 80%
Meaconing (100 ms delay)	10/10
Meaconing (100 ns delay)	10/10
Advanced	10/10

Synchronized	10/10
SCER	10/10

Table 4-1 GSD's performance robustness test

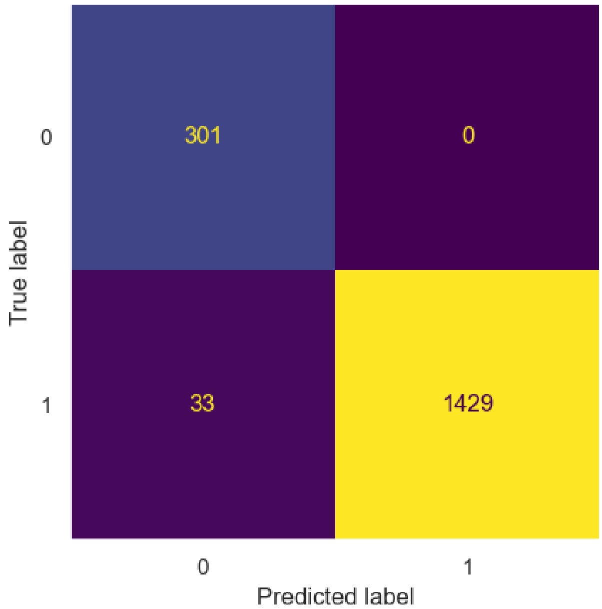

Figure 4-29 Confusion Matrix for the verification predictions of the GSD algorithm utilizing a single meaconing (100 ns delay) test campaign

S_02: Verify that GSD provides a time-tagged signal classification in a CSV format

We also verified that GSD's output was provided in a file named "GSD_solution.csv", including the GPS time indication and the corresponding spoofing flag for the entire epoch, as depicted in Figure 4-30

A	B	C
GPStime,Spoofing_flag		
1403514537,0		
1403514538,0		
1403514539,0		
1403514540,0		
1403514541,0		
1403514542,0		
1403514543,0		
1403514544,0		
1403514545,0		
1403514546,0		
1403514547,0		
1403514548,0		
1403514549,0		
1403514550,0		
1403514551,0		
1403514552,0		
1403514553,0		
1403514554,0		
1403514555,0		
1403514556,0		
1403514557,0		
1403514558,0		
1403514559,0		
1403514560,0		
1403514561,0		

GSD_solution

Figure 4-30 An example of output file for the GSD function