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# Assessment of GNSS based equipment in the context of AEBS based on the UNECE R152

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**Abstract**

For safety-critical systems in the automotive industry the assessment of all sensors and systems is mandatory using calibrated measurement equipment. In the last decade GNSS based sensors are used in a variety of applications starting in the context of information, merging to commercial and now entering safety critical applications. With the pan-European emergency call 112 eCall for the first time a regulation specified mandatory requirements for performance and assessment of GNSS based systems were defined. This trend progresses with new requirements in other areas like EETS and smart tachograph (see implementing regulation EU 2021/1228 [1]) in which the usage of GNSS based systems has become mandatory Similar concepts are specified in the field of driving assistance and automated driving, like the UNECE R152[2].

Conformity to such defined requirements is assessed by notified entities in this context. The calibration of measuring instruments is an essential prerequisite for the reliability of testing (see metrological traceability ISO 17025[3]). Since the observations of GNSS based reference measuring instruments are not directly traceable to SI units and accordingly cannot be calibrated through accredited calibration schemes, an ISO 17025[3] conform assessment, validation and qualification of the reference measuring systems must be performed instead of calibration.

For this purpose, NavCert has developed a test procedure for the assessment of GNSS reference receivers based on existing standards. The respective test scheme replicates for the calibrations the assessment of performance values for GNSS based equipment. The process is presented for exemplary assessing values in the area of time, position, speed and distance with certain devices. As an outlook, currently discussed further use cases and systems are briefly presented.

**Key words:** ISO 17025, Assessment, GNSS, AEBS, UNECE R152

## INTRODUCTION

The UNECE R152[2], where the fourth and latest amendment was released in December 2021, describes the approval for advanced emergency braking systems for M1 and N1 vehicles.

In the chapters “5. Specifications” and “6. “Test procedure” of the UNECE R152 and its amendments [2] requirements regarding the assessment in the area of speed, centreline offset and distance are defined. Hereby it needs to be mentioned that the distance is not directly addressed, but in form of the time to collision as function of distance and relative speed of the of the subject vehicle and the target.

These requirements are for example that the subject vehicle shall approach the target in a straight line for at least two seconds prior to the test with a subject vehicle to target centreline offset of not more than 0.2 m and that the tests shall be conducted with a vehicle travelling at different speeds with a tolerance of +0/-2 km/h [2].

These requirements are verified with reference equipment from the notified bodies or mandated accredited laboratories. Which reference equipment is used by these entities and if additional requirements apply is defined for each entity in standard operating procedures which follow quality standards like the ISO 17025 [3]. Hence the calibration of measuring instruments and references is an essential prerequisite for any laboratory to perform tests with reliable results.

In the UNECE R152 context the usage of GNSS based reference equipment is widespread, but also creates and issue, because one of the “default” requirements following ISO 17025[3] is the need of accredited calibration of the reference equipment.

According to the valid version of DIN 1319-1 [5], calibration is described as "determination of the relationship between a measured value (...) and the associated (...) correct value". Here, the correct value is defined according to the definition of the PTB [6] by means of measurement standards, which is a representation of an SI unit based on fundamental physical constants.

Thus for GNSS based measuring instruments a calibration by definition is not feasible, since the relevant measured quantities are not directly traceable to SI units.

The following presented work is a revision and update of the previous NavCert internal project presented in [7].

## STATEMENT OF THE PROBLEM

Typically a calibration certificate needs to be issued for all kinds of measuring instrument used in laboratories, because according DKD-L 13-1 [8], an issued calibration certificate is the proof of traceability to national standards, as required by DIN EN ISO/IEC 17025 [3].

Based on the developments in the last years and upcoming ones, GNSS receivers and GNSS based equipment are used as reference measuring instruments during type approval by notified bodies and qualification and voluntary certification tests by accredited laboratories. Current fields of application for GNSS receivers or GNSS based equipment as test objects in the automotive industry are for example the tests in the context of the type approval of advanced emergency braking system, see [2], for the measurement of speed, centreline offset and distance necessary (see chapter 5. and 6. of [2]). For these topics different test scenarios are defined like for example the warning and activation test with a stationary vehicle target like defined in [2] chapter 6.4 ff., where the defined speeds of 20, 42 and 60 km/h with a tolerance of 2 km/h, the time to collision of at least 4 seconds and a maximum centreline offset of 0.2 m need to be independently measured. Similar applies to the other applicable test cases like for moving pedestrian targets (see [2] 6.6.1).

For these measurements a reference measurement equipment is needed. The most common used measurement systems are either GNSS receiver or GNSS based equipment (e.g. INS).

Due to the typical system design of such units and usage of non-deterministic algorithms the PVT-output of such systems is nearly impossible to traceback to SI-units and currently not calibratable.

Due to the thus non-existing calibration possibility such system needs to be assessed according to laboratory requirements like stated for example in the ISO 17025 [3].

Additionally it needs to be mentioned that this applies not only the core reference system, but also to other services which are used together with the reference equipment (e.g. augmentation in the form of RTK-correction).

If such system (e.g. GNSS-RTK-Systems) has not been calibrated and validated, the proof of the quality of the measured values (e.g., reliability, accuracy, availability, integrity) is missing and the test result is doubtful.

To solve this problem as an accredited laboratory for GNSS NavCert conducted an internal project.

## INITIAL ANALYSIS

As a first step, an initial measurement and error analysis of typical GNSS receivers and GNSS based equipment was performed. The initial work for this was done in [7] and for the here presented revision an update in the area of inertial measurements was conducted. Hereby typical measurement quantities as well as output protocols are considered.

According to [8] chapter 3.3, the following measured quantities are the typical observed quantities of GNSS receivers:

- Pseudo range or code phase
- Carrier phase
- Doppler frequency shift

These typical observables can be outputted in the form of RINEX data in the observation part with additional information, such as information regarding observation time from specific receivers, and supplemented with the RINEX navigation part. In the past, receivers which could output RINEX were usually professional ones. However, this is changing in recent years due to the release of raw GNSS data in Android environments [9] for example. Usually RINEX data is used for GNSS post-processing, which is currently used for certain applications (e.g. determination of coordinates of static reference points). Currently the assessment of RINEX-data is not within the scope of the defined internal project and thus they are not further discussed in the current project phase.

Another standard output format in various forms and versions is NMEA, which is supported by quite every receiver. It is a real-time output protocol which provides information for example about visible satellites as well as the current position fix of the GNSS receiver. This document focuses on NMEA-0183 v 4.11 with RMC, GGA, VTG, GSA and GSV -message as defined in [10] as follows, which are for example used for tests according to DR 2017/79 Annex VI [4]:

- RMC: Recommended Minimum Specific GNSS Data
    - Includes time, date, position, speed, status, heading information.
- GGA: Global Positioning System Fix Data
    - Contains time, date, position, quality, altitude information, which is supplemented by the number of satellites used and information regarding correction data used.
- VTG: Course Over Ground & Ground Speed
    - Contains course, speed and status information
- GSA: GNSS DOP and Active Satellites
    - Contains status and satellite information regarding navigation satellites actively used for positioning, which is supplemented by PDOP, HDOP and VDOP
- GSV: GNSS Satellites in View
    - Contains information about possible and seen satellites

In addition to the two presented formats, there are further formats which are not discussed in this document.

Besides the GNSS measurement in this document also on IMU measurements are discussed on a high-level. These are according to [11] linear accelerations and angular rates. These measurements can be outputted by IMUs by using usually by the manufacturer defined output formats.

If the IMU is used in combination with a GNSS receiver or other sensors in a more complex localisation sensor system, we are speaking usually of an INS, where these measurements are combined internally via sensor data fusion algorithms with the GNSS measurements in one of the three typical data fusion levels (loosely, tightly, ultra-tightly).

Besides these measurements also the output of used augmentation/ correction services was analysed. The project is focused currently on NTRIP based RTK services which provide their correction data according to the RCTM definition [12]. These corrections originate from one or a network of GNSS reference stations and cover a large are of data, e.g., RTCM 3.3 message 1004 contains the extended L1 & L1 GPS observations.

Additionally to the measurement analysis and uncertainty analysis for the GNSS, IMU and RTK was conducted and the impact on the measurement results was evaluated. This analysis and its outcome are used to define certain critical scenarios or feared events which shall be acknowledged in the later test scheme.

The analysis followed the described process in [6] and [13] and usually contains six steps. But for the usage as for definition of the critical scenarios only the first four steps are from major importance. These steps are:

1. Description of the measurements
   The underlying measurements for the tests and of the equipment were described here based on the outcome of the initial analysis.
2. Modelling of the measurements
   The described measurements are modelled according to the process described in [14], whereby all impacting topics/input variables like for example personnel, environment, method, equipment are analysed and listed upon their impact
3. Evaluation of input variables
   The identified input variables are evaluated based on their probability, quantify and severity. Hereby the impact on the accuracy was the main focus, but also other performances like the integrity were evaluated.
4. Calculation of the best estimate and combined standard measurement uncertainty
   For the variables assessed as essential for the further process the best estimate quantity is calculated and carried over to the calculation of the combined uncertainty.

Hereby its needs to be highlighted that most of the critical scenarios which apply to the GNSS receiver also apply to the assessed correction services due to the usage static GNSS reference receivers for the generation of the correction data.

The detailed analysis is not highlighted in this paper due to its extend.

As outcome of the analysis it was determined that for this revision of the testing scheme the focus shall be put first on the integration of GNSS specific critical scenarios like:

- Shadowing
- Non-availability
- Multipath

- Jamming/ Interference
- Meaconing
- Spoofing

**STANDARDS**

The next step was an analysis of available standards for the assessment. The following standards were selected for the:

- Definition of the performance requirements
- Definition of test setups and test description

*Tab. 1: Overview of standards*

| Number | Version |
|---|---|
| ETSI TS 103 246-3 [15] | V1.3.1 (2020-10) |
| ETSI TS 103 246-5 [16] | V1.3.1 (2020-10) |
| DIN EN 16803-1 [17] | 2021-07 |
| DIN EN 16803-2 [18] | 2021-07 |
| DIN EN 16803-3 [19] | 2021-07 |
| ISO 17123-1 [20] | 15.08.2014 |
| ISO 17123-8 [21] | 15.06.2015 |
| DIN ISO 5725-1 [22] | 1997-11/1998-09 |
| ISO 5725-2 [23] | 2019-12 |
| ISO 5725-4 [24] | 2020-03 |
| DIN ISO 5725-6 [25] | 2002-08 |

**METRICS**

Based on the standards listed above, the metrics of the assessment scheme was defined. For this the following represents the metrics scope for this phase of the internal project for the basic performance part. It was defined that the GNSS equipment performance is asset for the horizontal position and the horizontal speed and the timing quality.

Hereby for the horizontal position and for the horizontal speed the focus was laid on the accuracy and availability. For the timing the focus was laid on the general performance, availability, and continuity.

Additionally, if correction services are used from the GNSS equipment, it was defined to also evaluated the correction service’s availability and continuity.

Background of this decision is that the accuracy is one of the fundamental and most crucial performances which has an effect on several system functionalities. The same applies to the topics of availability and continuity.

As second part of the test scheme the critical scenarios are defined like described in the chapter “Initial Analysis”. Here besides the above defined metrics also the integrity is considered in this phase of the internal project.

The following table represents the definition of the metrics, which follows definitions from the references [15] chapter 5.4.1 ff and [17] chapter 5.5 ff.:

- Position Quality
  - Horizontal Accuracy: The horizontal position accuracy is defined by the horizontal error of the valid position data in comparison to the reference.
  - Availability: The positions availability is described as the percentage of operating time intervals of length $T_b$ during which the system provides at least one valid output.
- Distance quality between two systems
  - Horizontal Accuracy: The horizontal distance accuracy is defined by the horizontal error of the differences of the valid position outputs in comparison to the reference.
  - Availability: The horizontal distance availability is described as the percentage of operating time intervals of length $T_b$ during which both systems provide at least one valid output.
- Speed Quality
  - Horizontal Accuracy: The speed accuracy is defined by the error of the valid speed outputs in comparison to the reference.
  - Availability: The speed availability is described as the percentage of operating time intervals of length $T_b$ during which the system provides at least one valid output.
- Time Quality
  - General performance: The general timing performance is defined by the time to first fix under cold start conditions warm start as wells as the reacquisition time.
  - Availability: The timing availability is described as the percentage of operating time intervals of length $T_b$ during which the system provides at least one valid output.
  - Continuity: The timing continuity is described as the percentage of operating time intervals of length T during which the system provides valid outputs at the required rate and without interruptions.

   - Relative delay: The timing delay of the is described as the relative time offset of the recorded trajectory between of the SUT and the reference determined by a cross-correlation analysis.
- Correction Service Quality
   - Availability: The correction service availability is described as the percentage of operating time intervals of length $T_b$ during which the system provides at least one valid output.
   - Continuity: The correction service continuity is described as the percentage of operating time intervals of length T during which the system provides valid outputs at the required rate and without interruptions.

As expression of these metrics in the test scheme the following representations are used:

- Accuracy: Mean error, standard deviation and the 75th and 95th percentile (see [15] chapter 5.2.2)
- Availability: Percentage (see [18] 5.5)
- Continuity: Percentage (see [18] 5.5)
- General timing performance: Mean value

**TEST DESCRIPTION**

As a next step, based on the requirements for laboratories of ISO 17025 [3], a description of the tests to be performed and a detailed analysis regarding the test topics, e.g. a measurement uncertainty analysis, was carried out based on the processes described in ISO Guide 98-3 [26], in DKD-L 13-1 [6] and DKD-L 13-2 [13].

For the measurement uncertainty analysis the process which is highlighted in the chapter "Initial Analysis" was used.

This process consists of six steps, which are highlighted in the following with the focus on the test scheme and used reference for the tests:

1. Description of the measurements: The underlying measurements for the tests and of the equipment were described here based on statements from [2] and the outcome of the initial analysis. The required measurements can be highlighted as followed:
   - Assessment of GNSS based reference equipment under consideration of used correction services in the domain of position and distance between two systems.
   - Assessment of GNSS based reference equipment under consideration of used correction services in the domain of velocity.

   As measurement method for the assessment different methods need to be considered due to the difference of the used systems, which is highlighted in the following:
   - GNSS receivers: A simulation-based approach based on [3] under consideration of inputs from [2] applies here where the output of the SUT is compared to the simulation reference.
   - GNSS-IMU-systems: A field testing approach based on [18] under consideration of [2] applies here where the output of the SUT is compared to a validated PVT-reference.
   - Correction services: The field-testing approach, which is described in [21], applies. It contains to steps, the static approach and the dynamic approach, which resemble a modified approach from [21] under consideration of [2].
2. Modelling of the measurements

   The described measurements are modelled according to the process described in [14], whereby all impacting topics/input variables like for example personnel, environment, method, equipment are analysed and listed upon their impact. This analysis applies to the described high level measurement methods described before and the chosen reference.

   Based on the requirements from [2] (for example velocity accuracy better than 2 km/h and position accuracy better than 0.1 m) and the analysis outcome the initial requirements for the reference for the assessment tests was defined. Hereby it was defined that the reference shall be in optimal case ten times better than the requirement.
3. Evaluation of input variables: The identified input variables are evaluated based on their probability, quantify and severity. Hereby the impact on the accuracy was the main focus, but also other performances like the integrity were evaluated.
4. Calculation of the best estimate and combined standard measurement uncertainty: For the variables assessed as essential for the further process the best estimate quantity is calculated and carried over to the calculation of the combined uncertainty.
5. Determining the expanded uncertainty: Based on the conducted sample analysis (see below) and under consideration of the prior analysis the expanded uncertainty is determined.
6. Specifying the complete measurement results: Based on all the previous information the expected uncertainty of the

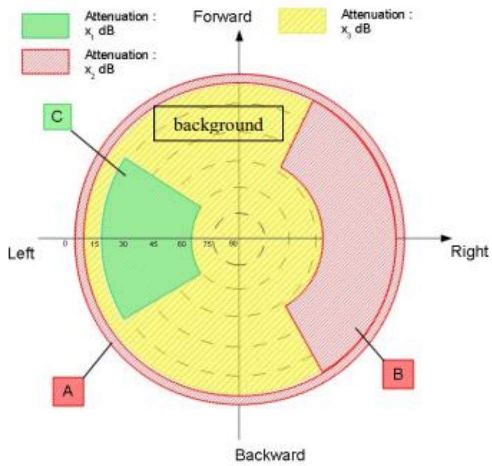
reference and the measurement method is statistically analysed and determined.

Additionally to support the measurement process as further topic a sample analysis according to [27] was performed, which is described in the following on a high level.

In order to obtain a sufficient significance of the test results, a certain confidence must be achieved, which influences the sample size and further values. Within the project, the confidence levels of 99% and 99.9% regarding the binomial distribution at an infinite population were considered. They were considered via the factor of 2.57583 and 3.29053, respectively, according to [27] A.5.

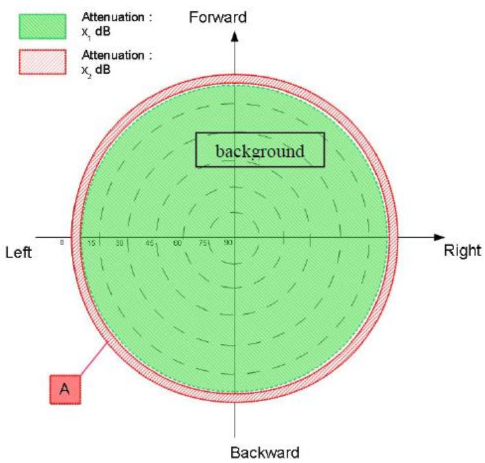
This results under consideration and inclusion of other parameters into a minimum sample size of about 16,600 resp. about 27,000 samples for each respective test.

During the presented analysis also all relevant topics regarding the test method like signal strength for the simulated signals, applicable GNSS environments for simulation and field tests, test setup are discussed and under consideration of the available standardisation defined. For example the open and urban environment (see Fig.1 and 2) was defined for certain tests.




| Zone | Elevation range (deg) | Azimuth range (deg) | Attenuation (dB) |
|---|---|---|---|
| A | 0 to 5 | 0 to 360 | $x_2$ = 100 |
| B | 5 to 60 | 30 to 150 | $x_2$ = 100 |
| C | 10 to 60 | 230 to 310 | $x_1$ = 0 |
| Back-ground | Angles out of Zones A, B, C | | $X_3$ = 15 |

*Fig. 1: Asymmetric GNSS-Environment according to [4] A..3.2*




| Zone | Elevation range (deg) | Azimuth range (deg) | Attenuation (dB) |
|---|---|---|---|
| A | 0 to 5 | 0 to 360 | $x_2$ = 100 |
| Back-ground | Angles out of Zone A | | $x_1$ = 0 |

*Fig. 2: Open GNSS-Environment according to [4] A.3.2*

In total three basic environment are defined according to [15] for the assessment. Hereby for the field tests a procedure is defined to determine the applicable environment on test side.

The kinematics for the tests are defined following requirements from [2] and [15]. Hereby generically static and dynamic movements are defined, whereby the kinematics are defined in the standard test case according [15] A.4. These are amended by the movement on straight lines following the description and requirements from [2], e.g. travelling speeds like 20,42 and 60 km/h.

Based on the initial analysis regarding critical scenarios the second part of the test scheme is defined, assessing the system's performance and behaviour under influence of such. The effect of shadowing and non-availability are already covered by the basic performance assessment. Like indicated in the initial analysis the test scheme covers the impact of

- Multipath
- Jamming
- Interference
- Meaconing
- Spoofing

Hereby the definitions from [15], [16] and [19] are followed. Due to the impact of such threats to the public the critical scenarios tests cannot usually be performed in open environment and thus a special environment is required. This can be either a shielded environment or a special restricted place.

As next part of the test scheme the assessment of the correction service is conducted. This follows the accredited NavCert testing schemes PPP80013 [28] and PPP80019 [29] which were adapted to represent the use case testing of reference measurement equipment for AEBS type approval according to [2]. The approach assesses the addressed quality of the service and the performance of the services together with the used receivers. The performance assessment of the services is combined with the basic assessment of the GNSS based systems in fields tests. The correction service quality on the topic of availability and continuity is asset via an QM-review of the service provider, long time data logs of the provider and spot checks during the tests.

Besides the single system performance assessment also the synchronic performance of two systems for the measurement of distance or relative positions are assets in this test scheme. For this in the current phase of the project the test systems are mounted for a field test to a moving platform with which at least three different independently asset distances can be set. Similar to the position assessment the test is conducted with different speeds and in different environments to determine the quality of the distance output of the combined system.

For the test setup different setups apply. In the standard operating procedure for this test scheme the following test setups are defined:

- GNSS simulation test setup
    - Shielded environment
    - Wired connection
- GNSS based equipment field test setup
- GNSS correction services test setup
- GNSS critical scenario setup
    - Shielded environment
    - Restricted testing area
- Distance test setup

In the following as representatives the setup for basic performance assessment for GNSS receiver testing (see Fig. 3 and 4) and the distance test setup (see Fig. 5) are presented.

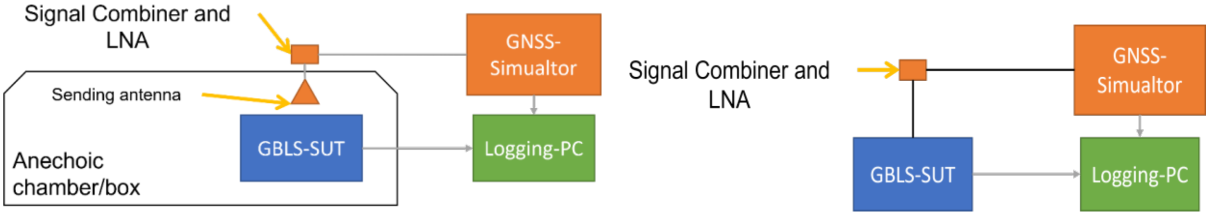



*Fig. 3: Test setup according to [16] Annex A A.1 System set up for tests in anechoic room and [16] Annex A A.2 System set up for tests with wired connections*

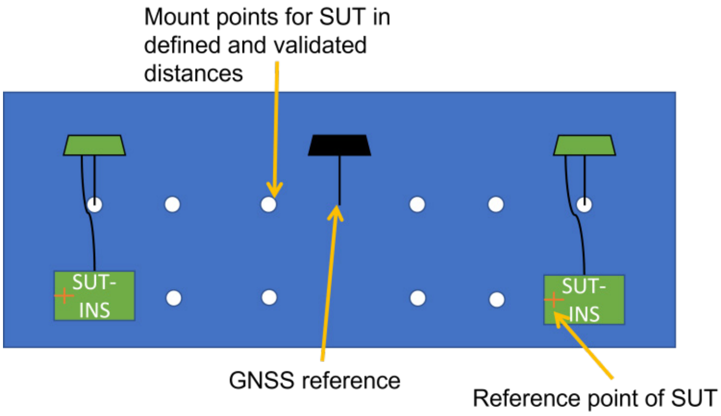



*Fig. 4: Test setup for distance assessment*

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The test setups for the GNSS receiver simulation test follow the description [5]. The test setup for the distance assessment is a self-developed approach. It contains beside the mount points for the GNSS based SUT (e.g. an INS) with evaluated distances to each other also a validated GNSS reference for checking the applicable environment and further topics which are required to create reproducible results.

At the end of the test scheme additional statistical tests are included to check and deliver proof that during the testing no errors for example were conducted. Examples for these statistical tests are for example null hypothesis testing, comparison of the critical range with the range of results and Cochran's test (see for example [23]).

## EVALUATION

To conclude in the following the according [3] required initial validation, verification and review including initial results are presented. The results are based partially on the previous work conducted in [7]. In the following three topics are presented and discussed:

- Determination of the position and speed error in simulation mode based on basic performance assessment
- Determination of the time error in simulation mode based on basic performance assessment
- Determination of distance error in field testing based on basic performance assessment

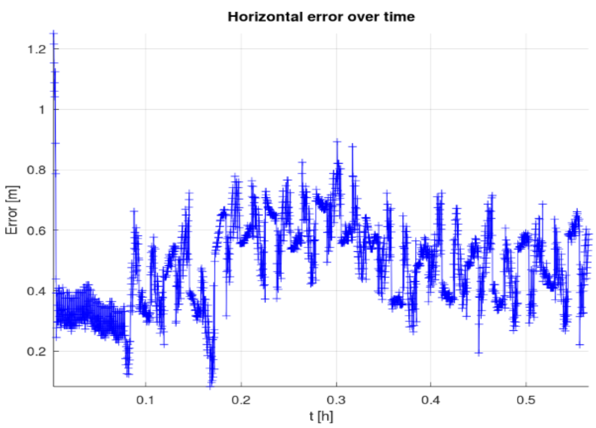
The first step after the definition of laboratory is the validation according [3]. This step is required and is here highlighted only. For the standardized methods a validation is only proposed, but due to the nature of the here presented a validation needs to be conducted to assure that the quality of the method. According to [3] different possibilities for the validation are available, which are not further detailed here. The initial validation of the presented methods was conducted successful, concluding that the chosen methods ensure the required quality.

After the successful validation the initial verification of the test scheme and its methods was conducted upon their suitability to the intended use. For this the required measurement equipment, the available measurement range and the respective accuracies are compared to the required measurement ranges for each method to assess that the full range of measurements is covered and can be assessed. Additionally, a prototypical test campaign is conducted using suitable equipment as the SUT. The initial results of the verification are presented in the following. Due to the ongoing project the formal topic of review is currently not conducted but will be conducted after finalization of the next phase.

For the verification here the results of the including prototypical test campaign are presented. Like described before the assessment of position, speed, time and distance will be shortly presented.

In the following the error vector, mean error and standard deviation are presented as way are the base for the definition of the values mentioned in the chapter "Metrics".

In the course of the subsequent laboratory verification of the test procedure, the NMEA data of a timing receiver and a geodetic receiver were compared with the validated reference data of the GNSS simulator within the project for the addressed simulation test methods. The following results were obtained:



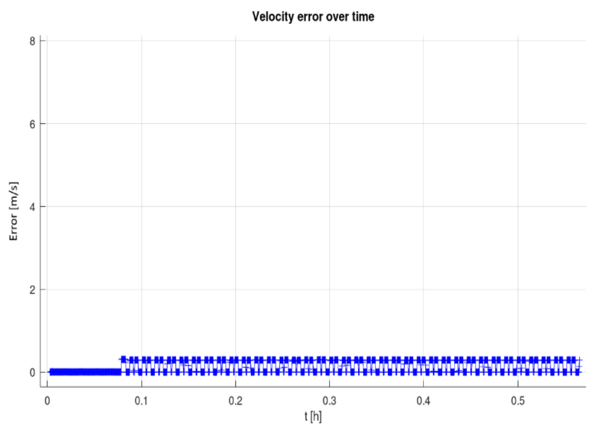




*Fig. 5: Horizontal error over time for the chosen timing receiver and speed error over time for the chosen geodetic receiver*

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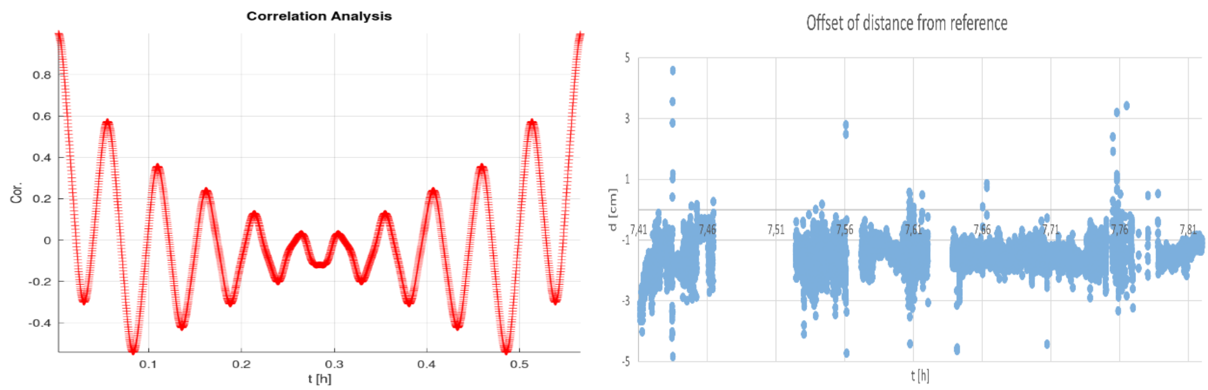


*Fig. 6: Cross-correlation results of the geodetic receiver and excerpt of distance analysis data for the high-quality solution*

Here, the geodetic receiver achieved a comparable time quality considering the resolution of 10 ms of the reference. The timing receiver achieved the same result regarding time quality, which was expected.

Regarding the position and the speed, values below 1m for the horizontal position error and below 0.25 m/s for the horizontal speed error were achieved in the SBAS mode for both receivers.

For the assessment of the distance a high-quality solution and a high-quality solution were checked. Hereby for the high-quality solution an uncertainty of the distance of 1,49 cm+/- 0,53 cm and the low-quality solution uncertainty of the distance of 1,02 m +/-3,88 m was determined.

## CONCLUSION AND OUTLOOK

As initially presented, calibration for GNSS based measuring equipment is due to the definition of calibration problematic. Accordingly, instead of calibration, an evaluation, validation and qualification of used systems need be conducted.

Based on current outcome it can be stated that the presented method shows a valid initial approach which can already be used for certain type of equipment. The performed and ongoing validation and verification of the test procedure according laboratory requirements hereby ensures that the developed procedure meets the initial expectations and can be used as a basic procedure for assessment, validation and qualification.

However, it provides only an initial assessment. Therefore, further refinement and elaboration is needed, like addressed before. This is currently under work and will be done in further ongoing of the project within NavCert. Here, for example, the planning is to include also RINEX data in the assessment and thus to check other GNSS observations such as pseudo-distance.

Additionally to widen the scope of the assessment further use cases and augmentation sensors and services need to be included in the scheme.

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