iTraceRT-MVT – the INS/GNSS based ADAS Vehicle Motion Verification Toolset

As vehicle safety advances in the future and becomes increasingly connected, testing will need to be conducted away from proving grounds, calling for an equally advanced verification toolset

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Introduction

ADAS (Advanced Driver Assistance Systems) functionality is available in quite a number of cars already and in the future this will be a fast-growing segment - and not only for top-of-the-range models. Such functions were once more or less advertised as “comfort features”, but the aim now is clearly about enhancing safety. Looking into the future, cars will either be interacting directly with the driver, or actively taking part in controlling the car in dynamic environments featuring other traffic participants such as cars, bicycles or pedestrians.

With iTraceRT-MVT iMAR provides an ADAS vehicle motion verification tool with high performance and reliability for real world environment. This paper describes the requirements for multi vehicle target (MVT) based ADAS verification and advantages of iMAR technology.

Technical Background

This raises new test requirements, however, because all of these functions need to be verified and certified before they can go into production. Most of the testing conducted in the past centered around vehicle dynamics, performed on proving grounds under pretty much open sky conditions using standalone GPS or GPS-aided inertial measurement units (IMUs) to reference the measured data. But so far there was no requirement for absolute positioning, or performing ADAS verification under real world conditions where GPS is not available all the time, like in urban or rural areas.

By today, testing requirements for current and future ADAS systems will differ, in that the reference systems being used for verification and testing should provide reliable accurate data under real world conditions - i.e. in areas where GPS signal blockage and multipath created by nearby obstacles such as buildings, trees or bridges are to be expected.

Figure 1: Testing an automatic distance control system using iMAR’s iTraceRT-MVT tool

The problem can be fixed partially by utilising all GNSS (Global Navigation Satellite System) signals like GPS and GLONASS (or even GALILEO and COMPASS in the near future) to enhance the satellite coverage.

But in those areas where no reliable position information can be attained from GNSS due to signal blockage and/or multipath, an Inertial Measurement Unit in combination with the IMU/GNSS data fusion (“filter”) will need to be employed to overcome blockage and multipath problems.

Two things must be considered with regard to the IMU and the IMU/GNSS integration: the first is the grade or performance of the IMU being able to fill those gaps where insufficient GNSS signals are available, running on “free wheeling” inertial only;

the second one being the type of filter used for the IMU/GNSS integration.

Commonly used systems are based on a so-called "loosely coupled" approach, as this one is a cheap and easy to implement solution and can use any kind of GNSS receiver. However, the more sophisticated and reliable method is the "deeply coupled" approach.

As the implemented data fusion has a severe effect on system performance, it makes sense to investigate both solutions in a little more detail.

Why Deeply Coupled ?

The **"loosely coupled"** solution is also known as "cascaded filters", because it contains multiple filters. There is usually one inside the GNSS receiver, the "GNSS filter", and one within the INS, the "Navigation Filter". It mostly uses a "car model" and a "single track model" filter to smooth the output data as well as to extract the slip angle.

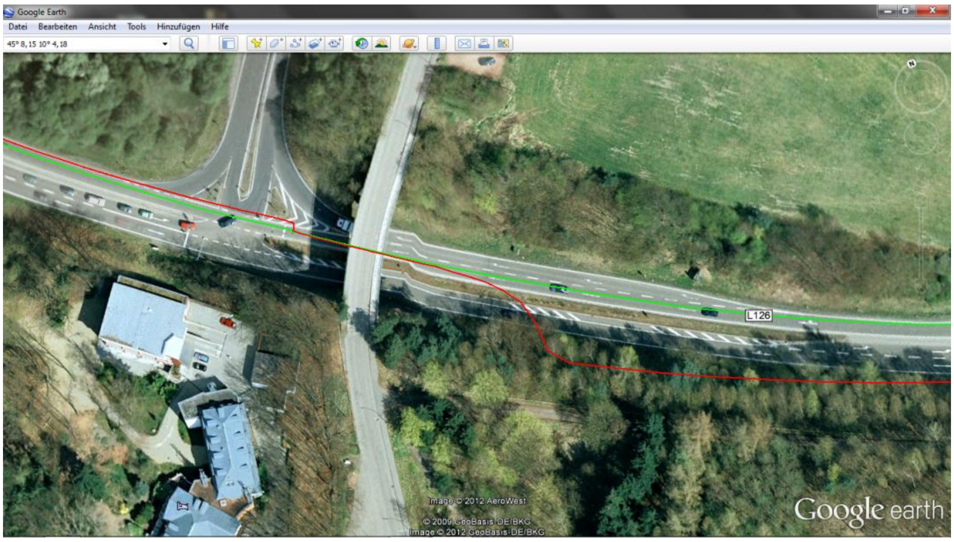

Figure 2: Advantage of the Deeply Coupled Architecture

The Navigation Filter uses the preprocessed data of the GNSS filter, so there is just a "one way" for the GNSS data flow and thus no bidirectional communication between the inertial navigation and the GNSS.

The disadvantage of such a simple approach together with a vehicle model is, that the result of such measuring tool is affected ("smoothed") by model assumptions, while a strict demand on every ADAS verification task is to guarantee independency between the used measurement tool and the device under test. Furthermore, due to the missing link from the IMS to the GNSS, degradation in performance in relation to the deeply coupled solution has to be accepted, as described in the next paragraph.

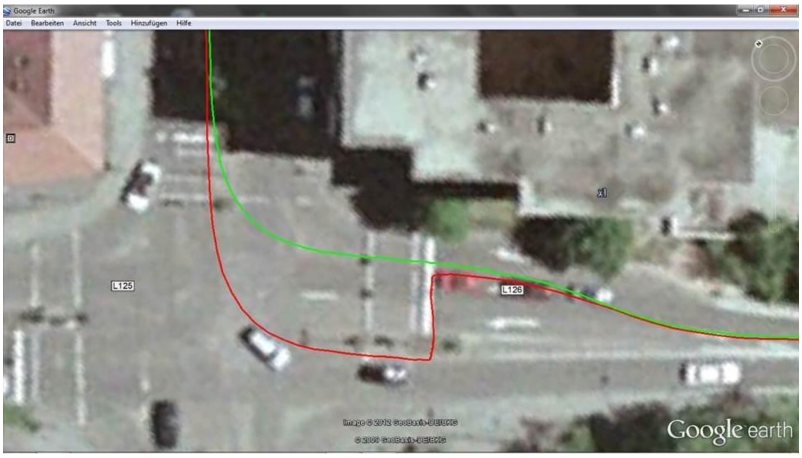

Figure 3: Behavior in urban canyons (9 m distortion of loosely coupled solution against deeply coupled solution)

In contrast, the **"deeply coupled"** solution processes all IMU and GNSS information together in one common filter, in doing so generating an integrated solution. All calculations are based on real-time raw measurement data from the IMU and the GNSS receiver. The bidirectional link between IMU and GNSS allows for a powerful aiding of the tracking loops of the GNSS receiver by IMU data and - in parallel - to estimate the error model parameters of the inertial sensors (gyros and accelerometers) by GNSS data.

The major advantage of this "deeply coupled" approach is that it is able to produce more valid GNNS solutions than the "loosely coupled" equivalent.

For example, being able to navigate even with less than five satellites, reducing the number and length of GNSS outages, combined with a two to three times faster recovery after loss of lock, resolving the carrier phase ambiguity (RTK-Solution) - typically only 12 second compared with 30 seconds - by being able to use the IMU information to validate individual satellite locks.

Figure 2 shows a typical example driving through a cutting in the landscape, which results in a loss of GNSS lock. Both systems, iMAR's iTraceRT-F400 (green) and a third party "loosely coupled" (red) system, are operated in the same car from the same antenna signal (with a splitter) so they are tested in a comparable environment, in this case by a well-known German car manufacturer. The red line goes off track and needs a while to recover, while the green line remains on track.

The "deeply coupled" solution also copes with the effect of multipath, usually not only being present in urban areas but also present when you drive on the motorway, for instance when you approach and path beneath a bridge. In such scenario, you might experience a heading error with a loosely coupled system before you reach the bridge, and recovery won't be established until you obtain a valid fix after coming out of the bridge, which takes significant time where the results of a loosely coupled system can be significantly distorted. You are likely to have seen "bridges" on proving grounds, which are used to let obstacles such as pedestrian dummies cross the path of the vehicle. The deeply coupled system, however, can cope with such a scenario.

The only good thing with multipath is that the portion created by the environment is going to be depressed by the speed of the vehicle, although as soon as you come to a standstill, it will adversely affect your navigation solution again. As can be seen in figure 3, the vehicle stopping at a traffic sign with a building on the right side, you see the "loosely coupled" solution going off track again (same color scheme as before) whereas the iTraceRT solution stays on track well.

Inertial Sensor Performance

Based on this experience, iMAR offers deeply coupled solutions for these applications. They also include a high-accuracy IMU with 1°/h FOG gyro and 2 mg accelerometer raw data performance (free of export control). This allows for a much faster converging of the filter with the advantage for the user being great time saving during ADAS testing, and providing high data reliability even in areas where only poor or even no GNSS solutions are achievable.

Figure 4: iTraceRT-F400 INS/GNSS system

These iTraceRT-F400 systems (figure 4) are widely used for automotive testing in general - for ADAS testing and verification as well as for autonomous driving, using its integrated interfaces for steering and driving robots.

Figure 5: Antenna setup on two test vehicles (GNSS, Radio Modem, WLAN for inter-vehicle-communication)

The fact that the iTraceRT offers true measurement results and is unaffected by any kind of dynamic model - and with very small latency of < 5 ms at a data rate up to 400 Hz - enables the testing technology to be used in a wide range of measurement and control applications on cars, bikes, ships and even aircrafts.

Multi Vehicle Tracking

In real-world environments, Multi Vehicle Tracking (MVT) is the core technology to verify ADAS functions also away from established proving grounds. In addition to the INS/GNSS iTraceRT-F400 measurement system itself, iMAR Navigation provides complete multi-vehicle installations including software and communication equipment for car-to-car (WLAN 5.8 GHz Link) and correction data networks (GSM, radio modem) for Multi Vehicle Tracking. These have some useful applications for ADAS already embedded. The software provides an open interface for standard or customer-defined test procedures to be implemented by the customer or iMAR upon request. The aim of these procedures is to guide the test driver through the test, as well as to monitor the correct execution, and then present the result at the end. The open interface therefore also supports the data integration into third-party data-acquisition systems.

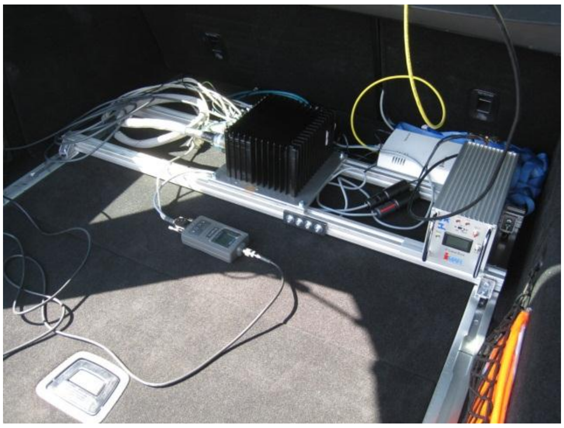

Figure 6: Small space setup with iTraceRT-400, GSM, Radio Modem and WLAN as well as a smart battery to bridge vehicle's power break-down during starting the engine.

The following table gives a rough performance overview using iTraceRT-F400 inside iTraceRT-MVT:

Measurement value	Accuracy	Range
Absolute Vehicle Position	0.02 m	worldwide
Relative Position between Vehicles	0.03 m 0.02 m	worldwide within CAR-to-CAR (WLAN)
Velocity	0.01 m/s	up to 150 m/s
Heading	0.05 deg	no limitation
Roll and Pitch	0.01 deg	no limitation

Figure 7: For autonomous users – using your own GNSS reference station

Easy Setup

Aside from high reliability and superior performance, compact dimensions, low weight and easy setup in the car are demanding requirements for future ADAS verification test systems. Figure 4 shows the antenna setup, which is easy to mount with magnetic feet. Figure 6 shows the setup inside the car, withstanding also dynamical forces and vibration up to 1 g and more without bad impacts. Figure 5, meanwhile, shows the setup of the GNSS reference data station in case the user doesn't want to use GSM-based RTK data.

For each vehicle the same hardware and software is used. Each test driver identifies his own vehicle as "EGO Vehicle" (lat.: *my vehicle*) and the other as "ALTER Vehicle" (lat.: *the other vehicle*). Each user in each vehicle can connect to each other vehicle to operate the equipment of other vehicles in remote control mode. So even one skilled user can operate a fleet of other vehicles from his own vehicle.

The powerful iTraceRT-Command software shows in real-time and simultaneously the position and trajectory of all vehicles (EGO and ALTERs) as well as the distance, the bearing and the time to collision between the EGO and the selected ALTER vehicle. Figure 8 shows a screenshot.

A wizard guides the user from system installation over the automatic GNSS antenna lever arm determination and the automatic misalignment correction and via the setup of a local grid, within the measurements shall be taken, up to performing maneuvers with multiple vehicles. Figure 9 shows a setup with two cars.

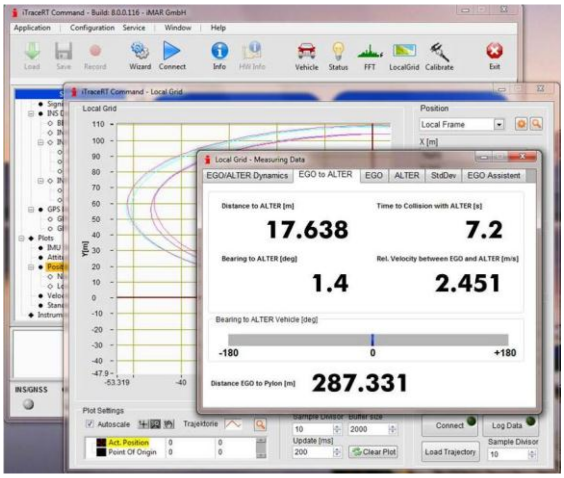

Figure 8: iTraceRT-Command software

Calibration of Verification Tools

It is common use to calibrate tools, which are used for verification tasks like ADAS vehicle motion verification.

iMAR Navigation operates a powerful calibration lab for inertial measurement systems and provides system calibration as a service. iMAR Navigation GmbH is certified according to ISO 9001, EN 9100 and EASA Part 21 G.

Not only for ADAS…

Beside of iTraceRT-F400 and iTraceRT-MVT, iMAR Navigation GmbH (www.imar-navigation.de) offers a wide range of useful products for the ADAS testing community, such as the iTraceRT-R300 based on RLG (Ring Laser Gyro) technology, used to create highly precise maps, and the iTraceRT-M100, based on MEMS gyro technology, for cost-effective fleet testing or the control of pedestrian dummies, bicycles or other small targets. These, too, are based on the same leading edge technology as the workhorse iTraceRT-F400.

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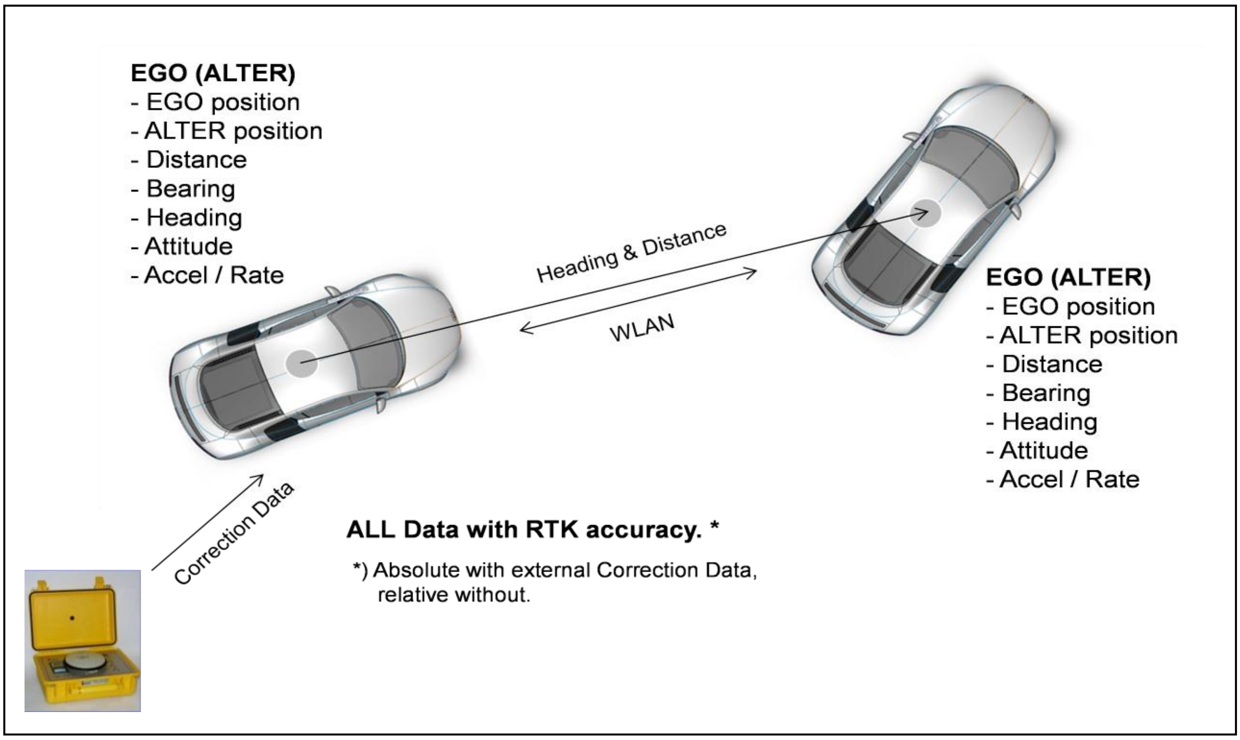


Figure 9: iTraceRT-MVT: System Setup with 2 x iTraceRT-F400, iREF-L1L2 and data transmission

iTraceRT-MVT

Multi Vehicle Tracking for ADAS Verification Tasks

It is in the focus of vehicle designers and developers of advanced driver assistance systems (ADAS) to know the driven trajectory and the dynamnic behaviour of one or between several vehicles to each another with high accuracy. The required task is called "multi vehicle tracking" (MVT) between an EGO vehicle ans seeral ALTER vehicles. Each vehicle contains identical hardware and software.

- MVT accuracy 0.05 ° / 2 mg / 0.001 °/s (under static and dynamic motion condition)
- < 2 cm position accuracy (trajectory accuracy without GPS outages) and 0.2 % of distance travelled (during short GPS outages using optional odometer information)
- interfaces: CAN / Ethernet / USB
- MVT setup supports one, two or more moving vehicles and RTK-GNSSS reference station.
- Using iMAR's well-known iTraceRT

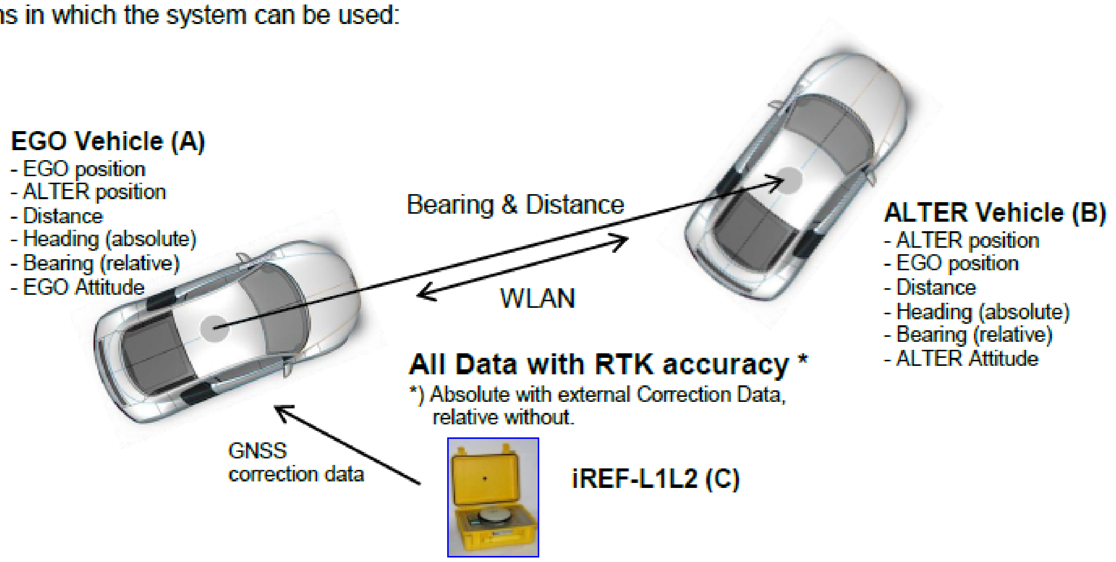
Due to its exceptional time synchronisation hardware, iMAR has prepared its inertial measurement systems of the family iTraceRT to be used for so-called MVT applications. For this the iTraceRT-F400 contains a powerful L1/L2 RTK-GPS receiver with deeply coupled INS/ GNSS realtime processing, a speed sensor (usable as an option), a wireless data transmission and as an option a postproc software.

The following sketch shows the three configurations in which the system can be used:

a) Both, vehicle A and vehicle B, are under motion and both are carrying an L1/L2 GPS antenna as well as an inertial platform iTraceRT-F400. The GNSS reference station C (iREF-L1L2 or ASCOS/ SAPOS modem) provides correction data to both vehicles. In this configuration the differential relation (distance, bearing, rel. velocity) between both moving vehicles as well as the absolute position is measured. For online result output, a wireless transmission between A, B and C is provided. The software iTraceRT-Command supports measuring and configuration.

b) Vehicle B can be used as a local RTK-GPS reference station, if at standstill condition. The L1/L2 antenna is mounted on the roof of the vehicle (or on top of a building), the RTK correction data are transmitted to vehicle A. The moved vehicle A also carries an L1/L2 antenna on its roof and contains an iTraceRT inertial platform. The iREF (C) is not required in this operational mode, as vehicle B acts like this.

c) If only the relative position between both, EGO and ALTER vehicle is required without high absolute position



need, the GPS receiver inside the iTraceRT of vehicle A or vehicle B can be operated in a so-called "Moving Base Station" mode to provide relative centimeter accuracy to the other vehicle if no GPS outages occur.

With the feature of the "Virtual Measuring Point" on the iTraceRT the position of every point of the vehicle can be calculated and provded in realtime as far as it can be assumed that the vehicle is a rigid body.

Technical Data of iTraceRT-F400 for MVT Applications:

Inertial System:	see data sheet of iTraceRT-F400 / iTraceRT-F400Q
RTK-GPS accuracy:	2 cm + 2 ppm of distance between rover and base station (no outages) 0.2 % of distance travelled (during RTK outages, odometer assumed)
Data output rate:	400 Hz (adjustable)
Installation aids:	automatic GNSS antenna leverarm calibration procedure; automatic mounting misalignment correction procedure
Output:	Ethernet, USB, CAN, RS232, interface for steering and driving robots (Ethernet, RS232)
Inputs:	RTK correction data; optional: odometer (A/B), event trigger
RTK-GNSS system:	included (L1/L2 receiver); GPS + GLONASS; option: dual GNSS antenna
Wireless transmission:	included for online processing
Sync. Reference:	UTC time, provided as time stamp
Power:	11...34 V DC, 25 W for iTraceRT-F400 (plus wireless transmission)
Temperature:	-25...+55 °C (operating within specification; case temperature)
Shock, protection:	60 g, 11 ms (depends on shock mounts), IP68
Weight:	3.6 kg iTraceRT-F400, plus Notebook and wireless modem
Size:	188 x 168 x 112 mm (iTraceRT-F400) Ø 85 x 30 mm (GPS antenna) approx.. 140 x 70 x 40 mm (wireless modem; depends on selection)
Software packages:	- iTraceRT-Command (online operation and offline visualisation) - iWP+ (INS/RTK-GPS postprocessing

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