

Rev.: 1.26 Date: 05.08.2023 Page: 1 von 53	User Manual for iNAT System Family iNAT-Rx/-Fx/-Hx, iNAT-M200, iNAT-CFM, iTraceRT-MVT, iSULONA, iCOMBANA, iPRENA, iATTHEMO	
Document No.: Reference:	DOC151228001 IEP-I000288	

User Manual

iNAT-Rx/-Fx/-Hx, iNAT-M200, iNAT-CFM, iTraceRT-MVT
(also for iSULONA, iCOMBANA, iPRENA, iATTHEMO, iCORUS etc.)

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DOCUMENT CHECK & APPROVAL REQUIREMENTS

CHECK required	APPROVAL by iMAR required	APPROVAL by Customer required
Yes	Yes	No

Acronyms of Functions

Industrial/MIL Projects / Industrie- & MIL-Projekte

CEO	Chief Executive Officer (Geschäftsführer)
CUST	Customer (Kunde)
DE	Design Engineer / Development Engineer (Entwicklungsingenieur)
HD	Head of Development (Entwicklungsleiter)
PJM	Project Manager (Projektleiter)
PM	Production Manager (Fertigungsleiter)
QA	Quality Assurance (Qualitätssicherung)
QM	Quality Manager (Qualitätsmanagement-beauftragter)
HoS	Head of Support

Aviation & Space Projects / Luft- und Raumfahrtprojekte

AM	Accountable Manager
CUST	Customer (Kunde)
DE	Design Engineer / Development Engineer (Entwicklungsingenieur)
HD	Head of Design (Entwicklungsleiter)
HoA	Head of Office of Airworthiness (Leiter Musterprüfleitstelle)
HoD	Head of Design Organisation
PJM	Project Manager (Projektleiter)
PM	Production Manager (Fertigungsleiter)
CVE	Compliance Verification Engineer (Musterprüfingenieur)
QA	Quality Assurance (Qualitätssicherung)
QM	Quality Manager (Qualitätsmanagementbeauftragter)

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How to use this Manual:

- Read this manual carefully before using any iNAT / iPRENA / iSULONA / iCOMBANA / iTraceRT-MVT / iATTHEMO / iCORUS system.
- Recommendations for a proper operation are marked with this sign: 
- Warnings and Dangers are marked with this sign: 

See chapter 15 for any support by iMAR Support Team and application engineers.

RELATED DOCUMENTS

This manual references to the following documents regarding the hardware and software of the iNAT-systems:

	Title	DocNo.	Comments
[1]	ICD_iNAT-RxFxHx_IEP-I000288	DOC141203029	Hardware ICD of iNAT-Rx/Fx family (drawings, connector pinout, GND concept)
[2]	ICD_iXCOM Protocol Specification for Customers	DOC170816002	Communication description of iNAT systems and list of all commands / data
[3]	ICD_ARINC825_iNAT	DOC141106133	ARINC825 CAN Implementation
[4]	iNAT-Rx/-Fx/-Hx/-M200 data sheets	several	Technical product specifications
[5]	Application Note iNAT Firmware Update	DOC141016031	How to install a new firmware on an iNAT hardware with 335xl kernel
[6]	MAN_iXCOM-CMD	DOC151112010	Manual of iXCOM-CMD GUI Software
[7]	MAN_UserManual_iNAT-RxFxHx_IEP-I000288	DOC151228001	User Manual for iNAT-Fx/-Rx/-Hx systems
[8.1]	CFG_Factory-Config-Table_iNAT-RxFxHx_IEP-I000288	LYT150803134	Template for factory settings for iNAT-RQT/RQH/FSSG/HQS systems
[8.2]	CFG_Factory-Config-Table_iNAT-M200	LYT160116002	Template for factory settings for iNAT-M200 systems
[9]	ICD_iNAT-M200	DOC140301006	Hardware ICD of iNAT-M200 family (drawings, connector pinout, GND concept)
[10]	MAN_Introduction-into-Inertial-Measuring-Technology	DOC151228003	General description of coordinate systems etc.
[11]	MAN_iXCOMHandler	DOC160127069	SDK for iXCOM communication - user manual
[12]	ICD_iMAR Simple CAN	DOC180907010	ICD for Simple CAN Implementation
[13]	ICD_iMAR ARINC429	DOC161005079	ICD iMAR ARINC429 Implementation
[14]	ANT_Boresight_Leverarm_Misalignment	DOC181103011	Application Note to determine lever arms and misalignment
[15]	ANT_Antenna_Overview	DOC170603001	Application Note for GNSS antenna selection and installation
[16]	ANT_Python-Client_for_iXCOM-protocol	DOC190819019	Application Note to use iMAR Python scripts to communicate with iNAT platforms
[17]	ANT_Gravity-and-Magenetic-Models	DOC220308081	Application Note for implemented Earth models
[18]	ICD_NMEA183_Implementation_iNAT	DOC211028078	ICD of supported NMEA183 messages

Table 1: Related Documents

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1 INTRODUCTION

This document will show the user how to operate the INS/GNSS systems, which contain the iMAR proprietry iNAT achitecture.

The following systems are part of the iNAT family and therefore this manual applies: iNAT-Rx/-Fx/-Hx/-Mx (i.e. iNAT-RQT, iNAT-RQH, iNAT-FSSG, iNAT-FSLG, iNAT-MSLG etc.), iNAT-M200, iNAT-M200-FLAT, iNAT-CFM, iNAT-M300, iNAT-U200 etc. as well as the automotive systems of series iTraceRT-MVT, the marine systems of series iATTHEMO, the gravimetry surveying systems of series iCORUS, the drilling systems of series iANARO, the pipeline systems of series iPST and the systems used in military applications of series iSULONA, iCOMBANA and iPRENA. They all are covered within this description under the name "iNAT", which describes the advanced system architecture.

It is recommended, initially to study the [short overview document \[10\]](#) as an introduction to inertial measurement techniques.

The iNAT family is a wide class of inertial measurement systems with integrated high performance GNSS engine, which is made for a wide range of operation in aided and unaided navigation, timing, surveying, guidance and control applications. Depending on the applied firmware, the systems can be used as full INS / IMS solution for Navigation, Surveying, Stabilization, Guidance & Control (standard usage) or as an specific Extended IMU with an interface for time synchronized calibrated raw data of inertial sensors, GNSS raw data and odometer data and nearly arbitrary time stamped external acquired aiding data (e.g. for very customer specific tasks, for instance using a customer desired specific external GNSS receiver), or e.g. as a GNSS reference station iREF-GNSS:

a. Navigation, Surveying & Control

Systems for **Navigation and Timing (iNAT)**, Stabilization, Guidance and Control, Surveying or Attitude Heading Reference System (AHRS) with advanced and qualified sensor and processing hardware for - but not limited to - land, sea, subsea, airborne and space applications.

Advanced strapdown navigation algorithms as well as the sophisticated 42+ states extended Kalman filter based INS/GNSS/ODO/VIS¹ data fusion are processed on the powerful integrated processor with ARM architecture. Additionally the data fusion can process furthermore external information like air data, magnetometer data or Doppler velocity aiding etc. (depending on application and sensor technology). The used strapdown and data fusion algorithms are a result of more than 25 years of experience in using inertial and satellite aiding technology in all areas of applications, from most precise antenna and optronc stabilization on moving carriers to the control of highest speed multi-mach supersonic targets, from deep-sea vessels to ultra high altitude airborne applications, from lightest weight systems to multi-g-resistant systems. For details see: www.imar-navigation.de



Figure 1: System of iNAT-Rx/-Fx Family



Figure 2: System of iNAT-M200 Family

¹ Inertial navigation / Satellite Navigation / Odometer aided / Visual (computer vision) aided

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b. Extended Inertial Measurement Unit

Systems, as explained under item a) above, but limited to the Feature “Extended Inertial Measurement Unit” (EIMU), providing calibrated inertial data (angular rates / accelerations, timestamp, BIT), GNSS raw data (single or dual antenna; GPS, GLONASS, GALILEO, Beidou, TerraStar corrections) or GNSS processed data (position, velocity, standard deviations etc.), odometer / airdata / magnetometer / Doppler log data (all time-stamped according to IMU data. Delivered as EIMU, the system does not contain the Kalman filter based data fusion. EIMU configurations are typically customized. They can also be delivered, as well as iNAT systems, with dedicated (customer defined) inertial sensors and dedicated GNSS receiver (according to customer request).

All mentioned before, time stamped calibrated raw data are also always available for the user if the system is operated as iNAT “Navigation & Timing” unit according to item a).

c. iREF-GNSS

Using a specific software add-on, any iNAT system can be also used as a GNSS reference station, i.e. as iREF-M200, i.e. providing NTRIP caster capability, based on an iNAT-M200 system.

A block diagram of the iNAT systems is given in Figure 3.

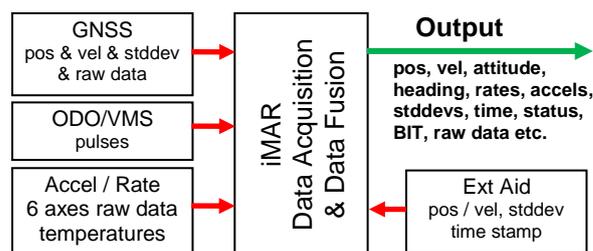


Figure 3: iNAT global Architecture

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2 SYSTEM SPECIFIC SETTINGS

Each delivered system can have factory specific features, depending on the purchase order and SOW. They are summarized in document [8] (see Table 1), which is provided for each delivered system individually. It contains the system type, the part number, the serial number and the configuration of the communication interfaces (UART, CAN, Ethernet, SYNC, USB, HDLC, ARINC429 etc.) at the time of delivery and the algorithm settings if agreed.

It is mandatory to have this configuration sheet on hand before you contact the iMAR support engineers for any reason.

3 TECHNICAL SPECIFICATION

The technical specification of performance of the iNAT systems is described in separate documents [4].

4 ELECTRICAL INTERFACE AND DATA INTERFACE

The hardware interface (mechanics, connectors and pinout, electrical signals, power supply, GND and earthing design etc.) is described in the system ICD (see e.g. [1], [9]).

The relation between the hardware interfaces on each connector and the software ports is also given in the system ICD.

5 COMMUNICATION INTERFACE AND COMMANDS

The communication interface iXCOM (data structures, commands etc.) is described in a separate document [2] (see Table 1). There is also described how to build up a communication to the system via UART or Ethernet. A short excerpt about the internal logical channel structure can also be found in the iXCOM-CMD manual [6].

An **SDK** is available which contains programming examples in **C++**, a header file and parser examples for the iXCOM interface [11].

Furthermore **Python scripts** are available for the user to support easy integration.

Also a **ROS 2** driver is available for plug & Play integration of iNAT systems into ROS 2 environment.

Additional **MatLab** drivers are available to support the reading of iXCOM based data files.

In [5] an application note is provided which describes how a firmware update can be installed on the controller of the iNAT system. Such update must not be applied without the agreement of an iMAR support engineer.

If the system is delivered including lab cables (these cables are called “lab cables” because they are not intended to be used in an aircraft or under harsh environmental conditions – if you need such cables, please contact iMAR for assistance if needed), this cable has a MIL connector at the one side and several TNC / SUB-D / RJ45 connectors at the other side, depending on application and to make a first usage of the iNAT system most simple for the user. The setup of the lab cable is described in the system ICD.

The pin out of the SUB-D15 female connector for the RS422 / UART ports is as follows:

```
Pin 2: RxD+
Pin 3: RxD-
Pin 6: TxD+
Pin 7: TxD-
Pin 9: GND
```

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The pin out of the SUB-D9 male connector for the CAN lines is as follows:

Pin 2: CAN-LO
Pin 3: GND
Pin 7: CAN-HI

The pin out of the RJ45 LAN connector (socket) is as follows:

Pin 1: TX-P
Pin 2: TX-N
Pin 3: RX-P
Pin 6: RX-N

The pin out of the SUB-D9 male connector for the ODOMETER lines is as follows (if any):

Pin 1: ODO-B-LO
Pin 3: ODO-B-HI
Pin 5: GND
Pin 6: ODO-A-HI
Pin 7: ODO-A-LO



The proper interface termination (120 OHM at UART RS422 and CAN) must be considered when building up the communication. Hints are given in [1], also see the system ICD for details (typically all RXD ports of RS422 interfaces are terminated inside of the system with 120 Ohm and also the CAN interface is terminated accordingly).

The pin out of the SUB-D25 female connector for the ARINC429 ports is as follows:

Pin 1 : ARINC429 (1) _TxD-A
Pin 2 : ARINC429 (2) _TxD-A
Pin 3 : ARINC429 (3) _TxD-A
Pin 4 : ARINC429 (4) _TxD-A
Pin 10: ARINC429 (4) _RxD-A
Pin 11: ARINC429 (3) _RxD-A
Pin 12: ARINC429 (2) _RxD-A
Pin 13: ARINC429 (1) _RxD-A
Pin 14: ARINC429 (1) _TxD-B
Pin 15: ARINC429 (2) _TxD-B
Pin 16: ARINC429 (3) _TxD-B
Pin 17: ARINC429 (4) _TxD-B
Pin 22: ARINC429 (4) _RxD-B
Pin 23: ARINC429 (3) _RxD-B
Pin 24: ARINC429 (2) _RxD-B
Pin 25: ARINC429 (1) _RxD-B
Case GND on SubD housing

Please refer to the dedicated documentation if available.

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6 INSTALLATION (HARDWARE AND COMMUNICATION)

6.1 Hardware Installation



In general, the INS can be installed inside the application / vehicle / aircraft / ship in any arbitrary orientation². The lever arm to the GNSS antenna(s) as well as the lever arm to the wheel sensor / odometer (if any) shall be as short as possible and has to be coordinated in the INS enclosure coordinate system. Details are described in [10] and [2] (see Table 1).



The installation shall be made at a location with reasonable low impact of vibration, shock and temperature gradients as the iNAT is, as every inertial measurement system, a high precision measurement instrument.



Any shock impact due to installation handling must be avoided. Even a small bump between two metal surfaces may induce a shock of several hundreds or even thousands of g. Falling down only a few millimeters on a hard (metal, concrete) surface may induce a several thousands g shock to the device (even if the duration is quite short) and may degrade or damage the system if not handled within the specification.



To avoid any RF interference, it is recommended to mount the GNSS antenna(s) not closer than 1 m to any electronics device.

For accurate mounting use fit screws and flat washers as usual (see also the recommendation within the ICD and the technical drawing).

6.2 Communication Installation

In the following chapters some basics are described, the detailed description and additional parameters are given in [2].

In [2] the chapter “How to install an iXCOM communication channel” gives a good introduction how to establish a communication to the iNAT system, to configure it and to read measurement data and status information. The usage of the iXCOM commands and the LOG commands are explained in detail as well as the meaning of other commands, messages, responses and parameters regarding to the iXCOM protocol definition.

In chapter 7 a Quick Start information is provided as an example how to build up a communication following the required actions step by step. The specific commands may depend in the used version.

In chapter 18 (appendix) instructions are given on how to connect from a local computer to the iNAT INS (Appendix: USB Driver INSTALLATION ON HOST PC).

6.3 Coordinate System, Lever Arms and Misalignment Angles

6.3.1 Definition of Frames within iXCOM Prorocol

We distinguish between 3 coordinate systems or frames:

1. Body Frame: It is given on the label printed on the enclosure of the INS
2. Output Frame, also called Vehicle Frame. It is the coordinate system, within the output data (vehicle angular rate, vehicle acceleration, vehicle velocity, vehicle roll/pitch/heading angles etc.) are provided. It can be with z-axis down (typically for aviation and marine applications; DIN 9300) or with z-axis up (typically for land navigation, according to DIN70'000 / ISO 8855)
3. Navigation Frame: Within the iNAT systems, the internal used navigation frame is always NED (locally North-East-Down) related, for definition see the iMAR document [10].

² Some dedicated systems require a specific orientation on the carrying platform – in this case, these information are found on the datasheet and in the ICD.

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The following chapters explain the coordinate systems in detail.

6.3.1.1 Body Coordinate System (Body Frame)

An iNAT system can be delivered with one of the three Options:

1. Label on the enclosure with body-z-axis downwards and body-x-axis away from the main connector (typically used for airborne and shipborne applications). For these applications typically as **Navigation Frame** the NED (north-east-down) frame is used.
2. Label with body-z-axis upwards and body-x-axis away from the main connector (typically used for land applications). For these applications typically as **Navigation Frame** the ENU (east-north-up) frame is used.
3. Customized Label according to specific requirements.

The Body Frame can be defined as factory set by an internal matrix rotation, which is applied after the raw data acquisition and sensor calibration stage. I.e. all publicly available calibrated raw data logs are referenced to this Body Frame coordinate system.

6.3.1.2 Vehicle Coordinate System (Vehicle Frame), Mounting Misalignment Angles

This vehicle coordinate system is defining the axes of the vehicle / vessel on which the INS is installed. Typically, the x-axis of this coordinate system is directed to "forward" and the z-axis of the vehicle coordinate system shall be directed

- downwards, if the application is airborne or seaborne, and
- upwards, if the application is land based.

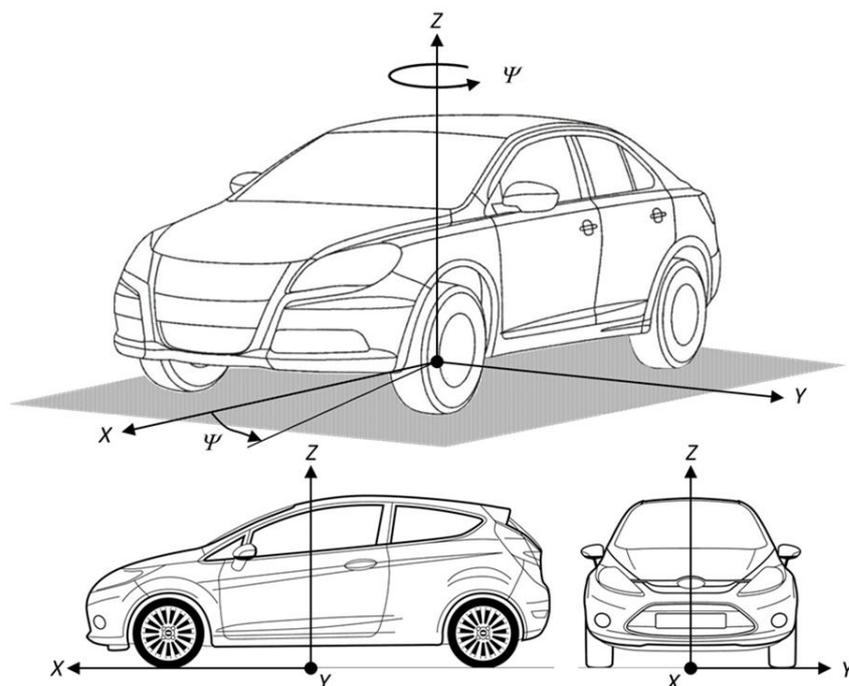


Figure 4: Land Vehicle Coordinate System according to ISO 8855

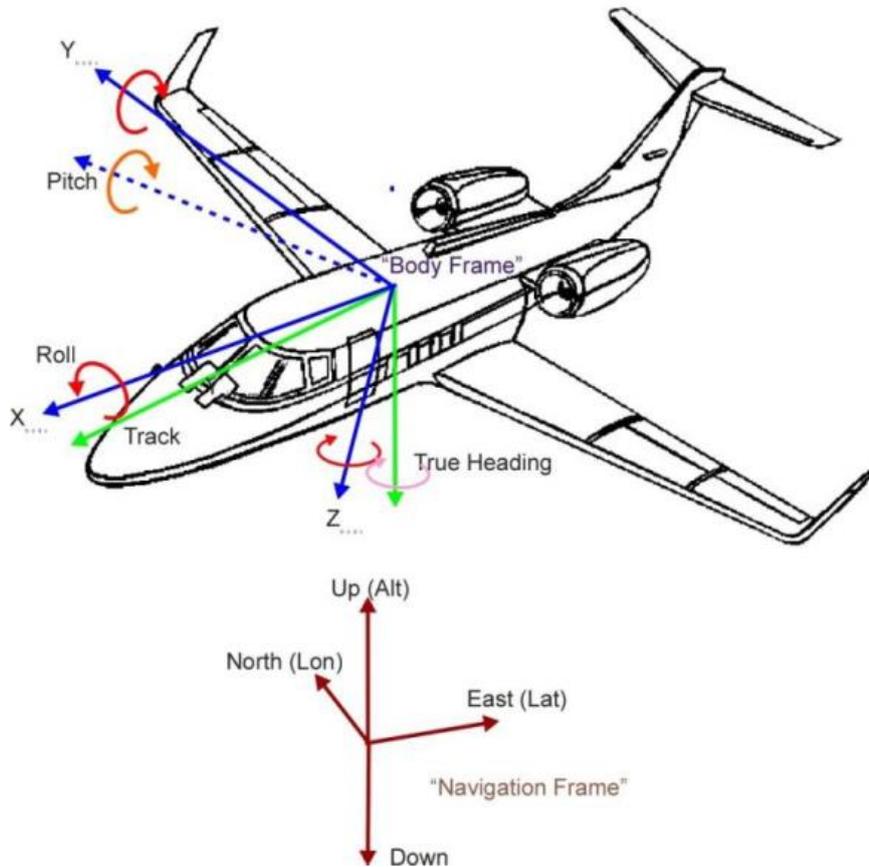


Figure 5: Navigation Frame (red) and Body Frame (blue) in Airborne Applications

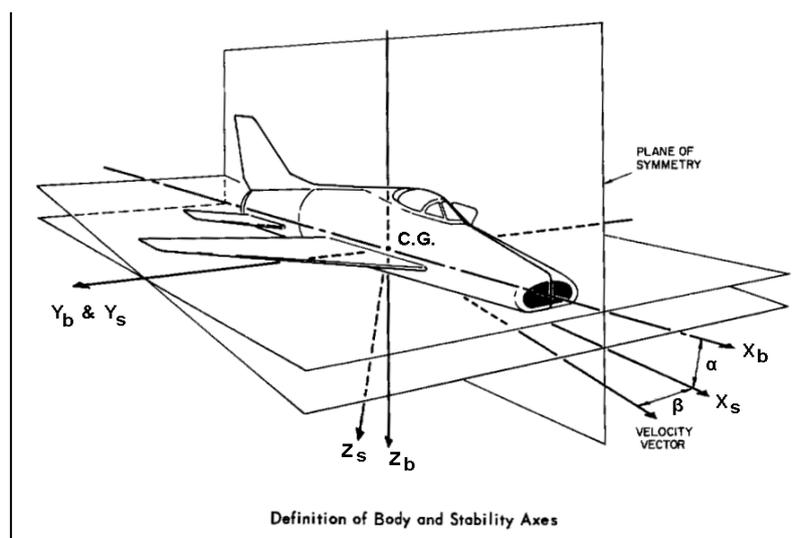


Figure 6: Side slip angle (beta) and angle of attack (alpha)

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The relation between the **Vehicle Frame** and the **Body Frame** is defined by a rotation matrix, which is built from three rotational (Eulerian) angles `delta_roll`, `delta_pitch` and `delta_yaw`, defining the sequential rotation around the three axes to obtain the Body Frame from the Vehicle Frame and to achieve the according data output. These delta-angles are called “mounting misalignment angles”.

The related parameter is **PARIMU_MISALIGN**. The definition of the rotation (including the correct sequence) is given in [2]. All information in output logs formerly expressed in Body Frame is subsequently expressed in Vehicle Frame (i.e. for example `INSVELBODY`, `INSRPY`, `INSDCM` or `INSQUAT` as well as the corresponding components of `INSSOL`). Internally the IMS is navigating in ECEF (geodetic reference frame) to allow a seamless navigation also during flights over the north or south pole.

Example: If the IMS uses a Body Frame with z-axis showing downwards and with the x-axis showing to the right side of the vehicle, the required mounting misalignment angles would be $0^\circ / 0^\circ / 90^\circ$ to rotate the Vehicle Frame into the Body Frame (after transformation: x data output for longitudinal vehicle axis, y data output for left lateral vehicle axis, z data output for vehicle down direction).

6.3.2 Navigation Frame

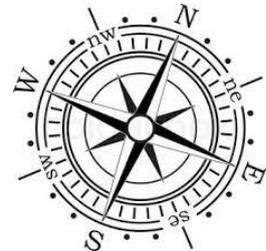
The Navigation Frame is the locally levelled coordinate system, where x is pointing to local East (ENU) or to local North (NED) and z resp. vertically up or down. Inside the iNAT systems all internal calculations including the sensor data fusion are performed in ECEF coordinates (Earth Centered Earth Fixed). An output transformation capability allows the output of data within all needed coordinate systems (NED, ENU; ECEF, UTM, MGRS etc.).

6.3.3 Heading vs. Yaw

We distinguish between heading and yaw.

The yaw angle is defined always as the third Eulerian angle to define a full rotation (roll, pitch, yaw).

In navigation it is tradition to measure the **heading** – it was initially derived from the usage of a magnetic compass. A heading of 0° indicates, that the platform’s nose points to north (true or magnetic north³), a heading of 90° indicates East direction. And it is tradition to measure the altitude / height upwards – both traditions have significant impact and disadvantages for a right-handed coordinate system. How to handle this according to navigational practice is explained in the following.



Due to mathematical reasons the yaw angle is always measured mathematically positive around the z axis of the **Navigation Frame** (!).

Attention: In NED the z-axis points vertical downwards, in ENU the z-axis points vertical upwards! I.e. in NED the yaw increases clockwise (like heading, like a magnetic compass), but in ENU the yaw increases counterclockwise!

Attention: While the NED frame provides the yaw clockwise as an advantage (similar to magnetic compass output), the altitude / height (z component of position vector) increases (by definition) if the height over sea level increases, while the velocity in z direction decreases (because z points downwards!).

To support the operating user within his online mission, in the iXCOM-CMD GUI always the heading is displayed, i.e. independent on the used frame, and not the yaw.

Data being stored on any memory are always yaw related and not heading related (heading is only an auxiliary value for better human understanding).

Data output is according to the general data output convention [10]. The Eulerian angles (roll, pitch, yaw) are obtained from the data output angles (roll, pitch, heading) as follows:

³ If we talk about „magnetic“ compass, we mean the behavior (approx. 0° corresponds to north), not considering magn. deviation etc. Of course, an inertial navigation determines true north while a conventional compass determines magnetic north.

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z-axis upward on the label on the IMS, ENU Navigation frame:

$$\text{yaw} = 90^\circ - \text{heading}$$

z-axis downward on the label on the IMS, NED Navigation frame:

$$\text{yaw} = \text{heading}$$

- Definition: The heading angle of the vehicle is (independent on the direction of the z.axis on the coordinate frame label on the IMS!) the clockwise (!) rotation of the leveled vehicle coordinate system (roll and pitch = 0°) around the vertical upward directed axis, starting with the x-axis pointing to north in the Navigation Frame.
- For small roll and pitch angles (< 15 °) these are approximately the angles of the y axis and resp. of the x axis against the horizontal plane.
- For larger roll or pitch angles it has to be taken into account, that these angles represent the sequential rotation around yaw, pitch and roll from the Navigation Frame into the Vehicle Frame.

The Vehicle Frame is used for all output data. The transformation using the above explained mounting misalignment angles is performed inside the iNAT systems behind the data fusion algorithms, just before generating the data output logs. This has the significant advantage, that the mounting misalignment angles could be even changed during operation without any impact on the signal processing.

It is important to remember, that all required lever arm measures (see chapter 6.3.4.1) as well as the lever arms to the virtual measurement points (VMP) and also the mounting misalignment angles (see chapter 6.3.1.2 and 6.3.4.5) are required / defined within the Body Frame, i.e. within the coordinate system printed on the label of the IMS and defined by the enclosure's reference points / fittings.

6.3.4 Lever Arms, Output Data Reference Point and Surveying Markers

6.3.4.1 Lever Arms to GNSS Antenna and Odometer and to other aiding Sensors

To achieve best system performance of the INS/GNSS/ODO solution, it is mandatory to know the lever arms from the inertial sensors to the GNSS antenna(s) as well as from the INS reference point to the odometer. These information are used inside the integrated data fusion algorithms and shall be made available by the operator with an accuracy, which is at least better than the data accuracy achieved from the GNSS receiver or the odometer (i.e. << 2 cm in case of using an aiding source of RTK level, i.e. about 1 cm accuracy). The same is valid for any other external aiding information regarding position or velocity (DVL, LiDAR, RADAR etc.).

Typically, the lever arm from the Enclosure Reference Point (ERP) [see Figure 7] to these devices (GNSS antenna, odometer / wheel sensor, camera, LiDAR, DVL etc.) or to the virtual measurement point(s) is surveyed with a theodolite or with a laser tracker inside of the application once the iNAT is installed. An alternative method will be to acquire the lever arm coordinates from the mechanical drawings of the setup. A third alternative is to let the lever arm be estimated by the data fusion algorithms inside the IMS itself – this typically requires the availability of high performance position aiding by RTK GNSS during this estimation phase and sufficient motion dynamics as well as GNSS availability.

For the following explanations the definition of body axes is important.

Standard enclosure measurement axes definition:

In general, the body x axis of an iNAT system is oriented from the system connectors to the opposite side of the enclosure (see Figure 7). The body z axis is oriented up or down, depending on the applied coordinate system (typically up for land vehicle applications and down for shipborne and aviation applications).

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To make the acquisition of the lever arm measures most feasible for the operator / surveyor, in all iNAT systems being manufactured with a standard enclosure, the Enclosure Reference Point (ERP) for surveying any lever arm is the circular fitting / mounting through hole at the bottom plate of the IMS located on the opposite side of the system connectors (i.e. if the body x axis is oriented into "forward" direction, this through hole is at the left forward corner of the enclosure, if looking from the system connectors into forward direction), and there specifically the mid of this hole⁴. The embedded software inside the IMS automatically performs the right transformation into the sensor's intersection point (for each enclosure the mechanical relations between the circular fitting hole and the sensor intersection point are stored inside the factory setup).

Important Information: The iXCOM-CMD HMI Software provides a powerful wizard, which supports the user / integrator efficiently to set all required parameters, incl. the lever arms.

The following picture shows this in detail.

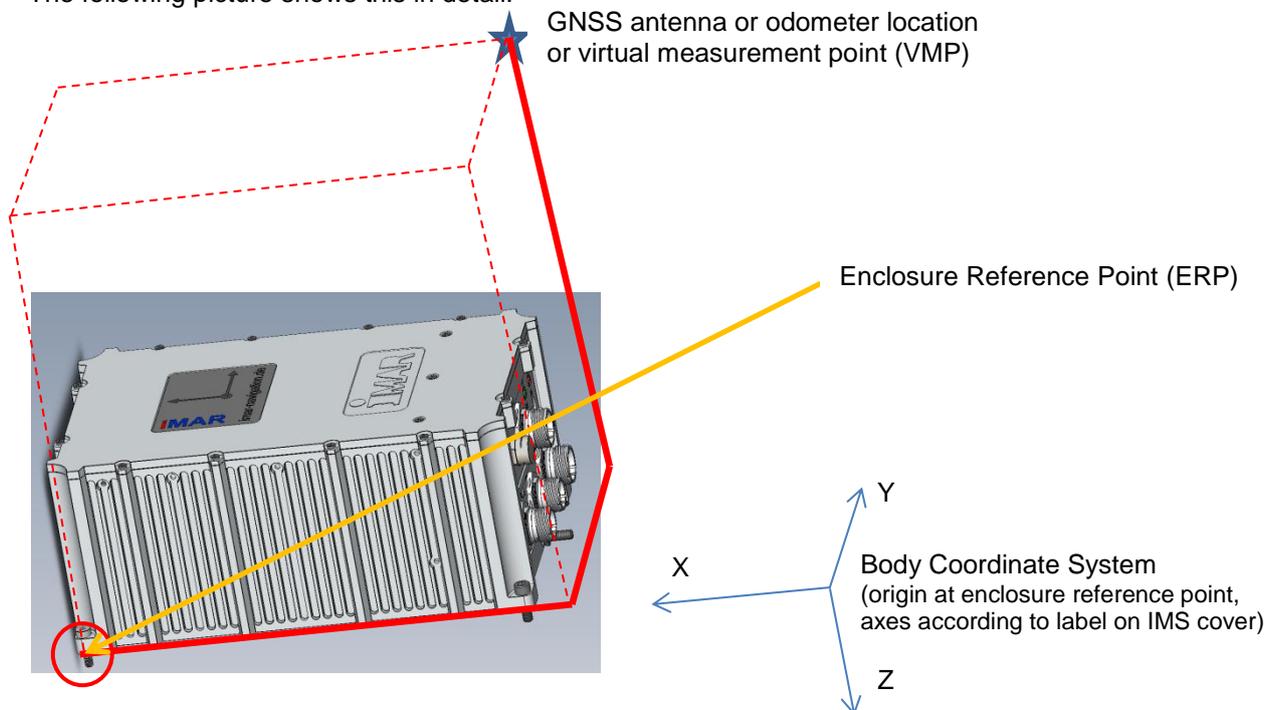


Figure 7: Lever Arm Definition

Any lever arm, to be entered by the user, is measured in all iNAT systems

- from the fitting hole marked with a red circle in the Figure 7, called enclosure reference point (it is always the IMS' base plate front hole on the left side, if you look onto from the system connectors to the front side of the system in direction of the positive body x axis, if the cover of the enclosure is showing upwards)
- to the blue marked star (location of GNSS antenna, odometer, virtual measurement point etc.).

Each lever arm is measured in Body Frame axes, as printed on the coordinate label being applied on the IMS. Example from the Figure 7:

⁴ Note: There are two fits available at the enclosure. Make sure that you use the through hole circular fit and not the through hole at the opposite side with elongated shape

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Lever-arm_x = - 364 mm
lever-arm_y = + 232 mm
lever-arm_z = - 312 mm

Take care, whether the body z axis is directed down or up on the label of the IMS coordinate system (both is possible, depending on system factory setting according to the foreseen application).

6.3.4.2 Data Output at Virtual Measurement Point

We distinguish three mechanical points of interest to output the data of the iNAT system:

- center point of all inertial sensors (CPIS) inside the iNAT enclosure
- Enclosure Reference Point ERP (see red circled fitting hole in Figure 7)
- Virtual Measurement Point VMP

The enclosure Reference Point (ERP) is always the reference point to measure the lever arms to GNSS antenna, to wheel sensor, to any other aiding sensor or to a virtual measurement point (VMP) → see chapter 6.3.4.1.

All output data of the iNAT systems like position, velocity, acceleration etc. as well as the IMS raw data are physically referenced to the center point of the inertial sensor cluster (CPIS) inside the IMS. If the usage of one or several Virtual Measurement Points (VMP) is deactivated, the output data of the iNAT are not transformed to any VMP.

To transform the output data of the iNAT (position, velocity, acceleration; with exception of the inertial raw data of the inertial sensors itself) into a Virtual Measurement Point, the usage of the Virtual Measurement Point (VMP) shall be activated (can be done via the GUI iXCOM-CMD or via direct command on the iXCOM interface). Furthermore the lever arm values (x,y,z) of the mechanical coordinates of the VMP have to be set in Body Frame coordinates (i.e. according to the enclosure reference point [red circled in Figure 7] within the coordinate system given on the label on the IMS as defined in chapter 6.3.4.1).

By default (factory set) VMS output is deactivated and all output data are provided at the center point of the inertial sensor cluster (CPIS).

If the user has overwritten this default lever arm and wants to return to these values, he can reload the factory settings of the IMS configuration (or extract the values from the IMS drawings).

Summary:

- if no VMS output is activated, the data output is referenced to the center point of inertial sensors (CPIS)
- If the VMS output feature is activated, the output data are transformed to the defined VMS, where a lever arm of (0, 0, 0) m defines an output at the Enclosure Reference Point (ERP)

 **Important Information:** The iXCOM-CMD HMI Software provides a powerful wizard, which supports the user / integrator efficiently to set all required parameters, incl. the lever arms.

6.3.4.3 Surveying Markers

Surveying markers can be used to survey position and orientation of an INS mounted inside a vehicle, regarding to the vehicle's coordinate system. The surveying markers on the enclosure are measured by a ZEISS Coordinate Measuring Machine (measurements only available if ordered in the customer's PO). This chapter shows the placement of the measurements if any applied.

The origin of the mechanical measurement for these markers is the center of the left hole Ø 6 H7 at the bottom side of the IMS' base plate (see figure below: looking onto the front side of the system connectors and cover upside).

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The surveying protocol contains the coordinates of the surveying markers (\emptyset_Ref_x) in respect to the point of surveying origin (enclosure reference point), all given in millimeters in x/y/z direction. The Surveying Marker coordinate system is always as given in the following figure (i.e. always z down, independent on the label on the cover of the IMS, which independently shows the Body Frame coordinate system).

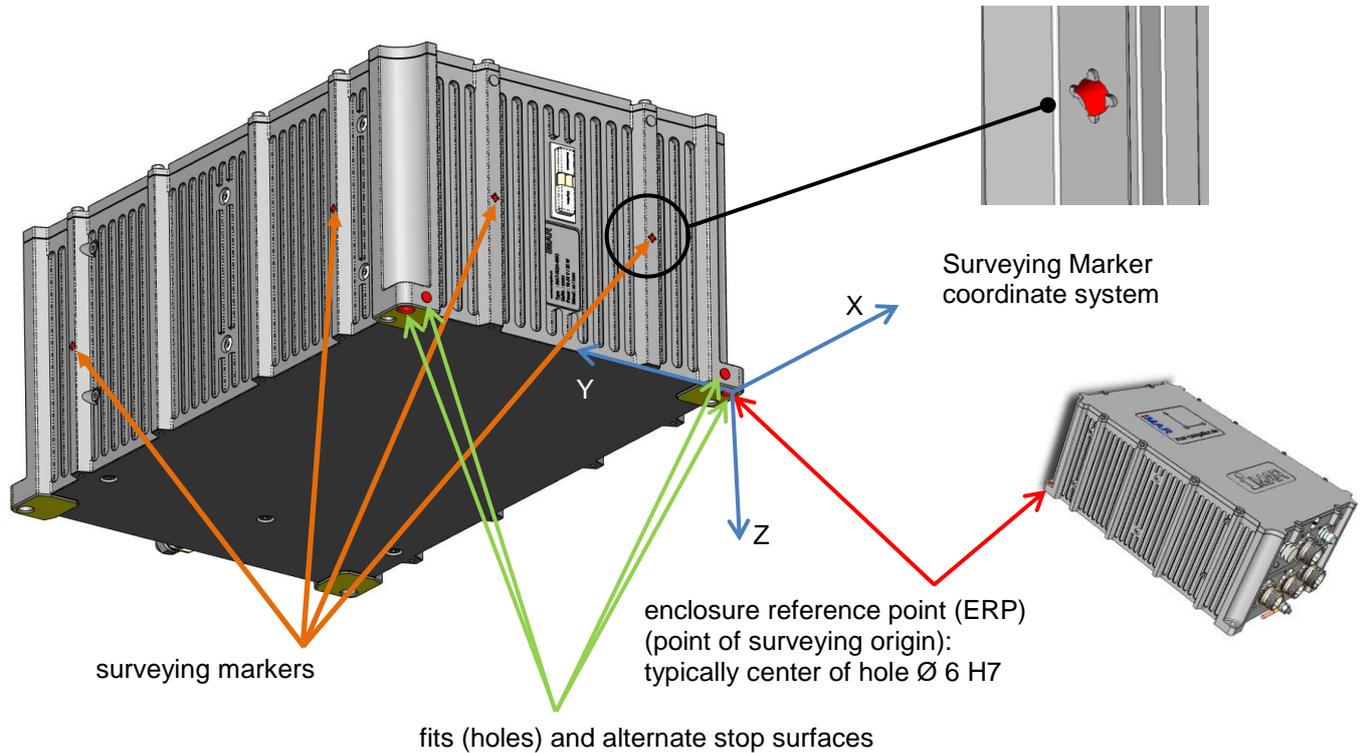


Figure 8: Marker Surveying Coordinate System Definition

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6.3.4.4 Accelerometer Intersection Point

The center point of the measured acceleration, especially the intersection point of the three accelerometers, is located somewhere inside of the inertial measurement system (IMS). This point is given in the mechanical drawings of the system (note: carefully distinguish between the sensor intersection point and the center of gravity of the measurement system).

The following drawings show the sensor intersection point (example only).

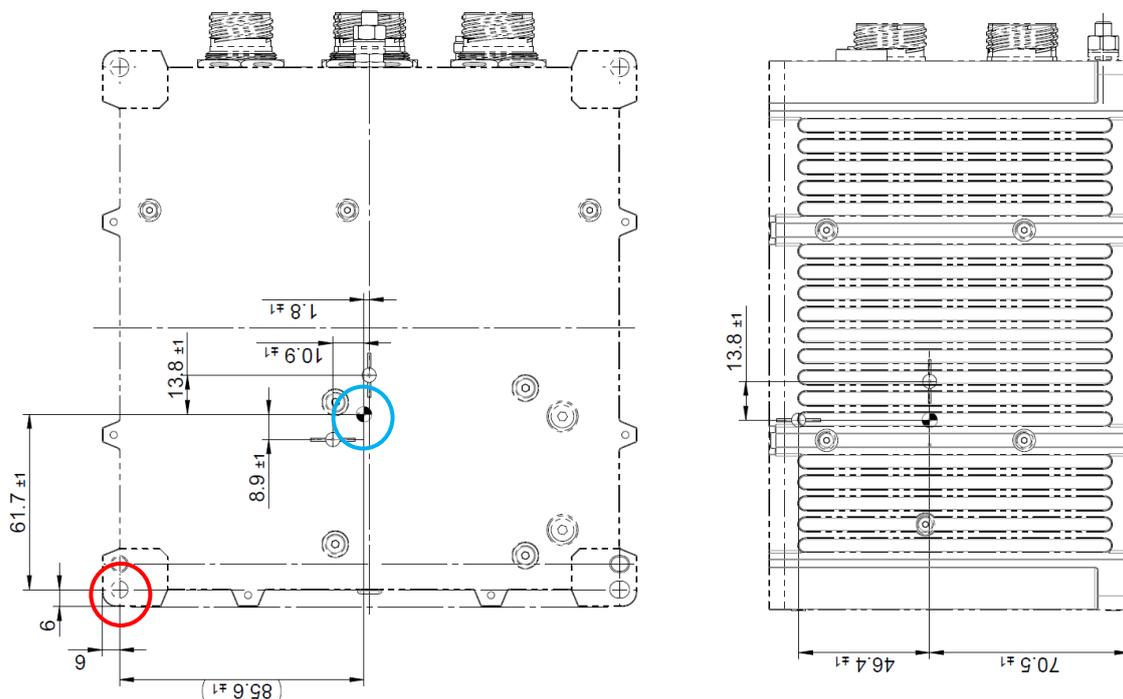


Figure 9: Sensor Intersection Point (Accelerometers) inside the Drawing

The red circle shows the relevant through hole fit (note: the drawing is given by **bottom view** here!), also called as “enclosure reference point”, the blue circle shows the sensor intersection point (not to be confused with the “center of gravity”), which is relevant for the internal algorithmic compensation.

6.3.4.5 Mounting Misalignment Angles

The mounting misalignment angles (e.g. if the IMS is installed being rotated by 90 deg around the body z axis) are always given by Eulerian angles starting the rotation around the z-axis of the Vehicle Frame and ending at the x axis around the Body Frame. To determine the rotation angles, install the IMS in the desired orientation and then rotate it (virtually) first around the Vehicle Frame z axis, then around the rotated Vehicle Frame y' axis and finally around the again rotated x" axis and insert the three mounting misalignment rotation angles. Details can also be found in the manual of the iXCOM-CMD HMI software and also in the wizard there.

Study application note [14] to get more information about the misalignment angle determination using a laser tracker or by performing a specific motion.

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6.3.4.6 GNSS Antenna Lever Arm

6.3.4.6.1 Static GNSS Antenna Lever Arm

To achieve best results in position and orientation determination, the system shall know the lever arm between the IMS and the GNSS antenna (or both GNSS antennas in case of a dual-antenna solution) as accurate as possible, but at least double as accurate as the expected GNSS standard deviation. For example standard GNSS accuracy is 1...2 m, therefore the lever arm shall be surveyed at least within 0.5 m accuracy. If the INS/GNSS system is used in RTK mode (2 cm position accuracy), the lever arm shall be surveyed with an accuracy of < 1 cm.

The GNSS lever arm can be defined using the parameter **PARGNSS_ANTOFFSET**.

It is recommended that the user mounts the INS as close as possible to the primary GNSS antenna, particularly in the horizontal plane. The uncertainty of the lever arm has to be provided together with the lever arm itself and should exceed the expected error.

The x, y and z values of the parameter represent the vector from the IMS' center of navigation (coordinated in Body Frame as given on the coordinate system label on the IMS) to the antenna phase center (use the reference point of the MS as described in chapter 6.3.4.1).

The applied extended Kalman filter, which is used for INS/GNSS sensor data fusion, supports an online antenna lever arm estimation if sufficient motion dynamics and GNSS observabilities are present.



A wrong setting will lead to a wrong input to the IMS' internal sensor data fusion (Kalman filter) and will lead to significantly disturbed or wrong results. A too large set standard deviation will prevent the data fusion to achieve the best achievable accuracy (i.e. the result will be not as good as it could be), and a too small set standard deviation will lead to too optimistic or even dramatically wrong results.

Study application note [14] to get more information about the lever arm determination using a laser tracker or by performing dynamic motion excitations to estimate the lever arm.

Attention:

If the lever arm accuracy is set to value x [m], the position accuracy (standard deviation) of the position output of the total system (obtained from the INS/GNSS data fusion) will never exceed an accuracy value better than x [m], because it can never provide a position accuracy which is better than the surveying uncertainty of the GNSS antenna leverarm.

Therefore, it is mandatory to survey the GNSS lever arm(s) as accurate as possible. But of course, never insert a value for uncertainty (standard deviation), which is better than the real uncertainty, because in that case the data fusion would be based on wrong information and the result will be corrupted.

Attention for dual-antenna installations:

If a dual antenna system is used, the heading of the dual-antenna approach of the GNSS receiver has to fit with the heading of the inertial measurement system (IMS). Therefore, the antenna lever arms are surveyed in the IMS body frame coordinate system (as printed on the IMS label).

The position of the second (slave) GNSS antenna in respect to the first (master) antenna on the vehicle is important to get the true heading of the vehicle. If each antenna is surveyed with e.g. a 2 cm accuracy and the baseline is e.g. 1 m, the heading uncertainty is already 4 cm / 1 m = 40 mrad = 0.7 deg, while the inherent GNSS heading error is only 0.2 deg / L[m], i.e. 0.2 deg at 1 m antenna baseline. I.e. it is most important that the antenna lever arms are known as accurate as possible (at least at short baselines). Attention: The uncertainty of the second antenna is not defined against the IMS but against the primary GNSS antenna, but of course in the IMS body frame.

A wizard in the iXCOM-CMD software supports the estimation of the lever arms.

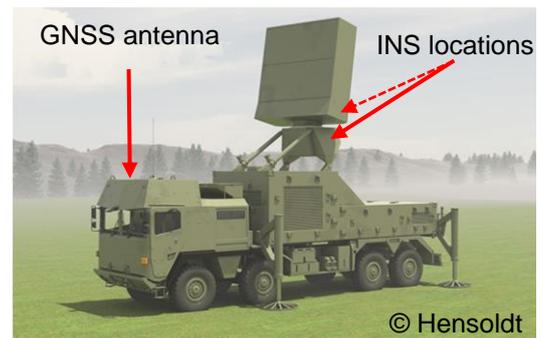
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6.3.4.6.2 How to handle a changing GNSS Antenna Lever Arm during Operation

Especially in applications, where the INS is not mounted directly on the same carrier where the GNSS antenna and the odometer are mounted, special constraints have to be taken into account to provide correct results.

I.e. if the iNAT is installed on a rotatable platform (e.g. radar antenna or launching pad), which itself is mounted on a moving platform (truck etc.). Therefore the lever arms of the iNAT in respect to the GNSS antenna and the odometer (vehicle motion sensor) is not static but it changes as a function of relative motion between the iNAT and the vehicle coordinate frame.

As an example, the INS might be installed on a truck mounted radio antenna and the radio antenna is erected while the truck is in parking position. Such configuration is called e.g. "out-of-travel-lock", while the orientation of the INS in respect to the truck situation, where the truck can travel (i.e. where the radio antenna is not erected but locked), is called "in-travel-lock". In both geometrical constellations the lever arms from the iNAT to the GNSS antenna(s) and to the wheel sensor as well as the misalignment angles between iNAT body frame and truck's vehicle frame are different.



To allow a seamless operation of the iNAT in and between both constellations (truck is moving on the road, then stops and erects the radio antenna incl. mounted INS during standstill of the truck), it is mandatory to perform the following steps to assure correct signal processing:

- Before moving the radio antenna, deactivate ZUPT (zero velocity updates) and GNSS updates by iXCOM command.
- Move the radio antenna incl. INS to "in-travel-lock" position on the truck (for road operation).
- Command the correct leverarms for GNSS antenna and wheel sensor. Activate automatic ZUPT again.
- Now the iNAT is ready for road driving operation.
- If desired, perform a static or dynamic alignment
- Move with the truck where you want, use GNSS and wheel sensor updates as desired (or not).
- Stop the truck where you intend to erect the radio antenna, i.e. where you intend to switch to "out-of-travel-lock" condition.
- Deactivate the GNSS aiding by iXCOM command before erecting the radio antenna (no GNSS data are used during antenna erection process). Also deactivate ZUPT.
- Now erect the radio antenna. During this short time the INS operates free inertial.
- As soon as the radio antenna is erected and the INS has reached its standstill position, activate again Automatic ZUPT. This assures that the INS position keeps frozen and also no GNSS spoofing or jamming has any influence on the antenna position, attitude and heading.
- In case that anyhow the GNSS position / velocity shall be used, the valid lever arms between INS and GNSS antenna(s) have to be set (see above).
- If the radio antenna is rotated / tilted with any impact on the INS (i.e. if the INS is not mounted in the center of rotation), always deactivate the ZUPT aiding during this change of significant position / orientation or define the aiding lever arm. If GNSS shall be used, update the GNSS lever arm continuously by iXCOM command.
- Before moving the antenna back to "in-travel-lock", deactivate the ZUPT aiding (and GNSS aiding), move the radio antenna back to its travel-lock position, set the now valid parameters for GNSS antenna lever arm(s) and odometer.
- Move the radio antenna and afterwards activate GNSS and automatic ZUPT aiding again.

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6.3.4.7 Magnetometer Misalignment Setup

If the IMS shall be aided by a magnetometer (not supported by all versions), the relative orientation of the magnetometer to the INS has to be entered. If the magnetometer axes do not coincide with the IMS enclosure axes, the parameter **PARMAG_MISALIGN** shall be used to rotate the magnetometer output data in a way that it fits to the IMS Body frame.

! A wrong setting will lead to a wrong input to the IMS' internal data fusion (Kalman filter) and will lead to significantly disturbed or wrong results.

Study application note [17] to get more information about the magnetic models used inside the iNAT systems.

6.3.5 Odometer Integration Setup

The odometer, also called vehicle motion sensor (VMS) or wheel sensor, can be used for zero velocity detection to perform ZUPTs (zero velocity updates) or additionally to aid the navigation by an information about current speed or distance travelled.

Two operational modes are distinguished:

- A/B quadrature mode (two by 90 deg phase shift provided pulse streams A and B; the phase (+90 deg or -90 deg) defines the motion direction). This mode gives highest resolution, because rising and falling edges on both lines can be counted
- A line signal for counts and B line signal level for direction.
- Other modes (e.g. A only, i.e. no direction information) are not suitable to aid an inertial navigation system, because changing the motion direction of the vehicle would immediately lead to a mismatch of information in the data fusion (Kalman filter).

! Example: Starting from zero velocity, the longitudinal accelerometer e.g. detects a negative acceleration (negative velocity in body frame) while the "A only" type odometer would provide a positive velocity to the data fusion algorithm because it can only measure the absolute value of the velocity and cannot provide the required direction information. **Therefore, it is strictly recommended not to use a wheel sensor with pure "A" information!**

The lever arm from the INS to the odometer is to be set with the parameter **PARODO_LEVERARM**. It shall be accurate within the centimeter range and is coordinated also within the Body Frame. Details see in chapter 6.3.4.1.

Typically the hardware implementation of the iNAT system series allows an input frequency on A and B line of up to 500 kHz. Example: Using an odometer with 1 mm / pulse scale factor, a 100 kHz pulse frequency is equivalent to a velocity of 100 m/s or 360 km/h.

If the INS is aided by an odometer / wheel sensor (not supported by all versions), an initial value of the scale factor of the odometer must be set. The parameter for this action is **PARODO_SCF**. It shall be at least accurate within +/-10 % for correct initialization of the internal Kalman filter, if GNSS aiding is at least initially available. The Kalman filter improves the accuracy of the scale factor over time as long as a reasonable GNSS aiding is available.

If a mission is executed without any GNSS aiding, the user has to set the scale factor as good as possible because finally the accuracy of the scale factor of the odometer limits the overall navigation performance (so-called dead-reckoning mode).

! The odometer should not be mounted on a driven or braked wheel to avoid non-linear slippage effects, which increase the uncertainty of the navigation solution.

The internal Kalman filter estimates the odometer boresight angles, if aiding with holonomic constraints is selected via **PARODO_CONSTRAINT**.

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The direction of the odometer measurement in respect to the Body Frame must be configured. There is a configurable matrix which is used to define e.g. whether the odometer forward direction is according to Body-y-axis or e.g. to Body-x-axis. Also the sign has to be set.

An automatic configuration mode is available which performs the correct settings (odometer lever arm, orientation of the odometer inside the Body frame, estimation of the odometer scale factor) automatically. The execution of this estimation requires sufficient GNSS accuracy and sufficient motion data.

6.4 Alignment

The system supports several alignment modes to determine attitude and heading prior to a mission (called static-alignment) or during a mission (called in-flight alignment or dynamic alignment). The alignment mode is defined using the parameter **PAREKF_ALIGNMODE**. For standard applications the dynamic alignment mode is used.

In general four situations can be distinguished, which depend on the specific application:

- a) An iNAT system **with gyro-compassing capability** is used (i.e. the day-to-day gyro bias⁵ is < 0.1 deg/hr)
 - a. A Reliable Motion Detection is available (i.e. an odometer is installed or the motion condition can be detected reliably from supervision of measured acceleration or/and angular rate):
 - i. In this case a **“static alignment”** is to be configured (see chapter 6.4.1.)
The Motion Detector is to be configured to detect motion by using the odometer information only (not using angular rate or acceleration⁶).
The iNAT starts in this configuration always with a “static alignment” (with automatic ZUPT⁷ aiding) and interrupts it automatically when a motion is detected. The iNAT then automatically changes into the “dynamic alignment” mode using GNSS and odometer information (if available) to achieve best navigation results. Later standstill phases are automatically detected and used to improve the alignment furthermore.
Note: This setup is recommended and easy to realize on most land vehicle applications and needs no interaction from the operator or from any mission control computer.
 - b. No Reliable Motion Detection is available (i.e. no odometer is installed and the motion condition cannot be detected reliably from supervision of measured acceleration or/and angular rate or inertial measured velocity):
 - i. **Using Pre-Knowledge from the Application:** The platform, on which the iNAT is installed, is **always in standstill condition** when performing the alignment, i.e. after power-on or any other alignment request (alignment = initial attitude & heading & position determination, which is needed for any following navigation, stabilization or control task).
In this case a **“static alignment”** (see chapter 6.4.1) is to be configured. After the static alignment has finished, the system automatically changes into the navigation mode and the platform can be arbitrarily moved.
Note: This setup can usually be used, if the platform operator (pilot, driver, captain...) has access to the iNAT status (alignment in progress, alignment ready...) to assure that no motion is applied during the “static alignment” process.
Attention: If the platform is nevertheless moved (against the pre-condition of “standstill”), before the static alignment has finished, the alignment fails and has to be repeated by command by the user.
 - ii. **Using Pre-Knowledge from the Application:** The platform, on which the iNAT is installed, is **always in significant motion condition** when performing the alignment and at least GNSS aiding or external velocity aiding is available with sufficient performance.

⁵ Remember: This is not the so-called bias stability or bias instability obtained from the Allan Variance!

⁶ If a land vehicle navigation system is to be configured and the vehicle shall be transported on deck of a ferry while in navigation mode (!), take into consideration the consequences of motion detection configuration!

⁷ Zero Velocity Update

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In this case a “**dynamic alignment**” (see chapter 6.4.2) is to be configured. The system does not start the gyro-compassing but waits for significant motion to perform a dynamic (“in-flight”) alignment. After the static alignment has finished, the system automatically changes into the navigation mode and the platform can be arbitrary moved.

Attention: As long as the platform is not moved after power-on or after commanding an alignment, it will not start a gyro compassing based static alignment.

- iii. **No Pre-Knowledge about initial Motion Status available:** The platform, on which the iNAT is installed, may be **in standstill condition or in motion condition** when performing the alignment (and if in motion, at least GNSS aiding or external velocity aiding is available with sufficient performance). The iNAT shall select by itself the best suitable alignment mode to achieve shortest alignment duration with best alignment accuracy.

In this case a “**static alignment**” (see chapter 6.4.1) is to be configured.

To change from “static alignment” mode to navigation mode in case of motion, two events are processed:

- a) Operator interaction by command (sending “Alignment Complete” command to stop the static alignment, before motion will be applied on the platform
- b) Automatic (heuristic) detection of a platform motion [in case that the operator cannot generate a signal as described in a)] and generating the “Alignment Complete” message internally inside the iNAT system.

A motion detector (see chapter 6.5), based only on inertial data (see pre-condition of this section: no odometer data available) has always a certain error-rate (“no acceleration detected” may indicate also any constant (!) or very slow increasing velocity, which is not equivalent to zero-velocity).

Therefore the state change from static alignment to navigation mode shall be indicated by a specific platform motion behavior: To interrupt a static alignment with confidence, the motion of the platform has to start with a certain change of heading (i.e. applying a significant steering angle to be detected by the motion detector): This give a good indication for the iNAT alignment algorithm to finish the static alignment mode and to continue with navigation mode (equivalent to dynamic alignment).

Note: This heuristic approach b) shall only be used, if approach a) will not be applicable.

- b) An iNAT system **without gyro-compassing capability** is used (i.e. the day-to-day gyro bias is > 0.1 deg/hr)
 - a. In this case always a “**dynamic alignment**” (see chapter 6.4.2) is to be configured. Start-up conditions can be configured too (start with “stored heading” etc., see chapter 6.6)
If the system is equipped with dual-antenna GNSS (for GNSS based heading determination at both standstill and motion condition), the system will try to determine the heading initially (and later on in case, that the heading should be not sufficiently observable by the platforms motion dynamics) using the dual-antenna GNSS solution. The behavior can be also configured.

The several alignment methods and their advantages and disadvantages are described in the following.

6.4.1 Static Alignment

A Static Alignment is used if the INS is definitively at standstill during the alignment phase. This mode leads to the fastest alignment results in roll and pitch (and if the system has gyro-compassing capabilities, also in heading) which is possible with the INS, because the internal Kalman filter can use ZUPTs (zero velocity updates) for aiding.

The alignment is separated into several phases:

- **Leveling:** Here the coarse roll/pitch of the INS is estimated by using the local gravity vector. This leveling takes typically only a few seconds. As an option during the same time the gyro bias can be estimated (only recommended if gyros are used inside the INS with a day-to-day drift which is significantly higher than the earth rate (15 deg/hr) and if the averaging time is sufficiently long in respect to the gyro noise / angular random walk).

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- **Coarse Alignment:** During the first phase of this alignment phase the roll/pitch angles determined during the leveling phase are refined and the calculated INS velocity is aided with ZUPTs (zero velocity updates) to improve the attitude performance.
For higher-grade INS (i.e. with gyro compassing capability) the earth rate measurement is used to determine a coarse heading.
For systems being equipped with dual-antenna GNSS, the coarse heading is determined from the dual-antenna GNSS solution.
For all other INS the system waits until some sufficient dynamic motion is applied. Then, using GNSS and INS information, the integrated Kalman filter estimates the coarse heading.
- **Navigation Mode / Fine Alignment:** After the Coarse Alignment is finished, the INS switches to the navigation mode of the Kalman filter, which starts with reasonable high covariances.
Depending on the INS performance class, the duration of the fine alignment varies to achieve a certain accuracy. For higher-grade INS (with gyro compassing capability, i.e. with a gyro day-to-day bias of about < 0.1 deg/hr) the alignment duration depends on the gyro bias and the gyro angular random walk. The current standard deviation of the determined heading (true north angle) drops down accordingly and can be read out.
As the data fusion algorithm being used for the Fine Alignment and for the Navigation Mode is the same, there is no break between both. This guarantees a seamless operation.

Depending on the activated startup mode, the initial values to be used for the alignment after power-up or after commanding a static alignment (initial heading, initial position) can be selected from stored values (stored during last power-down sequence), from forced values (provided from an external source, e.g. manually inserted) or from GNSS (standard operation for position and for heading, if a dual-antenna GNSS mode is supported). If the INS has no gyro compassing capabilities (e.g. MEMS based systems), the heading is determined as soon as the system is operated under sufficient dynamic motion after alignment. Useful motion contains several changes of heading, roll and pitch excitation and certain changes of velocity.

If the iNAT detects motion during static alignment, it switches automatically to dynamic alignment mode.

6.4.2 Dynamic Alignment / In-Motion-Alignment / In-Flight-Alignment

A Dynamic Alignment, also called In-Motion- or In-Flight-Alignment, is used if the alignment shall be operated under dynamic conditions. The filter performs a periodic gravity based alignment until a sufficient motion is detected. The alignment can be started at standstill or also during a motion, where an initial "steady flight" condition is preferred (but not mandatory) to reduce the alignment duration regarding leveling detection – if the motion dynamics is too high, the process will be repeated until a reasonably small dynamics is detected automatically. After the first part of the In-Motion-Alignment has been performed, the system transits into the Kalman filter based navigation mode and requires some change of heading to be able to observe true heading with best accuracy.

Depending on dynamics and sensor performance, the in-flight-alignment can last from less than 1 minute up to about 20 minutes to obtain the highest accuracy. The duration depends also on the performance of the provided external aiding (GNSS position / velocity or other external speed information or similar).

If specific constraints regarding the vehicle's motion are known (e.g. on rail vehicles the velocity can only be in forward or backward direction but not along the perpendicular direction), the alignment process can be supported with such information to shorten the alignment duration or to improve the performance of the alignment.

Attention: The dynamic alignment process needs some motion and information from an aiding sensor (e.g. GNSS) about the motion (velocity) to initialize and perform this alignment.

6.5 In-Motion Detection Algorithm

For specific navigation modes it is useful to know, whether the platform, on which the iNAT system is installed, is in motion or in standstill condition. So, such "In-Motion Flag" can be used to decide with a

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reasonable probability, whether e.g. to perform a so-called Zero Velocity Update (ZUPT) or whether to interrupt a running static alignment etc.

Three measurements are directly used in an optional combination to perform an **In-Motion Indication**:

- IF $v > v_0$ OR
(if usage of odometer pulses is activated)
- IF $a > a_0$ OR
(if usage of accelerometer data is activated)
- IF $\omega > \omega_0$
(if useage of angular rate data is activated)

THEN a motion of the vehicle is detected.

Additionally the INS velocity or the GNSS velocity may be used as an additional “in motion” indicator.

The **Standstill Indicator** is the inverse of the **In-Motion Indicator**.

6.6 Startup Mode

After power down, the INS can power up with a defined initial data setup (depending on dedicated hardware configuration). In general, we distinguish the following initialization capabilities for heading and position:

- Use heading from gyro compassing or dual-antenna GNSS setup (if available)
- Use stored heading (from last power-down)
- Use forced heading (from user / command input)

- Use position from GNSS measurements
- Use stored position (from last power-down)
- Use forced position (from user / command input)

The stored data are used from the information stored during last power-down. If no stored information is found, the system uses pre-defined default values, which can also be set by parameter command.

Typically, depending on configuration, the current information of position obtained from the integrated GNSS receiver is used.



A priority list can be configured which defines, which data shall be used if specific other data are not (yet) available. **Example:** Use Stored Position data in case, that GNSS would not provide valid data within 120 sec after starting the alignment process.

Important: Make sure that position and heading has not changed since last power-down if you use stored position and/or stored heading during start-up (power-up) of the system.

An automatic process is available to validate the stored heading value during the current “stored heading alignment”. If the heading is detected as valid, then the alignment duration can be reduced significantly. If the process detects an invalid stored heading value, a standard alignment will be performed.

6.7 Special Navigation Modes / Aiding

Special navigation modes can be made available to handle certain issues in aiding sources availability.

If no further valid GNSS updates (or air data updates) are available longer than a defined duration, the system can automatically activate a pre-defined aiding mode:

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- use true air speed
- use baro altitude

Depending on the available aiding sources, the system can enter a “pure gravity aided” operation mode, i.e. a steady state flight condition is required to determine a trustable roll/pitch information, when all aiding information for position and/or velocity is lost during a longer period.

Details are described in [2].

6.8 iXCOM Messages (excerpt)

This chapter gives a brief overview of the most relevant data logs being used to receive navigation output data from the INS. For details and latest information please see [2].

6.8.1 INSSOL

The `INSSOL` message includes the navigation data as a result of the internal data fusion (INS/GNSS/ODO integrated solution). It also contains the system status and the alignment status. The `INSSOL` message is available with a rate up to the rate of the inertial sensors.

6.8.2 GNSSOL

The `GNSSOL` message contains the GNSS receiver solution. The GNSS solution includes the WGS84 position, the undulation (ellipsoid/geoid height difference), the GNSS based NED velocity, the standard deviations, status and the number of tracked/used satellites. The maximum `GNSSOL` message rate depends on the GNSS receiver hardware being integrated in the INS.

6.8.3 GNSSTIME

The `GNSSTIME` message contains the UTC time-stamp. This message is needed to convert the GPS time to UTC time.

6.8.4 SYS_STAT

The `SYS_STAT` message contains the more detailed system status. The content of this message is variable and can be configured via the iXCOM parameter `PARDAT_SYSSTAT`. It is recommended to enable this message with the event based trigger. This means that the `SYS_STAT` message will only be sent if the content has been changed.

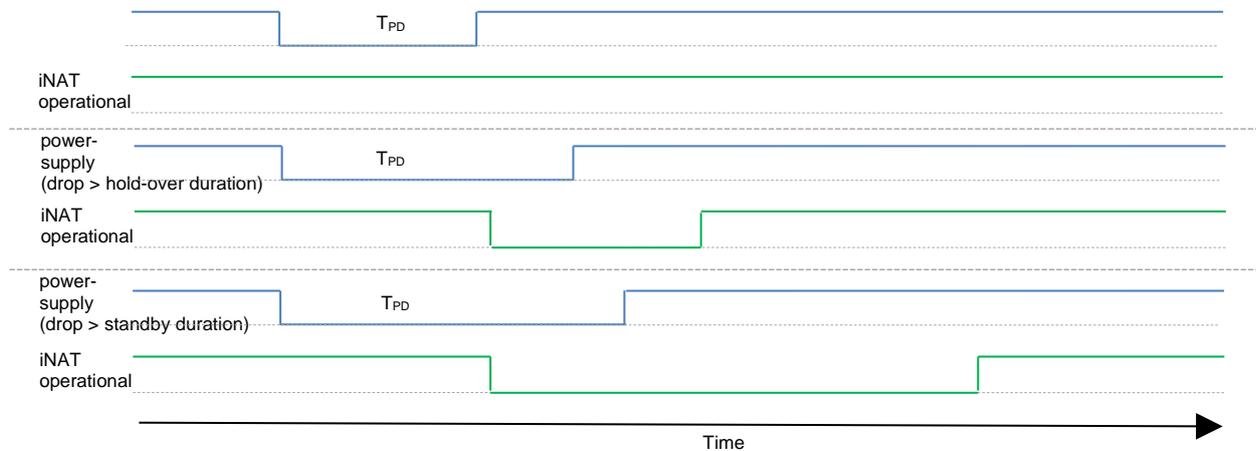
6.9 Behavior at Power Drops – Hold-Over Functionality

If the power supply is affected by short power drops (T_{PD}), the iNAT system continues its operation if the power drop is shorter than a defined hold-over duration (depends in the specific iNAT device). The hold-over duration T_{HO} demanded by aviation standards is 50 ms (DO160F), but several systems keep alive also over 100 ms or even 200 ms (see dedicated system specification).

The standby duration T_{SB} defines, how long the main processor inside the iNAT systems remains alive after start of the power drop (keeping communication capability alive and performing data storing and closing recording files), while the inertial sensors and the GNSS engine have already switched off internally.



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If the hold-over duration is expired, the iNAT stops operational work and the internal power supply of specific components (e.g. inertial sensors, GNSS receiver etc.) is switched off automatically and all internal system states are stored inside the non-volatile memory of the iNAT system. Then the main processor changes into standby mode.

If the external power supply recovers within the hold-over time, the system continues operation without any interruption.

If the external power supply recovers within the time when the main processor is already and still in standby mode (i.e. main processor supplied from the internal hold-over capacitors, but inertial sensors and GNSS engine already switched off), the main processor will change back from standby to operational mode and will switch on all internal components again. The restart from standby is faster than a full power-up and system boot cycle.

If the external power supply does not recover within the state of standby operation (i.e. in this case the entire iNAT system is off), the restart is a full power-up incl system boot cycle.

Recovery Mode Setup capability:

With the “recovery during standby” flag it can be controlled whether the system is allowed to perform a system recovery if the power supply recovers during the iNAT is still in standby mode. With the enumeration parameter it can also be defined how many times the system shall perform such recovery before it refuses any further recovery attempts (in this case to start the iNAT again, a power down is required, which lasts longer than the standby duration, i.e. typically > 1 s). The reason of providing such setup is to allow the user to protect the iNAT system against high frequent long lasting power drops from an erroneous power supply provided from the operator.

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7 QUICK START

This section describes the first steps with the iNAT system for configuration and operation. Many other commands and logs are available and can be found in document [2] (see Table 1) for more sophisticated operation.

It is recommended (at least for new users) to use the iXCOM-CMD tool (Table 1: Related Documents, item [6]) for system configuration and operation. If you intend to program your own communication interface to the iNAT system, we recommend to use our software development kit (SDK) which is available for MS Windows and Linux [11].

For direct communication with the iNAT systems also an extensive library of Python scripts is available. Details and a link to the scripts are described in [16].

For simple communication also a NMEA183 (UART) data output is available [18].

Attention:

Do not switch off the power supply of the system while storing a system configuration (initiated via GUI or via command interface) or while performing a firmware update!

Performing a power-cycle during these activities may locally damage the configuration file and the system will start with the default (factory set) configuration at the next power-on.

The following steps provide an informative basis for the first usage of the system.

1. Mount the antenna and connect the antenna cable to the correct connector (see system ICD, typically TNC or SMA connector). Survey the geometrical vector from INS to GNSS antenna in the coordinate axes labeled on the INS enclosure.
2. Connect the lab cables with the system connectors of the iNAT.
3. Connect the Ethernet (LAN) with the host PC. Alternatively connect the host PC via USB or via the RS422 UART port (typically COM3 for iNAT-Rx/-Fx/-Hx and COM1 for iNAT-M200). Take care for Rx/D / Tx/D logic as well as for polarity (Rx/D+ of the iNAT shall lead to Tx/D+ of the destination etc.). The iNAT typically provides internal 120 Ohm termination for its UART RS422 Rx/D lines.
4. Plug in the power connector of the iNAT (10-35 V DC or 16-35 V DC or 9-34 V, depending on iNAT type and version; confirm first regarding type plate!).
5. Switch power on
6. If you use the iXCOM-CMD GUI software, start the software, select the used communication port (Ethernet or UART or USB), apply the correct parameters (Ethernet: verify, whether the iNAT is set to a fix IP address or to DHCP; UART: select the correct Baud rate and COM Port at your local Host) and establish the connection ("Connect" button)

The following steps are only applied if you do not use the iXCOM-CMD GUI:

7. Open your serial port or Ethernet port on your local host computer and send the iXCOM command `XCOM` with the `OPEN` parameter (command ID 0x0005) to the iNAT (create a channel number etc. as described in [2]). This command is mandatory required to enable a specific iXCOM communication channel.⁸

⁸ Per default by factory set the „channel number“ 31 (zero) is existing with a pre-defined log list (output of certain data logs to be used by the iXCOM-CMD GUI). It is best practice to clear all logs at the beginning by the application and to command the logs being required by the specific application.

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8. Configuration of the data messages (INSSOL, GNSSOL, GNSSTIME and SYS_STAT) with the desired rates (inside of the given constraints of baud rate).
9. Configuration of the INS misalignment via the iXCOM parameter PARIMU_MISALIGN.
10. Configuration of the GNSS antenna lever-arm via the iXCOM parameter PARGNSS_ANTOFFSET.
11. Configuration of the alignment time via the iXCOM parameters PAREKF_ALIGNTIME and PAREKF_COARSETIME.
12. Configuration of the alignment mode via the iXCOM parameter PAREKF_ALIGNMODE.
13. Configuration of the Kalman filter start-up behaviour via the iXCOM parameter PAREKF_STARTUP.
14. Saving the configuration into the internal non-volatile memory via the iXCOM command CONF (command ID 0x0003).
15. Start a re-alignment via the iXCOM command EKF (command ID 0x0004).
16. After the mission is completed, the iXCOM communication channel shall be closed via the iXCOM command XCOM with the CLOSE parameter.

A proper GNSS antenna installation is mandatory to achieve best system performance. Study the application note [15] for details.

8 BUILD-IN-TEST

8.1 BIT Function Description

The INS contains the resources to perform a Built-In-Test (BIT) function. The BIT is designed to inform the user whether the outputs are valid, whether the internal hardware is operating correctly (internal voltages, temperatures and test signals) and whether the inertial sensors are providing correct data (within the range of testability).

8.2 Power-up BIT (PBIT)

During power-up, the INS auto-executes the PBIT function. Power-up to normal operation, including the PBIT, will take less than 15 seconds. Shorter durations TBD. The PBIT comprises sensor and electronics health and temperature monitoring.

8.3 Continuous BIT (CBIT)

During normal operation a CBIT is running as a permanent background process to monitor the health of the INS. The CBIT comprises sensor and electronics health and temperature monitoring.

8.4 LED Status Indicators

Up to two LEDs signalize the status of the system. The description can be found in the dedicated system ICD [1][9].

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The LED L1 indicates signal processing related high level information while the LED L2 indicates FPGA based low level information.

The meaning of the LED L1 is as follows:

Color	Frequency	Meaning
red	0 Hz (contin. on)	Will be shown since power-on until the hardware initialization is finalized
red	5 Hz	A hardware error or a rate sensor over-range has been detected
orange	5 Hz	Indicates, that the system is still awaiting a position information to start the processing. This position can be available from GNSS, from stored position, from forced position or from default position.
orange	1 Hz	Indicates, that the gyro compassing is in process (static alignment)
green	1 Hz	Indicates, that the alignment had been finished (by exceeding the required standard deviation, by time-out or by abort [e.g. due to detected motion]) and that the system has entered the navigation mode. A navigation / surveying mission can now be executed.

The LED 2 indicates with green, that no error has been detected in the FPGA and red indicates a detected error.

9 HARDWARE ARCHITECTURE

The hardware architecture of the INS is given in the dedicated system ICDs [1], [9] and others.

10 SPECIAL FEATURES

The system supports a lot of useful additional features. Not all of these features are available in every system configuration and not on each hardware type. In the following a few of these features are listed.

10.1 REC Parameter / Post Processing

The recording module (REC) records the sensor data and the INS/GNSS solution to the internal storage device of the INS hardware. The REC module can be configured to record specific data at a specific data rate. The secondary sensors with a low data rate such as GNSS, MAG or MADC will be recorded with their respective processing rate. This ensures that all aiding data are available for post-processing with related time stamps. The configurable recording rate refers to the IMU and the data fusion modules.

The REC feature can be configured by the iXCOM-CMD software or via dedicated commands sent by the user.

10.2 Data Output

Each iNAT system provides output data as inertial acceleration, inertial angular rate, gravity compensated acceleration, earth rate compensated angular rate, velocity, position, roll / pitch / yaw and quaternions /DCM, standard deviations etc. (data are available in several frames as WGS84 / LLH or ECEF).

Additionally, it provides further information like magnetic heading, obtained from the INS/GNSS heading by applying the WMM2015 (world magnetic model).

Each datum is precisely time stamped (better than 1 µsec), where the time stamp is coordinated in GPS time (without leap seconds, to guarantee time monotony all the time [UTC would perform time jumps when the leap second changes]).

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11 GROUND SUPPORT EQUIPMENT

The INS provides several data interfaces (Ethernet, RS422 UART) which can be used for operational as well as for diagnostics purposes. As GSE (ground support equipment) a standard PC can be used if it supports Ethernet (100 Mbit/s) and/or RS422 UART (baud rate adjustable up to 921.6 kBd). For standard notebooks commercial adapters (USB to RS422 UART or Ethernet to RS422 UART, e.g. from MOXA) are available on the market.

For the UART interface in general a standard terminal program is sufficient. For Ethernet, UART and USB interfaces iMAR provides a support and command software iXCOM-CMD. An iMAR internal FAT and BIT analyzing support software is available for customers, having a larger number of iNAT systems under operation (please contact iMAR support engineers for detailed information and conditions).

For operation in the lab a standard power supply is required (28 V DC / 1.5 A or 8...36 V DC, 50 W). Furthermore, one or two L1L2 GPS + GLONASS + L-Band antennas (depending on standard setup or dual-antenna setup) is required as well as a set of system lab cables.

12 PACKAGING & STORAGE

The INS is a highly accurate measurement tool, which requires a careful handling. Nevertheless of the ruggedized and the shock resistant design, mounting and transportation shocks shall be avoided where possible.

Also, high ESD impacts shall be avoided as usual.

Therefore, a proper packaging is mandatory before transportation or storage. This can be achieved by a double hull packaging within ESD protected foam.

The transportation and storage shall be executed within the specified environmental conditions (see datasheet).

As valid for every technical device, avoiding strong temperature gradients during operation or storage may increase the lifetime of the goods.

13 ROHS & REACH

In standard configuration the INS electronics does not contain environmental or health hazardous materials.

If the system is manufactured with Nickel plated connectors (standard configuration), they do not contain environmental or health hazardous materials.

Some of the inertial sensor assemblies (integrated optics, ring laser setup) may contain certain listed materials in very small volume (< 0.1 % by weight). This is required for a reliable operation and cannot be substituted.

14 HARDWARE & SOFTWARE DESIGN STANDARDS

Hardware and software of the iNAT-Rx/-Fx/-Hx as well as iNAT-M200, iNAT-M300, iNAT-CFM, iCORUS, iANARO, iPST (and accordingly the versions iSULONA, iCOMBANA and iPRENA for military applications) are developed under full configuration control (EN9100) according to iMAR standards. The equipment is designed to be used for advanced navigation, surveying and control applications. Certain equipment (see dedicated ICD of the product) is certified regarding environmental conditions and regarding EMI/EMC protection to be used in military and commercial aircraft (MIL-STD-810G, MIL-STD-461E, MIL-STD-704F, DO-160G). The design standards of DO254 and DO178C are not applicable for the current releases.

For navigation applications in military aircraft the usage of an independent navigation backup system (ESI) is recommended.

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15 SUPPORT

15.1 Asking for Support

For our support management system, we need to know the project number (Proj.No.) or alternatively P/N and S/N of the system you are speaking about.

These numbers are for example provided on the type plate (example shown in the Fig. on the right side).

Important:

Read chapter 22 (frequently asked questions / How To...) carefully before contacting our support.

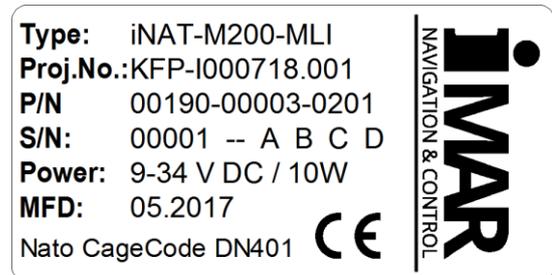


Figure 10: Example of iMAR type plate

15.2 Contact

You can find general information about our products, used technologies, and about inertial navigation, and GNSS based navigation at www.imar-navigation.de.

You can reach the iMAR Customer Support Team as follows:

-  support@imar-navigation.de
-  +49-6894-9657-15
-  **iMAR** Navigation GmbH
Customer Support
Im Reihersbruch 3
D-66386 St. Ingbert
Germany

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16 ABBREVIATIONS

Expression	Description
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
FTP	File Transfer Protocol
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
NAT	Navigation And Timing
OS	Operating System
PPS	Pulse Per Second
RNDIS	Remote Network Driver Interface Specification
USB	Universal Serial Bus

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17 APPENDIX: iXCOM-CMD CDU SOFTWARE

A software is available, which allows a quick access to the major data of the INS and to perform certain parameter settings.

The iXCOM-CMD CDU software can be operated on a standard PC, on a tablet or on specific handheld devices like GETAC™ terminals.



Figure 11: iXCOM-CMD Software Main Screen

Please refer to the document MAN_iXCOM-CMD.pdf (DOC151112010) for a detailed description of the software [6]. Also a training course document is available to support a quick start for new users (DOC160113001). Use the latest released software.



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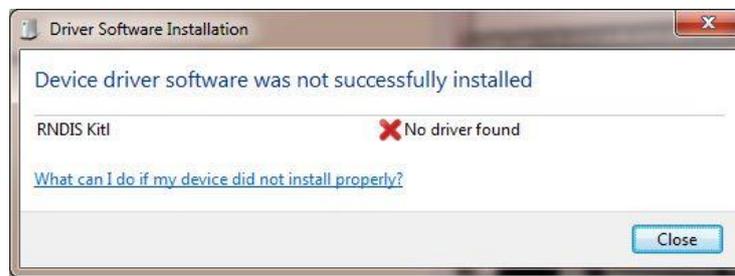
18 APPENDIX: USB DRIVER INSTALLATION ON HOST PC (WINDOWS 7)

To configure the system via a host PC, the user can connect to the INS direct via Ethernet, via RS422 (UART) or via USB. By logic the USB port is mapped in the PC like an Ethernet network port.

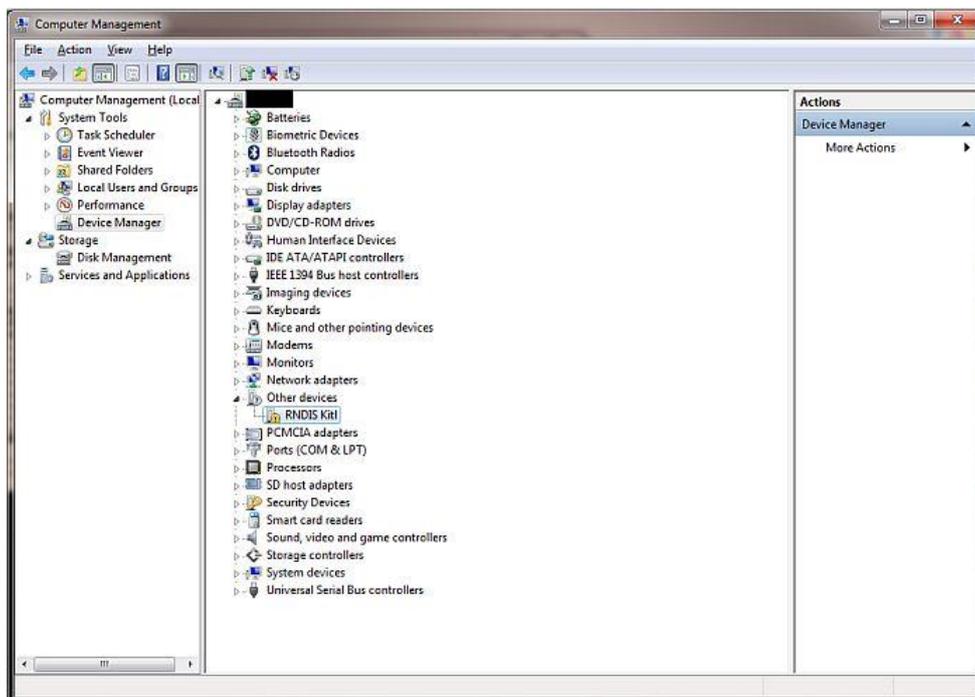
The USB peripheral will enumerate to the host as an Ethernet device, using the “usbnet” driver with Linux hosts or Microsoft's RNDIS driver with Windows hosts. The user has to set it up like any other two-host Ethernet link.

RNDIS driver is a part of the Windows 7 operating system, but the OS fails to detect it automatically. The following steps will help the user to install the RNDIS driver.

1. After the device is connected to the PC, the Windows OS will automatically search for the RNDIS driver. After it fails to find the driver, the following message will be shown.



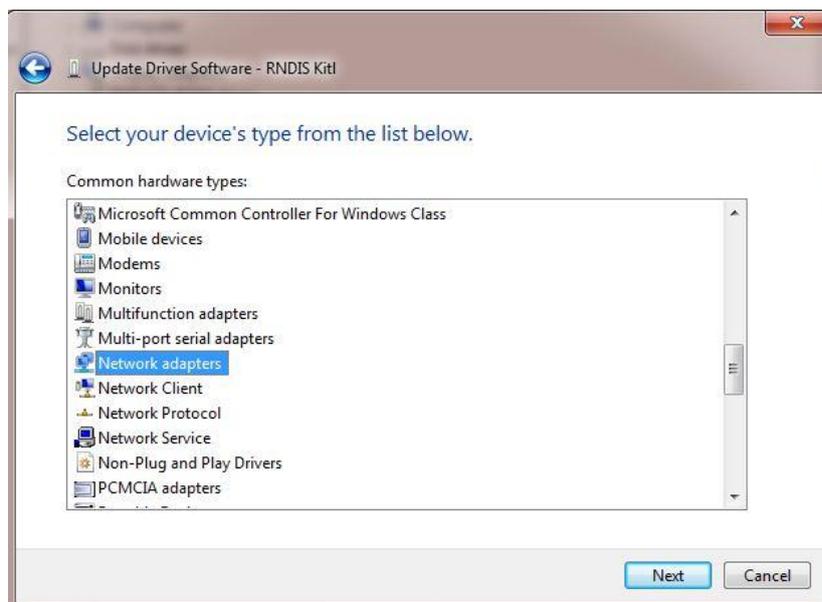
2. Right click on Computer and select Manage. From System Tools, select Device Manager. It will show a list of devices currently connected with the development PC. In the list, RNDIS can be seen with an exclamation mark implying that driver has not been installed.



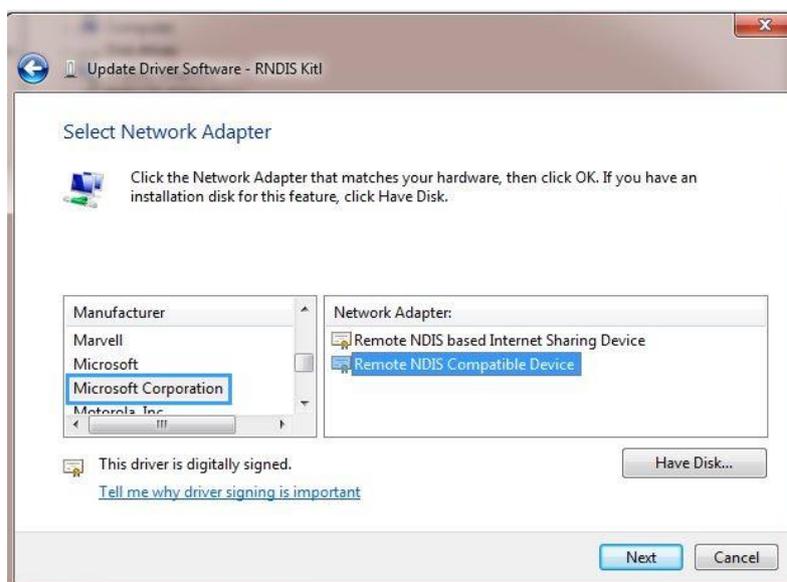
3. Right click on it and select Update Driver Software... When prompted to choose how to search for device driver software, choose Browse my computer for driver software.

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4. Browse for driver software on your computer will come up. Select “Let me pick from a list of device drivers on my computer”.
5. A window will come up asking to select the device type. Select Network adapters, as RNDIS emulates a network connection.

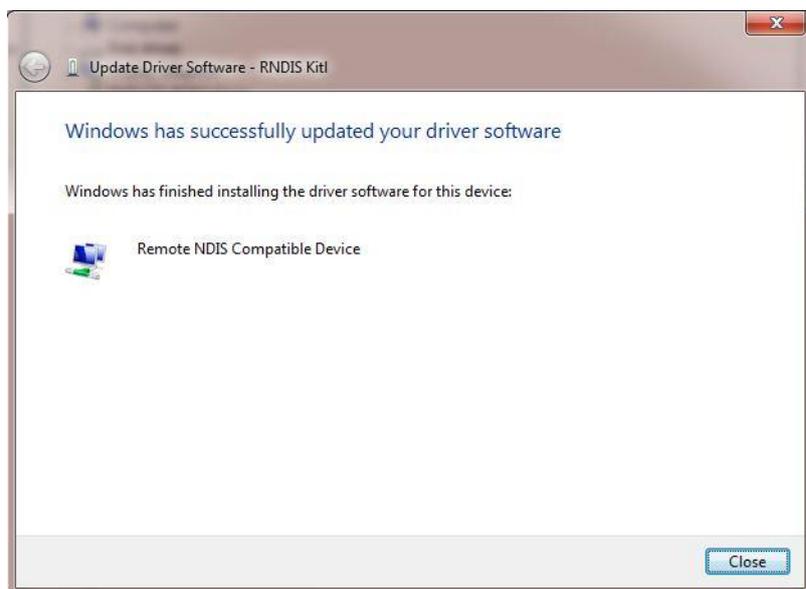


6. In the Select Network Adapter window, select Microsoft Corporation from the Manufacturer list. Under the list of Network Adapter, select Remote NDIS compatible device.



7. The RNDIS device is now installed and ready for use.

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After the driver is installed successfully, a further network adapter is available. It is required to use a static IP address for this network. The iNAT's IP address is by default **192.168.47.11** but can be adapted on the INS settings. Therefore, the new network adapter has to be in the same sub-network, but different from the iNAT address, i.e. in this example not equal to 11 in the last number (i.e. e.g. 192.168.47.**2**).

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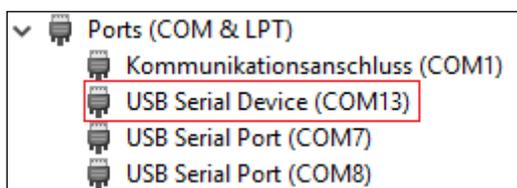
19 APPENDIX: USB DRIVER INSTALLATION ON WINDOWS 10 HOST PC

To configure an iNAT system via a host PC, the user can connect to the INS directly via Ethernet, via RS422 (UART) or via USB. By logic the USB port is mapped in the PC like an Ethernet network port.

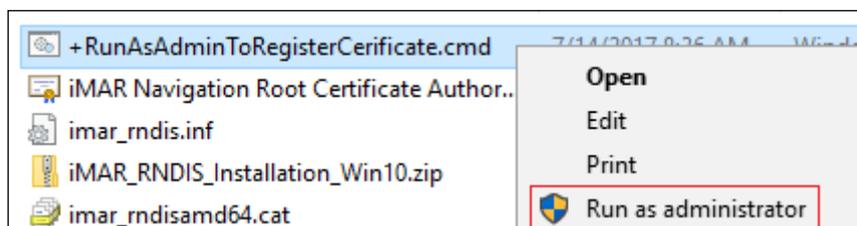
For Windows 10 users, the plugged in system falsely appears as a “Serial USB device (COMx)” in the device manager. **If Windows 10 already recognized your system device as an extra network card, you can skip the Device Driver Update chapter.**

19.1 Update device driver

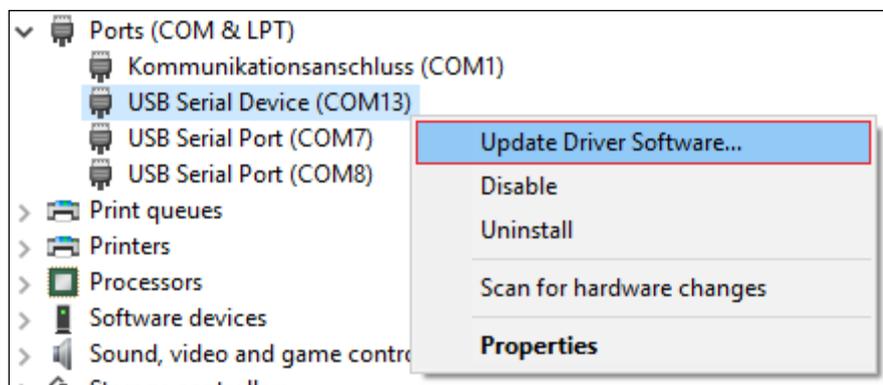
- a. After the device is connected to the PC, the Windows 10 OS will automatically search for a related driver for installation purpose. After that, the system will appear as a “Serial USB Device (COMx)” in the device manager.



- b. Unzip the provided *iMAR_RNDIS_Installation_Win10.zip* package to any location and run the cmd script **as administrator**. If you do not have access to this file, please contact iMAR support.

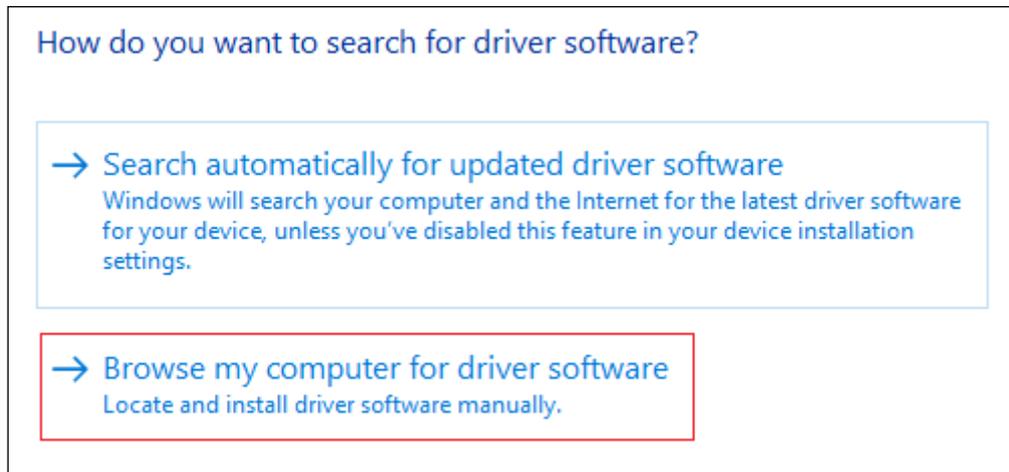


- c. For the next step, update the driver information of your falsely detected system. Go back to the Device Manager, right click the system and choose “Update Driver Software”

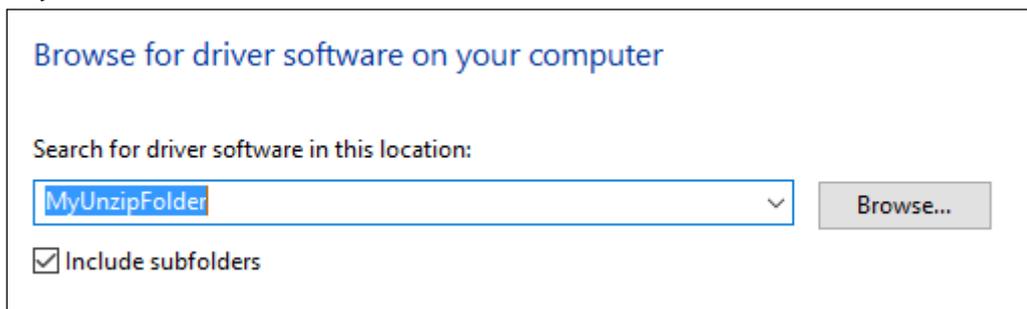


- d. In the appearing window, choose “Browse my computer for driver software”:

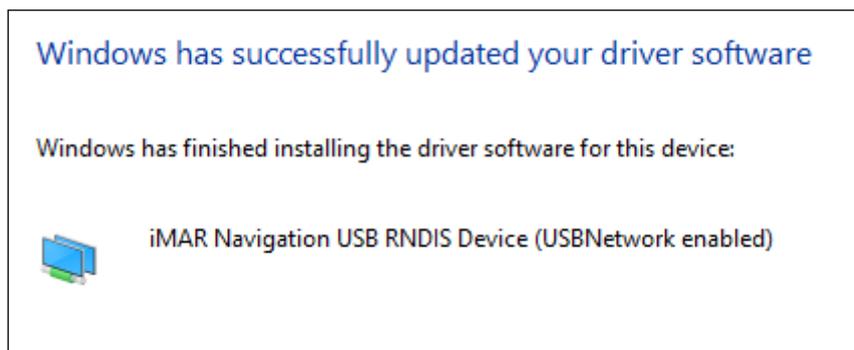
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- e. Choose the folder you recently unzipped the files from the package and press the “next” button to confirm your choice.



- f. Windows 10 will now try to install the newly available driver information. If the procedure succeeds, it will come back with the following screen:



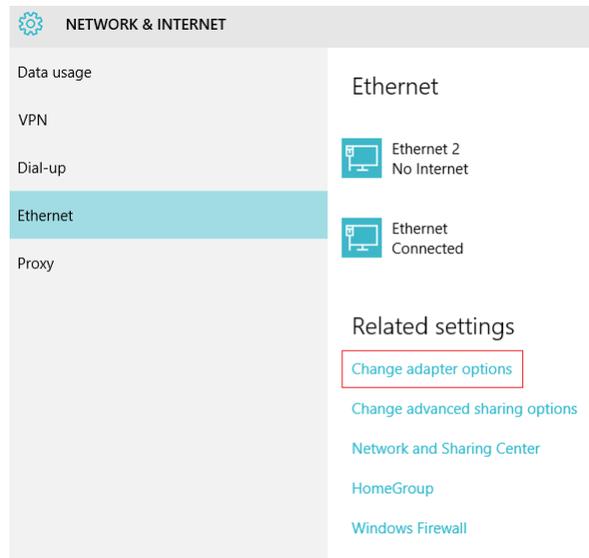
After the driver is installed successfully, a further network adapter is available.

19.2 Setting a static IP address in Windows 10 OS

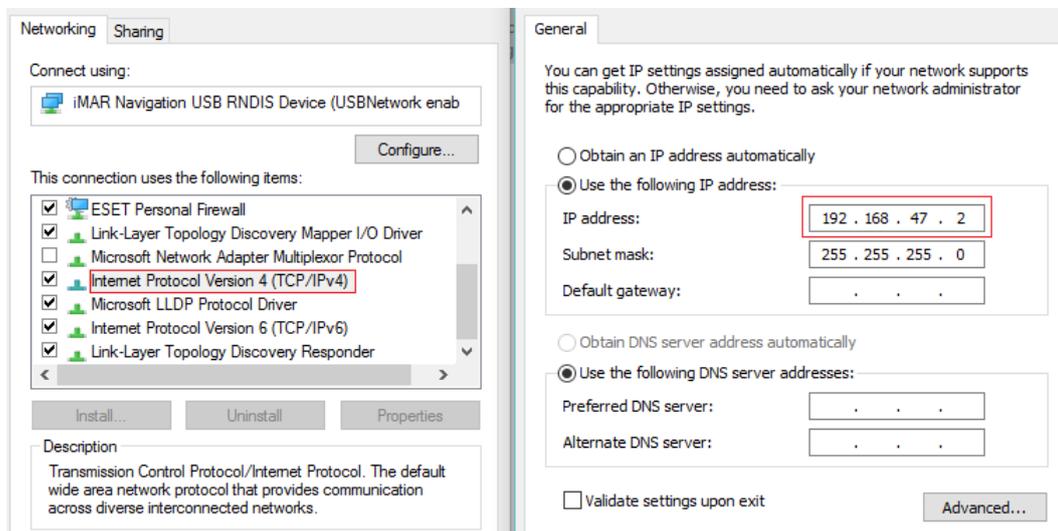
It is required to use a static IP address for your host PC when participating in this network. The system's IP address is by default **192.168.47.11** but can be adapted on the INS settings. Therefore, the new network

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adapter has to be in the same sub-network, but not equal to the iNAT USB IP address (e.g. 192.168.47.2). To set a new static IP address in Windows 10, you have to change the related adapter options, which can be found in the Ethernet settings window.



In the upcoming window, choose your newly created Ethernet connection with a right click and open the **Properties** window. Scroll down to the entry **Internet Protocol Version 4 (TCP/IPv4)**, open the related Properties window and set a new static IP address.



Be sure that the related subnet mask is set correctly.

That's all. You now should be able to communicate with the system via a "ping" or the common way as it were a "normal" network participant.

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20 APPENDIX: FTP ACCESS TO THE INS

The iNAT provides a user interface via FTP. We strongly recommend using the FTP access via the iXCOM-CMD software. As an alternative a FTP-Client such as Win-SCP⁹ or FileZilla¹⁰ can be used. The following example uses Win-SCP as FTP-Client.

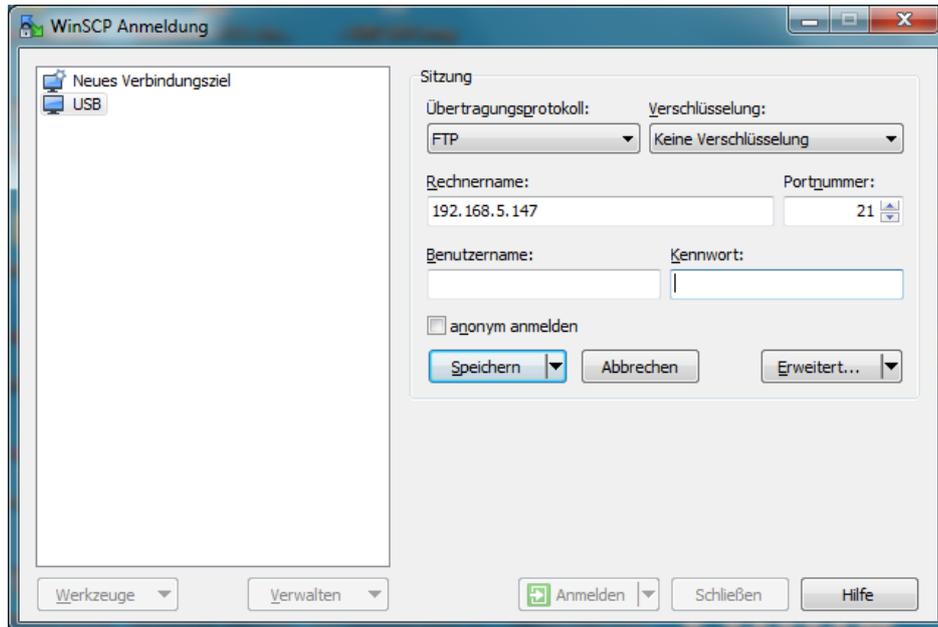


Figure 12: Win-SCP Connection Parameters

The connection parameters are:

- IP-Adresse: **192.168.1.30**
- Port: **21**
- Username: *not required* (select the ANONYMOUS checkbox)
- Password: *nor required*

Note: For systems being delivered until May 2016 a download of measurement data from the INS shall be performed via USB. If FTP is used, please use a switch of type NetGear FS108 (and not of type “ProSafe” like NetGear GS108). For systems delivered or upgraded after May 2016 the access is directly possible with direct connection as well with probably any type of switch.

The most comfortable solution is using the iXCOM-CMD software, This software supports file transfer with an integrated FTP client for download of stored data as well as for download and upload of configuration files.

⁹ Download: <http://winscp.net/eng/download.php>

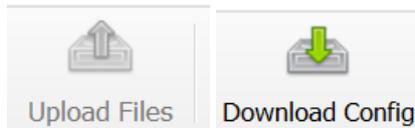
¹⁰ Download: <https://filezilla-project.org/download.php?type=client>

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21 APPENDIX: CONFIGURATION OF THE INTERNAL GNSS ENGINE

The user has the capability to adjust the configuration of the internal GNSS receiver. To do this, initially a configuration file (text file) with the name "GNSScustom.txt" has to be created which contains the relevant commands (using the script language of the internal NovAtel GNSS engine).

Use the iXCOM-CMD software for download and upload of configuration files:



"Download" loads automatically all relevant configuration files as well as a log file from the INS to the local PC's file system.

config.bin GNSSconfig.txt GNSScustom.txt syslog.txt update.log

"Upload" loads a dedicated configuration file directly into the Upload-Folder on the INS' file system.

Content of the configuration file for the GNSS receiver:

Name of File: GNSScustom.txt

Content of File:

```
# Set PPS pulse with negative slope, 1 Hz and width 50ms      (this is a comment)
PPSCONTROL ENABLE NEGATIVE 1.0 50000
```

This file must be copied on the INS into the "Update" folder. After that the system has to be restarted (power off/on).

If the update had been successful, the file is automatically deleted from the INS' Update folder.

If the update had not been performed by any reason, an error log is created with the appropriate error message inside the update.log file on the INS.

Note:

The Upload of the file GNSScustom.txt overwrites any existing file of this name on the INS. Therefore, if you want to add additional commands, first perform a download of the file, add the additional commands and then perform an upload again.

IMPORTANT HINT:

It is under user's responsibility to make any changes correctly in the system configuration files. If e.g. the slope of the PPS is inverted (positive instead of negative), this has significant impact on the time stamping of the internal IMU data and would in this case lead to complete wrong time synchronization between IMU and GNSS data and hence to wrong results of the data fusion. Therefore it is highly recommended to consult iMAR engineers before performing any changes.



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22 APPENDIX: FAQs / HOW TO...

The operation of the systems is described in the user manuals, which are referenced in **Table 1**.

If you need any further support, please refer to chapter 15.

But before contacting our support, check the general setup of your system integration, because most of the problems occur due to connecting the systems within a wrong environment (using wrong interface baudrate or wrong Ethernet IP, using wrong lever arms etc.).

To help you to overcome such common mistakes, the next typical “how to’s” are described here within the following Frequently Asked Questions.

22.1 CAN bus does not work

Please check the following:

- Is at least one of the connected CAN nodes operating on a different baud rate than the iNAT system does? (All connected CAN nodes have to operate on the same baud rate)
- Have you reversed the CAN-HI and CAN-LO cable? (on the CAN bus all lines of CAN-HI have to be connected together and all CAN-LO lines vice-versa)
- Is the 120 Ohm bus termination missing on your site? (The CAN bias has to be terminated at both sides with 120 Ohm)
- Is the connected CAN device sending an ACK? (one connected node has to acknowledge the CAN frames sent by the iNAT system, if the iNAT system is configured accordingly)

22.2 Ethernet connection does not work

Please check the following:

- Is the used IP address correct? Is your DHCP server configured correctly?

By default the iNAT system is waiting for a DHCP server in the network, which should provide the IP address. If this will not happen within the first about 20 seconds after system booting, the iNAT will start up with an internal preset static IP address (typically 192.168.1.30 – user configurable!). If the request for a DHCP server is disabled on the iNAT system, the iNAT is available with the static IP address within 10 sec after the system booting has finished.

Use e.g. WireShark to trace the connection.

Disable e.g. your DHCP server test-wise to check, whether you can get a connection via the static IP address.

If you do not know the internal set static IP address, you can also connect to the system via UART or USB interface and look into the internal system configuration (using iXCOM-CMD software – do not forget to use “Save Config” after you have modified parameters to get them active and to perform a power-cycle in case of changed interface parameters).

22.3 NMEA183 data output does not work

Please check the following:

- Is the UART port selected correctly?

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- Is the baud rate set correctly and large enough to transmit all selected data?
- If transmitted via RS422, is the termination of the interface (120 OHM) correct?

22.4 Standard Deviation of Position higher than expected

Please check the following:

- Check the values and the set standard deviation of the lever arm between INS and GNSS antenna. The standard deviation of the measured lever arm shall be realistic (according to your measurement capabilities).

Consider:

- If you chose the lever arm's standard deviation larger than it is (e.g. 1 m, nevertheless you are able to determine it with e.g. 5 cm), this uncertainty is also seen in all navigation results (position etc.) – i.e. the output of the standard deviation of the navigation result will be worse than necessary (in this case it will be about 95 cm in each direction too large).
- If you chose the lever arm's standard deviation smaller than it is (e.g. 1 cm, where you are only able to determine it with e.g. 5 cm), this wrong uncertainty induces errors in all navigation results (position etc.). Example: driving a circle, the internal data fusion would expect that the GNSS antenna follows the true trajectory with about 1 cm (plus the GNSS inherent errors), but in reality the GNSS antenna may provide only by the wrong lever arm an additional position error of about 5 cm, which even may depend on the heading (the lever arm is body related!).

So, it is important to provide the value and standard deviation of the lever arms (GNSS, odometer etc.) as accurate as possible.

- Check the standard deviation of the GNSS data. Are the correct GNSS satellites activated, is the usage of correction data (RTK, SBAS, ...) correctly configured?
- Has the iNAT system seen sufficient motion with GNSS aiding to be able to estimate the internal states of the data fusion sufficiently?

Example:

Consider a non-gyro-compassing single GNSS antenna system, which has to determine true north (by physical laws) from the data fusion of INS/GNSS (and optionally odometer, vision etc.) under motion. If such a non-gyrocompassing system is moving a long time straight forward with constant velocity (i.e. nearly zero acceleration!), it cannot be able to estimate true north. Reason are the physical laws and not the system itself.

Way out:

- Fly dynamics (curves or 8-shapes) from time to time (period depends on INS sensor performance)
- Use a dual-antenna GNSS system instead of a single GNSS system inside of the iNAT
- Use a true north finding, i.e. gyro-compassing iNAT system.

22.5 I want to start my iNAT system without GNSS availability

Please check the following:

- If you operate a gyro-compassing system (e.g. iNAT-Rx, iNAT-Hx, some iNAT-Fx, iPRENA etc.), you can use a "Forced" position (manually or via interface entered) or a "Stored" position (using the last position which was measured before last power-down –

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this mode has to be configured specifically within iXCOM-CMD software!). This avoids that the system will wait until it gets the first fix to GNSS satellites. The true heading is then determined by gyro-compassing, using the Align command.

- If you use a non-gyro-compassing system (e.g. iNAT-Mxx, iSULONA etc.), additional to the “Forced” or “Stored” Position (see item above) also a “Forced” or “Stored” Heading has to be provided. Also this can be configured within iXCOM-CMD.

Once GNSS will be available later on, it will be used to improve the system’s output accuracy.

22.6 I want to eliminate small sawtooths observed during aiding updates

The internal data fusion (Kalman filter) improves the inertial solution by using periodical or non-periodical external aiding information, like GNSS position or others. Such updates lead to minimization of the error, which is the best solution (decreasing position deviations as soon as an update is available).

If you see strong sawtooth behavior on the output data, check the correctness of the applied GNSS antenna lever arm(s). Measure them within INS body frame (as printed on the enclosure). Measure the lever arm as accurate as possible and set a realistic standard deviation of the measurement. **A wrong set lever arm to GNSS antennas or odometer is the reason for wrong data output in most support cases of the users.**

But in some applications such immediate position update (equivalent also on velocity, attitude and heading) cannot be handled by the receiver of the data (e.g. some vehicle motion controllers of some manufacturers). Therefore a smoothing function is available on all iMAR systems, which can be activated optionally. This function distributes the sawtooth, observed at the time of the Kalman filter measurement update, to the next duration of N seconds. A value of 0 means “no smoothing”.

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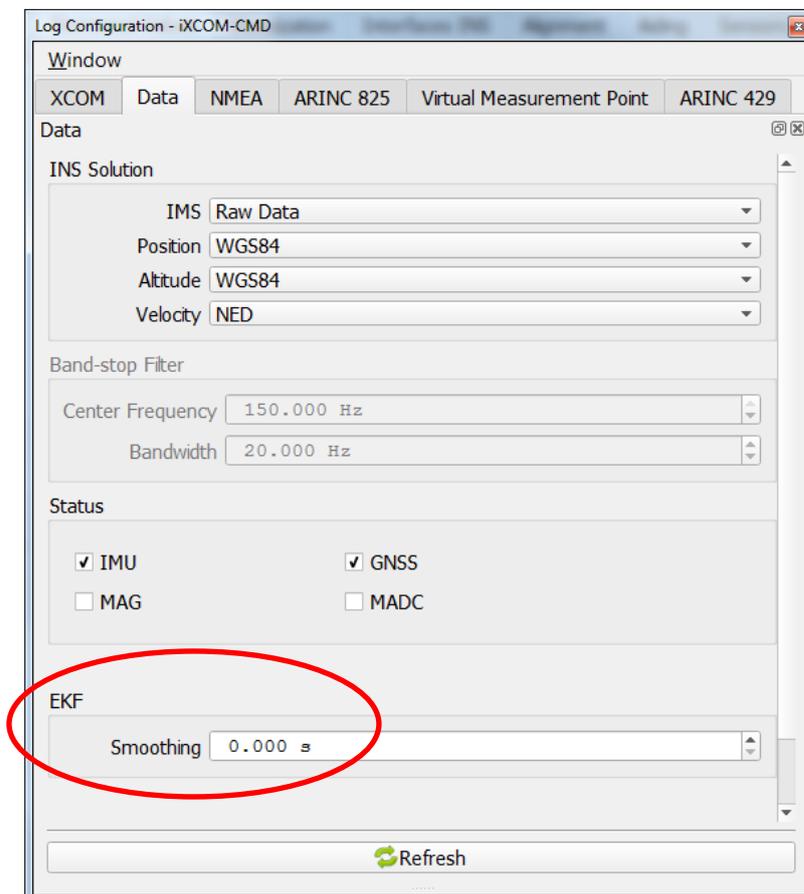


Figure 13: Screenshot from iXCOM-CMD to activate smoothing of output data

22.7 Heading obtained from Dual-Antenna GNSS is something noisy

Please check and consider the following:

- The GNSS antennas shall be mounted on top of ground planes. Each ground plane shall have a diameter of at least 25 cm (larger than GNSS wavelength) and shall be grounded. The GNSS antenna shall be mounted very close on top of the ground plane. In case of strong multipath in the environment use semi-choking antennas.
- To achieve heading information from a dual-antenna setup, the GNSS receiver processes those satellite information which are seen from both antennas. Make sure that both antennas have the view to the same area of the sky.
- A rough performance rule for dual-antenna heading measurement is as follows (1 sigma value !):

$$\text{heading [deg]} = 0.2 / L \text{ [m]} , \text{ where } L \text{ is the length of the antenna baseline}$$

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I.e. a baseline of 4 m will lead to a heading accuracy of 0.05 deg (i.e. 1 mil) 1 sigma
 Attention: These data are valid for best constellation and best environment. Any “real-world” distortion / multipath will degrade the result. This is the reason why a dual-antenna aiding is typically used in combination with an INS solution.

The following plot (Figure 14) shows a dual-antenna solution obtained with a NovAtel OEM7720 dual-antenna GNSS receiver inside iMAR’s iNAT-M200 INS/GNSS solution (the plot shows the raw dual-antenna heading without any data fusion with the inertial sensors). The antenna baseline was 5.8 m, i.e. the expected heading error is 0.034 deg (1 sigma) or 0.1 deg (3 sigma) or 0.2 deg (peak-2-peak) or 3.5 mil (peak-2-peak) [assuming a white noise process, which is only an approximation].

The first and second plot show the measured heading in deg and in mil, the third and fourth plot show the related standard deviation of the provided heading (also in deg and in mil)..

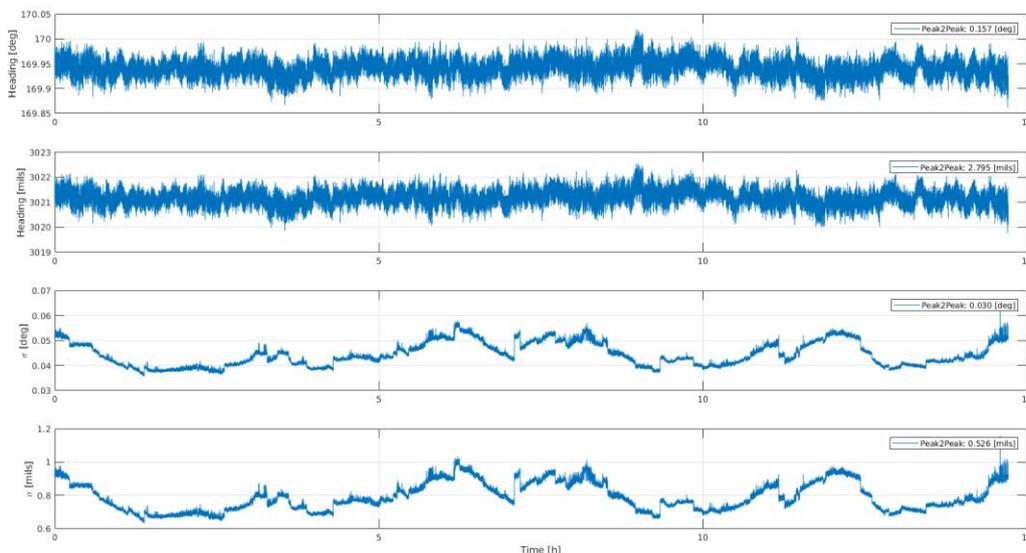


Figure 14: Results of dual-antenna GNSS measurements (1 Hz data sampling; OEM7720 receiver)

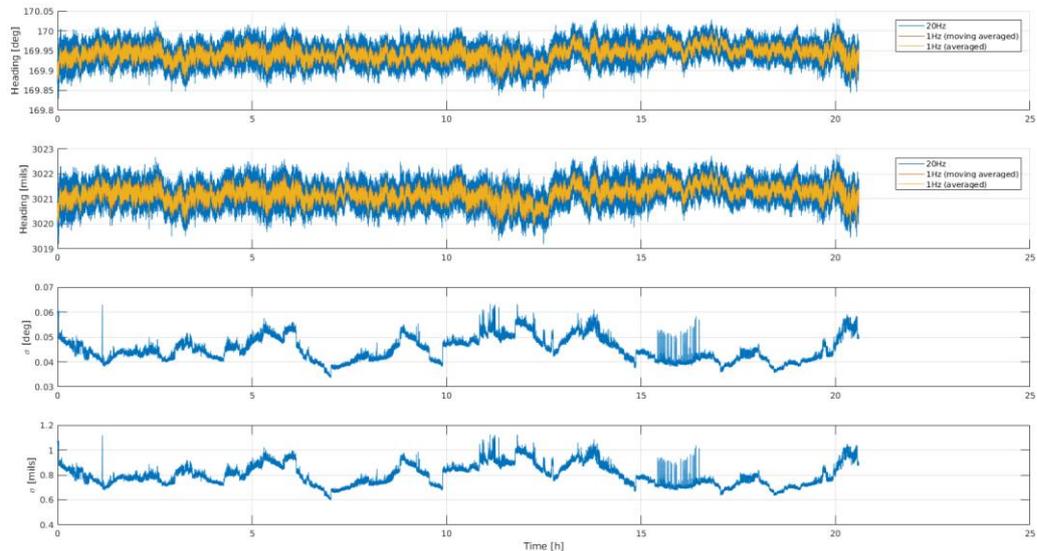


Figure 15: Results of dual-antenna GNSS measurements (20 Hz data sampling, filtered with 1 Hz; OEM7720 receiver)

Note: Two kind of 1 Hz filters have been plotted in Figure 15: a) with moving average (1st order) and b) down-sampling by merging always the last 20 values to one value [both results are very similar]. This shows that a high data rate of a GNSS engine leads to more noise. Hence in combination with a gyro system the data output rate is typically chosen to 1 Hz.

22.8 GNSS lever arm estimation seems not to be correct

The iXCOM-CMD wizard supports an automatic GNSS antenna lever arm estimation. This requires sufficient motion (e.g. by driving or flying several 8-shapes). To do this, the lever arm should be roughly measured and set inside the software. It is important, that the set corresponding standard deviation is reasonable: I.e., if the manual measured x coordinate of the antenna lever arm is 2.5 m with an uncertainty of 0.3 m, the corresponding standard deviation must not be set smaller than 0.3 m (recommended is even to set it to a larger, higher uncertainty). If you would set the initial uncertainty of e.g. only 2 cm, you tell the integrated data fusion algorithm that the manual lever arm measurement is already very precise and so the algorithm is not allowed to apply significant changes (even if the initial lever arm would be significantly wrong). Even if you set the initial standard deviation on a quite large value (e.g. 1 m or even greater), lever arm estimation performs quite fast and accurate if suitable GNSS data and motion dynamics is available.

22.9 Heading of Dual-Antenna GNSS has high standard deviation

Your observation: While the heading of the pure dual-antenna GNSS solution has expected standard deviation (see chapter 22.7), the heading of the data fusion (INS+GNSS) shows much higher standard deviation after alignment during standstill.

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Explanation: Probably you have surveyed the GNSS antenna lever arms with a high uncertainty while you use a short antenna baseline. This leads to a high heading uncertainty as long as the dual antenna heading is used to aid the IMS (see chapter 6.3.4.6 for explanation and solution).

22.10 Heading Misalignment Estimation does not fit as expected

The iXCOM-CMD wizard supports a procedure to estimate the INS mounting heading misalignment angle (i.e. if the x axis as an example would not point exactly into the forward direction of vehicle, we talk about a misalignment).

The wizard proposes a procedure to drive (or fly or swim or dive) on a straight forward line over a certain time to detect the remaining lateral velocity (which should be not there if the INS is correctly aligned inside the vehicle and the test drive would happen without lateral motion).

If the test road shows a significant tilt angle, a so-called side slip angle would be observed, which cannot be separated within such test procedure from a heading misalignment. Therefore, in this case, repeat the test, driving one time into the one direction, note the estimated misalignment, drive again into the opposite direction, note the estimated misalignment again, and if both are not identically, use the average of both as best estimation.

22.11 Unexpected “automatic ZUPT” detection

The iNAT system can be configured to perform an automatic ZUPT (zero velocity update) if a zero velocity condition is detected. If the iNAT is aided by a wheel sensor (odometer), such automatic zero-velocity detection is easy and very safe. If no wheel sensor is available, the zero-velocity state can only be detected by external command (from upper level system or from operator) or by analysis of the motion data, i.e. angular rate and acceleration and velocity obtained from the sensor data fusion.

iNAT allows to perform such automatic analysis of measured acceleration and angular rate to detect a ZUPT capable status of the vehicle. To allow a reliable automatic zero-velocity status detection, two thresholds are used: current rms noise threshold of angular rate and/or rms noise threshold of acceleration. iNAT allows the user to estimate / determine these thresholds automatically within a calibration process. Furthermore the inertial measured velocity can be used to distinguish between motion and standstill condition.

If the automatic ZUPT detection would not work, it could have several reasons:

- The noise threshold has been determined under wrong motion conditions.
Example: On a car it is important whether the thresholds are determined (“calibrated”) while in standstill during “engine off” (which is not representative in most applications) or during “engine on”. The following figure shows the differences as an example.
- The duration, over that the averaged / smoothed sensor noise of acceleration and/or angular rate has to be lower than the defined threshold to detect ZUPT, might be not sufficient (parameter name: “delay”).
If the duration is longer than necessary, the automatic ZUPT detection will not detect each desired ZUPT. If the duration is too short, ZUPTs might be performed where it is not expected.

The usage of angular rate and acceleration for Motion Detection or Standstill Detection might be quite dangerous, because it applies a heuristic rule, which might fail. If possible, use the odometer as a Motion Indicator only.

Note, that the Motion Indication follows the rules described in chapter 6.5. The Motion Indicator follows an OR logic (angular rate higher rate threshold OR acceleration higher accel. threshold OR odometer speed higher odom. threshold). The Standstill Indicator is NOT(Motion Indicator)

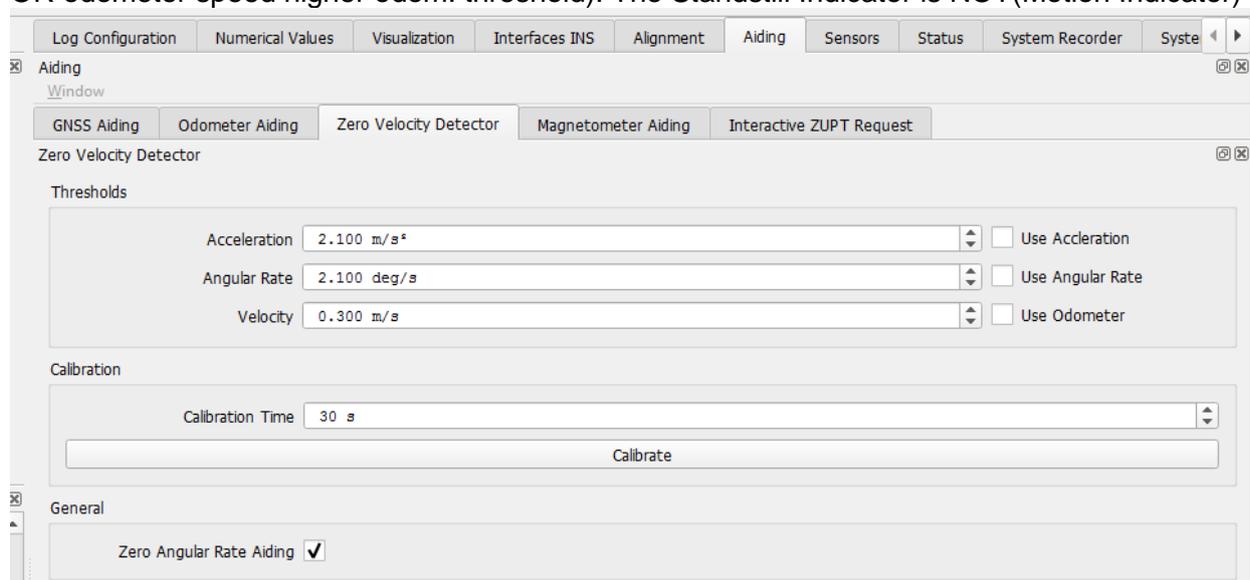


Figure 16: Parameter setting for automatic ZUPT detection in iXCOM-CMD

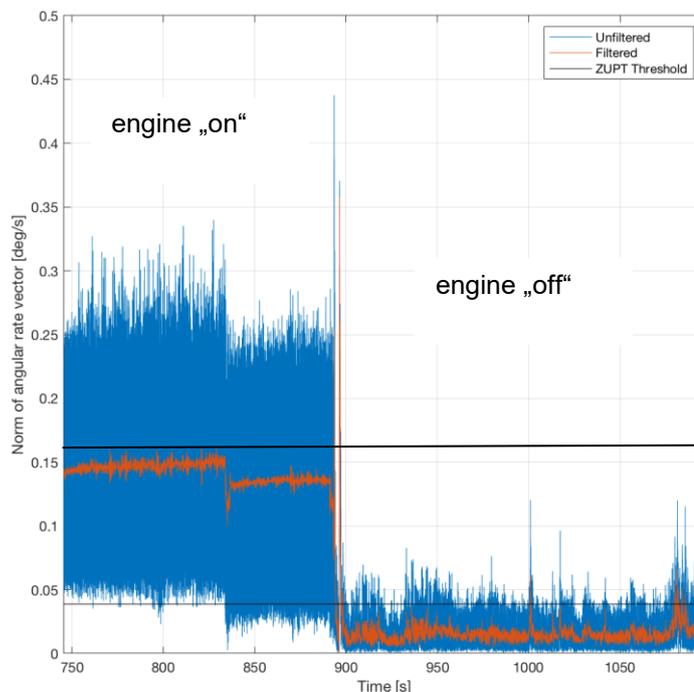


Figure 17: Motion noise level on angular rate during standstill, engine on and off

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22.12 How to handle a changing GNSS antenna lever arm during Operation

See chapter 6.3.4.6.2 for details.

22.13 Using an INS as GNSS Receiver Replacement

The iNAT INS provides much better measurements in position and velocity than a standard GNSS receiver. Can I use the iNAT to substitute a GNSS receiver and can the iNAT provide the same NMEA 183 interface?

Yes, the each iNAT system has the capability to output NMEA183 messages on its UART or UDP port. The most common NMEA183 messages are implemented, like GPGGA, GPGLL, GPGSA, GPGST, GPHDG, GPRMC, GPVTG, GPZDA. Additionally some iMAR specific messages are provided like PIAHS or PISTATUS1, which contain attitude, heading, heave or system status.

Nevertheless the message ID is always "GP" to provide best compatibility to users, which want to replace any other GPS engine.

The above messages contain the measurement results of the iNAT's INS/GNSS/xxx data fusion. Where needed, the data content can be switched between "GPS behavior" and "INS behavior".

Example: The message VTG contains "True Track" in the first field. This is the direction of motion of the GNSS antenna on the surface, i.e. there is no heading involved, because a single antenna GNSS receiver cannot provide heading but only track due to physical laws. But in many applications the user uses the GNSS based "true track" due to the lack of any better information. Now, using an INS instead of the previous GNSS receiver, also the true heading is available and therefore we provide a iXCOM parameter (also adjustable via the iXCOM-CMD GUI; name of the parameter: *XCOMPAR_PARNMEA_VTGSELECT*) where the user can select whether to receive "True Heading" or "True Track" in this field.

22.14 Changing configuration parameters on-the-fly

Is it allowed to change the GNSS antenna lever arm values (x,y,z) during operation?

No, in general such impact is not allowed. Example: Consider RTK accuracy on GNSS and assume that the navigation system is on the move and suddenly someone changes the GNSS antenna lever arm by 1 meter. In this case from one sample to the next the INS/GNSS data fusion receives a GNSS aiding position which has jumped by 1 meter while the standard deviation of the GNSS position stays with 2 cm (RTK). This would immediately lead to a GNSS outlier or data fusion mismatch, which can lead to significant disadvantages of the total navigation result.

So after changing the GNSS antenna lever arm parameter, an appropriate system alignment has to be performed.

Nevertheless, there are also a few parameters which might be adapted during motion by the operator, like Virtual Measurement Point (VMP) parameter, because they have no impact on the internal data fusion.

22.15 System does not start at lower end of specified supply voltage range

The specified input supply voltage is defined as measured voltage at the iNAT connector. Any electrical resistance of the connected cables or of additional connectors or fuses have to be considered, as usual. Consider also a certain additional input current during power-up to charge all internal capacitors.