User Manual

Version V1.0-20170609

Demo Program

For INS-T Inertial Navigation System

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Introduction

This manual is designed to study and use software for all modifications of Tersus™ Inertial Navigation System (INS) for its designed purposes.

Use of the INS should be restricted to only those who have read its user manual and are following the safety measures specified in that user manual.

Tersus provides three models of INS products:

- INS-B (Basic model) – uses MEMS grade magnetometers, high grade IMU and high grade single antenna GNSS receiver;
- INS-P (Professional model) – uses high-grade Fluxgate magnetometers, high grade IMU and high grade single antenna GNSS receiver;
- INS-D (Dual antenna model) – uses high grade IMU, dual-antenna GNSS receiver and measures static and dynamic Heading, independent on magnetic field disturbance.

Fig.1.1. Tersus INS-B and INS-P

Fig.1.2. Tersus INS-D

The most important notes

Subject	Note
To view and edit INS parameters	INS must be connected to computer and powered. Serial port number to which INS is connected and its baud rate should be chosen in the "Test options" menu (see section 4.1).
INS readiness for operations	INS is ready to receive commands and to output data after initialization time is completed (about 25-30 sec after power on) so LED indicator switched color from yellow to red.
At the first use	1. Please enter approximately true Latitude, Longitude, Altitude and Date in the "Devices options", "IMU" tab (see section 4.2.1). This allows correct INS start even at absence of visible GNSS satellites. 2. Set correct value of the magnetic declination there. This parameter is necessary to calculate true heading using measured magnetic heading. Since INS firmware version 2.2.0.2 the magnetic declination can be calculated in the INS continuously. Check «Auto» check-box in «Devices options…» to activate this option.
After INS and GNSS antenna installation	Measure the GNSS antenna position relative to the IMU (m) and enter these coordinates in appropriate fields in "IMU" tab of the "Device options" menu (see section 4.2.2).
Measurement rate (update rate)	It can be changed in the "Device options" menu, but it must not exceed maximum value shown in the Table 4.1 (see section 4.2.5).
Object hard and soft iron compensation	Do not forget to calibrate INS on hard and soft iron after mounting on the carrier object (see section 10.4). But if "Use_mags" switch is disabled in the "Settings" tab of «Correction options…» window, then such calibration is not necessary.
True or magnetic heading	If the magnetic declination is set correctly then INS outputs true heading, if magnetic declination is set to zero then INS outputs magnetic heading (see section 4.2.1).
Altitude or	User can select kind of vertical position measurement –

heave calculation	altitude or heave (for marine applications). See section 10.3.
Pressure sensor	If the INS has no access to the ambient external pressure (for example, if it is installed inside a pressurized cabin) or if the INS pressure sensor can be exposed to speed air streams, please uncheck the “Baro-altimeter enabled” checkbox in the "Pressure sensor" tab " of "Device options" menu to switch the INS vertical correction to the GNSS altitude only.
Automatic start	INS has ability to start operation automatically after power on, with continuous output data in desirable output data format (see section 10.6).
Changing parameters of GNSS receiver	After changing of the next parameters in “GNSS receiver” tab of the “Device options” menu: GNSS COM2 and COM3 ports settings, GNSS Correction it is necessary to switch off, switch on INS unit to restart onboard GNSS receiver
INS algorithm adjustment	Features of INS algorithm and possibilities of their adjustment are described in section “4.3.1. “Settings” tab of «Correction options…» window”.

1. General information

Operating system. This version of the Demo software is fully compatible with the operating system MS Windows XP, MS Windows Vista, MS Windows 7.

Working with the software. The “Tersus INS Demo” software is a windows-based Win32 application, and standard means used in the Windows (mouse and keyboard) are needed to use it. Directory structure necessary for data storage is created by user. All necessary configurations and calibration coefficients are stored in the INS nonvolatile memory, and they are automatically loaded into the INS microprocessor. Calibration coefficients are set by INS developers, and they can be changed, but only under guidance of the INS developer. Upon termination the “Tersus INS Demo” software creates a default.prm file for its operation, in which the latest used parameters of the microprocessor and shell are stored. During work with the INS, the files with extensions .txt, .rtf, .prm, .dat and .bin can be created. Files with extensions .txt and .rtf can be created by operator, and files with extensions .prm, .dat and .bin are created automatically by the software when it is saving text or graphical data.

Requirements to the system resources. The software requires 6 Mbytes of RAM for proper operation. Hard disk capacity required for proper operation is determined by the size of the Demo software files (approximately 12 MBytes) and by the files saved during operation, no more than 100 Mbytes. Recommended screen resolution is 1280x1024 pixels. The INS is connected to a computer through a standard COM port. The INS can also be connected to a PC through a USB port with a COM-to-USB converter. In this case, reliability of signal reception/transmission between a PC and the INS can greatly depend on the quality of the COM-to-USB converter and on correct configuration of its driver. INS manufacturer guarantees reliable operation of the INS if it is connected directly to the COM port. In the Appendix A, installation and configuration of drivers for one of the possible COM-to-USB converters is described.

Requirements to operators. The INS Demo software uses a standard Windows operating system. Therefore, operators should know the basic principles of PC operation to use the Demo software, and they should be able to use the MS Windows operating system.

2. Installation of drivers and configuration of PC parameters

The “Tersus INS Demo” software doesn’t require any installation. Just copy the software folder INS_Demo_002 to the working directory.

When you connect the INS to a standard computer COM port, drivers are not needed. If the INS is connected to a USB port with a COM-to-USB converter see “Appendix A. Installation of the COM-to-USB converter drivers and configuration of PC parameters” for more details.

If you use the INS with RS-422 interface you need to install RS422-to-USB converter driver. See “Appendix B. Installation of the MOXA Serial-to-USB converter drivers (for INS with RS-422 interface)”

To know the numbers of the PC COM ports click «**Device Manager**» in the «**Hardware**» tab of the «System Properties» window (Fig.2.1). In the opened «Device Manager» window (Fig.2.2) you will see the COM ports which will be marked as «**Communications Port (COMN)**» or «**USB Serial Port (COMN)**» or «**MOXA USB Serial Port (COMN)**». Number N in the port name is assigned by OS.

Fig.2.1

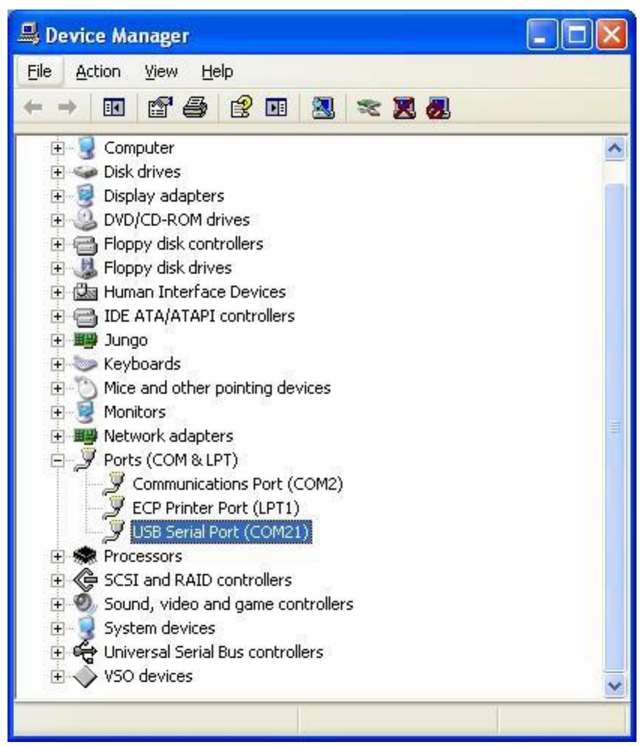


Fig.2.2

3. Main menu of the program

The main menu of the "Tersus INS Demo" software contains the following items (see Fig.3.1).

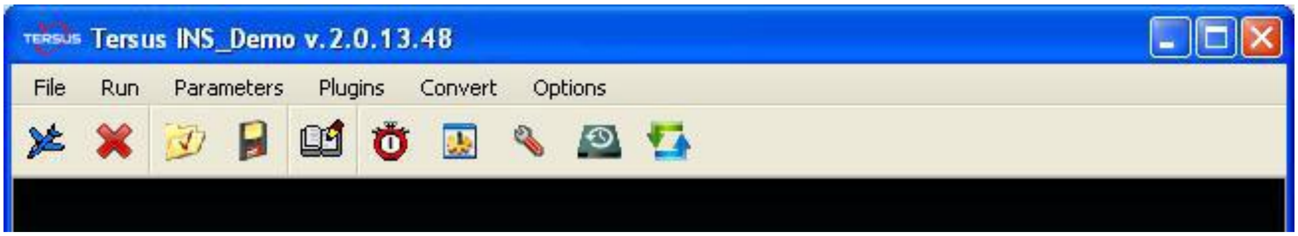


Fig.3.1

File Menu contains standard Windows file management commands (Fig.3.2).

Run Menu contains the INS control commands (Fig.3.3).

Parameters Menu contains operations with INS parameters (Fig.3.4).

Plugins Menu contains the INS Demo plugins (Fig.3.5).

Convert Menu contains conversion of binary data to the text format (Fig.3.6).

Options Menu contains the INS configuration commands (Fig.3.7).

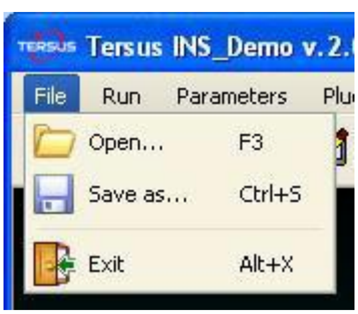
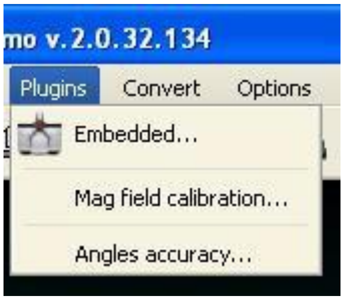


Fig.3.2

Fig.3.3

Fig.3.4



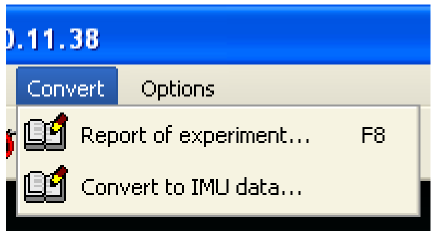


Fig.3.5 **Fig.3.6** **Fig.3.7**

Icons for the most often used commands are placed on toolbars.

Run:  - INS visualization, F4;

 - Stop INS;

Parameters:  - Restore parameters;

 - Save parameters;

Convert:  - Report of experiment, F8;

Options:  - Test options...;

 - Device options...;

 - Correction options…;

 - Swaying compensation options;

 - Magnetometers calibration options.

4. Options Menu

4.1. Test options

To set operation parameters of the INS, COM port, format of output data, select **«Test options…»** (Fig.3.7) from the **«Options»** menu (or click button). A **«Test Options»** dialog box (Fig.4.1) will be opened.

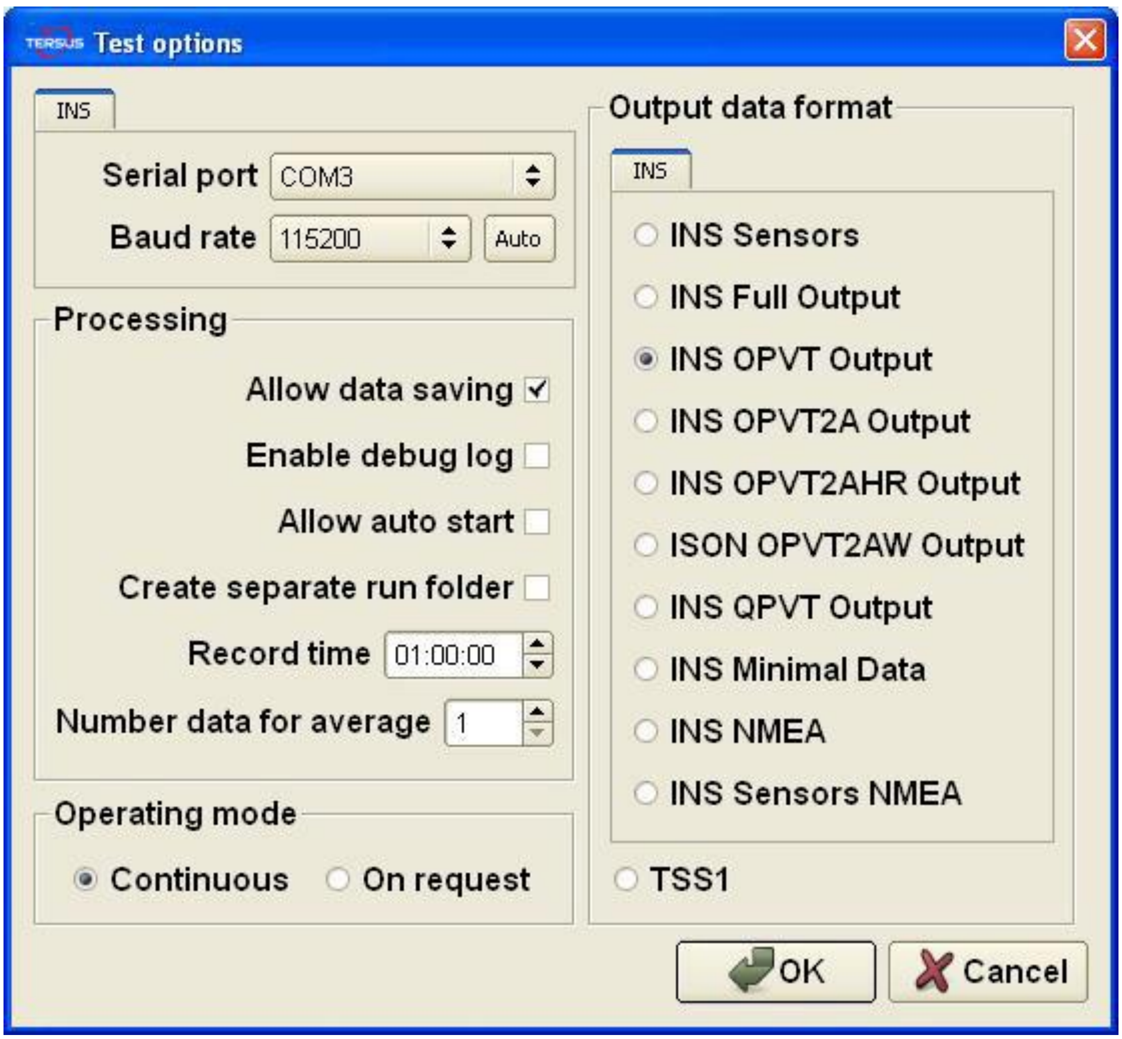


Fig.4.1

You can set the following parameters in the **«Test Options»** window:

- **Serial port** – number of the COM port to which INS is connected.

- **Baud rate** – is the set rate of computer COM port for connection of INS unit. See section 4.2.4 for details. The default value of the baud rate is 115200 bps.

- **Allow data saving** checkbox – allows to record the test data to file. If it is unchecked then no file will be created and no message «Data are writing in file» will be displayed.

- **Enable debug log** – allows to record the log file of test run. In case of the INS Demo crash it can be used to debug errors. Log file contains information about commands that were sent by the INS Demo and appeared errors. In case of errors this file should be sent to the Tersus with brief description of user actions.

- **Allow auto start** checkbox – allows operation with INS which was already started before run of the INS Demo software. See section 10.6 for details.

- **Create separate run folder** – allows automatic creation of separate data folder for each run. On default this option is disabled.

- **Record time** – sets data recording time in hours:minutes:seconds format. The parameter is active when data is being saved to file. Values of hours, minutes and seconds can be changed with the arrows or by entering the required value from a keyboard.

- **Number data for average** – the quantity of averaged data. This can be used for smoothing of viewed data. Note that averaging relates to the data output on the screen only and is not applied to the data written in a file. The minimal value for the parameter is 1 and changed with the arrows to ± 1 or by entering the required value from a keyboard. The default value is 1.

- **Operating Mode** – defines INS's output method, Continuous or stepped On Request. The default value is Continuous.

- **Output Data Format** – sets format of the INS output data. Select one of the formats:

  – «INS Sensors»,
  – «INS Full Output»,
  – «INS OPVT Output» (Orientation, Position, Velocity, Time),

- «INS OPVT2A» (Orientation, Position, Velocity, Time, Dual-antenna receiver data),
- «INS OPVT2AW» (Orientation, Position, Velocity, Time, Dual-antenna receiver data, GPS week),
- «INS OPVT2Ahr» (Orientation, Position, Velocity, Time, Dual-antenna receiver data, with high resolution),
- «INS QPVT Output» (Quaternion of orientation, Position, Velocity, Time),
- «INS Minimal Data»,
- «INS NMEA»,
- «INS Sensors NMEA»,

For more information on the output data format see Appendix C. The default value is «INS OPVT Output» data format.

4.2. Devices options

To set and control of INS operation parameters, select **«Devices options…»** from the **«Options»** menu (Fig.3.7), or click button (Fig.3.1). A **«Devices Options»** (Fig.4.2) dialog box will be opened. There are three tabs "IMU", "GNSS receiver", "Pressure sensor".

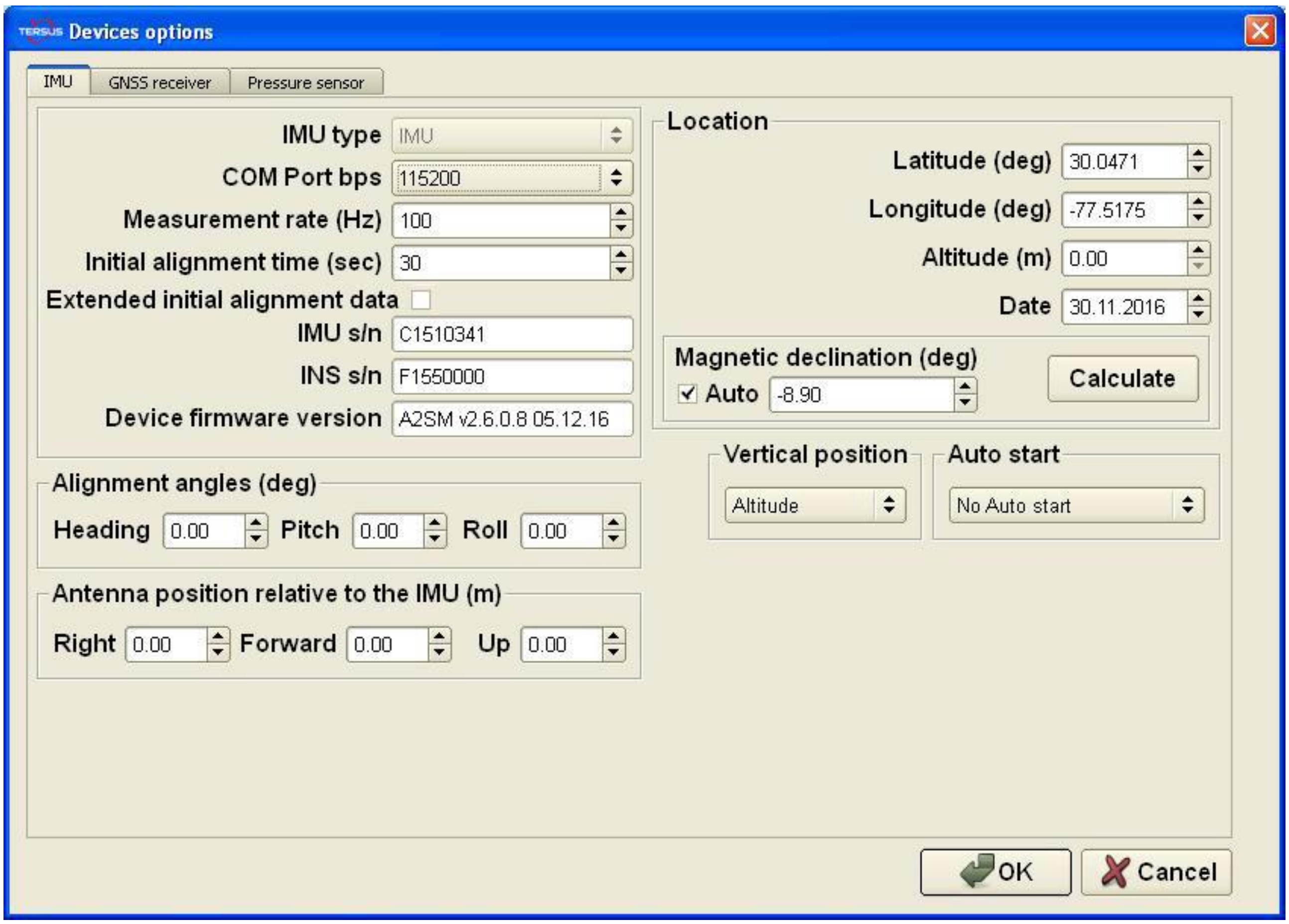


Fig.4.2

4.2.1. "IMU" tab of «Devices options…» window

There are options for the Inertial Measurement Unit (IMU). You can check or set the following parameters in the **"IMU"** tab of the «Devices Options» window Fig.4.2:

- **IMU type** shows type of IMU inside the INS unit. This parameter cannot be changed.

- **COM Port bps** – sets baud rate of the main INS COM port (see section "4.2.4. Change of the main COM port baud rate" for details). Default value is set to 115200 bps.

- **Measurement rate (Hz)** – sets data measurement rate in Hertz. Minimal value of the parameter is 1, maximal value is 200; it is changed with the arrows to ± 10 or by entering the required value from a keyboard. Default value is set to 100.

Important note: the maximum measurement rate is limited by chosen baud rate of the COM port which the INS unit is connected to, and also it depends on chosen output data format (see Fig.4.1) because of different number of transferred bytes. See section "4.2.5. Limitation of the INS maximum measurement rate" for details.

- **Initial alignment time (sec)** – sets the initial alignment time in seconds. The INS output data will be displayed in respective windows only after the time set in this parameter is over. During initial alignment the INS must be absolutely unmovable relative to the Earth. Minimum value of the parameter is 1 and it can be changed to ± 1 with arrows or by entering the necessary value from a keyboard. Default value is set to 30 seconds.

- **Extended Initial alignment data** checkbox specifies format of block of the initial alignment. If checkbox is set INS outputs extended initial alignment block after initial alignment is complete. This parameter can be changed after agreement with developer.

- **IMU s/n** – specifies the serial number of the IMU inside the INS unit. This parameter cannot be changed.

- **INS s/n** – specifies the serial number of the INS in use. This parameter cannot be changed.

- **Device firmware version** – the firmware version of the INS in use. It consists of symbols of the firmware type, firmware version and date of this version issue separated by blanks. This parameter cannot be changed.

- **Latitude (deg)** – initial latitude of the INS operating location.

- **Longitude (deg)** – initial longitude of the INS operational location.

- **Altitude (m)** – initial altitude above sea level of the INS operational location.

- **Date** – day, month and year when the INS is used.

Notes:
1. It is highly recommended to set current latitude, longitude and altitude for setting the initial position in case of the GNSS data may be not available at the INS start.
2. It is necessary to set current latitude, longitude, altitude and date before hard/soft iron calibration of the INS magnetometers (see section 8.2).

- **Magnetic declination (deg)** – sets magnetic declination at the place where the INS operates. The parameter value is changed by entering the required value from a keyboard or by automatic calculation by click on «Calculate» button, using Latitude, Longitude, Altitude and Date values. Default value of the magnetic declination is set to 0.

Notes:
1. It is important to set the magnetic declination correctly for the INS operation because it requires to know the true heading which is calculated by addition of the magnetic declination to measured magnetic heading.
2. Magnetic declination is calculated using the World Magnetic Model produced by the U.S. National Geophysical Data Center and the British Geological Survey, see http://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml

Since INS firmware version 2.2.0.2 the magnetic declination can be calculated in the INS continuously using calculated current position and time. Check **«Auto»** check-box (see Fig.4.2) to activate this option.

- **Alignment angles (deg)** – angles between the INS axes and the carrier object are set after INS mounting, see "Appendix E. Variants of the Tersus™ INS mounting relative to object axes". Default values are set to 0 degrees.

- **Vertical position** – specifies variant of vertical position calculation – altitude or heave. User can change this variant in INS-D unit only because other INS models INS-B, INS-P do not calculate heave but only altitude. See section 10.3 for details.

- **Auto start** – enables or disables automatic start of the INS and data output after power on without any command from the host computer. See section 10.6 for details.

- **Antenna position relative to the IMU (m)** – it sets the GNSS antenna mounting lever relative to the INS unit, in meters. After the INS unit and GNSS antenna installation on the carrier object it is necessary to measure the center of antenna position relative to the center of INS unit, in the object axes – on the right, forward and up. Then it is necessary to enter these coordinates in appropriate fields in the IMU tab (Fig.4.2) and click “OK” to apply these coordinates and store them in the INS nonvolatile memory.

Notes:

1. If after the INS mounting its axes X, Y, Z are parallel to the carrier object lateral, longitudinal and vertical axes, then the antenna coordinates should be measured in the directions of the INS X, Y and Z axes.
2. On the other hand, the INS unit can be mounted on the object in any known position (up to upside-down, upright etc., see Appendix E. Variants of the Tersus INS mounting relative to the object axes). In that case please set the GNSS antenna coordinates measured just in the object axes (on the right, forward and up directions), but not in the INS axes.

Before operation with the **«Options»** menu, it is desirable to select «**Stop INS»** in the «Run» menu or press **F7** key (Fig.3.3).

Note: **«Device option…»** item is available only if:

- INS is powered,
- and INS is connected to computer,
- and COM port number and its baud rate are chosen properly,
- and INS initialization time (about 25 sec after power on) is completed so LED indicator lights red.

In the other case the error window with message «**Cannot read parameters!**» appears over above window (see Fig.4.3). Click «OK», then close **«Device Options»** window and choose the correct COM port number (see section 4.1. Test options).

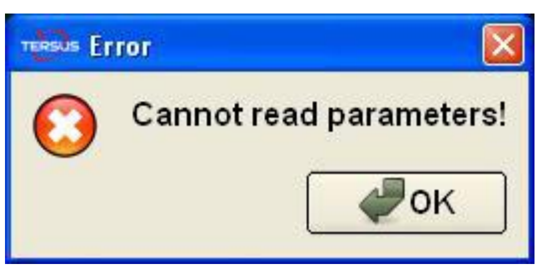


Fig.4.3

4.2.2. “GNSS receiver” tab of «Devices options…» window

There are options for the onboard GNSS receiver (see Fig.4.4). The first two rows show the next information: GNSS receiver name, model, serial number, firmware version and maximum data rate.

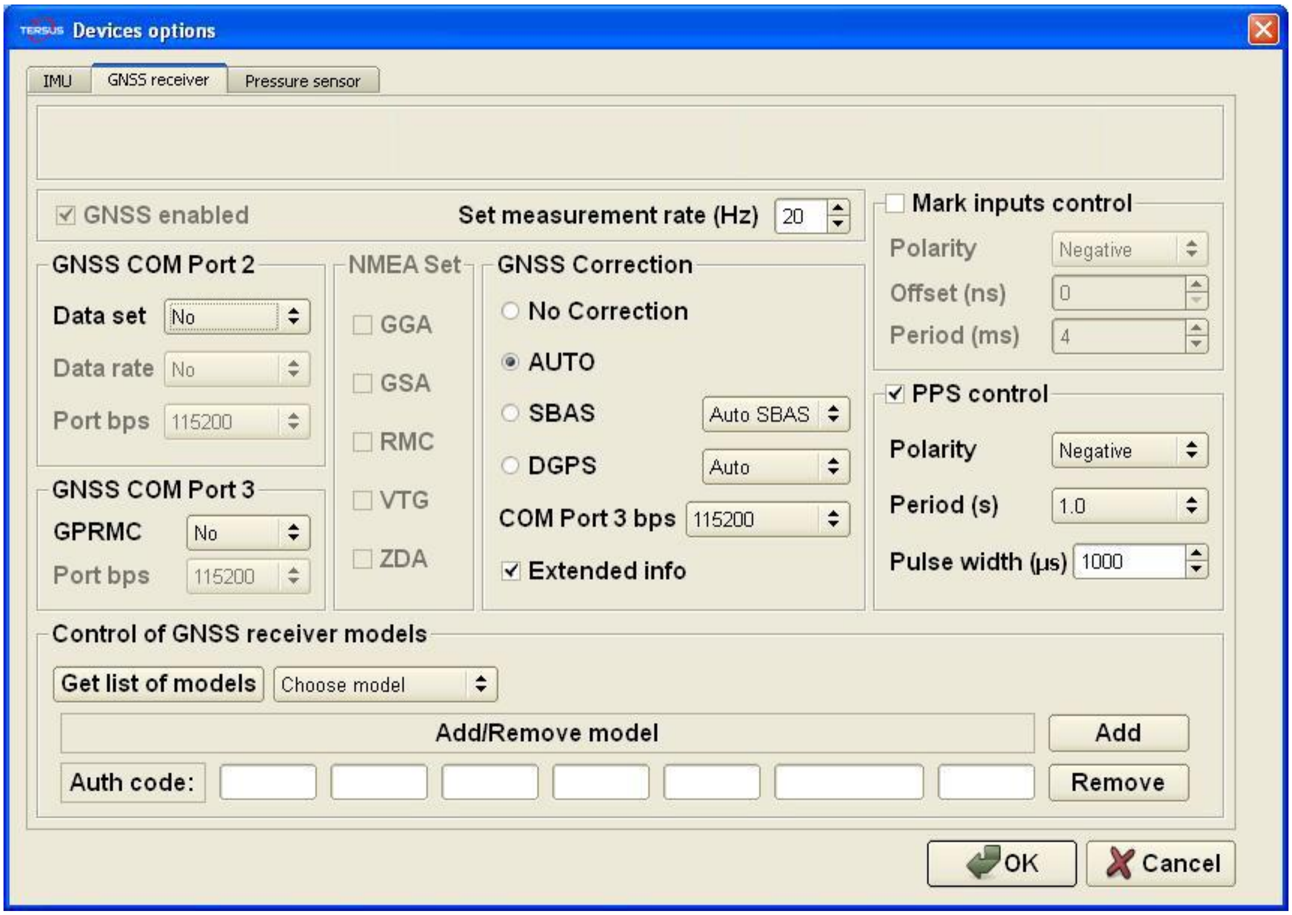


Fig.4.4

There are the next very important settings for the GNSS receiver:

- **GNSS enabled** – enables using of the GNSS data. This parameter cannot be changed.
- **Set measurement rate (Hz)** – rate of the GNSS data update. It is highly recommended to set this rate to the maximum value supported by the GNSS receiver.

- **GNSS COM Port 2 fields** configure COM2 port setting for output GNSS raw data or NMEA data set:

– **Data set** – allows choosing desirable set of GNSS receiver data for output through COM2 port. User can choose GNSS raw data or NMEA set output in the drop-down list (see Fig. 4.5). When "No" is chosen then no GNSS data are output. Default setting is "No".

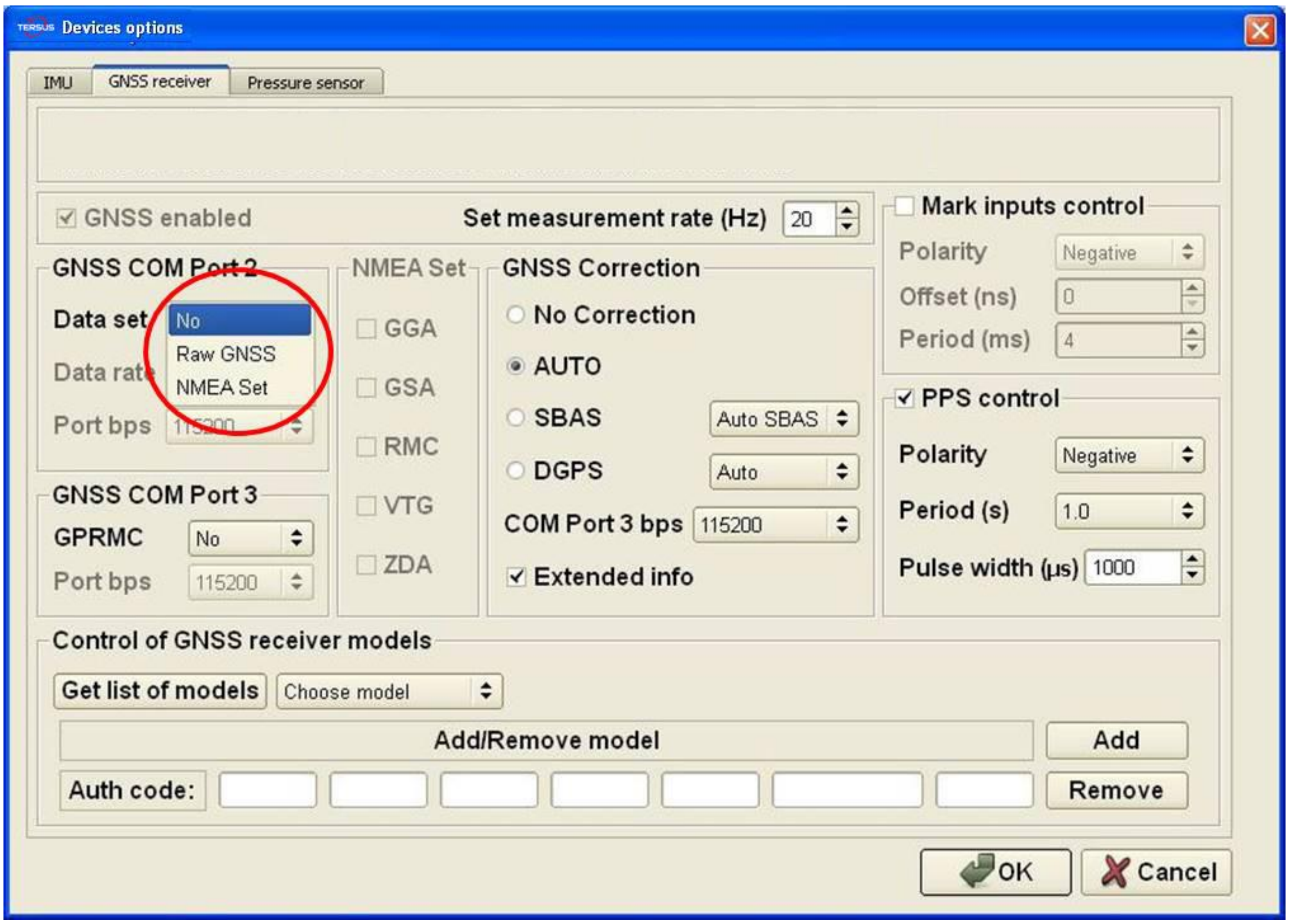


Fig.4.5

– **NMEA Set** – allows to set desired NMEA messages for output through COM2 port when **NMEA Set** is chosen in **Data Set** (see Fig. 4.6). By default INS outputs GPGGA, GPVTG and GPZDA if no checkboxes in NMEA Set are chosen.

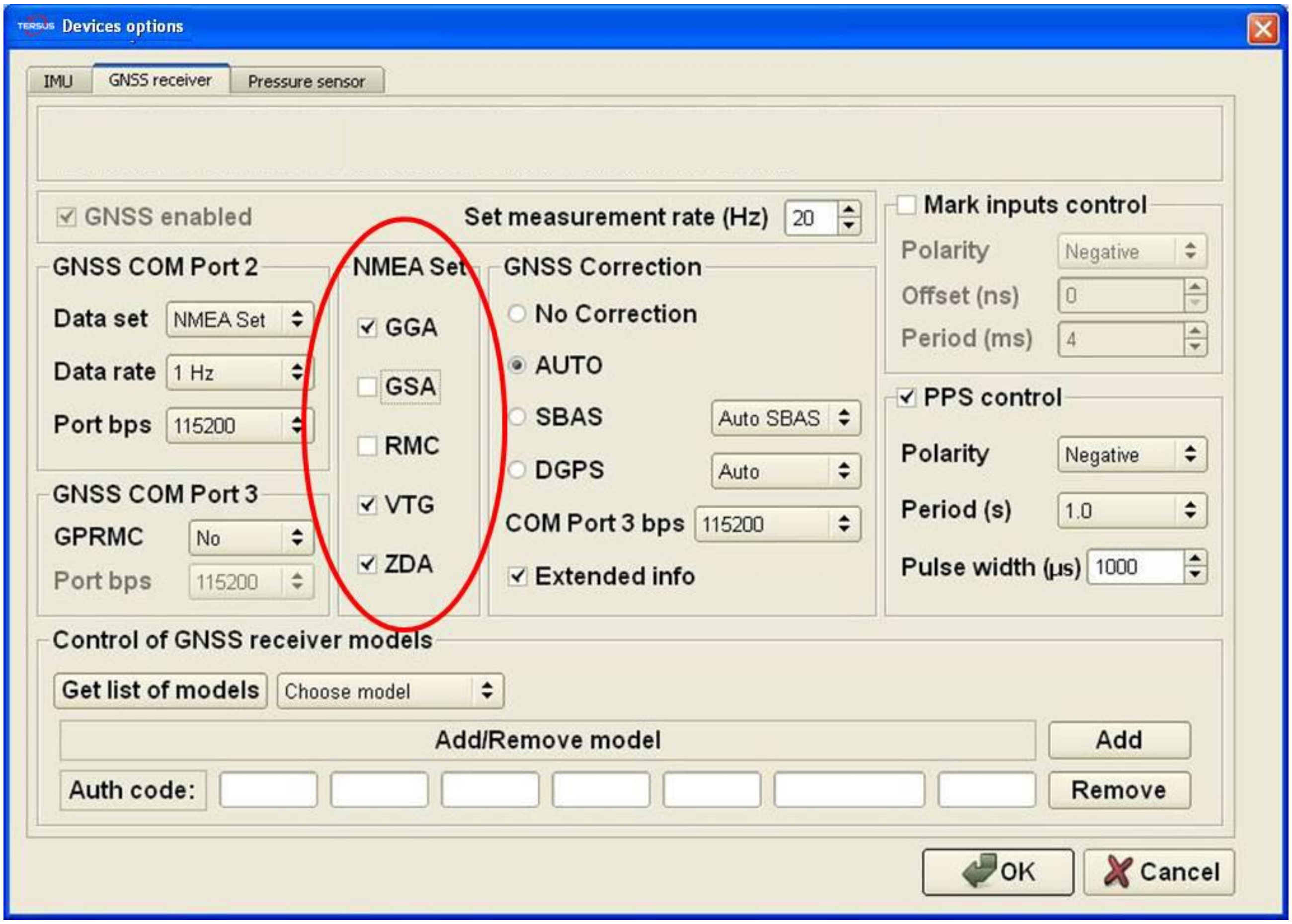


Fig.4.6

– **Data rate** – sets frequency of COM port 2 data output. When **Data set** is chosen other than “No” user can choose frequency of data output in the drop-down list (see Fig.4.7). See section “12.1. Recording of raw GNSS data” for more details.

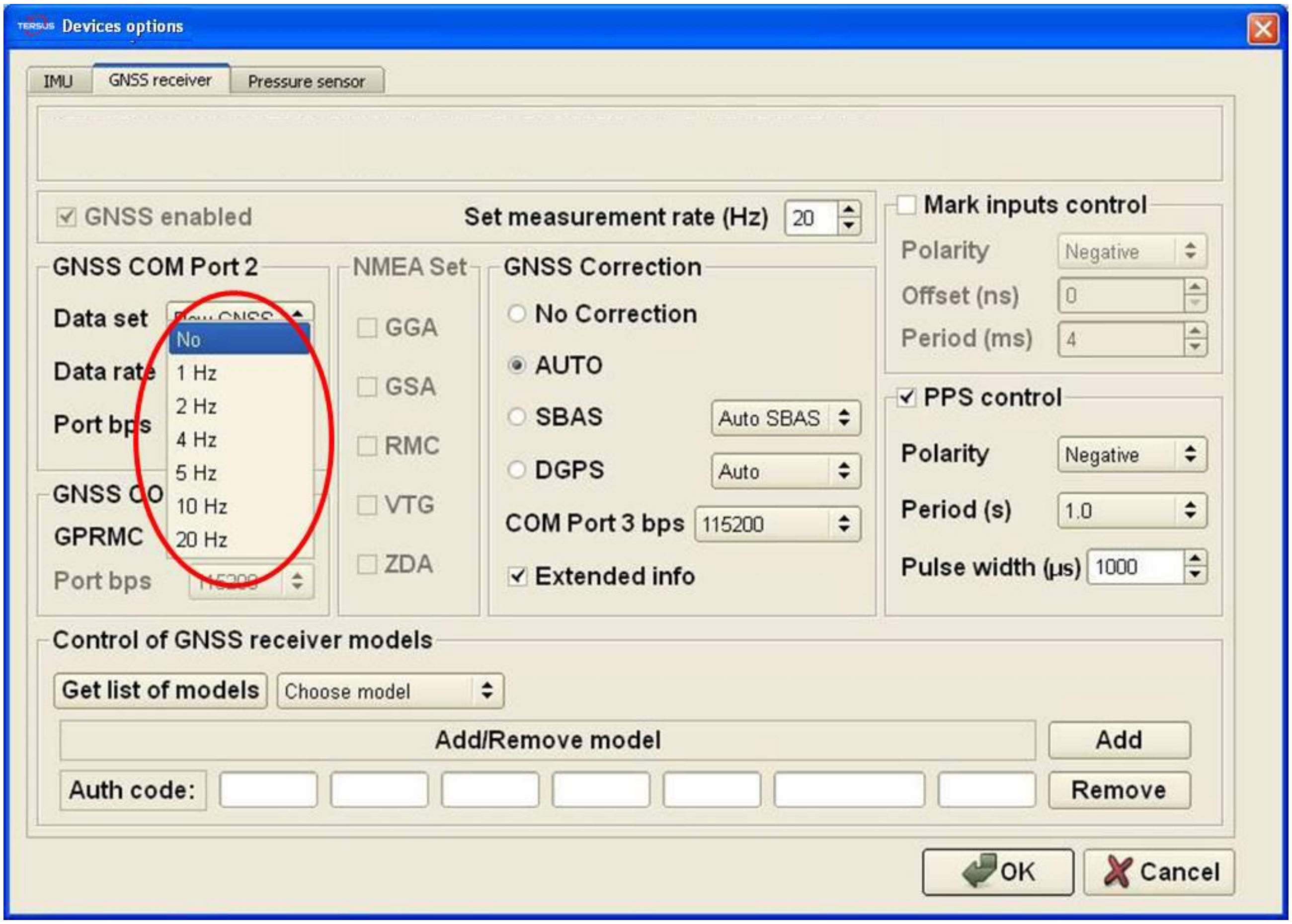


Fig.4.7

– **Port bps** – allows to set baud rate of the COM2 port for output raw GNSS data. User can choose needed COM2 port baud rate in the drop-down list (see Fig.4.8). Default value is “115200”. It is necessary to set the same COM Port baud rate in the **GNSS_Reader** program for raw GPS data recording (see section “12.1.Recording of raw GNSS data” for more details).

Note: The standard COM-port baud rate 115200 bps can provide GPS L1 raw data frequency up to 5 Hz. Raw data with higher frequency, using GPS + GLONASS, L1/L2 frequencies may contain gaps, so it is necessary to use USB port on host computer and to increase COM Port baud rate. Set 921600 bps baud rate to provide maximum 20 Hz GNSS raw data output. Please contact the Tersus about details.

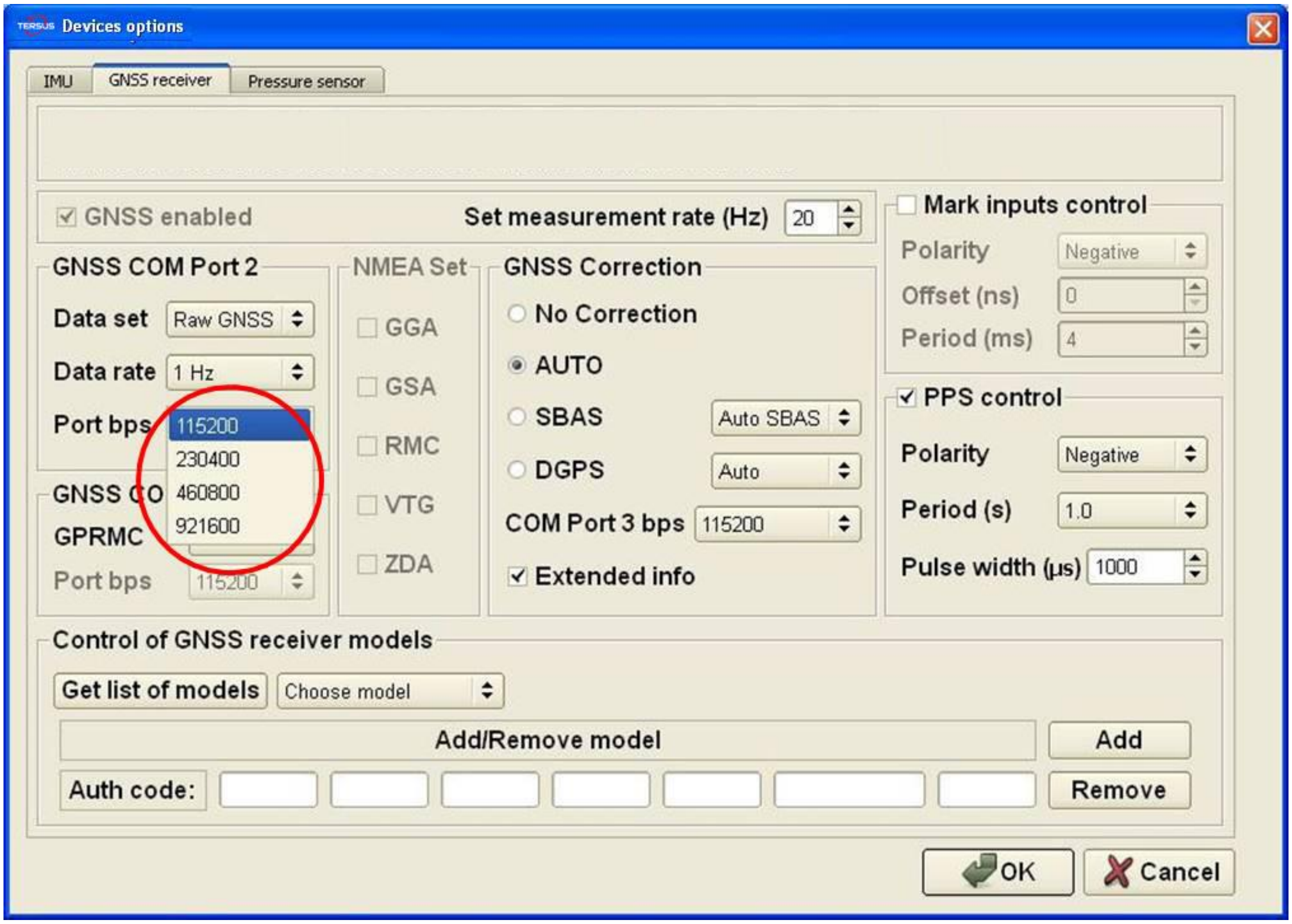


Fig.4.8

- **GNSS COM Port 3** fields configure COM3 port setting for output $GPRMC messages (they are used only for INS data synchronization with LiDAR):

  – **GPRMC** – sets frequency of $GPRMC messages issued from onboard GNSS receiver. User can choose this frequency in the drop-down list: 1, 2, 4, 5, 10, 20 Hz. When “No” is chosen then $GPRMC messages are not output. Default setting is “No”.

  – **Port bps** – allows to set baud rate of the COM3 port for output of $GPRMC messages. User can choose needed COM3 port baud rate in the drop-down list: 9600, 19200, 38400, 57600, 115200 bps. Default value is 115200 bps.

- **GNSS Correction** fields adjust correction of GNSS receiver data to improve position accuracy. Type of GNSS correction is chosen by radio button (see Fig.4.5). Default value is “AUTO”. See section “10.2.1. GNSS correction” for details.

- **Mark inputs control** – allows to adjust processing of mark input signal that can be used to trigger specific GNSS raw receiver data. See section “13.2. Processing of mark input signal” for details.

- **PPS control** fields adjust the pulse-per-second (PPS) signal generated by GNSS receiver for data synchronization with other devices. See section “13.1. Control of PPS output signal” for details.

- **Control of GNSS receiver models** field (see Fig.4.4) – this field is reserved for future release.

- **Extended info** checkbox – allows extended information about GNSS data. Uncheck this checkbox to provide compatibility of new INS Demo Program with INS units that have older firmware than 2.2.1.0. Default setting is enabled extended info.

***Important note*: after applying of any changes in the “GNSS receiver” tab by clicking “OK” button, it is necessary to switch off, switch on INS unit to restart onboard GNSS receiver.**

4.2.3. "Pressure sensor" tab of «Devices options…» window

There are settings for the pressure sensor that is used for the INS altitude correction (see Fig.4.9).

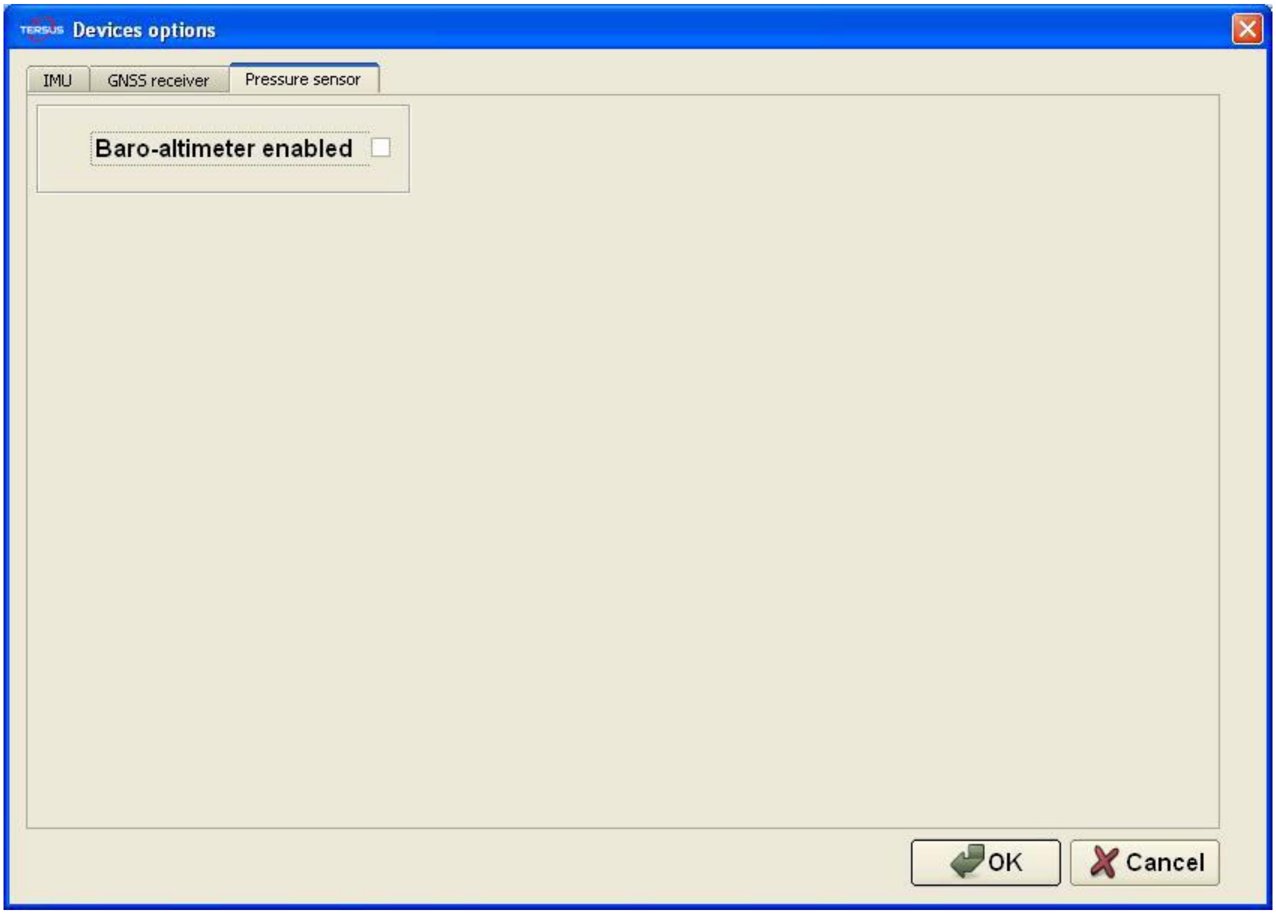


Fig.4.9

You can change only one parameter in the **"Pressure sensor"** tab of «Devices Options» window:

- "Baro-altimeter enabled" checkbox – allows to enable or disable using of the pressure sensor for altitude calculation. On default it is disabled.

See section "10.3. Features of Altitude and Heave calculation in the INS" for more detailed explanation of operations with the pressure sensor.

4.2.4. Change of the main COM port baud rate

The main COM port is used for the INS connection to the host computer for receiving commands and output of INS data. The default baud rate for the main COM port is set to 115200 bps (maximum for the standard COM-port). If the host computer requires other baud rate for the INS connection, then user can choose one from the next list: 4800, 9600, 14400, 19200, 38400, 57600, 115200, 230400, 460800 and 921600bps. The same baud rate must be set in the «**Test Options**» of the INS Demo Program.

Notes:

1. Baud rate change is implemented in the INS firmware version since 2.2.0.0 and it is supported by INS Demo Program since version 2.0.19.78 from 03/18/2016.
2. To allow baud rate change the INS unit must be connected to computer and powered.
3. Standard COM-port of a host computer (PC) does not support baud rate greater than 115200 bps. Therefore some Serial-to-USB adapter should be used for INS connection to the host computer.
4. Baud rate must be set the same both for INS unit and in the INS Demo Program to allow this software to control INS unit.

At the first, set correct COM port baud rate in the «**Test Options**» (see Fig.4.1). It must be the same as it set in the INS unit. If COM port baud rate in the INS unit is unknown then click «**Auto**» button. After several seconds window with caption "Serial port baud rate XXXXXX was successfully determined" will appear (see Fig.4.10) and determined baud rate will appear in the «**Test Options**» window.

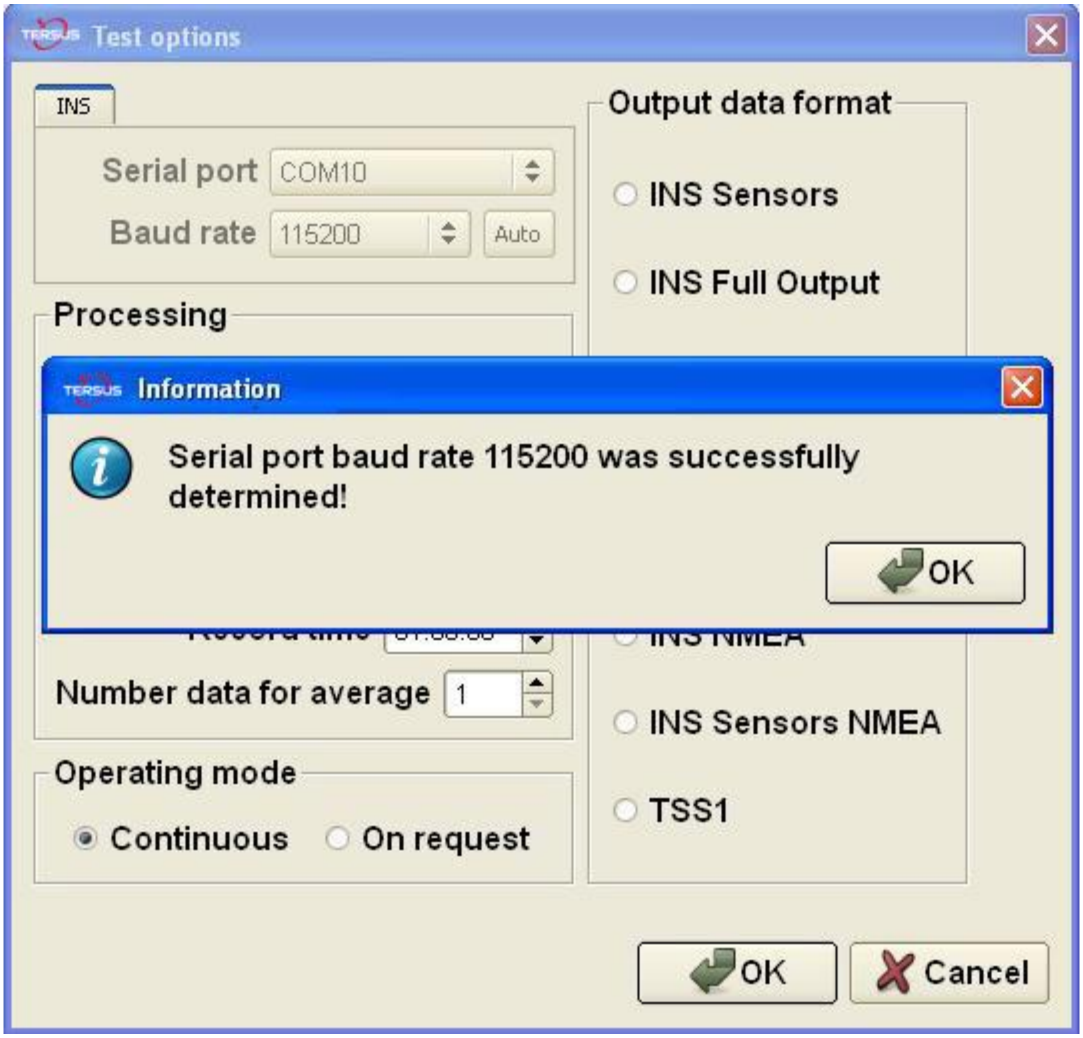


Fig.4.10

To change COM port baud rate in the INS unit go to the «**Devices Options**», "IMU" tab (see Fig.4.2) and choose necessary baud rate from the list as Fig.4.11 shows.

After the baud rate choice click «**OK**» button to load changed parameters to the INS nonvolatile memory. Then the information windows shown on the Fig.4.12 and Fig.4.13 appear. Click «**OK**» button to close these windows. Note COM port baud rate in the «**Test Options**» will change to chosen value, too, to keep communication between the INS Demo software and INS unit.

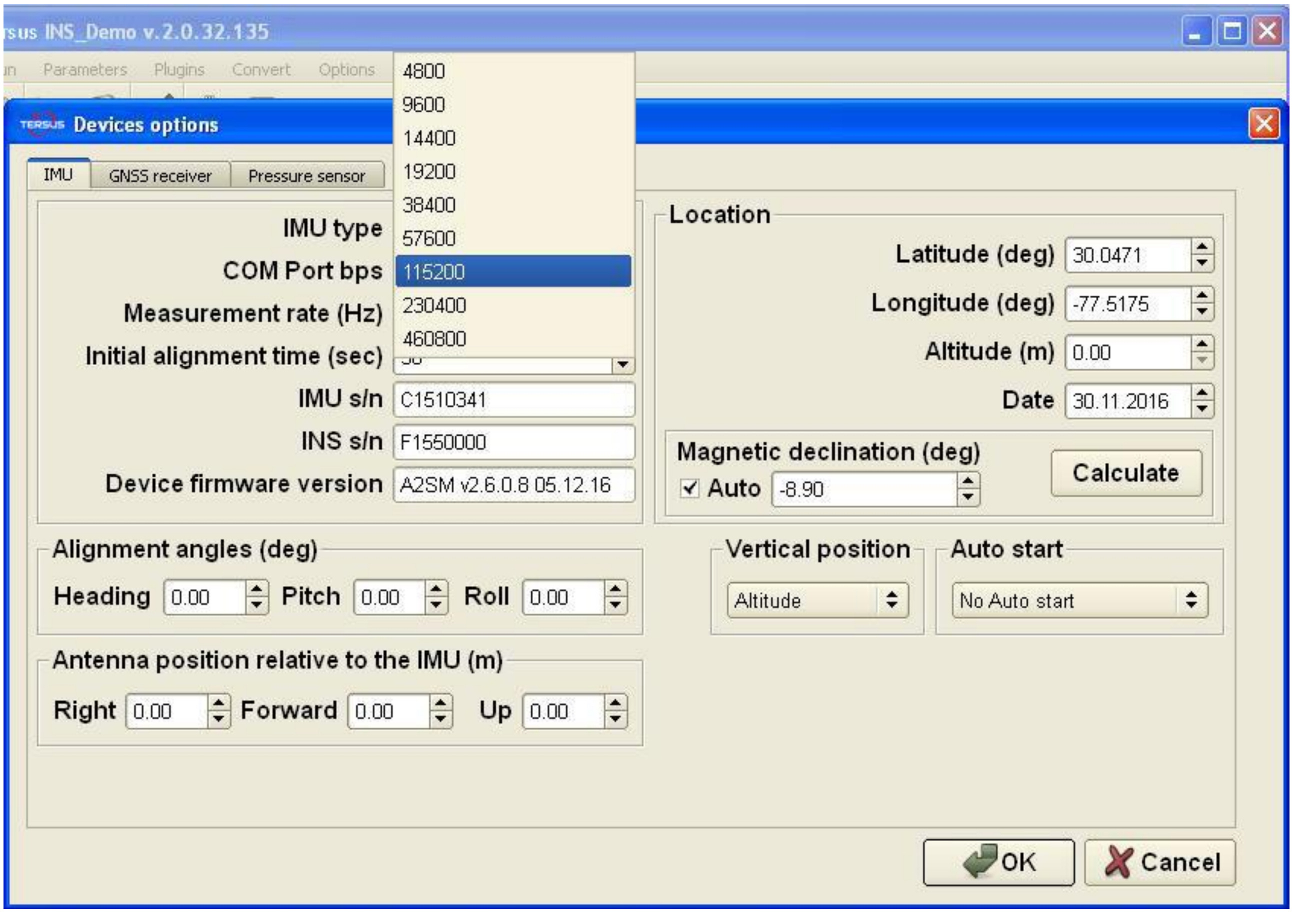


Fig.4.11

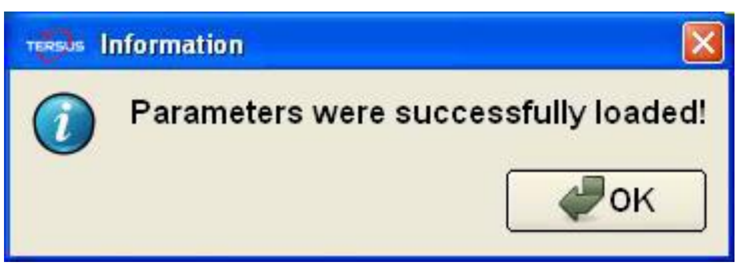


Fig.4.12

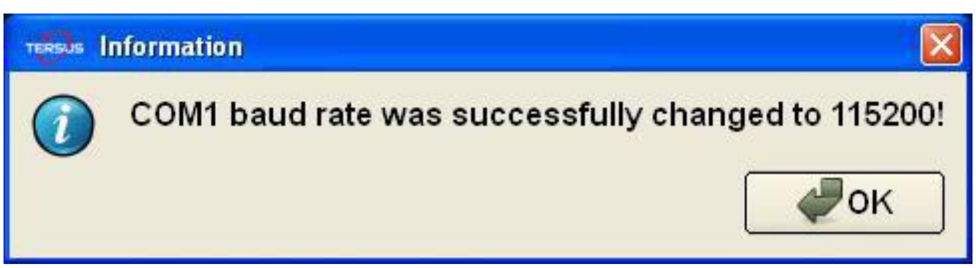


Fig.4.13

4.2.5. Limitation of the INS maximum measurement rate

When setting of the measurement rate for the INS unit in the «Devices Options», “IMU” tab (see Fig.4.2) it is essential to ensure the chosen baud rate is capable of handling the data throughput with desirable data rate. The maximum measurement rate (Hz) can be calculated using the baud rate and data package length:

$$max\_mean\_rate = \frac{COM\_baud\_rate}{bits\_per\_byte * package\_length}, \quad (4.1)$$

where COM_baud_rate is COM port baud rate (bits/s); bits_per_byte = 11 bits per one transferred byte of data; package_length for binary data = payload length plus 8 bytes of overhead. See Appendix C, Tables C.2, C.5, C.6, C.7, C.8, C.14 for payload length of binary output data formats. The package_length of the text output data formats correspond to their structure shown in Appendix C.

Table 4.1 contains data package length for each output data format and also maximum measurement rate calculated by formula (4.1) with some spare. Note the maximum measurement rate of INS data is limited by 200 Hz.

Table 4.1. INS maximum measurement rate for different output data formats

Output data format	Data package length, bytes	COM-port baud rate, bps					
		9600	19200	38400	**115200**	230400	460800
		Maximum measurement rate, Hz					
INS Sensors Data	84+8	9	10	30	**100**	200	200
INS Full Output Data	94+8	8	10	30	**100**	200	200
INS OPVT	92+8	8	10	30	**100**	200	200
INS QPVT	94+8	8	10	30	**100**	200	200
INS OPVT2A	101+8	8	10	30	**90**	190	200
INS OPVT2AW	103+8	7	10	30	**90**	180	200
INS OPVT2Ahr	129+8	6	10	20	**70**	150	200
INS Minimal Data	50	10	30	60	**200**	200	200
INS NMEA	93	9	10	30	**100**	200	200
INS Sensors NMEA	141	6	10	20	**80**	140	200

INS Demo Program controls correctness of the measurement rate setting. If user sets measurement rate in the «**Devices Options**» (see Fig.4.2) which exceeds limits shown in the Table 4.1, then warning window Fig.4.14 appears.

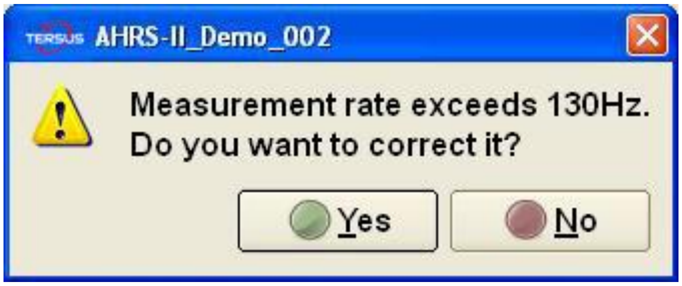


Fig.4.14

Click “Yes” button to correct entered measurement rate or “No” to ignore this warning. The last case makes sense if user wants to choose another output data format in the «**Test Options**» with less length of data package. But in any case INS controls acceptable measurement rate onboard at start to not allow excess of maximum value.

If user choose output data format in the «**Test Options**» window that does not match to set measurement rate then warning window Fig.4.15 appears.

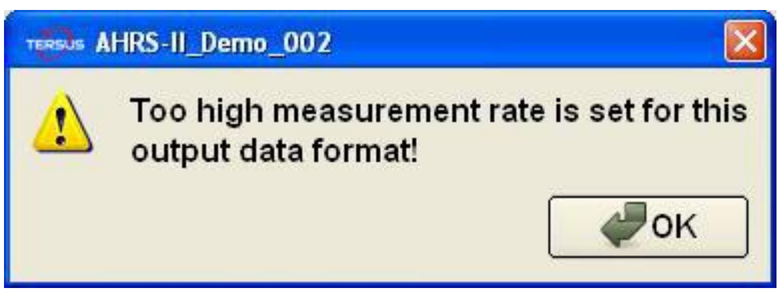


Fig.4.15

4.3. Correction options

There are parameters for adjustment of the INS algorithm in the part allowed for users. Select **«Correction options…»** from the **«Options»** menu (Fig.3.7), or click  button (Fig.3.1). A **«Correction Options»** dialog window will be opened (see Fig.4.16). There are two tabs: “Settings” and “Heave calculation”.

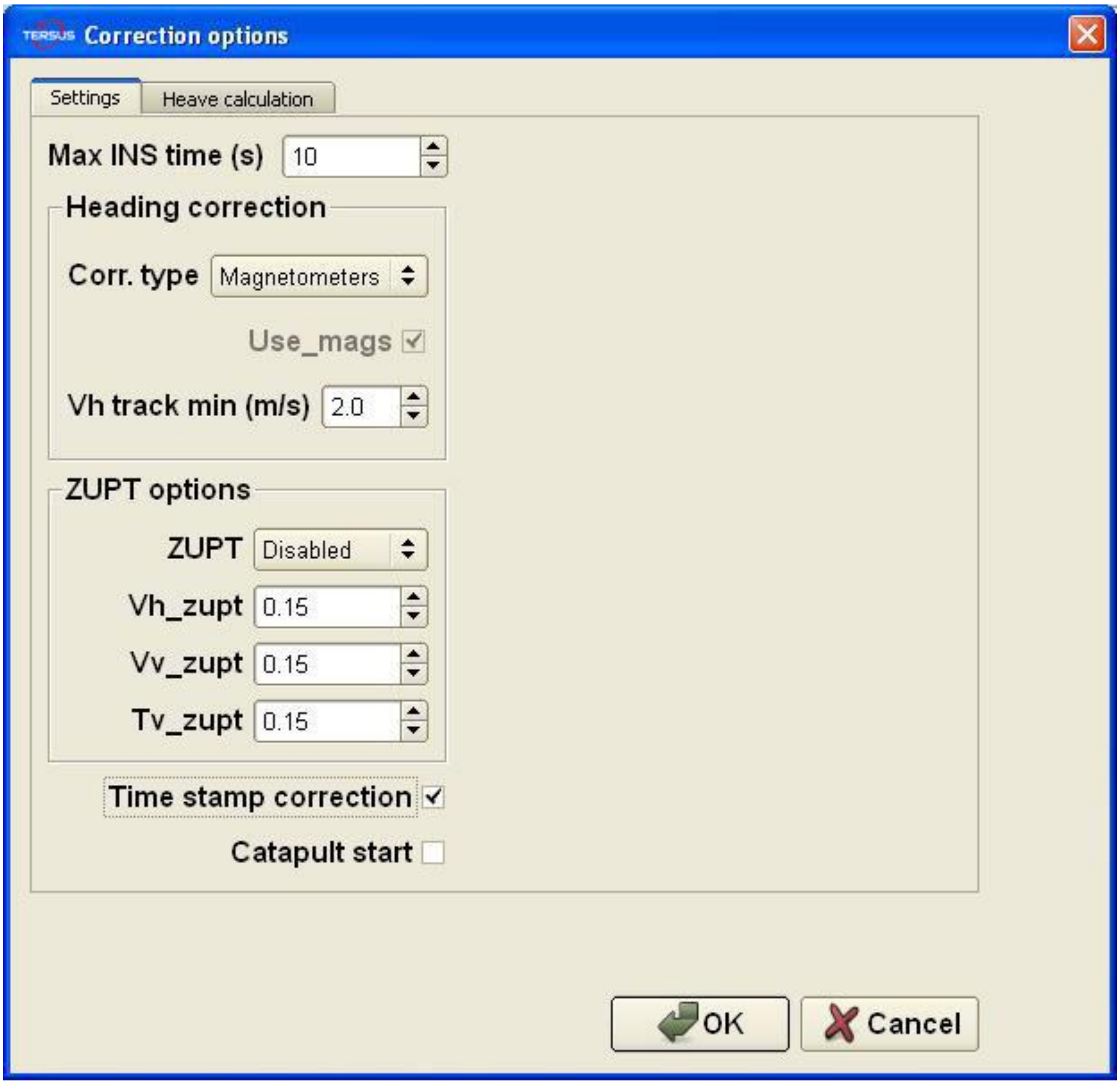


Fig.4.16

4.3.1. "Settings" tab of «Correction options…» window

There are the next settings for adjustment of the INS algorithm (see Fig.4.14):

- **Max INS time** – is the maximum time (in seconds) of autonomous INS operation at absence of GNSS data (GNSS outage). Because INS orientation and position data are calculated using integration of gyros and accelerometers data, then at absence of GNSS data the INS errors in orientation and position calculation are accumulated and increase with time significantly. At long time of GNSS outage, after "Max INS time" is reached, INS pauses calculation of position and velocity data but continues calculation of orientation (heading, pitch, roll) using algorithm of Attitude and Heading Reference System (AHRS).

Minimum value of the "Max INS time" is 1 sec and it can be changed to ± 1 sec with arrows or by entering the necessary value from a keyboard. Default value is set to 20 seconds.

- **Corr.type** – specifies data used for INS heading correction. There are four variants in drop-down list (see Fig.4.17):

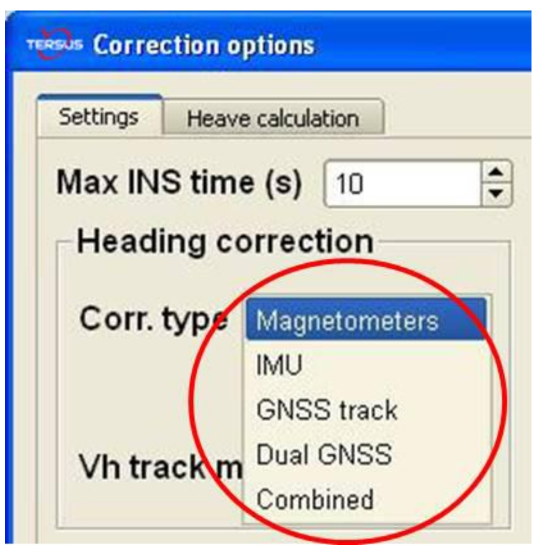


Fig.4.17

- Magnetometers – using magnetic heading as reference;
- AHRS – using gyro-magnetic heading calculated using AHRS algorithm;

- GNSS track – using GNSS track angle as heading reference for INS correction. This improves INS heading accuracy at bad magnetic environment for some applications like car, fixed wing aircraft and other vehicles that don't move sideways;

  INS starts use the GNSS track angle for heading correction after carrier object moves with horizontal speed at least twice more than “Vh track min” threshold. At the next stops of object the INS cancels correction from the GNSS track angle if horizontal speed is less than “Vh track min” threshold (object stop is detected). At this heading is calculated with correction from magnetometers (if “Use_mags” is switched on) or using only gyros data (if “Use_mags” is off).

  If “Use_mags” is switched off then initial heading is zero

- Dual GNSS – default **INS-D** correction using heading calculated by dual-antenna GNSS receiver inside INS-D unit. This is the most accurate heading reference for INS correction when GNSS data are available and narrow-integer RTK solution is achieved for GNSS heading calculation.

- Combined – this correction type uses switching between GNSS track angle and magnetometers for heading reference, with changes in INS algorithm. Combined correction is designed for special applications like UAV. Please contact Tersus about possibility of using this variant of INS correction in your application.

- **Use_mags** – enables or disables using of magnetometers for INS heading correction. If “Corr.type” is set to “Magnetometers” then “Use_mags” switch is ON and cannot be changed.

If “Corr.type” is set to “GNSS track” or “Dual GNSS” then at GNSS data lost the magnetometers can be used (at “Use_mags” enabled) to continue heading calculation. At “Use_mags” disabled the INS heading is calculated by integration of gyros when GNSS data are lost.

Note:

INS does not require calibration of its magnetometers on hard/soft iron if “Use_mags” switch is disabled.

- **Vh track min (m/s)** – is threshold for horizontal speed of carrier object to allow using of the GNSS track angle for INS correction (if it is chosen in "Corr.type" field). Default value is 1.2 m/s.

- **ZUPT options** – enables or disables "Zero Velocity Update" (ZUPT) option. When enabled, ZUPT allows the INS to reduce its accumulated errors when stop of the carrier object is detected. The stop is detected if filtered horizontal and vertical speed are less than Vh_zupt and Vv_zupt thresholds, and no rotation of the carrier object is detected.

When ZUPT is applied then INS orientation and position are "frozen".

Note for certain applications where it is known the system will never be stationary, such as marine or airborne applications, ZUPT option should be disabled. Default setting is ZUPT disabled.

- **Vh_zupt** – is minimum horizontal speed of carrier object in m/s below which stop of the carrier object is detected. Default value is 0.15 m/s;

- **Vv_zupt** – is minimum vertical speed of carrier object in m/s below which stop of the carrier object is detected. Default value is 0.15 m/s;

- **Tv_zupt** – is time constant (in seconds) of low-pass filter for horizontal and vertical speed used for detection of the carrier object stop. Default value is 0.10 s.

- **Time stamp correction** – is switch to use GNSS time for correction of INS time stamps. Each INS output data package contains time stamp – milliseconds from the beginning of the GPS reference week. Taking into account that INS time is not so accurate as GNSS time, INS time stamps are slowly drifted with time. For applications where INS synchronization with other devices is critical, enable INS time stamp correction from GNSS receiver time. Though at enabled "Time stamp correction" there will be periodical (approximately once per 5 – 8 minutes) jumps of INS timestamps on one step time. For example at 100 Hz output data there is possible 0.01 sec jumps in INS time stamps.

Disable "Time stamp correction" to provide continuous INS time stamps without jumps. Though INS time slowly drifts in comparison to very accurate GNSS time.

On default the "Time stamp correction" is enabled.

- **Catapult start** – is the special algorithm of the INS for using on the UAV with catapult launching.

Note: Catapult start is at the testing stage. Please contact Tersus about the possibility of using the Catapult start.

4.3.2. "Heave calculation" tab of «Correction options…» window

"Heave calculation" tab (see Fig.4.18) contains parameters for algorithm of heave calculation. See section "10.3.1. Adjustment of the algorithm of heave calculation in INS-D" for detailed explanation of parameters in the "Heave calculation" tab.

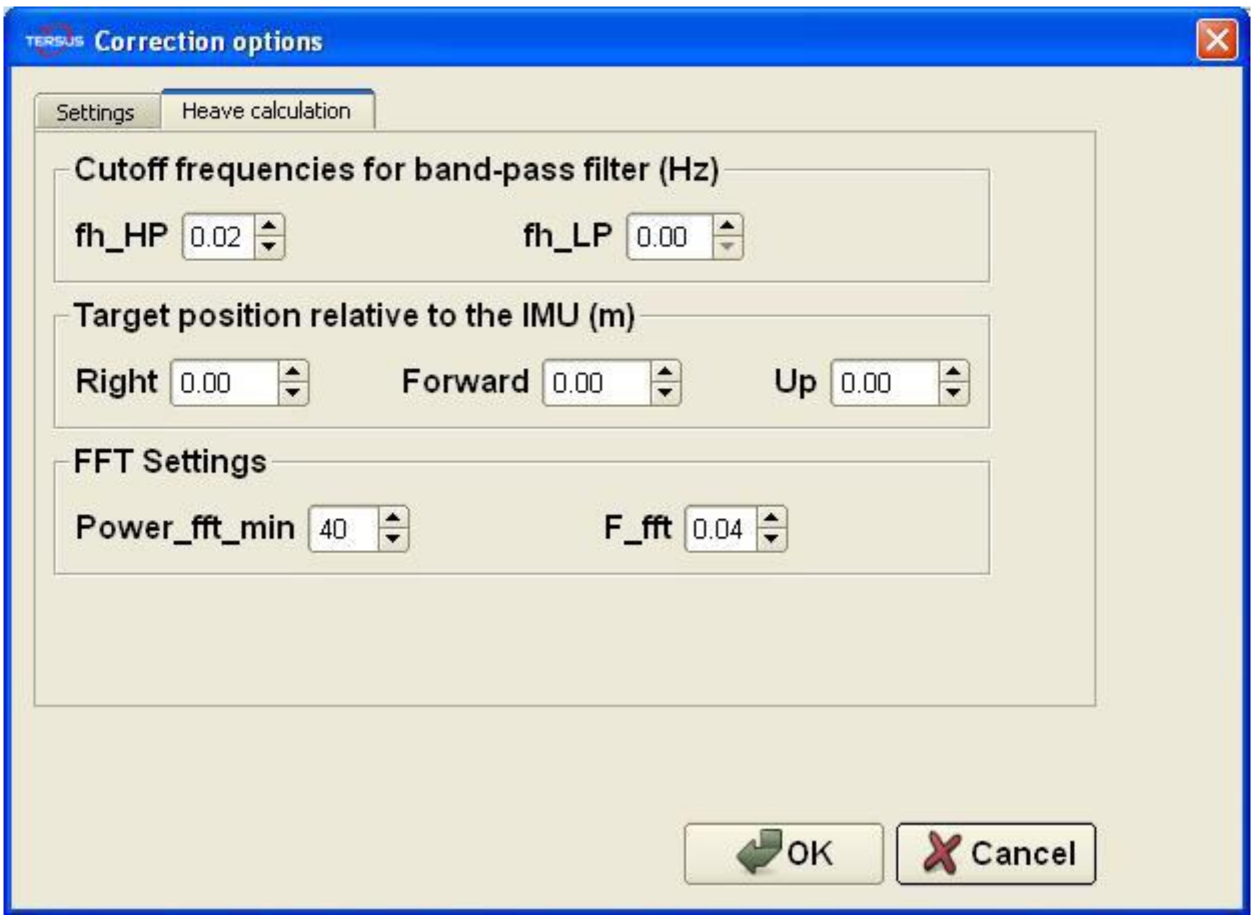


Fig.4.18

4.4. Swaying compensation

It is possible to increase the INS orientation accuracy at object swaying if to compensate linear acceleration at place of the INS mounting. For this purpose select «**Swaying compensation options…**» from the **«Options»** menu (Fig.3.7) or click button (Fig.3.1). A «**Swaying compensation options**» dialog box (Fig.4.19) will be opened that allow you to set the lever of the INS mounting relative to the center of the object Swaying (usually this is object center of gravity).

Fig.4.19

The lever must be set in the carrier object axes – on the right, forward and up. If after the INS mounting its axes X, Y, Z are parallel to the carrier object lateral, longitudinal and vertical axes, then the INS position should be measured in the directions of the INS X, Y and Z axes. If the INS unit is mounted on the object in othe known position (up to upside-down, upright etc., see Appendix E. Variants of the Tersus INS mounting relative to the object axes), then set the INS position just in the object axes (on the right, forward and up directions), but nit in the INS axes.

4.5. Magnetometers calibration options

The Tersus INS software allows compensation of influence of the carrier object hard and soft iron on the heading angle calculation accuracy. For this purpose, calibration of the INS magnetometers is provided. It is necessary to set group of parameters "Magnetomers field calibration". For this purpose select «**Magnetometers calibration options…**» from the **«Options»** menu (Fig.3.7) or click button (Fig.3.1). A «**Magnetomers calibration options**» dialog box (Fig.4.20) will be opened that allow you to set the lever of the INS mounting relative to the center of the object Swaying (usually this is object center of gravity).

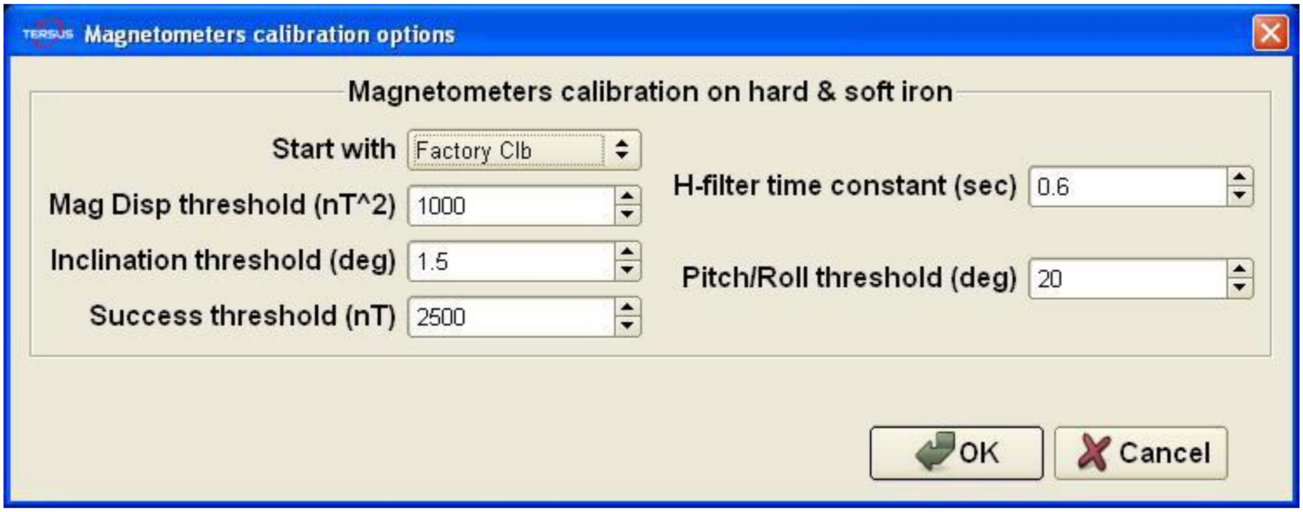


Fig.4.20

- Start with – specifies with what set of calibration parameters the INS starts. There are four sets: "Last INS Clb", "Factory Clb", "2D-2T, 3D, 2D Clb". Usually "Start with" parameter is set automatically after last calibration performed.

- Mag Disp threshold specifies calibration data that should be deleted from calibration procedure because of INS was not moved at this procedure. Default value 1000 nT^2 is set by developers and can be changed after agreement with them.

- Inclination threshold is valid for 2D and 2D-2T calibration types and determines acceptable pitch and roll deviation from their median in the calibration run. INS data over this threshold are not used at calculation of calibration parameters. Default value is 1.5 degrees. This parameter can be changed after agreement with developer.

- Success threshold is acceptable value of magnetic field calibration error to have successful result of the 3D calibration if its accuracy can not be estimated in degrees. Default value is 2500 nT. This parameter can be changed after agreement with developer.

The next thresholds in the right part of the "Magnetometers calibration on hard & soft iron" section are used to estimate the calibration quality in terms of possible INS heading accuracy:

- H-filter time constant is parameter for filtration of measured horizontal component of the Earth magnetic field. Default value is 0.6 seconds.
- Pitch/Roll threshold is used for detection of control circuit in the 3D calibration procedure. Default value is 20 degrees.

See section “10.4. Calibration of the INS” for detailed description of Magnetometers calibration procedure.

5. Run Menu

Control of the INS is done by the commands in the "**Run**" menu (Fig.3.3). This menu contains next items:

- "INS visualization" opens appropriate tab with different variants of visualization of the INS operation;
- "Stop INS" stops the INS;
- "Device Information" shows main information about connected device;

There are five styles of visualization of the INS outputs:

- INS 3D Demo;
- Cockpit;
- Snapshot (for the on-the-fly accuracy test);
- Data graphs;
- INS relative position.

5.1. INS 3D Demo

“**INS 3D Demo**“ is default variant of the INS visualization in which current orientation angles of the INS are shown as spatial orientation of an airplane (see Fig.5.1). To go to this visualization stile select **“INS visualization“** from the “**Run**“ menu (Fig.3.3), select on the toolbar, or press **F4** button.

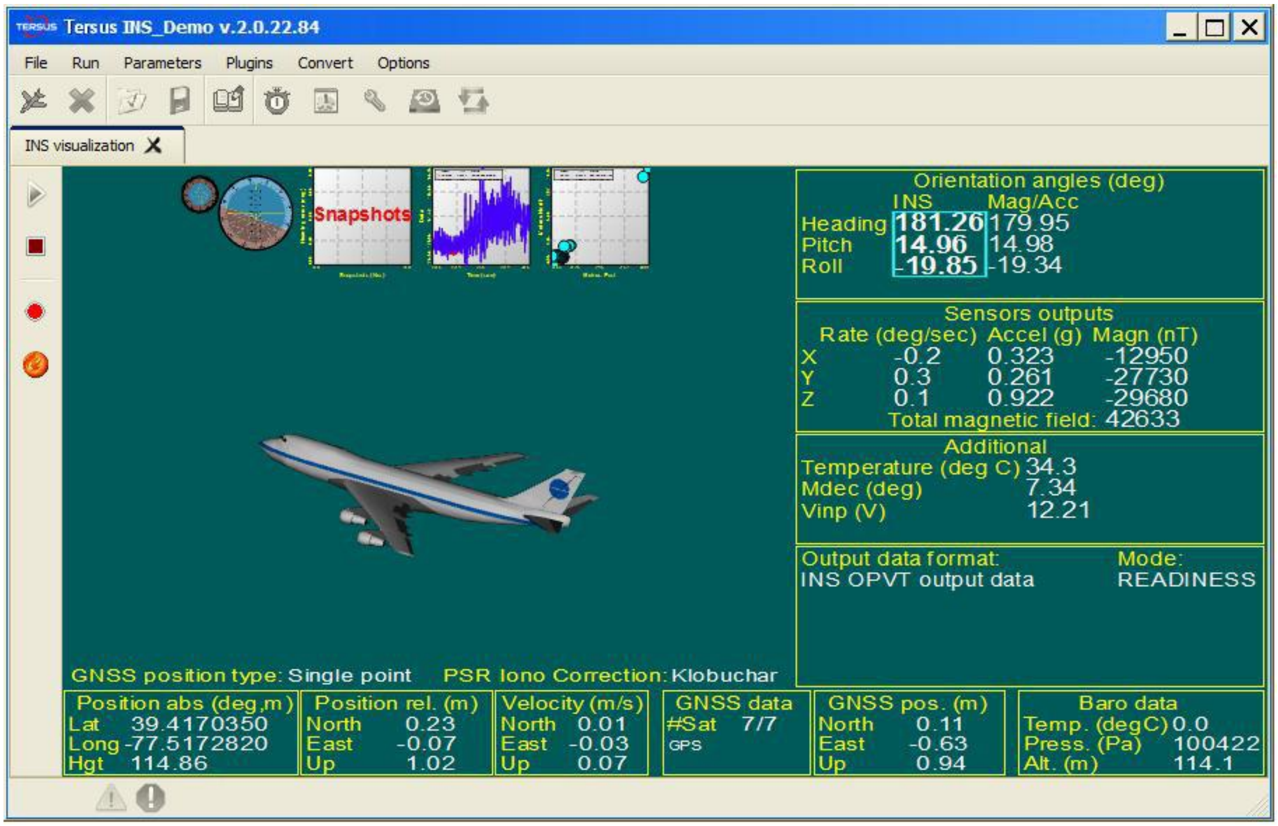


Fig.5.1

Some additional 3D models may be used for visualization of the INS orientation (see below Section 11. Choice of 3D model for visualization of the INS orientation).

In opened “INS visualization” tab, four control buttons (active “Start” and inactive yet: “Stop” ,“Write” and “Snapshot”) appear in the left vertical toolbar. If in the menu “Test Options” the data output method “On Request“ is chosen, then inactive button “Request” appears. Two icons appear in the status bar: “Warnings” and “Failures” .

Warning and failure messages are generated by INS in its Unit Status Word (see Appendix D) and appear near and icons. You can close these messages by clicking on them.

"INS visualization" tab consists from two vertical parts. Visualization panel of the INS outputs is situated on the left part of the tab. The right part displays text data from INS and additional information, it is the same for all visualization styles.

"**Start**" button starts the INS with parameters saved in the INS's microprocessor. Next initial alignment of the INS is performed with displayed message "Initial alignment. Please wait". Also a progress bar of initial alignment will appear in the status line of the main window. During the initial alignment <u>the INS has to be unmovable relative to the Earth</u>. Once the initial alignment time is over, observe changes in numeric data and graphical evolutions of a object.

<u>Note</u>. For visual convenience of the INS position perception displayed on the monitor and the INS real position, it is recommended to place the INS in parallel with the monitor before the beginning of work as follows: direct lateral axis X to the monitor and direct longitudinal axis Y in parallel with the monitor on the left.

Once the "**Start**" button is pressed, buttons "Stop', "Write" and "Snapshot" become active. If in the menu "Test Options" the data output method "On Request" is chosen, then button "Request" becomes active too.

Upon clicking the "**Write**" button the measured data are saved, which is signified by the message «Data are writing in file!» in the text part of the window. Note that the data are saved in binary file and can be used in two ways:

- visualization through opening the file in "**File**", **"Open"** menu item (see section "6.1. "Open" item");
- conversation to text file using "**Report of experiment**" from "**Convert**" menu item (see section "9. Convert Menu").

"**Stop**" button stops data output to the screen and data saving procedure with no data losses.

Button **"Snapshot"** is used for fixing the current values of measured data during continuous run (see section "10.5.2. On-the-fly accuracy test").

If in the menu "Options" the data output method "On Request" is chosen, then getting data from the INS is performed by clicking the button . In case of data saving (if the button "Write" is pressed), the measured data are written in one file sequentially.

Current orientation angles are displayed in the upper right part of the window Fig.5.1, position and velocity data are displayed in the bottom part of this window. Additional displayed data depend on selected output data format (see Appendix C for description of data formats). If default "INS OPVT Output" data format is chosen then the next data are displayed in the right part of the window Fig.5.1:

a) Orientation angles "Heading", "Pitch" and "Roll". In the "INS" column, angles calculated in the INS's microprocessor using the embedded main algorithm are output. The "Magn/Acc" column shows orientation angles calculated in the INS Demo Software using simplified algorithms based on magnetometers and accelerometers data. Angles in the "Magn/Acc" column are auxiliary; they are used by developers only to control operation of the main algorithm.

Note: If is important to set the magnetic declination correctly in the «Device Options» (see Fig.4.2) because the INS operation requires knowing the true heading but not magnetic one.

b) Output signals of the INS sensors: "Rate (deg/sec) " – angular rate values in deg/sec measured by angular rate sensors, "Accel (g)" – linear acceleration values in g measured by accelerometers, "Magn (nT)" – magnetic field intensity values measured by magnetometers in nT. Originally all sensors data are in INS axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). Axes X, Y, Z are object axes if non-zero alignment angles are set for INS mounting (see Appendix E. Variants of the Tersus INS mounting relative to object axes).

c) Total measured magnetic field value in nT "Total magnetic field".

d) Current temperature "Temperature (degC)" inside the INS.

e) The set value of the magnetic declination "Mdec (deg)".

f) Input supply voltage of the INS in VDC "Vinp (V)".

g) Format of output data "Output Data Format: …". This format is set in the «**Test Option**» window (Fig.4.1).

h) Current mode of the INS operation (Readiness, Awake or Sleep).

Current position and velocity are displayed in the bottom part of the window Fig.5.1:

a) In the "Position abs (deg, m)" column the INS absolute position is displayed – Latitude (degrees), Longitude (degrees), Height (meters) which are calculated in the INS.

b) In the "Position rel (m)" column the INS position relative to the start point is shown. There changes of latitude and longitude are recalculated to changes of linear coordinates in the North and East directions.

c) In the "Velocity (m)" column the North, East and Vertical components of the INS velocity are shown.

d) In the "GNSS data" column the next information about GNSS data is shown:

- #Sat – is number of satellites used in navigation solution.
- GPS / GLO / Gal /Bei – shows what navigation systems are currently used (GPS, GLONASS, Galileo, BeiDou).

e) In the "GNSS pos (m)" column the GNSS position relative to the start point is shown. There change for GNSS latitude and longitude are recalculated to change of linear coordinates in the North and East directions.

f) The "Baro data" column shows data measured by the pressure sensor: "Temp.(decC)" – is temperature in ₒ C, "Press.(Pa)" – is pressure in Pascals, "Alt.(m)" – is barometric altitude in meters.

There is detailed information about quality of GNSS solution above section with position and velocity data in the window Fig.5.1:

a) <u>GNSS position type</u> – shows what data were used by GNSS receiver for in navigation solution for position calculation:

- Single point position;
- DGPS (pseudorange differential solution);
- Solution calculated using corrections from SBAS;
- RTK (narrow-integer) solution;
- RTK (other) solution;
- Other.

b) <u>PSR Iono Correction</u> – shows what data were used for pseudorange ionosphere correction:

- Default (unknown or default Klobuchar model);
- Klobuchar Broadcast;
- SBAS Broadcast;
- Multi-frequency Computed;
- DGPS (pseudorange differential correction);
- Blended Iono Value.

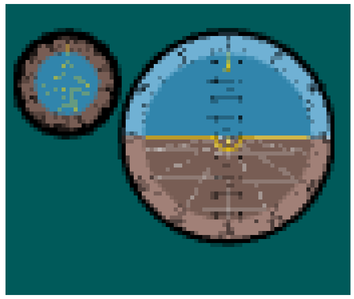
Note if "INS Sensors Data" format is chosen then instead of "GNSS position type" and "PSR Iono Correction" fields the GNSS extended solution status "Ext.sol." is shown on Fig.5.1 in the "GNSS data" column. See Appendix C, Table C.13 for details).

To stop data output from the INS click the "**Stop**" button .

To leave the INS visualization mode, click the  in the title of current tab.

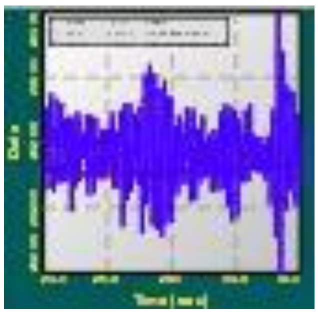
For other styles of visualization of the INS outputs there are clickable previews in the upper part of the "INS visualization" tab (Fig.5.2). It is possible to switch between visualization styles at any time of the INS operation by simple clicking on its preview.

a)

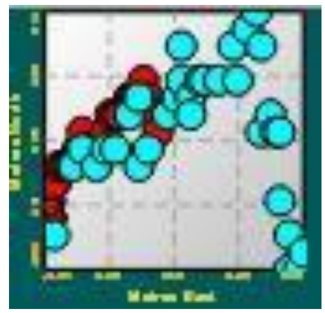


b)

c)



d)



e)

Fig.5.2

5.2. Cockpit style of visualization

"Cockpit" window allows to show current attitude of the INS in "Cockpit display" style (see Fig.5.3). To switch visualization to this mode click on preview shown in the Fig.5.2 (b) and window shown in the Fig.5.3 will appear.

There is heading indicator in the upper left corner of the tab. In the center part of the tab an attitude indicator (artificial horizon) is shown. Its vertical scale corresponds to pitch, limb corresponds to roll.

To switch to other than "Cockpit" style click on appropriate preview in the upper part of the "INS visualization" tab (Fig.5.3).

To stop data output from the INS click the "**Stop"** button .

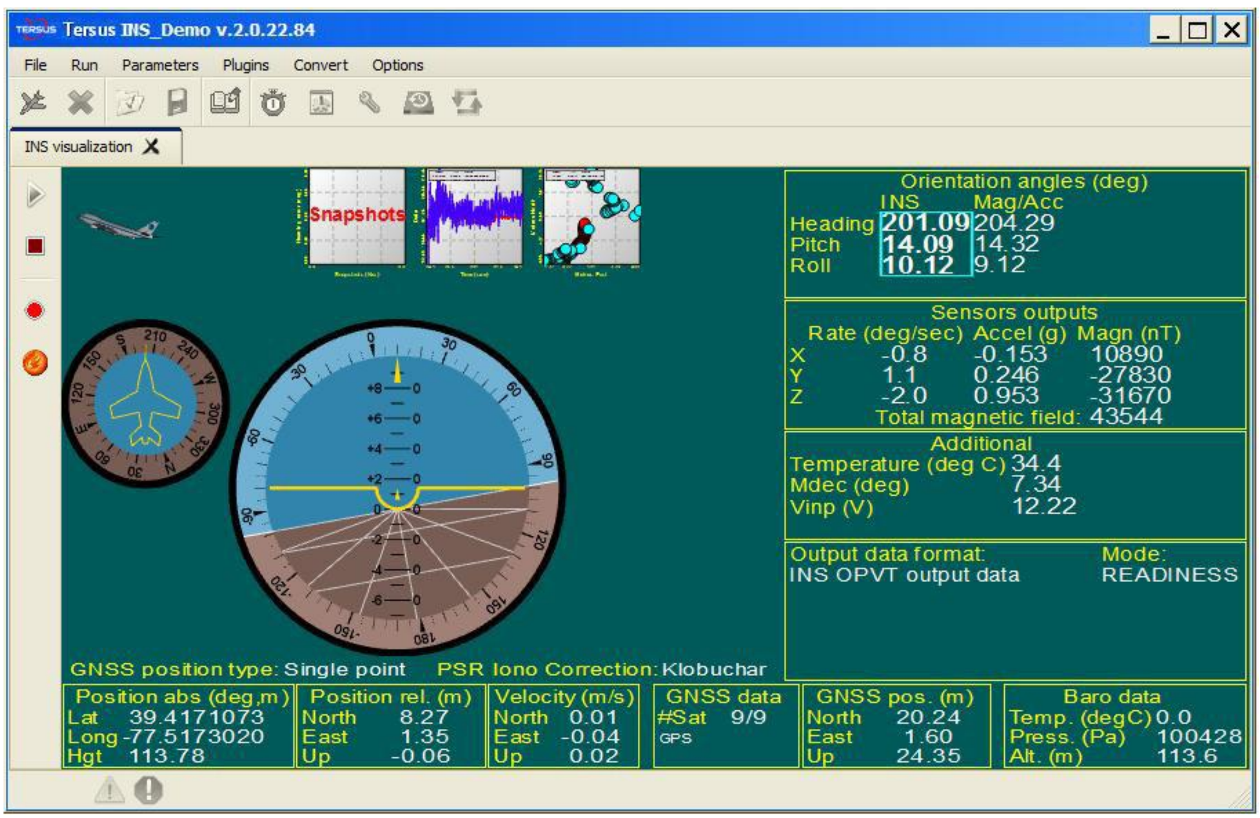


Fig.5.3

5.3. On-the-fly accuracy style of visualization

"On-the-fly accuracy" feature is designed for checking the INS accuracy at its ordinary operation when the INS can be directed to points with known orientation.

To switch visualization to this mode click on preview shown in the Fig.5.2 (c) and window shown in the Fig.5.4 will appear.

For more information about this type of visualization see section "10.5.2. On-the-fly accuracy test".

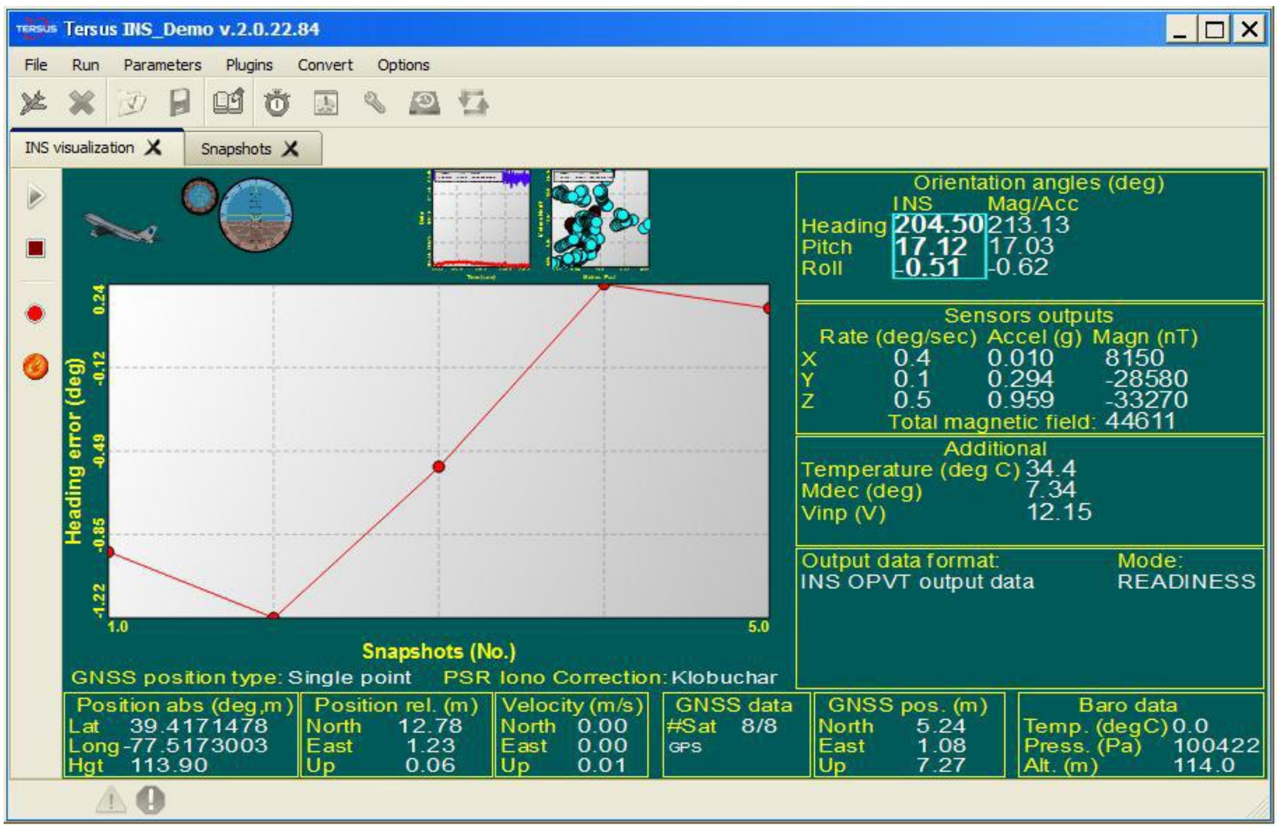


Fig.5.4

5.4. Data graphs style of visualization

“Data graphs” window allows to show graphs of current INS outputs (see Fig.5.5). To switch visualization to this mode click on preview shown in the Fig.5.2 (d) and window shown in the Fig.5.5 will appear.

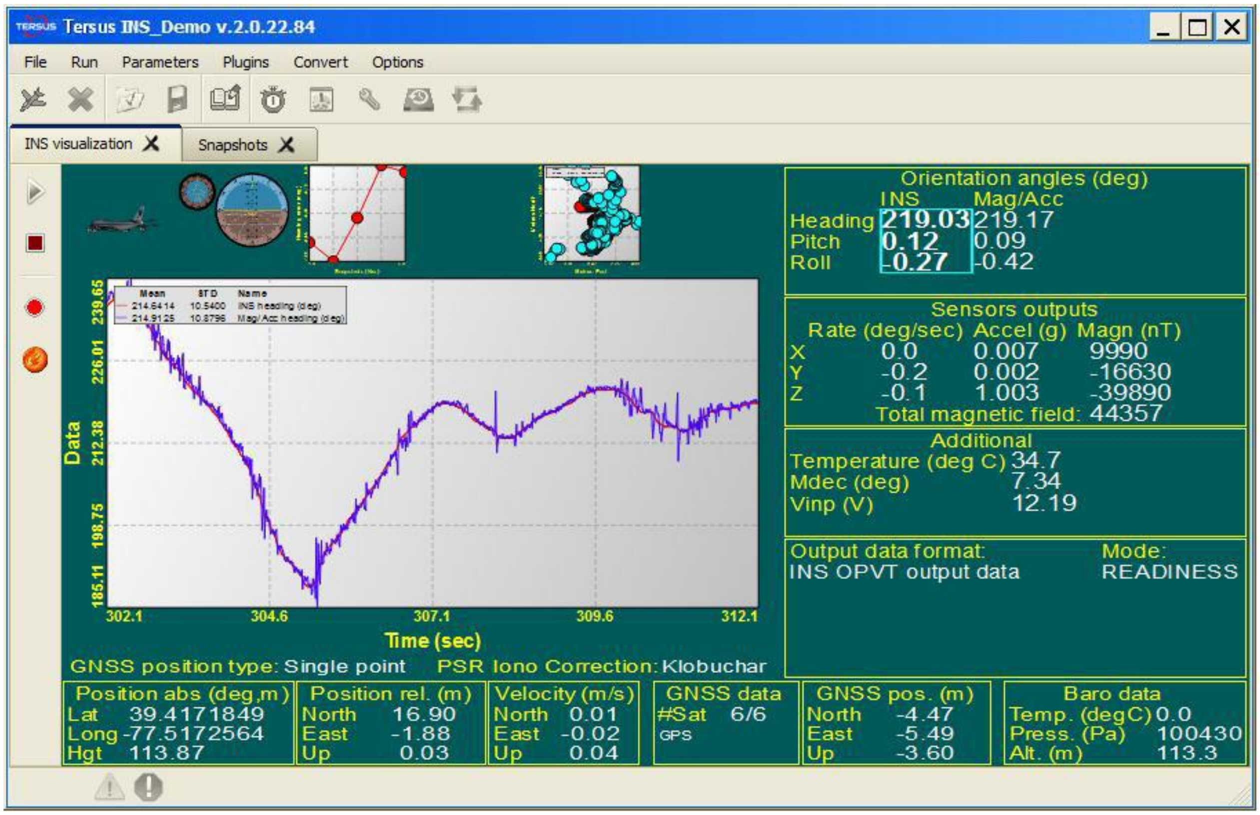


Fig.5.5

It is possible to select the signals you want to display by right-click on the graphs area. As a result window shown in the Fig.5.6 will appear.

You can select or deselect signals by clicking on their titles:

- INS heading (deg) – plots Heading angle calculated in the INS, in degrees;
- INS pitch (deg) – plots Pitch angle calculated in the INS, in degrees;
- INS roll (deg) – plots Roll angle calculated in the INS, in degrees;
- Mag/Acc heading (deg) – plots Heading angle calculated in the INS Demo Software based on the INS magnetometers and accelerometers data, in degrees;

- Accel pitch (deg) – plots Pitch angle calculated in the INS Demo Software based on the INS accelerometers data, in degrees;
- Accel roll (deg) – plots Roll angle calculated in the INS Demo Software based on the INS accelerometers data, in degrees;
- Gyro X (deg/sec) – plots output signal of the gyro X in deg/sec;
- Gyro Y (deg/sec) – plots output signal of the gyro Y in deg/sec;Gyro Z (deg/sec) – plots output signal of the gyro Z in deg/sec;
- Accelerometer X (g) – plots output data of the accelerometer X in g;
- Accelerometer Y (g) – plots output data of the accelerometer Y in g;
- Accelerometer Z (g) – plots output data of the accelerometer Z in g;
- Magnetometer X (nT) – plots output data of the magnetometer X in nT;
- Magnetometer Y (nT) – plots output data of the magnetometer Y in nT;
- Magnetometer Z (nT) – plots output data of the magnetometer Z in nT;
- Magnetic module (nT) – plots full module of the measured magnetic-field vector in nT;
- Temperature (deg C) – plots current temperature inside the INS in Celsius degrees;
- Latitude (deg, m) – plots latitude in meters;
- Longitude (deg, m) – plots longitude in meters;
- Height (deg, m) – plots height in meters;
- V_N (m/s) – plots North rate in meters per second;
- V_E (m/s) – plots Eath rate in meters per second;
- V_V (m/s) – plots Vertical rate in meters per second;
- Latitude GNSS (deg, m) – plots GNSS latitude in meters;
- Longitude GNSS (deg, m) – plots GNSS longitude in meters;
- Height GNSS (deg, m) – plots GNSS height in meters;
- V_N GNSS (m/s) – plots GNSS North rate in meters per second
- V_E GNSS (m/s) – plots GNSS Eath rate in meters per second
- V_V GNSS (m/s) – plots GNSS Vertical rate in meters per second

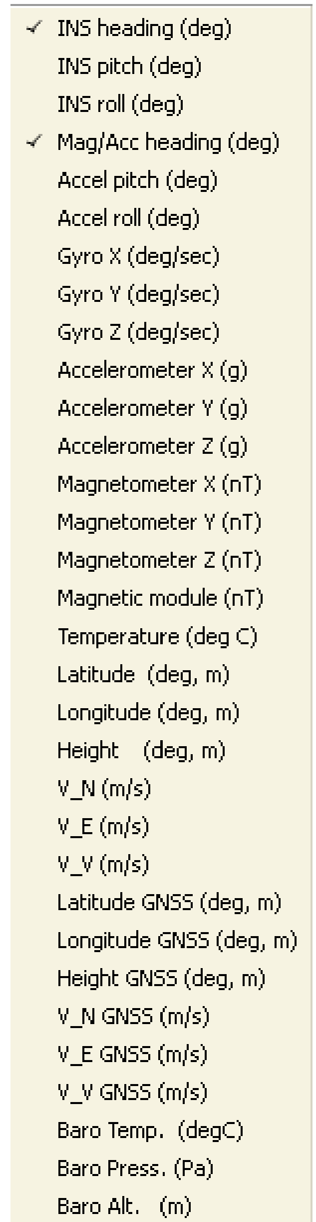


Fig.5.6

- Baro Temp. (deg C) – plots barometric temperature in Celsius degrees;
- Baro Press. (Pa) – plots barometric pressure in Pa;
- Baro Alt. (m) – plots barometric altitude in meters.

Plotted graphs are scalable. To zoom in please click and hold left button on mouse and drag mouse in down-right direction. Click and hold right button on mouse to shift plot. To zoom out please click and hold left button on mouse and drag mouse in up-left direction. Legend is located at the left upper corner of the tab. This legend shows mean value, STD and name of displayed signals.

5.5. Visualization of INS relative position

This is visualization of the INS current position relative to the start point (see Fig.5.5). To switch visualization to this mode, click on preview shown in the Fig.5.2 (e).

Changes of the INS latitude and longitude are recalculated to the changes of linear coordinates in the North and East directions. On the default there are coordinates provided by GNSS receiver (cyan markers) and coordinates calculated by INS (red markers). It is possible to select the data you want to display by right-click on the graphs area. As a result window shown in the Fig.5.8 will appear. There you can select or deselect data by clicking on their titles.

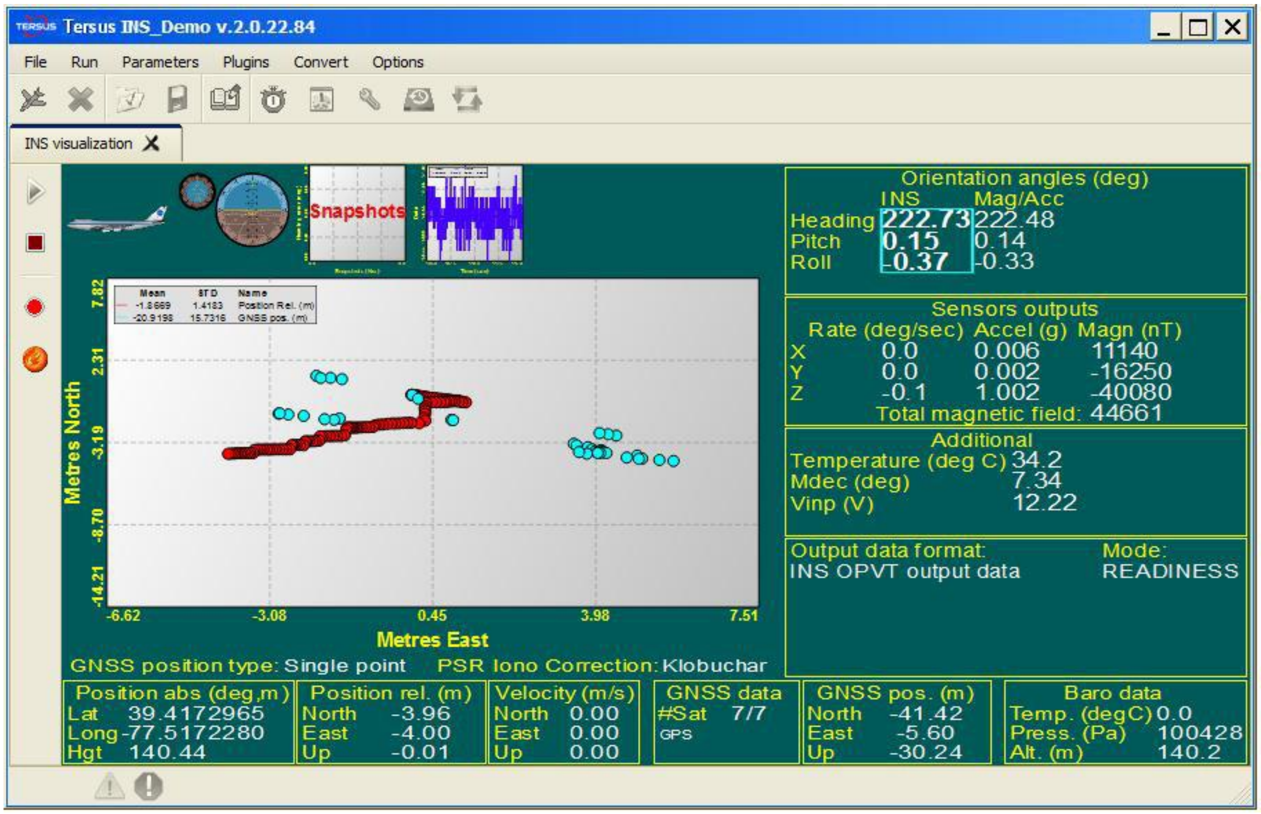


Fig.5.7

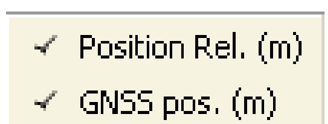


Fig.5.8

5.6. Peculiarities of data displayed at the "INS Sensors Data" format

At this data format the INS outputs data from separate devices inside INS (AHRS, GNSS receiver, pressure sensor), without integration of these data. So in the visualization windows Fig.5.1, Fig.5.3, Fig.5.4, Fig.5.5, Fig.5.7 some another kind of data are displayed in contrast to data described in section 5.1.

The upper right part of the window shows orientation calculated by the AHRS algorithm.

The bottom part of the window shows position and linear velocities provided by GNSS receiver and some additional information about GNSS data that differs from those described in section 5.1:

1. In the #Sat field there are two different numbers: the first is number of tracked satellites and the second one is number of satellites used in navigation solution.
2. Ext.sol. – extended solution status of the GNSS data (see Table C.13 in the Appendix C).

5.7. Other items of the Run menu

– **Stop INS** – stops the INS. In most cases it is used for correct termination of completed operations. For this command the hot key **F7** can be also pressed or button can be clicked.

– **Device Information** – opens tab with the INS main information: integrated device serial number and firmware version; AHRS serial number and firmware version; parameters of GNSS receiver; GPS reference week number; pressure sensor type (see Fig.5.9).

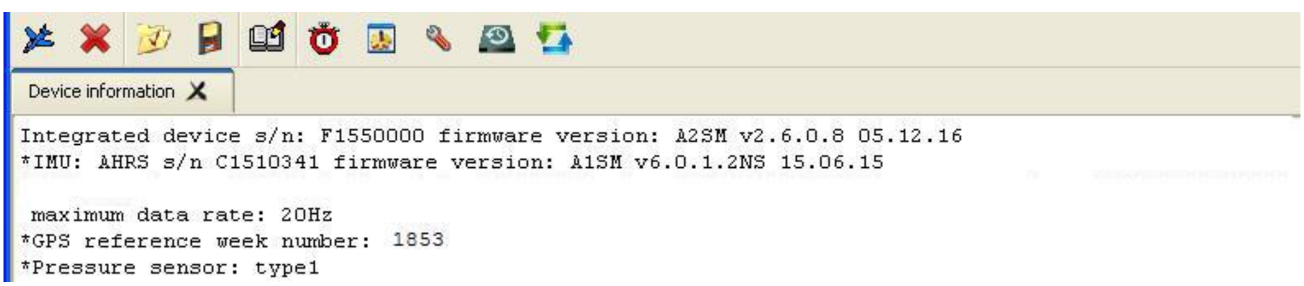


Fig.5.9

6. File Menu

“File” menu enable to work with already saved tests results. There are such items in the "File" menu:

- “Open”;
- “Save as”;
- “Exit”.

6.1. “Open” item

You can visualisate data saved to files during INS run. To open saved *.bin file choose item “Open” (Fig.3.2) or press **F3**. The standard window Windows “Open…” will appear, in which it is necessary to choose needed *.bin file saved previously when the INS was operating in its standard mode. After selection of file, data are read from it and new tab **“Data viewer”** shown in the Fig.6.1 will open.

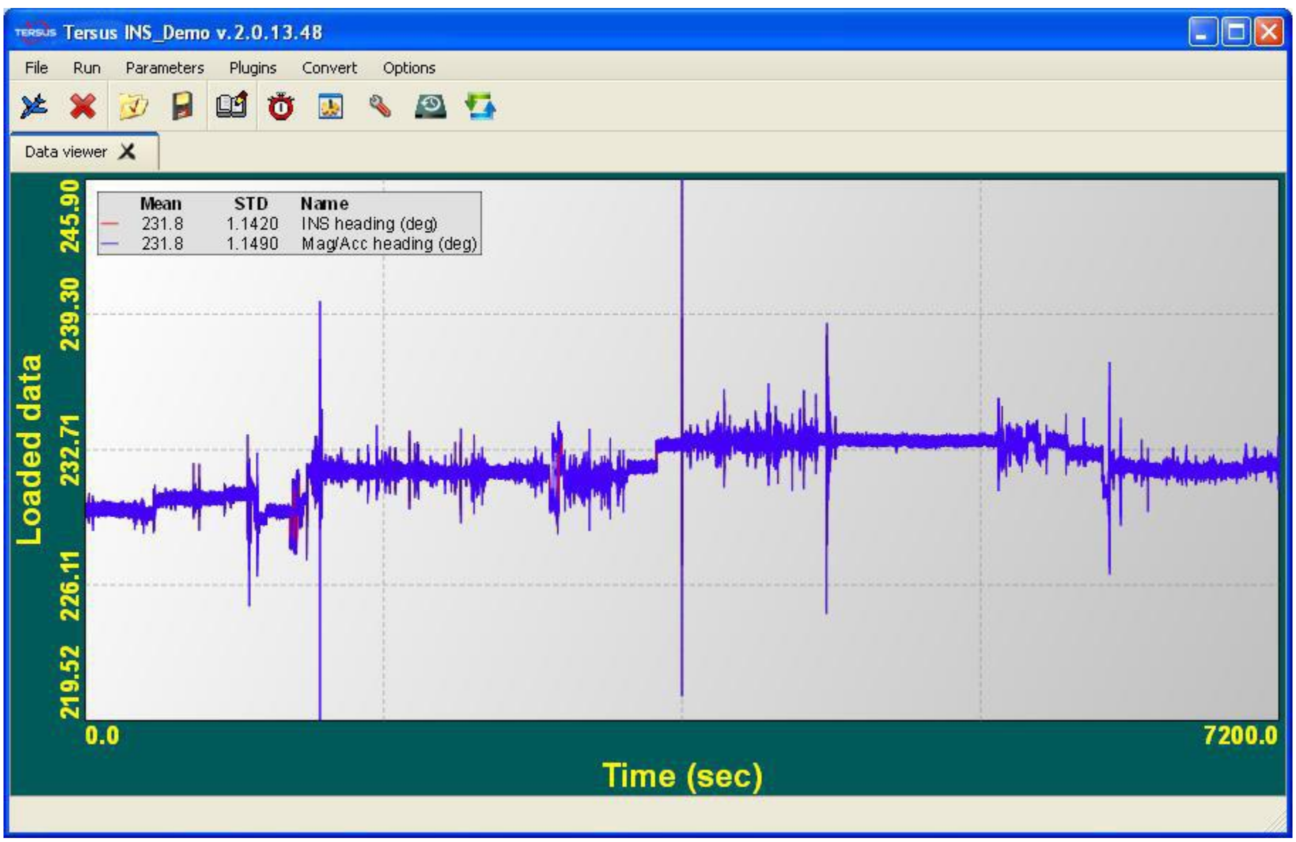


Fig.6.1

It is possible to select the data you want to display by right-click on the graphs area. As a result window shown in the Fig.5.6 will appear where you can select or deselect showed data by clicking on their titles.

Plotted graphs are scalable. To zoom in please click and hold left button on mouse and drag mouse in down-right direction. To zoom out please click and hold left button on mouse and drag mouse in up-left direction. Click and hold right button on mouse to drag the plot.

Legend is located at the left upper corner of the tab. This legend shows mean value, STD (standard deviation) and name of displayed data.

To close graphs please click the icon in the title of current tab.

6.2. “Save as” item

You can preset name of file for data writing. For this select **“Save as”** item (Fig.3.2) and enter desirable file name.

7. Parameters menu

“Parameters” menu enable to work with INS parameters. There are such items in the **“Parameters”** menu:

- Load block parameters;
- Read block parameters;
- Restore parameters;
- Save parameters;
- Preset parameters.

7.1. “Load block parameters” and “Read block parameters” items

These items are used to check operation of appropriate commands of the INS. But INS Demo software allows more convenient means to load the INS parameters to the INS nonvolatile memory (see section 7.2).

7.2. Restore parameters

“Restore parameters” command (see Fig.3.4) is used to quickly load the INS parameters to the INS nonvolatile memory. When **«Restore parameters»** command is selected, or button is clicked, a standard Windows «Open» window opens; in this window operator selects one of the previously saved files with .prm extension. Consequently, the parameters are automatically saved to the INS nonvolatile memory and to the Demo-Program shell. The same way is used to restore the factory settings of the INS parameters. In this case you should select original file with .prm extension that comes on CD with Tersus INS.

7.3. Save parameters

If you have changed some parameters of the INS (in «**Device options…**» window from the «**Options**» menu or other menus), and you want to save these parameters as variant for future work, you can save the INS current parameters in binary file with .prm extension. For this use «**Save parameters**» command (see Fig.3.4) or click button. After that a standard Windows «Save as …» window is opened; in this window operator is suggested to save current parameters of the INS to a «File of parameters» with .prm extension.

7.4. Preset parameters

The Tersus INS Demo provides preset of the INS parameters that adjust INS algorithm for some specific conditions of operations to get better dynamic accuracy of the INS. The latest INS Demo version contains preset parameters for the next conditions of the INS operations:

- Ordinary device parameters;
- Operation at vibrations;
- Load from file.

To modify INS parameters select **“Preset parameters”** item from the **«Parameters»** menu (Fig.3.4). The window Fig.7.1 will be opened. Select on of variants of the INS operations and click **“OK”** to update the INS parameters according to selected variant.

Note: you are able to apply **“Preset parameter variants”** only if INS is powered and connected to computer, and COM port number and its baud rate are chosen properly and INS initialization time (about 25 sec after power on) is completed so LED indicator lights red.

Ordinary device parameters correspond to those loaded in the INS by manufacturer and provides correct INS operation in the most of applications. Original file with .prm extension that comes on CD with the Tersus INS also contains parameters of the INS algorithm for ordinary INS operation.

Parameters for the INS operation at vibrations allow to get better dynamic accuracy of the INS at intensive vibrations than ordinary parameters of the INS algorithm. Possible shortcoming of the “vibration parameters” is decreasing of the INS dynamic accuracy at long-duration accelerations of the vehicle.

Please pay attention to possibility of increasing the INS accuracy at object swaying via compensation of linear acceleration at place of the INS mounting (see section 4.4. Swaying compensation).

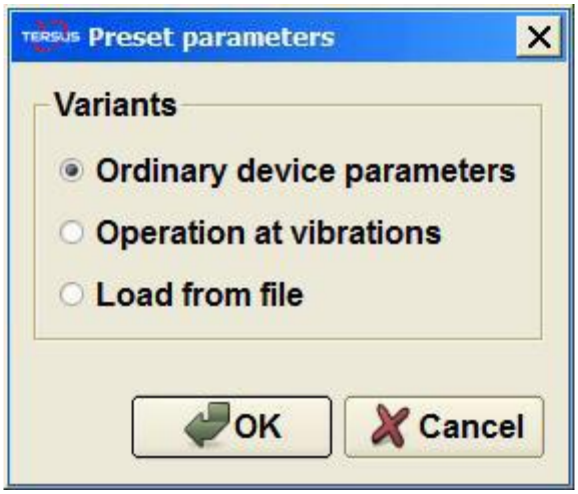


Fig.7.1

Load from file item allows to adjust the INS algorithm for specific conditions of operation that are not in the list of variants shown on Fig.7.1. In such case Tersus can provide additional .prm file with specific set of the INS parameters. Select the “Load from file” check box to load parameters of specific algorithm from .prm file without changing the individual INS parameters. Then “Load Parameters” button appears (see Fig.7.2).

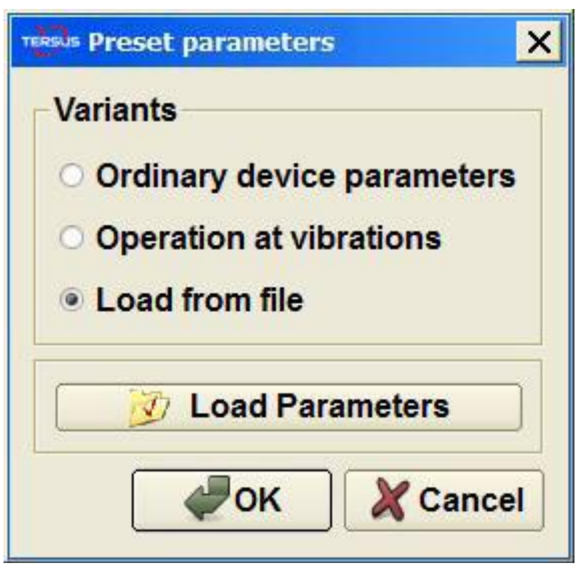


Fig.7.2

Click on the “Load Parameters” button. The standard window Windows “Open…” menu will appear, in which it is necessary to choose needed file with *.prm extension. After selecting the file, two checkboxes “IMU” and “INS” will appear in the “Preset parameters” window (Fig.7.3).

Then “IMU” or (and) “INS” checkbox should be chosen. Click “OK” button to load chosen parameters from file to the INS. After that parameters are loaded the information window shown on the Fig.7.4 appears.

Or you can click the “Cancel” button to close “Preset parameters” window without loading parameters.

<u>Note</u>: It is possible to use “Load from file” item since INS Demo Software ver.15.0.60 from 01/26/2016.

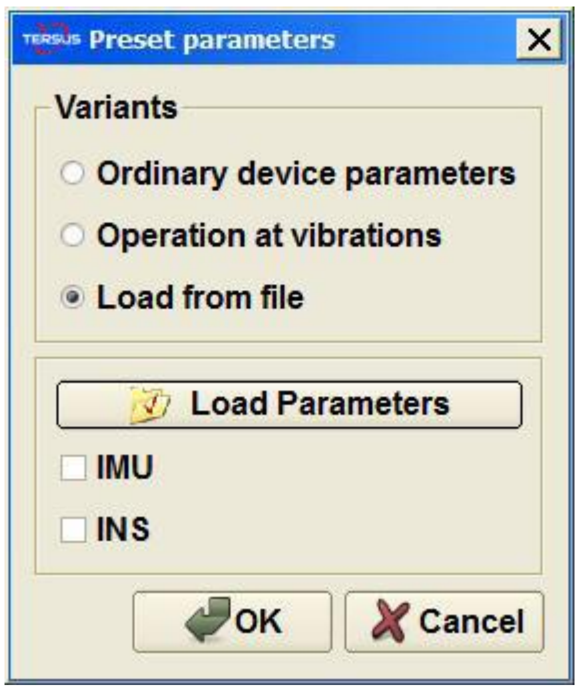


Fig.7.3

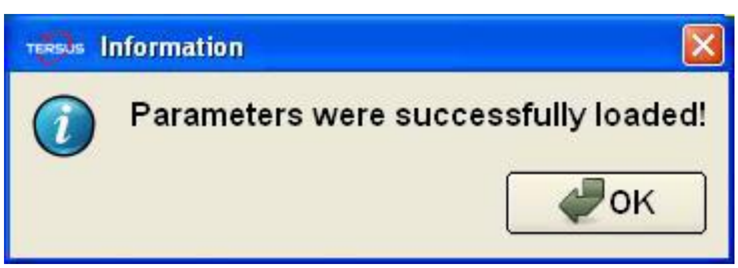


Fig.7.4

8. Plugins Menu

"**Plugins**" menu enable to run additional parts of the Demo software. There are such items in the "Plugins" menu:

- Embedded;
- Mag field calibration;
- Angles accuracy.

8.1. Embedded

The INS Demo software allows taking into account influence of the soft and hard iron of the carrier object on the heading calculation accuracy. For this purpose, field calibration of the INS magnetometers is provided. There are two ways to calibrate the INS: to use INS embedded procedures or procedures provided by INS Demo software.

The last way is more convenient (see section 6.2. Magnetometers field calibration). For INS embedded calibration procedure the **"Embedded"** menu item is used As a result of selection of this item the "Embedded Mag Field Calibration" window will appear (see Fig.8.1).

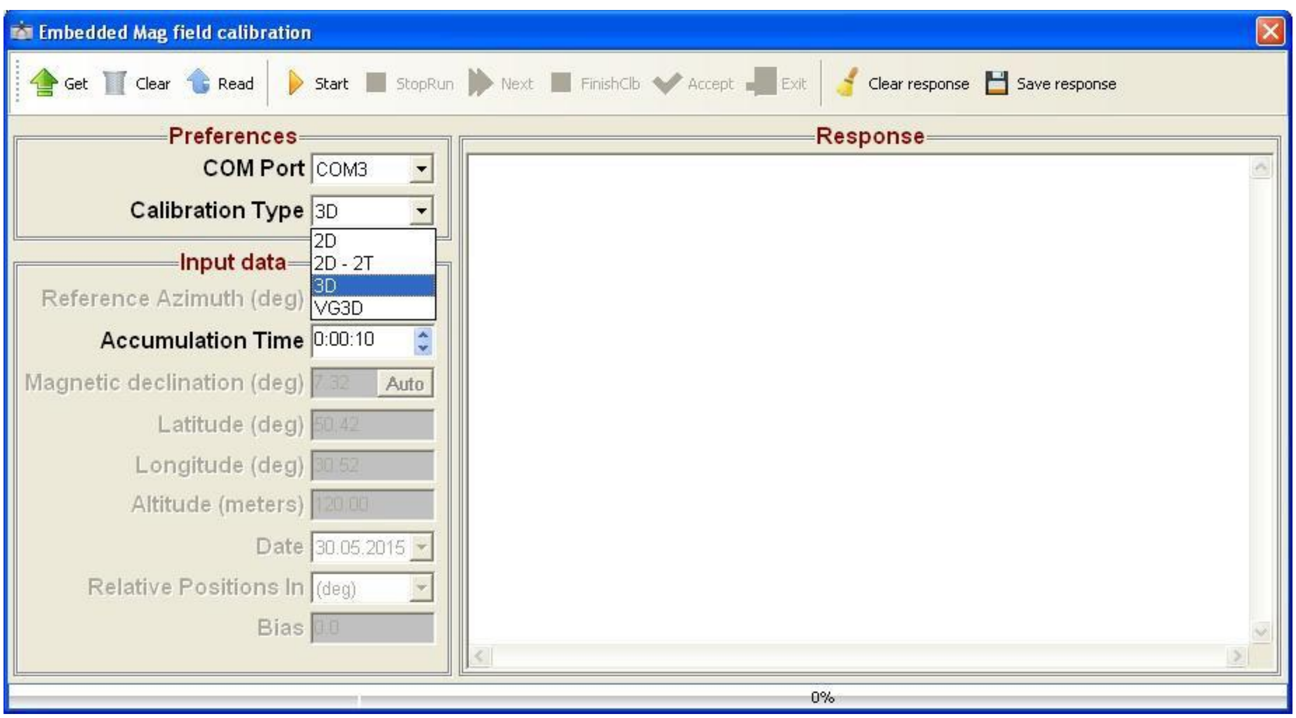
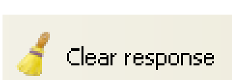


Fig.8.1

Buttons on the toolbar are used to send commands for the INS calibration that are described in the INS ICD. Below is list of these buttons and corresponding commands:

Icon	Command	Command code	Description
	GetClbRes	0x2A	Views the last calibration results stored in the INS memory
	ClearClb	0x2F	Clears calibration parameters
	–	–	Reads out the INS flash memory
	Start2DClb Start2D2TClb Start3DClb StartVG3DClb	0x21 0x22 0x23 0x25	Starts the 2D, 2D-2T, 3D or VG3D calibration
	StopClbRun	0x20	Early stops data accumulation in the calibration run before set accumulation time is reached
	StartClbRun	0x2B	Starts new run of the 2D-2T calibration
	FinishClb	0x2C	Finishes the calibration procedure with multiple runs (like 2D-2T)
	AcceptClb	0x2E	To accept the calibration parameters and to save them to the INS nonvolatile memory
	ExitClb	0xFE	To exit from the calibration without calculations and saving calibration parameters
	–	–	Clears the response window Fig.6.2
	–	–	Saves data from the response window to *.log file

Notes:

1. Command code in this table is payload of the command with 9-bytes structure.
2. VG3D calibration is at the testing stage. Please contact Tersus about the possibility of using the VG3D calibration.

When the INS answers on above commands then these answers appear in the Response window (see Fig.8.2).

Different buttons will be active depending on calibration type.

See additional document for detailed description of the embedded calibration procedures.

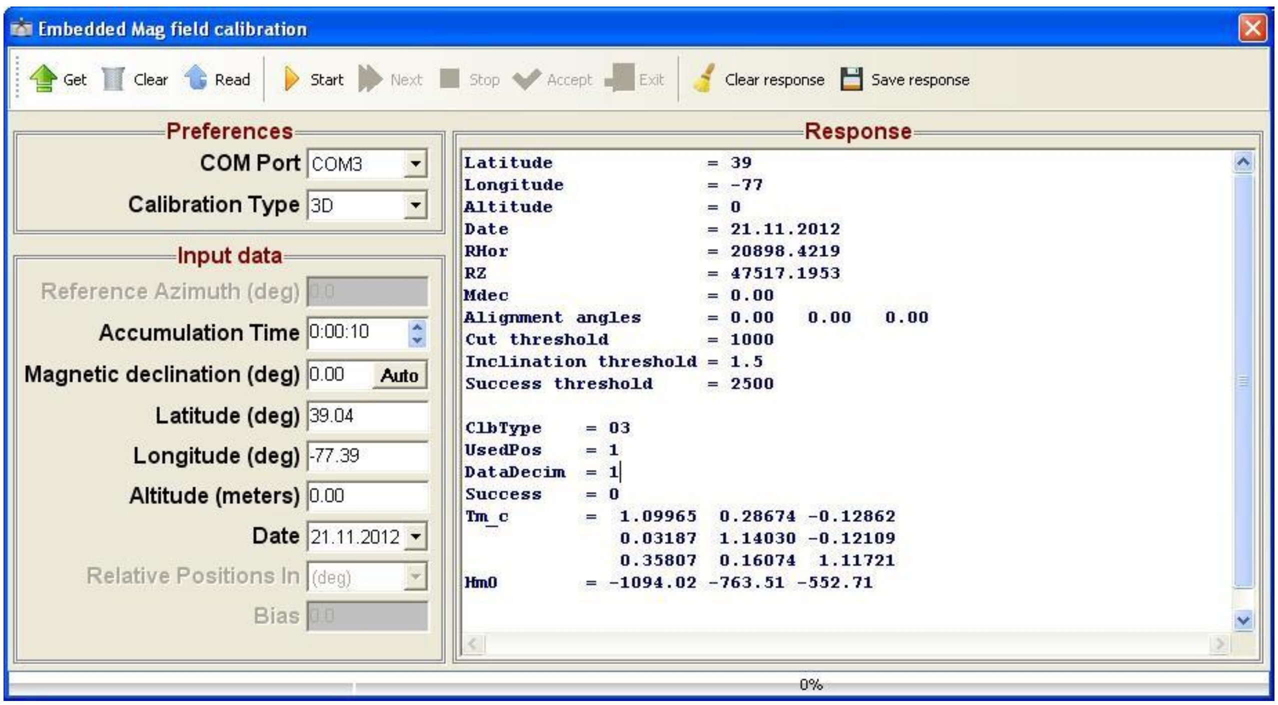


Fig.8.2

8.2. Magnetometers field calibration

Another and more convenient way for INS hard and soft iron calibration is provided by INS Demo software.

Before calibration please check in the **«Test Options»** dialog box (Fig.4.1) correct COM port number to which the INS is connected.

To start the calibration select "**Plugins**" menu and then "**Mag Field Calibration**" item (see Fig.3.4**)** from the main menu. "Mag Field Calibration" window will open (see Fig.8.3)**.**

Important note. For correct calibration it is necessary to set right coordinates "**Latitude**", "**Longitude**", "**Altitude**" and "**Date**" in accordance with place where INS is calibrated. Their values are set in the «Device Options» window (see Fig.4.2).

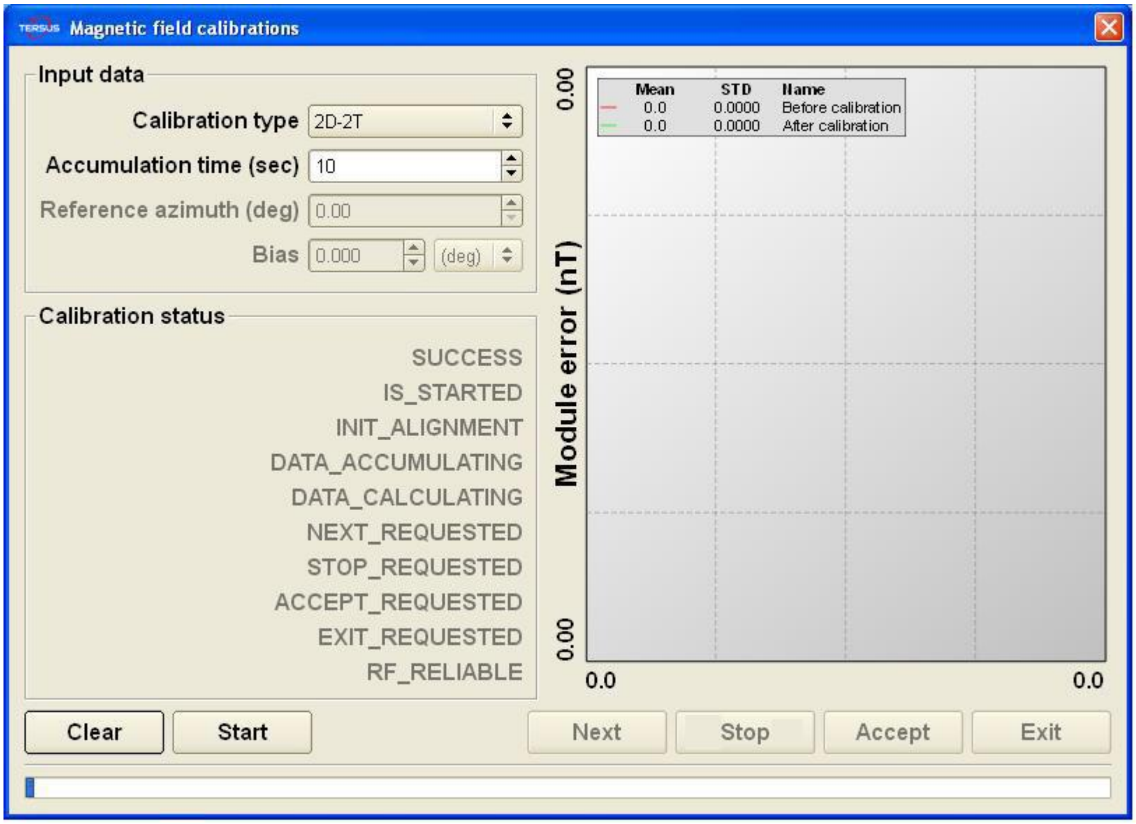


Fig.8.3

In the "**Calibration Type**" field choose from a list the type of the calibration – 2D, 2D-2T or 3D (see section 10.4 for explanation of these types).

The "**Accumulation Time**" field in window Fig.8.3 sets the time which is necessary to perform calibration procedure including at least one full 360° turn rotation in horizon plane (at least 2 full turns are recommended). This time can be set using arrows or by entering the necessary value from a keyboard. The default value is 60.

In **"Calibration status"** window the captions are highlighted that show current states of INS calibration and actions that can be performed.

See section 10.4 for detailed description of the INS calibration procedure.

If place of the INS mounting on the carrier object is changed, or if the carrier is changed, then calibration matrices for magnetometer biases and scale factors in INS memory should be cleared by clicking on the «**Clear**» button (see Fig.8.3).

8.3. Angles accuracy

To check accuracy of the INS set precisely its attitude in orientation angles with the help of special equipment and compare orientation angles produced by INS with the set angles.

To start the accuracy check select “**Plugins**” menu and then “**Angles accuracy**” item (Fig.3.4**)** from the main menu. After that the next window will appear (see Fig.8.4).

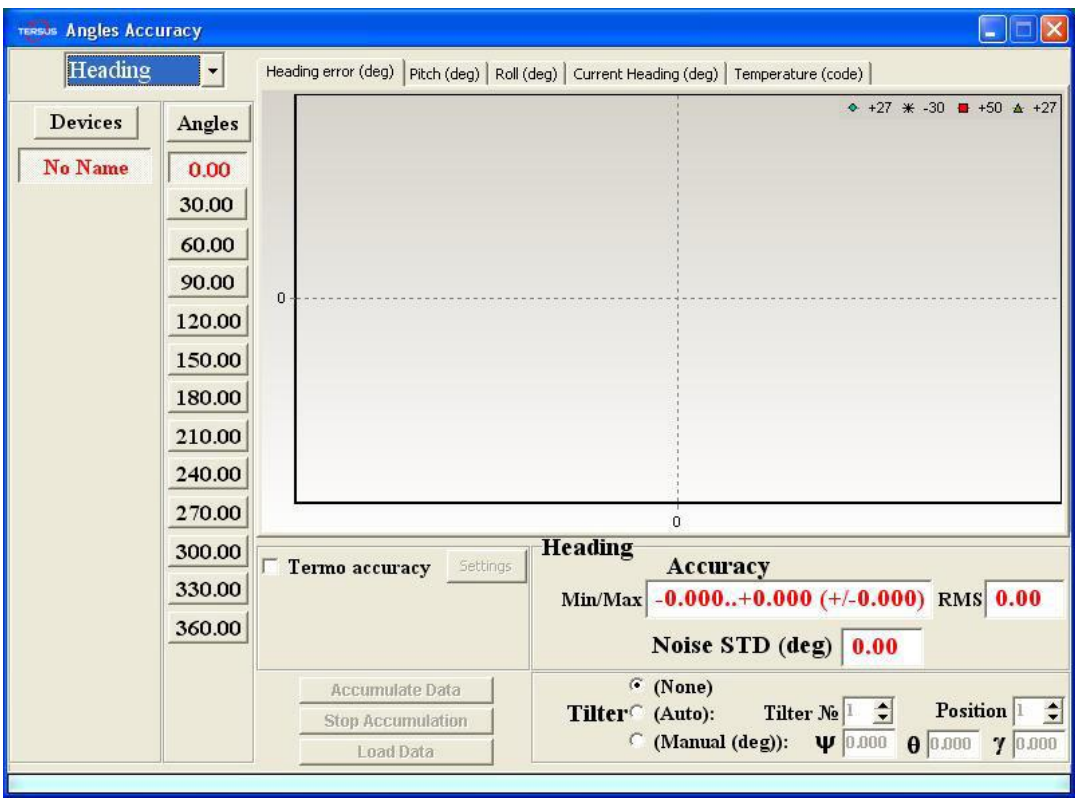


Fig.8.4

In a pulldown list in the left top corner there is an capability to choose an orientation angle (Heading, Pitch or Roll) on which the INS will be tested.

Depending on the chosen parameter the accuracy check window name which is shown in the Fig.8.4 will change.

The check of the INS heading (azimuth) angle accuracy is carried out by rotating the INS around the vertical on angles specified in the column “Angles” Fig.8.4.

The check of INS pitch angle accuracy is carried out by rotating the INS around the horizontally located lateral axis X of the INS on angles specified in the column “Angles” (see Fig.8.4). It is necessary to note that the accuracy control in angles 90°, 270° and close to them is not carried out because of uncertainty of two other orientation angles – Heading and Roll in this position.

The check of roll angle accuracy is carried out by rotating the INS around the horizontally located longitudinal axis Y of the INS on angles specified in the column “Angles” (see Fig.8.4).

In the left part of check accuracy window there is a button “Devices”, by clicking on which the window “Devices Properties” is opened (see Fig.8.5). In this window the operator in line “Number of Devices” sets the necessary quantity of simultaneously tested INS units. The minimal size of parameter 1 changes on $\pm$ 1 by means of arrows or by keyboard necessary value input. The size by default is 1. Then in the column “Port Name” the operator chooses COM port number to which the INS units are connected and in a column “Baud rate” he chooses COM-port speed which has the default value 115200 bps.

After that the operator clicks the button “Scan”. The Demo software serially polls specified COM-ports, and in column “Device Name” names of found INS units are displayed and button “OK” becomes active. By clicking the button “OK” (see Fig.8.5) names found in window “Devices Properties” are transferred to the left of a check accuracy window (Fig.8.4) instead of label “NoName”. Clicking the button “Cancel” or button “X” closes the window "Devices Properties” Fig.8.5.

In a check accuracy window there are control buttons. The button “Angles” opens the window “Angles Properties” Fig.8.6, in which the operator sets the necessary time “Accumulation Time” of data acquisition while the measurement in each position of the INS, checks accuracy angles “Accuracy checking points” and chooses the sensor, with the help of which the temperature control “Temperature Sensor” will be carried out. The minimal size of parameter “Accumulation Time” 1 changes on ± 1 with the help of arrows or by means of necessary value keyboard input. The default value is 20.

Fig.8.5

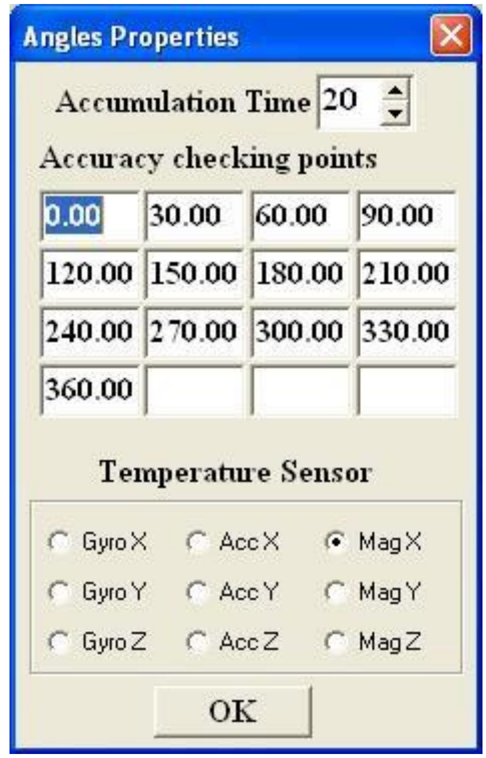


Fig.8.6

At accuracy tests it is possible to take into account misalignment angles of the INS installation on a test bench platform on which INS is tested. Such situation is possible if for INS installation on a test bench platform intermediate adaptations are used, for example tilter. If deviation angles of tilter adjusting bases for INS relatively to test bench platform are known, they are necessary for considering at accuracy check. For this purpose “Tilter” fields are used in the right bottom window corner Fig.8.4. Here it is possible:

- “(None)” is not to consider deviations of bases;
- “(Auto)” is to consider deviations for tilter used for Tersus internal tests “Tilter Q” and a corresponding cell (“Position”) in this tilter;
- “(Manual)” is to consider manually bases deviation angles on corresponding angles “ ”, “ ” ” “ ”.

Fields “Tilter” are used by the developer for internal tests of the INS. The question on their use for external tests should be coordinated with the developer – Tersus company.

The button “Accumulate Data” (see Fig.8.4) consistently starts INS units for operation. Automatically, in the top part of the check accuracy window the page “Current angle, deg” opens in which in the form of the graph the current measured angle (Heading, Pitch or Roll) is plotted. Upon completion of data collecting there is an averaging the measured data and switching on a following controllable angle, and in a folder where there is file INS_Demo.exe, the file of the report like Accuracy_*.txt is kept. It is a service file which can be used for continuation of testing INS after any possible failure in work. In that case for loading the previous measured data the button “Load Data” is used.

Notes.

1. The filename Accuracy_*.txt consists of the word Accuracy_ and 8-12 numbers of year, month, date, hour and minutes when the work was carrying out.
2. The button “Load Data” opens the standard window Windows “Open…”, in which it is necessary to choose and download a file Accuracy_*.txt with the last measured data.

In pages “Heading, deg”, “Pitch, deg”, “Roll, deg”, “Temperature, codes” the current same INS parameters are displayed in the form of graphs.

After the end of the accuracy test cycle the page “Angle Error, deg” is opened automatically, where Angle is Heading, Pitch or Roll, depending on the angle, where the test was carried out. In the page window the graph of given angle calculation error is displayed, and the minimal and maximal error values during the test, its root-mean-square value (RMS) are indicated. Also standard deviation (STD) of measurement noise at last position of the INS is displayed.

Note. Page “Current Heading, deg” changes its name on “Current Pitch, deg” or “Current Roll, deg” and the page “Heading Error, deg” changes its name on “Pitch Error, deg” “Roll Error, deg” depending on the chosen controlled parameter in left top corner of the window “Accuracy” (see Fig.8.4).

9. Convert Menu

There are two items:

- «**Report of experiment**» is used to convert saved binary data (pair of files *.bin, *.prm to the text file;
- «**Convert to IMU data**» converts saved binary data (file *.bin) to special binary file *.imu with raw IMU data used in the Inertial Explorer for post-processing of the INS and GNSS receiver data.

When **«Report of experiment»** item is selected, or button is clicked, or **F8** button is pressed (see Fig.3.6), a standard Windows «Open» window is opened. In this window operator selects one of the *.bin files saved previously when the INS was operating in its standard mode. Consequently, a report file with same name but with .txt extension is created. Note that file with an extension .prm and the same name as .bin should be present as well.

The «Report of experiment» creates text file according to the output data format of data in the binary *.bin file. Necessary data format is set by user in the «Test Options» window. Description of the text file is done in the “Appendix C.2. Text presentation of output data formats”.

10. The INS operation

10.1. The main operation modes of the INS

Step 1. Connect data transfer cable to the INS. Connect the other end of the data transfer cable to either COM port or USB port of the host computer. If connection between the computer and the INS is done through a USB port, a driver for a COM-to-USB converter needs to be installed. See Appendix A ‘Installation of the COM-to-USB converter drivers and configuration of PC parameters’ for details on the installation procedure. If it is connected to a standard PC COM port, then there are no needs to install any drivers. Note that INS manufacturer guarantees reliable operation of the INS if it is connected directly to the COM port.

Connect an active GNSS antenna to the INS TNC connector.

After power on, the INS LED indicator lights yellow. After completing of initialization of the onboard GNSS receiver (about 25 sec) the LED indicator lights red and the INS is ready for operation.

Step 2. Start INS_Demo.exe file to begin working with the Demo software. The main menu will appear (Fig.3.1).

Step 3. Select **«Test options…»** from the **«Options»** menu (see Fig.3.7) or click  button. «Test option» window (Fig.4.1) will open.

Step 4. Set the correct COM port number in the **«Serial port»** field and its baud rate as Fig.4.1 shows.

Step 5. (Not obligatory) In «Test option» window (Fig.4.1), if you need, you can set **«Record time»** of data writing when data is being saved to file and **«Number data for average»** (the quantity of averaged data) that can be used for smoothing of viewed data. Note that averaging relates to the data output on the screen only and is not applied to the data written in a file.

Note: To find the number of the COM port to which the INS is connected, see «2. Installation of drivers and configuration of the PC parameters» and «Appendix A. Installation of the COM-to-USB converter drivers and configuration of the PC parameters».

Step 6. In «Test option» window (Fig.4.1) set (check) data output mode in the «**Operating Mode**» group, and also **«Output Data Format»** (see Appendix B for more information on the output data format). Click «**OK**».

Step 7. (Not obligatory) If you want to change some parameters of the INS or its operation select «**Device options…**» or «**Swaying compensation options…**» from the **«Options»** menu – see Fig.3.7. Appropriate window (Fig.4.2 or Fig.4.17) will open. Set the necessary INS operation parameters. Click «**OK**».

Step 8. Select «**INS Visualization**» from the «**Run**» menu (Fig.3.3) or click button on the toolbar, or press **F4**. The window shown in Fig.5.1 will appear. You can switch to other visualization style by clicking on its preview on the tab. Depending on the selected style windows shown in Fig.5.3 – Fig.5.5 will appear.

Step 9. Click «**Start**» button. Initial alignment of the INS will start. This is signified by the message «Initial alignment. Please wait». Also a progress bar of initial alignment will appear in the status line of the main window. During the initial alignment the INS has to be unmovable relative to the Earth. Once the initial alignment time is over, observe changes in numeric data and graphical evolutions of the object.

Note: For visual convenience of INS position perception displayed on the monitor and the INS real position, it is recommended to place the INS in parallel with the monitor before the beginning of work as follows: direct lateral axis X to the monitor and direct longitudinal axis Y in parallel with the monitor on the left.

Step 10. If you have selected «On Request» operating mode, click «**Request**» button to get data from the INS each time if you want. Observe changes in numeric data and graphical evolutions of the object.

Step 11. To save data click «**Write**» button. Caption «Data are writing in file!» will appear. Also a progress bar of data writing and timer will appear in the status line of the main window.

In «On Request» operating mode data are written in file sequentially with the each clicking «**Request**» button.

Note: To allow data sawing the appropriate checkbox should be set in the **«Test Options»** window (see Fig.4.1).

Step 12. To stop readout and data displaying click «**Stop**» button. If the data were written in a file then the writing stops too.

Default directory for saved files is "data" subdirectory placed in the directory where file INS_Demo_*.exe is located. Default name of file with saved data is generated automatically and consists of the INS serial number, date and time digits separated by dash symbols where the first 4 digits are the year, the next 2 digits are the month, then 2 digits of day, next digits are hours, minutes and seconds of operation start. At the saving data, two files of the same name with .bin and .prm extensions are saved in the specified folder. In .bin files the measured data is saved, and in .prm files the INS microprocessor parameters, at which this data was obtained, are saved. For example, A1240013-2012-11-20-12-14-26.bin corresponds to data saved from the INS s/n A1240013 on 2012, November 20th, 2012, at 12:14:26.

Note. You can preset name of file for data writing. For this select item **«Save as»** in the **«File»** menu and enter desirable file name.

Step 13. Repeat Step 9 – Step 12 as many times as you need.

Step 14. To close standard operation mode window (Fig.5.1 – Fig.5.5) click the icon in the title of current tab.

Step 15. Select **«Stop INS» (**Fig.3.3) from the **«Run»** menu, or click button.

To get the saved data as text file, do the following:

Step 16. Select «**Report of experiment**» from the "**Convert**" menu (Fig.3.6) or press **F8** in the main menu or click button (Fig.3.1). A standard Windows «Open» window will open.

Step 17. Select the necessary file with extension .bin. Click «**OK**». A .txt file will be created with the same name and in the same folder as the selected .bin file, with format set in Step 6.

Note. When large file data is processed then some time is necessary for text file saving. If you will start new operations with Demo software before end of text file saving, then Demo software will appear as not responding or locked. Just wait some time for saving end, after that Demo software will be unlocked.

Also you can plot saved INS binary data using **"File"** menu. See section 6.1 for more details.

10.2. Control of the GNSS receiver

The Tersus INS has onboard high-grade Global Navigation Satellite System (GNSS) receiver which provide high accurate position using the next GNSS systems:

- GPS L1, L2;
- GLONASS L1;
- BeiDou B1, B3;

See sections "13.1.1. Control of PPS output signal" and "13.1.2. Control of mark inputs" for adjustment of synchro output and input signals for the GNSS receiver.

10.2.1. GNSS correction

The Tersus INS has three COM-ports. COM3 port can be used to receive data for differential corrections of GNSS.

GNSS corrections are used to improve position accuracy of the INS. There are two types of GNSS corrections: correction data from Satellite Based Augmentation Systems (SBAS) and Differential GPS (DGPS) correction data transmitted from a base station. For using GNSS correction open the "GNSS receiver" tab in the "Device options" menu (Fig.4.4), and follow the next steps to set GNSS correction:

Step 1. Set type of the GNSS correction by choosing one of the radio buttons in the “GNSS correction” field (see Fig.4.4):

- No correction – no GNSS corrections is used;
- AUTO – either SBAS or DGPS correction data can be used. DGPS has higher priority. If DGPS is not available then SBAS is used;
- SBAS – correction data from SBAS are used;
- DGPS – DGPS correction data transmitted from a base station are used.

Important note: If COM3 port is used for output of GPRMC messages (other than “No” variant is set in “GPRMC” field on Fig.4.4) then only SBAS correction can be used, all other variants are disabled.

Depending on the selected correction type parameters “Use SBAS” and “Correction format” will be available.

Step 2. If type of correction “AUTO” or “SBAS” is chosen then “Use SBAS” parameter is available. “Use SBAS” specifies type of SBAS correction. User can choose variant of SBAS correction in the drop-down list (see Fig.10.1). Default value is “Auto SBAS”.

Table 4.2. Available variants of SBAS data

Variant	Description
Auto SBAS	Automatically determines satellite system to use and prevents the receiver from using satellites outside of the service area (recommended)
Any SBAS	Uses any and all SBAS satellites found
WAAS	Uses only WAAS satellites
EGNOS	Uses only EGNOS satellites
MSAS	Uses only MSAS satellites
GAGAN	Uses only GAGAN satellites
QZSS	Uses only QZSS SAIF signals

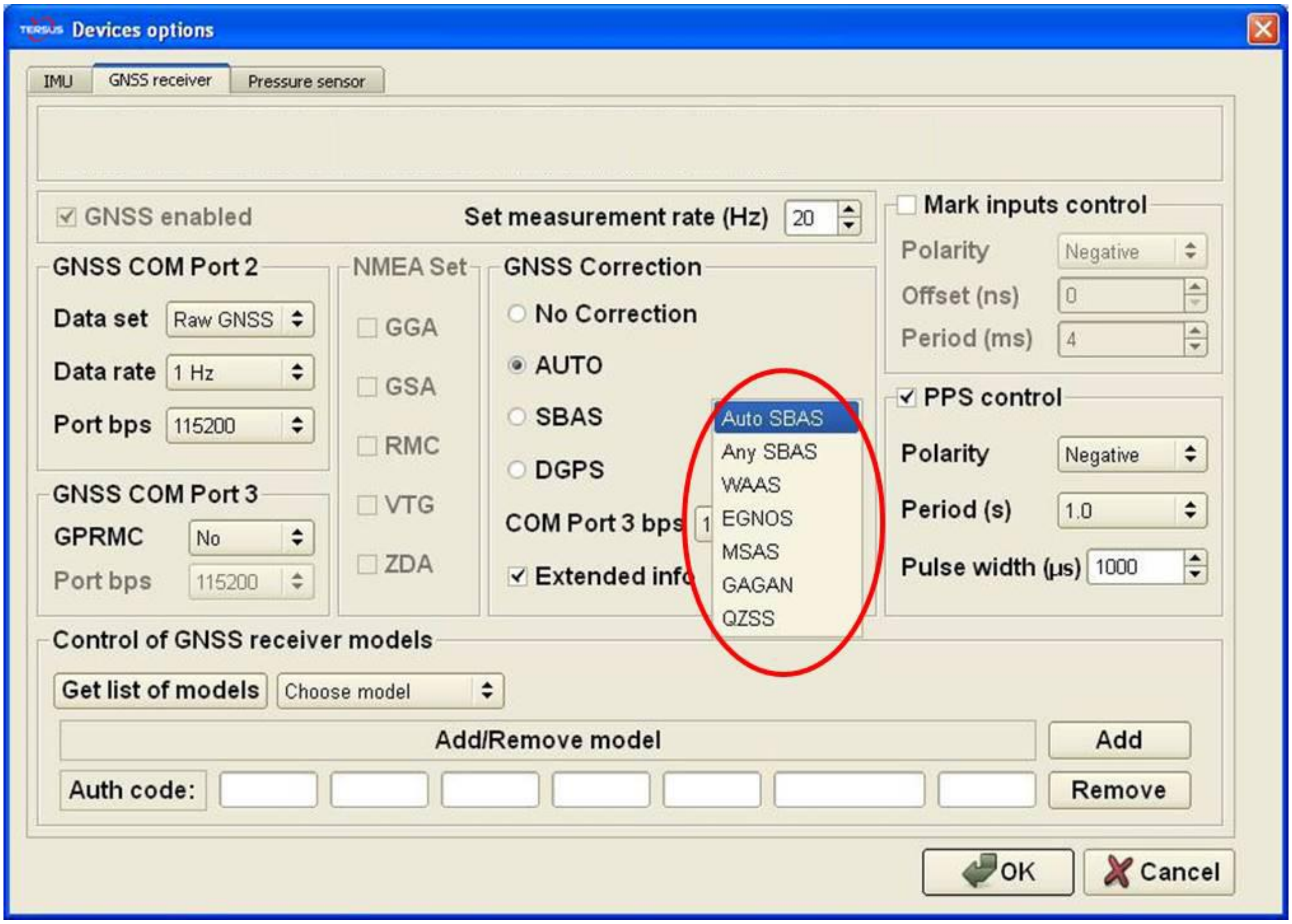


Fig.10.1

Step 3. When type of correction “AUTO” or “DGPS” is chosen then “Correction Format” parameter is available. “Correction Format” parameter specifies format of differential corrections. User can choose type of DGPS correction format in the drop-down list (see Fig.10.2):

- AUTO – auto-detection of correction format;
- RTCMv2 – accepting of corrections in format RTCM version 2;
- RTCMv3 – accepting of corrections in format RTCM version 3.

Default value is “Auto”.

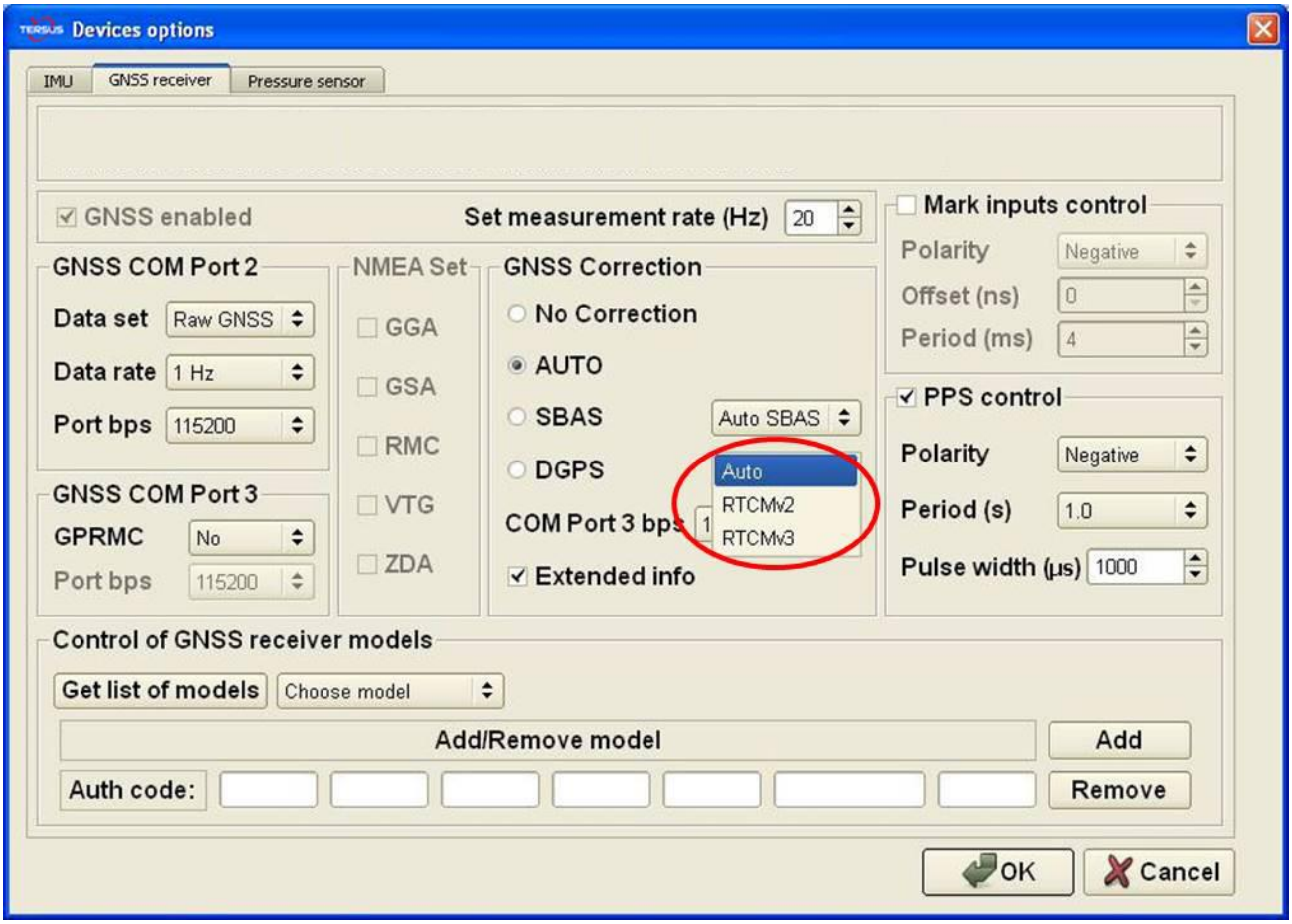


Fig.10.2

Step 4. When type of correction “AUTO” or “DGPS” is chosen it is necessary to set correct baud rate of the COM Port wich provides GNSS corrections in the “COM port bps” field. User can choose needed COM Port baud rate in the drop-down list (see Fig.10.3). Default value is “115200”.

Step 5. Click “OK” to send changed settings to the INS.

Important note: **it is necessary to power off / on the INS after changing any of parameters in GNSS Correction field to restart the GNSS receiver with new settings.**

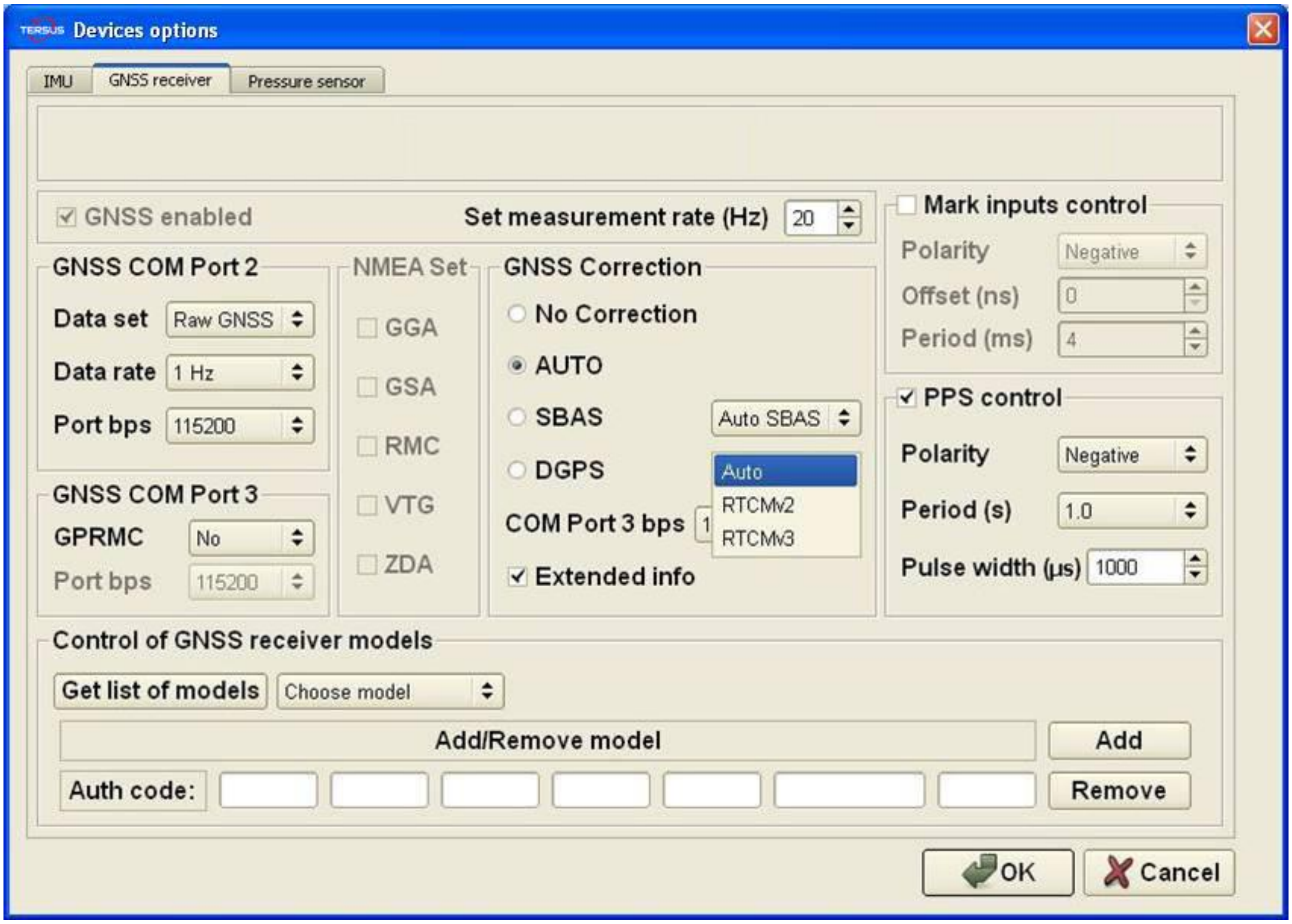

Devices options
IMU
GNSS receiver
Pressure sensor
GNSS enabled
Set measurement rate (Hz)
20
Mark inputs control
Polarity
Negative
Offset (ns)
0
Period (ms)
4
GNSS COM Port 2
Data set
Raw GNSS
Data rate
1 Hz
Port bps
115200
NMEA Set
GGA
GSA
RMC
VTG
ZDA
GNSS Correction
No Correction
AUTO
SBAS
Auto SBAS
DGPS
Auto
RTCMv2
RTCMv3
COM Port 3 bps
Extended info
PPS control
Polarity
Negative
Period (s)
1.0
Pulse width (µs)
1000
GNSS COM Port 3
GPRMC
No
Port bps
115200
Control of GNSS receiver models
Get list of models
Choose model
Add/Remove model
Add
Auth code:
Remove
OK
Cancel

Fig.10.3

10.3.Features of Altitude and Heave calculation in the INS

At its operation the Tersus INS calculates position using its sensors data with correction from the onboard GNSS receiver. Also, for altitude calculation the INS can use correction from the onboard pressure sensor.

In practice the GNSS altitude data are much less accurate than the horizontal position (because of high vertical dilution of precision). Using a static pressure sensor (barometer), as an aiding sensor for the altitude, increases the vertical accuracy. Though the relation between altitude and pressure is dependent on many factors, the most important is the “weather”.

The Tersus INS allows two variants of the altitude correction that depends on the “Baro-altimeter enabled” checkbox in the “Pressure sensor” tab of «Devices Options» window (see Fig.4.7):

a) correction by altitude and vertical velocity provided by GNSS data if Baro-altimeter is disabled;
b) correction by barometric altitude calculated using pressure sensor data and vertical velocity provided by GNSS data if Baro-altimeter is enabled.

The default value is Baro-altimeter disabled.

Important note: To measure barometric altitude the pressure sensor in the INS must have access to the ambient external pressure. Also the pressure sensor must not be exposed to high speed air streams. So if the INS is installed inside a pressurized cabin or outside the high-speed object, please uncheck the “Baro-altimeter enabled” checkbox (see Fig.4.7) to switch to the GNSS altitude for INS correction.

Note in both variants of the INS altitude correction, the initial altitude is equal to altitude provided by the GNSS receiver if it has solution. If GNSS data are not available then the initial altitude is equal to its value stored in the INS nonvolatile memory. There initial altitude can be changed in the “IMU” tab of the «Devices options…» window (see Fig.4.2).

Also the INS-D can calculates heave for marine applications. Heave is a ship motion along the vertical axis.

All output data formats (see Fig.4.1 and Appendix B) contain data about either altitude or heave depending on the switch “Vertical position” in the **“IMU”** tab of the «**Devices Options**» window (see Fig.4.2).

- “Altitude” causes output of the INS altitude;
- “Heave” causes output of heave.

Though the “Vertical position” switch is active only for INS-D units. INS-B and INS-P units do not calculate heave.

Note: Heave calculation also can use data from the pressure sensor (at Baro-altimeter enabled). In that case the pressure sensor in the INS must have access to the ambient external pressure, and the pressure sensor must not be exposed to high speed air streams.

10.3.1. Adjustment of the algorithm of heave calculation in INS-D

To calculate the heave as the INS-D vertical position with respect to its equilibrium position, the vertical acceleration is doubly integrated. However, because signals from accelerometers always contain a DC component as well as spurious low frequency components, after integration the heave error is accumulated and increases with time significantly. To avoid such error, integrated signals are filtered by High-Pass (HP) filter. Also, to decrease noise the Low-Pass (LP) filter can be applied.

Values of HP and LP cutoff frequencies, fh_HP and fh_LP for the heave filter can be set in the “Heave calculation” tab of the «Correction Options» window (see Fig.4.16).

The main adjustment parameter is cutoff frequency for heave HP filter, fh_HP. It must be much less than the main frequency of a ship vertical motion. But very low value of the fh_HP allow accelerometers’ bias instability to affect the heave accuracy. The default value is fh_HP = 0.02 Hz that should be enough for intensive vertical motion of a ship.

Value of the fh_LP must be not less than fh_HP.

For switch-off HP or LP filter pease set to thero appropriate cutoff frequency fh_HP or fh_LP. The default values are fh_HP = 0.02 Hz; fh_LP = 0.

The “Target position relative to the IMU (m)” parameters determine the position of target relative to the IMU in meters.

Since firmware version 2.0.1.2 it is possible to use the adaptive algorithm of heave calculation. For that purpose set parameters in the “FFT Settings” field.

Power_fft_min – is the threshold of fast Fourier transform (FFT) spectrum power at which the adaptive filter parameters are recalculated. F_fft is frequency of the adaptive filter parameters recalculation. The default values are Power_fft_min = 40 and F_fft = 0.04.

Notes

1. The FFT settings can be changed, but only under guidance of the INS developer.
2. Initialization of the adaptive algorithm takes approximately 100 seconds. During this initialization heave is calculated roughly.

10.3.2. Heave calculation for chosen point of the carrier object

Usually heave is calculated for place of the INS mounting on the carrier object. But it is possible to set desirable point on the carrier object for heave calculation. For this purpose please set coordinates of this point relative to the INS position, in the object axes – on the right, forward and up – in the “Heave calculation” tab of the «Correction Options» window (see Fig.4.16).

10.4. Calibration of the INS

For correct operation of the INS it is necessary that the calibrated sensors are not distorted by external influences. It is particularly important to provide non-distortion of the INS magnetic channel, as, due to the presence of the carrier’s hard and soft iron in the vicinity to the INS, its magnetometers will be outputting inaccurate data on the actual Earth magnetic intensity vector, and, accordingly, inaccurate carrier’s heading angle value.

The Tersus INS software allows compensation of influence of the carrier object soft and hard iron on the heading angle calculation accuracy. For this purpose, field calibration of the INS magnetometers is provided. This calibration does not require any additional equipment, but it requires turns of the carries object on which the INS is mounted.

Note **INS does not require calibration of its magnetometers on hard/soft iron if "Use_mags" switch is disabled in the "Settings" tab of «Correction options…» window Fig.4.14.**

The INS can be calibrated using 2D, 3D or 2D-2T calibration procedure.

2D calibration is designed for carrier objects that move with small pitch and roll angles (not more than a few degrees). The calibration procedure involves a few full 360° rotations in the horizon plane of the carrier object with the installed INS (see Fig.10.4). During this calibration pitch and roll angles must be as close to zero as possible.

3D calibration is designed for carrier objects that can operate with large pitch and roll angles. For this calibration the carrier object is rotated in the horizon plane (the Z-axis is up) with periodical stops about each 90 degrees for tilting in pitch and roll (see Fig.10.4 – Fig.10.6). After full 360° rotation the object with the INS is turned over (the Z-axis is down) and the procedure described above should be repeated. During this calibration the range of pitch and roll angles changing must be as much as possible.

2D-2T calibration is designed instead of 3D calibration for carrier object that operates with limited range of pitch and roll angles. This calibration involves several (two or more) 2D calibration procedures but with different pitch angles. During every 2D calibration run with set pitch angle, tilt angles must be constant as possible. In the calibration those INS readings are used only in which pitch and roll differ from their median not more than inclination threshold set in appropriate field Fig.4.3.

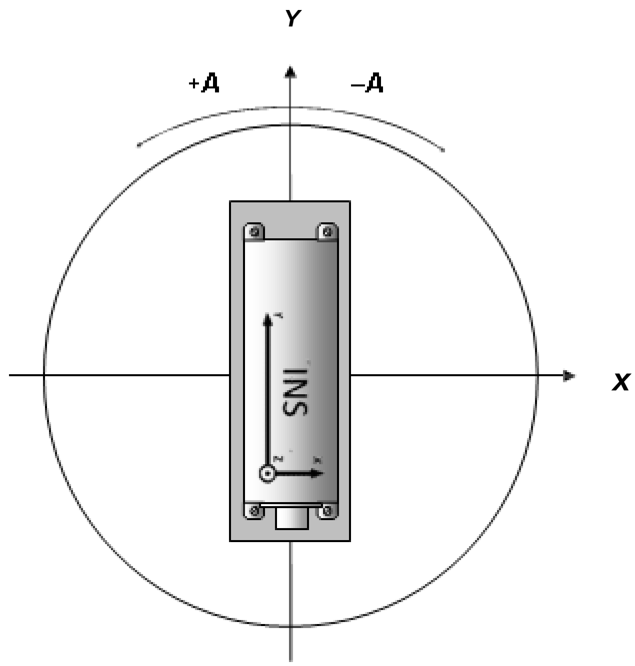


Fig.10.4. Rotation of a carrier object with INS in horizontal plane

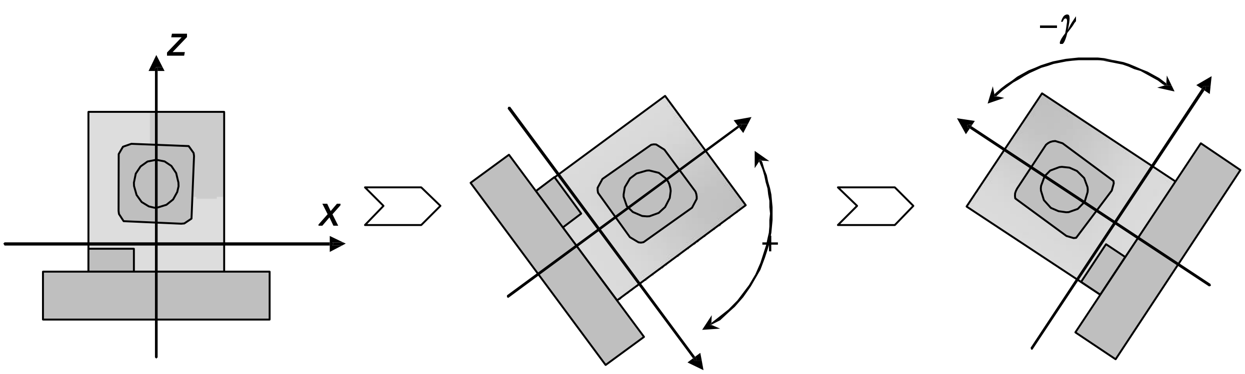


Fig.10.5. Rotation of a carrier with INS in roll

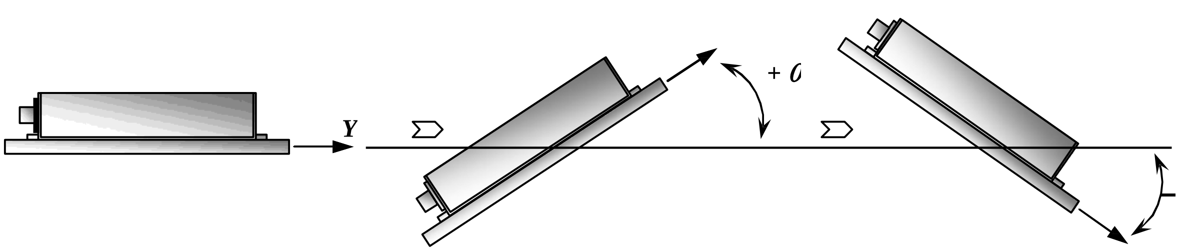


Fig.10.6. Rotation of a carrier with INS in pitch

Note that rotation of the carrier object with the INS both for all calibration procedures must include one or more full 360° turns in the horizon plane.

Field calibration procedures are developed by Tersus after type of the object, on which the Tersus® INS will be installed, is agreed on with a customer.

10.4.1. Description of the 2D, 3D and 2D-2T calibration procedures

Step 1 – Step 2. Perform Step 1 – Step 2 from the section 10.1.

Step 3. Set correct coordinates “**Latitude**”, “**Longitude**”, “**Altitude**” and “**Date**” in accordance with place where INS is calibrated. Their values are set in the «Device Options» window (see Fig.4.2).

Step 4. Select «**Mag Field Calibration**» item from the «**Plugins**» menu (Fig.3.4). «Mag Field Calibration» window (Fig.8.3) will open.

Step 5. Select «**2D**», «**2D-2T**», or «**3D**» calibration from drop-down list in the «**Calibration Type**» field.

Step 6. Using arrows or entering the necessary value from a keyboard set the time required for accumulating data which would be sufficient to accomplish the calibration procedure, in the «**Accumulation time»** window. Please set time which is enough for 1…3 full 360° turns of the carrier object in horizon plane. Usually 60 seconds for 2D calibration and 120 sec for 3D calibration are enough.

Step 7. Click «**Start**» button. In “Calibration status” window a few captions are highlighted (see Fig.10.7):

IS_STARTED – reports that calibration procedure is started;
NEXT_REQUESTED – asks to click the «**Next**» button to start the calibration run;
STOP_REQUESTED – informs you can click «**Stop**» button to stop calibration run;
EXIT_REQUESTED – informs you can click «**Exit**» button to exit from the calibration procedure.

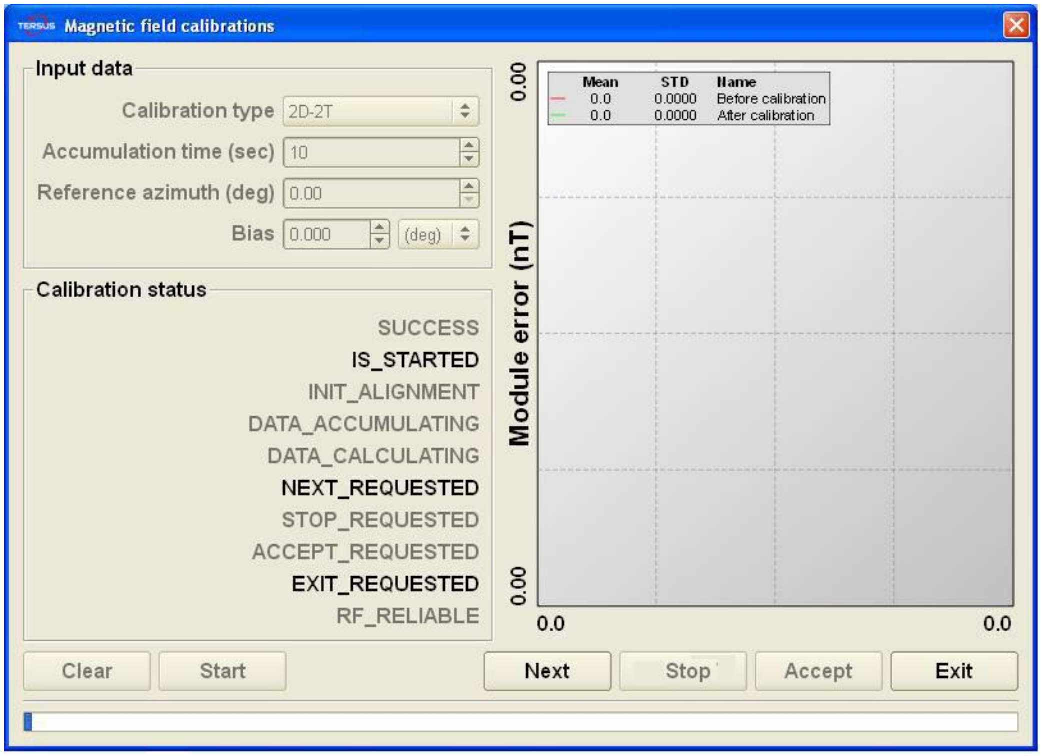


Fig.10.7

Step 8. Press "Next" button. Initial alignment of the INS will start, signified by the highlighted caption **INIT_ALIGMENT** (see Fig.10.8). During the initial alignment, the <u>INS should be unmovable relative to the Earth</u>.

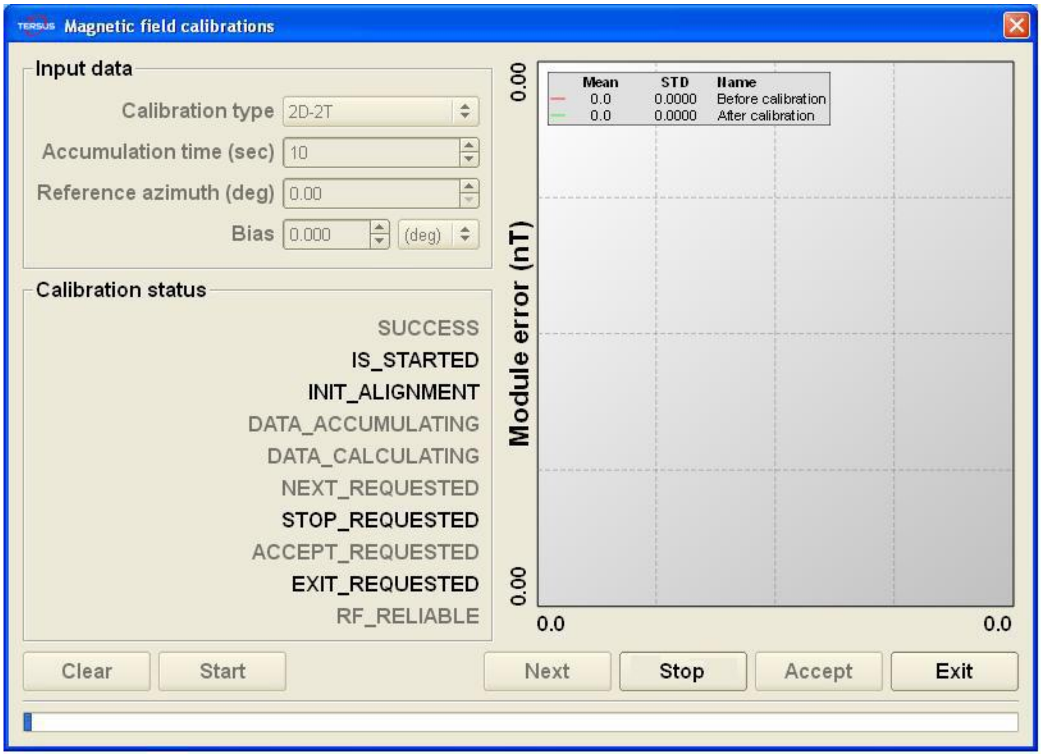


Fig.10.8

Once the initial alignment is completed, the INS starts accumulating data. This is signified by the highlighted caption **DATA_ACCUMULATING** and the progress bar of data accumulation in the status line (see Fig.10.9). At this time, rotation of the carrier object with the INS should be made.

If the **2D calibration** is chosen then rotation of the object with the INS in the horizon plane should be performed (see Fig.10.1). After time of the data accumulation expires then result window will appear (see Fig.10.10)

For **3D calibration** the carrier object is rotated in the horizon plane (the Z-axis is up) with periodical stops about each 90 degrees for tilting in pitch and roll (see Fig.10.1 – Fig.10.6), and then the carrier with the INS is turned over (the Z-axis is down) and the procedure described above should be repeated. Tilt angles range depends on the carrier object, but to obtain the better result increase the angles range as much as possible.

Note: the INS Demo Software provides estimation of 3D calibration quality in terms of possible INS heading accuracy. To allow this possibility it is necessary to include additional rotation of the INS with the carrier object in the horizon plane on about 360 degrees or more with pitch and roll near the level. Acceptable pitch and roll change are set by the "Pitch/Roll threshold" parameter in the "Magnetometers calibration options…" window Fig.4.20.

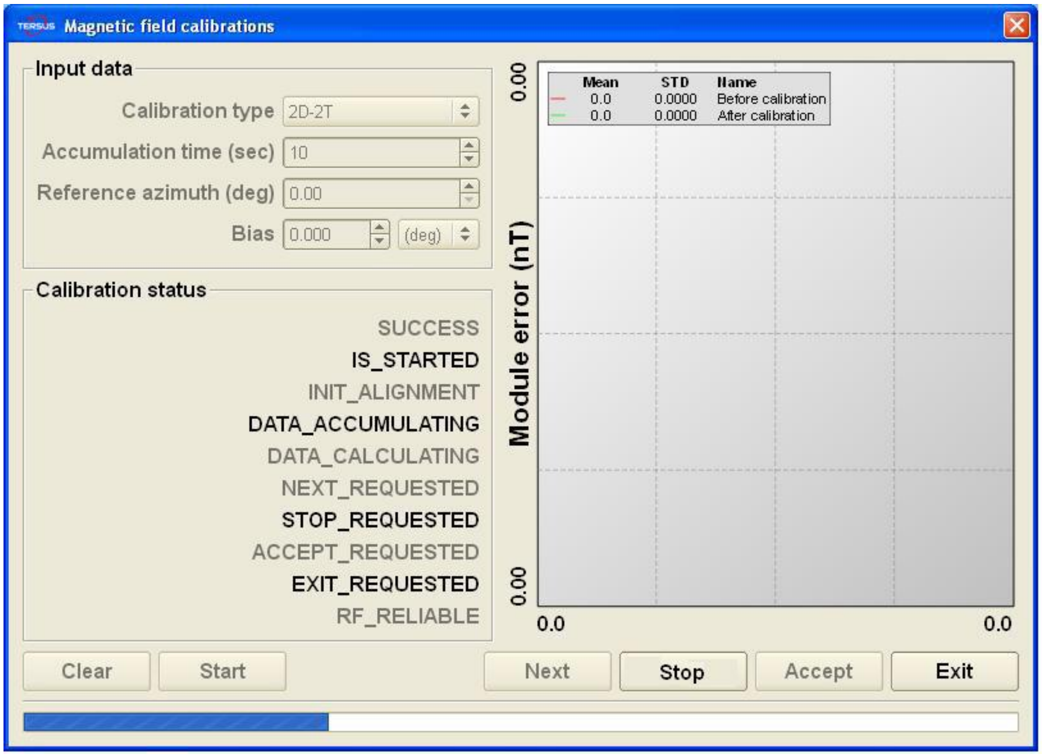


Fig.10.9

After time of the data accumulation expires then result window will appear (see Fig.10.10).

Result window Fig.10.10 includes the next information:

- success of the calibration;
- calibration error is predicted maximum (3 sigma) heading error of the INS at accepting the calibration;
- used points is percent of accumulated data used at calculations.

Click "**OK**" to close information message.

The **2D-2T calibration** consists of several runs. Set the object with the INS to specific pitch angle (for example, to the minimum pitch angle). Rotate object in azimuth with approximately constant pitch and roll. After time of the first run of the INS rotation will be reached result window will appear (see Fig.10.11). Based on the calibration accuracy it is necessary to accept or decline this run. Then it is necessary to set the INS to the next pitch angle and repeat calibration procedure as the next run.

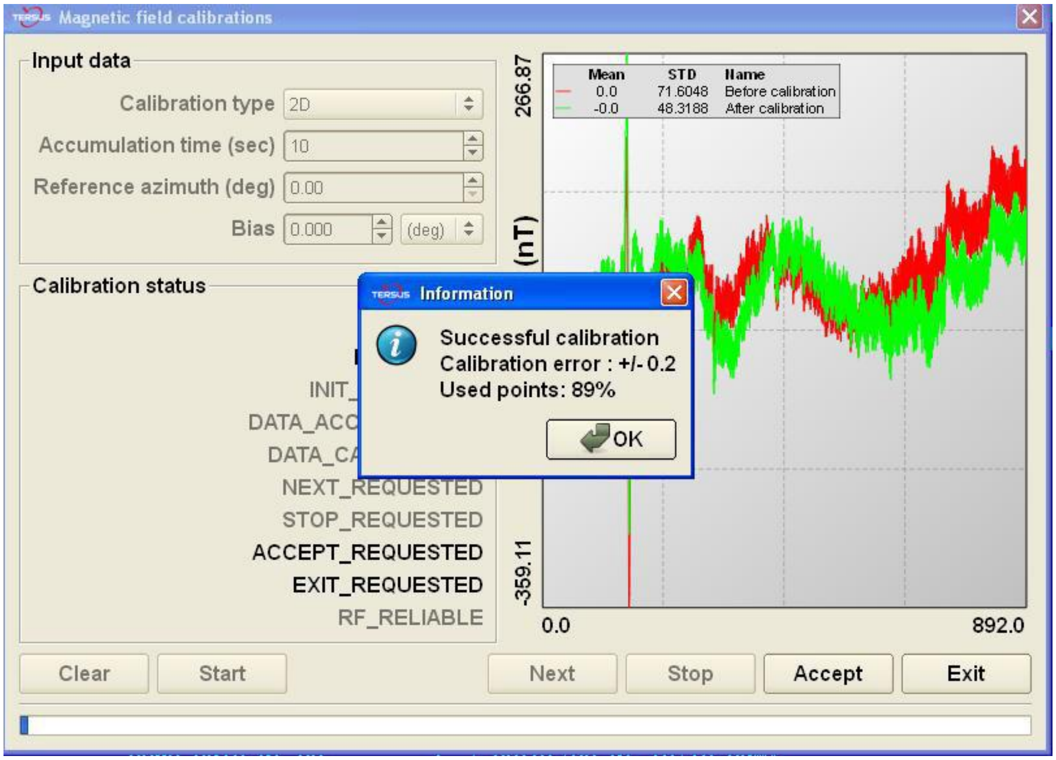


Fig.10.10

Quality of the 3D calibration will be estimated in terms «Excellent calibration!», «Good calibration» or «Acceptable calibration» (see Fig.10.12) instead of predicted INS heading error if 3D calibration run did not include additional rotation of the INS in the horizon plane on about 360 degrees or more with pitch and roll near the level (see above Note).

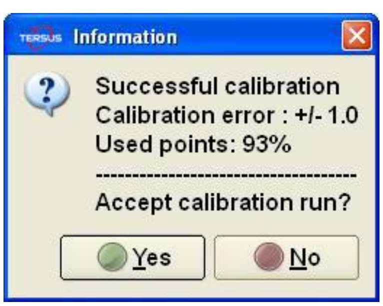


Fig.10.11

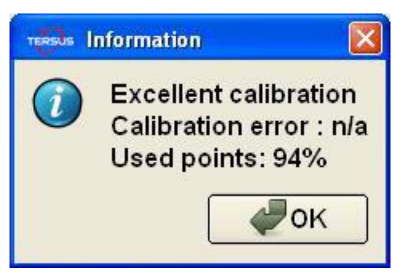


Fig.10.12

If the INS detected not successful initial alignment or other mistakes in INS operation, then the error like «Non-zero USW was detected 0000000000000001» appears Fig.10.13. Meaning of other non-zero bits of

USW see in Appendix D. The Unit Status Word definition. In case of non-zero USW the calibration run should be not accepted.

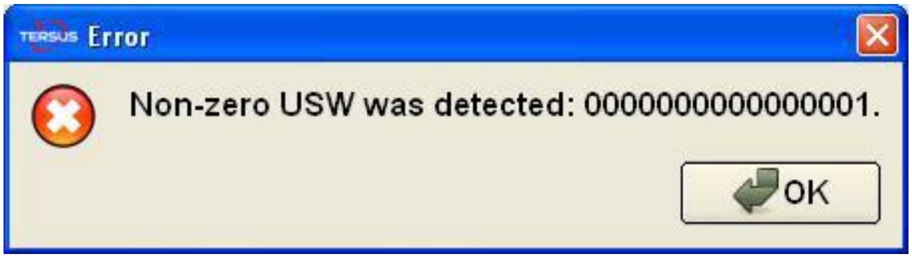


Fig.10.13

If calibration quality is acceptable caption **ACCEPT_REQUESTED** is highlighted (see Fig.10.14).

If the INS detected not successful initial alignment or other mistakes in INS operation, then repeat Step 8.

For the next run of the **2D-2T calibration** the object with INS should be turned to the next pitch angle. Click «Next» button on window Fig.10.14 and repeat calibration procedure as in the second stage.

2D-2T calibration allows making as many stages with different pitch angles as needed.

Note: Rotation of the object with the INS in the horizon plane both for 2D, 2D-2T and 3D calibration must include one or more full 360° turns. Please, correct the time required for saving data in the «**Accumulation time»** window to attain necessary rotations.

Step 9. Once the data accumulation time is over at 2D, 3D calibration, or 2D-2T calibration is stopped after any stage, then window Fig.10.14 appears where graphs of errors before and after calibration are shown. Plotted graphs are scalable. To zoom in please click and hold left button on mouse and drag mouse in down-right direction. Click and hold right button on mouse to shift plot. To zoom out please click and hold left button on mouse and drag mouse in up-left direction. Legend is located at the left upper corner of the tab. This legend shows mean value, STD and name of displayed graphs. It is possible to select the graphs you want to display by right-click on the graphs area.

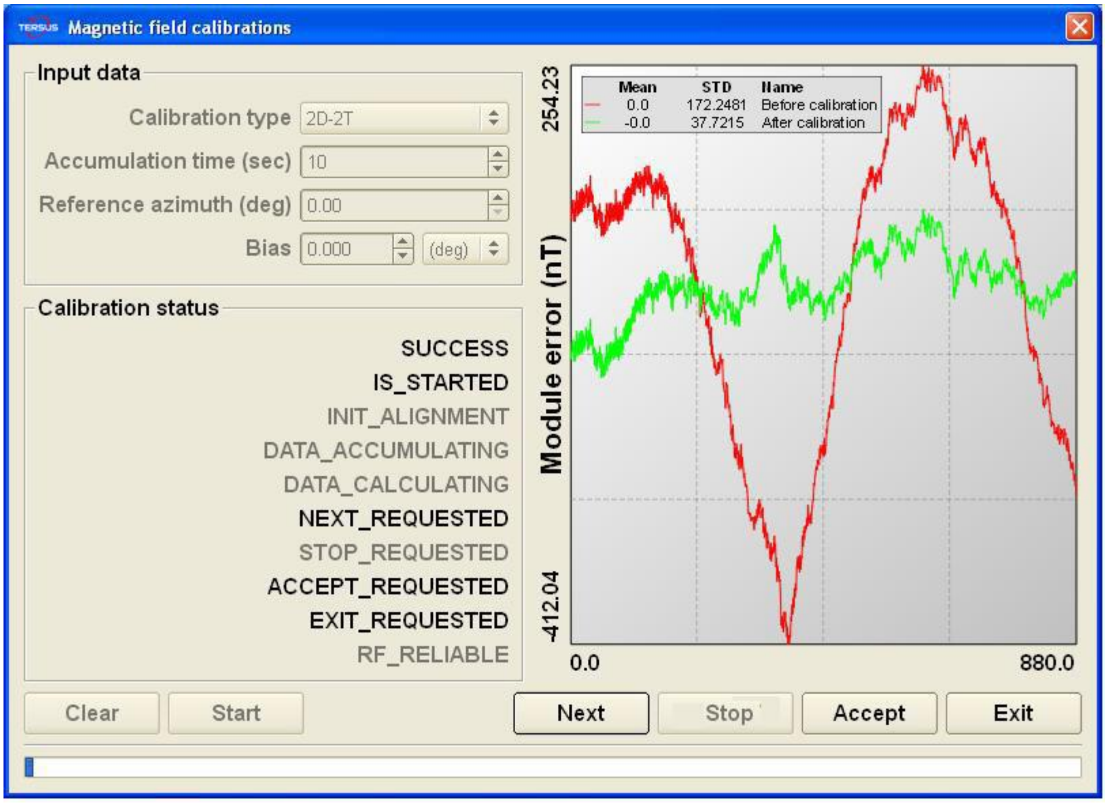


Fig.10.14

Step 10. Estimate the calibration quality. If the calibration was successful and predicted heading accuracy is acceptable on window Fig.8.8 or captions «Excellent calibration!» or «Good calibration» appear in the window Fig.10.12, then click «**Accept**» button (Fig.10.14) to accept calibration parameters. «Acceptable calibration» caption is satisfactory too but we recommend to recalibrate the INS.

There are two highlighted captions:

ACCEPT_REQUESTED – informs you can click «**Accept**» button to accept calibration parameters;
EXIT_REQUESTED – informs you can click «**Exit**» button to exit from the calibration procedure without saving of calibration parameters.

If to click the «**Accept**» button, then calibration matrix of the magnetometer biases and scale factors will be calculated and saved to the INS nonvolatile memory automatically.

If calibration results were accepted then in the directory in which the INS_Demo.exe file is located, files with .prm, and .amd extension will be created.

Notes.

1.Filename consists of the INS serial number, text _ MagField _ and 6 digits that indicates time when the file was saved (2 digits of hours, 2 digits of minutes, 2 digits of seconds). The last symbols in filename corresponds to type of the performed calibration: _2D corresponds to data of 2D calibration; _3D – for 3D calibration; _2D_2T – for 2D_2T calibration. Example of files name: 106A0016_MagField_140838_2D.prm, 106A0016_MagField_140838_2D.amd.

2.Default directory for saved files is “data” subdirectory placed in the directory where file INS_Demo_*.exe is located.

Step 11. If the calibration is unsuccessful, then window Fig.10.15 appears with a caption «Unsuccessful calibration. Try again!».

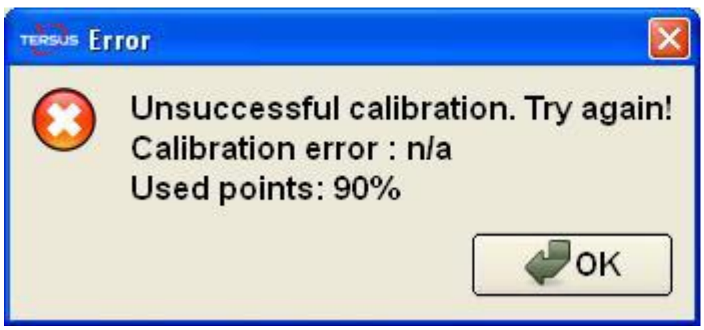


Fig.10.15

One reason of unsuccessful calibration may be small range of angles of the INS real rotation. In this case a caption «Calibration failure! Rotation of the device is required!» appears (see Fig.10.16). To avoid this please repeat calibration procedure with rotation of the INS as it is described in the beginning of this section. Some more reasons of unsuccessful calibration are discussed in the section “10.4.3.Conditions of successful calibration of the INS”.

Fig.10.16

Step 12. If you want to finish the calibration without accepting of calibration result click «**Exit**» button on the calibration window. Calculated calibration parameters are not saved to the INS nonvolatile memory and no files are created with calibration results.

Step 13. Click button to close the calibration window.

10.4.2. Clearing of the soft and hard iron calibration parameters

To remove results of magnetometers field calibration from the INS memory, follow Step 1, Step 2 from the section 10.1. Then select «**Mag Field Calibration**» item from the «**Plugins**» menu and click the «**Clear**» button in opened window (see Fig.8.3). Soft and hard iron calibration parameters will be removed from INS memory. The window with message «**Magnetic field calibration parameters were cleared successfully!**» appears over above window (see Fig.10.17). Click «OK» and close calibration window.

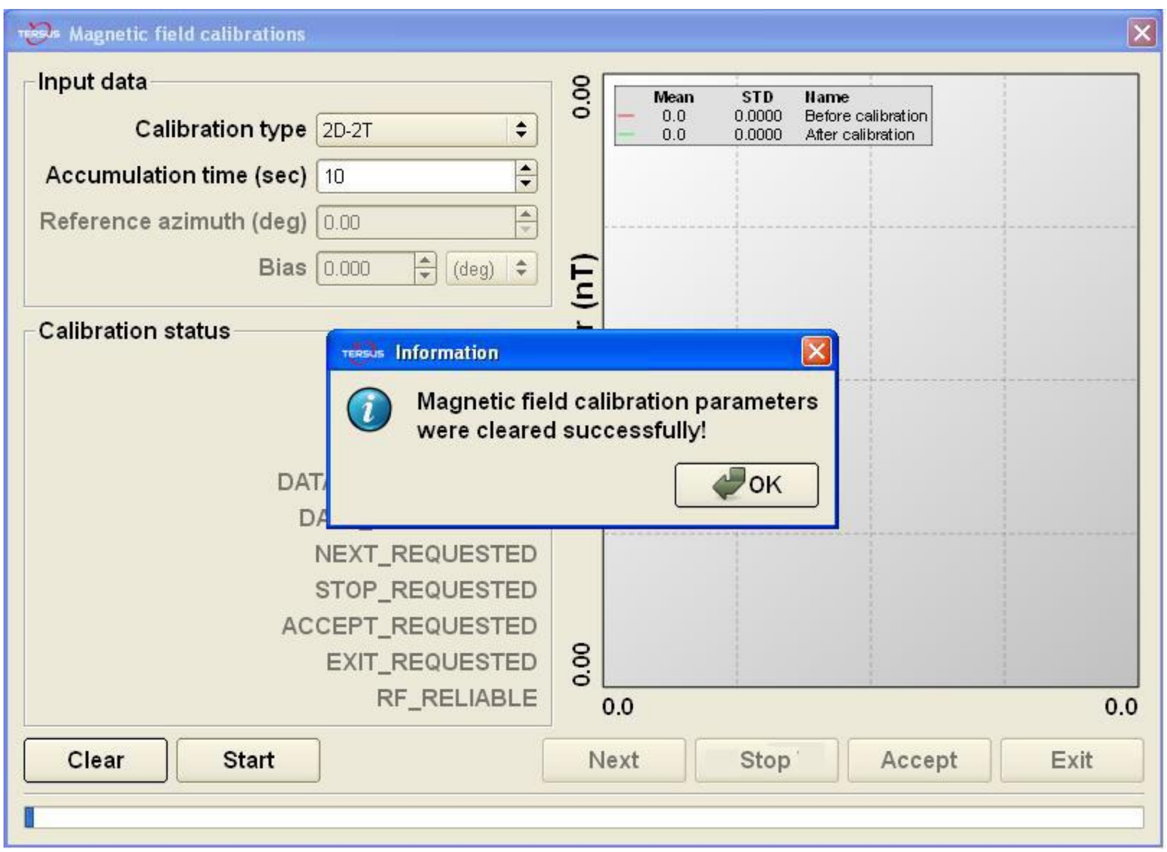


Fig.10.17

After parameters removing the file *.prm will be created with name *_CLEAR.prm (for example 106A0016_MagField_115942_CLEAR.prm).

You must clear parameters of the soft and hard iron calibration if you uninstall the INS from carrier object to avoid incorrect heading calculation. Please remember that performed soft and hard iron calibration is valid until the INS is mounted on the object with which the calibration was performed.

When calibration was accepted then during operation with INS in the “INS visualization” window (see Fig.7.1) a capture “**Soft/hard iron corrected**” appears In the lower right part of this window. If calibration parameters are cleared in the INS, then capture “Soft/hard iron corrected” disappears.

10.4.3. Conditions of successful calibration of the INS

Success of the INS calibration on soft and hard iron of the carrier object essentially depends on magnetic environment at the place where this calibration is performed.

The best results will be got if calibration is performed in homogeneous magnetic environment where the magnetic force lines are parallel to each other. In this case only influence of the carrier object on the INS magnetometers take place, and this influence can be compensated after calibration procedure.

However, magnetic environment often is not homogeneous at place where calibration of the INS is performed. This may lead to degradation of the calibration results since INS magnetometers are disturbed both by iron of the carrier object and by curved outward magnetic field. In this case it may be very difficult to separate influence of these 2 disturbance sources on the INS.

Tersus engineers have developed special calibration procedure for separation of these sources of magnetic disturbance to take into account and compensate just influence of the magnetic field of the carrier object. But residual influence of non-uniformity of environmental magnetic field may still decrease calibration accuracy. After a lot of experiments Tersus engineers have determined acceptable limits of non-uniformity of environmental magnetic field at which the INS heading accuracy after calibration is satisfactory.

If the INS calibration procedure was performed in the strict accordance with procedure described in section 10.4 but calibration is unsuccessful, then place of the calibration has large distortion of the Earth uniform magnetic field. To repair this problem please change place of the calibration. For example, usually bad places for the calibration are office room, laboratory with large quantity of computers and other electronics equipment, road with underground communications or pipelines, place near electric mains, etc.

But even in bad magnetic environment the calibration can be successful if the INS rotates around its magnetometers (around the point about 15 mm away from the INS forward end). In this case influence of non-uniformity of environmental magnetic field is minimal.

Finally, please remember that if the carrier object is changed or if place of the INS mounting on the carrier object is changed, the new calibration should be performed. If the INS will be used alone without mounting on any object then calibration results should be cleared by clicking on the «**Clear**» button (see Fig.8.3).

10.5. Orientation accuracy test of the INS

To check INS accuracy it is recommended to use “Tersus INS Demo” software, which allows to estimate accuracy of a INS in given range of orientation angles. At the same time it is necessary to use special device allowing to set angular positions of the INS strong with respect to tested angles. The INS should be rotated just in plane of one of its base surfaces.

The “Tersus INS Demo” software allows two variants of INS accuracy test:

- Angles accuracy, at which the INS restarts each time after it set on new reference angle;
- On-the-fly accuracy when INS operates continuously at setting and changing of reference angles (See section "5.3. On-the-fly accuracy style of visualization").

“Angles accuracy” is more convenient for further analysis. In this case separate data file is created for each tested INS position. “On-the-fly accuracy” is designed for continuous INS operation at it setting to different reference angles. This has sense at magnetic interference tests, for example.

10.5.1. Separate accuracy test for each reference angle

Step 1. Carefully set INS by two reference surfaces on platform of the test bench designed for accuracy check.

Step 2 - Step 5 – Perform Step 1- Step 4 from the section 10.1.

Step 6. Select **“Angles Accuracy”** from the **”Plugins”** menu (Fig.3.4). Accuracy check window will appear (Fig.8.4). In the left upper corner of the dropdown window choose orientation angle (Heading, Pitch or Roll) for the INS testing.

Step 7. Click «Devices…» button. «Devices Properties…» window (Fig.8.5) will appear.

Step 8. Select required amount of the tested INS units in «Number of Devices» field.

Step 9. In the column «COM-port» in dropdown windows «COMN» choose COM-ports to which the INS units are connected. Click «Scan» button. In the column «Device Name» INS units are determined in accordance with chosen COM-ports. Button «OK» becomes active.

Step 10. If all INS units under test successfully determined, click button «OK». Window «Devices Properties…» will close and found connected INSs will appear in the accuracy check window instead of label “NoName”.

Step 11. If orientation angles of the INS indicated in the column «Angles…» correspond to angles with which testing will be carried out, then this step can be omitted. Otherwise, click the button “Angles” and window “Accuracy Properties” will appear (see Fig.8.6), in which the operator sets check accuracy angles “Accuracy checking points”, the necessary time “Accumulation Time” of data collecting while the measurement in each position of the INS, and chooses (if necessary) «Temperature Sensor» for the temperature control.

Step 12. If angles of obliquity of the INS set on the test bench platform are known, input their values in fields of the «Tilter» window.

Step 13. With the help of special setup device set sequentially angular positions of the INS in accordance with the values indicated in «Angles» column. Then click on "Accumulate Data" button to start INS. See in the window the behavior of INS angle. After time of run complete, the window is opened with averaged errors of the INS.

Step 14. Repeat Step 13 for each reference angle indicated in the «Angles» column.

Step 15. After the end of the accuracy test cycle in all positions given in the column «Angles», on the page "Angle Error, deg" the plot of given angle calculation error is displayed and the minimal and maximal error values during the test, its root-mean-square value (RMS) are indicated. Also standard deviation (STD) of measurement noise at last position of the INS is displayed.

Step 16. To close the accuracy check window (Fig.8.4) click button « » in the right upper corner of the window. At this window is appeared with question about saving plot of error to .bmp file.

For each run the .txt file is created with saved INS data in the "data" subdirectory. File name consists of s/n of INS, indication what INS angle was tested (H – heading, P – pitch, R – roll), reference angle, reference temperature, time of run. For example, file "106A0016_H(38.22)_T(+27)_1831.txt" corresponds to data saved from the INS s/n 106A0016 at Heading accuracy test for target angle 38.22。 at 18:31.

Also the file of the report like Accuracy_2010991830.txt is created where numbers are year, month, day, hours, minutes of performed test. there are averaged data for each INS run at accuracy test. In the first column of this file there is INS s/n, second column is number of reference angle starting from zero, 6^{th} – 7^{th} columns are averaged Heading, Pitch and Roll measured by INS.

10.5.2. On-the-fly accuracy test

Step 1. Carefully set INS by two reference surfaces on platform of the test bench designed for accuracy check.

Step 2 - Step 7 – Perform Step 1- Step 6 from the section 10.1.

Step 8. Select **“INS visualization”** in the **“Run”** menu (Fig.3.3) and then click on the “Snapshot” preview shown in the Fig.5.2c. Window shown in the Fig.5.4 will appear.

Step 9. Click «**Start**» button. Initial alignment of the INS will start. This is signified by the message «Initial alignment. Please wait». Also a progress bar of initial alignment will appear in the status line of the main window. During the initial alignment the INS has to be unmovable relative to the Earth. After initial alignment completes, see changes in numeric data of INS.

Step 10. (Not obligatory) To save INS data click «**Write**» button. See a progress bar of data writing and timer will appear in the status line of the main window. Note the accuracy test data are written to file *.csv independently on saving the INS main data.

Step 11. When the INS is set in necessary position and is ready to save data, click **“Snapshot”** button. Window shown in Fig.10.18 will appear.

Depending on known target orientation (its relative or absolute azimuth and pitch/elevation) select **“Heading”** or/and **“Pitch”** checkboxes (see Fig.10.18).

Fig.10.18

Enter values according to true reference angles. This angles can be set using arrows or by entering the necessary value from a keyboard.

If no checkboxes are checked then only current INS angles are saved.

Then press **“OK”** button. New tab “Snapshots” like shown in Fig.10.19 will open. Return to previous tab by clicking on its title “INS visualization”

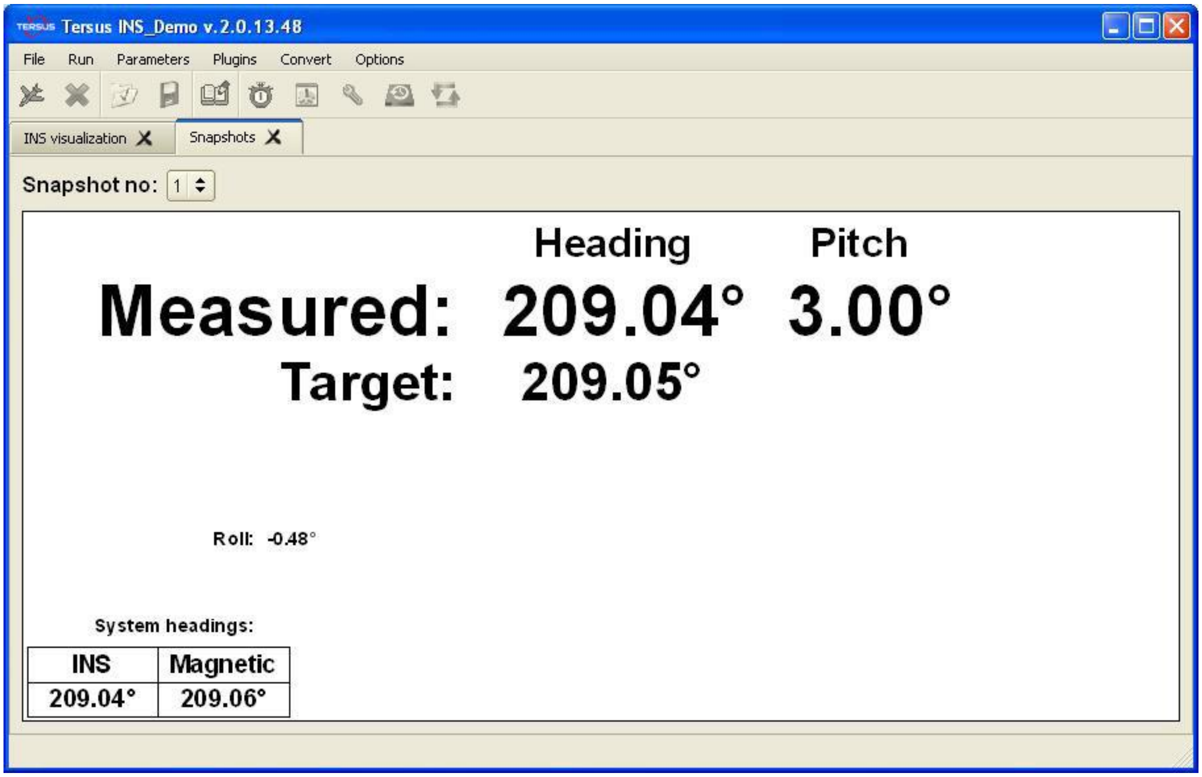
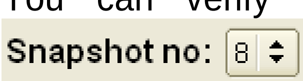


Fig.10.19

Step 12. Rotate INS in the next position and repeat Step 11 as many times as you need. Azimuth value for each new position can be entered in the **“Heading”** field directly or as relative azimuth in the right field. It is measured by means of object sight unit or separate device (like theodolite). Azimuth of these relative position can be set in degrees or in mils depending on chosen item in drop-down list «**(deg) / (mils)**». Relative azimuth in degrees is considered to be positive in case of clockwise rotation from reference to calibration point and negative in case of counter-clockwise rotation. Relative azimuth in mils is positive in case of counter-clockwise rotation from reference to calibration point and negative in case of clockwise rotation (according to sight unit scale).

You can verify all snapshots data by clicking on the arrow button 

. After each snapshot calculation is performed and graph

Heading Error is plotted (Fig.10.20). “Heading error (deg)” graph shows difference between INS measurements and reference angles.

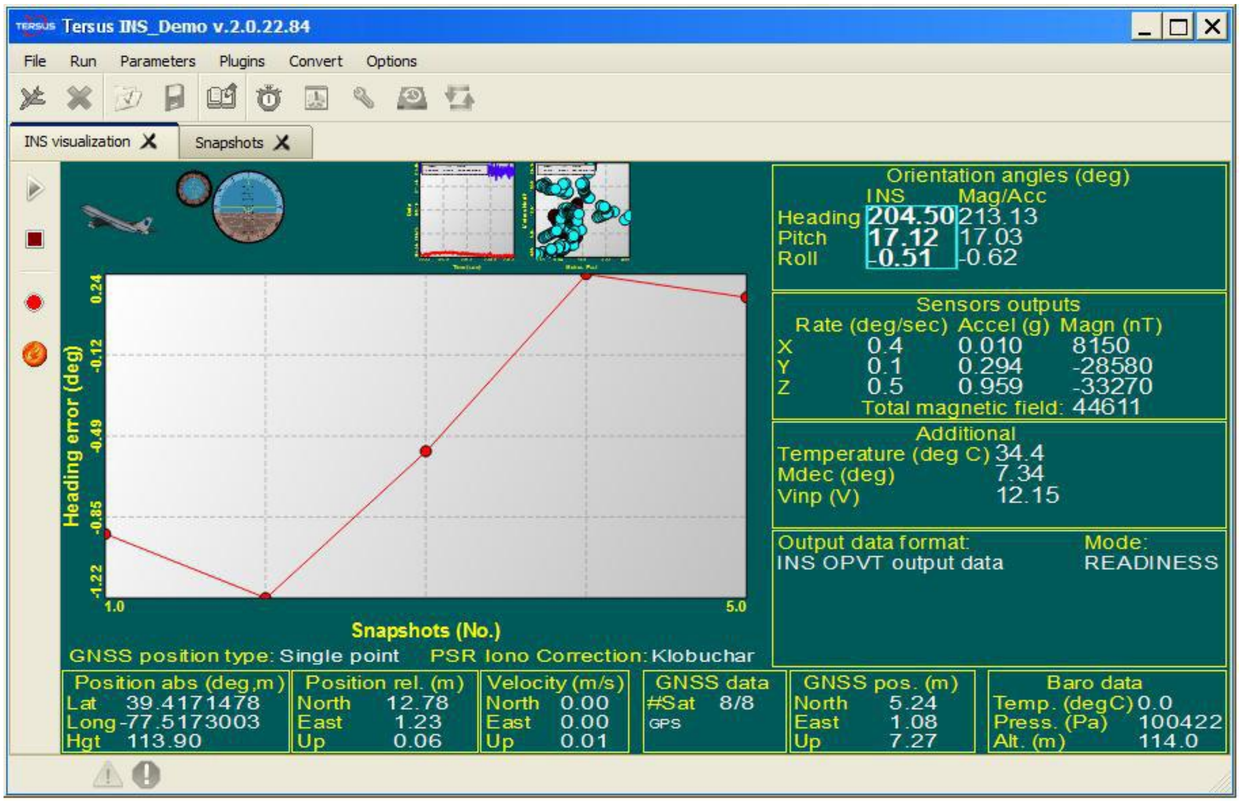


Fig.10.20

Plotted graph is scalable. To zoom in please click and hold left button on mouse and drag mouse in down-right direction. To zoom out please click and hold left button on mouse and drag mouse in up-left direction. Click and hold right button on mouse to shift plot.

Step 13. To stop the accuracy test click «**Stop**» button. If the INS data were writing and time set in «**Record time**» in the «Options \ Test option» menu was reached then accuracy test will be stopped too.

Step 14. To close the “On-the-fly accuracy” tab simple go to the other visualization style or close “INS visualization” tab by clicking the in the title of current tab.

Accuracy test data are automatically saved to the *.csv file. Its name consists of "TestFullData" word, date and time digits separated by dash symbols where the first 4 digits are the year, the next 2 digits are the month, then 2 digits of day, next digits are hours, minutes and seconds of operation (f.e. TestFullData-2013-03-05-15-44-47.csv).

This is common text file with comma-separated values of test data for each snapshot. Example of the *.csv file is shown in the Table 10.1.

Table 10.1. Example of the *.csv file created at accuracy test

Snaoshot	hrs:min:sec	Measured_H	Measured_P	Measured_R	Mag_H	Target_H	Target_P	Mag_Dec	Vdd	USW(L)	USW(H)
1	15:44:47	200.09	-0.33	-0.09	200.11	200.06	nan	0	5.917	0	0
2	15:45:08	210.04	-0.29	-0.15	210.07	210.07	nan	0	5.918	0	0
3	15:45:29	220.07	-0.25	-0.21	220.1	220.08	nan	0	5.918	0	0
4	15:45:52	230.04	-0.2	-0.26	230.07	229.99	nan	0	5.918	0	0

This file includes 13 columns:

1. "Snapshot" – number of snapshot;
2. "hrs:min:sec" – time when the snapshot was made;
3. "Measured_H" – measured heading angle;
4. "Measured_P" – measured pitch angle;
5. "Measured_R" – measured roll angle;
6. "Mag_H" – value of the heading angle based on the INS magnetometers;
7. "Target_H" – reference (true) heading;
8. "Target_P" – reference (true) pitch;
9. "Mag_Dec" – the magnetic declination;
10. "Vdd" – input voltage of the INS;
11. "USW (L) "– Unit Status Word (low byte), see Appendix D for details.
12. "USW (H) "– Unit Status Word (high byte), see Appendix D for details.

10.6. INS automatic start

Since firmware version 1.0.2.0 the Tersus INS auto start is implemented that allows start of its operation and data output after power on without any command from the host computer. There is possible to choose desirable output data format for auto start. See Appendix B for more details about data formats.

The auto start option can be enabled or disabled in the drop-down list “Auto start” in the “IMU” tab of the «Devices Options» window – see Fig.4.2. To allow this option the INS should be connected to PC and powered.

The drop-down list “Auto start” contains list of all available output data formats, see Fig.10.21. Please choose desirable output data format for the INS auto start. Default is “No Auto start” option that disables automatic start.

Usually just INS Demo software is used to start and stop the INS operation. To allow the INS Demo to receive data from the INS that was started automatically, it is necessary to select the “Allow auto start” checkbox in the «Test options» window – see Fig.4.1. After the “Allow auto start” checkbox is selected, it is necessary to close the INS Demo and start it again to apply this setting. Operation with automatically started INS is close to those described in the section 10.1, with a little difference.

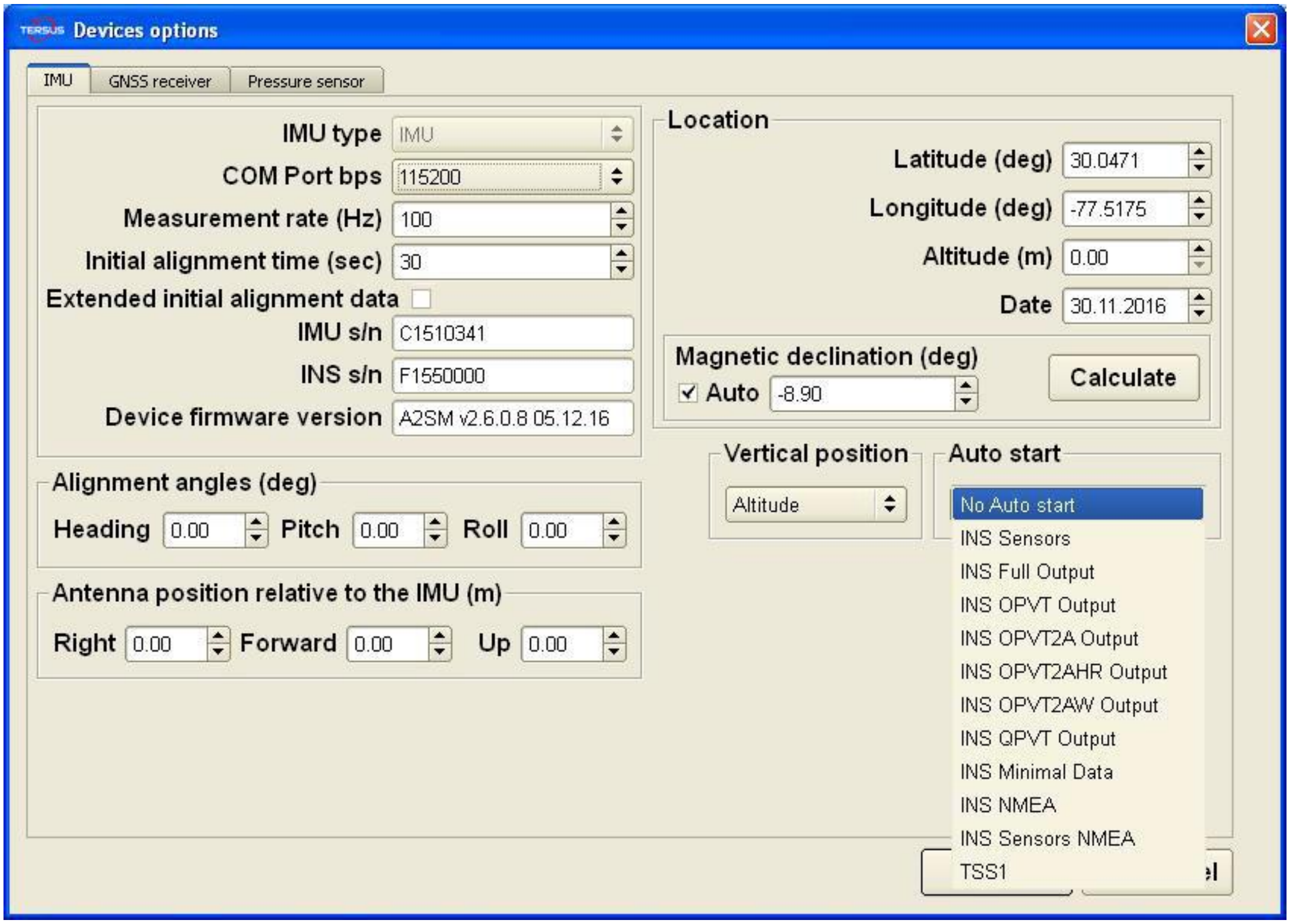


Fig.10.21

Step 1. Connect the INS to PC and power on. The INS LED indicator will light yellow during about 15 seconds until the GNSS receiver initialization is completed. After that the INS starts calculations and its LED indicator changes color to green.

Step 2. Wait not less than set time for the initial alignment (30 seconds on default) and run the INS Demo program. If the COM port number was set correctly and “Allow auto start” checkbox was selected then INS Demo will show the INS continuous data in chosen output data format.

The next possible steps are the same as described in sction 10.1, steps 11 – 17. For example, you can:

Step 3. To save data to file please click the «Write»  button.

Step 4. To stop the INS click «Stop»  button. If the data were being written in a file then the writing is stopped too.

11. Continuous self-monitoring of the INS health

The Tersus INS has continuous built-in monitoring of the INS health. In the main mode the INS sends out Unit Status Word (USW) in each data block (see also Appendix B).

The low byte (bits 0-7) of USW indicates failure of the INS. If this byte is 0 then the INS operates correctly, if it is not 0, see “Appendix D. The Unit Status Word definition” for type of failure or contact the developers directly.

The high byte (bits 8-15) contains a warning or is informative for the user. Status of each bit of the USW warning byte is specified in the “Appendix D. The Unit Status Word definition”.

Since INS Demo version 2.0.29.110 from 09/02/2016 the Demo software stops the INS unit if failure of gyro, accelerometer or GNSS receiver is detected. After the INS unit stop window Fig.11.1 appears with a caption about failure and information that device was stopped.

Fig.11.1

12. INS and GNSS data post-processing

For applications requiring highly accurate post-mission position, velocity and orientation, the INS and GNSS data post-processing can be used. Contact Tersus support for more about the post-processing software.

For such post-processing the raw GNSS and raw IMU data should be used.

12.1. Recording of raw GNSS data

The Tersus INS uses the second COM port (COM2) for output the raw GNSS receiver data.

Raw GNSS data consists of necessary logs for post-processing. There are synchronous and asynchronous logs. The data for synchronous logs are generated with set frequency. In order to output the most current data as soon as they are available, asynchronous data are generated at irregular intervals.

List of generated logs of raw GNSS data is shown in the Table 12.1.

Table 12.1. Logs for raw GNSS data

Log	Description
Asynchronous	
CLOCKSTEERING	Clock steering status
GLOCLOCK	GLONASS clock information
ALMANAC	Decoded GPS Almanac
GPSEPHEM	Decoded GPS ephemerides
RAWALM	Raw Almanac data
RAWEPHEM	Raw ephemeris
RAWGPSSUBFRAME	Raw subframe data
RAWCNAVFRAME	Raw CNAV frame data
RAWGPSWORD	Raw navigation word
GLOALMANAC	Decoded GLONASS Almanac
GLOEPHEMERIS	Decoded GLONASS ephemeris
GLORAWALM	Raw GLONASS Almanac data
GLORAWEPHEM	Raw GLONASS Ephemeris data
GLORAWFRAME	Raw GLONASS frame data
GLORAWSTRING	Raw GLONASS string
MARK2POS	Position at time of mark input event (see note below)
MARK2TIME	Time of mark input event (see note below)
Synchronous	
CLOCKMODEL	Current clock model status
TIMESYNC	Synchronize time between GNSS receivers
TIME	Time data
RANGE	Satellite range information
RANGEGPSL1	L1 version of the RANGE log
TRACKSTAT	Tracking status

Note: If input marks are enabled ("Mark inputs control" checkbox is checked in the "GNSS receiver" tab of the "Devices options" menu item on Fig.4.4) then asynchronous MARK2POS and MARK2TIME logs are added to the raw GNSS data when a pulse is detected at GPIO mark input (see section "13.3. INS operation with LiDAR").

Frequency of the synchronous logs logging is changeable and is specified in "Data rate" field (see section "4.2.2. "GNSS receiver" tab" for details). Note the standard COM-port baud rate 115200 bps can provide frequency of GPS L1 raw data up to 5 Hz. Raw data with higher frequency, L1/L2, using GPS + GLONASS may contain gaps, so it is necessary to use USB port on host computer and to increase COM Port baud rate. Set 921600 bps baud rate to provide maximum 20 Hz GNSS raw data output. Please contact the Tersus about details.

For raw GPS data recording from receiver an external program **GNSS_Reader** can be used. The GNSS_Reader is supplied with the **“Tersus INS Demo”** software.

Main window of GNSS Reader is shown in the Fig.12.1

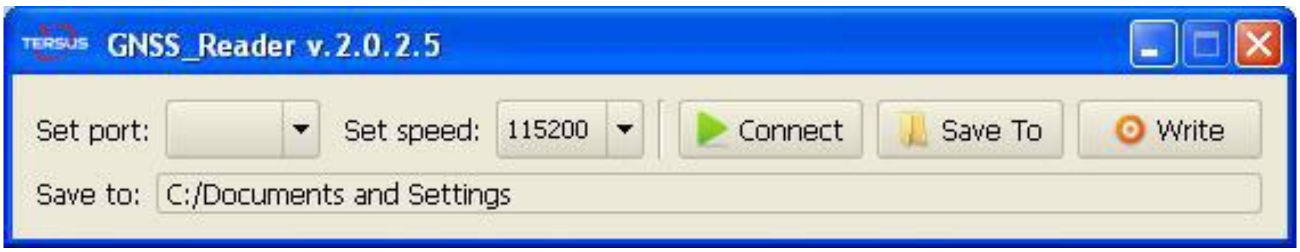


Fig.12.1

To perform data recording follow next steps:

Step 1. Click on the 

button to choose port to which the INS COM2 port is connected. Select the correct COM port number from the dropdown list” (see Fig.12.2).

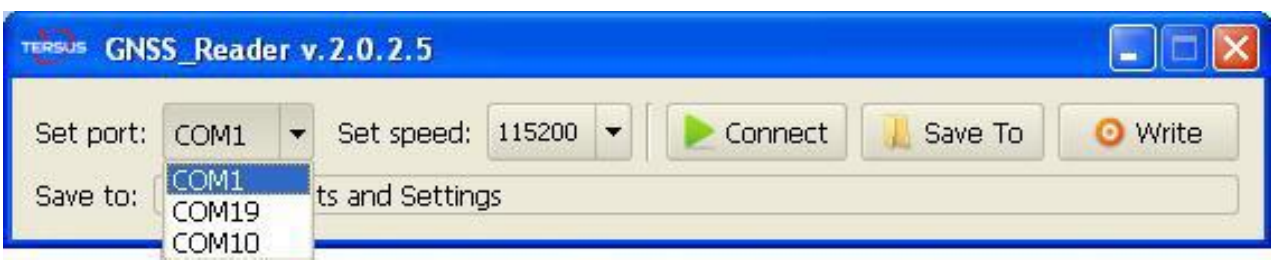
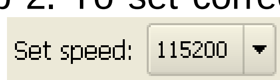


Fig.12.2

Step 2. To set correct baud rate COM Port which outputs raw GNSS data click 

. Select the correct speed from the dropdown list” (see Fig.12.3). Make sure this COM port baud rate corresponds to baud rate which is set in the GNSS receiver tab in the Device options menu (see section 4.2.2. “GNSS receiver” tab, Fig.4.6).

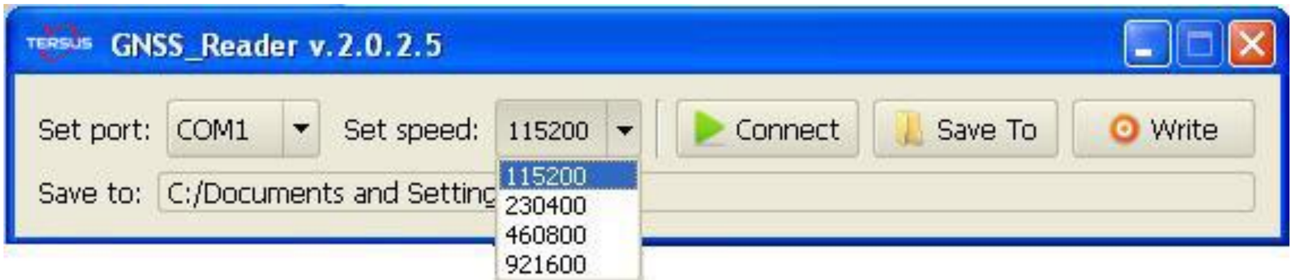
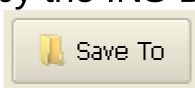


Fig.12.3

Step 3. Default folder for saving GNSS data is the same as for files written by the INS Demo software. To change folder for raw GNSS data click on the 

button. Then a standard Windows «Save» window is opened. After specifying the file path click «OK» button. Then full path to the folder will be shown in the «Save to» label.

Step 4. To connect the program to the chosen COM port click on the 

button. After that name of the button will be changed to 

and COM port button will become inactive. To disconnect simply click on «Disconnect» button.

Step 5. To begin the data recording click on the 

button and data recording will start. The button will remain during whole recording process. pressed 

Note: Each click on the "Write" button will create a new file for the data recording.

Step 6. When required amount of data is recorded, unpress the «Write» button. And click «Disconnect» button.

If data recording was performed correctly new file with .gps extension will appear in the folder which was specified during the Step 3.

Note: Name of the file with recorded GPS data consists from date and time when test was performed. For example name of the file 2015-09-01-10-59-63.gps means that test was performed on September 1, 2015 at 10:59:63.

12.2. Raw IMU data generation

Raw IMU data can be created from files with extension .bin which were written during the test run. To convert .bin file into IMU data, do the following:

Step 1. Select «**Convert to IMU data**» from the “**Convert**“ menu (Fig.3.6). A standard Windows «Open» window will open.

Step 2. Select the necessary file with extension .bin. Click «**OK**». A .imu file will be created with the same name and in the same folder as the selected .bin file.

Binary Structure of IMU file is shown in the Table 12.2.

Table 12.2. Binary Structure of raw IMU data

Word	Size (bytes)	Type	Description
GpsTime	8	real	time of the current IMU rate measurements in GPS seconds of the week
GyroX	4	long	scaled X-body axis gyro measurement as an angular rate
GyroY	4	long	scaled Y-body axis gyro measurement as an angular rate
GyroZ	4	long	scaled Z-body axis gyro measurement as an angular rate
AccelX	4	long	scaled X-body axis accelerometer measurement as an acceleration
AccelY	4	long	scaled Y-body axis accelerometer measurement as an acceleration
AccelZ	4	long	scaled Z-body axis accelerometer measurement as an acceleration

To use this .imu file for post-processing with NovAtel software, user needs to convert it into the Waypoint's generic IMR format. For this purpose **IMU Data Converter** developed by NovAtel should be used (see manual provided with NovAtel software).

It is necessary to create new Conversion Profile. Do the following:

Step 1. Launch the **IMU Data Converter**.

Step 2. In the main window of **IMU Data Converter** click on the "New" button, window shown in the Fig.12.4. will appear. In the "Name" field type name of new profile and click the "OK" button.

Fig.12.4.

Step 3. In the opened window in the **"Sensor/Timing Settings"** tab insert following parameters (see Fig.12.5.):

In the **"Gyro Measurements"** field:

- Set in the **"Inverse Gyro Scale Factor"** edit box 10000 value;
- Select **"Data is angular rate"** radio button.

In the **"Accelerometers Measurements"** field:

- Set in the **"Inverse Accelerometer Scale Factor"** edit box 10000 value;
- Select **"Data is acceleration"** radio button.

In the **"Timing Settings"** field:

- In the **“Data Rate”** edit box set the measurement rate according to the value in the IMU tab of the “Device options” menu (see section 4.2. Devices options);
- Leave **“GPS-IMU time-tag bias offset”** value by default (0 s).

In the **“Byte Odred”** field select **“Intel”** radio button.

In the **“Time Tag Format”** select **“GPS seconds of week”** radio button.

In the **“Time Tag Source”** select **“GPS Corrected Time”** radio button.

Step 4. To save all configurations and close this window click on the “Save” button.

No changes are needed in the **“Sensors Orientation”** and **“Decoder Settings”** tabs.

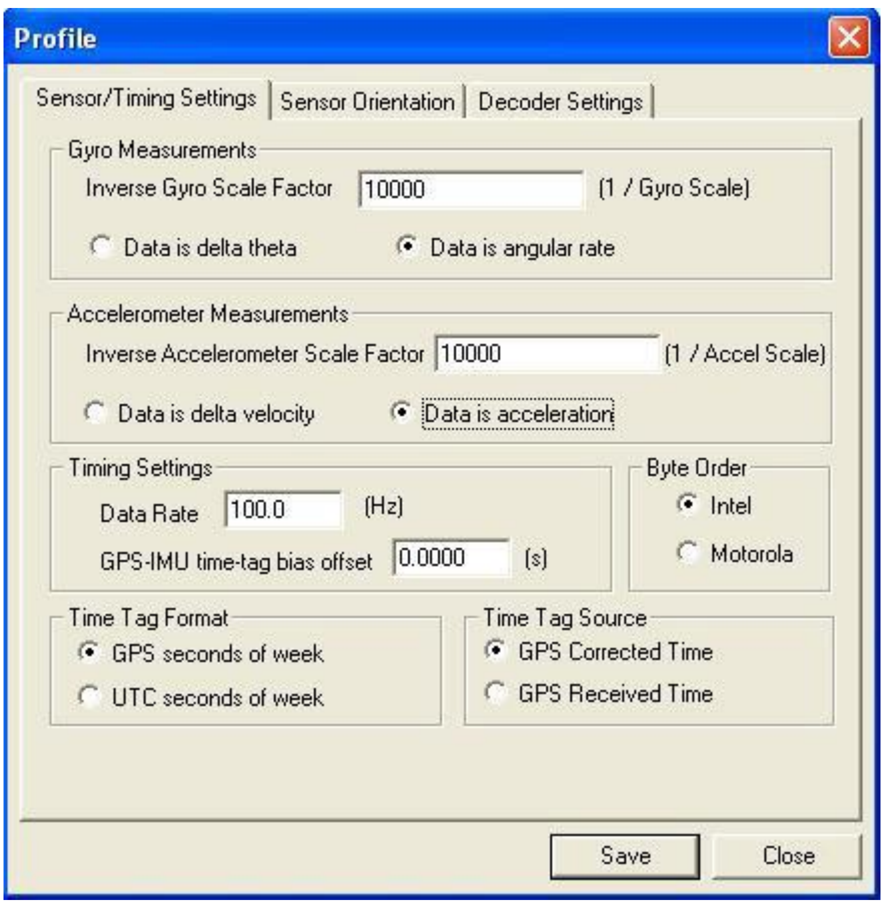


Fig.12.5.

Created Conversion Profile is saved in the **IMU Data Converter** and is available in the list of profiles at future operations.

12.3. INS sensors error model for INS + GNSS data post-processing

For data post-processing in the Waypoint Inertial Explorer it is necessary to choose error model of IMU sensors. There are preset models in Inertial Explorer. Use "NovAtel SPAN (ADIS 16488)" error model as the most close for Tersus INS performance, see Fig.12.6.

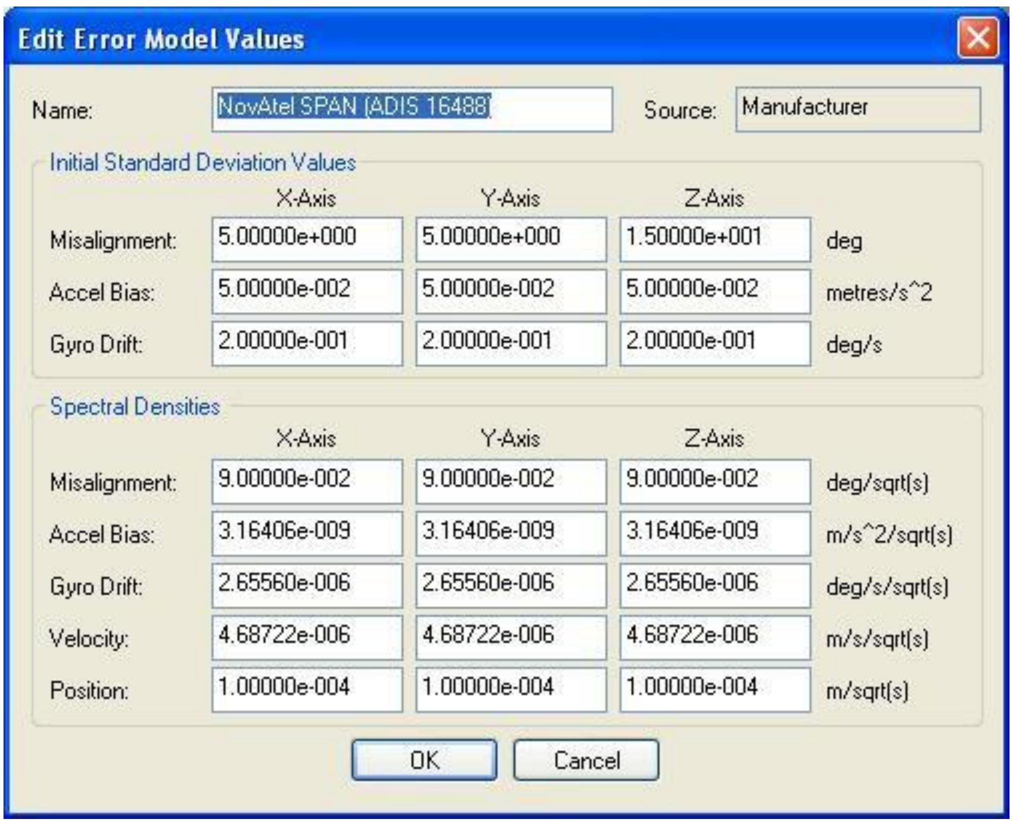


Fig.12.6.

13. Synchronization of INS data with LiDAR and other devices

Synchronization of the Tersus INS measurements with data form other devices is very important in many applications. The INS can trigger other devices, or an external device can trigger the INS measurements.

To trigger external devices the Tersus INS outputs accurate pulse per second (PPS) signal generated by on-board GNSS receiver. The PPS signal is provided by appropriate pin of the INS main connector (see INS ICD, Table 5.1 and Table 5.2). The Tersus INS Demo Program allows to adjust the PPS signal -- see section “13.1. Control of PPS output signal”.

There are two ways to trigger the INS data from external device. At the first, the INS can operate in the “On Request” (on demand) mode when the INS sends one data block after each Request command issued from the host computer. See INS ICD, section “6.3.2. SetOnRequestMode command – getting INS data on request (on demand)” for details.

The second way of the INS data synchronization is using of General Purpose Input Output (GPIO) line to trigger the INS output data by external devices. GPIO line is connected to appropriate pin of the INS main connector (see INS ICD, Table 5.1 and Table 5.2 and section “5.4. GPIO description”). Currently the GPIO is used to trigger GNSS raw data in INS. The Tersus INS Demo Program allows to adjust receiving of synchro pulses through GPIO – see section “13.2. Processing of mark input signal”.

13.1. Control of PPS output signal

The Tersus INS outputs the pulse-per-second (PPS) signal generated by GNSS receiver. PPS pulse is shown on the Fig.13.1.

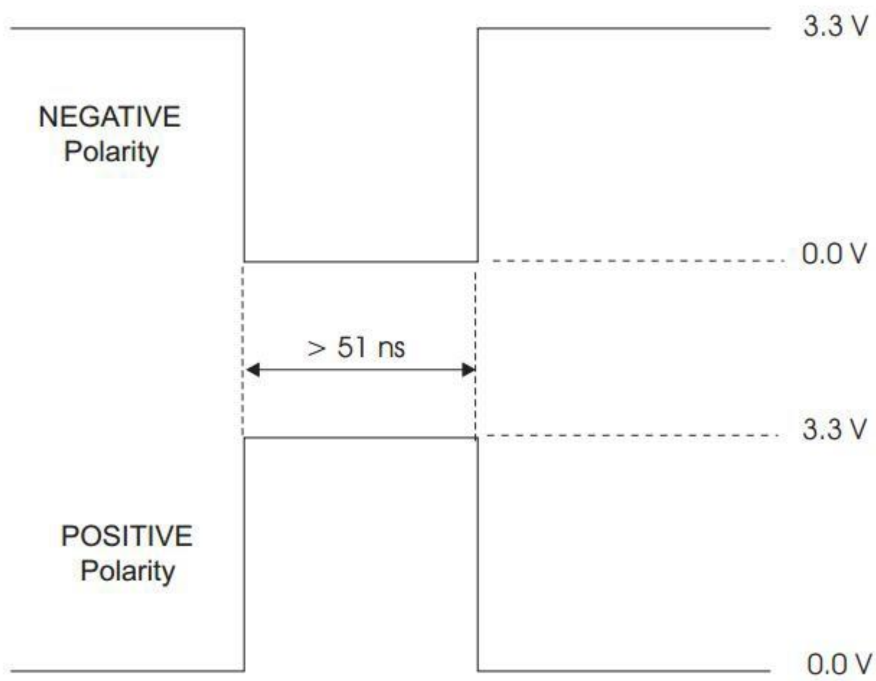


Fig.13.1. PPS pulse

The leading edge of the PPS pulse is always the trigger / reference:

- Negative – generates a normally high, active low pulse with the falling edge as the reference;
- Positive – generates a normally low, active high pulse with the rising edge as the reference.

Since the INS firmware version 2.2.0.3 the PPS parameters are adjustable and can be set using the Tersus INS Demo Program since version 2.1.22.84 from 04/22/2016. For this go to **«Options»** menu, then to **«Devices Options»**, **"GNSS receiver"** tab (see Fig.4.4). It is possible there:

- to enable or disable PPS output using check box. Default is PPS enabled;
- to change PPS polarity (negative or positive). Default is negative polarity;
- to change PPS period. Default is 1 second period;
- to change PPS width. Default is 1000 microseconds.

13.2.Processing of mark input signal

Since the INS firmware version 2.2.0.3 the General Purpose Input Output (GPIO) line can be used for mark input signal to trigger specific GNSS raw receiver data. TTL mark pulse configuration is the same as Fig.13.1 shows. Adjustment of processing of the mark input signal is provided by the Tersus INS Demo Program since version 2.0.22.84 from 04/22/2016.

To control the processing of the mark input please go to **«Options»** menu, then to **«Devices Options»**, **"GNSS receiver"** tab (see Fig.4.4). It is possible there:

- to enable or disable processing of the mark input signal using check box. Default is disabled processing of mark input;
- to specify mark polarity (negative or positive). Default is negative polarity;
- to set an offset, in nanoseconds, to be applied to the time the mark input pulse occurs. Default value is zero offset;
- to set a time period, in milliseconds, during which subsequent pulses after an initial pulse are ignored. Default value is 4 milliseconds, minimum value is 2 milliseconds.

When a pulse is detected at GPIO mark input then the GNSS receiver generates asynchronous MARK2POS and MARK2TIME logs which are added to the raw GNSS data listed in the Table 12.1 in section "12. INS and GNSS data post-processing".

13.3.INS operation with LiDAR

For integration of Tersus INS data with LiDAR it is necessary to make the next connections of INS to LiDAR system:

- use INS COM1 port for output of the main INS data;
- use INS COM2 port for output of GNSS raw data generated by INS onboard GNSS receiver;
- connect INS COM3 port for output of $GPRMC messages issued by INS onboard GNSS receiver to LiDAR;

- connect pulse-per-second (PPS) signal generated by INS onboard GNSS receiver to LiDAR;
- optionally, for camera synchronization – connect General Purpose Input Output (GPIO) line for input signal from camera to trigger specific GNSS receiver data (MARK2POS and MARK2TIME logs)

All these data and signals are available on the main INS connector – see INS ICD, section “5. Electrical interface”.

Then it is necessary to make adjustment of INS data and signals using INS Demo Program. Note INS unit must be connected to PC and powered to allow adjustments. Also correct PC COM port number and its baud rate should be set.

13.3.1. Configuration of INS main data

Using **«Devices options…»** from the **«Options»** menu (see section “4.2. Devices options”) set required baud rate of the main COM port, measurement rate of INS data, and change other settings if necessary.

If INS should be started automatically after power on, choose necessary variant of output data in “Auto start” field. See section 10.6 for details.

If INS will be started using INS Demo Program then leave “No Auto start” variant in “Auto start” field. Required variant of INS output data is set in **«Test options…»** from the **«Options»** menu (see section “4.1.Test options”).

13.3.2. Configuration of COM2 port for output of GNSS raw data

Use **«Devices options…»**, **«GNSS receiver»** tab from the **«Options»** menu to make necessary settings in the “GNSS COM Port 2” fields (see Fig.4.4): Data set and Data rate. Note COM2 port baud rate restricts maximum rate of GNSS raw data. See section “12.1. Recording of raw GNSS data” for details.

13.3.3. Configuration of COM3 port for output of $GPRMC messages

Use **«Devices options…»**, **«GNSS receiver»** tab from the **«Options»** menu to make necessary settings in the "GNSS COM Port 3" fields (see Fig.4.6). For example, if Velodyne VLP-16 LiDAR is used then set:

- 1 Hz for GPRMC data;
- 9600 bps for COM3 port.

13.3.4. Configuration of PPS signal

Use **«Devices options…»**, **«GNSS receiver" tab»** from the **«Options»** menu to make necessary settings in the "PPS control" fields (see Fig.4.6). For example, if Velodyne VLP-16 LiDAR is used then set:

- positive polarity;
- default 1.0 second period;
- default 1000 microseconds pulse width.

13.3.5. Configuration of mark input signal

If mark input signal processing is enabled, then when INS gets a mark pulse (from camera) it adds MARK2POS and MARK2TIME logs into raw GNSS data transferred through COM2 port of INS. Then Waypoint Inertial Explorer can process raw data and output results which only contain the marked points.

Use **«Devices options…»**, **«GNSS receiver" tab»** from the **«Options»** menu to make necessary settings in the "Mark inputs control" fields (see Fig.4.6) to make necessary settings. See section "13.2. Processing of mark input signal" for details.

14. Control of compatibility between the INS firmware and INS Demo versions

Firmware of the Tersus INS is developing continuously. The INS hardware also can be changed. Sometimes the INS features are so new that are not supported by old versions of the INS Demo software. On the other hand, some functions of the old INS Demo software were deleted from the new software versions.

We recommend strongly to use version of the INS Demo software that comes on CD with the INS until the INS firmware is updated.

If the INS has too old firmware version then before execution of any command sent from the Demo Software to the INS the warning window appears (see Fig.14.1) that informs about incompatible version of the INS firmware. Click “OK” and continue work.

Fig.14.1

15. Choice of 3D model for visualization of the INS orientation

The INS Demo software allows to use different 3D models for visualization of the INS orientation angles when «**INS visualization**» item from the «**Run**» menu is used for work with the INS.

The default 3D model is an aircraft as Fig.5.1 shows. Other models are on CD in the subfolder “3D_Models” of folder with the INS Demo software. There are files model.mgl which contain these models and appropriate screenshot files.

To set desirable 3D model for the INS visualization, just copy the file **model.mgl** from appropriate folder of 3D models to the “configs” subfolder in folder with INS Demo software. At this you should replace existing file.

Some examples of 3D models for the INS visualization are shown on Fig.15.1.

Helicopter

Ferrari_F40

Clipper

Submarine

Fig.15.1

16. Troubleshooting

16.1. How to repair the INS parameters

Need to repair of the INS parameters appear in some cases, for example at incorrect loading of parameters into the INS memory.

You can use original file with .prm extension that comes on CD with the Tersus INS, or use own files created by «**Save parameters**» command (if these files contain valid data of course).

Follow next steps to restore INS parameters.

1. Connect the INS to PC and power it.

2. Start the INS Demo software. The main menu will appear (see Fig.3.1).

3. Select **«Test options…»** from the **«Options»** menu (or click button) – see Fig.3.7. «Test options» window (Fig.4.1) will open.

4. Select the correct COM port number and its rate **«Baud rate:115200»**. Click «**OK**».

Note. For the number of the COM port to which the INS is connected, see section «2. Installation of drivers and configuration of the PC parameters» and «Appendix A. Installation of the COM-to-USB converter drivers and configuration of the PC parameters».

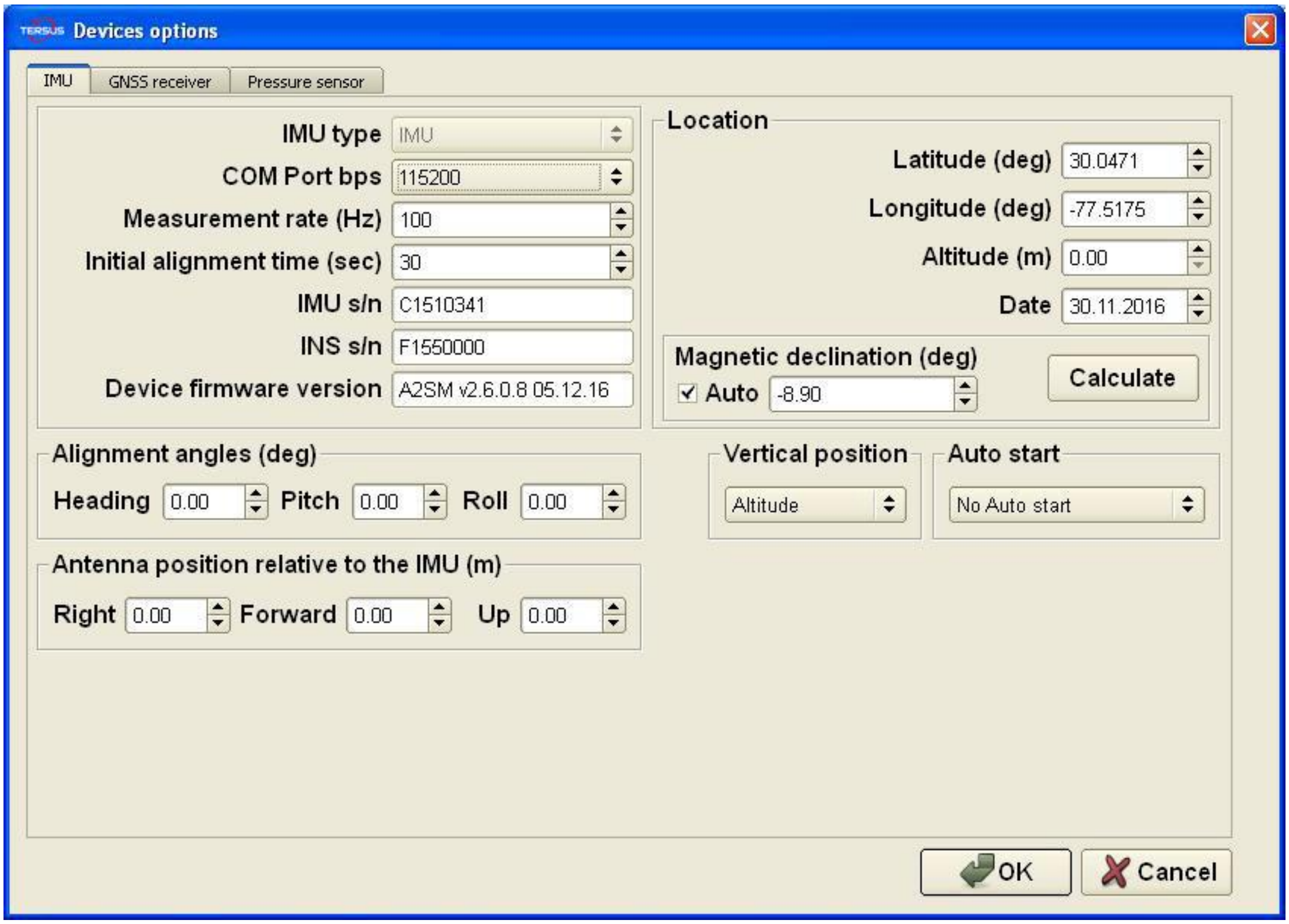
5. Select **«Restore parameters»** in the **«Parameters»** menu (see Fig.3.4) or click button. A standard Windows «Open» window will open.

6. Select file with extension .prm containing the factory settings of the INS parameters or own file created by «**Save parameters**» command (if this file contains valid data of course). Click «**OK**». These parameters will be loaded into INS memory automatically.

16.2. What do you have to do at strange behavior of the INS

If you see strange behavior of the INS, first check whose parameters are loaded in the connected INS. This may occur, for example, if you have restored parameters that correspond to another INS with not proper serial number. Please use **«Restore parameters…»** command accurately to avoid wrong parameters loading into the INS's memory.

To check whose parameters are loaded in the connected INS please select «**Device options …**» from the **«Options»** menu (or click button) – see Fig.3.7. «Device options**»** window (Fig.4.2) will open:



In the field **"INS s/n"** you will see serial number of the INS. It must correspond to serial number that is placed on label on INS's nose.

If **"INS s/n"** doesn't correspond to serial number of the connected INS then you must restore original parameters as that described in above section.

If **"INS s/n"** corresponds to the INS serial number, but you continue see strange behavior of the INS in heading, then this may be due to improper hard/soft iron calibration parameters are loaded into INS's memory.

If you have removed INS from carrier object, then you must clear parameters of soft/hard iron calibration. See section "10.4.2. Clearing of the soft and hard iron calibration parameters" for details.

If you mount the INS in another place in carrier object, or move it to another carrier object, then you must repeat soft/hard iron calibration procedure as it described in section “10.4. Calibration of the INS”.

16.3.What do you have to do if messages “Cannot read parameters!”, “Cannot load parameters!”, or “Cannot start INS” appear

When you use Tersus INS Demo Software, the most of operations are started with reading data from the INS nonvolatile memory to control correct INS status. For this purpose the INS should be powered and connected to COM-port or USB-port using COM-to-USB adapter.

When you see one of messages that Fig.15.1 shows, then you should check the next items:

- The INS is powered and its LED indicator lights red.
- The INS is connected to COM-port or USB-port using COM-to-USB adapter.
- The number of COM-port and its baud rate are set correctly in the **«Serial port»** field in **«Test options…»** window from the **«Options»** menu as Fig.4.1 shows.

Then simply click «**OK**» button and repeat your operation.

Fig.15.1

APPENDIX A.
Installation of the COM-to-USB converter drivers and configuration of PC parameters

Tersus INS developer highly recommends connection of the INS with RS-232 interface to a computer through a standard COM-port for guaranteed reliable operation of the INS. If connection of the INS to a computer is done through a USB port, it is necessary to install a COM-to-USB converter driver. The converter driver is in the folder COM_to_USB_Driver placed on the CD provided with the INS. Sequence of the converter driver installation is as follows:

– Connect the converter to a computer. The computer automatically starts a search and installation program for the necessary drivers of the connected device. A window (Fig.A.1) opens. Select «**No, not this time**» from the menu and click on the «**Next**» button.

Fig.A.1

– Window (Fig.A.2) will appear on the display. Select «**Install from a list or specific location (Advanced)**» from the menu and click on the «**Next**» button.

Fig.A.2

– Window (Fig.A.3) will appear on the display. Check «**Include this location in the search:**» and click on «**Browse**». Show the path to the converter drivers folder in the window (Fig.A.4) which appears on the top of the previous one (folder name may differ from the name in Fig.A.4) and click «**OK**» (if a folder containing no driver files is selected, «**OK**» button will remain inactive). Next, in the window Fig.A.3, which will be looking like the window in Fig.A.5, a path will be defined. Using this path the installation program will search for the necessary converter driver. Press «**Next**» to continue installation.

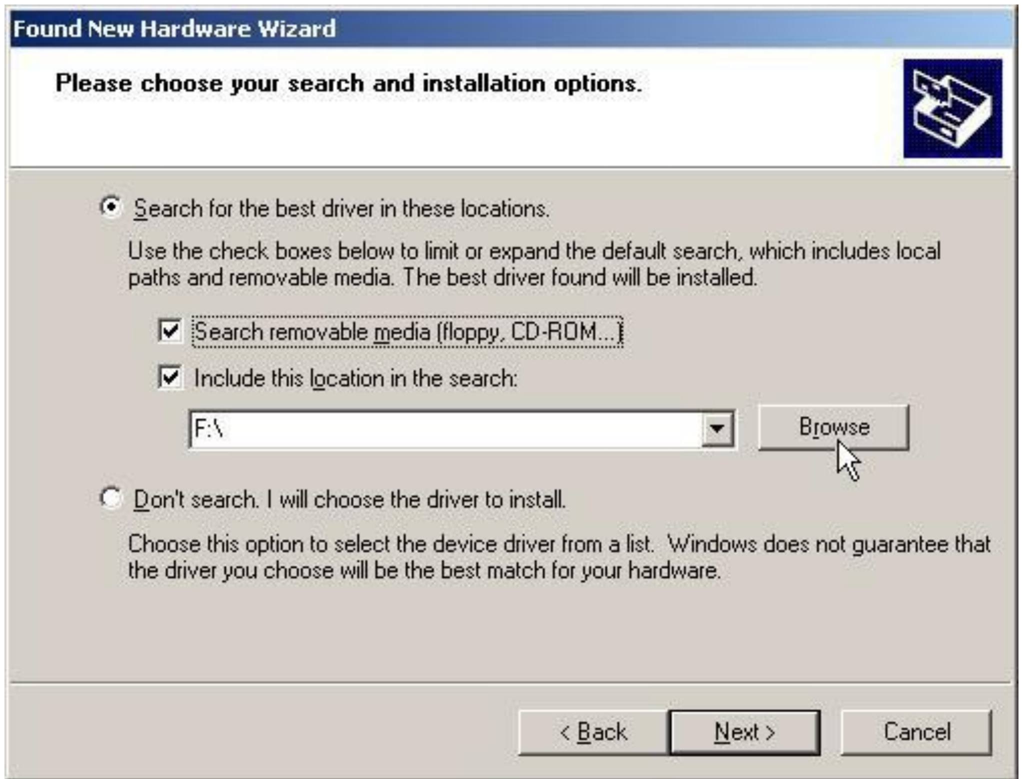

Found New Hardware Wizard
Please choose your search and installation options.
Search for the best driver in these locations.
Use the check boxes below to limit or expand the default search, which includes local paths and removable media. The best driver found will be installed.
Search removable media (floppy, CD-ROM...)
Include this location in the search:
F:\
Browse
Don't search. I will choose the driver to install.
Choose this option to select the device driver from a list. Windows does not guarantee that the driver you choose will be the best match for your hardware.
< Back
Next >
Cancel

Fig.A.3


Browse For Folder
Select the folder that contains drivers for your hardware.
My Documents
My Computer
Local Disk (C:)
DVD Drive (D:)
Tersus_iAHRS (E:)
COM_to_USB_Driver
Documentation
Tersus_AHRS_Demo_Program
To view any subfolders, click a plus sign above.
OK
Cancel

Fig.A.4

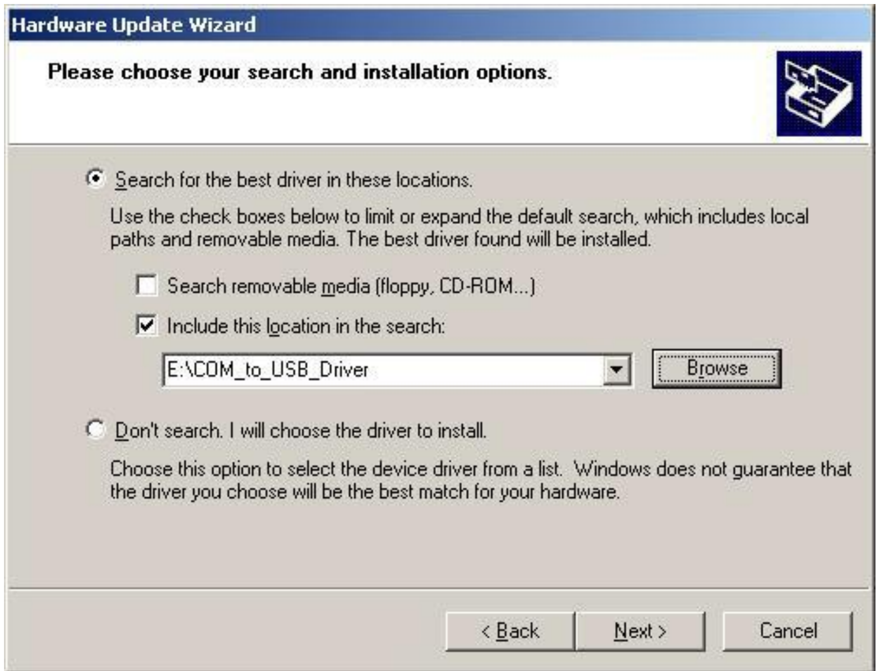


Fig.A.5

– If the program finds the necessary files, it will automatically start the driver installation. If installation is completed successfully, the window in Fig.A.6 will appear on the screen. Press «**Finish**» to complete installation procedure for the COM-to-USB converter driver.

Fig.A.6

If the necessary drivers are not installed, an error message (Fig.A.7) will appear. In this case, click «**Back**» and set the correct path to the driver files in the window in Fig.A.3.

Once the converter driver is installed, you will need to know the number of the additional COM-port set by the system and configure parameters of this port for correct operation of the INS. To do this, press the «**Device Manager**» button in the «System Properties» window, in the «**Hardware**» page. In the opened «Device Manager» window (Fig.A.8) the additionally set COM-port will be marked as «**USB serial port (COMN)**». Number N in the port name will be assigned by the computer.

Next, open the Properties window of this port «USB serial port (COMN) Properties» (Fig.A.9) and press the «**Advanced**» button. In the opened «Advanced Settings for COMN» window set the parameters:

– Latency Timer (msec) to **1**;
– Minimum Read Timeout (msec) to **100**;
– Minimum Write Timeout (msec) to **100**;

as it is shown in Fig.A.10, and click «**OK**».

Fig.A.7

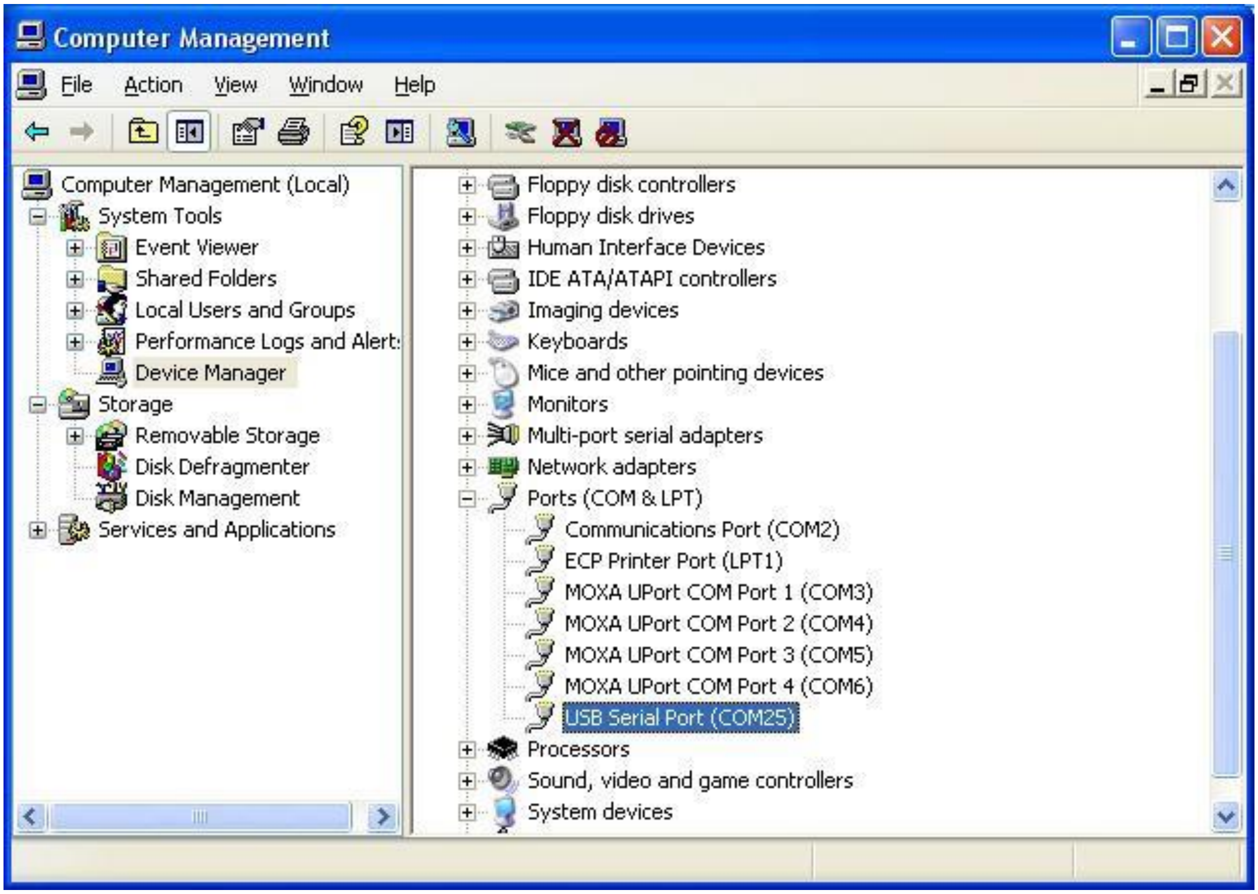


Fig.A.8

In the case of problems in COM-to-USB driver operation please make one more adjustment of the driver. In the «Device Manager» window (see Fig.A.9) go to the «Universal Serial Bus controllers» section, item «USB Serial Controller» (see Fig.A.11). Twice click on this item to set its properties. The window «USB Serial Controller Properties» will be opened where go to «Advanced» tab and check «Load VCP» box (see Fig.A.12).

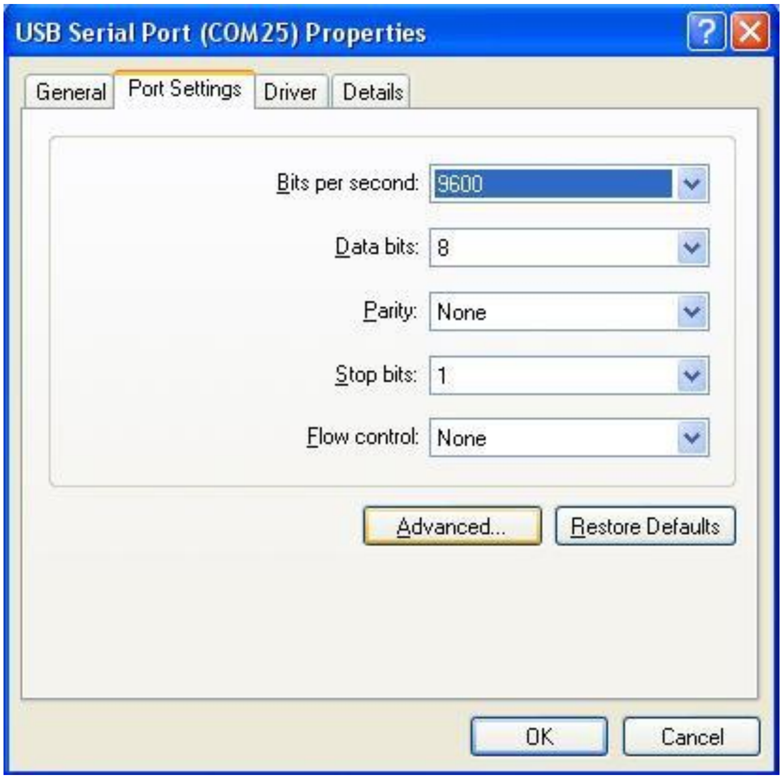


Fig.A.9

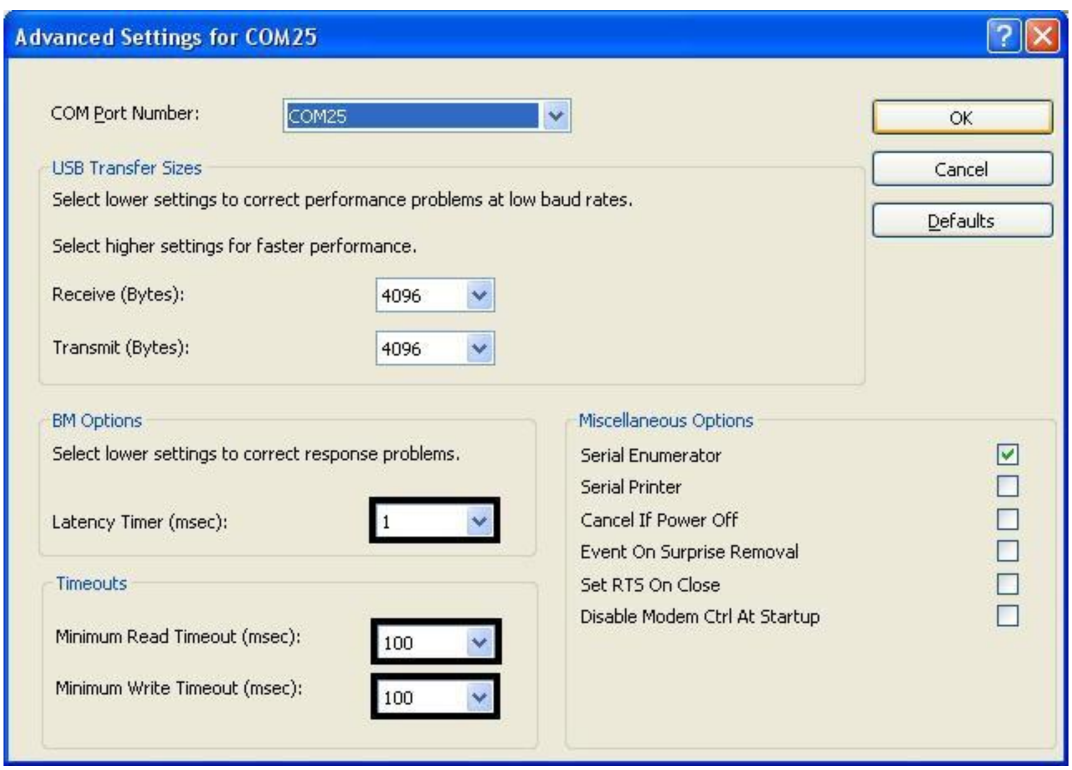


Fig.A.10

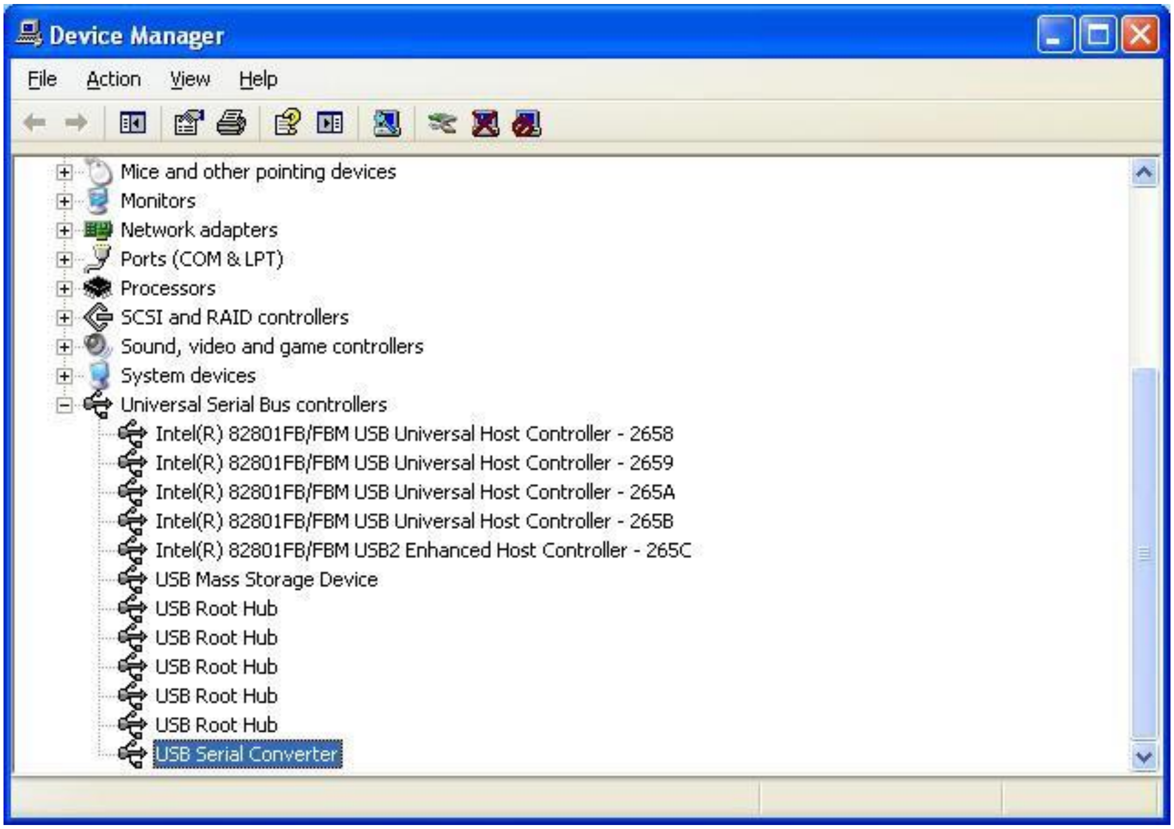


Fig.A.11

Fig.A.12

APPENDIX B.
Installation of the MOXA Serial-to-USB converter drivers (for INS with RS-422 interface)

The Tersus INS with RS-422 interface can be connected to PC USB port using Serial-to-USB MOXA 1130 converter, which is supplied with the INS unit by the Tersus. In this case it is necessary to install appropriate driver which can be downloaded from the official MOXA site. Make sure that driver completely suits your operating system.

Sequence of the MOXA 1130 converter driver installation is as follows:

Click twice on icon of downloaded driver window shown on the Fig.B.1 will appear.

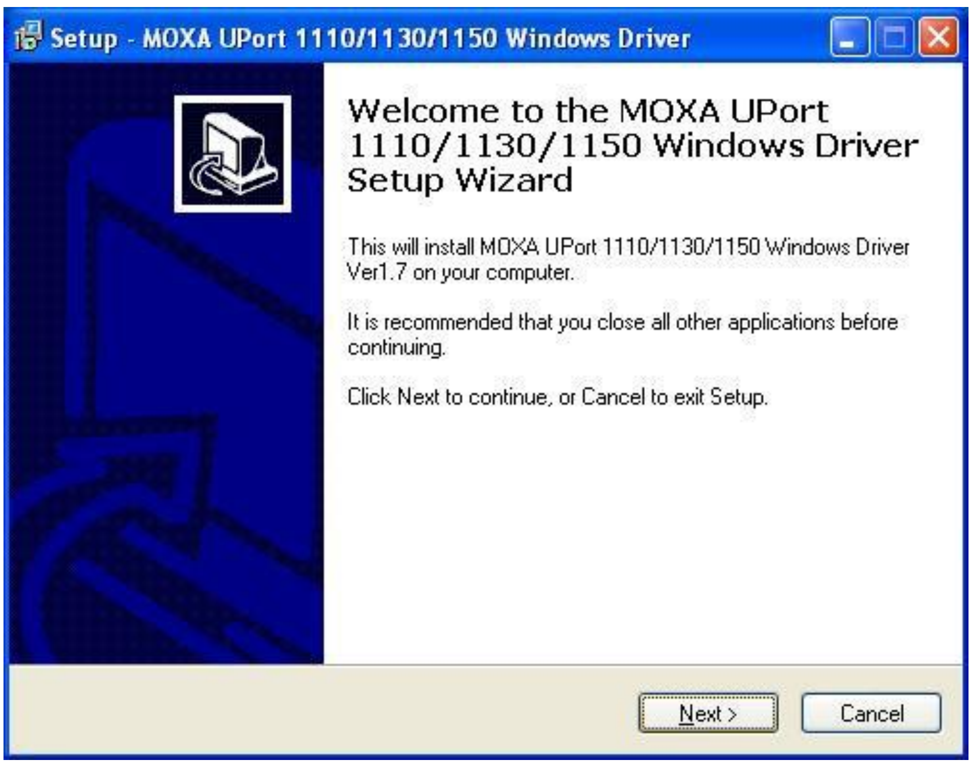


Fig.B.1

Click «**Next**» button and window shown on the Fig.B.2 will appear. In the address box put the exact location where the drivers have been installed to.

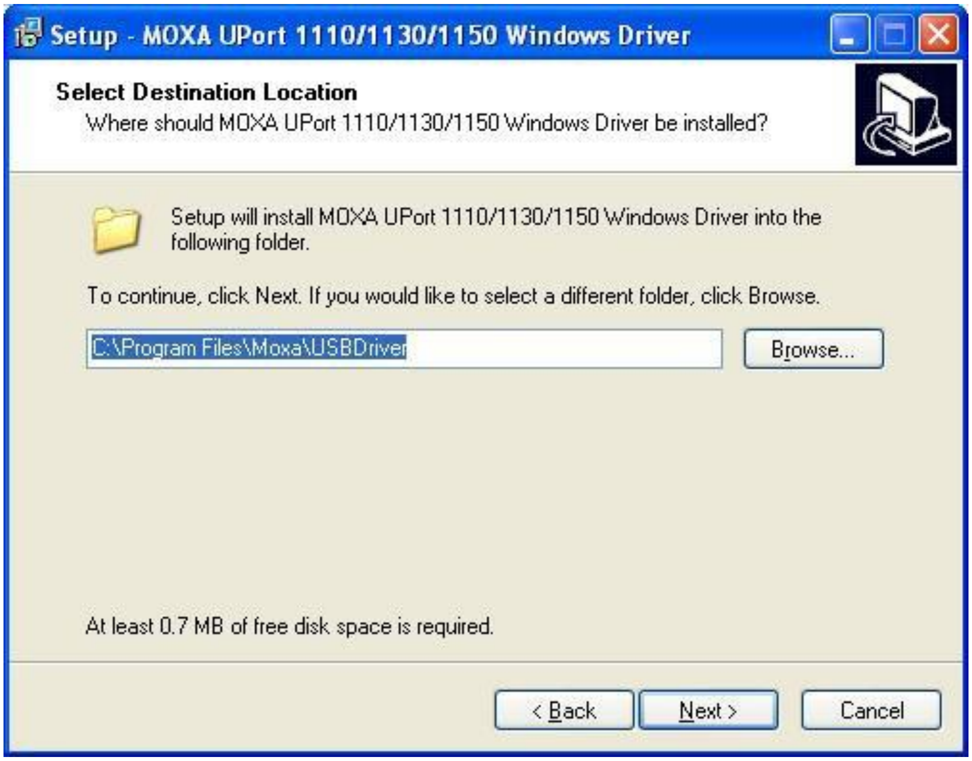
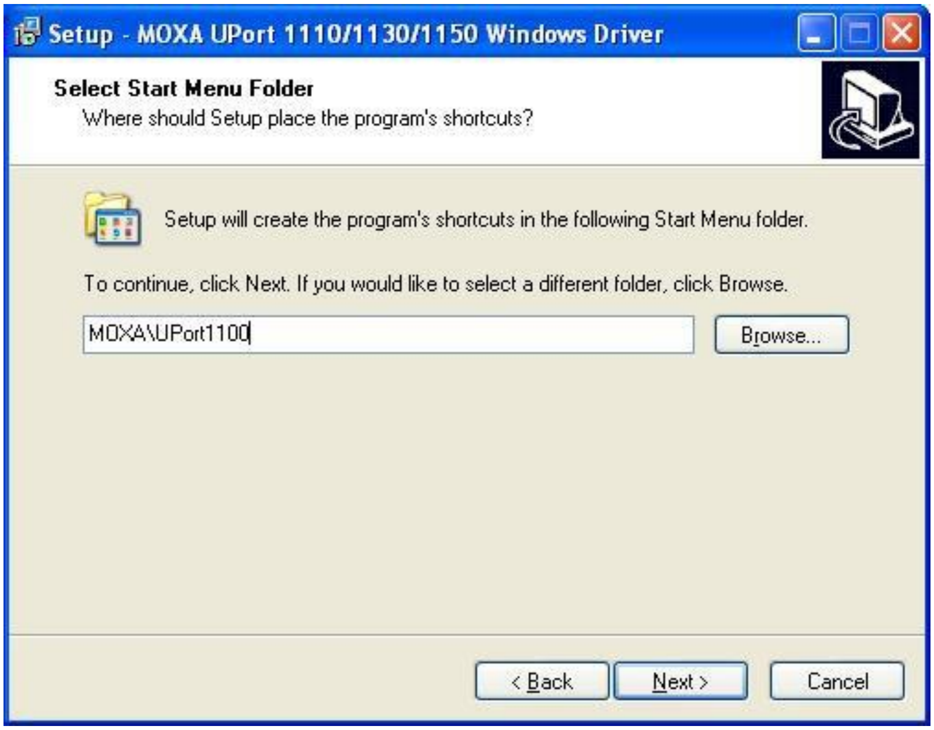


Fig.B.2

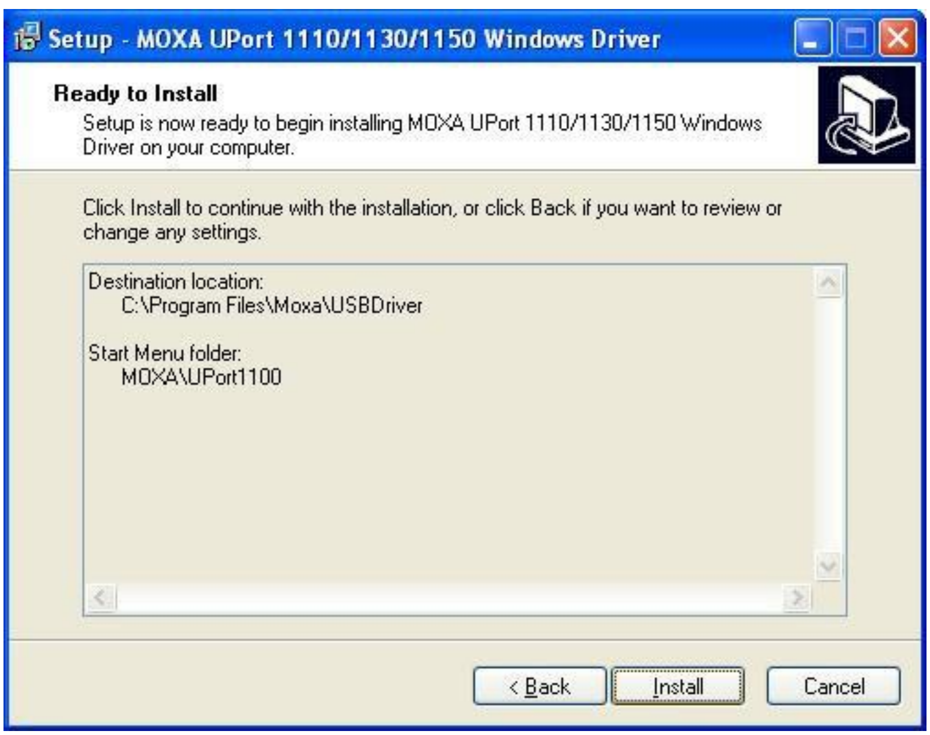
Click «**Next**» to continue installation. Then window shown on the Fig.B.3 will appear. In the address box put location and name of the program's shortcuts and click «**Next**» button.

Window Fig.B.4. will appear where you can check the correctness of settings. If data are correct click «**Install**» button. In the other case click «**Back**» button to rewiew and change any settings. If installation completed successfully window shown on the Fig.B.5 will appear. Click «**Finish**» button to close installation window.



Setup - MOXA UPort 1110/1130/1150 Windows Driver
Select Start Menu Folder
Where should Setup place the program's shortcuts?
Setup will create the program's shortcuts in the following Start Menu folder.
To continue, click Next. If you would like to select a different folder, click Browse.
MOXA\UPort1100
Browse...
< Back
Next >
Cancel

Fig.B.3



Setup - MOXA UPort 1110/1130/1150 Windows Driver
Ready to Install
Setup is now ready to begin installing MOXA UPort 1110/1130/1150 Windows Driver on your computer.
Click Install to continue with the installation, or click Back if you want to review or change any settings.
Destination location:
C:\Program Files\Moxa\USBDriver
Start Menu folder:
MOXA\UPort1100
< Back
Install
Cancel

Fig.B.4

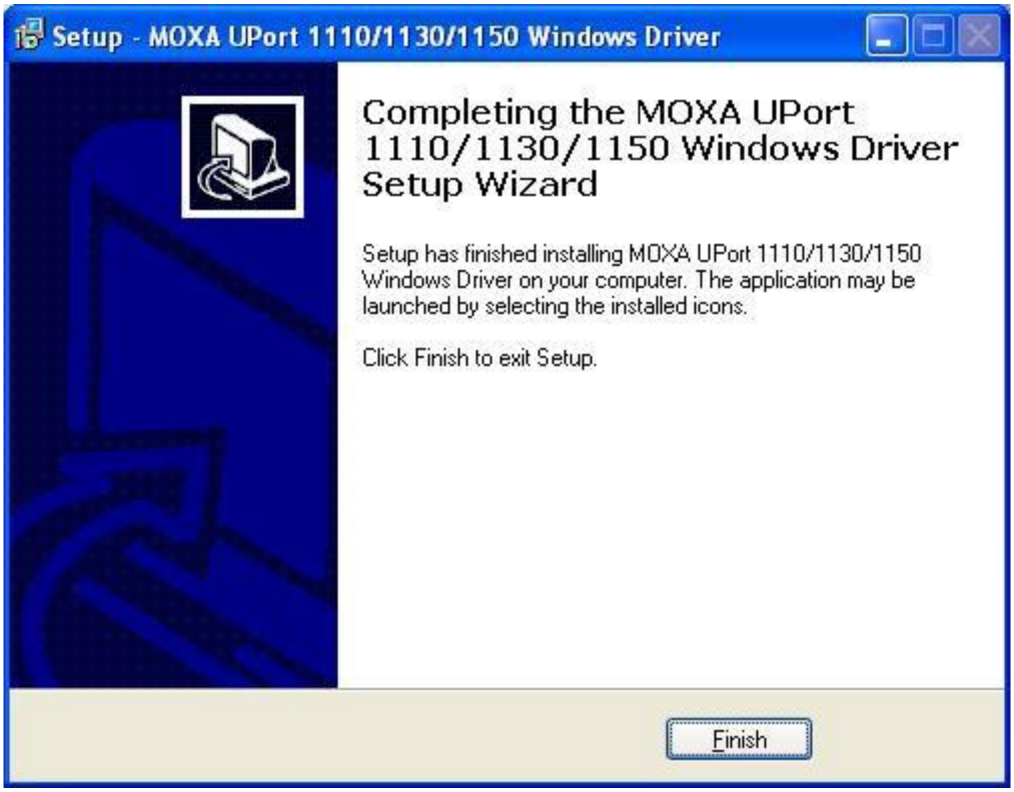


Fig.B.5

The next step is configuration of the installed driver. To do this, press the «**Device Manager**» button in the «System Properties» window, in the «**Hardware**» page. In the opened «Device Manager» window (see Fig.B.6) select device «**Uport 1130**» in the «**Multiport serial adapters**» group.

Double click on this device to show its properties where go to the «**Ports Configuration**» tab (see Fig.B.7). Please check that there is set **RS-422** interface as Fig.B.7 shows. If other interface is set then click on the «**Port Setting**» button, and in opened window Fig.B.8 select just **RS-422** interface. Click «**OK**» button to accept configuration.

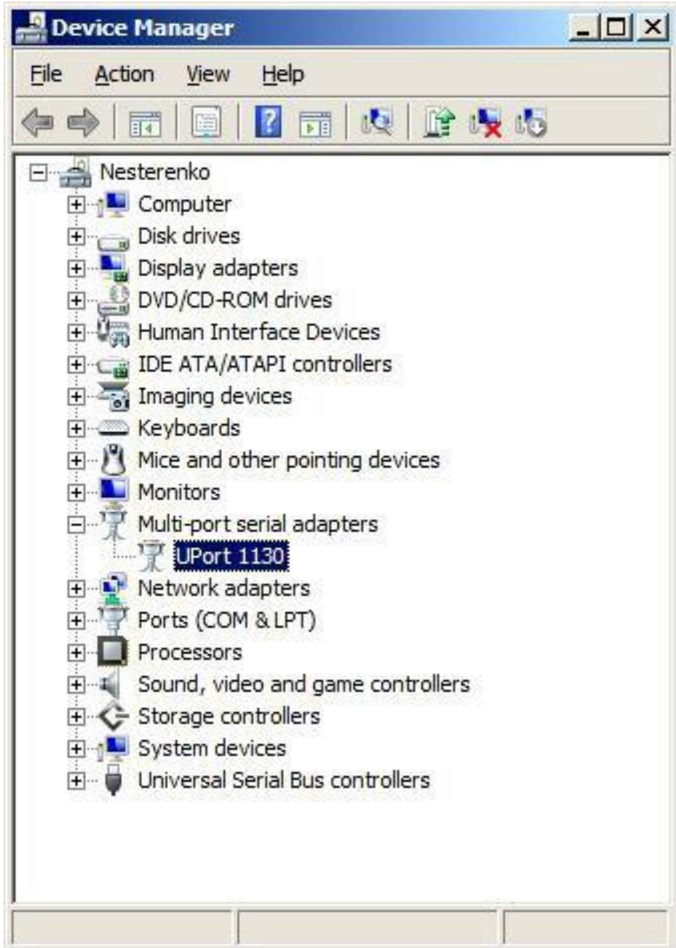

Device Manager
File
Action
View
Help
Nesterenko
Computer
Disk drives
Display adapters
DVD/CD-ROM drives
Human Interface Devices
IDE ATA/ATAPI controllers
Imaging devices
Keyboards
Mice and other pointing devices
Monitors
Multi-port serial adapters
UPort 1130
Network adapters
Ports (COM & LPT)
Processors
Sound, video and game controllers
Storage controllers
System devices
Universal Serial Bus controllers

Fig.B.6

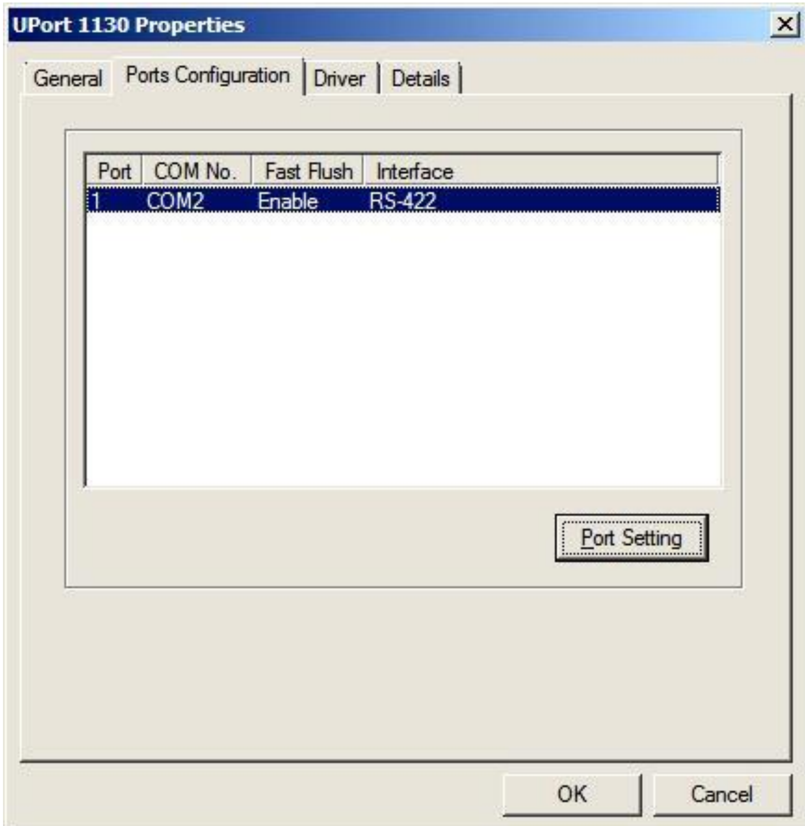

UPort 1130 Properties
General
Ports Configuration
Driver
Details
Port
COM No.
Fast Flush
Interface
1
COM2
Enable
RS-422
Port Setting
OK
Cancel

Fig.B.7

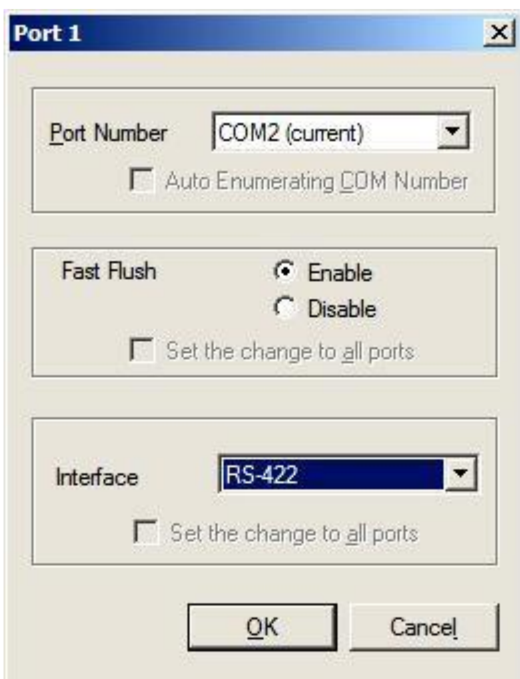

Port 1
Port Number
COM2 (current)
Auto Enumerating COM Number
Fast Flush
Enable
Disable
Set the change to all ports
Interface
RS-422
Set the change to all ports
OK
Cancel

Fig.B.8

Once the converter driver is installed and configured, you will need to know the number of the additional COM-port set by the system and configure parameters of this port for correct operation of the INS. To do this, go again to the «**Device Manager**» window Fig.B.6 and look the «**Ports (COM & LPT)**» list. There additional COM-port is appeared, «**MOXA USB serial port (COMN)**» (see Fig.B.9). Number N in the port name is the necessary port number assigned by the computer.

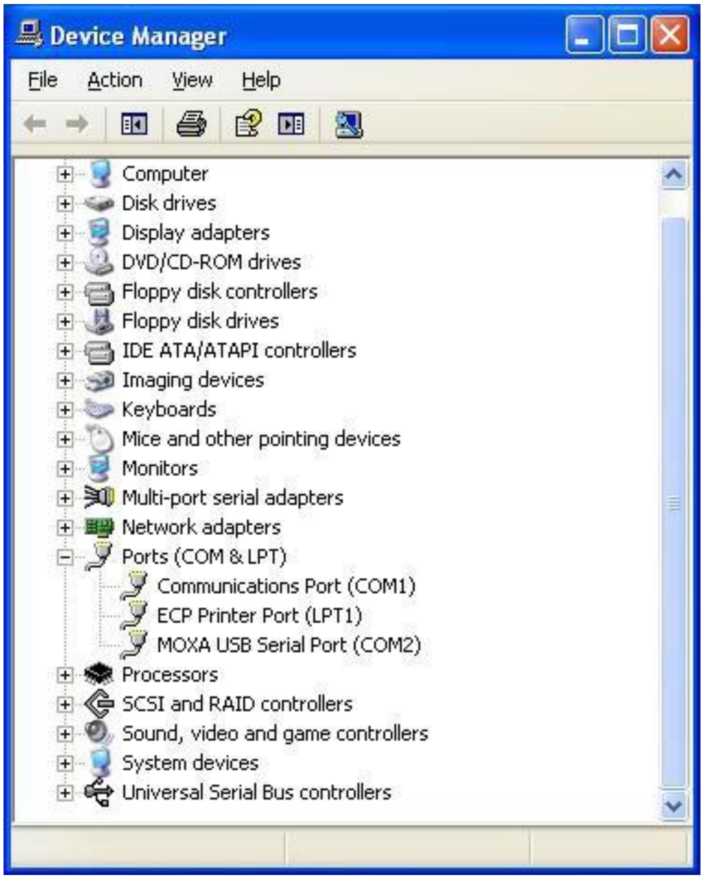


Fig.B.9

APPENDIX C.
Description of data files

The Tersus INS Demo software creates data files if “**Write**” button is pressed after INS start. These are two binary files with the same name and extensions .prm and .bin, where .prm file contains the INS parameters, and .bin file contains the INS outputs. Select «**Report of experiment**» item from the **“Convert**“ menu of the INS Demo or press F8 or click button to convert these binary data to text file (see section 9 for more details).

Structure of binary and text files is described below. Note that text file is more convenient for analysis.

C.1. Structure of binary file

If user has possibility to work with binary file directly, below is description of the binary .bin file. This file structure copies structure of the INS output data that is described in the Tersus INS Interface Control Document (ICD).

The first 50 bytes of the *.bin file are results of the INS initial alignment, see Table C.1.

Table C.1. Structure of the first 50 bytes of *.bin file (block of initial alignment data)

Byte	Parameter	Format	Length	*Note*
0-11	Gyros bias	float	3*4	3 numbers in ADC codes
12-23	Average acceleration	float	3*4	3 numbers in ADC codes
24-35	Average magn. field	float	3*4	3 numbers in ADC codes
36-39	Initial Heading	float	4	degrees
40-43	Initial Roll	float	4	degrees
44-47	Initial Pitch	float	4	degrees
48-49	USW	word	2	0 – successful initial alignment; 0 – unsuccessful

Notes:

1. USW is Unit Status Word (see Appendix D. The Unit Status Word definition, for details).
2. In the Table C.1 and in all next there is denoted:
word = unsigned 2 byte integer;
sword = signed 2 byte integer.
3. The low byte is the first.

All the next data in the *.bin file are blocks of the INS output data written at INS operation with set data rate. Each data block has structure according to the chosen output format – "INS OPVT", "INS QPVT", "INS OPVT2A", "INS OPVT2AW", "INS OPVT2Ahr", "INS Full Output Data", "INS Sensors Data" and "INS Minimal Data", "INS NMEA", "INS Sensors NMEA". Structure of data block is described in Table C.2, Table C.5, Table C.6, Table C.7, Table C.8, Table C.9, Table C.10 and Table C.16 for each output data format.

Table C.2. The INS message payload at the "INS OPVT" (Orientation, Position, Velocity, Time) data format

Byte number	0 – 1	2 – 3	4 – 5	6 – 11	12 – 17	18 – 23	24 – 25	26 – 27	28 – 29
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	USW	Vinp	Temper
Length	2 byte word	2 byte sword	2 byte sword	3 2 byte sword	3 2 byte sword	3 2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Angular rates, deg/s *KG	Accele-rations g*KA	Magne-tic fields, nT/10		Supply voltage, VDC* 100	Temper ature, ºC*10

Table C.2 (continued)

Byte number	30 – 33	34 – 37	38 – 41	42 – 45	46 – 49	50 – 53
Parameter	Latitude	Longitude	Altitude or Heave	East speed	North speed	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	m/s*100	m/s*100

Table C.2 (continued)

Byte number	54 – 57	58 – 61	62 – 65	66 – 69	70 – 71	72 – 75
Parameter	Latitude GNSS	Longitude GNSS	Altitude GNSS	Horizontal speed	Track over ground	Vertical speed

Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	2 byte word	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	deg*100	m/s*100

Table C.2 (continued)

Byte number	76-79	80	81	82	83-84	85-86	87-90	91
Parameter	ms_gps	GNSS_info1	GNSS_info2	#solnSVs	Latency	P_bar	H_bar	New GPS
Length	4 byte	1 byte	1 byte	1 byte	2 byte	2 byte word	4 byte integer	1 byte
Note	ms				s*1000	Pa/2	m*100	

Notes:

1. Values of KG, KA are scale factors depending on gyro and accelerometer range:

Gyro range, deg/sec	250 or 300	450 or 500	1000	2000
KG	100	50	20	10

Accelerometer range, g	2	6	8
KA	10000	5000	4000

2. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). The INS orientation relative to the carrier object axes is set by alignment angles (see Appendix E. Variants of the Tersus INS mounting relative to the object axes).
3. USW is unit status word (see Appendix D for details).
4. Vinp is input voltage of the INS.
5. Temper is averaged temperature in 3 gyros.
6. ms_gps are milliseconds from the beginning of the GPS reference week;
7. GNSS_info1, GNSS_info2 contain information about GNSS data (see Table C.3, Table C.4);
8. #SolnSVs is number of satellites used in navigation solution;
9. V_latency is latency in the velocity time tag in milliseconds;
10. Choice of altitude or heave and appropriate rate for output is supported in INS-D units and depends on switch “Vertical position” in the “IMU” tab of the «Devices Options» window (see section 10.3 for details).
11. P_bar, H_bar – pressure and barometric height.
12. New_GPS is indicator of new update of GPS data;
13. The low byte is transmitted by first.

Table C.3. GNSS_info1 – information about GNSS data

Bit	Value and Description
0 – 3	<u>Position type</u>: 0 – Single point position;

	1 – DGPS (pseudorange differential solution); 2 – Solution calculated using corrections from SBAS; 3 – PPP solution; 4 – RTK (other) solution; 5 – RTK (narrow-int) solution; 6 – Other.
4 – 7	Pseudorange iono correction: 0 – unknown or default Klobuchar model; 1 – Klobuchar Broadcast; 2 – SBAS Broadcast; 3 – Multi-frequency Computed; 4 – DGPS (pseudorange differential correction); 5 – Blended Iono Value.

Table C.4. GNSS_info2 – information about GNSS data

Bit	Value and Description
0 – 1	Solution status: 0 – GNSS solution is computed; 1 – insufficient observations; 2 – not yet converged from cold start; 3 – other reason of absent solution.
2 – 3	GPS reference time status: 0 – time validity is unknown; 1 – time is coarse set and is being steered; 2 – position is lost and the range bias cannot be calculated; 3 – time is fine set and is being steered.
4	1 – GPS GNSS signal is used
5	1 – GLONASS GNSS signal is used
6	1 – Galileo GNSS signal is used
7	1 – BeidDou GNSS signal is used

Table C.5. The INS message payload at the "INS QPVT" (Quaternion of orientation, Position, Velocity, Time) data format

Byte number	0-7	8 – 13	14 – 19	20 – 25	26 – 27	28 – 29	30-31
Parameter	Lk0, Lk1, Lk2, Lk3	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	USW	Vinp	Temper
Length	4 2 byte sword	3 2 byte sword	3 2 byte sword	3 2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Quaternion of orientation *10000	Angular rates, deg/s *KG	Accele-rations g*KA	Magne-tic fields, nT/10		Supply voltage, VDC* 100	Temper ature, ºC*10

Table C.5 (continued)

Byte number	32 – 35	36 – 39	40 – 43	44 – 47	48 – 51	52 – 55
Parameter	Latitude	Longitude	Altitude or Heave	East speed	North speed	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	m/s*100	m/s*100

Table C.5 (continued)

Byte number	56 – 59	60 – 63	64 – 67	68 – 71	72 – 73	74 – 77
Parameter	Latitude GNSS	Longitude GNSS	Altitude GNSS	Horizontal speed	Track over ground	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	2 byte word	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	deg*100	m/s*100

Table C.5 (continued)

Byte number	78-81	82	83	84	85-86	87-88	89-92	93
Parameter	ms_gps	GNSS_info1	GNSS info2	#SolnSVs	Latency	P_bar	H_bar	New GPS
Length	4 byte	1 byte	1 byte	1 byte	2 byte	2 byte word	4 byte integer	1 byte
Note	ms				s*1000	Pa/2	m*100	

Notes:

1. The “INS QPVT” data format is implemented in INS firmware since version 2.1.2.0.
2. See detailed description for correct relationship between orientation angles and quaternion in the INS ICD, rev.1.7 or higher, “APPENDIX D. Forms of the Tersus INS orientation presentation”.
3. Values of KG, KA are scale factors depending on gyro and accelerometer range:

Gyro range, deg/sec	250 or 300	450 or 500	1000	2000
KG	100	50	20	10

Accelerometer range, g	2	6	8
KA	10000	5000	4000

4. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X

is lateral axis, Y is longitudinal axis, Z is vertical axis). The INS orientation relative to the carrier object axes is set by alignment angles (see Appendix E. Variants of the Tersus INS mounting relative to the object axes).

5. USW is unit status word (see Appendix D for details).
6. Vinp is input voltage of the INS.
7. Temper is averaged temperature in 3 gyros.
8. ms_gps are milliseconds from the beginning of the GPS reference week;
9. GNSS_info1, GNSS_info2 contain information about GNSS data (see Table C.3, Table C.4);
10. #SolnSVs is number of satellites used in navigation solution;
11. V_latency is latency in the velocity time tag in milliseconds;
12. Choice of altitude or heave and appropriate rate for output is supported in INS-D units and depends on switch “Vertical position” in the “IMU” tab of the «Devices Options» window (see section 10.3 for details).
13. P_bar, H_bar – pressure and barometric height.
14. New_GPS is indicator of new update of GPS data;
15. The low byte is transmitted by first.

Table C.6. The INS message payload at the “INS OPVT2A” (Orientation, Position, Velocity, Time, Dual-antenna receiver data) format

Byte number	0 – 1	2 – 3	4 – 5	6 – 11	12 – 17	18 – 23	24 – 25	26 – 27	28 – 29
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	USW	Vinp	Temper
Length	2 byte word	2 byte sword	2 byte sword	3 2 byte sword	3 2 byte sword	3 2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Angular rates, deg/s *KG	Accele-rations g*KA	Magne-tic fields, nT/10		Supply voltage, VDC* 100	Temper ature, ºC*10

Table C.6 (continued)

Byte number	30 – 33	34 – 37	38 – 41	42 – 45	46 – 49	50 – 53
Parameter	Latitude	Longitude	Altitude or Heave	East speed	North speed	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	m/s*100	m/s*100

Table C.6 (continued)

Byte number	54 – 57	58 – 61	62 – 65	66 – 69	70 – 71	72 – 75
Parameter	Latitude GNSS	Longitude GNSS	Altitude GNSS	Horizontal speed	Track over ground	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	2 byte word	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	deg*100	m/s*100

Table C.6 (continued)

Byte number	76-79	80	81	82	83-84	85	86-87	88-89
Parameter	ms_gps	GNSS_info1	GNSS_info2	#solnSVs	V_latency	Angles position type	Heading GNSS	Pitch GNSS
Length	4 byte	1 byte	1 byte	1 byte	2 byte	1 byte	2 byte word	2 byte sword
Note	ms				s*1000		Orientation angles, deg*100	

Table C.6 (continued)

Byte number	90-91	92-93	94-95	96-99	100
Parameter	Heading STD GNSS	Pitch STD GNSS	P_bar	H_bar	New GPS
Length	2 byte word	2 byte word	2 byte word	4 byte integer	1 byte
Note	STD, deg*100		Pa/2	m*100	

Notes:

1. Values of KG, KA are scale factors depending on gyro and accelerometer range:

Gyro range, deg/sec	250 or 300	450 or 500	1000	2000
KG	100	50	20	10

Accelerometer range, g	2	6	8
KA	10000	5000	4000

2. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). The INS orientation relative to the

carrier object axes is set by alignment angles (see Appendix E. Variants of the Tersus INS mounting relative to the object axes).
3. USW is unit status word (see Appendix D for details).
4. Vinp is input voltage of the INS.
5. Temper is averaged temperature in 3 gyros.
6. ms_gps are milliseconds from the beginning of the GPS reference week;
7. GNSS_info1, GNSS_info2 contain information about GNSS data (see Table C.3, Table C.4);
8. #SolnSVs is number of satellites used in navigation solution;
9. V_latency is latency in the velocity time tag in milliseconds;
10. Angles position type is GNSS position type at orientation calculation (see Table C.12);
11. Choice of altitude or heave and appropriate rate for output is supported in INS-D units and depends on switch “Vertical position” in the “IMU” tab of the «Devices Options» window (see section 10.3 for details).
12. P_bar, H_bar – pressure and barometric height.
13. New_GPS is indicator of new update of GPS data;
14. The low byte is transmitted by first.

Table C.7. The INS message payload at the “INS OPVT2AW” (Orientation, Position, Velocity, Time, Dual-antenna receiver data, GPS Week) format

Byte number	0 – 1	2 – 3	4 – 5	6 – 11	12 – 17	18 – 23	24 – 25	26 – 27	28 – 29
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	USW	Vinp	Temper
Length	2 byte word	2 byte sword	2 byte sword	3 2 byte sword	3 2 byte sword	3 2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Angular rates, deg/s *KG	Accele-rations g*KA	Magne-tic fields, nT/10		Supply voltage, VDC* 100	Temper ature, ºC*10

Table C.7 (continued)

Byte number	30 – 33	34 – 37	38 – 41	42 – 45	46 – 49	50 – 53
Parameter	Latitude	Longitude	Altitude or Heave	East speed	North speed	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	m/s*100	m/s*100

Table C.7 (continued)

Byte number	54 – 57	58 – 61	62 – 65	66 – 69	70 – 71	72 – 75
Parameter	Latitude GNSS	Longitude GNSS	Altitude GNSS	Horizontal speed	Track over ground	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	2 byte word	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	deg*100	m/s*100

Table C.7 (continued)

Byte number	76-79	80-81	82	83	84	85-86	87
Parameter	ms_gps	GPS week	GNSS_info1	GNSS_info2	#solnSVs	V_latency	Angles position type
Length	4 byte	2 byte word	1 byte	1 byte	1 byte	2 byte	1 byte
Note	ms					s*1000	

Table C.7 (continued)

Byte number	88-89	90-91	92-93	94-95	96-97	98-101	102
Parameter	Heading GNSS	Pitch GNSS	Heading STD GNSS	Pitch STD GNSS	P_bar	H_bar	New GPS
Length	2 byte word	2 byte sword	2 byte word	2 byte word	2 byte word	4 byte integer	1 byte
Note	Orientation angles, deg*100		STD, deg*100		Pa/2	m*100	

Notes:

1. Values of KG, KA are scale factors depending on gyro and accelerometer range:

Gyro range, deg/sec	250 or 300	450 or 500	1000	2000
KG	100	50	20	10

Accelerometer range, g	2	6	8
KA	10000	5000	4000

2. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). The INS orientation relative to the carrier object axes is set by alignment angles (see Appendix E. Variants of the Tersus INS mounting relative to the object axes).

3. USW is unit status word (see Appendix D for details).
4. Vinp is input voltage of the INS.
5. Temper is averaged temperature in 3 gyros.
6. ms_gps are milliseconds from the beginning of the GPS reference week;
7. GNSS_info1, GNSS_info2 contain information about GNSS data (see Table C.3, Table C.4);
8. #SolnSVs is number of satellites used in navigation solution;
9. V_latency is latency in the velocity time tag in milliseconds;
10. Angles position type is GNSS position type at orientation calculation (see Table C.12);
11. Choice of altitude or heave and appropriate rate for output is supported in INS-D units and depends on switch "Vertical position" in the "IMU" tab of the «Devices Options» window (see section 10.3 for details).
12. P_bar, H_bar – pressure and barometric height.
13. New_GPS is indicator of new update of GPS data;
14. The low byte is transmitted by first.

Table C.8. The INS message payload at the "INS OPVT2Ahr" (Orientation, Position, Velocity, Time, Dual-antenna receiver data, with high resolution) data format

Byte number	0 – 1	2 – 3	4 – 5	6 – 17	18 – 29	30 – 35	37 – 37	38 – 39	40 – 41
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ	USW	Vinp	Temper
Length	2 byte word	2 byte sword	2 byte sword	3 4 byte integer	3 4 byte integer	3 2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Angular rates, deg/s *1.0e5	Accele-rations, g*1.0e6	Magne-tic fields, nT/10		Supply voltage, VDC* 100	Temper ature, ºC*10

Table C.8 (continued)

Byte number	42 – 49	50 – 57	58 – 61	62 – 65	66 – 69	70 – 73
Parameter	Latitude	Longitude	Altitude or Heave	East speed	North speed	Vertical speed
Length	8 byte integer	8 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer
Note	deg*1.0e9	deg*1.0e9	m*1000	m/s*100	m/s*100	m/s*100

Table C.8 (continued)

Byte number	74 – 81	82 – 89	90 – 93	94 – 97	98 – 99	100 – 103
Parameter	Latitude GNSS	Longitude GNSS	Altitude GNSS	Horizontal speed	Track over ground	Vertical speed
Length	8 byte integer	8 byte integer	4 byte integer	4 byte integer	2 byte word	4 byte integer
Note	deg*1.0e9	deg*1.0e9	m*1000	m/s*100	deg*100	m/s*100

Table C.8 (continued)

Byte number	104-107	108	109	110	111-112	113	114-115	116-117
Parameter	ms_gps	GNSS_info1	GNSS_info2	#solnSVs	V_latency	Angles position type	Heading GNSS	Pitch GNSS
Length	4 byte	1 byte	1 byte	1 byte	2 byte	1 byte	2 byte word	2 byte sword
Note	ms				s*1000		Orientation angles, deg*100	

Table C.8 (continued)

Byte number	118-119	120-121	122-123	124-127	128
Parameter	Heading STD GNSS	Pitch STD GNSS	P_bar	H_bar	New GPS
Length	2 byte word	2 byte word	2 byte word	4 byte integer	1 byte
Note	STD, deg*100		Pa/2	m*100	

Notes:

1. Angular rates, linear accelerations and magnetic fields are in the carrier object axes (X is lateral axis, Y is longitudinal axis, Z is vertical axis). The INS orientation relative to the carrier object axes is set by alignment angles (see Appendix E. Variants of the Tersus INS mounting relative to the object axes).
2. USW is unit status word (see Appendix D for details).
3. Vinp is input voltage of the INS.
4. Temper is averaged temperature in 3 gyros.
5. ms_gps are milliseconds from the beginning of the GPS reference week;
6. GNSS_info1, GNSS_info2 contain information about GNSS data (see Table C.3, Table C.4);

7. #SolnSVs is number of satellites used in navigation solution;
8. V_latency is latency in the velocity time tag in milliseconds;
9. Angles position type is GNSS position type at orientation calculation (see Table C.12);
10. Choice of altitude or heave and appropriate rate for is supported in INS-D units and depends on switch "Vertical position" in the "IMU" tab of the «Devices Options» window (see section 10.3 for details).
11. P_bar, H_bar – pressure and barometric height.
12. New_GPS is indicator of new update of GPS data;
13. The low byte is transmitted by first.

Table C.9. The message payload at the "INS Full Output Data" format

Byte number	0 – 1	2 – 3	4 – 5	6 – 23	24 – 25	26 – 27	28 – 29	30 – 31	32 – 33
Parameter	Heading	Pitch	Roll	Ugyro, Uacc, Umag	Reser-ved	Mdec	USW	Vdd	Utermo
Length	2 byte word	2 byte sword	2 byte sword	9 2 byte	2 byte sword	2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Raw sensor data (gyros, accelerometers, magnetometers)		deg*100		Combi-ned voltage	Temper ature in each sensor

Table C.9 (continued)

Byte number	34 – 37	38 – 41	42 – 45	46 – 49	50 – 53	54 – 57
Parameter	Latitude	Longitude	Altitude or Heave	East speed	North speed	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	m/s*100	m/s*100

Table C.9 (continued)

Byte number	58 – 61	62 – 65	66 – 69	70 – 73	74 – 75	76 – 79
Parameter	Latitude GNSS	Longitude GNSS	Altitude GNSS	Horizontal speed	Track over ground	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	2 byte word	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m/s*100	deg*100	m/s*100

Byte number	80 – 83	84	85	86	87-88	89-90	91-92	93
Parameter	ms_gps	GNSS_ info1	GNSS _info2	#SolnSVs	V_latency	UP	UT	New GPS
Length	4 byte integer	1 byte	1 byte	1 byte	2 byte	2 byte word	2 byte word	1 byte
Note	ms				s*1000			

Notes

1. Mdec is magnetic declination (see section 1.3 for details), since INS firmware version 2.2.0.2.
2. USW is unit status word (see Appendix D for details).
3. The following data are recorded in the field «Vdd» sequentially:
   - the INS input voltage, Vinp, VDC*100;
   - stabilized voltage supplied to the INS sensors, Vdd, VDC*1000;
4. In the «Utermo» field ADC codes are recorded sequentially from 7 temperature sensors inside gyros, accelerometers and magnetometers.
5. ms_gps are milliseconds from the beginning of the GPS reference week;
6. GNSS_info1, GNSS_info2 contain information about GNSS data (see Table C.3, Table C.4);
7. #SolnSVs is number of satellites used in navigation solution;
8. V_latency is latency in the velocity time tag in milliseconds;
9. Choice of altitude or heave and appropriate rate for output is supported in INS-D units and depends on switch “Vertical position” in the “IMU” tab of the «Devices Options» window (see section 10.3 for details).
10. UP and UT are raw data from the pressure sensor – pressure and temperature.
11. New_GPS is indicator of new update of GPS data;
12. The low byte is transmitted by first.

Table C.10. The message payload at the “INS Sensors Data” format

Byte number	0 – 1	2 – 3	4 – 5	6 – 23	24 – 25	26 – 27	28 – 29	30 – 31	32 – 33
Parameter	Heading (AHRS)	Pitch (AHRS)	Roll (AHRS)	Ugyro, Uacc, Umag	Reser-ved	Reser-ved	USW	Vdd	Utermo
Length	2 byte word	2 byte sword	2 byte sword	9 2 byte	2 byte sword	2 byte sword	2 byte word	2 byte word	2 byte sword
Note	Orientation angles, deg*100			Raw sensor data (gyros, accelerometers, magnetometers)				Combi-ned voltage	Temper ature in each sensor

Byte number	34 – 37	38 – 41	42 – 45	46-47	48 – 49	50 – 51	52-55	56-57	58-61
Parameter	Latitude GNSS	Longitude GNSS	Altitude GNSS	Latitude STD	Longitude STD	Altitude STD	Horizontal speed	Track over ground	Vertical speed
Length	4 byte integer	4 byte integer	4 byte integer	2 byte word	2 byte word	2 byte word	4 byte integer	2 byte word	4 byte integer
Note	deg *1.0e7	deg *1.0e7	m*100	m*1000	m*1000	m*1000	m/s*100	deg*100	m/s*100

Table C. 10 (continued)

Byte number	62 – 65	66	67	68	69	70	71	72
Parameter	ms_gps	TS_gps	sol_stat	pos_type	#SVs	#SolnSVs	#SolnL1SVs	#SolnMultiSVs
Length	4 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte
Note	ms							

Table C. 10 (continued)

Byte number	73	74	75	76-77	78-79	80-81	82	83
Parameter	ext_sol_stat	Galileo and BeiDou	GPS and GLONASS	V_latency	UP	UT	New GPS	Reserv
Length	1 byte	1 byte	1 byte	2 byte	2 byte word	2 byte word	1 byte	1 byte
Note				s*1000				

Notes

1. USW is unit status word (see Appendix D for details).
2. The following data are recorded in the field «Vdd» sequentially:
   - the INS input voltage, Vinp, VDC*100;
   - stabilized voltage supplied to the INS sensors, Vdd, VDC*1000;
3. In the «Utermo» field ADC codes are recorded sequentially from 7 temperature sensors inside gyros, accelerometers and magnetometers.
4. ms_gps are milliseconds from the beginning of the GPS reference week;
5. TS_gps is time status which indicates the quality of the GPS reference time (see Table C.3);
6. sol_stat is GNSS solution status (see Table C.11);
7. pos_type is GNSS position type (see Table C.12);
8. #SVs is number of satellites tracked;
9. #SolnSVs is number of satellites used in navigation solution;
10. #SolnL1SVs is number of satellites with L1/E1/B1 signals used in solution;
11. #SolnMultiSVs is number of satellites with multi-frequency signals used in solution;
12. ext_sol_stat is GNSS extended solution status (see Table C.12);

13. GPS and GLONASS is GPS and GLONASS signal-used mask (see Table C.14);
14. Galileo and BeiDou is Galileo and BeiDou signal-used mask (see Table C.15);
15. V_latency is latency in the velocity time tag in milliseconds;
16. Choice of altitude or heave and appropriate rate for output is supported in INS-D units and depends on switch “Vertical position” in the “IMU” tab of the «Devices Options» window (see section 10.3 for details).
17. UP and UT are raw data from the pressure sensor – pressure and temperature.
18. New_GPS is indicator of new update of GPS data;
19. The low byte is transmitted by first.

Table C.11. sol_stat – GNSS solution status

Value	Description
0	Solution computed
1	Insufficient observations
2	No convergence
3	Singularity at parameters matrix
4	Covariance trace exceeds maximum (trace > 1000 m)
5	Test distance exceeded (maximum of 3 rejections if distance >10 km)
6	Not yet converged from cold start
7	Height or velocity limits exceeded (in accordance with export licensing restrictions)
8	Variance exceeds limits
9	Residuals are too large
13	Large residuals make position unreliable
18	When a FIX POSITION command is entered, the receiver computes its own position and determines if the fixed position is valid a
19	The fixed position, entered using the FIX POSITION command, is not valid
20	Position type is unauthorized - HP or XP on a receiver not authorized

Table C.12. pos_type – GNSS position or velocity type

Value	Description
0	No solution
8	Velocity computed using instantaneous Doppler
16	Single point position
17	Pseudorange differential solution
18	Solution calculated using corrections from an WAAS
19	Propagated by a Kalman filter without new observations
20	OmniSTAR VBS position (1)
32	Floating L1 ambiguity solution
33	Floating ionospheric-free ambiguity solution
34	Floating narrow-lane ambiguity solution

48	Integer L1 ambiguity solution
50	Integer narrow-lane ambiguity solution
64	OmniSTAR HP position (1)
65	OmniSTAR XP or G2 position (1)
68	Converging PPP solution (2)
69	PPP solution (2)

Notes

(1) A subscription for OmniSTAR or use of a DGPS service is required. It is not realized in the Tersus INS firmware yet.

(2) PPP solution requires access to a suitable correction stream, delivered either through L-Band or the internet. For L-Band delivered TerraStar or Veripos service, appropriate receiver software model is required, along with a subscription to the desired service. It is not realized in the Tersus INS firmware yet.

Table C.13. ext_sol_stat – GNSS extended solution status

Bit	Mask	Description
0	0x01	If an RTK solution: Fixed solution has been verified Otherwise: Reserved
1-3	0x0E	Pseudorange Iono Correction 0 = Unknown or default Klobuchar model 1 = Klobuchar Broadcast 2 = SBAS Broadcast 3 = Multi-frequency Computed 4 = PSRDiff Correction 5 = Blended Iono Value
4	0x10	Reserved
5	0x20	0 = No antenna warning 1 = Antenna information is missing
6-7	0xC0	Reserved

Table C.14. GPS and GLONASS signal-used mask

Bit	Mask	Description
0	0x01	GPS L1 used in solution
1	0x02	GPS L2 used in solution
2	0x04	GPS L5 used in solution
3	0x08	Reserved
4	0x10	GLONASS L1 used in solution
5	0x20	GLONASS L2 used in solution
6-7	0x40-0x80	Reserved

Table C.15. Galileo and BeiDou signal-used mask

Bit	Mask	Description
0	0x01	Galileo E1 used in solution
1-3	0x02-0x08	Reserved
4	0x10	BeiDou B1 used in solution
5	0x20	BeiDou B2 used in solution
6-7	0x40-0x80	Reserved

Table C.16. The message payload at the "INS Minimal Data" format

Byte number	0 – 1	2 – 3	4 – 5	6 – 7	8 – 9	10 – 11	12 – 15	16 – 19	20 – 23
Parameter	Heading	Pitch	Roll	USW	Vinp	Temper	Latitude	Longitude	Altitude or Heave
Length	2 byte word	2 byte sword	2 byte sword	2 byte word	2 byte word	2 byte sword	4 byte integer	4 byte integer	4 byte integer
Note	Orientation angles, deg*100				Supply voltage, VDC*100	Temperature, ºC*10	deg *1.0e7	deg *1.0e7	m*100

Table C.16 (continued)

Byte number	24 – 27	28 – 31	32 – 35	36-39	40	41
Parameter	East speed	North speed	Vertical speed	ms_gps	GNSS_info1	#SolnSVs
Length	4 byte integer	4 byte integer	4 byte integer	4 byte integer	1 byte	1 byte
Note	m/s*100	m/s*100	m/s*100			

Notes:

1. USW is unit status word (see Appendix D for details).
2. Vinp is input voltage of the INS.
3. Temper is averaged temperature in 3 gyros.
4. ms_gps are milliseconds from the beginning of the GPS reference week;
5. GNSS_info1 contains information about GNSS data (see Table C.3);
6. #SolnSVs is number of satellites used in navigation solution.
7. The low byte is transmitted by first.

At the **“INS NMEA”** output the INS data are transmitted in the form of sentences with printable ASCII characters like the NMEA 0183 format. Each sentence starts with a "$" sign and ends with <CR><LF> (carriage return 0xD and line feed 0xA symbols). All data fields are separated by commas. The general form of the “NMEA Output” sentence is the next

$PAPR,LLmm.mmmm,n,YYYmm.mmmm,x,AAAA.aa,B,RRRR.rr,PPP.pp, HHH.hh,ttttttttt,TTT.t,VV.v,SSSS*CC<CR><LF>

where PAPR is identifier and other fields are listed below:

- **LLmm.mmmm** is unsigned latitude, where LL are degrees, mm.mmmm are minutes;
- **n** is N or S (North or South);
- **YYYmm.mmmm** is unsigned longitude, where YYY are degrees, mm.mmmm are minutes;
- **x** is E or W (East or West);
- **AAAA.aa** is altitude or heave in meters;
- **B** denotes kind of height data that is defined by switch “Barometric altitude” in the “Pressure sensor” tab of the «Devices Options» window (see section 10.2):
  ‘a’ – altitude;
  ‘h’ – heave.
- **RRRR.rr** is roll in degrees;
- **PPP.pp** is pitch in degrees;
- **HHH.hh** is heading in degrees;
- **ttttttttt** is timestamp (milliseconds from the beginning of the GPS reference week);
- **TTT.t** is temperature inside INS (averaged value for 3 gyros);
- **VV.v** is input voltage of the INS;
- **SSSS** is unit status word, USW (see Appendix D for details). It is hex written with ASCII;
- **CC** is check sum that consists of a "*" and two hex digits representing XOR of all characters between, but not including "$" and "*".

The **“INS Sensors NMEA output”** data have structure close to the “INS NMEA”, with addition of gyros and accelerometers data. So, at the **“INS Sensors NMEA output”** the INS data are transmitted in the form of sentences with printable ASCII characters like the NMEA 0183 format. Each sentence starts with a "$" sign and ends with <CR><LF> (carriage return 0xD and line feed 0xA symbols). All data fields are separated by commas. The general form of the “INS Sensors NMEA output” sentence is the next

$PAPS,LLmm.mmmm,n,YYYmm.mmmm,x,AAAA.aa,B,RRRR.rr,PPP.pp, HHH.hh,GGGG.xx,GGGG.yy,GGGG.zz,AA.xxxx,AA.yyyy,AA.zzzz,ttttttttt, TTT.t,VV.v,SSSS*CC<CR><LF>

where PAPS is identifier and other fields are listed below:

- **LLmm.mmmm** is unsigned latitude, where LL are degrees, mm.mmmm are minutes;
- **n** is N or S (North or South);
- **YYYmm.mmmm** is unsigned longitude, where YYY are degrees, mm.mmmm are minutes;
- **x** is E or W (East or West);
- **AAAA.aa** is altitude or heave in meters;
- **B** denotes kind of height data that is defined by switch “Barometric altitude” in the “Pressure sensor” tab of the «Devices Options» window (see section 10.2):
  ‘a’ – altitude;
  ‘h’ – heave.
- **RRRR.rr** is roll in degrees;
- **PPP.pp** is pitch in degrees;
- **HHH.hh** is heading in degrees;
- **GGGG.xx** is gyro X data in degrees/s;
- **GGGG.yy** is gyro Y data in degrees/s;
- **GGGG.zz** is gyro Z data in degrees/s;
- **AA.xxxx** is accelerpmeter X data in g;
- **AA.yyyy** is accelerpmeter Y data in g;
- **AA.zzzz** is accelerpmeter Z data in g;
- **ttttttttt** is timestamp (milliseconds from the beginning of the GPS reference week);
- **TTT.t** is temperature inside INS (averaged value for 3 gyros);
- **VV.v** is input voltage of the INS;
- **SSSS** is unit status word, USW (see Appendix D for details). It is hex written with ASCII;
- **CC** is check sum that consists of a "*" and two hex digits representing XOR of all characters between, but not including "$" and "*".

C.2. Text presentation of output data formats

User can choose one of the formats to view and save INS data depending on the necessary information (see Fig.4.1). Select «**Report of experiment**» from the **"Convert**" menu or press F8 button to convert binary data to text file for convenience. Examples of these files are shown below. In the beginning of each file, after the text «Test report», serial number of the tested INS is specified, and next are the INS firmware version, date and time of file saving. Below are examples of the saved data in each of available data formats..

INS Sensors

P11 Test report Date\Time 15.07.2015 11:53:00, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________________ 60
Magnetic declination ____________________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.395 Altitude= 120.00 Date= 2015.4128
Initial alignment ____________________ Heading = 278.010 Roll = -1.372 Pitch = 0.297

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
278.01	0.30	-1.35	-31	25	-48	51	-137	4164	-5112	-418	-7308	0	0	8525	12.2
278.00	0.29	-1.34	-30	14	-52	52	-142	4166	-5110	-396	-7308	0	0	9401	5.01

(continuation)

USW (L/H)	Latitude	Longitude	Height	LatRMS	LonRMS	HgtRMS	hor_spd	trk_gnd	ver_spd	ms_Pos	TS
0000000 00000000	39.0492073	-77.3909065	121.63	3.959	-7.62	11.776	0.02	71.80	0.02	291206400	180
0000000 00000000	39.0492073	-77.3909065	121.63	3.959	-7.62	11.776	0.02	71.80	0.02	291206400	180

(continuation)

sol_stat	pos_type	#SVs	#solnSVs	L1SVs	Multi	ext_sol	Gal_Bei	GPS_GLO	latency	UP	UT	New_GPS
0	16	4	4	4	0	2	0	1	0.150	41350	28309	3
0	16	4	4	4	0	2	0	1	0.150	41350	28309	0

Note: saved data units

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
deg	deg	deg	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	–	–	ADC code	VDC

(continuation)

USW (L/H)	Latitude	Longitude	Height	LatRMS	LonRMS	HgtRMS	hor_spd	trk_gnd	ver_spd	ms_Pos	TS	sol_stat
– –	deg	deg	m	m	m	m	m/s	deg	m/s	ms	–	–

(continuation)

pos_type	#SVs	#solnSVs	L1SVs	Multi	ext_sol	Gal_Bei	GPS_GLO	latency	UP	UT	New_GPS
–	–	–	–	–	–	–	–	s	ADC code	ADC code	–

In the Temperature column ADC codes are recorded sequentially from 7 temperature sensors of the gyros, accelerometers, magnetometers.
In the Vdd column the INS input voltage and stabilized voltage supplied to the INS sensors are recorded sequentially.
USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS Full Output

P12 Test report Date\Time 15.07.2015 11:53:31, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________ 60
Magnetic declination ____________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ____________ Heading = 278.016 Roll = -1.416 Pitch = 0.318

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
278.01	0.32	-1.41	-31	15	-47	57	-137	4164	-5112	-418	-7308	0	0	8525	12.2
278.00	0.32	-1.41	-30	21	-45	61	-142	4166	-5110	-396	-7308	0	0	9393	5.02

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
0000000 00000000	39.0492073	-77.3909065	121.63	0.00	0.00	0.00	39.0492073	-77.3909065	121.67	0.05
0000000 00000000	39.0492073	-77.3909065	121.63	0.00	0.00	0.00	39.0492073	-77.3909065	121.67	0.05

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	UP	UT	New_GPS
296.51	-0.14	291237600	00010000	00011100	5	0.150	41348	28312	3
296.51	-0.14	291237600	00010000	00011100	5	0.150	41348	28312	0

Note: saved data units

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
deg	deg	deg	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	ADC code	–	–	ADC code	VDC

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
– –	deg	deg	m	m/s	m/s	m/s	deg	deg	m	m/s

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	UP	UT	New_GPS
deg	m/s	ms	–	–	–	s	ADC code	ADC code	–

In the Temperature column ADC codes are recorded sequentially from 7 temperature sensors of the gyros, accelerometers, magnetometers.
In the Vdd column the INS input voltage and stabilized voltage supplied to the INS sensors are recorded sequentially.
USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS OPVT Output

P13 Test report Date\Time 15.07.2015 11:54:00, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________ 60
Magnetic declination ____________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ____________ Heading = 277.999 Roll = -1.430 Pitch = 0.327

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Temperature	Vdd
277.97	0.32	-1.43	0.02	-0.020	0.020	0.025	0.006	1.005	21880	70	-38050	36.1	12.16
278.07	0.32	-1.43	-0.02	0.060	-0.020	0.024	0.006	1.007	21900	50	-38060	36.1	12.19

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00	39.0492073	-77.3909065	120.67	0.04
0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00	39.0492073	-77.3909065	120.67	0.04

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	P_Bar	H_Bar	New_GPS
89.77	0.25	291267650	00010000	00011100	4	0.150	99792	120.42	3
89.77	0.25	291267650	00010000	00011100	4	0.150	99790	120.51	0

Note: saved data units

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
deg	deg	deg	deg/s	deg/s	deg/s	g	g	g	nT	nT	nT	–	–	deg C	VDC

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
– –	deg	deg	m	m/s	m/s	m/s	deg	deg	m	m/s

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	P_Bar	H_Bar	New_GPS
deg	m/s	ms	–	–	–	s	Pa	m	–

USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS QPVT Output

P24 Test report Date\Time 15.07.2015 11:54:00, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________ 60
Magnetic declination ____________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ____________ Heading = 277.999 Roll = -1.430 Pitch = 0.327

Lk0	Lk1	Lk2	Lk3	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Temperature
0.6128	-0.0099	0.0056	0.7902	0.02	-0.020	0.020	0.025	0.006	1.005	21880	70	-38050	36.1
0.6128	-0.0099	0.0056	0.7902	-0.02	0.060	-0.020	0.024	0.006	1.007	21900	50	-38060	36.1

(continuation)

Vdd	USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS
12.16	0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00	39.0492073	-77.3909065	120.67
12.19	0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00	39.0492073	-77.3909065	120.67

(continuation)

Hor_spd	Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	P_Bar	H_Bar	New_GPS
0.04	89.77	0.25	291267650	00010000	00011100	4	0.150	99792	120.42	3
0.04	89.77	0.25	291267650	00010000	00011100	4	0.150	99790	120.51	0

Note: saved data units

Lk0	Lk1	Lk2	Lk3	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature
–	–	–	–	deg/s	deg/s	deg/s	g	g	g	nT	nT	nT	–	–	deg C

(continuation)

Vdd	USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS
VDC	– –	deg	deg	m	m/s	m/s	m/s	deg	deg	m

(continuation)

Hor_spd	Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	P_Bar	H_Bar	New_GPS
m/s	deg	m/s	ms	–	–	–	s	Pa	m	–

USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS OPVT2A Output

P29 Test report Date\Time 15.07.2015 11:54:00, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ________ 60
Magnetic declination ________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ________ Heading = 277.999 Roll = -1.430 Pitch = 0.327

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Temperature	Vdd
277.97	0.32	-1.43	0.02	-0.020	0.020	0.025	0.006	1.005	21880	70	-38050	36.1	12.16
278.07	0.32	-1.43	-0.02	0.060	-0.020	0.024	0.006	1.007	21900	50	-38060	36.1	12.19

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00	39.0492073	-77.3909065	120.67	0.04
0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00	39.0492073	-77.3909065	120.67	0.04

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	anglesPosType	Heading_GNSS	Pitch_GNSS
89.77	0.25	291267650	00010000	00011100	4	0.150	50	277.95	0.31
89.77	0.25	291267650	00010000	00011100	4	0.150	50	277.95	0.31

(continuation)

Heading_STD_GNSS	Pitch_STD_GNSS	P_Bar	H_Bar	New_GPS
0.16	0.38	99792	120.42	3
0.16	0.38	99790	120.51	0

Note: saved data units

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
deg	deg	deg	deg/s	deg/s	deg/s	g	g	g	nT	nT	nT	–	–	deg C	VDC

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
– –	deg	deg	m	m/s	m/s	m/s	deg	deg	m	m/s

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	anglesPosType	Heading_GNSS	Pitch_GNSS
deg	m/s	ms	–	–	–	s	–	deg	deg

(continuation)

Heading_STD_GNSS	Pitch_STD_GNSS	P_Bar	H_Bar	New_GPS
deg	deg	Pa	m	–

USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS OPVT2AW Output

P31 Test report Date\Time 15.09.2016 11:54:00, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v2.5.0.5 15.09.16
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ________________ 90
Magnetic declination ________________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ________________ Heading = 277.999 Roll = -1.430 Pitch = 0.327

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Temperature	Vdd
277.97	0.32	-1.43	0.02	-0.020	0.020	0.025	0.006	1.005	21880	70	-38050	36.1	12.16
278.07	0.32	-1.43	-0.02	0.060	-0.020	0.024	0.006	1.007	21900	50	-38060	36.1	12.19

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
0000000 00000000	39.04	-77.39	120.42	0.00	0.00	0.00	39.04	-77.39	120.67	0.04
0000000 00000000	39.04	-77.39	120.42	0.00	0.00	0.00	39.04	-77.39	120.67	0.04

(continuation)

Trk_gnd	Ver_spd	ms_gps	GPS_Week	GNSS_info1	GNSS_info2	#solnSVs	latency	anglesPosType	Heading_GNSS	Pitch_GNSS
89.77	0.25	291267650	180	00010000	00001100	4	0.150	50	277.95	0.31
89.77	0.25	291267650	180	00010000	00001100	4	0.150	50	277.95	0.31

(continuation)

Heading_STD_GNSS	Pitch_STD_GNSS	P_Bar	H_Bar	New_GPS
0.16	0.38	99792	120.42	3
0.16	0.38	99790	120.51	0

Note: saved data units

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
deg	deg	deg	deg/s	deg/s	deg/s	deg/s^2	deg/s^2	deg/s^2	T	T	T	–	–	deg C	VDC

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
– –	deg	deg	m	m/s	m/s	m/s	deg	deg	m	m/s

(continuation)

Trk_gnd	Ver_spd	ms_gps	GNSS_info1	GNSS_info2	#solnSVs	latency	anglesPosType	Heading_GNSS	Pitch_GNSS
deg	m/s	ms	–	–	–	s	–	deg	deg

(continuation)

Heading_STD_GNSS	Pitch_STD_GNSS	P_Bar	H_Bar	New_GPS
deg	deg	Pa	m	–

USW (Unit Status Word) is in binary form with low and high bytes listed in the last two columns. Status of each bit of the USW is specified in the Appendix D.

INS OPVT2Ahr Output

P30   Test report Date\Time 15.07.2015 11:54:00, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________ 60
Magnetic declination ____________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ____________ Heading = 277.999 Roll = -1.430 Pitch = 0.327

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Temperature	Vdd
277.97	0.32	-1.43	0.02345	-0.02098	0.01838	0.025112	0.006391	1.005762	21880.0	70.0	-38050.0	36.1	12.16
278.07	0.32	-1.43	-0.01342	0.06523	-0.02711	0.024321	0.006302	1.007171	21900.0	50.0	-38060.0	36.1	12.19

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
0000000 00000000	39.049207321	-77.390906543	120.424	0.00	0.00	0.00	39.049207318	-77.390906531	120.675	0.04
0000000 00000000	39.049207375	-77.390906511	120.421	0.00	0.00	0.00	39.049207392	-77.390906513	120.671	0.04

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	anglesPosType	Heading_GNSS	Pitch_GNSS
89.77	0.25	291267650	00010000	00011100	4	0.150	50	277.95	0.31
89.77	0.25	291267650	00010000	00011100	4	0.150	50	277.95	0.31

(continuation)

Heading_STD_GNSS	Pitch_STD_GNSS	P_Bar	H_Bar	New_GPS
0.16	0.38	99792	120.42	3
0.16	0.38	99790	120.51	0

Note: saved data units

Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z	Acc_X	Acc_Y	Acc_Z	Magn_X	Magn_Y	Magn_Z	Reserv1	Reserv2	Temperature	Vdd
deg	deg	deg	deg/s	deg/s	deg/s	g	g	g	nT	nT	nT	–	–	deg C	VDC

(continuation)

USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up	Lat_GNSS	Long_GNSS	Height_GNSS	Hor_spd
– –	deg	deg	m	m/s	m/s	m/s	deg	deg	m	m/s

(continuation)

Trk_gnd	Ver_spd	ms_Pos	GNSS_info_1	GNSS_info_2	#solnSVs	latency	anglesPosType	Heading_GNSS	Pitch_GNSS
deg	m/s	ms	–	–	–	s	–	deg	deg

(continuation)

Heading_STD_GNSS	Pitch_STD_GNSS	P_Bar	H_Bar	New_GPS
deg	deg	Pa	m	–

USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS Minimal Data

P14 Test report Date\Time 15.07.2015 11:54:27, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________ 60
Magnetic declination ____________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ____________ Heading = 277.983 Roll = -1.476 Pitch = 0.349

Heading	Pitch	Roll	Temperature	Vdd	USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up
277.98	0.34	-1.47	36.1	12.16	0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00
277.98	0.35	-1.47	36.1	12.19	0000000 00000000	39.0492073	-77.3909065	120.42	0.00	0.00	0.00

(continuation)

ms_Pos	GNSS_info_1	#solnSVs
291267650	00010000	4
291267650	00010000	4

Note: saved data units

Heading	Pitch	Roll	Temperature	Vdd	USW (L/H)	Latitude	Longitude	Height	V_East	V_North	V_Up
deg	deg	deg	deg C	VDC	– –	deg	deg	m	m/s	m/s	m/s

(continuation)

ms_Pos	GNSS_info_1	#solnSVs
ms	–	–

USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS NMEA Output

Example of the INS message in NMEA format:

```
$PAPR,3902.4227,N,07723.4368,W,0120.12,b,-001.48,000.35,277.94,036.1,12.1,0000*6C
$PAPR,3902.4227,N,07723.4368,W,0120.12,b,-001.48,000.35,277.95,036.1,12.1,0000*6D
```

See **APPENDIX C. Description of data files** for details of the INS message in INS NMEA Output format

NMEA data messages can be saved to more convenient text form using «Report of experiment» item from the "Convert" menu. Example of converted NMEA messages to *.txt file is shown below.

Example of the text form of INS NMEA format:

P20 Test report Date\Time 15.07.2015 11:54:53, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________________ 60
Magnetic declination ____________________ Mdec= -10.5 Latitude= 39.04 Longitude= -77.39 Altitude= 120.00 Date= 2015.4128
Initial alignment ________________________ Heading = 277.948 Roll = -1.486 Pitch = 0.351

Latitude	Longitude	Height	B	Heading	Pitch	Roll	Temperature	Vinp	USW (L/H)
39.0492073	-77.3909065	120.12	0	277.93	0.34	-1.47	36.1	12.09	0000000 00000000
39.0492073	-77.3909065	120.12	0	277.94	0.34	-1.47	36.1	12.09	0000000 00000000

Note: saved data units

Latitude	Longitude	Height	B	Heading	Pitch	Roll	Temperature	Vinp	USW (L/H)
deg	deg	m	–	deg	deg	deg	deg C	VDC	– –

USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

INS Sensors NMEA Output

Example of the INS message in Sensors NMEA format:

```
$PAPS,3902.4357,N,07723.4422,W,0000.00,h,0001.21,-00.18,255.30,0000.00,0000.28,-000.02,-0.0210,-0.0031,00.9999,483805170,040.9,12.1,0000*63
$PAPS,3902.4357,N,07723.4422,W,0000.00,h,0001.22,-00.18,255.30,0000.01,0000.19,-000.02,-0.0215,-0.0032,00.9988,483805190,040.9,12.2,0000*68
```

See **APPENDIX C. Description of data files** for details of the INS message in INS Sensors NMEA Output format

NMEA data messages can be saved to more convenient text form using «Report of experiment» item from the "Convert" menu. Example of converted INS Sensors NMEA messages to *.txt file is shown below.

Example of the text form of INS Sensors NMEA format:

```
P20   Test report Date\Time 15.07.2015 11:54:53, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________________ 60
Magnetic declination ____________________ Mdec= -10.5  Latitude= 39.04  Longitude= -77.39  Altitude= 120.00  Date= 2015.4128
Initial alignment _______________________ Heading =   277.948    Roll =    -1.486    Pitch =    0.351
```

Latitude	Longitude	Height	B	Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z
39.0492073	-77.3909065	120.12	0	255.30	-0.18	1.21	0.00	0.28	-0.02
39.0492073	-77.3909065	120.12	0	255.30	-0.18	1.21	0.01	0.19	-0.02

(continuation)

Acc_X	Acc_Y	Acc_Z	Timestamp	Temperature	Vinp	USW (L/H)
-0.0210	-0.0031	0.9999	483805170	40.9	12.10	0000000 00000000
-0.0215	-0.0032	0.9998	483805190	40.9	12.20	0000000 00000000

Note: saved data units

Latitude	Longitude	Height	B	Heading	Pitch	Roll	Gyro_X	Gyro_Y	Gyro_Z
deg	deg	m	–	deg	deg	deg			

(continuation)

Acc_X	Acc_Y	Acc_Z	Timestamp	Temperature	Vinp	USW (L/H)
g	g	g	ms	deg C	VDC	– –

USW (Unit Status Word) is in binary form with low and high bytes listed in two columns. Each bit of the USW is specified in the Appendix D.

TSS1

Example of the INS message in TSS1 format:

```
:0300E3 -0025H 1372 -2435
:030100 -0025H 1372 -2436
```

See **APPENDIX B. Description of data files** for details of the INS message in TSS1 format

TSS1 data messages can be converted to more convenient text form using «Report of experiment» item from the "Convert" menu. Example of converted TSS1 messages to *.txt file is shown below.

Example of the text form of TSS1 format:

```
P19   Test report Date\Time 15.07.2015 11:55:24, GPS reference week number 1853
Integrated device s/n: F1550000 firmware version: A2SM v1.0.1.6 14.07.15
*IMU: AHRS s/n C1510341 firmware version: A1SM v6.0.1.2NS 15.06.15

*Pressure sensor: present
Measurement rate, Hz ____________________ 60
Magnetic declination ____________________ Mdec= -10.5  Latitude= 39.04  Longitude= -77.39  Altitude= 120.00  Date= 2015.4128
Initial alignment _______________________ Heading =   277.975     Roll =    13.510     Pitch =    -24.357

     H_Acc        V_Acc        Heave        Roll        Pitch
     0.11         0.01419      -25          13.72       -24.35
     0.11         0.01600      -25          13.72       -24.36
```

Note: saved data units

H_Acc	V_Acc	Heave	Roll	Pitch
m/s^2	m/s^2	cm	deg	deg

APPENDIX D.
The Unit Status Word definition

The Unit Status Word (USW) provides the INS state information. The low byte (bits 0-7) of USW indicates failure of the INS. If this byte is 0, the INS operates correctly, if it is not 0, see the Table D.1 for type of failure. The high byte (bits 8-15) contains a warning or is informative for the user. Status of each bit of the USW warning byte is specified in the Table D.1.

Since INS Demo version 2.0.29.110 from 09/02/2016 the Demo software stops the INS unit if failure of gyro, accelerometer or GNSS receiver is detected.

Table D.1.The INS message format

	Bit	**Parameter**	**Performance**
Low (failure) byte	0	Initial Alignment	0 – Successful initial alignment 1 – Unsuccessful initial alignment due to INS moving or large change of outer magnetic field
	1	INS Parameters	0 – Parameters are correct 1 – Parameters are incorrect
	2	Gyroscope Unit	0 – No failure 1 – Failure is detected
	3	Accelerometer Unit	0 – No failure 1 – Failure is detected
	4	Magnetometer Unit	0 – No failure 1 – Failure is detected
	5	Electronics	0 – No failure 1 – Failure is detected
	6	GNSS receiver	0 – No failure 1 – Failure is detected
	7	Reserved	–
High (warning) byte	8	Incorrect Power Supply	0 – Supply voltage is not less than minimum level 1 – Low supply voltage is detected
	9		0 – Supply voltage is not higher than maximum level 1 – High supply voltage is detected
	10	Angular Rate Exceeding Detect	0 – X-angular rate is within the range 1 – X-angular rate is outrange

	11		0 – Y-angular rate is within the range 1 – Y-angular rate is outrange
	12		0 – Z-angular rate is within the range 1 – Z-angular rate is outrange
	13	Large Magnetic Field Detect	0 – Total magnetic field within the range 1 – Total magnetic field limit is exceeded
	14	Environmental Temperature	0 – Temperature is within the operating range 1 – Temperature is out of the operating range
	15	Reserved	–

APPENDIX E.
Variants of the Tersus INS mounting relative to object axes

The Tersus INS has axes orientation shown on Fig.E.1. At usual installation of the INS on carrier object the INS X, Y, Z axes should be parallel to the object lateral, longitudinal and vertical axes.

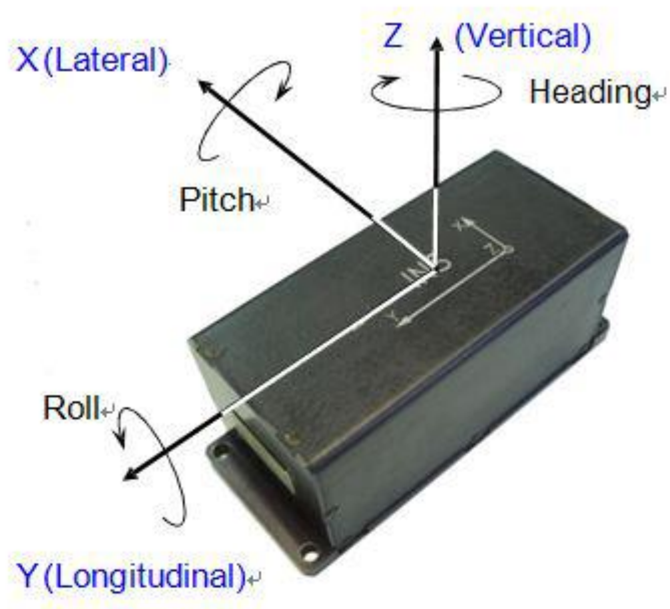


Fig.E.1. Coordinate system of the Tersus INS

But the Tersus INS can be mounted on the object in any known position (up to upside-down, upright etc.) relative to the object axes. Such mounting doesn't change right calculation of the object orientation if angles of the INS mounting are correctly stored in the INS nonvolatile memory.

To set these angles select item «Device option …» from the «Options» menu. In opened window Fig.4.2 angles of the INS mounting are in the "Alignment angles" section.

The INS alignment angles are set in the next order (like azimuth, pitch and roll setting):

- first alignment angle sets position of the INS longitudinal axis Y relative to longitudinal axes of the object measured in the horizontal plane of the object. Clockwise rotation is positive;
- second alignment angle is equal to angle of inclination of the INS longitudinal axis Y relative to the horizontal plane of the object. Positive direction is up;
- third alignment angle is equal to inclination angle of the INS lateral axis X measured around INS's longitudinal axis. Positive rotation is X axis moving down.

All angles are set in degrees.

Some examples of the Tersus INS mounting relative the object are shown on Fig.E.2.

To check correctness of the alignment angles please run the INS using the Tersus INS Demo program.

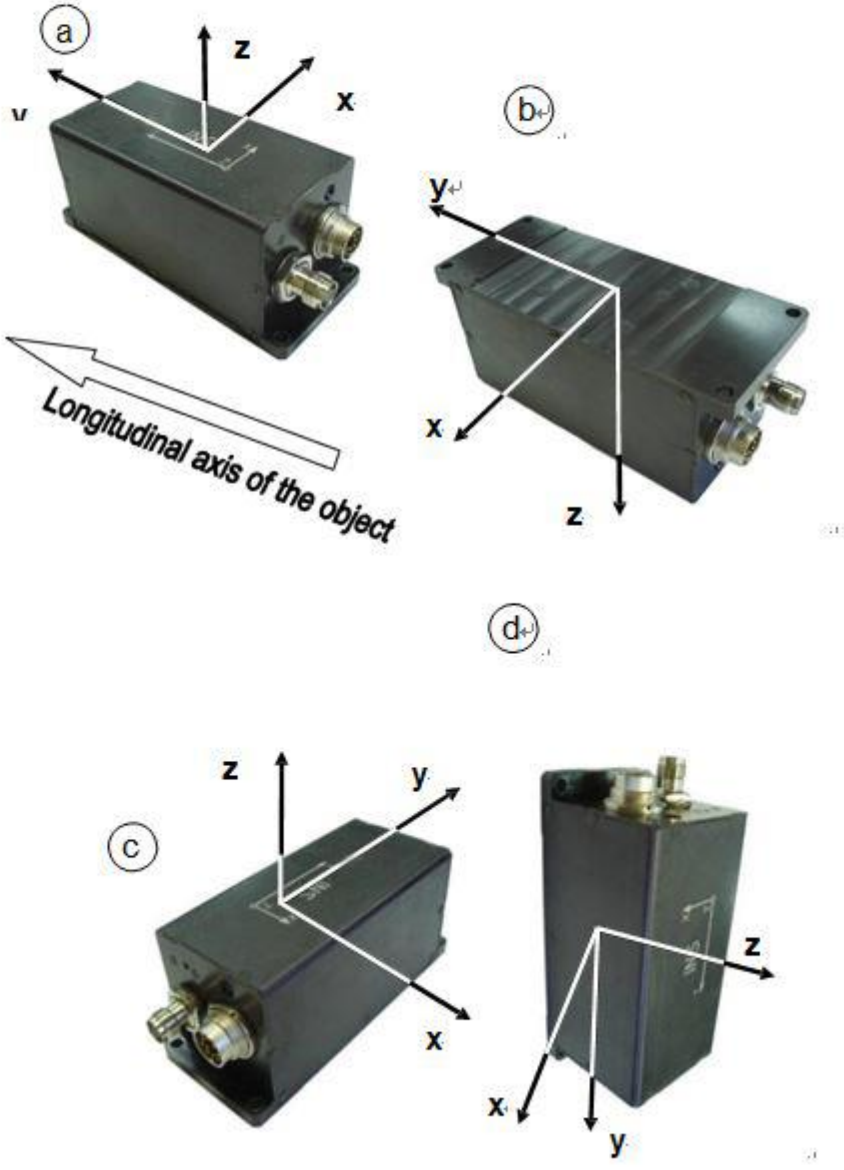


Fig.E.2. Examples of the Tersus INS mounting on the carrier object

a – alignment angles are 0, 0, 0 (degrees);
b – alignment angles are 0, 0, 180 (degrees);
c – alignment angles are 90, 0, 0 (degrees);
d – alignment angles are 180, -90, 0 (degrees).

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