IG-500E
Aided Navigation & AHRS
User Manual

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Index

1. Introduction 6
1.1. IG-500E Overview 6
1.2. Product codes and options 7
1.3. Provided development kit 8
1.3.1. Content of the development kit 8

2. IG-500E Presentation 9
2.1. Block diagram 9
2.2. Extended Kalman filter 9
2.2.1. Purpose 9
2.2.2. Heading observation 10
2.2.3. Aiding sensors : GPS, Barometer, External sensors 11
2.2.4. Dead reckoning in case of short GPS outages 12
2.3. Motion profiles 13
2.3.1. General Purpose 13
2.3.2. Airplane 14
2.3.3. Airplane – High dynamics 14
2.3.4. Helicopter 15
2.3.5. Automotive 15
2.3.6. Marine 16
2.3.7. Underwater 16
2.3.8. IMU 500 17
2.4. Heave computation 17
2.5. Internal Sensors 18
2.5.1. Inertial and magnetic sensors sampling and filtering 18
2.6. Integration with external sensors 21
2.6.1. External Navigation sensor integration 21
2.6.2. Odometer integration 22
2.6.3. 1D or 2D odometer inputs 22
2.6.4. Odometer calibration aiding by GPS 22
2.6.5. Odometer direction 22
2.7. IG-500E timing and synchronization with other devices 23
2.7.1. Synchronization Inputs 23
2.7.2. Synchronization Output 24
2.7.3. Computation and transmission delays 25
2.7.4. Synchronization Examples 27

2.8. Specifications....28
2.8.1. Performance....28
2.8.2. Internal sensors specifications....29
2.8.3. Communication Interfaces....30
2.8.4. Electrical specifications....31
2.8.5. Physical specifications....31

3. Optimal installation guidelines and limitations....32
3.1. Optimal sensor placement....32
3.1.1. Application specific considerations....32
3.1.2. Heading considerations....32
3.1.3. Accelerations....34
3.1.4. Vibrations....34
3.2. GPS antenna / aiding sensor placement....35
3.3. Odometer considerations....35
3.3.1. Odometer placement....35
3.3.2. IG-500E placement with respect to odometer....35
3.4. Environmental considerations....36
3.5. Power supply....36

4. Quick and efficient device operation....37
4.1. Driver and software installation....37
4.2. Provided software and libraries....37
4.2.1. The sbgCenter....37
4.2.2. Communication with the device....38
4.2.3. Low level communication with the IG-500E....39
4.2.4. Matlab and Labview integration....39
4.3. Getting optimal results....40

5. IG-500E Outputs....41
5.1. Calibrated sensors output....41
5.2. Orientation and navigation outputs....42
5.3. Other outputs....43
5.3.1. Advanced GPS output....45

6. Orientation, position and velocity representation....46
6.1. Coordinate systems....46
6.1.1. Device coordinate system....46
6.1.2. Fixed coordinate system (North – East - Down)....47
6.1.3. Geographic coordinate system....47
6.2. Orientation representation....49
6.2.1. Euler Angles....49
6.2.2. Rotation matrix (Direction Cosine Matrix)....49
6.2.3. Quaternions....50
6.2.4. Other useful conversion formulas....51

7. Configure your IG-500E....52
7.1. Protocol configuration....52
7.1.1. Serial communication versions....52
7.1.2. CAN Bus Version....54
7.1.3. Common protocol settings....56
7.2. General purpose configuration....57
7.2.1. User ID....57
7.2.2. User Buffer....57
7.2.3. Synchronization....57
7.3. Kalman filter configuration....58
7.3.1. Motion profiles....58
7.4. Navigation options and features....60
7.4.1. Select position and velocity source....60
7.4.2. Set the local gravity constant....60
7.4.3. Setting the reference pressure for ground level....60
7.5. External device management....61
7.5.1. Select the external device type....61
7.5.2. External devices specific configurations....61
7.5.3. Setting GPS antenna lever arm....61
7.5.4. Odometer configuration....62
7.6. Coordinate frames transformation....63
7.6.1. Pre-Rotations....63
7.7. Calibration procedures....64
7.7.1. Magnetometers calibration....64
7.7.2. Gyro bias calibration....64
7.8. Advanced options....65
7.8.1. Miscellaneous....65
7.9. Device default settings....66

8. Electrical and mechanical specifications....67
8.1. Absolute maximum ratings....67
8.2. Box version....68
8.2.1. Mechanical outline....68
8.2.2. Box device connectors....69

9. Warranty and Support....71

10. Appendix: Accessories....72
10.1. UsbToUart interface....72
10.2. CAN specific cables....72
10.2.1. UsbToCAN interface....72
10.2.2. CAN to USB2CAN cable....73
10.2.3. Power Adapter....73
10.3. Other cables....74
10.3.1. 7 ways cable....74

1. Introduction

1.1. IG-500E Overview

The IG-500E is a high performance miniature and cost effective aided inertial navigation and orientation sensor (AHRS). Thanks to a revolutionary architecture, the IG-500E accepts various external aiding information to deliver unmatched precision for both attitude and position measurements.

The IG-500E combines a MEMS based calibrated Inertial Measurement Unit (IMU) and an on board real time Extended Kalman Filter to fuse inertial data with external aiding information such as GPS position, true heading or even odometer velocities. A 1000Hz coning integration enables highest orientation tracking accuracy during highly dynamic motion.

Figure 1: IG-500E overview

At a very affordable price, the IG-500E provides a precise drift-free 3D orientation and a smooth position even in difficult conditions such as in urban canyons or during short GPS outages.

By removing transient accelerations, calculated using external aiding information, the attitude accuracy is greatly improved compared to traditional AHRS.

Thanks to the exclusive Motion Profile technology, the IG-500E Kalman Filter can easily and finely adapted to all application dynamics and constraint.

Outputs provided by the IG-500E are:

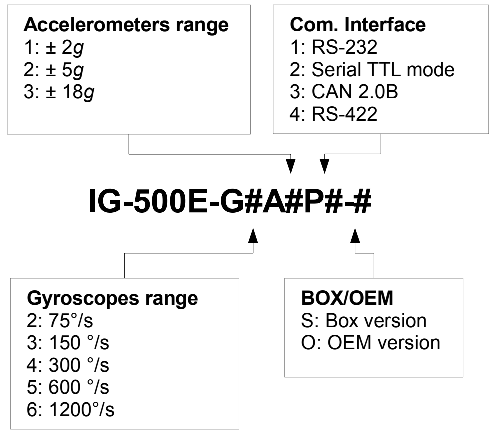
- 3D Orientation (Euler Angles, Matrix or Quaternion),
- 3D Position and velocity,
- Heave,
- Calibrated Sensor data (3D Acceleration, 3D Rotational speed, 3D Magnetic field, Temperatures),
- Delta Angle output,
- Raw sensor data, Raw GPS Position,
- Pressure,
- Barometric altitude (if the external sensor can handle it)
- Advanced GPS information
- UTC referenced timing information

1.2. Product codes and options

Standard version is the box version, with ± 300°/s gyroscopes, ± 5g accelerometers, RS-232 communications with synchronization capabilities.

The standard product code is:

IG-500E-G4A2P1-S



1.3. Provided development kit

The IG-500 Development Kit is an essential tool that has been designed to provide easy and efficient IG-500E integration. Provided software and libraries will give the opportunity to rapidly develop powerful applications. In addition, it is made very easy to connect the IG-500E to a PC with the provided USB interface.

1.3.1. Content of the development kit

Each DK is provided with the following elements:

- An UsbToUart converter with a 3m cable, or USB Can interface with associated 3M cable and power supply
- A set of compatible screws for easy mounting
- A quick start manual
- A CD-Rom containing :
  - USB interface driver
  - sbgCenter analysis software
  - sbgUpdater software to maintain your software up to date
  - sbgFirmwareUpdater software for firmware upgrades
  - sbgCom C library
  - sbgCan C library
  - sbgMatlab plug-in for Matlab for serial devices
  - sbgLabView plug-in for LabView for serial devices
  - Example projects with source code
  - Full documentation:
    - IG-500E User Manual
    - IG-Devices Serial Protocol Specifications
    - IG-Devices CAN Protocol Specifications
    - OEM Integration manual
    - sbgCom Library Reference Manual
    - sbgCan Library Reference Manual
    - Magnetometers Calibration Tools
    - sbgCenter User Manual
    - Various application notes

Figure 2: Development Kit

Apart from the development kit, SBG Systems provides spare cables to easily connect your IG-500E to an external aiding sensor.

2. IG-500E Presentation

2.1. Block diagram

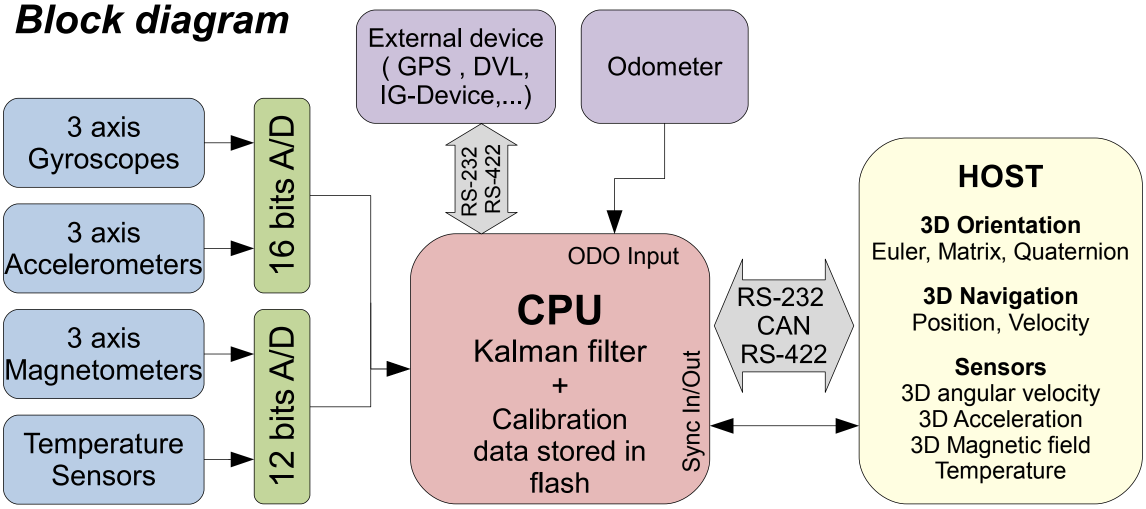


Figure 3: IG-500E simplified block diagram

2.2. Extended Kalman filter

2.2.1. Purpose

The IG-500E includes a real time 17 states Extended Kalman Filter. It delivers precise device orientation, position and velocity, as well as sensor information such as gyroscopes and accelerometers bias estimation. All this information is obtained by data fusion between all inertial sensors, magnetometers, GPS receiver and the barometric altimeter. To understand why data fusion is so important, consider this:

- Gyroscopes integration allows calculating orientation very precisely in a short term. As integration sums rotational speed as well as a small amount of error, the orientation error which is small at the beginning, becomes bigger and bigger.
- By detecting magnetic north (or another source for heading measurement) and local gravity, accelerometers and magnetometers can measure a very accurate orientation, but only in static conditions. Movements make the accelerometers precision decrease, and magnetometers can be disturbed by irons, and magnets. These sensors give good orientation knowledge, but with a low bandwidth.
- The same remark can be done for position and velocity: Accelerometers give a good instantaneous precision, but the double integration from accelerations to position data generates rapidly a huge amount of error. In the opposite, the GPS receiver gives a noisy estimate of position, but is in long term stable.

The onboard Kalman filter estimates in real time how much it can trust all of these sensors to perform an optimal attitude, position and velocity estimation.

Two advantages of this Kalman filter are first it provides much higher frequency output for position and velocity than traditional GPS receivers. Therefore small and rapid movements can be tracked with the IG-500E. Secondly, attitude accuracy is improved by GPS aiding compared to other AHRS.

In addition, the Kalman filter computes orientation and position data at up to 100 Hz. If lower output rates are required, it is possible to divide the output frequency while keeping the efficiency of a high internal rate and a low data rate.

2.2.2. Heading observation

As the IG-500E provides both navigation and orientation data in a consistent coordinate system, a good heading observation is a key requirement for nominal operation. All applications cannot rely on magnetometers and therefore, SBG Systems has developed several alternatives to the traditional magnetic heading. Here are the different heading observation methods:

1. Magnetometers. This method provides good accuracy when the device is exposed to a clean magnetic field, and a proper calibration has been performed.
2. GPS Course: This method provides a reliable heading observation as long as the device is precisely aligned with X axis turned into the trajectory direction. In addition the vehicle should only move in “forward” direction (no side slip is allowed). Therefore this observation method is recommended for automotive applications.
3. GPS + Accelerometers: This method provides very reliable and accurate heading measurements as soon as the sensor is regularly subjected to accelerations. The Kalman filter compares accelerometers reading with GPS data to estimate the true heading.
4. GPS true heading: A true double antenna GPS heading can be used.
5. User heading input: Any heading information can be fed to the Kalman filter enabling very advanced usage scenarios.

2.2.3. Aiding sensors : GPS, Barometer, External sensors

2.2.3.1. Position and velocity aiding by external sensor

The Kalman filter used in the IG-500E is called “loosely coupled”. We say that because the external receiver provides position and velocity information to the Kalman filter to correct inertial integration of position and velocity.

2.2.3.2. Velocity aiding by Odometer

In addition to the main external navigation sensor, the IG-500E Kalman filter includes an odometer input which can improve greatly performance in challenging environments such as urban canyons. The odometer provides a reliable velocity information even during GPS outages. This increases significantly the dead reckoning accuracy.

Odometer aiding by GPS

When using simultaneously an Odometer with a GPS receiver, the IG-500E Kalman filter is able to finely adjust odometer's gain. This will limit to the minimum odometer gain errors inherent to this technology.

2.2.3.3. Altitude aiding by barometric altimeter

Due to atmosphere structure and the GPS principles, altitude data provided by GPS receivers is not always as accurate as the horizontal position.

If the external sensor provides barometer data (IG-Devices), it's then possible to compute a more stable estimate of altitude. Because weather changes can affect the absolute pressure at a given altitude, this barometric altimeter actually acts as a “variometer” by tracking only altitude changes.

The result is that the altitude is mainly computed by the barometer, but is referenced to the GPS. One state (or variable) of the Kalman filter is dedicated to altitude estimation with the GPS receiver and barometric data.

2.2.3.4. Attitude aiding by velocity sensor

The second important point is that the external sensor is not only used for position and velocity tracking. The measured velocity also improves attitude estimate by removing transient accelerations caused by the device motion. Therefore, gravity estimation, which is used as a vertical reference for attitude, is enhanced by removing other sources of acceleration.

> ***Note:*** *Position measurement is not needed for attitude aiding. Only an external velocity or odometer is required.*

2.2.4. Dead reckoning in case of short GPS outages

2.2.4.1. Pure inertial dead reckoning during GPS outage

The IG-500E is designed to operate properly in case of short GPS outages by propagating position and velocity with its inertial sensors. However after a few seconds without GPS information, position and velocity errors can grow significantly. Some reasons are explained here:

- The MEMS sensors used inside the IG-500E have been carefully and individually calibrated but some residual errors are still uncorrectable. Consider that only $0.02\, m \cdot s^{-2}$ bias on the accelerometers integrated during only 10 seconds will lead to about 1 meter error.
- Gravity is generally the major part of the acceleration measured. If there is a small orientation error, the IG-500E will not be able to remove efficiently the gravity from the acceleration vector and therefore, a significant error in position and velocity can occur if integrated for some time.

In practice, the IG-500E will be able to track motion for several seconds. If the GPS outage is too long, (more than 10 seconds) the IG-500E will keep freely integrating position and velocity, but it will automatically reset its position and velocity at the next GPS fix.

In all cases, orientation is always estimated. A reduced accuracy may be observed after 10 seconds without any velocity measurement, due to the impossibility to use transient accelerations for attitude aiding.

2.2.4.2. Dead reckoning optimizations

If an odometer is used as velocity sensor, then the navigation accuracy can be greatly enhanced. Velocity keeps in all cases an optimal accuracy, and positioning is stable for a few minutes without any position aiding.

Setting the appropriate motion profile can also help limiting the drift rate when the sensor is exposed to GPS outages: With non-holonomic constraints used in the automotive motion profile, the position drift rate can be greatly reduced during GPS outages.

In all cases, attitude keeps its accuracy as long as the odometer gives optimal measurements.

2.3. Motion profiles

Each application has particular requirements, and constraints such as angular rate dynamics, vibrations, presence of long term accelerations, magnetic disturbances and others. Instead of having different products for each environment, SBG Systems has developed a cutting edge technology able to adapt the sensor in each situation.

The Motion Profile technology is tightly integrated with the embedded Kalman Filter, inertial sensors and GPS receiver. It provides with a simple application selection a deep and fine IG-500 configuration.

Different motion profiles have been designed to fit with most typical applications and should provide optimal performance, but it's still possible to finely tune a specific motion profile for a particular requirement.

Each motion profile includes parameters relative to magnetic field and other heading observation methods. It's then possible to select different heading sources within a motion profile configuration.

The following motion profiles are available by default on the IG-500E. Their characteristics and assumptions are described and special recommendations are also provided if required.

2.3.1. General Purpose

Assumptions	Comments
Description	This motion profile is well suited for many applications that have medium vibrations and accelerations, such as land robots, camera stabilization It should be used if other motion profiles do not well describe the user application. 
Update rate	100Hz
Vibrations	Low to medium vibrations are tolerated.
Accelerations	Low long term accelerations
Magnetic field	Good confidence in magnetic field measurement.
GPS aiding	Good confidence in GPS aiding.
Recommended heading sources	Magnetometers (3D, 2D or 2D Horizontal mode) GPS course GPS + Accelerations
Specific assumptions	No specific assumption is made.
Placement requirements	-

2.3.2. Airplane

Assumptions	Comments
Description	This motion profile is well suited for general aircraft applications that have low to medium dynamics. This motion profile can be used only for fixed wings vehicles of any size. 
Update rate	100Hz
Vibrations	High vibrations are tolerated.
Accelerations	Presence of long term accelerations assumed.
Magnetic field	Good confidence in magnetic field measurement.
GPS aiding	Good confidence in GPS aiding.
Recommended heading sources	Magnetometers (3D, 2D or 2D Horizontal mode) GPS + Accelerations GPS True Heading
Specific assumptions	A significant velocity is assumed.
Placement requirements	Sensor coordinate frame must be aligned within less than 1° to the airplane coordinate frame: IG-500 X axis must be turned toward the airplane nose direction, and Z axis should be turned downward.

2.3.3. Airplane – High dynamics

Assumptions	Comments
Description	This motion profile provides a similar configuration as the airplane one but is finely tuned for highly dynamic flights. 
Update rate	100Hz
Vibrations	High vibrations are tolerated.
Accelerations	Presence of long term accelerations assumed.
Magnetic field	Good confidence in magnetic field measurement.
GPS aiding	Good confidence in GPS aiding.
Recommended heading sources	Magnetometers (3D, 2D or 2D Horizontal mode) GPS + Accelerations GPS True Heading
Specific assumptions	High speed is assumed.
Placement requirements	Sensor coordinate frame must be aligned within less than 1° to the airplane coordinate frame: IG-500 X axis must be turned toward the airplane nose direction, and Z axis should be turned downward.

2.3.4. Helicopter

Assumptions	Comments
Description	This motion profile is well suited for helicopter applications, as well as many land robots with significant vibration level. 
Update rate	100Hz
Vibrations	High vibrations are tolerated.
Accelerations	Presence of long term accelerations assumed.
Magnetic field	Good confidence in magnetic field measurement.
GPS aiding	Good confidence in GPS aiding.
Recommended heading sources	Magnetometers (3D, 2D or 2D Horizontal mode) GPS + Accelerations GPS True Heading
Specific assumptions	No significant velocity is assumed (stationary flight)
Placement requirements	Sensor coordinate frame must be aligned within less than 1° to the airplane coordinate frame: IG-500 X axis must be turned toward the airplane nose direction, and Z axis should be turned downward.

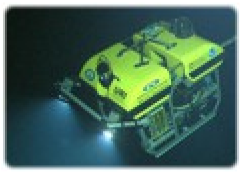
2.3.5. Automotive

Assumptions	Comments
Description	This motion profile is well suited for automotive applications as well as land robots that do not perform side slip. 
Update rate	100Hz
Vibrations	Medium vibrations are tolerated.
Accelerations	Presence of medium/long term accelerations assumed.
Magnetic field	Magnetic field not recommended.
GPS aiding	Low confidence in GPS measurements (Urban canyons)
Recommended heading sources	GPS course GPS + Accelerations
Specific assumptions	No lateral velocity nor vertical velocity allowed. Medium velocity is assumed.
Placement requirements	Sensor coordinate frame must be aligned within less than 1° to the vehicle coordinate frame. X axis must be turned toward vehicle direction of travel, and X axis must be turned down.

2.3.6. Marine

Assumptions	Comments
Description	This motion profile is dedicated to general marine applications. 
Update rate	100Hz
Vibrations	Medium vibrations are tolerated.
Accelerations	Low long term accelerations.
Magnetic field	Medium confidence in magnetic field measurement.
GPS aiding	Good confidence in GPS aiding.
Recommended heading sources	Magnetometers (3D, 2D or 2D Horizontal mode) GPS True Heading
Specific assumptions	No significant velocity is assumed
Placement requirements	-

2.3.7. Underwater

Assumptions	Comments
Description	This motion profile is designed for underwater and quasi static applications. 
Update rate	100Hz
Vibrations	Medium vibrations are tolerated.
Accelerations	Very Low long term accelerations.
Magnetic field	Aggressive magnetic field disturbances filtering.
GPS aiding	-
Recommended heading sources	Magnetometers (3D)
Specific assumptions	No significant velocity is assumed
Placement requirements	-

2.3.8. IMU 500

Assumptions	Comments
Description	This special motion profile disables the internal Kalman filter and provides reduced output latency as well as 500Hz output rate. 
Update rate	500Hz
Vibrations	-
Accelerations	-
Magnetic field	-
GPS aiding	-
Recommended heading sources	-
Specific assumptions	-
Placement requirements	-

2.4. Heave computation

Mainly used in marine applications, we refer here to ship motion computation. Vertical motion is called heave.

Aside from the EKF, the IG-500 computes at 100Hz ship motion data from accelerometers double integration. As this double integration generates drift due to orientation error or sensor bias, the best way to get a stable output is to use a high pass filter design that will remove any constant component in the motion.

SBG Systems has developed an advanced filter design that ensures no phase and gain errors are generated as long as correct average heave period is provided by user.

As there is a high pass filter, the heave data will always return to zero in static conditions.

If a step is performed, the heave output will show the step and then will smoothly come back to zero. It may take a few minutes to stabilize the output after a step.

For best accuracy, the IG-500E is able to use of GNSS receiver data to compensate for accelerations that could disturb ship motion computations during turns or acceleration phases.

> ***Note:*** *As these outputs are relative to local position, Ship motion data cannot be used as navigation data.*

2.5. Internal Sensors

2.5.1. Inertial and magnetic sensors sampling and filtering

The IG-500E includes advanced sampling and filtering techniques that avoid as much as possible common aliasing effects. This allows a very high vibration immunity, as well as optimal noise reduction. The following block diagram explains the overall sensor sampling structure:

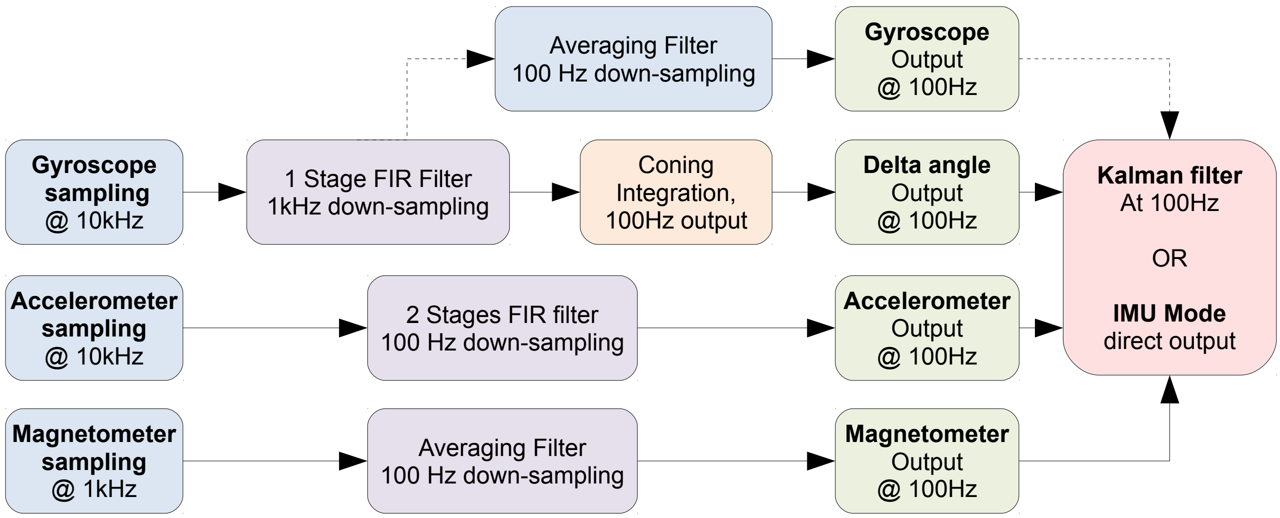


Figure 4: Advanced and high efficiency sampling and filtering design

2.5.1.1. Accelerometers

Accelerometers outputs are first fed into a hardware one pole low pass filter. This filter ensures anti aliased sampling. Once sampled by a 16 bit SAR (Successive Approximation Register) Analog to Digital Converter, measurements are fed into a 2 stages high efficiency FIR filter. This filter provides the best vibration isolation.

The filter cascade generates a small delay between a stimulus and output response. Overall accelerometer delay is: 31.9 ms.

2.5.1.2. Gyroscopes

Gyroscopes are first filtered by a 2 poles hardware low pass filter that provides high frequency rejection before sampling. The 10kHz samples are then fed into a high efficiency FIR filter that provides a 1kHz down-sampling. After that, Coning integration at 1kHz provides high performance orientation tracking. At the same time, the gyroscopes output is filtered down by an averaging filter to provide the 100Hz output.

The filter cascade generates a small delay between stimulus and output response. Overall delay are the following:

Delta Angle delay: 1.8ms

Gyroscope output delay: 6.4ms

2.5.1.3. Magnetic sensors

Magnetometers are first filtered by a 1 pole hardware low pass filter that reduces high frequency noise coming from RF interferences for example. (F > 2 kHz). The 3 channels are then over-sampled at 1 kHz by a 12 bit SAR ADC. These samples are fed into an averaging filter that remove all the noise comprised between the Kalman filter frequency and 500 Hz.

The filter cascade generates a small delay between stimulus and output response. Overall delay for magnetometers is 4.5 ms.

Note: *Due to hardware requirement of magnetic sensors, the magnetic noise comprised between 500 Hz to 2 kHz cannot be well filtered, and must be avoided for proper operation.*

2.5.1.4. Factory calibration procedure

Our products are provided with fully calibrated inertial sensors and magnetometers. We calibrate and test each product in our factory. A calibration report is also shipped with each product.

This calibration procedure allows taking the maximum precision of each sensor. This procedure contains:

- Temperature compensation of gain and bias for accelerometers and gyroscopes,
- Temperature compensation of gain for magnetometers,
- Cross-axis and misalignment effects compensation for accelerometers, gyroscopes and magnetometers,
- Non linearity correction for gyroscopes over temperature.
- Gyro-G effect compensation for gyroscopes.

Note 1: *For best accuracy, each gyroscope channel is calibrated with its own internal temperature sensor. Accelerometers and magnetometers use a dedicated external temperature sensor for calibration.*

Note 2: *There is no temperature compensation of bias for magnetometers because it is stable over temperature by hardware design.*

2.5.1.5. Magnetometers in place calibration

Magnetometers are fully calibrated in factory. However, they are very sensitive to their close environment and mainly the object on which they are strapped. Some ferromagnetic materials can produce magnetic field distortions causing errors in heading estimation. These distortions are often called Hard and Soft Iron effects and must be addressed for good attitude results.

The IG-500E includes a powerful algorithm especially designed to easily compensate both **Hard AND Soft** iron effects. We advise user to call this procedure when:

- A loss of precision is observed in heading estimation,
- The device is mounted on an object that may contain ferromagnetic materials or magnets,
- The device is removed from an object containing ferromagnetic materials or magnets.

Note: *Please refer to the Magnetometers Calibration Tools documentation for a complete description of the magnetometers calibration procedure.*

2.5.1.6. Gyroscopes bias

Bias is a common concern with gyroscopes, and in particular MEMS gyros.

The IG-500E includes an industrial grade gyroscope which is very stable. Nevertheless, bias variations can still be observed due to:

- Temperature variations (this effect is mostly compensated by the factory calibration),
- Noisy power supply,
- Random walk effect, which change slowly bias over time.

It's also important to know that fast temperature changes cannot be modeled by the temperature compensation algorithms, and therefore induce bias. Optimal performance is obtained with a stable ambient temperature.

Note: *The Kalman filter inside the IG-500E is designed to estimate in real time gyro bias evolutions, but a static gyro bias reset sequence can be made to provide faster bias estimation, and faster Kalman filter stabilization. In addition, the gyro bias can be saved into nonvolatile memory in order to get faster filter convergence.*

2.6. Integration with external sensors

2.6.1. External Navigation sensor integration

The most exciting IG-500E feature is probably its ability to interface with most GPS receivers and other navigation devices.

The IG-500E extension communication port allows direct communication with a remote GPS receiver, or another IG-Device. In addition, an odometer input can be used to significantly enhance navigation performance in challenging environments such as urban canyons.

2.6.1.1. External NMEA GPS aiding

Through its NMEA interface, the IG-500E handles any NMEA compliant GPS output. This integration allows many different features and benefits:

- RTK GPS support, as well as professional L1/L2 GPS receivers. This provides better navigation accuracy to the IG-500E. Compared to an RTK alone solution, a better handling of short GPS outages or jumps is provided.
- Dual antenna GPS support for magnetometer free heading solution: It provides a true heading data, even if the application is not moving, or if the actual heading is not the same as trajectory direction. In addition, heading is more stable and reliable as a GPS only solution due to inertial aiding.
- Existing GPS solution enhancement. The NMEA interface provides a cost efficient way to improve existing navigation solutions performance, thanks to the inertial / GPS fusion algorithm.

2.6.1.2. Remote IG-Device aiding

Some applications have challenging requirements concerning heading data: GPS cannot provide a reliable heading information, and magnetometer placement is not compliant with the IMU location. (For proper operation, the magnetometer has to be placed in a homogeneous magnetic environment, and the IG-500E has to be placed near the system Center of Gravity).

In such applications, the IG-500E can be aided by a remote IG-Device (IG-30G or IG-500N). The remote IG-Devices will then provide remote magnetic field data for heading information, and also all GPS data needed for proper navigation. The internal IG-Device barometer data is also forwarded to the IG-500E for altitude barometric aiding.

2.6.2. Odometer integration

Land vehicles often have very strong accuracy requirements, and are also used in very challenging environments, such as urban canyons, where GPS suffers from multipath effects.

Unlike GPS receivers, odometers provide direct traveled distance measurements, but they cannot measure the travel direction. This is why for proper operation, odometer data has to be taken as a velocity sensor ($V = \frac{Dist.}{time}$) Each velocity data is then reintegrated into the right direction using the IG-500E orientation.

Odometer integration with the IG-500E provides a reliable velocity information, even in GPS denied environments. Position drift rate can then be reduced and the IG-500E can provide reliable position information for much longer times than with pure inertial dead reckoning.

2.6.3. 1D or 2D odometer inputs

Although most applications might only use one odometer axis, some robots that can be driven in two directions can use the two IG-500E logic inputs as two different odometer channels, one for each axis.

2.6.4. Odometer calibration aiding by GPS

No system is perfect, and a few considerations have to be taken using odometers systems:

- Slipping is not advised as the odometer will not sense any motion while the wheel is blocked. Inertial sensors and GPS can handle short term slipping but it is not the normal system operation.
- Odometers accuracy is mostly driven by the distance per pulse calculation. If the tire is a bit under-inflated or over-inflated, it may affect wheels diameter, ant therefore distance per pulse information. An automatic odometer gain calibration allows optimal gain computation when GPS velocity is also available.

2.6.5. Odometer direction

The IG-500E odometer integration allows different possibilities to handle the direction of travel:

- User defined direction: The user can configure a direction (positive or negative direction). It's possible to change in real time the odometer direction through the communication protocol.
- Odometer direct direction sensing. By using a second odometer logic input the IG-500E can handle odometer dual channels quadrature outputs or a direction signal. As no GPS synchronization is allowed in this mode, it's only recommended in odometer only systems.

2.7. IG-500E timing and synchronization with other devices

When dealing with external devices, time synchronization can be a very important point to consider because of different calculation delays within each device associated with transmission times. The IG-500E includes two synchronization inputs and one synchronization output in order to provide an optimal timing accuracy.

2.7.1. Synchronization Inputs

The IG-500E accepts two independent logic inputs (Sync In and Odo In) signals to synchronize the IG-500E with external devices, or host clock. Events can be generated on rising, falling edge, or on level change. In addition, a software delay can be added after the actual trigger time.

The following events are supported on both inputs:

1. Event input: Here the IG-500E computes freely its orientation with its internal clock. When a new event is received, the IG-500 will send the last computed data. A jitter as long as the computation period can be observed.
2. GPS Time pulse: This kind of event allows the IG-500E to accurately synchronize its clock with an external GPS. If properly connected, it will then be able to deliver accurate absolute UTC timing information, as well as time optimized navigation data.
3. Odometer velocity input: Each pulse detected on the pin is considered as the specified traveled distance. Pulse frequency corresponds to device velocity.
4. Odometer direction input: Used in conjunction with an odometer velocity input to determine velocity direction.

2.7.2. Synchronization Output

The Synchronization output pin allows the user application to synchronize itself on the internal IG-500E clock, and also on the UTC time reference. It is possible to set different output types depending on user needs. A high/low pulse can be sent, or the output level can be changed on the following event conditions:

1. Main loop start: It corresponds to the exact time when all inertial sensors are sampled. Once the sensors are sampled, the Kalman filter will estimate orientation, and navigation data. At the end of the loop, if some data has to be sent, it will correspond to this synchronization output pulse time.
2. Main loop divider: This event is also activated at the main loop start time, but its frequency is divided by the output divider. So a continuous/triggered output is set with a frequency divider, the pulse will only be set when an output will be sent at the end of the loop.
3. The External sensor PPS copy: This output will then be synchronized with the external device, but not actually with the IG-500E output. It is in general synchronized with the UTC time seconds.
4. Virtual odometer: This outputs provide a sync pulse, each time the sensor travels the specified distance.

Note: *The synchronization output is an open drain output. Please connect a pull-up resistor for proper operation.*

2.7.3. Computation and transmission delays

The following diagram shows what happens when user sets the output divider to 2 (one data frame is send each two loops), and a synchronization output is enabled. This example covers serial devices, but similar considerations can be used on CAN bus devices.

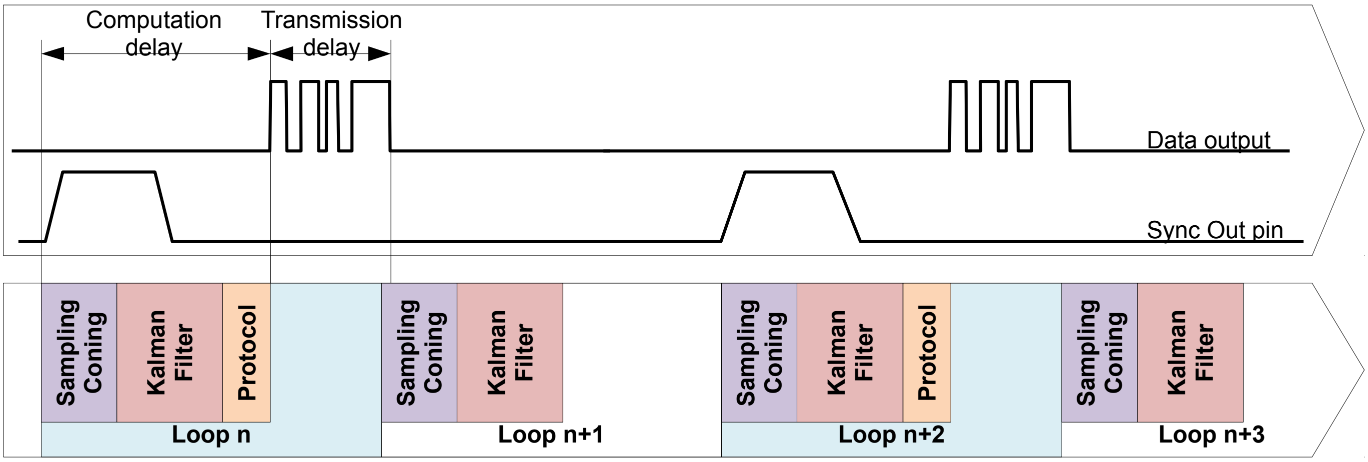


Figure 5: Timing diagram with synchronization output and output divider set to 2

2.7.3.1. Strategies to reduce overall latency

As shown with Figure 5, final delay is divided into two main parts: Computational delay that includes sensor sampling, Kalman filtering and Protocol management, and transmission delay, directly linked to the amount of data to transfer and bus speed. It's possible to optimize both delays and minimize them taking into account the following considerations:

- Computational latency
  1. Avoid Heave and Euler angles computation if not required
  2. Avoid using simultaneously binary and ASCII protocols
  3. Avoid sending the data into "Fixed Point" format. Standard IEEE floating point format is preferred.
  4. If ultra low latency is required, consider using the High performance power mode.
- Transmission latency
  1. Increasing the baudrate limits the transmission time
  2. Reducing the data throughput limits the transmission time.
  3. Use triggered mode instead of continuous mode when transmitting GPS Raw data.

2.7.3.2. Computational time specifications

Output Options	Computational latency
Output mask: *Time since reset, device status, Euler Angles,* Accelerometers, Gyroscopes, Magnetometers, Position, Velocity **Output format**: *Fixed point*	1.9 ms
Output mask: Time since reset, device status, *Euler Angles*, Accelerometers, Gyroscopes, Magnetometers, Position, Velocity **Output format**: *Floating point*	1.85 ms
Output mask: *Time since reset, device status, Quaternion, Accelerometers, Gyroscopes, Magnetometers, Position, Velocity* **Output format**: *Floating point*	1.7ms
Output mask: *Time since reset, device status, Quaternion, Accelerometers, Gyroscopes, Magnetometers, Position, Velocity, Heave* **Output format**: *Floating point*	2.5ms

Table 1: Computational latency depending on output options and power mode

Now the next table shows transmission latency with different output sets and baudrates:

Output mask	Transmission delay
Output mask: *Time since reset, device status, Euler Angles, Accelerometers, Gyroscopes, Magnetometers, Position, Velocity* **Baudrate**: *115 200bps*	8.6 ms
Output mask: *Time since reset, device status, Euler Angles, Gyroscopes, Position* **Baudrate**: *115 200bps*	5.55 ms
Output mask: *Time since reset, device status, Euler Angles, Gyroscopes, Position* ***Baudrate***: *921 600bps*	0.694 ms

Table 2: Transmission delays with several output configurations

Note: *Output format is not available in CAN devices so this consideration cannot be taken into account. But the CAN bus speed has an effect on transmission delay, as well as CAN Bus usage. If the CAN bus is used by many different devices, a higher transmission delay can be expected.*

2.7.4. Synchronization Examples

Here we describe basically how to use the IG-500 synchronization inputs and outputs. In this example, we consider a camera that requires an accurate timing, position and orientation of each filmed frame. The GPS time pulse is connected on the IG-500E for high accuracy timing. The IG-500E compute with its internal clock its orientation, and each time it starts a new computation loop, it sends a sync Out pulse. User application can here synchronize itself on the IG-500E.

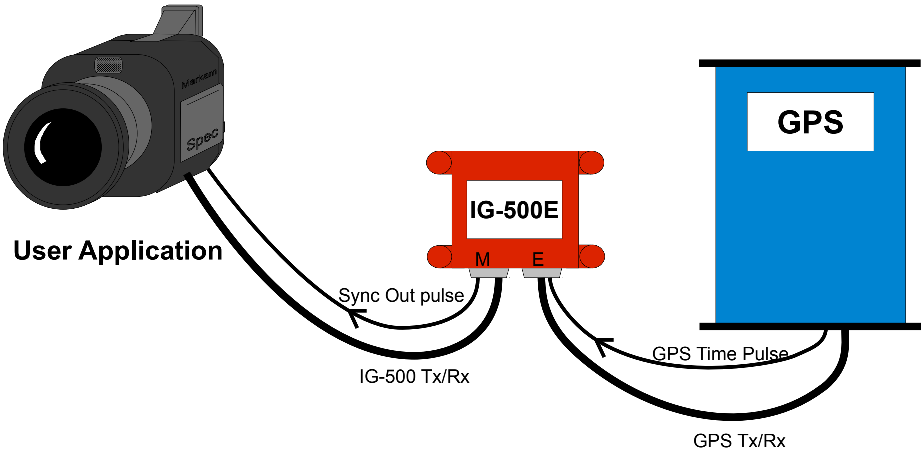


Figure 6: Basic synchronization example with sync pulse Output

A second example shows how the IG-500E can synchronize itself on user application. The Event input trigger is here used, so the camera needs to send pulses corresponding to each required IG-500 data sample.

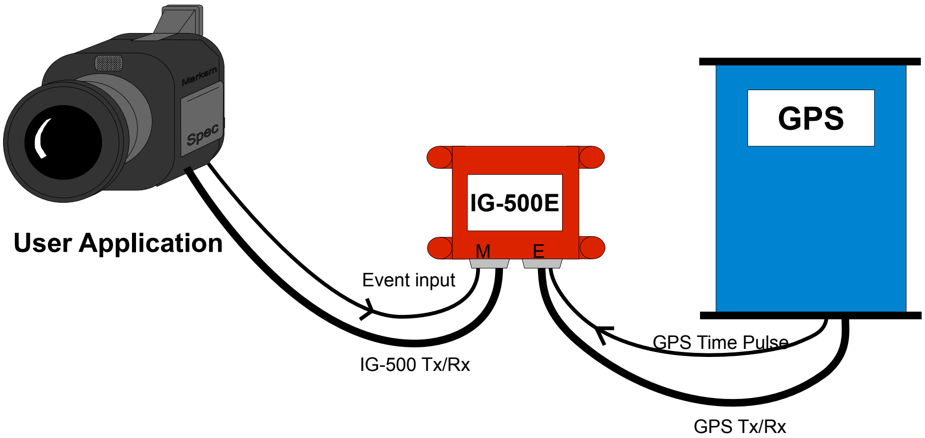


Figure 7: Basic synchronization example with sync pulse Input

2.8. Specifications

All specifications are valid in the full temperature range -40°C to 85°C unless otherwise specified.

2.8.1. Performance

Parameter	Specification	Remarks - Conditions
Sensing range	360° in all axes, no mounting limitation	Solid state sensors
Accuracy *Underwater applications*	± 0.35° RMS (Pitch, Roll) ± 0.8° RMS (Heading)	2*g* accelerometer – 150°/s gyroscope Homogeneous magnetic environment
Accuracy *Marine applications*	± 0.45° RMS (Pitch, Roll) ± 1° RMS (Heading)	2*g* accelerometer – 150°/s gyroscope Reliable heading observation
Accuracy *Automotive applications*	± 0.5° RMS (Pitch, Roll) ± 0.5° RMS (Heading)	5*g* accelerometer – 300°/s gyroscope Good GPS and odometer availability Reliable GPS course observation
Accuracy *Airborne applications*	± 1.0° RMS (Pitch, Roll) ± 1.0° RMS (Heading)	5*g* accelerometer – 300°/s gyroscope Good GPS aiding availability Reliable heading observation
Repeatability	0.2°	
Resolution	< 0.05°	
Integration method	1 000Hz Coning integration	For accurate fast motion tracking
Heave	10 cm or 10%	Whichever is greater

Table 3: Orientation performance specifications

2.8.2. Internal sensors specifications

Accelerometers	**A1**	**A2**	**A3**	**Remarks - Conditions**
Measurement range	± 2*g*	± 5*g*	± 18*g*	
Non-linearity	< 0.2%	< 0.2%	< 0.2%	% of full scale
Bias at startup	± 2 m*g*	± 5 m*g*	± 10 m*g*	Over full temperature range
Bias in-run stability	± 0.04 m*g*	± 0.06 m*g*	± 0.08 m*g*	Allan variance – constant temperature
Orientation residual	0.1°	0.3°	0.6°	Static orientation error due to initial bias
Scale factor stability	< 0.1%	< 0.1%	< 0.1%	Over full temperature range
Noise density	0.22 mg/√Hz	0.25 mg/√Hz	0.32 mg/√Hz	
Alignment error	< 0.05°	< 0.05°	< 0.05°	
Bandwidth	250 Hz	250 Hz	250 Hz	
Sampling rate	10 000 Hz	10 000 Hz	10 000 Hz	Advanced anti-aliasing FIR filter

Table 4: Accelerometers specifications

Gyroscopes	**G2**	**G3**	**G4**	**G5**	**G6**	**Remarks - Conditions**
Measurement range	± 75°/s	± 150°/s	± 300°/s	± 600°/s	± 1200°/s	
Non-linearity	< 0.1%	< 0.1%	< 0.05%	< 0.05%	< 0.05%	% of full scale
Bias at startup	± 0.5°/s	± 0.5°/s	± 0.5 °/s	± 0.5°/s	± 1°/s	Over full temperature range
Bias in-run stability	20 °/h	20 °/h	20 °/h	30 °/h	30 °/h	Allan variance – constant temperature
Scale factor stability	< 0.05 %	< 0.05 %	< 0.05%	< 0.05 %	< 0.05 %	
Noise density	0.04 °/s/√Hz	0.04 °/s/√Hz	0.05 °/s/√Hz	0.05 °/s/√Hz	0.05 °/s/√Hz	
Alignment error	< 0.05°	< 0.05°	< 0.05°	< 0.05°	< 0.05°	
Bandwidth	240 Hz	240 Hz	240 Hz	240 Hz	240 Hz	
Sampling rate	10 000 Hz	10 000 Hz	10 000 Hz	10 000 Hz	10 000 Hz	Advanced anti-aliasing FIR filter

Table 5: Gyroscopes specifications

Magnetometers	**Specification**	**Remarks - Conditions**
Measurement range	± 1.2 Gauss	Check optional sensors specifications
Non-linearity	< 0.2%	% of full scale
Bias stability	± 0.5 mGauss	Over full temperature range
Scale factor stability	< 0.5%	Over full temperature range
Noise density	0.01 mGauss/√Hz	
Alignment error	< 0.1°	
Bandwidth	500 Hz	
Sampling rate	1 000 Hz	

Table 6: Magnetometers specifications

2.8.3. Communication Interfaces

Main communication interface : Serial		Remarks - Conditions
Interface type	RS-232, RS-422, TTL 3.3V, USB	Product codes P1; P2; P4
Protocols	IG-Devices Serial Protocol (Binary) NMEA and proprietary ASCII protocol	ASCII protocol only for data output
Outputs (binary)	Euler angles, quaternion, rotation matrix, velocity, position, heave, calibrated sensor data, delta angles, odometer data, device status, raw GPS data, UTC time reference, ...	Each output can be enabled or disabled
Outputs (ASCII)	GPGGA; GRMC; GPZDA; HEHDT, HEHDM, PSXN23, SBG01 (Euler angles)	Each output can be enabled or disabled
Baudrate	9 600 to 921 600 bps ; Fast or Slow Slew Rate	User selectable
Output rate	500 Hz 100 Hz	IMU mode (sensors data only) INS mode (orientation & navigation data)

Table 7: Serial interface specifications

Main communication interface : CAN		Remarks - Conditions
Interface type	CAN 2.0 A / B, USB	Product code P3
Protocol	IG-Devices CAN Protocol	Each frame can be configured, enabled or disabled
Outputs	Euler angles, quaternion, rotation matrix, velocity, position, heave, calibrated sensor data, delta angles, odometer data, device status, raw GPS data, UTC time reference, ...	Each output can be enabled or disabled
Bit-rate	10 to 1 000 kbps	User selectable
Bus termination	Not included	Contact SBG Systems if bus termination is required

Table 8: CAN interface specifications

External serial interface		Remarks - Conditions
Supported sensors	Standard NMEA with True heading support Remote SBG IG-Device	
Interface option	RS-232 or RS-422	User selectable
Serial data rate	9 600 to 921 600 bps Fast or Slow Slew Rate	High baudrates are recommended. User selectable

Table 9: External interface specifications

2.8.4. Electrical specifications

Parameter	Specification		Remarks - Conditions
Operating voltage	3.3 to 30V		
Power consumption	650 mW @ 5.0V		Normal performance mode
Logic Inputs	0 Level: < 0.8 V 1 Level: > 2.0V	Input Range : ± 20V Input Delay: <150 ns	
Logic Output	*Type* *Pull-up Voltage:* *Switching OFF delay:*	Open drain [-0.3;25V] <100 ns	Use a pull up resistor for proper operation.
Start-up time	< 2s		First valid data
Fully stabilized time	< 10 min		For optimal attitude measurement

Table 10: Electrical specifications

2.8.5. Physical specifications

Parameter	Specification	Remarks - Conditions
Dimensions	36x49x25 mm	
Weight	49 grams	
Operating temperature	-40° to 85°C	Non condensing environment
Storage temperature	-40° to 85°C	
Operating vibrations	3g RMS (20Hz to 2 kHz per MIL-STD 810G)	Valid for a 18g accelerometers
Shock limit	1 000 *g* (Powered), 2 000 *g* (unpowered)	Check absolute maximum ratings

Table 11: Physical specifications

3. Optimal installation guidelines and limitations

3.1. Optimal sensor placement

3.1.1. Application specific considerations

As explained in section Motion profiles, some sensor alignment requirements have to be observed for proper operation.

This alignment is not always possible mechanically. Therefore a software alignment procedure (pre-reset) can be used to realign sensor coordinate frame with the system or vehicle coordinate frame.

3.1.2. Heading considerations

Depending on the heading observation method used, particular placement considerations have to be followed.

In addition to the motion profile alignment constraints, heading source alignment constraints may be added or not.

3.1.2.1. Magnetometers use

Ferromagnetic materials or magnets that are placed in the vicinity of the device can generate error in the magnetometers readings by distorting the magnetic field. High current power supplies or the associated wires may also generate magnetic fields.

The IG-500E should be placed as far as possible from ferromagnetic materials, particularly those who can be moved independently with respect to the IG-500E. In practice placing the device more than 1 meter away from moving ferromagnetic materials is enough to avoid generating error.

In most cases, a calibration procedure can be performed to map the magnetic distortions and therefore get the full performance of the unit. The IG-500E can compensate both Hard and Soft iron interferences.

Note 1: *See Iron Calibration Tools documentation for more information about the magnetometers calibration procedure.*

Note 2: *Some disturbances of the magnetic field cannot be predicted: a magnet passing suddenly near the device or a cell phone communication for example. The internal Kalman filter is able to cope with short term magnetic disturbances. Ultimately if magnetic field direction changed for a long period, the IG-500 will realign itself to the new magnetic field direction.*

Note 3: *As any magnetometer or compass based system, the heading provided by the device will not be valid near north and south poles (magnetic field inclination higher than 80°).*

Magnetometers 2D Horizontal calibration requirements

If you perform a 2D horizontal magnetometers calibration, you have to respect carefully the following placement requirements.

The IG-500 coordinate frame must be consistent with the vehicle coordinate frame. The X axis must be turned toward the front of the vehicle, whereas the Z axis has to be turned downward. If mechanical alignment is not possible, a pre-rotation reset can be used to re-align by software the sensor coordinate frame.

Note: *This placement requirement is also seen in several motion profiles.*

3.1.2.2. GPS course use

When heading is derived from GPS course, the device *X* axis has to be properly aligned with the trajectory direction (in general *X* is turned toward the front of the vehicle).

This heading mode is only relevant in situations where the vehicle is only moving forward (no side slip allowed, no reverse gear).

In the case a mechanical alignment is not possible, a software “pre-rotation” alignment can be performed in order to realign sensors axes to vehicle axes.

3.1.2.3. GPS + Accelerations use

This mode has no particular alignment requirements and should be used if both magnetometers or GPS course heading are not reliable heading observation methods.

The sensor should be regularly accelerated to achieve good heading observability. 0.5 g acceleration is already sufficient to provide heading observability.

3.1.2.4. True heading

True heading input needs to be consistent with the IG-500E coordinate frame.

Most of the time, this will imply the heading direction being aligned with IG-500E X axis. In some applications, it's possible that such alignment is not mechanically possible; therefore a proper rotation matrix can be entered to realign GPS true heading output with the IG-500E coordinate system.

3.1.2.5. User heading

When using the User heading source, the IG-500E assumes that the heading provided is consistent with the IG-500E X axis direction. It belongs to user to realign heading value if required.

3.1.3. Accelerations

3.1.3.1. Transient acceleration when no aiding is available

When the IG-500E does not have any aiding information available, the IG-500E still estimates velocity and position. However, this information cannot be considered as reliable if no aiding data is available for more than 10s.

In this condition, it is also not possible to differentiate the gravity and free acceleration from accelerometers measurements. Care should be taken to place the device where you expect to get the least transient accelerations. Generally, the center of gravity is the best choice for placing the IG-500E. In that location, rotating the object would not generate centripetal accelerations.

3.1.3.2. Low gravitational fields

The device needs the gravity to estimate the local vertical. It will not work properly in low gravitational fields, such as during spaceflights.

3.1.4. Vibrations

As a rule of thumb, the IG-500E must be **mechanically isolated as much as possible** from any vibrations to get the best performance. Vibrations generate accelerations that are measured by accelerometers. SBG Systems has designed the IG-500E with a high sampling frequency (10 kHz) as well as high efficiency anti aliasing FIR filters to limit vibration issues. Nevertheless, a good mechanical isolation will ensure getting the full sensor performance:

High amplitude vibrations generate a bias in accelerometer reading. This cannot be compensated during factory calibration as this effect depends on vibration frequency and amplitude. This effect is called the VRE (Vibration Rectification Error) and comes from the internal accelerometer non-linearity.

Ultimately, very high amplitude vibrations cause the sensor to saturate. The bias observed will be drastically increased, leading to a huge error on orientation.

If proper mechanical isolation cannot fully prevent high amplitude vibrations, consider using an 18*g* accelerometers unit, which has a lower VRE than the standard 5g accelerometers.

> ***Note:*** *High frequency vibrations (> 9 kHz) could generate aliasing in accelerometers measurements. In most applications, this should not be a problem because vibrations above 1 kHz can be easily filtered using simple mechanical dampers.*

3.2. GPS antenna / aiding sensor placement

The GPS antenna or external sensor can be placed at a different location from the IG-500E. Some recommendations will ensure proper behavior:

1. When the distance between external sensor and the IG-500E becomes significant, it should be measured to at least 10 cm accuracy and correctly configured into the IG-500E.
2. Although distance between the aiding sensor and the IMU is taken into account by a “lever arm” configuration, a long distance (10 meters or higher) should be avoided as it would generate a lot of noise on the measurements. Distance between the external sensor an the IMU should then be minimized.

3.3. Odometer considerations

3.3.1. Odometer placement

For best accuracy, the odometer must be installed on a non steering wheel. In general it is one of the rear wheels. Distance (lever arm) between the IG-500E and the odometer needs also to be properly entered for best performance.

Figure 8: Odometer is mounted on the rear wheel

Note 1: *Odometer lever arm is not the same configuration as the GPS lever arm.*

Note 2: *As for external aiding sensor lever arm, odometer's lever arm should not exceed 10m.*

3.3.2. IG-500E placement with respect to odometer

When using an odometer as a velocity sensor, a key point to consider is the IG-500E alignment with the odometer. Two kind of alignment errors can degrade dead reckoning performance:

1. The first one is linked to a static (constant) alignment error between odometer sensing direction and IG-500E coordinate frame.
2. The second one is inherent to the vehicle suspensions that generate a vehicle pitch angle during acceleration/deceleration phases.

The first error source can be compensated by an IMU alignment (pre-rotation). In most applications, odometer placement considerations will ensure that the velocity direction will be accurately centered on a single axis with respect to the vehicle. The goal is then to ensure that the IG-500E is accurately aligned to vehicle coordinate frame within less than one degree.

The second error source cannot be compensated for but should be negligible in most applications.

3.4. Environmental considerations

The normal condition to operate the IG-500E is within the industrial range: -40 to +85°C, in a dry and non condensing environment. If the device is operated beyond absolute maximum ratings, expressed in 19, the device may be damaged.

Temperature variations cannot be modeled in the sensor calibration. This is why for optimal results the temperature during measurements should be as stable as possible. Moreover, a 10 minutes warm-up should be allowed to the IG-500E in order to get optimal results.

The IG-500E should be protected from humidity and dust, as it can damage the internal hardware.

The IG-500E should be protected from drops onto hard surfaces and violent handling, as it can cause shocks higher than those specified in the absolute maximum ratings.

3.5. Power supply

The power supply of the IG-500E has been designed to isolate as much as possible sensors from power supply noise. However keep in mind that a noisy power supply can decrease sensors performance. For best performance, power supply should be isolated from high frequency by inductors or ferrite beads and from low frequency by a regulator.

4. Quick and efficient device operation

4.1. Driver and software installation

This easy installation is described in the “IG-500 Quick start Guide”.

4.2. Provided software and libraries

4.2.1. The sbgCenter

The sbgCenter is a very powerful program suit. It allows deeply analyzing outputs of the IG-500E, by displaying, recording, and exporting a set of data. Graphs can be displayed, as well as a 3D representation of orientation.

A powerful time management allows deep exploration of any recording, with the ability to display in a single frame 50 ms of recording, or the whole record.

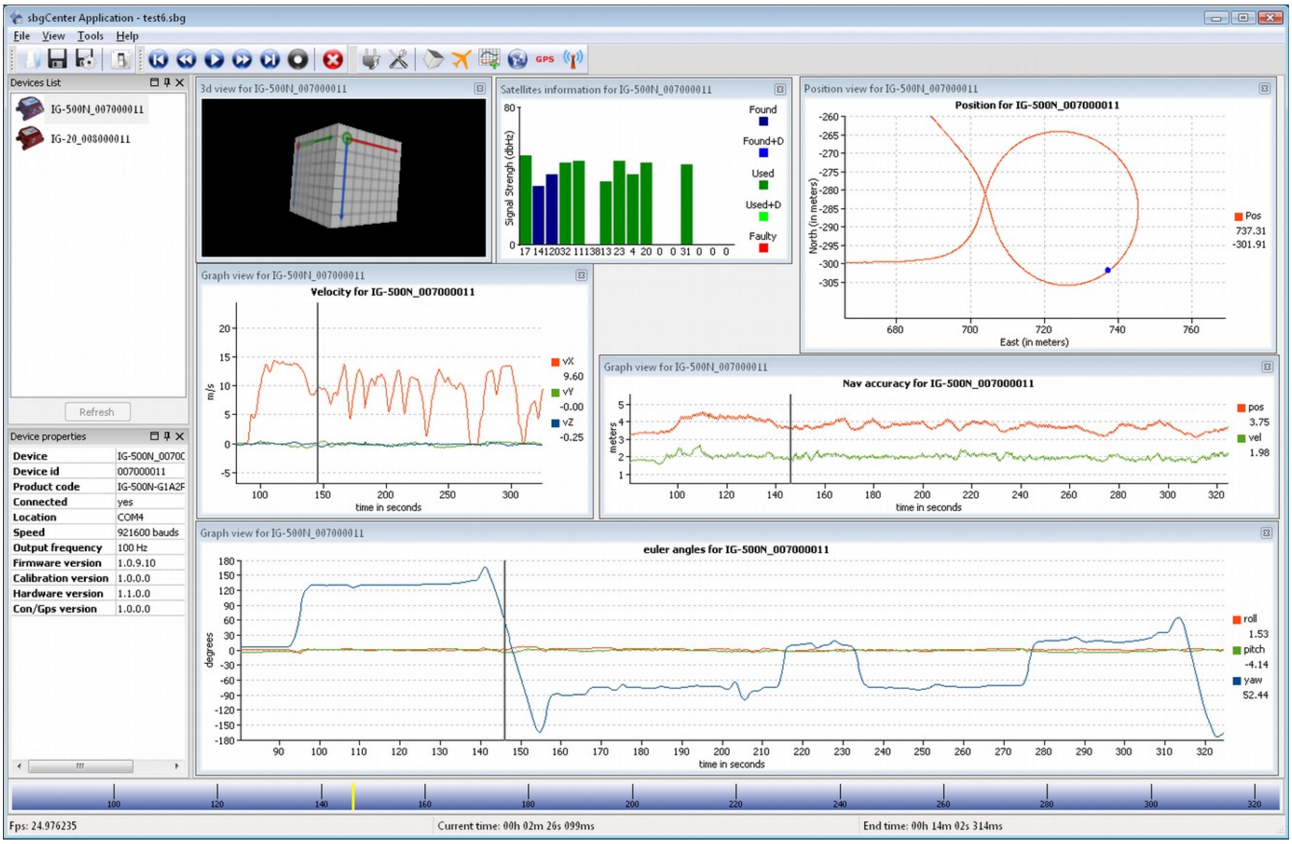


Figure 9: sbgCenter is an excellent analysis tool

***Note:** Please refer to the sbgCenter User Manual for more information*

4.2.2. Communication with the device

SBG Systems provides multiple ways to interface the IG-500E with another system. An easy solution is to use the C library sbgCom or sbgCan included in the DK. You can also refer to the IG-Devices Serial Protocol Specifications and IG-Devices CAN Protocol Specifications to directly communicate with the device.

For even easier integration into existing systems and drop-in replacement of GPS receivers, the IG-500E is able to output several standard NMEA 0193 and other compatible ASCII sentences.

4.2.2.1. The C libraries sbgCom / sbgCan

The IG-500E DK provides an easy access to the device with the libraries sbgCom and sbgCan. These libraries allow access to all functions of the IG-500E, including continuous mode of communication.

These libraries are developed for most popular OS: Ms Windows, Linux, and Mac OS X. They should also be easily compiled on all UNIX platforms.

sbgCom/sbgCan were designed to simplify the work needed to port the libraries to a specific platform, by separating the low level communication functions such as serial com port from the high level one.

> ***Note:*** *Please refer to the sbgCom and sbgCan Reference Manual to have a complete description of these two libraries.*

Provided example programs

- **Minimal example:** This small C example is simply the smallest program you can write to use the IG-500E. Only 6 lines of code are needed to initialize the device, start communications and display in real time results. This example illustrates the simplicity of use of sbgCom.
- **3D Cube:** This 3D Cube is a small C example, which source is available in the SDK. To use it, you just have to define the right com port and serial communication baud rate in the file "main.c" and compile the project. If everything goes well, you should obtain the two windows below:

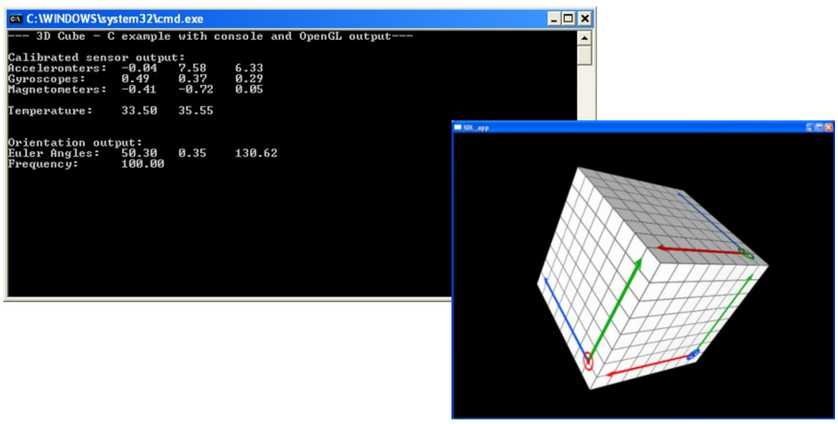


Figure 10: Overview of the 3D Cube example

4.2.3. Low level communication with the IG-500E

When it is not possible to use sbgCom or sbgCan libraries, you can still communicate directly with the device, by implementing its low level communication protocol based on the provided documentation.

Note: *Please refer to the IG-Devices Serial Protocol Specifications or IG-Devices CAN Protocol Specifications to have a complete documentation of the protocol format, the commands and their parameters.*

4.2.4. Matlab and Labview integration

4.2.4.1. Matlab

The sbgMatlab plug-in developed by SBG Systems allows a direct access in real time to your IG-500E. All functions of the sbgCom have been implemented in a Matlab class CSbgMatlab, providing an easy interface for users.

The plug-in is based on a DLL for Windows platform. A UNIX version of this dynamic library is being finalized and will be available in a next release.

A few example codes may help you in your developments. Also note that continuous mode has to be enabled in order to retrieve outputs from the IG-500E.

4.2.4.2. Labview integration

The sbgLabView library provides a full support of the IG-500E on Labview 8.2. An example using this library is provided for a better understanding of the library. Also note that continuous mode has to be enabled in order to retrieve outputs from the IG-500E.

4.3. Getting optimal results

The IG-500E is a measuring device, and in order to reach optimal performance, some checks and considerations have to be carefully done. If it is not the case, performance of the device can be rapidly affected.

We consider here the Optimal installation guidelines and limitations have been followed.

Before starting a measurement:

1. Connect correctly your external aiding sensors to the IG-500E.
2. Configure properly your device
    a. Select required outputs and baudrate. A Higher baudrate allows more data to be transmitted. Check in the device status that the “protocol” flag is set to Yes; If it's not, increase baudrate or reduce data throughput.
    b. Set appropriate Kalman filter options: Motion profile should be chosen accordingly to your application dynamics, as well as heading, velocity and position aiding sources.
    c. If the heading source is set to “Magnetometers”, a hard and soft iron calibration has to be performed in the place where the sensor is used. (Check the Iron Calibration Tools documentation for more information). By default, the local magnetic declination will be automatically computed.
    d. If the sensor can be considered as static at startup, then initialization time can be greatly reduced by enabling “initial static condition until motion is detected” option. It would ensure fast gyro bias acquisition and faster Kalman filter convergence. This is particularly useful when heading source is set to GPS course or GPS + Accelerations.
    e. Configure carefully the distance between the GPS antenna and the device within 10 cm accuracy, with the GPS Lever Arm option.

When you start a measurement:

1. Let some time for the device’s electronics to warm up. It can take up to 10-15 min. If the device is not fully warmed up, the sensors might have a degraded performance or bias. In the same time, you also let the Kalman filter stabilize. Filter Stabilization requires several minutes before reaching best performance. Before that time, it's possible to use the sensor but accuracy will improve over time until reaching optimal accuracy after about 10-15 min.
    a. The gyro bias can be estimated fully only if a heading is observable (or if configured to use an initial static condition). Depending on the heading source, this condition is not the same: the GPS course is observable only if the device is moving. Magnetometers need a homogenous magnetic field, without important disturbances. If the source is set to “User”, user has to feed measurements regularly to the device.
    b. Accelerometers bias estimation needs a velocity measurement. If the velocity source is set to the GPS, it simply implies that it needs a good GPS velocity measurement. If the source is set to “User”, user has to feed regularly the device with new velocity measurements.

5. IG-500E Outputs

The following section describes all IG-500E outputs. Please refer to the IG-Devices Serial Protocol Specifications and IG Devices CAN Protocol Specifications for more information about all outputs such as units.

5.1. Calibrated sensors output

The IG-500E includes 14 calibrated sensors: 3 accelerometers, 3 gyroscopes, 3 magnetometers and 5 temperature sensors. These 14 calibrated sensors values can be outputted by the device. By calibrated value, we mean compensated for any sensor errors (temperature effects, linearity errors, sensor misalignment, gyro-G effect…).

Gyroscopes values

Gyroscopes calibrated values are the three rotational speeds around the device's axes *X*, *Y* and *Z*.

Delta Angles values

1 kHz coning integration output. These angles should be used in the same way as gyroscopes values, but provide better integration accuracy with high dynamic applications. These can be considered as rotational speed around the device's axes *X*, *Y* and *Z*.

Accelerometers values

Accelerometers calibrated values are the three accelerations measured on device coordinate frame.

Magnetometers values

Magnetometers calibrated values reflect the local magnetic field in the device coordinate system. These values are temperature compensated and corrected for soft and hard iron effects (as evaluated in the last calibration procedure).

Magnetometers values are expressed in an arbitrary unit and in homogeneous magnetic field, the norm of the magnetic field vector should be the same in all orientations and ideally equal to 1.0.

Temperature values

The temperature calibrated output is the temperature measured by the external magnetometers and accelerometers temperature sensor, and the internal ADC temperature sensor

Gyroscopes Temperature values

The gyroscopes temperature output is the temperature measured by the three temperature sensors included in the gyroscopes.

> ***Note:*** *The temperature sensors inside the IG-500E have a very good repeatability, required for sensor calibration, but only a poor absolute accuracy, especially the gyroscopes internal temperature sensors.*
>
> *If absolute measurement is needed, the accelerometers/magnetometers temperature sensor should give best results, with an absolute accuracy of [-2/+4] °C over the full -40 to 85 °C range.*
>
> *This accuracy can be enhanced to 0.5°C by performing a bias calibration at +25°C.*

5.2. Orientation and navigation outputs

Euler angles

Euler angles provide Roll, Pitch and Yaw values. (If the device can be rotated in all directions, you would prefer rotation matrix or quaternion forms as they do not suffer from singularities when pitch approaches $\pm\frac{\pi}{2}$.

Rotation Matrix

This form provides the nine coefficients of the rotation matrix representing the IG-500E orientation.

> ***Note:*** *Rotation matrix output is only available with serial output devices (P1, P2 and P4 options)*

Quaternion

The quaternion is the smallest form that provides a full coverage of 3D orientations.

> ***Note:*** *Please refer to chapter 4. to have more information about how orientation can be represented and the coordinate frames of the IG-500E.*

Position output

The IG-500E provides a 3D position in terms of latitude, longitude, and altitude, in the WGS84 format. Altitude might be referenced above Ellipsoid or mean sea level, depending on configuration.

Velocity output

The IG-500E provides a velocity output with respect to the device coordinate frame.

Heave Output

High pass filtered altitude output for wave height measurement. This output is expressed in meters above mean altitude.

5.3. Other outputs

Accuracy indicators

These three indicators represent the attitude accuracy, the velocity accuracy and position accuracy estimates. They can provide good real time information about the robustness of the filter.

Raw sensors output

Accelerometers, magnetometers, gyroscopes and temperatures can be output by the IG-500E in raw form. The raw sensor output is the reading of the Analog to Digital Converter, then filtered by the averaging filter and eventually the low pass filter. These values are not exploitable directly but may sometimes be useful as they reflect the real values of the physical sensors.

Time since last reset

This output provides in ms the time elapsed since the last reset of the IG-500E. This time is measured at the beginning of the sampling and calculation loop of the device.

UTC Time reference

The IG-500E outputs a UTC time reference derived from the external GPS receiver. This time references the sample time, with an accuracy better than 1 µs. This output contains the full date information: Year, Month, Day, Hour, Minutes, Seconds, and Nano-Seconds.

Before receiving any GPS time data, the timer starts on January 1st, 2009.

In addition to this UTC time reference, three flags are available in the next output (Device Status). These flags inform the user about the quality of the time information:

- The first flag is set if the GPS already knows the “Leap seconds” between UTC time and GPS atomic clocks time. A leap second is introduced to keep the GPS time close to the mean solar time (which is not perfectly constant by nature). At the time of writing those lines, there are 15 positive leap seconds. This is why when this flag become set, the time output jumps of several seconds. It may take up to 15-20 minutes for the GPS receiver to obtain leap seconds information.
- The seconds informs the availability of a “rough accuracy”. This 0.25s accuracy is achieved when The GPS receiver starts sending valid time information (independently of the leap seconds), but without sending synchronization pulses. The accuracy comes from the unknown calculation time of the GPS data, and is achieved when the GPS receiver actually tracks satellites, but has no position fix.
- The third flag states that the UTC clock is “synchronized”. In that case, the timer achieve better than 1µs accuracy. The synchronization is done by the use of a synchronization pulses from the GPS receiver. These pulses are sent as soon as the GPS receiver has a valid position fix. If the GPS receiver loses its position fix for more than 2 minutes, the time accuracy is degraded to “rough accuracy”.

Device Status

The IG-500E performs at start-up a sensor Self-Test, as well as some internal initialization checks. This self test inform the user of potential device failure. Some other outputs are updated in real time and inform about the health of the Kalman filter.

Note: *that the sensor self test is only reliable if the device is not moving during start-up.*

Bit	Name	Description
0	SBG_CALIB_INIT_STATUS_MASK	Set to 1 if the calibration structure is well initialized
1	SBG_SETTINGS_INIT_STATUS_MASK	Set to 1 if the settings structure is well initialized
[2 – 4]	SBG_ACCEL_X_SELF_TEST_STATUS_MASK	Set to 1 if the X accelerometer has passed self test
5	SBG_ACCEL_RANGE_STATUS_MASK	Set to 1 if the readings of accelerometers do not exceed operating range.
[6 – 8]	SBG_GYRO_X_SELF_TEST_STATUS_MASK	Set to 1 if the X gyroscope has passed self test
9	SBG_GYRO_RANGE_STATUS_MASK	Set to 1 if the readings of gyroscope do not exceed operating range.
10	SBG_MAG_CALIBRATION_STATUS_MASK	Set to 1 if the magnetic field calibration looks OK
11	SBG_ALTI_INIT_STATUS_BIT_MASK	Set to 1 if altimeter could initialize
12	SBG_GPS_INIT_STATUS_BIT_MASK	Set to 1 if GPS receive could initialize properly
13	SBG_G_MEASUREMENT_VALID_MASK	Set to 1 if gravity is observable sufficiently for proper Kalman filter operation
14	SBG_HEADING_MEASUREMENT_VALID_MASK	Set to 1 if heading is observable sufficiently for proper Kalman filter operation
15	SBG_VEL_MEASUREMENT_VALID_MASK	Set to 1 if velocity is observable sufficiently for proper Kalman filter operation
16	SBG_POS_MEASUREMENT_VALID_MASK	Set to 1 if position is observable sufficiently for proper Kalman filter operation
17	SBG_UTC_VALID_MASK	Bit mask for GPS UTC Validation: Leap Seconds already known
18	SBG_UTC_ROUGH_ACCURACY_MASK	Bit mask for UTC time validation with rough accuracy
19	SBG_FINE_ACURACY_MASK	Bit mask for UTC time synchronization
20	SBG_PROTOCOL_OUTPUT_STATUS_MASK	Set to 1 in protocol normal operational Set to 0 in case of output buffer saturation
[21 – 31]	-	Reserved – Set to 0

Table 12: Device status bit-field

Magnetic field Calibration Data

This buffer contains data used for the SBG Systems Magnetic Calibration tools.

Check the Magnetic calibration tools documentation for more information about this output.

Absolute pressure

Absolute pressure is given by pressure sensor.

Relative altitude

According to the Standard Atmosphere model, altitude is calculated with respect to the ground pressure.

Raw GPS information

The IG-500E provides direct GPS measurements in terms of 3D position (Latitude Longitude Altitude), 3D velocity in Earth coordinate frame, GPS course, GPS True Heading and various information about GPS fix quality, GPS time of week.

5.3.1. Advanced GPS output

When the IG-500E is connected to a GPS that handles this type of data, it's possible to get the receiver channels data. Each channel can track one satellite (or Space Vehicle). Information retrieved from each channel is:

Field	Type	Comments
satelliteID	uint8	Space Vehicle ID
flagsQuality	uint8	**Bit [0 – 4] : Bit-mask, made up of the following bit values** • 0x01 = SV is used for navigation • 0x02 = Differential correction data is available for this SV • 0x04 = Orbit information is available for this SV (Ephemeris or Almanach) • 0x08 = Orbit information is Ephemeris • 0x10 = SV is unhealthy / shall not be used **Bit [5-7] : Signal Quality Indicator (range 0..7). Different QI values are:** • 0: This channel is idle • 1, 2: Channel is searching • 3: Signal detected but unusable • 4: Code Lock on Signal • 5, 6: Code and Carrier locked • 7: Code and Carrier locked, receiving 50bps data
signalStrength	uint8	Carrier to Noise Ratio expressed in dbHz
azimuth	int8	Azimuth of the SV. 1 LSB = 32/45 °
elevation	int8	Elevation of the SV. 1 LSB = 32/45 °

Table 13: GPS Space Vehicle Information frame

> ***Note:*** *On serial output versions, this information is not available with the triggered/continuous output. A specific command in Question/Answer mode has to be sent to retrieve satellites information.*

6. Orientation, position and velocity representation

6.1. Coordinate systems

User has to distinguish two coordinate frames when working with an inertial measurement unit, such as the IG-500E. The first coordinate frame is the inertial (or device) coordinate frame, in which values are expressed in this local coordinate frame. This coordinate frame follows the movements of the device. The fixed coordinate frame represents the environment of the device.

In other words, the device frame is moving and rotating in the fixed frame. When the two frames are aligned (*X*, *Y*, *Z* axes of the two frames are aligned), the device should output no rotation (*yaw = pitch = roll = 0*).

In all case, all coordinate systems are "Right handed" and the positive direction for rotations is clockwise in the direction of the axis:

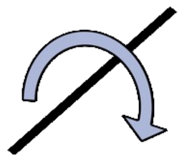


Figure 11: Positive Rotations

6.1.1. Device coordinate system

Below is defined the inertial coordinate frame.

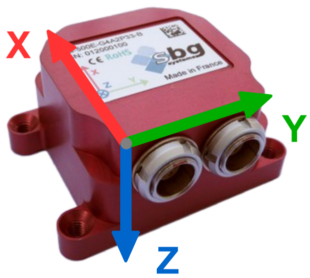


Figure 12: Inertial coordinate frame

6.1.1.1. Origin of the device coordinate system

If highest precision are needed for velocity and position measurements, it may be useful to know the real center of accelerations as measured by the device. The diagram below describes the position of the 3D accelerometer. Note that this information is in general negligible if only accurate orientation is needed.

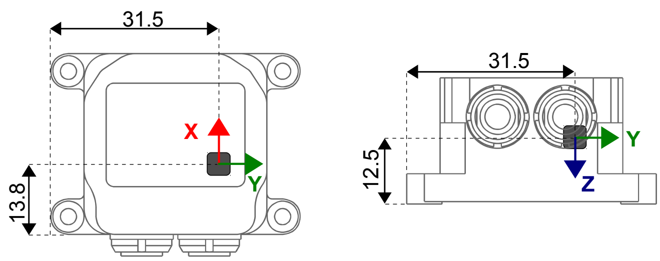


Figure 13: 3D Accelerometer physical location in box.

Dimension are in mm.

6.1.2. Fixed coordinate system (North – East - Down)

The fixed coordinate frame is defined by these three vectors:

- *X* vector is aligned with the local magnetic north,
- *Z* vector is aligned with the local gravity, turned down,
- *Y* vector is chosen such as the coordinate frame is “right-handed”. Therefore, *Y* is turned toward East.

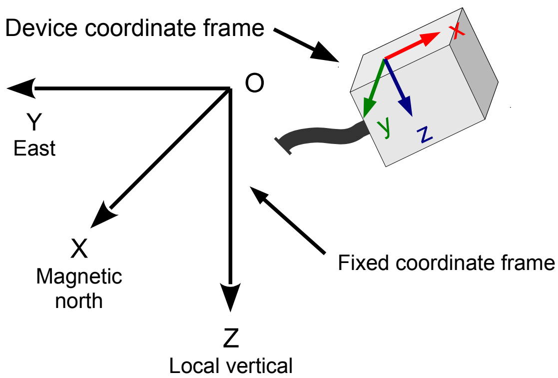


Figure 14: Sensor and fixed coordinate frames

6.1.2.1. Magnetic North vs. true North

In order to achieve good performance, it is important that the device’s representation of the Earth fixed coordinate system is aligned with the one used by the GPS receiver.

However, magnetometers are not aligned with the true north, but with the magnetic north. In the opposite, the GPS system is always referenced to the real north. The difference between the real north direction and the magnetic north direction is called declination.

The magnitude of declination may vary significantly: About 0.5° near Paris, it may grow to 20° in Canada and even more in other locations. The declination depends on the location on Earth, as well as the current date, as the declination may vary over time.

It is possible to evaluate automatically the local declination of the device, or to set manually the magnetic declination.

6.1.3. Geographic coordinate system

It is common to represent position on Earth in terms of Latitude, Longitude and Altitude. This geographic coordinate system allows locating any point on the ellipsoid shape of Earth.

Most of the GPS systems use the standard WGS84 physical model of Earth. Some countries use local physical models which are locally more accurate, but these local models cannot be used on the whole globe. The IG-500E uses the standard WGS84 as reference.

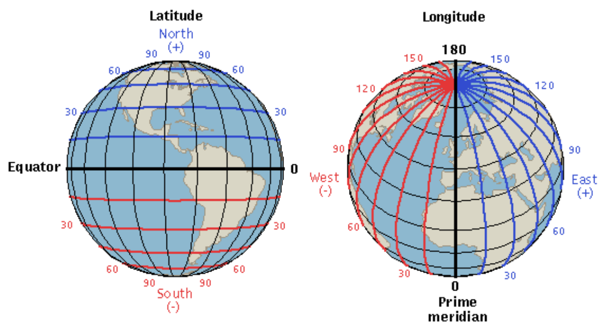


Figure 15: Geographic coordinates on Earth

6.1.3.1. Local tangent plane

The geographic coordinate system is not directly compatible with the Cartesian Fixed Coordinate System.

A linearization around the device's location is performed so that the Fixed Coordinate system, defined in section 6.1.2 is locally aligned on the geographic coordinate system. This linearization is the local tangent plane to the Earth surface.

In order to reduce the error generated by the linearization to the maximum, a new linearization is performed at each time the Kalman filter receives a new position data from the GPS receiver. In practice the amount of error generated by the linearization is much lower than the error due to the noise measurement of the sensors.

6.1.3.2. Altitude reference

Altitude can be expressed in several different ways. The mostly used are the "Altitude above mean sea level", and "Altitude above Ellipsoid".

In order to understand the difference between these two representations, you have to understand that Earth's surface is irregular. The geoid shape is often used to approximate Earth's irregularities. But actually a geoid is much smoother than the real Earth surface. There are many geoid models with different precision. Normally, the mean sea level is always at zero altitude on a geoid surface.

In the opposite, all GPS systems use an ellipsoid shape to approximate Earth's surface, which is much simpler mathematically than a geoid representation. The WGS84 standard defines the ellipsoid parameters. As there are some differences between the geoid and the ellipsoid, the altitude of the sea level is not always at zero if we are based on the ellipsoid.

It is possible to convert the altitude between the two models with correction tables. The total variation between a perfect ellipsoid shape and a geoid is less than 200m.

The diagram below shows the Earth's surface and the different shapes:

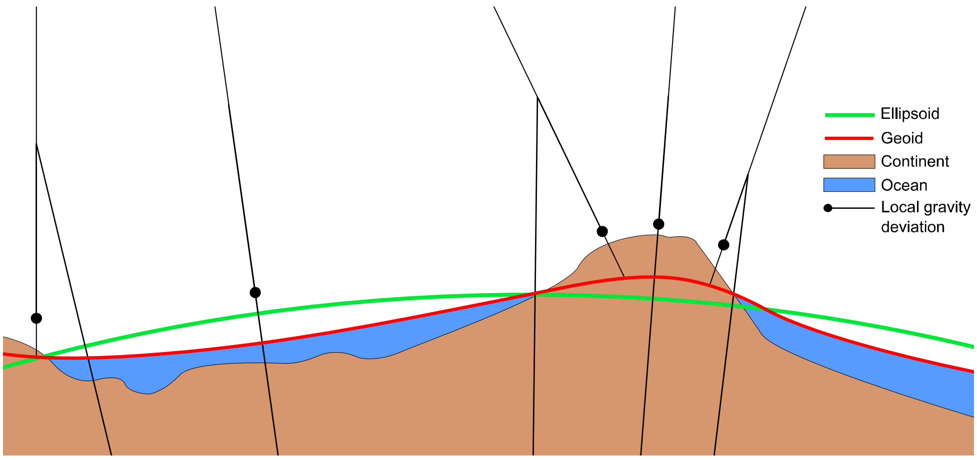


Figure 16: Ellipsoid and Geoid representation

When the external sensor can handle it, the IG-500E can be configured to output altitude referenced either to Ellipsoid, using the standard WGS 84, or Mean Sea Level. If the external sensor does not handle different altitude references, the altitude provided will be directly used.

6.2. Orientation representation

There are several ways to represent the orientation of the device that are provided by the IG-500E. Some are easy to understand, others are very efficient such as quaternion form:

6.2.1. Euler Angles

Euler angles are a commonly used representation of spatial orientation. Euler angles are in fact a composition of rotation from the reference (Earth fixed) frame. This spatial orientation is defined by the sequence of the three rotations around X, Y and Z axis of the fixed frame.

Euler angles are widely used because of their ease of interpretation. The three parameters: Roll, Pitch and Yaw define rotations around the fixed frame's axes:

- Roll *(φ)*: Rotation around *X* axis. $\varphi \in [-\pi ; \pi]$
- Pitch *(θ)*: Rotation around *Y* axis. $\theta \in \left[-\frac{\pi}{2} ; \frac{\pi}{2}\right]$
- Yaw *(Ψ)*: Rotation around *Z* axis. $\psi \in [-\pi ; \pi]$

Note: *As Euler angles suffer from a singularity called "Gimbal lock", when Pitch approaches ± π/2 , we do not advise to use Euler angles if the sensors has to be used in a wide range of orientations. Quaternion and Rotation matrix do not suffer from this problem.*

6.2.2. Rotation matrix (Direction Cosine Matrix)

The Direction Cosine Matrix (DCM) is a rotation matrix that transforms one coordinate reference frame to another. Rotation matrices are a complete representation of a 3D orientation, thus there is no singularity in that model.

A DCM locates three unit vectors that define a coordinate frame. Here the DCM transforms the sensor coordinate frame to the earth fixed coordinates. The DCM is the combination of the three rotation matrices RM_φ , RM_θ and RM_ψ respectively around Earth *X*, *Y* and *Z* axes.

Here is defined a DCM in terms of Euler Angles:

$$DCM = RM_\psi \, RM_\theta \, RM_\varphi$$

$$DCM = \begin{pmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & -\sin\varphi \\ 0 & \sin\varphi & \cos\varphi \end{pmatrix}$$

$$DCM = \begin{pmatrix} \cos\theta\cos\psi & \sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi & \cos\varphi\sin\theta\cos\psi + \sin\varphi\sin\psi \\ \cos\theta\sin\psi & \sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi & \cos\varphi\sin\theta\sin\psi - \sin\varphi\cos\psi \\ -\sin\theta & \sin\varphi\cos\theta & \cos\varphi\cos\theta \end{pmatrix}$$

As for any rotation matrix, the inverse rotation equals to the transposed matrix:

$$DCM^{-1} = DCM^T$$

In order to transform a vector expressed in the sensor coordinate system into the Earth fixed frame, user will use the DCM as expressed below:

$$V_{Earth} = DCM \cdot V_{Sensor}$$

Reciprocally:

$$V_{Sensor} = DCM^T \cdot V_{Earth}$$

6.2.3. Quaternions

Quaternions are an extension of complex numbers, as defined here:

$Q = q_0 + i \cdot q_1 + j \cdot q_2 + k \cdot q_3$ Where i, j and k are imaginary numbers.

Particular quaternions such as $\|Q\| = 1$ can represent, as DCMs, a complete definition of the 3D orientation, without any singularity.

Quaternion algebra do not require a lot of computational resources, they are therefore very efficient for orientation representation.

The inverse rotation of Q is defined by the complex conjugate of Q , denoted $\overline{Q}$:

$$\overline{Q} = q_0 - i \cdot q_1 - j \cdot q_2 - k \cdot q_3$$

Quaternion can be defined in terms of the DCM coefficients:

$$q_0 = \frac{1}{2}\sqrt{1 + DCM_{11} + DCM_{22} + DCM_{33}}$$
$$q_1 = \frac{1}{4 q_0}\left(DCM_{32} - DCM_{23}\right)$$
$$q_2 = \frac{1}{4 q_0}\left(DCM_{13} - DCM_{31}\right)$$
$$q_3 = \frac{1}{4 q_0}\left(DCM_{21} - DCM_{12}\right)$$

Or in terms of Euler Angles:

$$q_0 = \frac{1}{2}\sqrt{1 + \cos\theta\sin\psi + \sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi + \cos\varphi\cos\theta}$$
$$q_1 = \frac{1}{4 q_0}\left(\sin\varphi\cos\theta - \cos\varphi\sin\theta\sin\psi + \sin\varphi\cos\psi\right)$$
$$q_2 = \frac{1}{4 q_0}\left(\cos\varphi\sin\theta\cos\psi + \sin\varphi\sin\psi + \sin\theta\right)$$
$$q_3 = \frac{1}{4 q_0}\left(\cos\theta\sin\psi - \sin\varphi\sin\theta\cos\psi + \cos\varphi\sin\psi\right)$$

6.2.4. Other useful conversion formulas

Some other conversion formulas can be useful for many users, and are listed below:

6.2.4.1. Quaternion to DCM

It may be useful to compute a DCM based on the quaternion's parameters:

$$DCM=\begin{pmatrix} 2q_0^2+2q_1^2-1 & 2q_1q_2-2q_0q_3 & 2q_0q_2+2q_1q_3 \\ 2q_1q_2+2q_0q_3 & 2q_0^2+2q_2^2-1 & 2q_2q_3-2q_0q_1 \\ 2q_1q_3-2q_0q_2 & 2q_2q_3+2q_0q_1 & 2q_0^2+2q_3^2-1 \end{pmatrix}$$

6.2.4.2. Quaternion to Euler

Here is the quaternion translated into Euler angles.

$$\varphi=\tan^{-1}\left(\frac{2q_2q_3+2q_0q_1}{2q_0^2+2q_3^2-1}\right)$$
$$\theta=-\sin^{-1}\left(2q_1q_3-2q_0q_2\right)$$
$$\psi=\tan^{-1}\left(\frac{2q_1q_2+2q_0q_3}{2q_0^2+2q_1^2-1}\right)$$

6.2.4.3. DCM To Euler

Finally the DCM matrix is converted into Euler Angles.

$$\varphi=\tan^{-1}\left(\frac{DCM_{32}}{DCM_{33}}\right)$$
$$\theta=-\sin^{-1}\left(DCM_{31}\right)$$
$$\psi=-\tan^{-1}\left(\frac{DCM_{21}}{DCM_{11}}\right)$$

7. Configure your IG-500E

The IG-500E is a widely configurable device. Everything has been done to improve user experience: most of the default configuration should be suitable to all users, but advanced users who desire to tune the IG-500E can do this very deeply. All configurable settings can be saved in the non-volatile memory or not. Thanks to this mechanism, the user can configure his device permanently or temporary depending on his needs.

Indeed, all settings stored in volatile memory will be erased when the device is turned off.

7.1. Protocol configuration

7.1.1. Serial communication versions

7.1.1.1. Baudrate

The following baudrates can be configured on the IG-500E.

`[9 600; 19 200; 38 400; 57 600; 115 200; 230 400 460 800; 921 600]`

Default configuration is 115200 bps.

7.1.1.2. Output mode (serial communication)

On serial communication devices, the output mode contains two configurations that may be combined. This configuration is only provided on the serial communication version.

Endianness		**Decimal formats**	
Little-endian	**Big-endian**	**Float – double**	**Fixed point 32 – 64 bits**
Words are transmitted with the LSB first	Words are transmitted with the MSB first	Decimal numbers are provided in the standard IEEE 754 format, in single or double precision. All numbers are in float format, except the position data which requires the double precision.	Decimal numbers are provided in fixed point format. **32 bit format** is in [12:20] (1 sign bit, 11 integer bits, 20 fractional bits) **64 bit format** is in [32:32] (1 sign bit, 31 integer bits, 32 fractional bits) All numbers are in 32 bits, except the position data which require 64 bits precision.

Table 14: Serial communications Output format

The default configuration for output mode is big-endian, and float.

Note: *The fixed point format requires additional computation time. Therefore, we only advise this output mode in case the host system cannot handle floating point numbers.*

7.1.1.3. Default output mask

The IG-500E protocol allows polling all the output information (sensors data, orientation for example) in one frame. The default output mask is used to configure which information is included in the default output frame.

By default, the default output mask contains a standard set of data:

- Orientation: quaternion, Euler angles
- 3D position and velocity
- Gyroscopes, accelerometers and magnetometers calibrated data, and temperature,
- Time since last reset.

7.1.1.4. Normal, Continuous and Triggered modes

Normal mode

The normal mode is a classical Question / Answer mode. Each question of the user is acknowledged or answered by the device. This also means that user has to spend some time to ask his questions.

Continuous mode

The continuous mode allows the unit to send automatically a fixed set of data at a constant rate. This kind of output is very simple and is very efficient as it requires no user action.

Note 1: *The normal mode is still functional while continuous mode is enabled.*

Note 2: *When continuous mode is enabled, some continuous frames can be skipped if the user is asking some other questions and the device's answer is too big for the serial buffer. Normal mode has always priority over the continuous mode. Once the serial buffer is not saturated anymore, the continuous frames will be sent again.*

Triggered mode

In addition to the basic continuous mode, the IG-500E supports a triggered output mode which offers the possibility to send only newly computed data. It is really suitable with data that are not continuously updated such as GPS fix or barometer data. Some triggers inform about newly received/sampled data and can generate the output.

User can activate 4 different triggers conditions (see section 7.1.3.2 for triggers definitions), corresponding to a specific output buffer. All trigger conditions are then combined to generate a unique output frame that contains a trigger mask that informs what triggers are active, an output mask to inform of what data is transmitted and the actual output buffer.

Note : *For some users, it could be interesting to only use a trigger frame on the main filter loop rather than using the traditional continuous mode. Indeed, each trigger frame indicates which data has been updated and the used output mask. This approach can reduce data transmitted on the serial port and perfectly fit for data logging applications.*

7.1.1.5. NMEA and ASCII outputs

The IG-500E is able to output several NMEA 0183 sentences. Configuration has to be made through the main IG-Devices Serial protocol. This allows drop-in replacement of existing GPS systems.

The following messages are supported:

Message	Content
$GPGGA	Provides Latitude, Longitude, Altitude, time and Fix status.
$GPRMC	Minimum recommended output for GPS: Provides Latitude, Longitude, Date, Time, speed and course over ground and fix status.
$GPZDA	Date and time
$SBG01	Euler angles and orientation accuracy in degrees.

Table 15: Supported NMEA and ASCII sentences

Each sentence can be enabled with the same mechanism as triggered output; in addition, each sentence can use a specific main loop divider.

> ***Note:*** *Please consult the IG-Devices Serial Protocol Specifications for more details about NMEA and ASCII outputs.*

7.1.2. CAN Bus Version

7.1.2.1. Bitrate and propagation segment

The IG-500E CAN version supports the following standard CAN bus bitrates:

- `1 000 kBit/s`
- `500 kBit/s`
- `250 kBit/s`
- `125 kBit/s`
- `100 kBit/s`
- `50 kBit/s`
- `20 kBit/s`
- `10 kBit/s`

Default Configuration is 1 000 kBit/s.

The CAN bus implementation and especially timing settings respects the CAN in Automation (CiA) DS-102 standard.

7.1.2.2. Frames Identifiers (CAN bus)

CAN devices have to be able to adapt to a user CAN bus. It is possible to configure the device to use standard or extended CAN messages ids. In addition, for each CAN message, handled by the device, it's possible to define it's id or even disable it.

> ***Note:*** *Please check the IG-Devices CAN Protocol Specifications in order to see the best way to configure CAN identifiers*

7.1.2.3. Output modes

On CAN devices, each data has been separated into dedicated frames. Each frame can be configured to be sent automatically or on demand. The following output frames are enabled by default:

- Time since last reset and trigger mask
- 3D orientation using quaternions
- 3D orientation using Euler angles
- 3D position and velocity
- Gyroscopes, accelerometers and magnetometers calibrated data
- Device temperature

Normal mode

The normal mode is a classical Question / Answer mode. Each question of the user is acknowledged or answered by the device. This also means that user has to spend some time to ask his questions.

Continuous/Triggered mode

With the CAN protocol, each output frame can be configured independently to be sent automatically with several conditions. It can be transmitted each time the continuous divider is updated, or at different trigger conditions.

The most important advantage of this communication mode is that once the device is configured, the data is transmitted automatically, at the best update rate.

7.1.3. Common protocol settings

7.1.3.1. Main loop divider

The continuous / triggered outputs can be configured with a main loop frequency divider. The output frequency is then defined as follows:

$$F_{DataOutput} = \frac{F_{Filter}}{divider}$$

When this divider is set to a value larger than one, the IG-500E will send a new output frame each N loops in order to limit output bandwidth.

7.1.3.2. Available Triggers

The following triggers sources can generate outputs. Multiple triggers can be active in the same time so that an output is generated by multiple triggers,

- Main Loop frequency divider trigger (equivalent to the basic continuous mode)
- New magnetometers data available
- New user event input
- New Barometer data available
- New GPS velocity data available
- New GPS position data available
- New GPS course data available
- New hardware GPS Time pulse
- New odometer 0 velocity available
- New odometer 1 velocity available
- New GPS True Heading data available
- New virtual odometer trigger

Note : Please referrer to the IG-Devices Serial Protocol Specifications and IG-Devices CAN Protocol Specifications for more details about triggers configuration and frame definition.

7.2. General purpose configuration

7.2.1. User ID

Each device can be configured with a user ID. This ID can help user to identify sensors if many sensors are connected to the same computer. Default configuration is 0.

7.2.2. User Buffer

As a User ID complement , the IG-500E includes a 64 bytes buffer reserved for user needs. This buffer can be written, read, and saved to non volatile memory.

7.2.3. Synchronization

The IG-500E embeds a synchronization input (hard wired to external GPS time synchronization pin) and one synchronization output, which can be configured depending on user requirements.

7.2.3.1. Synchronization Inputs

The two synchronization inputs are independent, and can be configured to fit each application. Here are the different options provided:

- Event type: GPS time pulse, Event input, or odometer input
- Input Sensitivity: Rising Edge, Falling edge, or level change can be set
- Input delay: A custom delay can be added before the event is actually processed.

Note: *In addition to this standard configuration, the sync In channel 0 physical location can be defined on RS-232 version (On main connector or on External connector)*

7.2.3.2. Synchronization Output

This single synchronization output allows the user to synchronize its system with the IG-500E. The following options are provided:

- Output type: GPS time pulse copy, Main loop start, or Continuous divider trigger
- Output polarity: Rising edge pulse, Falling edge pulse, Level change. When the Rising/falling edge is set, a pulse duration is also configured.

7.3. Kalman filter configuration

The IG-500E Kalman filter can be configured by a set of independent parameters. Theses options provide an easy access to deep sensor behavior configuration.

7.3.1. Motion profiles

The IG-500E Kalman filter is configured through the motion profile. Please check section 2.3 Motion profiles for more information about motion profiles.

The following motion profiles can be implemented into the IG-500E.

- General Purpose
- Airplane
- Airplane – High Dynamics
- Helicopter
- Automotive
- Marine
- Underwater
- IMU 500Hz.

7.3.1.1. Select heading source

In conjunction with the motion profile, different heading source allow choosing the best heading observation method depending on each application requirement.

Each heading source has different advantages and constraints and are listed in the table below:

Heading Source	Constraints for optimal use	Example application
Internal Magnetometers (Default)	• Needs a reliable magnetic fled environment	• Unmanned vehicles • Marine • Aircraft
GPS Course	• Side slip is not allowed. • The device must be carefully installed with X axis in the direction of the motion. If it is not possible, user must set a "pre-rotation" matrix to put the sensor in the right coordinates.	• Car motion analysis • Rail industry
GPS + Accelerations	• Device must be regularly accelerated for proper heading observability	• Dynamic applications • Magnetometers denied environments • Applications where course is not the same as heading (side slip allowed).
GPS true heading	• Requires a dual antenna GPS receiver with a medium to good signal reception • The heading offset between the GPS antennas and the internal heading has to be carefully set.	• Car motion analysis • Marine • Airplanes
User heading	• Sensor must be fed with regular heading information, coming from an external heading sensor. One data per second is a minimum for optimal operation. • User heading information must be aligned with true north.	• Applications where magnetometers and GPS heading cannot be used.

Table 16: Heading sources

7.3.1.2. Setting the local magnetic declination

Although the IG-500E embeds the World Magnetic Model (WMM2010), a first GPS fix is required to compute the local magnetic declination.

In locations where magnetic declination can be large, it can be a good idea to store the local magnetic declination into the non volatile memory for faster filter convergence.

7.3.1.3. Heave computation

If this output is required and enabled, added computations will increase output latency by approximately 2ms.

7.4. Navigation options and features

7.4.1. Select position and velocity source

The IG-500E offers an option that may be extremely useful to enhance precision, or to use the device when no GPS is available (mainly indoor applications). An external velocity and position sensor (odometer or high precision GPS for example) can be interfaced with the IG-500E through the main communication protocol.

In addition when the position source is set to “GPS + Baro”, the GPS altitude will be enhanced using the barometric altimeter (Only available with an external IG-Device).

It is possible to change the source of velocity and position in real time, without a reset of the device.

Options are:

Velocity source	Position source
• **External/GPS (default)** • **Odometer** • **User**	• **GPS (Default)** • **GPS + Baro** • **User**

Table 17: Navigation sources

> ***Note:*** *The IG-500E internal Kalman filter can handle external position and velocity measurements up to 10Hz. Feeding external measurements to the Kalman filter with a higher frequency is not recommended as it would decrease performance.*

7.4.2. Set the local gravity constant

As magnetic declination, local gravity can be automatically computed once a GPS fix is available, thanks to the WGS84 gravity model.

It's still possible to configure the local gravity and store it into non volatile memory.

Default value for gravity constant is $g=9.809\,m\cdot s^{-2}$.

7.4.3. Setting the reference pressure for ground level

A barometric altimeter gives only a poor accuracy if we do not take into account a reference pressure at ground level. Weather changes can introduce a large error on the altitude computation and especially when the sensor is placed near the ground.

This is why we allow user to configure the pressure at ground. Two possibilities are offered: Use the current pressure as the ground pressure (to set during the initialization of the device for example), or set a specific pressure (therefore, the ground pressure can be updated during the flight of a small UAV for example).

> ***Note:*** *This reference is not used by the internal Kalman filter, and only altitude changes are used. Only “Altitude Baro” output is affected by this setting.*

7.5. External device management

7.5.1. Select the external device type

As the IG-500E allows multiple external devices to be used, it is possible to set the external device type. The following types are allowed:

- **Standard NMEA GPS.**
  - This type is virtually compatible with almost all GPS receivers.
  - If supported by the GPS, True Heading is handled by the IG-500E.
- **Remote IG-Device.**
  - External U-Blox GPS receiver
  - Remote magnetometer and barometer.

External device baudrate can also be configured. In addition, user can set the communication type to RS-232 or RS-422.

7.5.2. External devices specific configurations

Most of the supported external devices have some particularities, and might require a specific configurations. This is done through the use of a specific command set for each external device.

> ***Note:*** *Please refer to the corresponding documentations for more information about each connected device.*

7.5.3. Setting GPS antenna lever arm

The requirements for the GPS antenna placement (or the external position/velocity aiding device) are not always compatible with the IG-500E placement. Therefore, user can set a 3D offset defining where is placed the GPS antenna. Offset is expressed in meters, in the device coordinate system (signed distance).

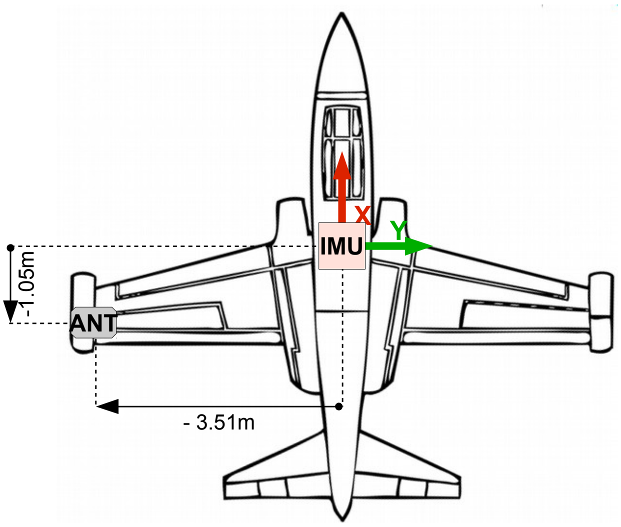


Figure 17: GPS antenna Lever Arm example

> ***Note:*** *It is important to set accurately the distance between GPS antenna and the IG-500E in order to have optimal performance.*

7.5.4. Odometer configuration

Odometer integration requires a few elements to be configured:

7.5.4.1. Setting Odometer options

The odometer channels have to be configured to set on which axis velocity is measured.

In addition, user has to provide the number of odometer pulses per meter traveled (one configuration per odometer channel).

7.5.4.2. Setting Odometer direction

1. User defined direction: Here, the main communication protocol is used to provide to the IMU the odometer direction of travel. It is possible to change in real time the direction of travel.
2. When a single odometer is used, the second IG-500E logic input can be used as direction indicator, as provided by most odometers (dual quadrature output encoders for example). This is the best solution for accurate velocity measurement.

Note: *When the second option is used for odometer direction sensing, the two logic inputs are used for odometer. It is then not possible to input the GPS PPS Signal for IMU/GPS synchronization.*

7.5.4.3. Setting Odometer Lever arm

As for the GPS or external navigation sensor, the odometer requires a lever arm (signed distance between the IG-500E and the odometer) to be set for optimal use.

You can find below an example of how setting the odometer lever Arm.

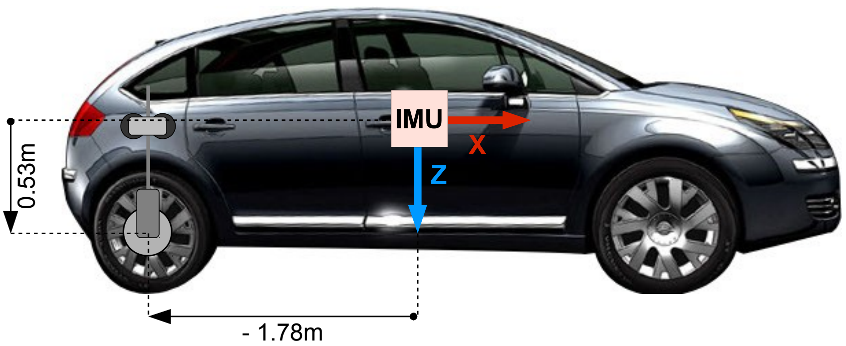


Figure 18: Odometer Lever Arm example

7.6. Coordinate frames transformation

7.6.1. Pre-Rotations

Sometimes, it is hard to align the device local axes with the object on which it is installed. IG-500E devices have an easy way to manage these kinds of problems. Those three functions allow user to realign the local coordinate frame with the object axes.

We call that kind of transformations “pre-rotations” as it is applied on sensors input. Once this transformation is set, all sensors calibrated data and orientation output will be expressed with respect of the new coordinate frame.

> ***Note:*** *Calibrated sensors are affected by pre-rotations, as well as orientation and velocity output. Raw sensor output, altitude and GPS data will remain unchanged.*

7.6.1.1. Z Reset

This procedure can be called when the device's *X* axis is not aligned to the object *X* axis.

To perform this calibration procedure, align the object in direction of the magnetic north and call the function. Once performed, the device will express its values in the object coordinate frame.

7.6.1.2. XY Reset

In that kind of reset, we assume that the device is strapped on the object pointing to the same heading (*X* axis of the device is in the *XZ* plane of the object). The object must be set horizontal while calling this function. After reset, the device's sensors data will be realigned in the object coordinate system.

7.6.1.3. XYZ Reset

This function can be used if the device is strapped in a fully arbitrary orientation on the object. The object must be first precisely aligned with the magnetic north and set horizontal for this procedure to be well executed.

> ***Note:*** *Results of Z and XYZ resets in pre-rotations are only valid when magnetometers source of heading is selected.*

7.6.1.4. Manual transformation

Reset functions are easy to execute, but have some limits: It is not always possible to level properly the object, or align it with the magnetic north.

With the manual procedure, user can set a rotation matrix to perform the transformation. This is the best method to keep the full precision of the device.

7.7. Calibration procedures

7.7.1. Magnetometers calibration

As explained in the Magnetic sensors section, a calibration procedure have to be performed when the IG-500E is placed near ferromagnetic objects.

Once the calibration is performed, user can save the results to the non-volatile flash memory.

> ***Note 1:*** *When using magnetometers for heading, you have to calibrate the magnetometers carefully after installing the IG-500E into your application. If the magnetometers calibration is incorrect, all measurements including roll and pitch could be greatly impacted.*

> ***Note 2:*** *The whole procedure is described in the Magnetometers Calibration Tools documentation.*

7.7.2. Gyro bias calibration

The onboard Kalman filter performs a live gyro bias estimation. An accurate gyro bias tracking requires some time. In addition, a good heading observability, or significant rotations are required to get accurate and 3D gyro bias tracking.

Some application cannot provide a 3D gyro bias tracking at startup (when the device is stationary without heading data). In order to get faster Kalman filter convergence, it's possible to use a “no motion” assumption, either automatically at startup or on demand, during sensor operation.

Using such assumption makes it possible to estimate quickly the gyro bias in all three axes.

It's then possible to save a well estimated gyro bias in non volatile memory.

7.8. Advanced options

7.8.1. Miscellaneous

Finally some various options can be enabled or disabled to fit user needs:

Option	Comments
Use coning integrals for attitude computation	Most of the time it's better to use coning integrals. But in high vibration environments, it can be a better idea to use direct filtered gyroscopes measurements.
Capture gyroscopes bias at device startup for 10s	Allows faster Kalman filter convergence. If a motion is detected during startup, this initialization is ignored.
Capture gyroscopes bias at device startup until a motion is detected	Same as previous option. Gyro estimation is performed until a small movement is detected on gyroscopes. Best for long term stationary runs.
Output unbiased gyroscopes and delta angles	When checked, gyroscopes and delta angles are Kalman filter enhanced; Otherwise, only the factory calibrated sensor data will be provided.
Output unbiased accelerometers	Same option for accelerometer measurements.
Use Altitude above Mean Sea Level instead of Ellipsoid	May not be supported on all external devices.
Enable automatic magnetic declination computation	When checked, the local magnetic declination setting will be automatically updated when a GPS fix is available using WMM2010 model.
Enable automatic local gravity computation	When checked, the local gravity setting will be automatically updated when a GPS fix is available using WGS84 model.
Force the use of an horizontal magnetometer calibration	May be useful in airplane applications when magnetometers cannot get a real in-flight 3D calibration.

7.9. Device default settings

Here are summarized the default parameters for the IG-500E:

Parameter	Default value
Serial protocol	
Protocol mode	115 200 bauds
Output mode	big-endian, float
CAN protocol	
Bit rate	1 000 Kbit/s
Propagation segment	1
Message ids format	Standard identifiers (11 bits)
Common settings	
User ID	0
Default output mask	Quaternion, Euler angles 3D position and velocity Gyroscopes, accelerometers, magnetometers calibrated data Device internal temperature, device status, Time since last reset (with triggers for CAN devices)
Output divider	2 (100 Hz / 2 -> 50Hz output)
Motion profile	General Purpose. 100Hz operation
Local Magnetic declination	0°
Heading Source	Internal Magnetometers
Heave computation	Disabled
Velocity Source	External
Position Source	External
External device configuration	No external device connected
Local gravity constant	9.809 m.s-2
Ground reference pressure	1013.25 HP
GPS Lever arm	[0; 0; 0]
Power modes	IMU: Normal mode GPS: Max performance
Sensor pre-rotation	No rotation
Sync Out Pin	Disabled
Sync In Pins	Disabled
Odometer channels (1&2)	Axis: X Direction: Positive Gain: 1.0 pulse per meter Gain error: 5%
Advanced options	Use Coning integrals Output unbiased gyroscopes, delta angles Output unbiased accelerometers Enable automatic magnetic declination computation Enable automatic local gravity computation Altitude above Ellipsoid reference

Table 18: IG-500E Default settings

8. Electrical and mechanical specifications

8.1. Absolute maximum ratings

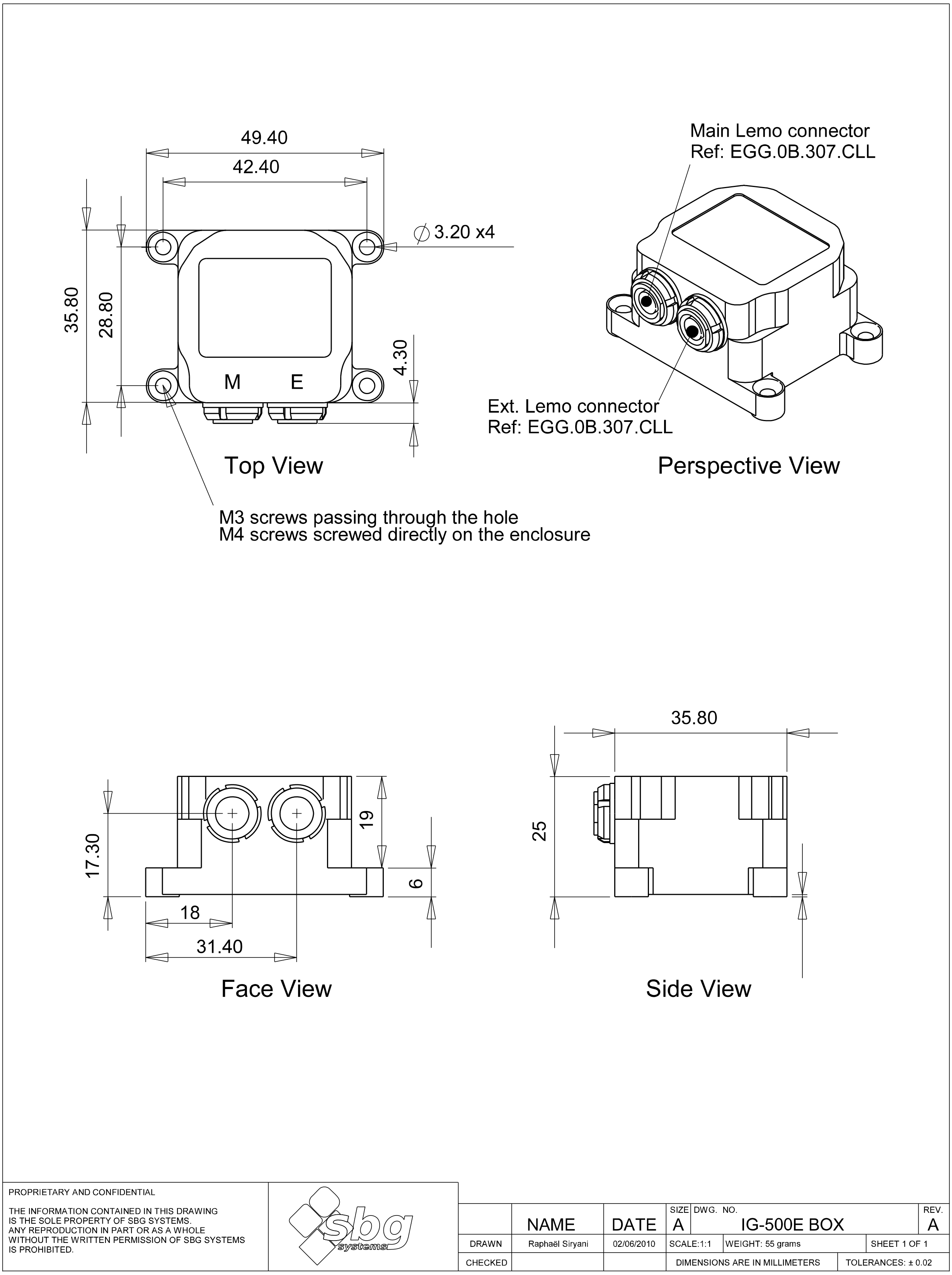
Stresses above those listed under the Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Parameter	Rating
VDD - GND	-0.3 V to 30V
Acceleration (powered)	+ 1 000 g for 0.3ms
Acceleration (unpowered)	+ 2 000 g for 0.3ms
I_{Vreg} (OEM)	10 mA
Rx pin input voltage (OEM)	-0.3V to 4.0V
Rx pin input voltage (Box)	±25V
Logic output voltage	-0,3V - +25V
Logic output Max current	180mA
CANH, CANL (Box)	±80V
Operating temperature range	-40 to 85°C
Storage temperature range	-40 to 85°C

Table 19: Absolute maximum ratings

8.2. Box version

8.2.1. Mechanical outline



8.2.2. Box device connectors

All signal lines are expressed from IG-500E side. For example, Tx line is IG-500-E Tx so it's an output.

8.2.2.1. Main and Extended connectors

Both Main and Extended connectors are a Lemo receptacle which mates with a seven way Lemo connector, ref FGG.0B.307.CLAD35. Other suppliers such as ODU provide compatible connectors.

Figure 19: The FGG.0B Lemo plug

Pins numbering is the following for both connectors:

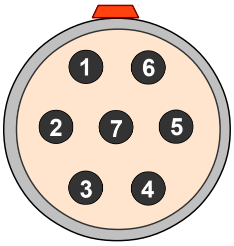


Figure 20: 7 way Lemo connectors pin-out (Solder Face)

Main connector

The main connector contains the power supply and all necessary signals to communicate directly with the IG-500E. An "M" locates on the box the main connector. Depending on the protocol used, the pins connections are the following:

Pin	Signals version P1/P2, RS-232 / TTL	Signals Version P3 : CAN 2.0	Signals Version P4: Rs 422
1	VCC	VCC	VCC
2	GND	GND	GND
3	-	Sync_In	Tx+
4	Tx	-	Tx-
5	Rx	CANH	Rx+
6	Sync_In	CANL	Rx-
7	Sync_Out	Sync_Out	Sync_Out

Table 20: Main connector pin-out

Extended connector

The extended connector contains all signal required to connect any external device to the IG-500E. Communication and logic inputs are available here. An “E” locates on the box the extended connector.

Pin	RS-232 configuration	RS-422 configuration
1	ODO_In	ODO_In
2	GND	GND
3	-	Tx+
4	Tx	Tx-
5	Rx	Rx+
6	-	Rx-
7	Sync_In	Sync_In

Table 21: Extended connector pin-out

9. Warranty and Support

Support information

Our goal is to provide the best experience to our customers. If you have any question, comment or problem with the use of your IG-500E, we would be glad to help you, so please feel free to contact us. Please do not forget to mention your IG-500E Device ID (written on your IG-500E's label).

You can contact us by:

- Email : support@sbg-systems.com
- Phone : +33 1 80 88 45 00

Warranty

All products shipped by SBG Systems are provided with a 1 (ONE) year warranty, from date of shipment.

Return procedure

Before returning any product, please contact the support team. SBG Systems will not accept any return without a valid RMA (Return Merchandize Authorization) provided by SBG Systems.

SBG Systems provide the detailed return procedure on demand by email or phone.

Postal Address

Use the following address for all product returns.

SBG Systems
S.A.V.
3bis, chemin de la Jonchère
92500 Rueil Malmaison
FRANCE

10. Appendix: Accessories

10.1. UsbToUart interface

For RS-232 and RS-422 products, the development kit provides the UsbToUart interface. It features the following characteristics:

- 64x42x20 mm box
- 3 meters long cable
- USB 1.1 or higher compatible
- Communication speed allowed up to 921 600 bps
- IG-500 device is directly powered by the USB port.
- Operating temperature range: 0 – 70°C

Figure 21: UsbToUart interface

The following ordering codes are available:

Ordering code	Description
USB2UART-P1-S	Interface used with the RS-232 output
USB2UART-P2-O	Interface used with TTL serial versions, in OEM (the IMU is fixed on usb2uart board).
USB2UART-P4-S	Interface used for RS-422 devices.

Table 22: USB2UART Ordering codes

10.2. CAN specific cables

10.2.1. UsbToCAN interface

CAN devices development kit is shipped with the UsbToCan interface. It has the following characteristics:

- Transfer rates up to 1 Mbit/s
- Compliant with CAN 2.0A and 2.0B
- CAN bus connection via D-Sub, 9-pin (to CiA® 102)
- NXP SJA1000 CAN controller
- 82C251 CAN transceiver
- Operating temperature: -40 – 85°C

Ordering code: **USB2CAN**

Figure 22: USB2CAN interface

10.2.2. CAN to USB2CAN cable

The CAN development kit also includes a cable required to connect the IG-500E to the USB2CAN interface. It has the following features:

- 3 meters long shielded cable with twisted pairs for data transmission.
- Connector A: Lemo FGG.0B.307.CLAD35
- Connector B: Standard Sub D9
- Connector C: 2,1mm Jack connector for power supply
- 60Ω resistor included for CAN bus termination.

Ordering code: **CA-3M-7-CAN**

Figure 23: CA-3M-7-CAN cable

10.2.3. Power Adapter

The power adapter included in the CAN devices Development Kit provides the IG-500E power supply. It has the following features:

- 1.8m cable length
- US, UK and Europe standards, support
- 12 V output @ 500mA
- Operating temperature range: 0 – 40°C

Ordering code: **CA-POWER**

Figure 24: Power adapter

10.3. Other cables

Those cables provide rapid access to the IG-500E without having to manage the Lemo plug soldering. They consist on a 3m cable, connected on one side to the IG-500E Lemo plug, and on the other side to a 1.25mm Molex connector.

Figure 25: Straight cable

10.3.1. 7 ways cable

This cable can be connected on main or extended connector.

- Connector A: Lemo FGG.0B.307.CLAD35
- Connector B: Molex 51021-0700

The connections on the MOLEX connector are described in the table below:

Pin	Color	Signal with P1 version (RS-232)	Signals with P4 versions (RS-422)	Signals with P3 version (CAN 2.0)
1	**Red**	VCC	VCC	VCC
2	**Black**	GND	GND	GND
3	**Yellow**	-	Tx+	-
4	**Green**	Tx	Tx-	-
5	**Blue**	Rx	Rx+	CANH
6	**Brown**	-	Rx-	CANL
7	**White**	Sync_Out	Sync_Out	Sync_Out

Table 23: 7 ways 3meters cable pin-out

Ordering code: **CA-3M-7-UART**