TECH NOTE #063: Integrating GNSS (GPS) Sensors or Inertial Measurement Units (IMU) into QuantumX or SomatXR for geographical or kinematics based overall data analysis

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Abstract

This Tech Note describes **satellite-based position measurement** in general and its value in mobile data acquisition, testing and analysis by true fusion of data physics, helpful in many different applications and industries. It describes the different **satellite services**, **sensor types** and **Inertial Measurement Units** (IMU) focussing on vehicle kinematics. Plus, it describes HBKs measurement and data recording setups based on **QuantumX** and / or **SomatXR** and its online processing software **catman** and HBK **nCodeDS** for post-process data analysis.

Intro

When developing ground vehicles, aircrafts, or any other moving machine many key parameters like function, ride&handling, driving assistance and autonomy, performance, efficiency, structural and thermal durability, overall reliability, acoustics, comfort and safety needs to be assured and validated.
Many parameters can be designed, simulated and virtually tested in office or labs with simulated environmental conditions. Still, true field tests are vital and get its deserved priority, but with less and less prototypes available and tested. Still many different load conditions and environments, standardized manoeuvres, exceptions or influences are tested in dedicated areas like proving grounds and are still key milestones on the way to start of production (SOP).

A state-of-the art data recorder allows **sensor and data fusion** acquiring additionally, installed **high quality sensors** and **transducers**, video cameras, and satellite-based position GNSS sensor or IMU for kinematics. Adding embedded sensor signals and parameters via the **vehicle's digital bus network and its on-board electronics** complements the overall setup.

The acquired data in return is used for many purposes:

- Validate, verify, qualify or certify an overall system or design
- Improve lab-based testing by replaying true field data
- Improve computer-based simulation and testing
    - Multi body simulation (MBS) improving vehicle dynamics
    - Fatigue simulation (FEA) for reliability and life-time simulation
    - Functional control and plant model engineering (MiL, SiL, HiL)
- Benchmarking and comparing with products already established in the market
- Tracking faults or behaviour in certain use or load cases and field trials
- And many more…

The HBK Data Recorders CX22B-W (QuantumX) and CX22B-R (SomatXR) are perfect tools for mobile data acquisition and testing. The different analog and vehicle bus frontends can be easily scaled and even distributed and connected by a single cable allowing all kind of sensors to be acquired like strain, pressure, acceleration, torque, force, temperature, displacement, voltage, current and many more in addition to digital bus signals. In addition to that position-based sensors or IMU's enable engineers to easily correlate all measured data to a geographical position and to vehicles overall kinematics and centre of gravity visualized in time or frequency domain and map it to a certain track in 2D or 3D.

What is GNSS?

GNSS stands for **G**lobal **N**avigation **S**atellite **S**ystem and describes a system that uses satellites to provide autonomous geo-spatial positioning. It allows small electronic receivers to determine their location (longitude, latitude, and altitude/elevation) to a certain precision using time signals transmitted along a line of sight by radio from satellites.

GPS stands for **G**lobal **P**ositioning **S**ystem and is originally based on the US satellite system **NAVSTAR**. The system from Russia is called **GLONASS** which stands for **GLO**balnaja **N**awigazionnaja **S**putnikowaja **S**istema and is also open for public use. The system from the European Union is called **GALILEO**. Chinas satellite based geographical localization system is called **B**eiDou Navigation **S**atellite **S**ystem (BDS). In the following we keep it short and just write GNSS.

A GNSS sensor receives basically the following information from satellites circling around the orbit:

- position in x, y and z axis (longitude, latitude and altitude)
- time (some sensors have a direct PPS signal output, an encoded time signal)
- number of visible satellites

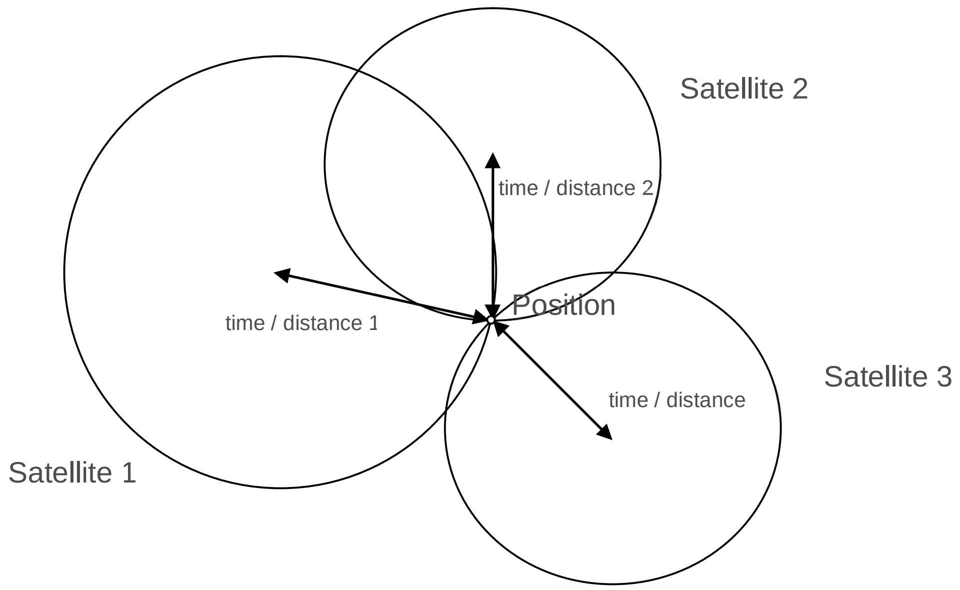
GNSS is used to precisely calculate latitude and longitude of a specific position. The GNSS system is based on a network of many satellites that orbit the earth twice every 24 hours. The precise orbit of the satellites and their use of very accurate clocks allow precise triangulation of a vehicles or users position. Each satellite transmits its exact position and a very accurate time. The accurate time required for GNSS is provided by atomic clocks at the U.S. Naval Observatory to the satellite system, so that the complete system works fully synchronised.

At the moment GNSS sensors need a clear view to the sky, for example mounted on the roof top of a vehicle with a 360° view to the sky to get the maximum number of satellites. This also needs to be checked before testing.

The logger software can then calculate distance travelled, direction, acceleration and so on based on position data.

How does GPS work?

GPS is a navigation system based on 29 satellites (minimum of 24 active satellites). The full name of the system is “Navigational Satellite Timing and Ranging – Global Positioning System – NAVSTAR-GNSS. In the origin this system has been developed by the US Department of Defence. The system has been launched 1995 officially. All satellites circle on an exact orbit so that receiving signals from 6-10 satellites from every position in the world and a minimum of 4 at the same time is possible. Every GPS satellite sends C/A coded data in L1 frequency band with 1575.42 MHz for civil purposes. Beside position and time also a special satellite code is sent to clearly differentiate from other satellites. The GPS receiver decodes these signals (CDMA). The highly precise military P/Y code is not public.



If the GPS sensor receives signals from minimum 3 satellites **latitude** and **longitude** can be precisely analysed from the sensor. 4 satellites allow calculation of **altitude** or height above mean sea level in addition. In aviation “height” is generally used to measure distance between sensor and ground. The more satellites, the better is the stability and the higher the accuracy. Once you power up the GPS sensor first time, it will begin searching for satellites. You need to consider this startup-time in your application. This process can last up to 5 minutes! After the GPS sensor has been initialized it usually lasts less than a minute to get all the signals. Please read the datasheet of your sensor carefully or ask the vendor.

How accurate is GNSS?

Position accuracy depends on many factors. The more satellite signals the GNSS receiver acquires the better is the signal normally. The position of the satellites and thus the energy level of the signal received is also a driving factor in terms of accuracy Object that is located between the satellite and the sensor, such as a tall building can cause inaccuracy because of non-receivable or reflective signals. The quality of a standard GNSS sensor in general can achieve accuracies of less than 10 m / yard.

Who uses GNSS?

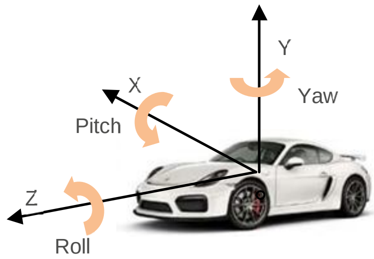
GNSS is used in many forms - for direct navigation and engineering of vehicles but also for recreational activities like hiking, mountain biking or geo cashing and even in monitoring applications. Smart phones and digital cameras are more and more equipped with a GNSS receiver focussing on many different service aspects. Meteorologists use it for weather forecasting. Geologists use it to survey or measure tectonic motions for earthquake studies. IMU’s are also used in a wide range of different applications. In military and aerospace, it is used as main source for guided vehicle navigation. In automotive industry we find kinematic or motion analysis or also validation of vehicles according to standards like ISO4138, ISO7401, ISO7975 or ISO3888-2 (elk test), just to name a few. One of the hot topics at the moment is full autonomous driving and the light version driver assistance systems (ADAS) of cars, trucks or other machines.

QuantumX Data Recorder focusses in motion analysis and load data acquisition of vehicles like cars, trucks, busses, motorcycles, ships, trains and machines for material handling, agriculture and construction.

QuantumX is a flexible tool for all kind of measurement, testing and monitoring purposes acquiring analog and digital data in addition to bus signals from CAN, CCP or XCP in parallel to motion picture (video) and GNSS or IMU data.

What is an Inertial Measurement Unit and who uses it?

One major trend in the market in certain application is the need for higher precision. Because of this market demand more and more companies add extra sensors, electronics and software into the unit in addition to GNSS/GNS receivers. The overall system forms then a new class of “intelligent sensor” named **Inertial Measurement Unit (IMU).**



IMUs are typically used in navigation, stabilization, guidance and control for aerospace, defence, geodetic, industrial and automotive and commercial vehicle applications and measures the overall body position and movement in direction, speed and angular rates (pitch, slip, yaw), using a combination of satellite-based sensors, accelerometers and gyroscopes (gyro). All information is calculated to each other allowing the IMU to deliver high precision data at an overall higher rate. IMUs are typically used to manoeuvre.

Connecting a GNSS sensor to QuantumX/SomatXR

Typical data rates of GNSS receivers are between 1…10 Hz. As a rule of thumb we can say the higher the performance, speed and accuracy the more interfaces are available and the higher the price. Data is normally transmitted according to the international standard NMEA 0183.

QuantumX Data Recorder CX22B-W supports the following three types of digital interfaces:

- **USB 2.0 or 3.0**
- **RS232 / DSub-9**
- **CAN bus**: via MX840B or MX471B/C

SomatXR Data Recorder CX22B-R supports the following three types of digital interfaces:

- **USB 2.0**
- **RS232** via Serial to USB adapter
- **CAN bus**: via MX840B-R or MX471B-R/C-R

RS232 based GNSS Sensors

The following GNSS-Sensors have been tested together with QuantumX:

- GARMIN GNSS 18-5 Hz
- GARMIN GNSS 19x HVS
- GARMIN GNSS 35 tracpak
- Racelogic VBSS 5/10/20/100 Hz

These types of GNSS sensors come with an integrated antenna and an update rate between 1 and 5 Hz and low power consumption. Most receivers can track up to 12 satellites. This type of sensor is mostly used for “just” position tracking of less agile vehicles. An extra power cable needs to be soldered as the RS232 from CX22B does not supply any power.

HINT: HBM offers such a sensor in the SOMAT product range which comes along with a M8 male connector. Material number: 1-EGPS-5HZ-2. You can cut the connector and wire it to a DSub-9. DSub-9

DSub-9

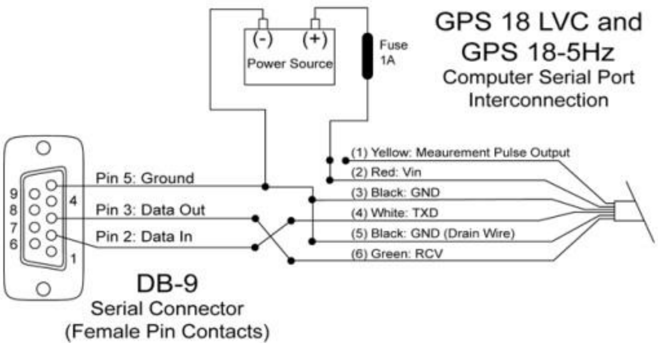
Pin Assignment
-
2 = R_X data in
3 = T_X data out
-
5 = ground

GPS 18 LVC & GPS 18-5Hz PINOUT

GPS 18 Pin #	Color	Signal Name	Wire Gauge
1	Yellow	Measurement Pulse Output	28
2	Red	Vin	26
3	Black	Ground	28
4	White	Transmit Data	28
5	Black	Ground	26
6	Green	Receive Data	28

Table 1: GPS 18 LVC & GPS 18-5Hz Wire Pinout

GPS 18 LVC & GPS 18-5Hz WIRING DIAGRAMS



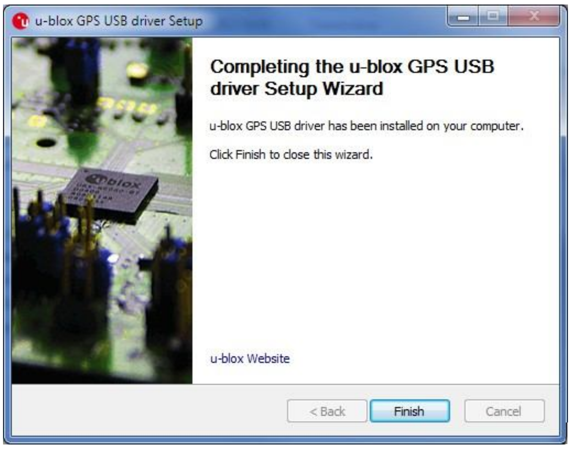
USB based GNSS sensor

The following USB based GNSS sensor can be recommended to work with the QuantumX Data Recorder.

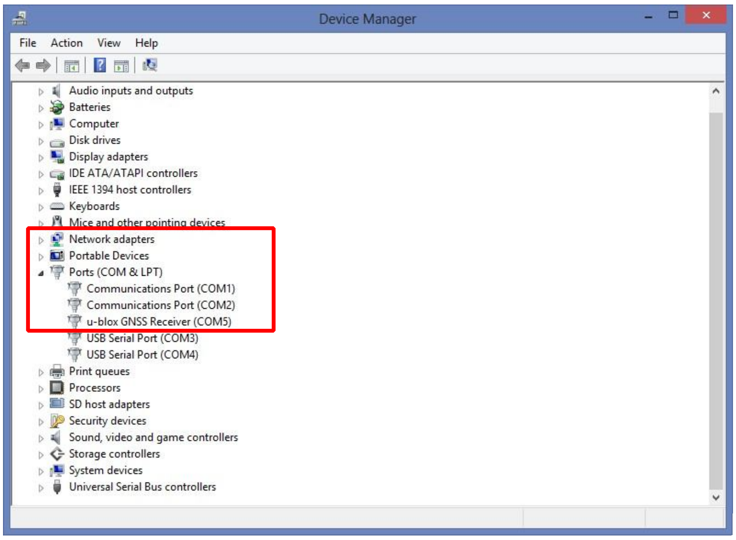
- NAVILOCK NL-602U GNSS, USB based (GPS, GLONASS, BDS support)

This type of sensor is easy to connect. A special USB driver maps everything to a COM port like above with RS232. The protocol is also NMEA.

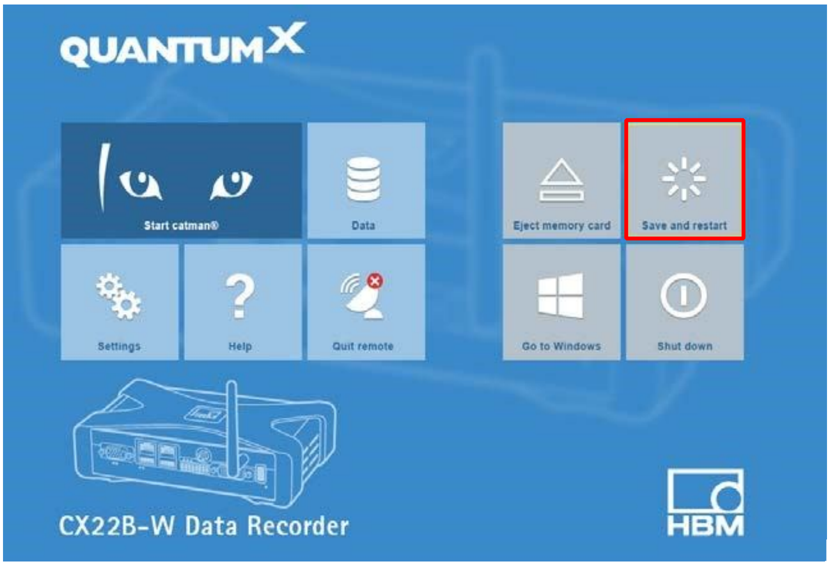
- Install the software and device driver on the Data Recorder CX22B-W.



- Now start the device manager and you will find the GNSS sensor mapped to a dedicated COM port.



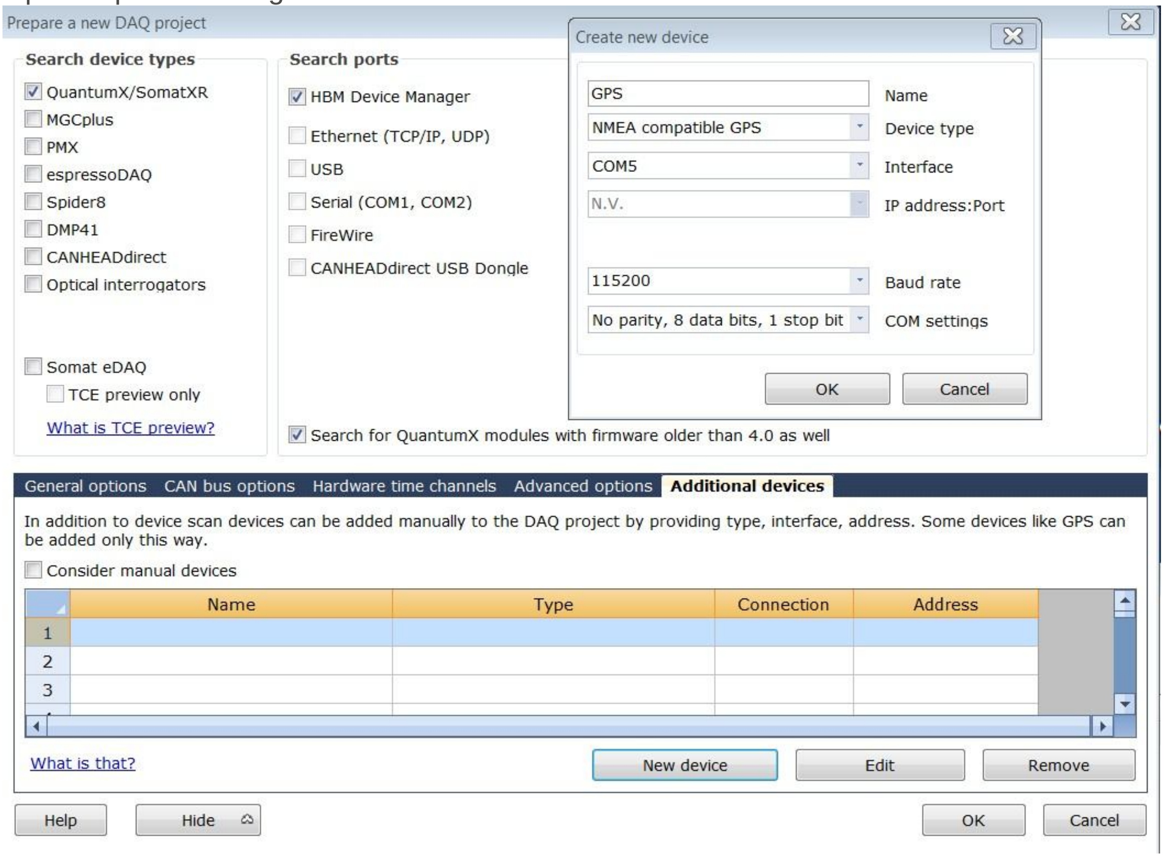
- In case you installed the driver by yourself on the Data Recorder please "save and restart" this configuration making it permanently available.



Work with GNSS connected to the Data Recorder

1. Start catman and open "select device type"

2. Open “Options” and go to the tab "Additional devices” and add a “new device”



3. Configure the port according to your settings. Here COM5, 115000 baud rate.

4. Highlight “Consider manual devices" and finish configuration with OK

From now on your GNSS sensor is connected automatically to all projects.

5. Check the sensor data in the channel list. You will find longitude, latitude, altitude, speed and time coming from the GNSS sensor

Channel name	Reading	Sample rate/Filter	Sensor/Function	Zero value
MX840A Universal				
load cell	-0.00342 kN	1200 Hz / BE 100 Hz (Auto)	C18 100kN	-8.117 kN
microphone	-0.00040 V	1200 Hz / BE 100 Hz (Auto)	DC Voltage	0.00000 V
voltage input	-0.00090 V	1200 Hz / BE 100 Hz (Auto)	DC Voltage	0.00000 V
MX840A Universal_CH 4	526.1 V	1200 Hz / BE 100 Hz (Auto)	DC Voltage	0.00000 V
speed sensor	0.00000 U/min	1200 Hz / BE 100 Hz (Auto)	Pulse count: 2-phase, 4-fo	0.00000 U/min
MX840A Universal_CH 6	No signal	1200 Hz / BE 100 Hz (Auto)	Thermocouple Type T	0.00000 °C
MX840A Universal_CH 7	No signal	1200 Hz / BE 100 Hz (Auto)	DC Voltage	0.00000 V
MX840A Universal_CH 8	No signal	1200 Hz / BE 100 Hz (Auto)	DC Voltage	0.00000 V
Navilock_GPS_COM5				
Navilock_GPS_COM5_Latitude	49.89 () °	10 Hz / NA	LATITUDE	0.00000 °
Navilock_GPS_COM5_Longitude	8.643 () °	10 Hz / NA	LONGITUDE	0.00000 °
Navilock_GPS_COM5_Altitude	121.0 () m	10 Hz / NA	ALTITUDE_M	0.00000 m
Navilock_GPS_COM5_Speed	0.9760 () km/h	10 Hz / NA	SPEED_OVER_GROUND_	0.00000 km/h
Navilock_GPS_COM5_Time	55525 (1/1/1970 3:2	10 Hz / NA	TIME	0.00000 s
Navilock_GPS_COM5_Date	42427 (2/26/2016) --	10 Hz / NA	DATE	0.00000 ----
Navilock_GPS_COM5_SatStatus	0.00000 () ----	10 Hz / NA	SATELLITE_STATUS	0.00000 ----
Navilock_GPS_COM5_Gyro_Pitch	No signal	10 Hz / NA	GYRO_PITCH	0.00000 °
Navilock_GPS_COM5_Gyro_Roll	No signal	10 Hz / NA	GYRO_ROLL	0.00000 °
Navilock_GPS_COM5_Gyro_Yaw	No signal	10 Hz / NA	GYRO_YAW	0.00000 °
Navilock_GPS_COM5_MagHeading	0.00000 () °	10 Hz / NA	MAGNETIC_HEADING	0.00000 °
Navilock_GPS_COM5_TrueHeading	0.00000 () °	10 Hz / NA	TRUE_HEADING	0.00000 °
Navilock_GPS_COM5_TurnRate	No signal	10 Hz / NA	TURN_RATE	0.00000 °/s
Navilock_GPS_COM5_WindDirectio	No signal	10 Hz / NA	WIND_DIRECTION	0.00000 °
Navilock_GPS_COM5_WindSpeed	No signal	10 Hz / NA	WIND_SPEED	0.00000 m/s

IMPORTANT: At least one QuantumX DAQ module is necessary in parallel.

Connecting a CAN or Ethernet based GNSS / IMU to a QuantumX/SomatXR Data Recorder

Most of the modern IMUs come along with a digital **CAN bus** interface which allows an integration into QuantumX / SomatXR in an easy way by pre-configured parameter file in ARXML or DBC format. We recommend using a private bus between IMU and the CAN FD / CAN bus port. Bus termination might be necessary on both sides, depending on the cable length between the two units. MX471C/-R or MX840B-R CAN bus ports are equipped with an internal 120 Ohm termination resistor which can be activated via software terminating the bus on the recorder side. When using a short cable between the devices single terminator might be OK, too.

Most IMUs offer the following signals:

- Satellite and GNSS-based latitude, longitude, altitude, and velocity, but tuned by
- Embedded sensor-based
  - 3D acceleration
  - Rate of turn
  - Roll/pitch (Inclination)
  - Yaw (relative/gyro-based)
  - Yaw (absolute/magnetic North-referenced)

Potential suppliers:

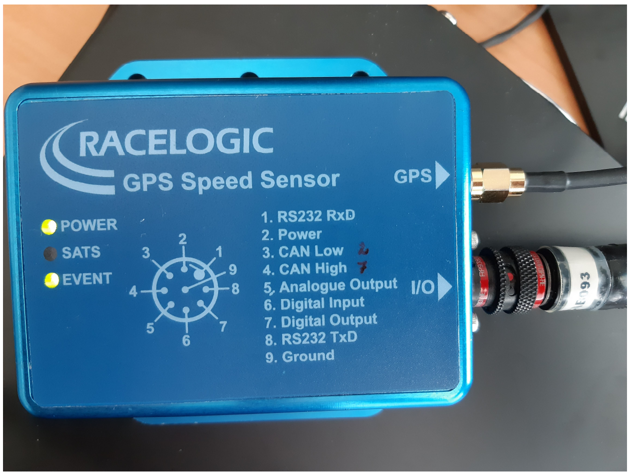
- HBM / HBK, offers the EGPS
- NovAtel, offers FlexPak
  - Connection: CAN
  - http://www.novatel.com/products/gnss-receivers/enclosures/flexpak6/
- VectorNav, offers VN200 or VN300

- Connection: USB
- https://www.vectornav.com/products

- Racelogic, offers VBOX Speed Sensor like 3iS
  - Connection: CAN
  - http://www.racelogic.co.uk/
- XSENS
  - MTi 600 Series like MTi 670 GNSS/INS
  - https://www.xsens.com/products/mti-600-series
- OXTS, offers RT3000
  - Output: Ethernet, Serial
  - https://www.oxts.com/products/rt3000-v3/
- Race Technology, offers SPEEDBOX
  - Connection: CAN
  - http://www.race-technology.com/gb/industrial/products/speedbox
- iMAR, offers iTraceRT-MVT
  - highest resolution in positioning for ADAS/Autonomous/Platooning
  - Connection: CAN, Ethernet, Serial
  - http://www.imar-navigation.de

How to use a GNSS (exemplary Racelogic VBOX Speed Sensor) with catman software:

- **RACELOGIC VBSS GPS-Speed Sensor 100Hz**



Features:

- GPS/GLONASS receiver
- 100Hz output rate
- RS232 and CAN bus communication
- Signal data
  - Time
  - Position
  - Velocity
  - Vertical velocity
  - Heading
  - Height
  - Radius of turn
  - Longitudinal & lateral acceleration
  - Distance
  - Trigger to zero distance, trigger time, trigger speed

- Wide 6.5 V – 30 V operating range

Inputs:
- **GPS Antenna**
  3 V Active Antenna (inc) / 5 V for 100 Hz version

Outputs:
- **CAN Bus**
  Output Data Rate: 125 kBit, 250 kbit, 500 kbit & 1 Mbit selectable baud rate.
  Software controlled CAN termination

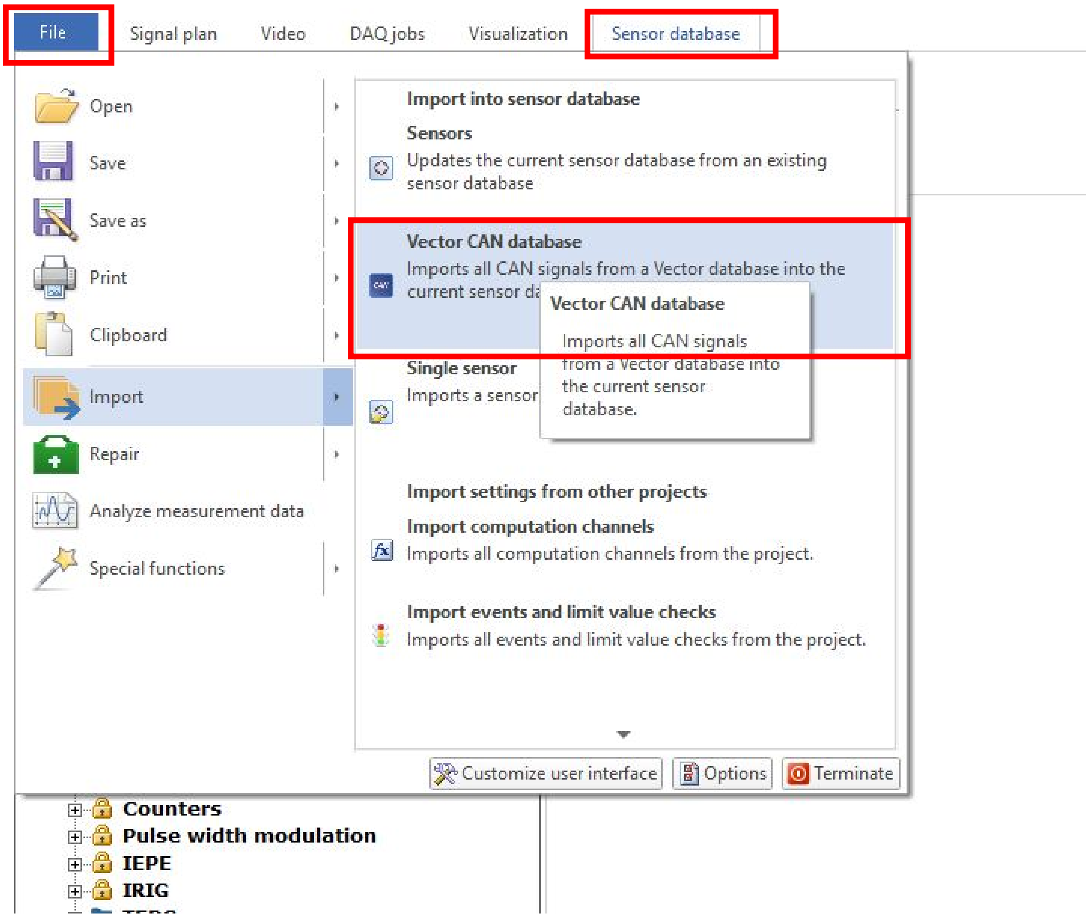
- **Connection to QuantumX module**

Connect QuantumX module to power, and via Ethernet to PC (or Network).
Connect GPS sensor with CAN connector to channel 1 of QuantumX module. Sensor needs external power supply of 6.5 to 30V.
When using MX840B, you need an adapter SUBHD9 male to SUBHD15 male:

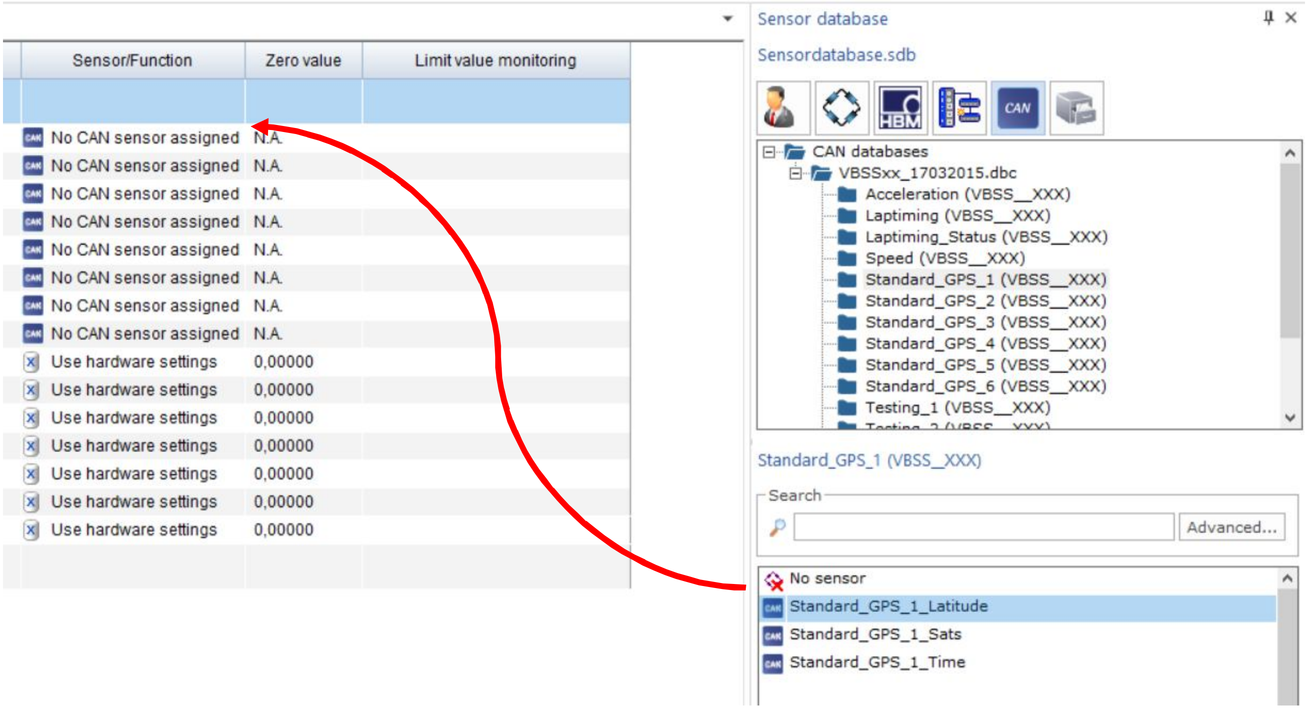
	SUBHD9 MX471B/C	**SUBHD15** MX840B	**ODU** MX840B-R	**M12** MX471B-R/C-R
CAN-Low	2	8	11	4
CAN-High	7	7	12	5

- **Implementation into catman software**

1. Start catman on your PC and start a new DAQ project with the MX840.
2. Then go to 'Sensor database' and import Vector CAN database by opening your .dbc-file. The sensors will appear in the Sensor database.



3. Now drag & drop the channel configurations you want to the MX840 channels.



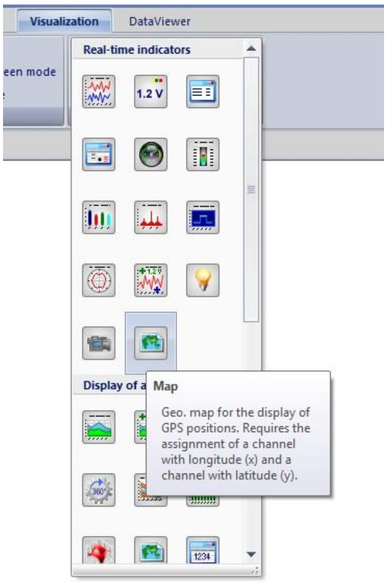
4. Check CAN Bus settings. Baud rate of GPS sensor should be 500 kBit/s by default.

Map based Visualization and Analysis

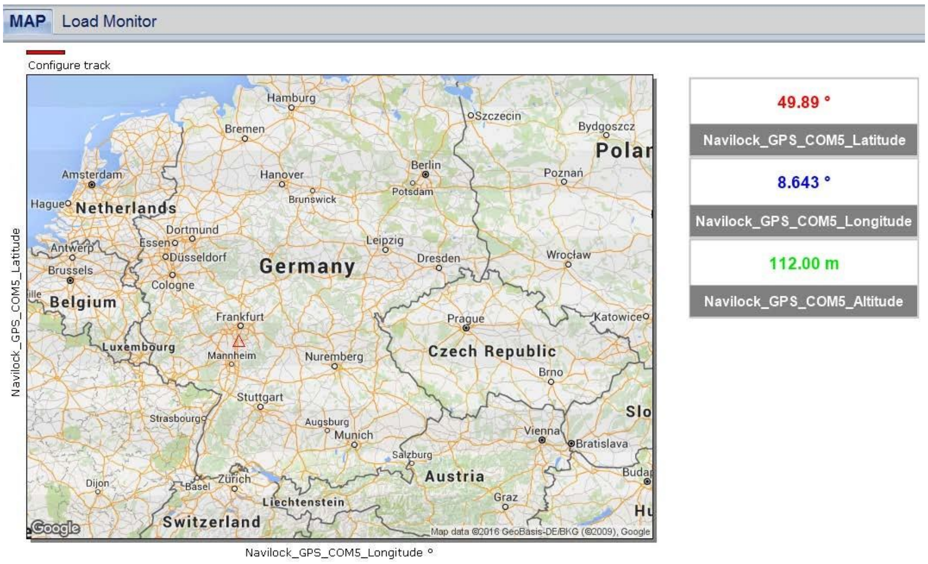
The Data Recorder software catman can be extended by an add-on package named EasyRoadLoad.
This package allows visualization of GNSS data in *google maps*. Initially internet access is necessary to get the maps. After this you can store your track as picture locally.

To activate this functionality a valid license key is necessary.

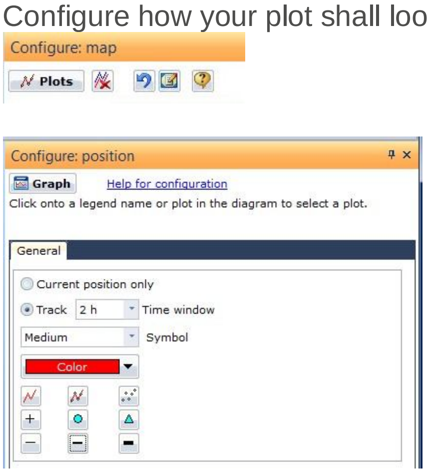
- Go to Visualization tab and select the map out of the objects.



- Assign the inputs for longitude and latitude to the map. You can visualize alitude as digital indicator:

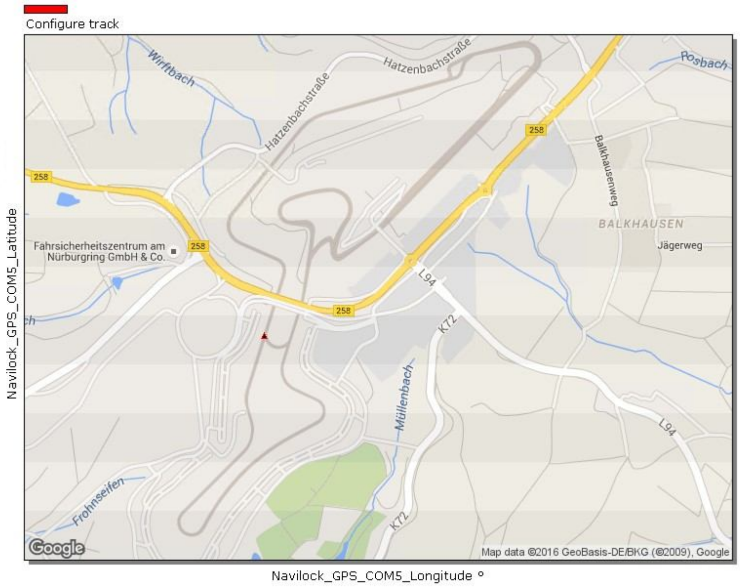


- Configure how your plot shall look like in the map: **current position or track**:



- Configure the map type (street map, satellite, terrain or hybrid)

- In most of the cases you won’t have internet access. In this case enter the rough coordinates of your test track and zoom into the map for positioning.
  Example: Racetrack Nuerburgring in Germany with



- Save the map

- And load it when in the field for testing.

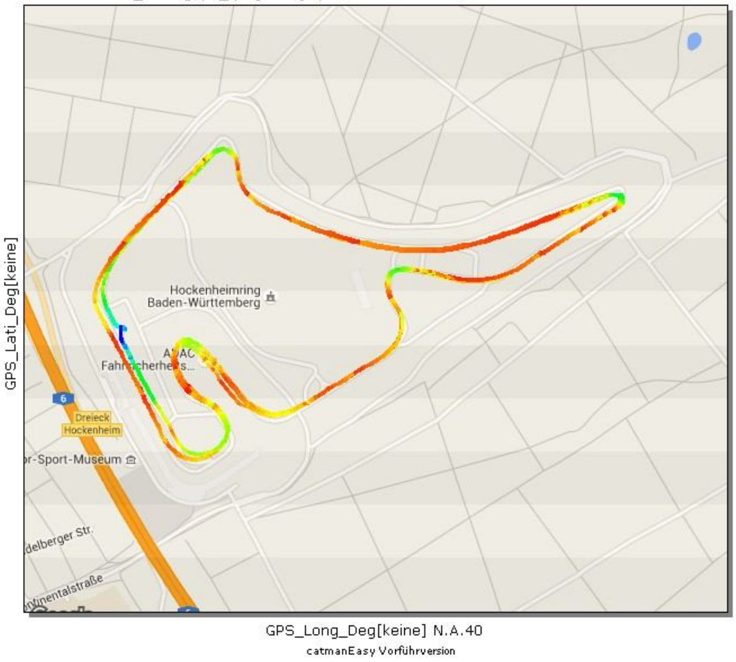
Map based post process analysis in catmanAP

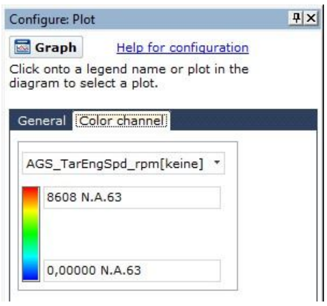
Back in office download all data from the Data Recorder. Now you can nicely analyse it with catmanAP.

You can visualize a reference signal in a coloured style according to its value in the map.
Example: Engine speed from 0 (blue)…. 8600 rpm (red) mapped to a certain position at that time.

Others are vehicle speed, gear, brakes or analog inputs like strain, acceleration, temperature, direct torque, pressure, battery voltage, etc.

Example shows the Hockenheim Ring in Germany:





Map based post process analysis in nCodeDS and sharing in collaboration with AQIRA

You can also visualise and automatically analyse your data in a block based mathematical way using the powerful graphical and post processing tool nCodeDS from HBK. The fully flexible data flow tool allows you to display GNSS data in coloured geographical maps. Multiple gage types can display **any input** from sensors or bus data, and **video** in a synchronized way. The tool is especially helpful for teams working with **Gigabytes** of data, comparing multiple setups and share it **web-based in collaboration** with HBK AQIRA for quick decision making in a managed way and to bridge the gap to simulation and CAE.

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