
Document MT1600P, Revision 2020.A, June 2020

# MTi Family Reference Manual

General information for Xsens MTi series

| Revision | Date | By | Changes |
| --- | --- | --- | --- |
| 2019.A | Sept 2019 | AKO/MCR | Initial release |
| 2019.B | Dec 2019 | AKO | Xsens brand update |
| | | SGI | Added list of abbreviations |
| 2020.A | June 2020 | AKO | Added info about MTi-680G |

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## List of Abbreviations

| Abbreviation | Description |
|---|---|
| AHRS | Attitude and Heading Reference System |
| AHS | Active Heading Stabilization |
| API | Application Programming Interface |
| a.u. | Arbitrary unit |
| BASE | Xsens' Online Community Forum, Tutorial Videos and FAQ |
| BID | Bus Identifier |
| BIT | Built-In self-Test |
| CAN | Controller Area Network |
| CS | Checksum |
| CR | Centre of Rotation |
| DCM | Direction Cosine Matrix (Rotation Matrix) |
| DID | Device Identifier |
| DK | Development Kit |
| DLL | Dynamic Link Library |
| DOF | Degrees Of Freedom |
| DOP | Dilution of Precision |
| DSP | Digital Signal Processor |
| ECEF | Earth-Centered, Earth-Fixed |
| EDR | Extended Dead-Reckoning |
| eMTS | extended Motion Tracker Specifications |
| FWU | Firmware Updater |
| GNSS | Global Navigation Satellite Systems (GPS, GLONASS, Galileo, BeiDou, QZSS) |
| GPS | Global Positioning System |
| GUI | Graphical User Interface |
| HR | High Rate (applies to MTi outputs AccelerationHR and RateOfTurnHR) |
| HW | Hardware |
| $I^2C$ | Inter-Integrated Circuit |
| ICC | In-run Compass Calibration |
| IMU | Inertial Measurement Unit |
| INS | Inertial Navigation System |
| KML/KMZ | Keyhole Markup Language (Zipped) |
| LLA | Latitude, Longitude, Altitude |
| LLCP | Low-Level Communication Protocol |
| LSB | Least Significant Bit |
| LTP | Local Tangent Plane |
| $L_{XYZ}$ | Local (Earth-fixed) coordinate system |
| MEMS | Micro Electrical-Mechanical System |
| MFM | Magnetic Field Mapper |
| MGBE | Manual Gyro Bias Estimation |

| | |
|---|---|
| MID | Message Identifier |
| MIL-STD | United States Military Standard |
| MP2 | Multi-Purpose cable (available for MTi 10/100-series devices) |
| MSB | Most Significant Bit |
| MT(i/w) | Motion Tracker (industrial/wireless) |
| MTB | MT Binary format |
| MTBF | Mean Time Between Failures |
| MTM | MT Manager |
| MTSS | MT Software Suite |
| MTSSP | MT Synchronous Serial Protocol |
| NMEA | National Marine Electronics Association |
| ODR | Output Data Rate |
| OEM | Original Equipment Manufacturer |
| OpenGL | Open Graphics Library |
| $O_{XYZ}$ | Object coordinate system |
| PCB | Printed Circuit Board |
| PLCC | Plastic-Leaded Chip Carrier |
| PPS | Pulse Per Second |
| PVT | Position, Velocity, Time |
| RepMo | Representative Motion (part of the In-Run Compass Calibration feature) |
| ROS | Robotic Operating System |
| RTK | Real Time Kinematics |
| SBAS | Satellite-Based Augmentation System |
| SCR | Sensor Component Readout (uncalibrated/raw output mode) |
| SDI | Strapdown Integration |
| SDK | Software Development Kit |
| SMD | Surface Mount Device |
| SPI | Serial Peripheral Interface |
| SVInfo | Space Vehicle Information |
| $S_{XYZ}$ | Sensor coordinate system |
| UART | Universal Asynchronous Receiver-Transmitter |
| USB | Universal Serial Bus |
| UTC | Coordinated Universal Time |
| VRU | Vertical Reference Unit |
| WGS | World Geodetic System |
| WMM | World Magnetic Model |
| Xbus | Xsens Communication Protocol |
| XDA | Xsens Device API, the communication API between the MTi and the user application. |
| XDI | Xsens Data Identifier |
| XEE | Xsens Estimation Engine |
| XFF | Xsens Firmware File format |
| XKF | Xsens Kalman Filter |
| XML | eXtended Markup Language |

# 1 Xsens Customer Support and BASE

BASE by Xsens is an online support platform with a knowledge base and community forum on 3D motion tracking technology and products. This enables faster and easier system integration by offering a large source of high-quality technical information.

Knowledge base (FAQ)
The knowledge base provides articles written by Xsens Field Application Engineers and Product Specialists. Topics discussed are best practices, tips and tricks for the use of Xsens' products and inside information about installation, MEMS sensors and GNSS receivers, hardware design, CAD-files, system architecture, low-level communication and sensor fusion algorithms.

Community forum
The community forum is an online forum that gives direct access to Xsens' engineers and other Xsens users. As users may have faced similar challenges, the answer may already be on the forum.

The knowledge base and user community are searchable simultaneously. A search query thus shows results irrespective of the source.

Please visit https://base.xsens.com to complete your 1-minute registration.

Additionally, tutorial videos on products, features and releases are available on BASE by Xsens via: https://tutorial.xsens.com/.

# 2 Introduction

This manual gives an overview of the latest generation Xsens products (MTi 1-series and MTi 600-series) and their usage. For previous generations, refer to *MTi User Manual*[1]. The MTi product portfolio from Xsens currently has family members ranging in functionality from Inertial Measurement Units (IMU’s), Vertical Reference Unit (VRU), Attitude and Heading Reference System (AHRS) to a fully integrated GNSS/INS (Global Navigation Satellite System/Inertial Navigation System). All products contain a 3D IMU composed by a gyroscope and an accelerometer plus a 3D magnetometer, with optionally a barometer and GNSS receiver.

The MTi product range is divided in several series, the MTi 1-series, the MTi 600-series, the MTi 10-series and the MTi 100-series.
The MTi 1-series is a low-cost Surface-Mount Devices (SMD) module.
The MTi 600-series is a cost effective product line for easy integration.
The MTi 10-series[2] is Xsens’ entry level model with robust accuracy.
The MTi 100-series is a Xsens’ proven high end class of MEMS IMU’s, orientation and position sensor modules.

Table 1 summarizes all available official documents for the Xsens MTi product line. It is highly recommended to review all documents applicable to your Xsens Motion Tracker.

Table 1: MTi product documentation overview[1]

| MTi 1-series | MTi 600-series | MTi 10/100-series |
|---|---|---|
| MTi Family Reference Manual | | MTi User Manual |
| MTi 1-series Datasheet | MTi 600-series Datasheet | |
| MTi 1-series DK User Manual | MTi 600-series DK User Manual | |
| MTi 1-series HW Integration Manual | MTi 600-series HW Integration Manual | |
| | MT CAN protocol Documentation | |
| MT Manager Manual | | |
| Magnetic Calibration Manual | | |
| MT Low Level Communication Protocol Documentation | | |
| Firmware Updater User Manual | | |

[1] Links to the latest available documentation can be found via the following link: [Xsens MTi Documentation]
[2] not recommended for new designs

## 2.1 From IMU to GNSS/INS

Within each MTi series, Xsens offers several product variants. Each variant is based on a firmware version which enables different functionalities. Figure 1 summarizes the functionality of each variant.

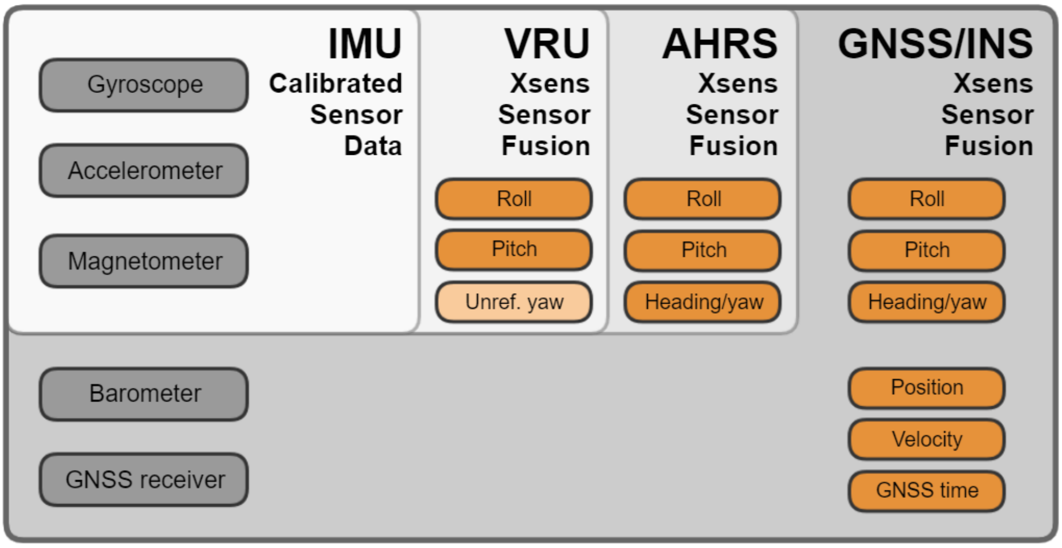


Figure 1: From IMU to GNSS/INS

### 2.1.1 IMU

The IMU variant is an Inertial Measurement Unit that measures 3D acceleration and 3D rate of turn with the addition of 3D magnetic field data and, depending on the product, barometric pressure. It does not fuse sensor data to deliver orientation estimates. The IMU can also be configured to output data generated by the strapdown integration algorithm (orientation increments $\Delta q$ and velocity increments $\Delta v$).

### 2.1.2 VRU

The Vertical Reference Unit (VRU) adds the first layer of algorithms which uses gravity as a reference for roll and pitch calculations. Essentially it delivers the same data as the AHRS, except for the yaw. The yaw estimate of a VRU product is unreferenced, which means that it is computed without any geographic/magnetic reference, though still superior to just gyroscope integration (e.g., when using the gyro bias estimation techniques). All data outputs from the IMU are also available in this product version. The AHS feature is also available in this product variant (see also chapter 4.4.7)

### 2.1.3 AHRS

This is the full Attitude and Heading Reference System (AHRS). It gives various outputs: roll, pitch and heading (true magnetic North referenced yaw). In addition, all functionality of the IMU and VRU are also available in this product variant.

### 2.1.4 GNSS/INS

The GNSS/INS variant is a product with an interface to an external or internal (RTK) GNSS receiver as well as a barometer. It provides roll, pitch, yaw/heading, as well as 3D position, 3D velocity and time data. In addition, all data outputs of the IMU, VRU and AHRS are also available in this product variant.

## 2.2 *Xsens MTi hardware platforms*

This section summarizes all available Xsens MTi platforms (see Table 2).

### 2.2.1 MTi 1-series

The MTi 1-series is the Xsens' smallest (12.1mm x 12.1mm), lightest (<1gr) and most cost effective product suitable for SMD (Surface Mountable Device) integration. It is compatible with the JEDEC PLCC-28 standard footprint. Designed for integration in high volume applications.

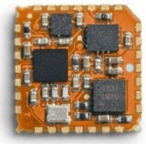

Figure 2: MTi 1-series

Available in IMU, VRU, AHRS and GNSS/INS (with external GNSS receiver) product versions.
Please refer to the *MTi 1-series Datasheet* for more information.

### 2.2.2 MTi 600-series

The MTi 600-series modules are designed to be lightweight, cost effective and easy to integrate. It can be integrated in two ways: either with the header facing downwards, directly mounted on a PCB, or standalone, using a flat cable for communication. The rugged MTi-680G features an integrated RTK GNSS receiver. Additionally they feature a CANbus interface.


Figure 3: MTi 600-series

Available in IMU, VRU, AHRS and GNSS/INS product versions.
Please refer to the *MTi 600-series Datasheet* for more information.

### 2.2.3 MTi 10-series

The MTi 10-series offers inertial and orientation data at an affordable price. It features a sturdy anodized aluminium housing, and robust push/pull connectors. The MTi-10 series can easily be recognized by the aluminium silver base plate.

Figure 4: MTi 10-series

Available in IMU, VRU and AHRS product versions.
Please refer to the *MTi User Manual* for more information. This product is not recommended for new designs.

### 2.2.4 MTi 100-series


Figure 5: MTi 100-series including the MTi-G-710

The MTi-100 series is the high-performance product range of the MTi product portfolio, with accuracies surpassing conventional MEMS motion trackers, because of the use of superior gyroscopes and a new optimization filter, going beyond standard Extended Kalman Filter implementations. In addition, the factory calibration is more accurate, repeatable and robust.
The MTi 100-series can be recognized by the dark-grey/black base plate and the small barometer holes on one side of the casing. The MTi-G-710 has an extra SMA connector to allow a GNSS antenna to be attached.

Available in IMU, VRU, AHRS and GNSS/INS (with internal GNSS receiver) product versions.
Please refer to the *MTi User Manual* for more information.

Table 2: Xsens MTi portfolio overview.

| | MTi 1-series | MTi 600-series | MTi 10-series | MTi 100-series |
|---|---|---|---|---|
| IMU | MTi-1 IMU | MTi-610 IMU | MTi-10 IMU | MTi-100 IMU |
| VRU | MTi-2 VRU | MTi-620 VRU | MTi-20 VRU | MTi-200 VRU |
| AHRS | MTi-3 AHRS | MTi-630 AHRS | MTi-30 AHRS | MTi-300 AHRS |
| GNSS/INS | MTi-7 GNSS/INS | MTi-670 GNSS/INS<br>MTi-680G RTK GNSS/INS | - | MTi-G-710 GNSS/INS |

This document focusses mainly on the MTi 1-series and MTI 600-series. For more information on the MTi 10-series and MTi 100-series, please refer to the *MTi User Manual.*

# 3 Getting Started with the MTi

## 3.1 Overview MTi Development Kit

The MTi development kit is a very easy to use starter's kit that allows for fast and easy integration of the MTi in any user scenario. Figure 6 shows a typical Development Kit, containing an MTi. All software and installation instructions are available online via http://www.xsens.com/setup.


Figure 6: MTi Development Kit

Depending on the model of MTi you have purchased, the Development Kit can contain any of the following items:

Table 3 Description of hardware components of Development Kit

| Component | Description |
|---|---|
| An MTi Motion Tracker | |
| Development board | A tool for prototyping and validation |
| (micro) USB (converter) cable | A cable to connect the MTi device to a USB port |
| multi-purpose (flat) cable | A cable which exposes all physical lines to a MTi device |
| GNSS daughter card | An accessory which fits the MTi 1-series and MTi 600-series development board which contains a GNSS receiver (click-board™ compatible) |
| GNSS antenna | |
| Test and Calibration certificate | |

Table 4 Description of software components of Development Kit

| Component | Description |
|---|---|
| MT Software Suite (MTSS) | available for download via http://www.xsens.com/setup |
| Xsens MTi USB driver | Part of the MTSS |
| MT Manager for Linux and Windows | Part of the MTSS |
| MT Software Development Kit (MT SDK) for multiple OS | Part of the MTSS, containing the following components:<br>• XDA public source files (C, C++ wrapper ; any OS)<br>• Example source code and examples<br>○ C++<br>○ C#<br>○ Python<br>○ MATLAB<br>○ Robotic Operating System (ROS)<br>○ Embedded examples (ST Nucleo) |
| Magnetic Field Mapper – MFM (Windows and Linux) | Part of the MTSS, containing the following component:<br>• MFM SDK (Windows and Linux) |
| Firmware Updater | Separate component design to update MTi device firmware |
| Documentation | Part of the MTSS, PDFs are available online, containing the following components:<br>• Links to online manuals<br>• Xsens Device API library |
| MFM SDK Library | Library for the Magnetic Field Mapper |

***NOTE:*** the most recent version of the software, source code and documentation can always be downloaded on www.xsens.com/mt-software-suite. Links to documentation can be found on BASE: http://xsens.com/xsens-mti-documentation
The latest firmware and firmware updater can be found here: https://www.xsens.com/mt-firmware/

### 3.1.1 Getting Started with MT Manager software

The easiest way to get started with your MTi is to use MT Manager. MT Manager is a software tool to easy get to know and to demonstrate the capabilities of the MTi and to configure the device to suit your needs.

Additionally MT Manager allows you to:

- record data and playback/review data;
- view orientation, position and velocity in real-time;
- view inertial and magnetic sensor data in real time;
- view low-level communication and XDA communication via message terminals;
- export log files to ASCII and KMZ (format viewable in Google Earth);
- change and/or view various device settings and properties;
- reprocess recorded data with different settings.

Please refer to the *MT Manager User Manual*[3] for more information on MT Manager.

[3] Links to the latest available documentation can be found via the following link: Xsens MTi Documentation

### 3.1.2 MT Software Development Kit (MT SDK)

The Xsens Device API (XDA) serves as a starting point for system integrators interested in assessing the basics of the SDK. The main objective of the SDK is to facilitate the development of user-specific host applications based on Xsens motion trackers.
The MT Software Development Kit (MT SDK), part of the MT Software Suite installation, provides examples based on XDA for multiple programming languages. These programming examples can be used as a starting point for further software development.

The MT SDK (and the MT Software Suite) is designed for the MTi 1-series, MTi 600-series, MTi 10-series and MTi 100-series. Links to the latest available documentation can be found via the following link: Xsens MTi Documentation
See also: Introduction to the MT SDK programming examples for MTi devices

### 3.1.3 Low-level Communication

The low-level communication protocol (named Xbus protocol) offers full control and functionality. It is essential on platforms that do not support the Xsens Device API, such as custom embedded computers and microcontrollers.

The low-level communication is extensively described in the *MT Low-Level Communication Protocol Documentation*[3]. Next to that, source code is delivered to make driver development and Xbus message parsing for the MTi as easy and quick as possible.

### 3.1.4 Terms of use of MT Software Suite

The installer of the MT Software Suite can install 4 components: MT Manager, MT SDK, Magnetic Field Mapper (MFM) and MFM SDK. The Firmware Updater is a separate installer. The MT Software Suite has a Restricted License Agreement that you need to accept. In Table 5, the conditions for use of each component are summarized.

Table 5: Conditions for the use of the MT Software Suite

| Component | Conditions |
|---|---|
| MT Manager | For use with Xsens products only<br>Not allowed to re-distribute<br>Not allowed to reverse engineer<br>Not allowed to modify |
| MT SDK | For use with Xsens products only<br>Allowed to re-distribute “as is” or embed in programs<br>Not allowed to reverse engineer<br>Allowed to execute, reproduce, modify and compile (modified) source code to use with Xsens products only<br>Not allowed to modify DLL<br>Include License Agreement with distribution |
| MFM | For use with Xsens products only<br>Allowed to re-distribute “as is”<br>Not allowed to reverse engineer<br>Not allowed to modify<br>Include License Agreement with distribution |
| MFM SDK | For use with Xsens products only<br>Allowed to re-distribute “as is” or embed in programs<br>Not allowed to reverse engineer |

| | |
|---|---|
| | Allowed to execute, reproduce, modify and compile (modified) source code to use with Xsens products only<br>Not allowed to modify DLL<br>Include License Agreement with distribution |
| FWU | For use with Xsens products only<br>Allowed to re-distribute “as is”<br>Not allowed to reverse engineer<br>Not allowed to modify<br>Include License Agreement with distribution |

# 4 MTi System Overview

## 4.1 Test and Calibration

A correct calibration of the sensor components inside the MTi is essential for an accurate output. The quality and importance of the calibration are of highest priority. Each Xsens' MTi is calibrated and tested by subjecting each device to a wide range of motions and temperatures.

The individual calibration parameters are used to convert the sensor component readout (digitized voltages) to physical quantities as accurately as possible, compensating for a wide range of deterministic errors. Additionally, the calibration values are used in Xsens sensor fusion algorithms, as discussed later in this document.

Each MTi contains individual test and calibration data in its eMTS (electronic Motion Tracker Settings). It is digitally signed by a Test Person and states the calibration values determined during the calibration of the MTi at Xsens' calibration facilities. The values can be seen by connecting the MTi to MT Manager and navigating to Device Settings → Modelling Parameters.

Next to the calibration values shown in MT Manager, each device is calibrated according to more complicated models to ensure accuracy (e.g. non-linear temperature effect, cross coupling between acceleration and angular rate[4]).

## 4.2 Coordinate systems

Data from the MTi is represented in various coordinate systems, which are explained below.

### 4.2.1 Calibrated inertial data and magnetic field data

The default sensor-fixed frame ($S_{xyz}$) is a right-handed Cartesian coordinate system that is fixed to the device. When the sensor is rigidly attached to another object or vehicle but not aligned, it may be convenient to rotate the sensor coordinate system $S_{xyz}$ to an object coordinate system ($O_{xyz}$).
Refer to BASE by Xsens - MTi reference co-ordinate systems for more information on the available orientation resets.

$S_{xyz}$ or $O_{xyz}$ are the coordinate frames used to express the rate of turn, acceleration and magnetic field outputs. The encased version of the MTi shows $S_{xyz}$ on the sticker. Figure 9 and Figure 8 depict the sensor coordinate system on the MTi 600-series and MTi 1-series. Later in this document, small x, y and z are the axes labels for $S_{xyz}$ and $O_{xyz}$. Capital X, Y and Z stand for the local-earth fixed coordinate system ($L_{XYZ}$).

[4] Also known as "g-sensitivity".

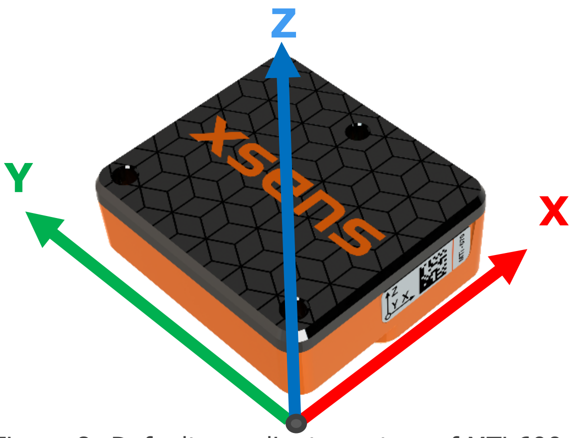


Figure 8: Default coordinate system of MTi 600-series

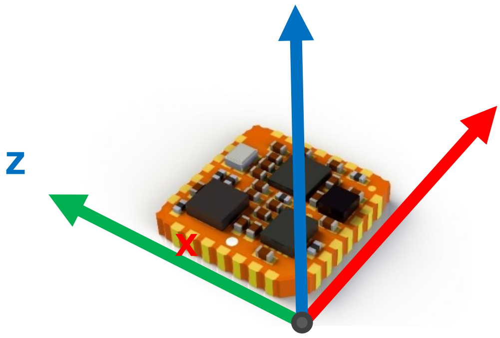


Figure 7: Default coordinate system of MTi 1-series

The housing and PCB of the MTi 600-series are carefully aligned with the output coordinate system during the individual factory calibration. The non-orthogonality between the axes of $S_{xyz}$ is <0.05°. This also means that the output of 3D linear acceleration, 3D rate of turn and 3D magnetic field data all will have orthogonal xyz readings within <0.05°.

Some of the commonly used data outputs and their reference coordinate systems are listed in Table 6.

Table 6: Data outputs with reference coordinate systems

| Data | Reference coordinate system | Details |
|---|---|---|
| Acceleration | Sensor-fixed frame ($S_{xyz}$) or $O_{xyz}$ | 4.2.1 |
| Rate of turn | Sensor-fixed frame ($S_{xyz}$) or $O_{xyz}$ | 4.2.1 |
| Magnetic field | Sensor-fixed frame ($S_{xyz}$) or $O_{xyz}$ | 4.2.1 |
| Velocity increment | Sensor-fixed frame ($S_{xyz}$) or $O_{xyz}$ | 4.2.2 |
| Orientation increment | Sensor-fixed frame ($S_{xyz}$) or $O_{xyz}$ | 4.2.2 |
| Free acceleration | Local earth-fixed frame ($L_{XYZ}$), default ENU | 4.3.4 |
| Orientation | Defined as the difference between Sensor-fixed frame (($S_{xyz}$) or $O_{xyz}$) and local earth-fixed frame ($L_{XYZ}$), default ENU | 4.2.3 |
| Velocity | Local earth-fixed frame ($L_{XYZ}$), default ENU | 4.2.4 |
| Position | Local earth-fixed frame ($L_{XYZ}$), default ENU | 4.2.5 |

### 4.2.2 Orientation increment and Velocity increment (dq and dv)

The Strap Down Integration (SDI) output of the MTi contain orientation increments (dq) and velocity increments (dv). These values represent the orientation change and velocity change during a certain interval based on the output rate. The output rate is selectable up to 100 Hz or 400 Hz depending on the product. The dq and dv values are always represented in the same coordinate system as calibrated inertial data and magnetic field data, which can be $S_{xyz}$ or $O_{xyz}$.

### 4.2.3 Orientation data

By default, the local earth-fixed reference coordinate system $L_{XYZ}$ is defined as a right-handed Cartesian coordinate system with[5]:

- X positive to the East (E).
- Y positive to the North (N).
- Z positive when pointing up (U).

This coordinate system is known as ENU (East-North-Up) and is the standard in inertial navigation for aviation and geodetic applications. See Figure 9 for a visualization. Note that it is possible to change $L_{XYZ}$ into a different convention, like NWU (North-West-Up) or NED (North-East-Down), by changing an alignment matrix or applying an orientation reset. Refer to [BASE by Xsens - MTi reference co-ordinate systems](#) for more information on the available orientation resets.

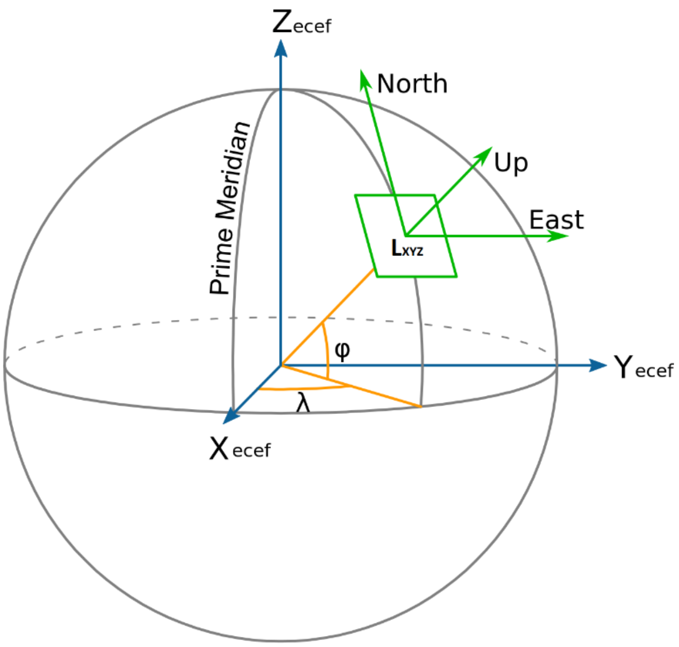


Figure 9: Visualization of the local earth-fixed coordinate system ($L_{XYZ}$) and Position representation systems WGS84 (φ, λ) and ECEF ($X_{ecef}$, $Y_{ecef}$, $Z_{ecef}$)

The 3D orientation output is defined as the orientation between the body-fixed coordinate system, $S_{xyz}$ or $O_{xyz}$, and the local earth-fixed co-ordinate system, $L_{XYZ}$.

**Orientation output modes**

The output orientation can be presented in different equivalent representations:

[5] The default reference coordinate system $L_{XYZ}$ only applies to the MTi in Normal (Xbus) or CAN output mode. Refer to the Low Level Communication Protocol Documentation for detailed orientation output specifications when using the ASCII (NMEA) output mode.

- Unit Quaternions;
- Euler angles[6]: roll, pitch, yaw (XYZ Earth fixed type) are output following the aerospace sequence (Z-Y'-X");
- Rotation Matrix (directional cosine matrix).

A positive rotation is always "right-handed", i.e. defined according to the right-hand rule (corkscrew rule), see Figure 10. This means a positive rotation is defined as clockwise in the direction of the axis of rotation.

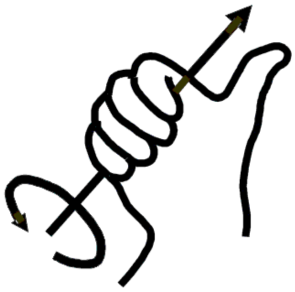

Figure 10: Right hand rule

Refer to BASE by Xsens to find more information on how quaternions, Euler angles and the rotation matrix relate to each other.

**Interpretation of yaw as heading**

Heading is defined as the angle between the north direction and the horizontal projection of the roll axis. Heading is positive about the local vertical axis following the right-hand rule[7].

With the default ENU $L_{XYZ}$ coordinate system, Xsens yaw output is defined as the angle between East (X) and the horizontal projection of the sensor roll axis (x), positive about the local vertical axis (Z) following the right-hand rule. Table 7 shows the different yaw values corresponding to the different local coordinate systems that are available for the MTi.

[6] Please note that due to the definition of Euler angles there is a mathematical singularity (gimbal lock) when the sensor-fixed x-axis is pointing up or down in the earth-fixed reference frame (i.e. pitch approaches ±90°). In practice, this means roll and pitch is not defined as such when pitch is close to ±90 deg. This singularity is in ***no way*** present in the quaternion or rotation matrix output mode.

[7] IEEE Std 1559™-2009: IEEE Standard for Inertial Systems Terminology

Table 7: Yaw in different coordinate systems (applies only to VRU/AHRS and GNSS/INS product types). The MTi is assumed to be mounted with its roll-axis (X) aligned with the roll-axis of the vehicle (front of the vehicle).

| Local coordinate system (output) | Roll-axis of the vehicle | Yaw value |
|---|---|---|
| East-North-Up (ENU) | Pointing North | 90 deg |
| East-North-Up (ENU) | Pointing East | 0 deg |
| North-West-Up (NWU) | Pointing North | 0 deg |
| North-East-Down (NED) | Pointing North | 0 deg |

When using the ENU convention (default), the yaw output is 0º when the vehicle (x-axis of the MTi) is pointing East (X axis of $L_{XYZ}$). When it is required that the yaw output is 0º when the x-axis of the MTi is pointing North, it is recommended to select NWU or NED as the local coordinate system. In section 0 the various alignment resets are described.

When using the INS/GNSS products in an automotive application, as a best practice pay proper attention to mounting of the MTi on the automotive platform/vehicle. It is recommended to always mount the MTi with the x-axis pointing to the front of the vehicle irrespective of the local coordinate frame used for the output data.

**True North vs. Magnetic North**
As defined above, the output coordinate system of the MTi is with respect to local Magnetic North. The deviation between Magnetic North and True North (known as the magnetic declination) varies depending on the location on earth and can be roughly obtained from the latest World Magnetic Model[8] of the earth's magnetic field as a function of latitude and longitude. The MTi accepts a setting of the declination value. This is done by setting the position in the MT Manager, SDK or by Low level communication. The yaw/heading will then be corrected for the declination calculated internally and thus referenced to "local" True North. The GNSS/INS products set automatically the current position when a GNSS-position fix is available, therefore the user does not have to insert it.

### 4.2.4 Velocity data

Velocity data, calculated by the sensor fusion algorithm is provided in the same coordinate system as the orientation data ($L_{XYZ}$), and thus adopts orientation resets as well (if any is applied). The velocity output is available in all GNSS/INS products (MTi-G-710, MTi-7, MTi-670 and MTi-680G).

Note that the velocity data coming directly from the PVT (Position Velocity Time) data retrieved from any GNSS receiver provided with any Xsens development kit is represented in the NED reference frame. Different GNSS receivers may represent the velocity in different coordinate frames.

[8] Xsens releases a firmware update when a new WMM version is available

### 4.2.5 Position data

Position data, calculated by the sensor fusion algorithm is represented in Latitude, Longitude and Altitude as in the WGS84 datum. The position output is available in all GNSS/INS products (MTi-G-710, MTi-7, MTi-670 and MTi-680G).

It is possible to retrieve position data calculated by the sensor fusion algorithm in Earth Centered – Earth Fixed (ECEF) format. See Figure 9 for a visualization and the *MT Low Level Communication Protocol Documentation* for more information.

## *4.3 Physical sensor model*

This section explains the basics of the individual calibration parameters of each MTi.

The physical sensors inside the MTi (accelerometers, gyroscopes and magnetometers)[9] are all calibrated according to a physical model of the response of the sensors to various physical quantities, e.g. temperature. The basic model is linear and according to the following relation:

$$\boldsymbol{s} = \boldsymbol{K_T}^{-1}(\boldsymbol{u} - \boldsymbol{b_T})$$

During factory calibration, to each MTi has been assigned a unique gain matrix, $\boldsymbol{K_T}$ and the bias vector, $\boldsymbol{b_T}$. This calibration data is used to relate the sampled digital voltages, $\boldsymbol{u}$, from the sensors to the respective physical quantity, $\boldsymbol{s}$.

The gain matrix is split into a misalignment matrix, $\boldsymbol{A}$, and a gain matrix, $\boldsymbol{G}$. The misalignment specifies the directions of the sensitive axes with respect to the ribs of the sensor-fixed coordinate system ($S_{xyz}$) housing. E.g. the first accelerometer misalignment matrix element $\boldsymbol{a_{1,x}}$ describes the sensitive direction of the accelerometer on channel one. The three sensitive directions are used to form the misalignment matrix:

$$\boldsymbol{A} = \begin{bmatrix} a_{1,x} & a_{1,y} & a_{1,z} \\ a_{2,x} & a_{2,y} & a_{2,z} \\ a_{3,x} & a_{3,y} & a_{3,z} \end{bmatrix}$$

$$\boldsymbol{G} = \begin{bmatrix} G_1 & 0 & 0 \\ 0 & G_2 & 0 \\ 0 & 0 & G_3 \end{bmatrix}$$

$$\boldsymbol{K_T} = \begin{bmatrix} G_1 & 0 & 0 \\ 0 & G_2 & 0 \\ 0 & 0 & G_3 \end{bmatrix} \begin{bmatrix} a_{1,x} & a_{1,y} & a_{1,z} \\ a_{2,x} & a_{2,y} & a_{2,z} \\ a_{3,x} & a_{3,y} & a_{3,z} \end{bmatrix} + \boldsymbol{O}$$

With $\boldsymbol{O}$ representing higher order models, temperature modelling, g-sensitivity corrections, etc.

Each individual MTi is modeled for temperature dependence of both gain and bias for all sensors and other effects. This modeling is not represented by the simple model in the

[9] The barometer and GNSS receiver do not require additional calibration.

above equations but is implemented in the firmware with the temperature coefficient being determined individually for each MTi device during the calibration process. The basic indicative parameters in the above model of your individual MTi can be found in MT Manager (Device Settings dialog).

### 4.3.1 Calibrated Δq and Δv outputs

The calibrated Δq (delta_q) and Δv (delta_v) outputs are the coning and sculling compensated strapdown integrated data in the sensor-fixed coordinate system ($S_{xyz}$) or ($O_{xyz}$). Note that the value of the output depends on the output frequency, as the values are integrated over the sample time. Delta_q can also be noted as dq, delta_angle, del_q or OriInc. Delta_v can also be noted as dv, delta_velocity, del_v or VelInc.

Table 8: Output specifications Δq and Δv outputs

| Output | Unit |
|---|---|
| Delta_q (DataID 0x8030) | a.u. (quaternion values) |
| Delta_v (DataID 0x4010) | m/s |

It is possible to multiply consecutive delta_q values to find the total orientation change over a specific period. Note that this data is not drift free, it still contains the sensor bias, as it has not been processed by the sensor fusion algorithm. Use the orientation output for drift free orientation.

### 4.3.2 Calibrated inertial and magnetic data outputs

Output of calibrated 3D linear acceleration, 3D rate of turn and 3D magnetic field data is in sensor-fixed coordinate system ($S_{xyz}$) or ($O_{xyz}$). The units of the calibrated data output are as shown in Table 9.

Table 9: Output specifications inertial and magnetometer data outputs

| Vector | Unit |
|---|---|
| Acceleration (DataID 0x4020) | $m/s^2$ |
| Angular velocity (RateOfTurn) (DataID 0x8020) | rad/s |
| Magnetic field (DataID 0xC020) | a.u. (arbitrary units; normalized to earth field strength at the location the MFM is performed) |

### 4.3.3 High-rate (HR) inertial data outputs

High-rate calibrated 3D acceleration (accelerometer) and 3D rate of turn (gyroscope) are outputted in sensor-fixed coordinate system ($S_{xyz}$) or ($O_{xyz}$). The units of the calibrated data output are as shown in Table 10. HR calibrated data is available at a higher rate than regular calibrated inertial data outputs. It is outputted as a separate data packet next to the other data outputs. The maximum output rate, degree of signal processing, and calibration applied depends on device type.
Refer to *MT Low Level Communication Protocol Documentation*[10] for more details.

[10] Links to the latest available documentation can be found via the following link: Xsens MTi Documentation

Table 10: Output specifications high rate calibrated inertial data outputs

| Vector | Unit |
|---|---|
| AccelerationHR (DataID 0x4040) | $m/s^2$ |
| RateOfTurnHR (DataID 0x8040) | rad/s |

### 4.3.4 Free acceleration

Free acceleration (Data ID 0x4030) is the acceleration in the local frame ($L_{XYZ}$) from which the local gravity is deducted. The output is in $m/s^2$.

## 4.4 Xsens Sensor Fusion Algorithms

The orientation and position output of the VRU, AHRS and GNSS/INS are computed by Xsens' proprietary sensor fusion algorithm. It uses signals of the rate gyroscopes, accelerometers, magnetometers and optionally a GNSS receiver and barometer to compute a statistical optimal 3D orientation and position estimates of high accuracy without drift for both static and dynamic movements.

The design of a typical algorithm can be summarized as a sensor fusion algorithm where the measurement of gravity (by the 3D accelerometers) and Earth magnetic north (by the 3D magnetometers) compensate for otherwise slowly, but unlimited, increasing (drift) errors from the integration of rate of turn data (angular velocity from the rate gyroscope). This type of drift compensation is often called attitude and heading referencing and such a system is referred to as an Attitude and Heading Reference System (AHRS).

In products where a GNSS receiver is available, GNSS data is continuously used to aid the estimation of the device's roll, pitch and heading next to position and velocity. An additional benefit is that short term GNSS outages can be coped with, through dead-reckoning, ensuring continuous data output. Such a system is referred to as GNSS/INS.

### 4.4.1 Internal Sensor Bias Estimation

The Xsens algorithm continuously estimates the gyroscope bias. For the rate of turn around the x-axis and the y-axis (roll and pitch axes), the gyroscope bias is estimated using gravity (accelerometers). In a homogenous magnetic field and with filter profiles using the magnetometer, also the gyroscope bias around the z-axis will successfully be estimated.

In some situations, the heading cannot be referenced to the (magnetic) north. This is the case when the magnetic field is not used (for example for VRU devices) or when the magnetic field is distorted. There are several ways to mitigate the drift in yaw (rotation around the z-axis):

1. When the MTi has sufficient movement in roll and pitch (>30 degrees for more than 10 seconds), the gyroscope bias will be estimated for the z-gyroscope. When rotating the MTi back to roll and pitch around 0 degrees, the yaw will be more stable than before the roll/pitch movements.
2. The yaw drift can also be stabilized by using Active Heading Stabilization (AHS). Refer to section 4.4.7 of this document for more details.
3. It is also possible to estimate the gyro bias using the manual gyro bias estimation when the MTi does not rotate (also called no-rotation update). A tutorial of the Manual Gyro Bias Estimation is available online through the following link: BASE by Xsens - Manual Gyro Bias Estimation Tutorial

### 4.4.2 Roll and Pitch estimation

The Xsens sensor fusion algorithm stabilizes the inclination (i.e. roll and pitch combined) using the accelerometer signals. An accelerometer measures the specific force that is composed of the gravitational acceleration plus the linear acceleration due to the movement of the object with respect to its surroundings. The algorithm uses the assumption that on average the acceleration due to the movement is zero. Using this assumption, the direction of the gravity can be observed and used to stabilize the attitude. The orientation of the MTi in the gravity field is accounted for such that centripetal accelerations or asymmetrical movements cannot cause a degraded orientation estimate performance. The key here is the amount of time over which the acceleration must be averaged for the assumption to hold. During this time, the gyroscopes must be able to track the orientation to a high degree of accuracy. In practice, this limits the amount of time over which the assumption holds true.

However, for some applications this assumption does not hold. For example, an accelerating automobile may generate significant permanent accelerations for time periods lasting longer than the maximum duration the MT's rate gyroscopes can reliably keep track of the orientation. This may degrade the accuracy of the orientation estimates because the application does not match the assumptions made in the algorithm. Note however, that as soon as the movement again matches the assumptions made, the algorithm will recover and stabilize. The recovery to optimal accuracy can take some time.

***NOTE:*** To be able to accurately measure orientations as well as position in applications which can encounter long-term accelerations we offer solutions that use aiding data from a GNSS receiver: the MTi-7 GNSS/INS, MTi-670 GNSS/INS or MTi-G-710 GNSS/INS.

### 4.4.3 Heading/yaw estimation

By default, yaw is referenced by using the local (earth) magnetic field (e.g. in the AHRS product versions). In other words, the measured magnetic field is used as a compass. If the local Earth magnetic field is temporarily disturbed, the algorithm will track this disturbance instead of incorrectly assuming there is not disturbance. However, in case of structural magnetic disturbance (>10 to 30 seconds, depending on the filter profile settings) the computed heading will slowly converge to a solution using the 'new' local magnetic north. Note that the magnetic field has not direct effect on the inclination estimate.

The filter profile 'Fixed Mag Ref' will assume a magnetic reference upon startup and keep that reference regardless of new magnetic environments (available only on MTi 600-series, see *MTi 600-series Datasheet*).

In the special case the MTi is rigidly strapped to an object containing ferromagnetic materials, structural magnetic disturbances will be present. In that case, Xsens offers an easy-to-use solutions to recalibrate the magnetometers based on those structural magnetic disturbances (refer to chapter 6.3 of this document.

Next to the solutions described on the article Estimating Yaw in magnetically disturbed environments to mitigate effects from magnetic disturbances, the sensor fusion algorithm in a GNSS/INS device makes use of data from the GNSS receiver. This means that the GNSS/INS device has an increased resistance towards magnetic disturbances. It is for example possible to estimate the heading based on comparison between accelerometer data and the GNSS acceleration. For GNSS/INS devices, the magnetometer data is only actively used in the GeneralMag filter profile, the other filter profiles are completely independent of the magnetic field.

### 4.4.4 Velocity and Position estimation

Transient accelerations

The GNSS/INS algorithm adds robustness to its orientation and position estimates by combining measurements and estimates from the inertial sensors and GNSS receiver in order to compensate for transient accelerations. It results in improved estimates of roll, pitch, yaw, position and velocity.

Loss of GNSS

When the GNSS/INS device has limited/mediocre GNSS reception or even no GNSS reception at all, the sensor fusion algorithm seamlessly adjusts the filter settings in such a way that the highest possible accuracy is maintained. The GNSS/INS MTi will continue to output position, velocity and orientation estimates, although the accuracy is likely to degrade over time as the filters will have to rely on dead-reckoning. The GNSS status will be monitored continuously such that the filter can take GNSS data into account again when available and sufficiently trustworthy. In case the loss of GNSS lasts longer than a specific period (depending on product type, e.g. 45 seconds), the device will enter a state in which it stops outputting position and velocity estimates, and no longer uses velocity estimates in its sensor fusion algorithms until GNSS reception is re-established.

### 4.4.5 Initialization

The Xsens sensor fusion algorithms do not only estimate orientation, but also keeps track of variables such as sensor biases or properties of the local magnetic field. For this reason, the orientation output may need some time to stabilize once the MTi is put into measurement mode. Time to obtain optimal stable output depends on a number of factors. An important factor determining stabilizing time is determined by the time to correct for small errors on the bias of the gyroscopes. The bias of the gyroscope may slowly change due to different effect such as temperature change or exposure to impact.

### 4.4.6 Filter Profile options

As described above, the algorithm uses assumptions about the acceleration and the magnetic field to obtain orientation. Because the characteristics of the acceleration or magnetic field differ for different applications, the Xsens algorithm makes use of filter profiles to be able to use the correct assumptions given the application. This way, it can be optimized for different types of movement. For optimal performance in a given application, the correct filter profile must be set by the user. Each product offer different filter profile options, refer to the specific documentation to know more about the filter profiles[11].

### 4.4.7 Additional setting options and features

Table 11 summarizes the additional options offered to adapt and optimize the algorithm to cover more scenarios and possible corner cases.

[11] Datasheet for the MTi 1-series and MTi 600-series. MTi User Manual for the other Xsens MTi products

Table 11: Supplementary features and settings

| | |
|---|---|
| **Active Heading Stabilization (AHS)** | Active Heading Stabilization (AHS) is a software component within the sensor fusion engine designed to give a low-drift unreferenced (not North-referenced) yaw solution even in a disturbed magnetic environment. It is aimed to tackle magnetic distortions that do not move with the sensor, i.e. temporary or spatial distortions.<br><br>AHS is not tuned for nor intended to be used with GNSS/INS devices. Therefore, Xsens discourages the use of this feature for GNSS/INS devices.<br><br>For the MTi 600-series, the AHS feature is embedded in the filter profiles.<br><br>For more information on the activation and use of AHS, refer to the BASE-article: BASE by Xsens - AHS tutorial |
| **Orientation Smoother** | The Orientation Smoother is a software component within the sensor fusion engine that is currently only available for the MTi-670, MTi-680G and MTi-G-710. This feature aims to reduce any sudden jumps in the Orientation outputs that may arise when fusing low-rate GNSS receiver messages with high-rate inertial sensor data.<br><br>The Orientation Smoother can be enabled from the Device Settings window in MT Manager, or by using the setOptionFlags low-level command (see *MT Low Level Communication Protocol Documentation*[12]). |
| **Position / velocity Smoother** | The Position/velocity Smoother is a software component within the sensor fusion engine that is currently only available for the MTi-680G. This feature aims to reduce any sudden jumps in the position outputs that may arise when fusing low-rate GNSS receiver messages with high-rate inertial sensor data.<br><br>The Position/velocitySmoother can be enabled from the Device Settings window in MT Manager, or by using the setOptionFlags low-level command (see *MT Low Level Communication Protocol Documentation*[13]). |

[12] Links to the latest available documentation can be found via the following link: Xsens MTi Documentation

[13] Links to the latest available documentation can be found via the following link: Xsens MTi Documentation

| | |
|---|---|
| **GNSS Platform** | u-Blox GNSS receivers support different dynamic platform models in order to adjust the navigation engine to the expected application environment. The GNSS/INS products can be configured to communicate a desired platform model upon start-up. This enables the user to adjust the u-Blox receiver platform to match the dynamics of the application. The setting influences the estimates of Position and Velocity and therefore it affects the behavior of the Xsens filter output. Currently, only the Portable (default) and Airborne (<4g) platforms are supported.<br><br>The platform model can be configured using MT Manager or low-level communication. For more details on GNSS platform settings, refer to the u-Blox Receiver Description Manual.<br><br>Alternatively, when using interfacing with a GNSS receiver through NMEA communication, the received NMEA position data is used 'as is', independent of the GNSS platform setting. |
| **In-run Compass Calibration (ICC)** | In-run Compass Calibration (ICC) provides a solution to calibrate the sensor for magnetic distortions caused by objects that move with the MTi. Examples are the cases where the MTi is attached to a car, aircraft, ship or other platforms that can distort the magnetic field. It also handles situations in which the sensor has become magnetized. ICC is an alternative for the offline MFM (Magnetic Field Mapper). It results in a solution that can run embedded on different industrial platforms (leaving out the need for a host processor like a PC) and relies less on specific user input.<br>ICC is currently a feature in beta. For more information, refer to the BASE-article on ICC: BASE by Xsens - ICC Tutorial. |

## 4.5 MTi series interface options

The MTi series product lines are able to communicate and output data via many different interfaces. Table 12 provides a convenient overview for the MTi 1-series and 600-series. Details on the interfaces for each product are available in the respective datasheets or hardware integration manuals.

Table 12: overview of interface options in MTi portfolio

| Interface | MTi 1-series | MTi 600-series modules | MTi-680G |
|---|---|---|---|
| **I²C** | • | | |
| **SPI** | • | | |
| **UART** | • | • | |
| **USB** | Development Board | Development Board or UART2USB Converter | Via cable and USB converter |
| **RS232** | | • | • |
| **RS485** | | | |
| **RS422** | | Dev. Board | |
| **CAN** | | • | • |

## 4.6 Timing and synchronization

The MTi products support multiple features for synchronizing data with external devices and timing. Please refer to the respective datasheets or manuals for more information.

# 5 Input and Output Specification

In this chapter the various output modes of the MTi are described. The MTi's have several output options. It is possible to select a different output frequency and/or output format (e.g. float or double) per output or group of outputs. A full overview of the output options can be found in the *MT Low Level Communication Protocol Documentation*[14].

Performance specifications on orientation, position and sensor data can be found in the specific datasheets of each MTi series.

## 5.1 Overview of data output protocols

The MTi supports different data protocols: the binary (hexadecimal) XBus protocol, NMEA (ASCII) messages and CAN 2.0. Refer to *MT Low Level Communication Protocol Documentation*[14] and MT CAN Protocol Documentation to learn more about the structure of the protocols and how to switch between them.

NOTE: The MTi 1-series only supports the binary XBus protocol.

## 5.2 Overview of data inputs

The MTi-7 and MTi-670 require GNSS receiver data to provide a full GNSS/INS solution. This can be achieved by using the UBX protocol (uBlox proprietary protocol) or with NMEA input (supported by the MTi-670 only).

### 5.2.1 uBlox proprietary protocol (ubx)

When connecting a uBlox receiver (e.g. uBlox MAX-M8), the MTi will configure it correctly on start-up. No prior configuration of the uBlox receiver is required. It is however recommended to inform the MTi of what type of uBlox receiver is connected. An Xbus message called SetGnssReceiverSettings, described in the *MT Low Level Communication Protocol Documentation*[8], can be used to select one of the officially supported uBlox receiver series: MAX-M8 (default), NEO-M8 or ZED-F9.

### 5.2.2 NMEA input (NMEAin)

Alternatively, NMEA input (NMEAin) is a functionality that allows the input of data from an external GNSS receiver using the NMEA protocol. As almost all GNSS receivers support the output of NMEA messages, this functionality enables the use of virtually any GNSS receiver.
It is important to note that when using the NMEAin both the GNSS receiver and the MTi must be configured prior to connecting both systems to each other. The NMEAin for the MTi-670 can be enabled through the SetGnssReceiverSettings Xbus message. For the GNSS receiver settings, please review the *MTi 600-series Datasheet*[10].

The MTi-7 does not support NMEAin, please contact your sales representative for more information.

[14] Links to the latest available documentation can be found via the following link: Xsens MTi Documentation

### 5.2.3 RTCM

RTCM messages contain position correction data which is required by the MTi-680G to achieve cm-level positioning. The protocol which is supported by the MTi-680G is RTCMv3 with a standard 1Hz frequency.

## 5.3 Built-in self-test

All MTi's feature a built-in self-test (BIT). The self-test actuates the mechanical structures in the MEMS accelerometer and gyroscope by inducing an electric signal. This allows checking the proper functioning of the mechanical structures in the MEMS inertial sensors as well as the signal processing circuitry. For the magnetometer, the self-test checks the integrity of the sensor component.

A passed self-test will result in a valid self-test flag in the status byte. Because the self-test influences the sensor data, the self-test is only available in Config mode. For more information, look for *RunSelftest* in *MT Low Level Communication Protocol Documentation.*

## 5.4 Timestamp and packet counter output

Each data message can be accompanied by a packet counter and/or timestamp. Refer to *MT Low Level Communication Protocol Documentation* detailed information on the various time outputs.

## 5.5 Status word

The status word includes information about the status of the MTi, its sensors, the filter and user inputs.
Information contained within the status word are for example:

- Selftest
- Filter valid
- GNSS fix
- No rotation update status
- Representative motion
- Clip flags of all axis gyroscopes, accelerometers and magnetometers
- SyncIn / SyncOut
- Filter modes

Refer to *MT Low Level Communication Protocol Documentation* for detailed information on the Status Word output.

# 6 Installation tips and tricks

## 6.1 Transient accelerations

The 3D linear accelerometers in the MTi are primarily used to estimate the direction of gravity to obtain a reference for attitude (pitch/roll). During long periods (more than tens of seconds) of transient "free" accelerations (i.e. 2$^{nd}$ derivative of position) the observation of gravity cannot be made. The sensor fusion algorithms can mitigate these effects to a certain extent, but nonetheless it is impossible to estimate true vertical without additional information.

The impact of transient accelerations can be minimized when you take into account a few things when positioning the device when installing it in the object you want to track/navigate/stabilize or control.

If you want to use the MTi to measure the dynamics of a moving vehicle it is best to position the measurement device at a position close to the centre of rotation (CR) of the vehicle/craft. Any rotations around the centre of rotation translate into centripetal accelerations at any point outside the centre of rotation. For a GNSS/INS device with a valid GNSS-fix, the detrimental effect of transient accelerations on orientation estimates is overcome by integrating GNSS measurements in the sensor fusion engine.

## 6.2 Vibrations

The MTi samples IMU signals at high frequency per channel, processing them using a strapdown integration algorithm with coning/sculling compensation. Proper coning/sculling compensation already mitigates errors that poorly designed signal processing pipelines introduce when the device is under vibration. For best results however, it is recommended that the MTi be mechanically isolated from vibrations as much as possible: since vibrations are measured directly by the accelerometers, the following two conditions can make the readings from the accelerometers invalid;

1. The magnitude of the vibration is larger than the measurement range of the accelerometer. This will cause the accelerometer to saturate, which may be observed as a "drift" in the zero-level of the accelerometer. This will show up as an erroneous roll/pitch.
2. The frequency of the vibration is higher than the bandwidth of the accelerometer. In theory, such vibrations are rejected, but in practice they can still give rise to aliasing, especially if close to the bandwidth limit. This can be observed as a low frequency oscillation. Further, high frequency vibrations often tend to have large acceleration amplitudes (see item 1).

There is an effect on the gyroscopes as well and especially when the vibrations include high-frequent coning motion, the gyroscope readings may become invalid.

## 6.3 Magnetic materials and magnets

When an MTi is placed close to or on an object that is either magnetic or contains ferromagnetic materials, the measured magnetic field is distorted (warped) and causes an error in the computed heading. The earth magnetic field is altered by the presence of ferromagnetic materials, permanent magnets or power lines with strong currents (several amperes) in the vicinity of the device. The distance to the object and the amount of ferromagnetic material determines the magnitude of disturbance introduced. Errors in estimated yaw due to such distortions can be quite large, since the earth magnetic field is very weak in comparison to the magnitude of the sources of distortion.

By default, the AHRS and the GNSS/INS versions (when using the GeneralMag filter profile) stabilize heading using the local Earth's magnetic field. In other words, the measured magnetic field is used as a compass. In addition, the gyroscope biases are continuously estimated by the MTi's on-board filter. For the rate of turn around the x-axis and the y-axis (roll and pitch axes), the gyroscope bias is estimated using gravity (i.e. by using the accelerometers). In a homogeneous magnetic field, the gyroscope bias around the z-axis can be successfully estimated as well by monitoring the direction of the magnetic field.

The magnetic field can be distorted by the presence of ferromagnetic materials, permanent magnets or power lines with strong currents (several amperes) in the vicinity of the device. The distance to the object and the amount of ferromagnetic material determines the magnitude of disturbance introduced. If the local Earth magnetic field is temporarily disturbed, the on-board filters will initially track this disturbance instead of incorrectly assuming that the device has rotated. However, in case of continuous magnetic disturbances (>10 to 30 s, depending on the filter settings) the computed heading will slowly converge to a new solution using the 'new' local magnetic north. Note that the magnetic field has no direct effect on the inclination estimate.

In the special case that the MTi is rigidly strapped to an object containing ferromagnetic materials, constant magnetic disturbances will be present. Using a so-called 'magnetic field mapping' (MFM, i.e. a 3D calibration for soft and hard iron effects), these magnetic disturbances can be completely calibrated for, allowing the MTi to be used as if it would not be secured to the object containing ferromagnetic materials.

For more information please review the *Magnetic Calibration Manual*[15].

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[15] Links to the latest available documentation can be found via the following link: Xsens MTi Documentation

# 7 Warranty and liability

Xsens Technologies B.V. warrants the products manufactured by it to be free from defects in material and workmanship for a period of two years from the date of delivery. Products not subjected to misuse will be repaired, replaced or credit issued at the sole option of Xsens Technologies B.V. Contact Xsens via www.xsens.com/support for return material authorization (RMA) prior to returning any items for calibration, repair or exchange. The product **must be returned in its original packaging** to prevent damage during shipping.

The warranty shall not apply to products repaired or altered or removed from the original casing by others than Xsens Technologies B.V. so as, in Xsens Technologies B.V. opinion, to have adversely affected the product, products subjected to negligence, accidents or damaged by circumstances beyond Xsens Technologies B.V.'s control.

***NOTE***: Xsens reserves the right to make changes in its products in order to improve design, performance, or reliability.

Subject to the conditions and limitations on liability stated herein, Xsens warrants that the Product as so delivered shall materially conform to Xsens' then current specifications for the Product, for a period of one year from the date of delivery. ANY LIABILITY OF XSENS WITH RESPECT TO THE SYSTEM OR THE PERFORMANCE THEREOF UNDER ANY WARRANTY, NEGLIGENCE, STRICT LIABILITY OR OTHER THEORY WILL BE LIMITED EXCLUSIVELY TO PRODUCT REPAIR, REPLACEMENT OR, IF REPLACEMENT IS INADEQUATE AS A REMEDY OR, IN XSENS' OPINION IMPRACTICAL, TO REFUND THE PRICE PAID FOR THE PRODUCT. XSENS DOES NOT WARRANT, GUARANTEE, OR MAKE ANY REPRESENTATIONS REGARDING THE USE, OR THE RESULTS OF THE USE, OF THE PRODUCT OR WRITTEN MATERIALS IN TERMS OF CORRECTNESS, ACCURACY, RELIABILITY, OR OTHERWISE. Xsens shall have no liability for delays or failures beyond its reasonable control.

## *7.1 Customer Support*

Xsens is glad to help you with any questions you may have about the MTi, or about the use of the technology for your application. The fastest way is Xsens' Help Center, where engineers and other Xsens users meet. Please visit this Help Center, contact Xsens' distributor, or if you are a direct customer of Xsens, our Customer Support:

- ➔ Online Help center: https://base.xsens.com
- ➔ Support page (firmware and software downloads): https://www.xsens.com/support/
- ➔ Distributor network: https://www.xsens.com/en/company-pages/company/distributors
- ➔ Telephone EMEA/Pacific: +31(0)88-9736700 (+31 88 XSENS 00)
- ➔ telephone US (Los Angeles, CA): +1 310-481-1800

To be able to help you, please mention your Motion Tracker **Serial Number** when requesting support.