INGENIEURS POLYTECH LILLE

Informatique, Microélectronique et Automatique

Compte rendu de projet de 4ème année

Réalisation d'une commande autonome d'un robot holonome

Réalisé par : MOULE Alexandre

TAHRY Ismaïl

Année 2013/2014

SOMMAIRE

I) INTRODUCTION :

Dans le cadre de la réalisation de projets en 4ème année du département IMA, nous avons choisi de nous intéresser à la commande autonome d'un robot holonome. En effet, notre projet repose sur la création d'une commande d'un robot omnidirectionnel qui aura pour but de se déplacer dans l'espace dans lequel il se trouve, de façon totalement autonome.

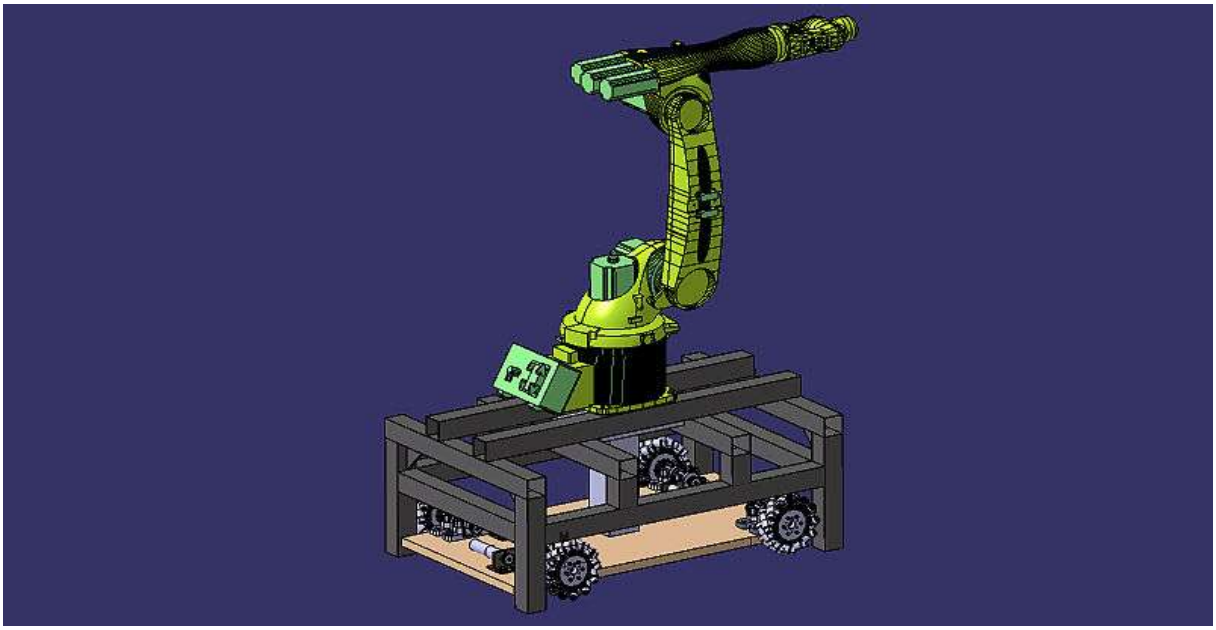
Ce projet entre dans le cadre d'une collaboration avec le centre de curiethérapie de Lille, car il permettrait de déplacer facilement un robot industriel de type Kuka (qui est doté d'une masse assez importante rappelons le) pour lequel notre robot fait office de plateforme. Ce dernier peut par la suite réaliser plusieurs opérations médicales très précises.

II) PRISE EN MAIN DU PROJET :

1) Description du matériel :

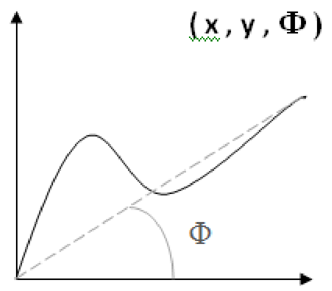
A notre prise en main du projet, celui-ci était déjà constitué de :

- ✓ Un robot industriel de type Kuka (n'interviendra pas dans le cadre du projet).
- ✓ 1 chassis de soutien au Kuka de type robot holonome.
- ✓ 4 roues motrices commandées par un ensemble moteur + contrôleur.
- ✓ 1 module CompactRIO qui est un système de contrôle et d'acquisition embarqué
- ✓ 1 raspberry pi connecté aux 4 contrôleurs des roues par des sorties numériques qui permettent de commander le sens de rotation des roues, préalablement programmé pour faire fonctionner le robot à l'aide d'un PAD ou d'une manette Wii.

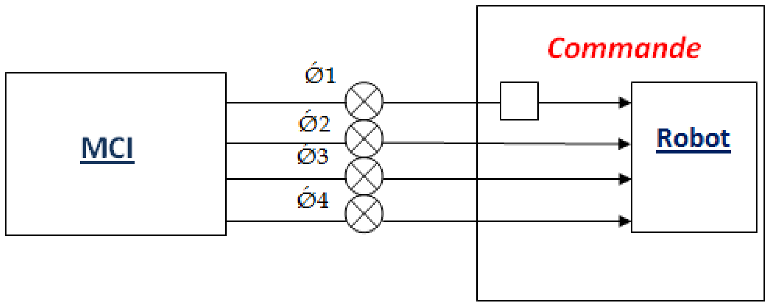


2) Objectif du projet :

L'objectif principal de ce projet est de pouvoir générer une trajectoire aléatoire qui sera ensuite suivie et réalisée par notre robot.



Génération de la trajectoire



3) Cahier des charges :

- Effectuer le modèle cinématique inverse de la position de notre robot afin de commander les 4 roues motrices en vitesse. Ce modèle sera calculé en fonction des mesures effectuées grâce aux capteurs de position situés sur le centre de gravité de chacune des roues.
- Créer une simulation du modèle obtenu et de la commande permettant d'automatiser le robot.
- Ajouter des capteurs infrarouges au châssis du robot afin que celui-ci puisse éviter d'éventuel obstacle au cours de son déplacement.
- Implémenter le résultat.

III) ETAPES DE REALISATION :

1) Modélisation du système :

Une première étape dans tout projet digne de ce nom, qu'il soit industriel ou simplement à visée pédagogique, est la modélisation. Pour vérifier que ce que l'on veut implémenter ait des chances de fonctionner, il faut tout d'abord le modéliser puis le simuler.

Pour ce fait, nous avions tout d'abord songé à réaliser un Modèle Géométrique Inverse (MGI) de notre système afin d'en avoir une approche plus scientifique. Mais cette perspective fut vite abandonnée car vouée à l'échec d'office, notre système n'étant pas tout à fait adapté à une telle modélisation. Par la suite, nous avons basculé vers un Modèle

Cinématique Inverse (MCI) qui nous semblait plus adéquat à notre système. Pour ce faire, nous avons tout d'abord réalisé le modèle direct, que l'on a validé après concertation avec notre professeur encadrant.

Le résultat de cette modélisation nous donne le système suivant qui a pour entrée les 4 vitesses angulaires des roues et en sortie la position en X, Y et Phi (angle de lacet) du robot :

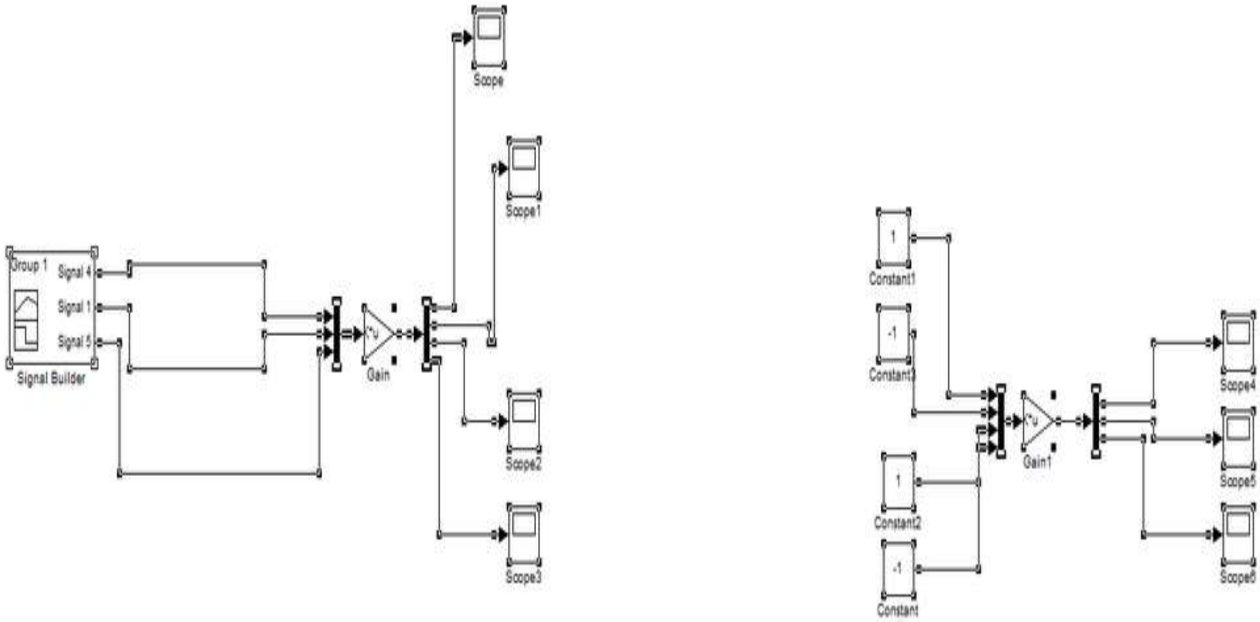
$$\begin{bmatrix} \frac{1}{4}R & \frac{1}{4}R & \frac{1}{4}R & \frac{1}{4}R \\ \frac{Rr}{d} & -\frac{Rr}{d} & \frac{Rr}{d} & -\frac{Rr}{d} \\ \frac{R}{d} & \frac{R}{d} & \frac{R}{d} & \frac{R}{d} \end{bmatrix}$$

Par la suite et à l'aide d'un logiciel de calcul formel tel que Maple par exemple, nous pouvons obtenir le modèle inverse de ce système en quelques lignes de commande. Cette fois ci, les entrées seront donc les positions X et Y ainsi que l'angle Phi, tandis que les sorties seront représentées par les vitesses angulaires des roues :

$$M = \begin{matrix} 1/R & -r*d/(4*R*(r^2+1)) & d/(4*R*(r^2+1)) \\ 1/R & -r*d/(4*R*(r^2+1)) & -d/(4*R*(r^2+1)) \\ 1/R & -r*d/(4*R*(r^2+1)) & d/(4*R*(r^2+1)) \\ 1/R & -r*d/(4*R*(r^2+1)) & -d/(4*R*(r^2+1)) \end{matrix}$$

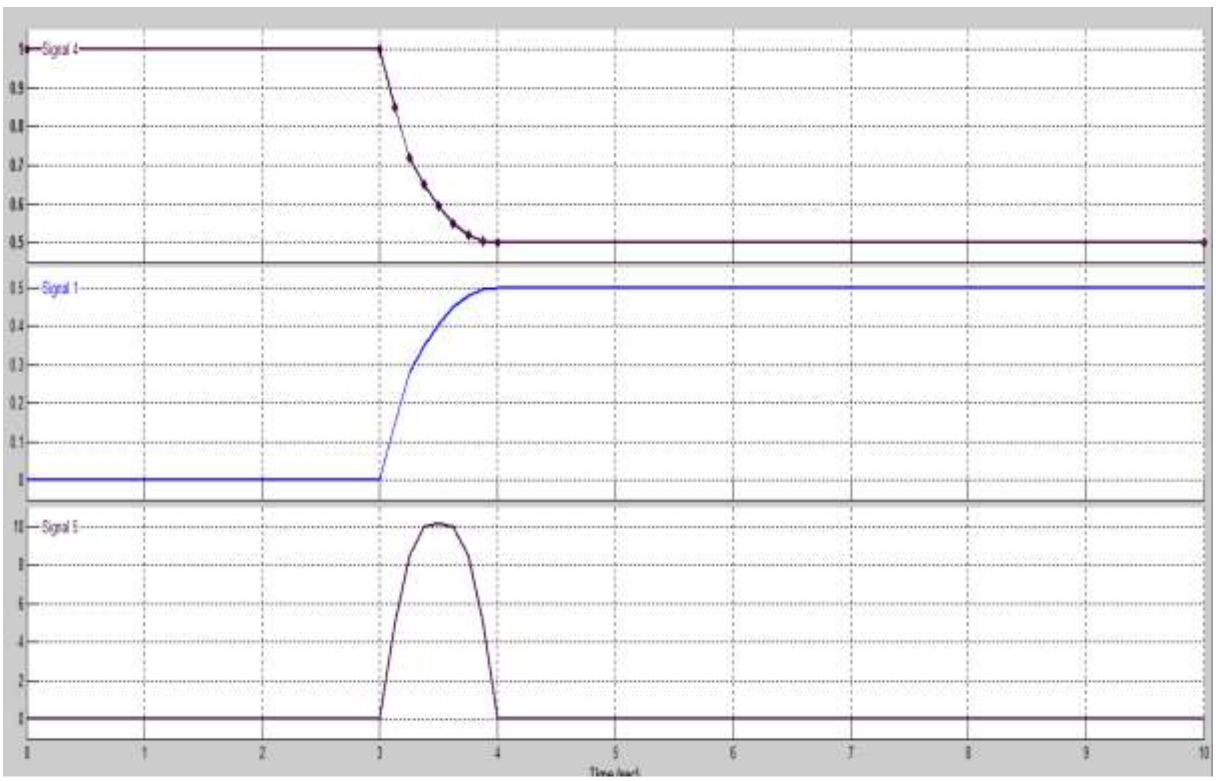
A ce stade, nous pouvons envisager une simulation concrète de notre système, à l'aide de logiciels tels quel que Matlab Simulink. On prend alors des mesures – les plus précises possibles - au niveau de notre robot pour déterminer R, r et d (respectivement le rayon de la roue, la distance perpendiculaire entre l'axe des roues et le centre de gravité, la distance entre deux roues) afin de pouvoir implémenter nos matrices et d'avoir un résultat reflétant la réalité.

Pour cela, nous réalisons le modèle Simulink suivant :

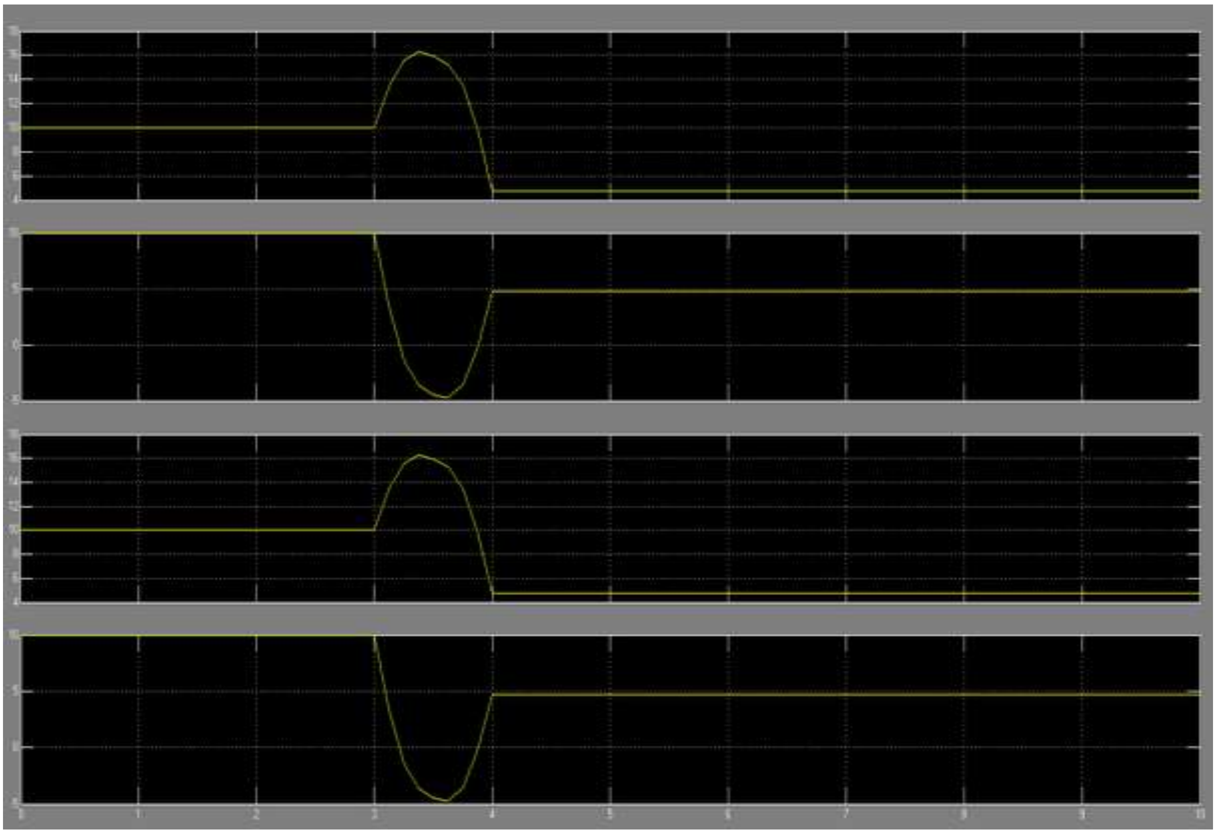


On peut voir de gauche à droite, la simulation du modèle direct et celle du modèle inverse.

Pour être plus précis, voici les « signal builder » que l'on a utilisé pour le premier système :



Dès lors que nous avons fini de configurer tous les paramètres et de saisir toutes les données nécessaires à la simulation, nous pouvons exécuter celle-ci sans problème. Le résultat de la simulation du modèle direct est assez clair :



Le résultat est parfaitement cohérent par rapport aux entrées que l’on a configurées, il corrobore ainsi le résultat obtenu mathématiquement.

La prochaine étape sera donc de tester ce résultat en réel. Pour cela, ce dernier sera implémenté à partir de Labview sur le CompactRIO.

2) Utilisation de la centrale inertielle

a) Présentation de la centrale inertielle :

Pour ce projet, nous disposions d'une centrale inertielle, la centrale inertielle Xsens MTi.

Centrale inertielle Xsens MTi

Cette centrale inertielle est équipée de trois gyroscopes, de trois accéléromètres et de trois magnétomètres. Nous avons utilisé la centrale inertielle afin d'obtenir la vitesse en X, en Y et du lacet. Ces données nous serviront à réguler le système en comparant celles-ci à celles de la consigne.

Afin de rendre le robot médical autonome, il faut donc implanter le traitement des données et le contrôle des moteurs directement sur le robot.

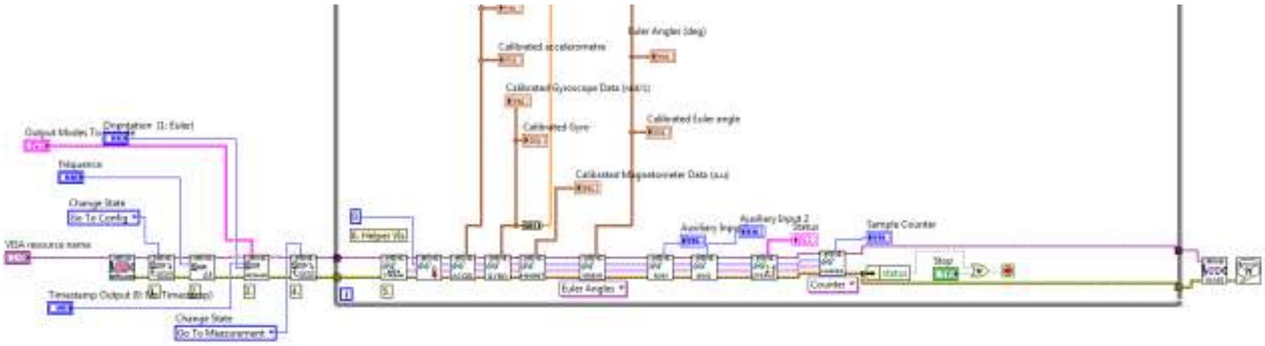
b) Programmation de l'acquisition des données sous le logiciel LabVIEW :

Le robot holonome dispose d'un module compact RIO. Ce module est un système de contrôle et d'acquisition embarqué. Il permet d'effectuer des calculs et il est actuellement utilisé pour contrôler le bras robotique.

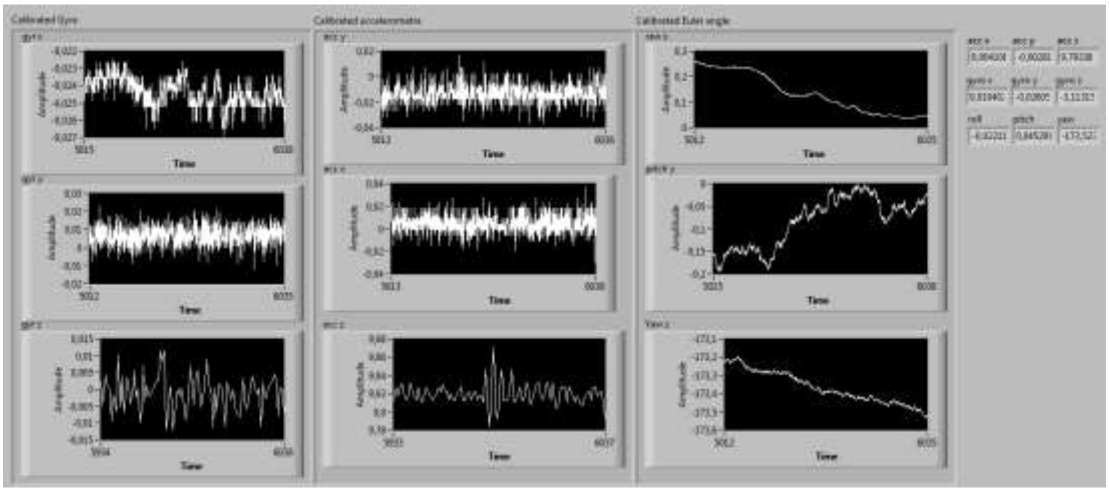
Ce module est programmable en utilisant le logiciel Labview. Donc, nous avons travaillé sous LabVIEW pour la partie acquisition et traitement des données.

Tout d'abord, nous avons créé un programme afin de récupérer les données envoyés par la centrale inertielle.

Ce programme fait directement les réglages nécessaires afin de trouver les données et d'initialiser la centrale inertielle et récupère les données en lisant sur les bits correspondants (voir documentation en annexe).



Programme LabVIEW pour la récupération des données



Résultats reçus par l'utilisateur

En plus de recevoir l'accélération en X, Y et Z et la vitesse de rotation en X, Y et Z, l'utilisateur reçoit les angles d'Euler. Les angles d'Euler sont les angles indiquant la position du repère de la centrale inertielle par rapport au repère terrestre.

c) Problèmes pour le traitement des données

Lorsque l'on ne bouge pas la centrale inertielle, on s'aperçoit que les accélérations et les vitesses de rotation ne sont pas nulles. De plus, elles ne sont jamais stables et leurs valeurs moyennes est différentes de zéro.

Cela pose un problème pour la récupération de la vitesse. En effet, il faut intégrer l'accélération pour obtenir la vitesse. Or, les vitesses n'étant pas nulle, on obtient une pente infinie même à l'arrêt

De même, les angles d'Euler ne sont pas stables et, suite à un mouvement, ils mettent beaucoup de temps à devenir à peu près stable (entre 5 et 10 secondes).

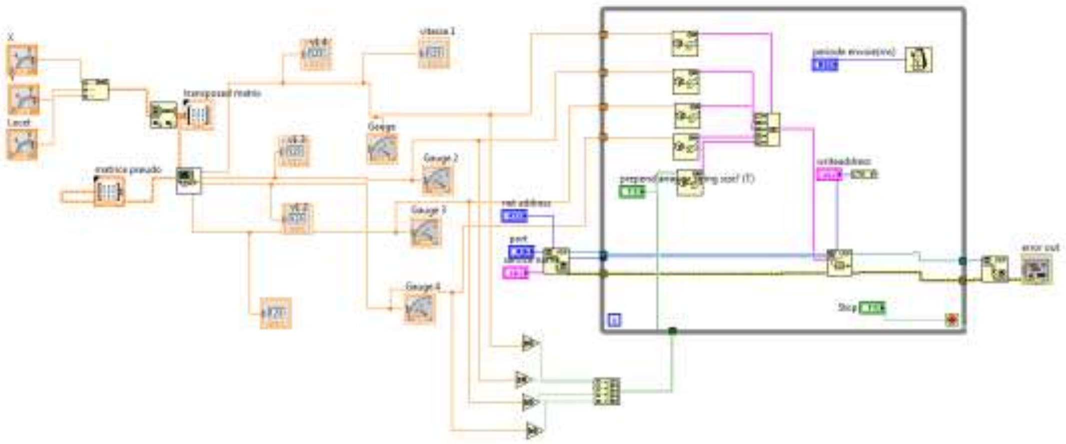
Or, dans la centrale inertielle, ces données sont déjà traitées et il ne devrait pas avoir ce problème. En effet, dans la centrale, les données sont filtrées par un filtre de Kalman. De plus, elle utilise l'accélération de la gravité pour stabiliser les données ainsi que le champ magnétique terrestre.

Pour pouvoir récupérer des données correctes, nous aurions du utiliser le modèle Xsens MTi-G qui est muni d'un GPS. Celle-ci fournit directement la position et la vitesse avec une grande précision.

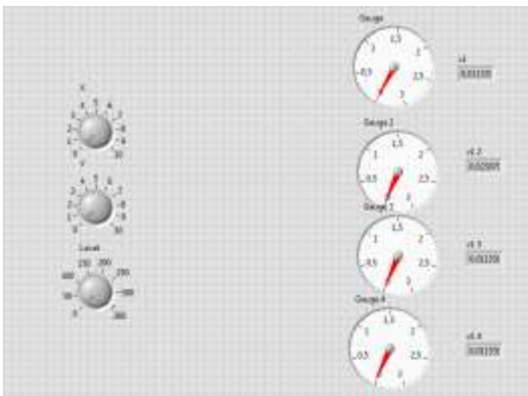
3) Traitement des données et transfert sous LabVIEW

On a implémenté la matrice pseudo-inverse vue précédemment sous LabVIEW.

On multiplie cette matrice avec les valeurs des vitesses X, Y et du lacet voulu. A partir de ce produit, on obtient les vitesses sur chaque roue.



Programme sous LabVIEW



Interface utilisateur

Ces données sont ensuite envoyées à la raspberry ou elles sont traitées puis envoyées aux moteurs.

La transmission des données se fait par Ethernet par protocole UDP. On envoie tout d'abord les vitesses sur chaque roue puis sur les quartes derniers bits, on envoie le sens de rotation (1 pour le sens normal et 0 pour le sens inverse).

Si les données par la centrale inertielle étaient correctes, nous aurions pu les utiliser avec les données de consignes et les intégrer dans une boucle contenant un PID afin de réguler le système.

4) Prise en main du raspberry pi :

Etant donné que les contrôleurs de nos roues sont connectés aux « Input » du raspberry pi, une prise en main de ce dernier est indispensable pour l'implémentation du programme. Le but ici est donc de pouvoir recevoir des données du CompactRIO sous forme de mots de plusieurs bits, par protocole UDP, et d'envoyer ensuite ces informations sur les roues afin de faire rouler le robot dans le sens désiré.

Mais avant toute chose, nous avons réalisé une sauvegarde de la carte SD après une entrevue avec notre prédécesseur qui nous l'a fortement recommandé.

Ensuite, nous avons commencé par nous connecter à ce composant en SSH afin de récupérer les programmes qu'il contient et de pouvoir se familiariser avec le langage python, un langage simple d'utilisation à première vue, mais que nous n'avions jamais utilisé auparavant.

Une fois que l'on a compris les programmes déjà présents, les GPIO à utiliser pour communiquer avec les contrôleurs des roues, on peut réaliser notre propre programme. Ce dernier ne sera au final pas très différent des autres au niveau de la gestion des sens de rotations des roues pour déterminer le sens de fonctionnement du robot, ceux-ci étant toujours les mêmes .

De ce fait, la principale fonction que l'on se doit d'ajouter est celle qui nous permettra de communiquer avec le CompactRIO, en suivant un protocole UDP, qui est un protocole utilisé par ce composant également.
En réalisant quelque recherche sur le net pour nous aider à réaliser cette fonction, on peut trouver un exemple simple à exploiter et à implémenter correctement à notre système :

```
import socket

UDP_IP = "127.0.0.1"
UDP_PORT = 5005

sock = socket.socket(socket.AF_INET, # Internet
                     socket.SOCK_DGRAM) # UDP
sock.bind((UDP_IP, UDP_PORT))

while True:
    data, addr = sock.recvfrom(1024) # buffer size is 1024 bytes
    print "received message:", data
```

A partir de la, on peut donc recevoir des messages sous forme de plusieurs bits. Il suffit alors de traiter ces messages, de récupérer les bits qui indiquent le sens de rotation de chaque roue et d'affecter ces informations aux contrôleurs adéquats.

IV) BILAN DU PROJET :

Après avoir passés plusieurs heures en salle de projet à exécuter différentes tâches dans le cadre de la réalisation de notre projet, nous n'avons malheureusement pas pu le conduire jusqu'au bout lorsque le temps imparti fut écoulé.

Au final, nous avons pu réaliser un modèle adéquat et concret de notre projet que l'on a implémenté sur Labview. Nous avons pu correctement programmer la centrale inertielle qui fonctionne comme il se doit sur Labview également. Mais des difficultés logicielles ne nous ont pas permises de pouvoir implémenter ces résultats sur le CompactRIO afin de les tester, comme c'était convenu au départ.

Côté Raspberry pi, une esquisse de programme à été réalisée. Cette dernière aurait pu être perfectionnée et implémenté sur la Raspberry pi, tout en ajoutant une option au menu préalablement réalisé afin de pouvoir choisir une commande autonome du robot parmi les choix proposés (comme la commande en PAD ou en manette Wii). Mais étant donné que la partie antérieure du projet n'a pu être implémentée, cette seconde partie n'a pu être testée ni améliorée le cas échéant.

V) CONCLUSION :

Afin de conclure ces quelques semaines de labeur, on peut dire que, malgré un projet inachevé, cette expérience nous a beaucoup apportée. Nous avons su nous montrer débrouillards et autonomes face à la difficulté, en menant un projet de A à Z que l'on à du apprendre à gérer par nous même, que se soit au niveau de l'organisation du travail ou la gestion du temps. Nous avons démontré nos capacités à aller chercher l'information là ou elle se trouve en utilisant différents moyens, ainsi que notre aptitude à appliquer des principes et des connaissances vus durant nos différents cours, à l'image des TP réalisés au cours du semestre.

Par ailleurs, ce projet était très enrichissant car il touchait quasiment à tous les domaines abordés au sein de la section IMA. Nous avons pu faire de l'informatique en langage python et appliquer nos acquis des cours de réseau, nous avons réalisé un modèle qui requiert des connaissances dans le domaine de la mécanique, sans oublier la partie simulation et logicielle qui montre que l'on a bien su cerner l'importance de cette étape dans un projet.

En somme, avec un projet tel que celui-ci, nous touchons au domaine de la mécatronique qui est un domaine très prisé dans le monde professionnel et industriel, un domaine qui peut nous ouvrir plusieurs portes dans le cadre de carrières futures.

ANNEXE :

MTi and MTx User Manual and Technical Documentation

Document MT0100P, Revision N, 27 May 2009

Xsens Technologies B.V.
phone +31 88 97367 00
fax +31 88 97367 01
email info@xsens.com
internet www.xsens.com

Revisions

Revision	Date	By	Changes
A	June 1 2005	PSL	First version.
...	...		
I	January 30 2007	SSM	Removed specification of MTi-28A##G##D (analog outputs) Specified additional interfaces in section 6.2 Physical properties overview Updated the input resistance of SyncIn (section 6.4) Changed the input voltage specification (section 6.3) Updated address information of Xsens Minor text updates
J	April 1 2008	PSL	Updated to XKF and firmware rev 2.0 and higher Added information to Absolute max ratings Added FCC DoC Added info on WakeUp procedure Added IP rating on housing Added origin definition of MT Updated: SyncIN detailed specs Updated performance specification for new generation devices
K	July 1 2008	PSL	Updated to include new device type with 18g acc range Updated DoC Various editorial changes and updates Updated FCC DoC
L	August 8 2008	PSL	
M	October 31 2008	MMI HLU	Added FCC DoC and CE DoC for the USB converters Added NoRotation feature
N	May 27 2009	MHA	Added timing specification Added updates of XKF scenarios Added Test & Calibration certificate explanation Added advices for machine_nomag and SyncIn New corporate design

Table of Contents

1 References

Reference id	Document description
[LLCP]	"MT Low-Level Communication Protocol Documentation.pdf", document id MT0101P
[SDK]	"MT Software Development Kit Documentation.pdf", document id MT0200P
[MTM]	"MT Manager User Manual.pdf", document id MT0216P

2 Introduction

The MTi and MTx are both complete miniature inertial measurement units with integrated 3D magnetometers (3D compass), with an embedded processor capable of calculating roll, pitch and yaw in real time, as well as outputting calibrated 3D linear acceleration, rate of turn (gyro) and (earth) magnetic field data.

The major difference between the MTi and the MTx is in the casing shape and weight, connector and general ruggedness. The MTi further supports various advanced IO options such as RS-422 and a synchronization output.

This documentation describes the use, basic communication interfaces and specifications of both the MTi and the MTx. Where they differ it is clearly indicated.

2.1 Product Description

2.1.1 MTi – miniature gyro-enhanced Attitude and Heading Reference Sensor

The MTi is a miniature, gyro-enhanced Attitude and Heading Reference System (AHRS). Its internal low-power signal processor provides drift-free 3D orientation as well as calibrated 3D acceleration, 3D rate of turn (rate gyro) and 3D earth-magnetic field data. The MTi is an excellent measurement unit for stabilization and control of cameras, robots, vehicles and other equipment.

Fields of use
- robotics
- aerospace
- autonomous vehicles
- marine industry
- bore industry

2.1.2 MTx – miniature inertial 3DOF Orientation Tracker

The MTx is a small and accurate 3DOF inertial Orientation Tracker. It provides drift-free 3D orientation as well as kinematic data: 3D acceleration, 3D rate of turn (rate gyro) and 3D earth-magnetic field. The MTx is an excellent measurement unit for orientation measurement of human body segments.

Example fields of use
- biomechanics
- exercise and sports
- virtual reality
- animation
- motion capture

2.2 *Overview MTi and MTx Development Kit*

Figure 1: Photo of the MT Development Kit (with MTi)

2.2.1 Contents

- MTi or MTx miniature inertial measurement unit
- Device individual Calibration Certificate
- A letter with your individual software license code.
- USB-serial data and power cable, 5 meters (CA-USB2)
- Quick Setup Sheet
- MTi and MTx User Manual and Technical Documentation [MT0100P][1]
- MT Software Development Kit CD-ROM
  - o MT Low-level communication Documentation PDF [MT0101P]
  - o Quick Setup PDF
  - o MT SDK setup
    - Xsens WHQL USB driver
    - MT Manager
    - **XsensCMT.DLL**
      - **COM-object Level 4**
      - **DLL C-interface**
    - **XsensCMTstatic.LIB**
    - **CMT Source files (C++)**
    - Example source code (MATLAB)
    - Documentation
      - MTi and MTx User Manual and Technical Documentation [MT0100P]
      - MT Low level communication Documentation [MT0101P]
      - MT Magnetic Field Mapper Documentation [MT0202P]
      - CMT doxygen HTML documentation

NOTE: the most recent version of the software, source code and documentation can always be downloaded on the support section of www.xsens.com.

[1] this document

When updating the firmware in your MTx and/or MTi, please make sure to use the latest Firmware Updater (as part of the MT SDK) and the latest firmware, which are all available at our website www.xsens.com. Not using the up-to-date Firmware and/or Firmware Updater can render your sensor inoperable in which case the sensor may need to be returned to Xsens for recovery.

2.3 Typical User Scenarios

This section is intended to help you find the right documentation for the way you want to use your MTi or MTx.

2.3.1 Getting Started with the MT Manager

The easiest way to get started with your MTi or MTx is to use the MT Manager software for Windows XP/Vista. This easy to use software with familiar Windows user interface allows you to:

- record data
- view 3D orientation in real-time
- view inertial and magnetic sensor data in real time
- export log files to ASCII
- change and view various device settings and properties
- interactively “chat” with the MTi or MTx through a terminal emulator.

The MT Manager is therefore an easy way to get to know and to demonstrate the capabilities of the MTi or MTx and to configure the device easily to suit your needs.

Applies to: Windows PC platform

Please refer to the MT Manager User Manual for more information on this topic!

2.3.2 Interface through COM-object API

If you want to develop a Windows software application that uses the MTi or MTx, you can consider using the COM-object API (XsensCMT.DLL). In particular if you are developing your application within another application such as MATLAB, LabVIEW, Excel, etc. the COM-object is the preferred interface. The XsensCMT.DLL COM-object provides easy to use function calls to obtain data from the sensor or to change settings.

A COM-object is a DLL that is registered on the operating system (Windows), so if properly installed you can access the functions of the COM-object in all Windows applications that support COM. The name of the function interface (IDispatch) is “MotionTracker.CMT”.

The COM-object takes care of the hardware communication interfacing and it is an easy way to get (soft) real-time performance. Typically this is preferred when you want to access the MTi or MTx’s capabilities directly in application software such as MATLAB, LabVIEW, Excel (Visual Basic), etc. (examples included in MT SDK). Both polling and events based methods are supported.

Applies to: Windows PC platform

Please refer to the MT Software Development Kit Documentation for more information on this topic!

2.3.3 Interface through DLL API

If you want to develop a Windows software application using a programming language (C, C++, etc.) that uses the MTi or MTx you can consider using the DLL API. This method of interfacing (the function calls) is similar to the COM object, but is based on a standard C dynamic linked library interface method. So, there is no need to register the DLL on the operating system, the functions are accessed directly in your source code by linking the DLL. The DLL to be used is the XsensCMT.DLL, so it is the same binary as the COM-object, but a different interface. If you program in C, C++ or other programming languages you will find that the DLL interface provides easier support for structured data, and this is therefore the recommended method.

Applies to: Windows PC platform

Please refer to the MT Software Development Kit Documentation for more information on this topic. For a detailed function listing, please refer to the HTML/CHM doxygen documentation.

2.3.4 Direct low-level communication with MTi or MTx

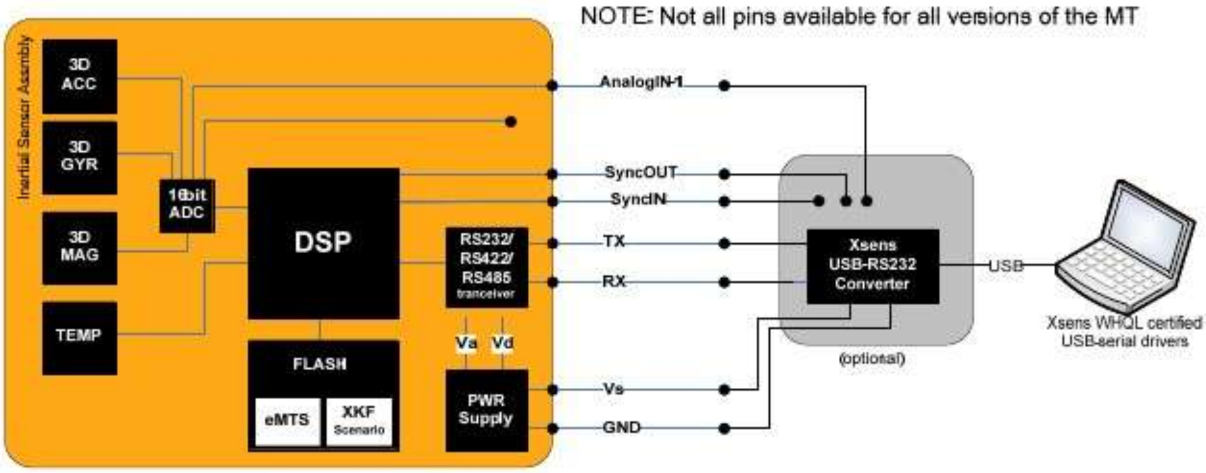
Direct interfacing with the MTi or MTx (RS-232) is the natural choice if you are looking for full-control, maximum flexibility and/or have hard real-time performance requirements. The MTi or MTx's low power embedded DSP performs all the calculations/calibration, you just retrieve the data from the serial port using the MT binary communication protocol using streaming (free-running) mode or polling (request) mode. Even this part is made easy for you by the inclusion of the source code (C++) of the Communication MT C++ classes (the CMT source code) in the MT SDK. Example C++ application code should get you quickly started on your development platform of choice. Example code that has been functionally checked and compiled on both Windows and Linux is included.

Applies to: Any (RT)OS or processor platform (C++)

Please refer to the **MT Low-level communication protocol documentation** and the **doxygen** HTML documentation for more information on this topic.

3 MTi and MTx System Overview

3.1 Overview



NOTE: Not all pins available on the connector of all versions of the MT. Please refer to section 6.4 for details.

3.2 Xsens Kalman Filter for MTi and MTx

The orientation of the MTi and MTx is computed by Xsens Kalman Filter for 3 degrees-of-freedom (3DoF) orientation (XKF-3). XKF-3 uses signals of the rate gyroscopes, accelerometers and magnetometers to compute a statistical optimal 3D orientation estimate of high accuracy with no drift for both static and dynamic movements.

The design of the XKF-3 algorithm can be explained 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 gyros). This type of drift compensation is often called attitude and heading referenced and such a system is often called an Attitude and Heading Reference System (AHRS).

3.2.1 Using the acceleration of gravity to stabilize inclination (roll/pitch)

XKF-3 stabilizes the inclination (i.e. roll and pitch combined, also known as “attitude”) using the accelerometer signals. An accelerometer measures gravitational acceleration plus acceleration due to the movement of the object with respect to its surroundings.
XKF-3 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 MT in the gravity field is accounted for so that centripetal accelerations or asymmetrical movements can not cause a degraded orientation estimate performance. This assumption is surprisingly powerful, almost all moving objects undergo accelerations if they are moving, but in most cases the ***average acceleration with respect to the environment during some period of time is zero. The key here is the amount of time over which*** the acceleration must be averaged for the assumption to hold. During this time, the rate 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. For the class of miniature MEMS rate gyroscopes used in the MT this period of time is about 10-20 seconds maximum.

However, for some applications this assumption does not hold. For example an accelerating automobile may generate significant accelerations for time periods lasting longer than the maximum time the MT's rate gyroscopes can reliably keep track of the orientation. This will severely degrade the accuracy of the orientation estimates with XKF-3, because the use scenario (application) does not match the assumptions made. Note however, that as soon as the movement does again match the assumptions made, XKF-3 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 a solution that incorporates a GPS receiver (the MTi-G).

3.2.2 Using the Earth magnetic field to stabilize Heading (Yaw)

By default, the heading is stabilized using the local (earth) magnetic field. In other words, the measured magnetic field is used as a compass. If the local Earth magnetic field is temporarily disturbed, XKF-3 will track this disturbance instead of incorrectly assuming there is no disturbance. However, in case of structural magnetic disturbance (>10 to 20 s) the computed heading will slowly converge to a solution using the 'new' local magnetic north. Note that the magnetic field has no direct effect on the inclination estimate.

In the special case the MTi or MTx is rigidly strapped to an object containing ferromagnetic materials, structural magnetic disturbances will be present. Using a so-called 'magnetic field mapping' (i.e. a 3D calibration for soft and hard iron effects), these magnetic disturbances can be completely calibrated for, allowing the MTi/x to be used as if it would not be secured to an object containing ferromagnetic materials. See section 7.2.3 for more details.

3.2.3 Initialization

The XKF-3 algorithm not only computes 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 MT 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 rate gyroscopes. The bias of the rate gyroscope may slowly change due to different effect such as temperature change or exposure to impact. To reduce stabilizing time, the last computed gyroscope bias can be stored in the sensor unit non-volatile memory. If the MTi/x is used after only a short period of power-off the gyro biases will generally not have changed a lot and the stabilizing time will typically be less than 10 seconds. Furthermore, XKF-3 will converge faster and reach optimal robustness faster if it is started in an area without magnetic disturbances.

3.2.4 XKF Scenarios

As described above, XKF-3 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, XKF-3 makes use of scenarios to be able to use the correct assumptions given the application. This way, XKF-3 can be optimized for different types of movement. For optimal performance, the correct scenario must be set by the user. For information on how to specify a scenario in XKF-3, please refer to the MT Manager User manual or the MT low-level communication protocol documentation.

The different scenarios are divided in ***'human', 'machine'*** and ***'marine'*** types of motion and are discussed below.

Human		
	●	●
Human_large_accel	●	●
Machine	●	●
Machine_nomag	●	
Marine	●	●

Table 1: The XKF-3 orientation algorithm uses different sources of information or assumptions depending on *the application scenario that is selected.*

Human
Two different scenarios are designed for human movements. The scenario 'human' assumes the somewhat slower movements, also taking into account magnetic disturbances typical for an indoor environment. The scenario 'human_large_accel' is optimized for the fast movements up to an angular velocity of 1200 deg/s and accelerations up to 5 g that may occur during impact.

Machine
The machine scenario is designed for a very broad range of different movements. These include accelerations that are generally slower and of longer periods of time than accelerations typical for human movement.

A separate machine scenario is designed for situations in which the local earth magnetic field is too distorted to be useful. This scenario is labelled 'machine_nomagfield', it does not make use of the local earth magnetic field to obtain a heading estimate. This can be advantageous in scenarios in which extreme magnetic disturbances occur, but it has the disadvantage that the heading can not be stabilized and that the gyro bias of the "vertical" gyroscope can not be observed. In other words: a heading change (delta) can be accurately tracked, but for longer periods of time the absolute heading can not be stabilized. Note that the roll and pitch (the inclination, or attitude) are still accurately tracked using rate gyroscopes and accelerometers alone. Consider utilizing the "NoRotation" feature to improve gyro bias observability and decrease heading drift when using this scenario, see also section 3.3.

Marine
The marine scenario is optimized for low, long term accelerations and mild magnetic disturbances. It is assumed that in a typical marine setting, almost all magnetic disturbances can be accounted for by a so-called magnetic field mapping procedure. See section 7.2.3 for more details.

3.3 *No rotation assumption for XKF-3*

This section describes the background of the so-called 'NoRotation' message and filter initialization setting. The MT can be configured to estimate the biases of the rate gyroscopes and other states assuming that the MT is not rotating (i.e. quasi-static) [2] for a certain period of time. This 'NoRotation' procedure can be configured to be invoked automatically at power-on and/or Reset, or can be invoked manually be sending a message to the MT (SetNoRotation message).

Please note that under normal circumstances and normal use the MT will successfully automatically estimate the rate gyroscope biases and there is no need to use the NoRotation feature. Please also note that **if** the NoRotation procedure is used, the MT must absolutely NOT be rotating during the given period of time that the procedure is active. Otherwise large errors can be introduced in the estimated orientation output. Some error checking is performed to estimate the validity of the NoRotation assumption. Please refer to the MT Data Status byte, for details see [LLCP] or for MT Manager see [MTM]. Ultimately, the user must be able to assure the validity of the assumption if NoRotation is used. If the validity can not be assured, it is not advisable to use this feature.

There are some very particular situations where the NoRotation feature can be considered. Specifically, in applications that can not use the local magnetic field to estimate heading, see [1.5.4], and at the same time does not have significant (>10 deg), and regular, variations in roll and pitch, the gyro bias of the "vertical" rate gyroscope is not observable by XKF-3. In practice this will mean that the heading will drift by the rate of the vertical gyro bias at that given time. The heading drift rate will not be reduced over time because XKF-3 can not estimate the "vertical" gyro bias.

Using the NoRotation feature appropriately will make the "vertical" gyro bias observable for a short period of time, giving XKF-3 the opportunity to quickly estimate the "vertical" gyro bias. In practice this will significantly reduce heading drift. However, note that the "vertical" gyro bias is only observable during the period of time that the NoRotation update is applied. So, heading drift over time in such a situation can fundamentally not be prevented, but it can be reduced greatly using the NoRotation feature at least once (at power-on) or, ideally, regularly if you know the MT is not rotating.

If the MT experiences significant and regular variations in roll and pitch using the NoRotation feature should not be necessary. XKF-3 continuously estimates the gyroscope biases and accounts for them. In case no magnetometer can be used, the gyro bias of only two of the three axes can be estimated in a given orientation. By using the MTi/MTx in different roll and pitch orientations, the gyro bias will slowly be observable in all three axes, since all rate gyro axes will at some point be the vertical one, at least to some degree. Again, this will reduce the rate of heading drift, but some degree of heading drift will always be present unless the magnetic field can be used as a heading reference.

As discussed, the NoRotation feature, can be applied by default on power-on and/or Reset, or can be activated during MeasurementMode. In the first case, the duration of the NoRotation is fixed to 2 seconds. In the latter case a duration in seconds may be specified, depending on knowledge about the duration that the MT is still (to a maximum of 255 seconds). Although the bias estimate will improve for longer intervals, intervals longer than 3 seconds will not significantly improve bias estimate and are therefore not recommended as the chance of error (i.e. not conforming to the absolute assumption of no rotation) will increase.

For details on how to use the NoRotation feature using the SDK, see [SDK] and [LLCP], for MT manager see [MTM].

---

2 The Earth rotation can be neglected for practical purposes.

4 Output Specification

In this chapter the various output modes of the MTi and MTx are described. The two major modes, Orientation output and Calibrated data output, are discussed separately. However, please note that the two output modes can easily be combined, so that you get a combined data packet of orientation data and inertial calibrated data together, with the same time stamp.

4.1 Co-ordinate systems

4.1.1 Calibrated Sensor readings

All calibrated sensor readings (accelerations, rate of turn, earth magnetic field) are in the right handed Cartesian co-ordinate system as defined in figure 1. This co-ordinate system is body-fixed to the device and is defined as the sensor co-ordinate system (S). The 3D orientation output is discussed below in section 4.1.2.

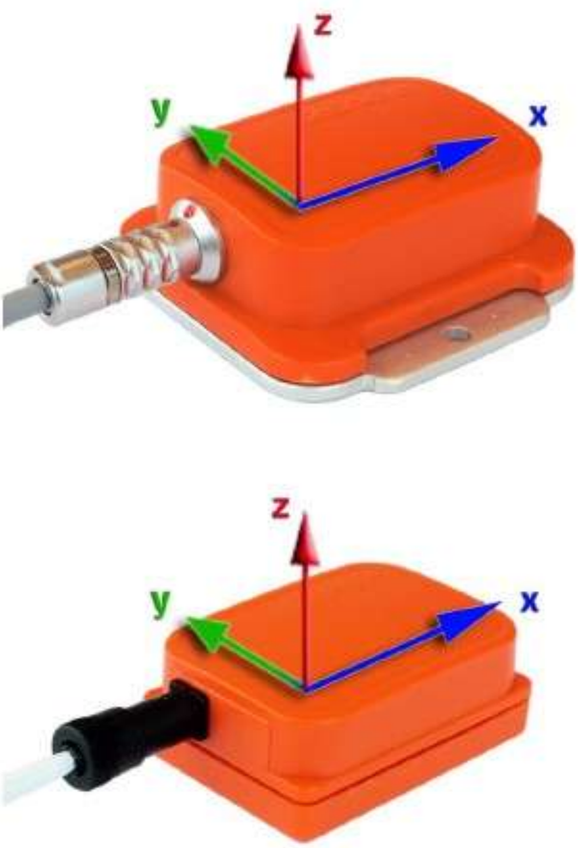


Figure 2 MTi and MTx with sensor-fixed co-ordinate system overlaid (S).

The co-ordinate system is aligned to the external housing of the MTi and MTx.

The aluminum base plate of the MTi is carefully aligned with the output coordinate system during the individual factory calibration. The alignment of the bottom plane and sides of the aluminum base-plate with respect to (w.r.t.) the sensor-fixed output coordinate system (S) is within 0.1 deg.

High accuracy alignment between the (plastic) housing and the sensor-fixed output coordinate system (S) is not possible for the MTx for obvious reasons. The actual alignment between the S co-ordinate system and the bottom part of the plastic housing is guaranteed to <3°.

The non-orthogonality between the axes of the body-fixed co-ordinate system, S, is <0.1°. This also means that the output of 3D linear acceleration, 3D rate of turn (gyro) and 3D magnetic field data all will have orthogonal XYZ readings within <0.1° as defined in figure 1.

4.1.2 Orientation co-ordinate system

The MTi and MTx calculate the orientation between the sensor-fixed co-ordinate system, S, and a earth-fixed reference co-ordinate system, G. By default the local earth-fixed reference co-ordinate system used is defined as a right handed Cartesian co-ordinate system with:

- X positive when pointing to the local magnetic North.
- Y according to right handed co-ordinates (West).
- Z positive when pointing up.

The 3D orientation output (independent of output mode, see section 4.3) is defined as the orientation between the body-fixed co-ordinate system, S, and the earth-fixed co-ordinate system, G, using the earth-fixed co-ordinate system, G, as the reference co-ordinate system. ordinate system.

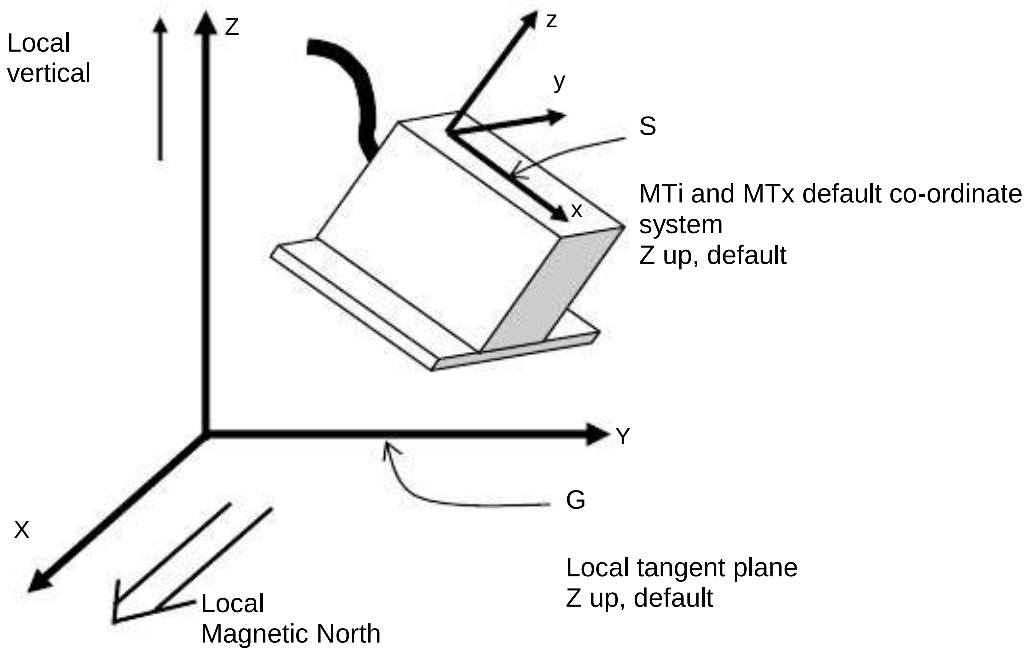


Figure 3: MT in the earth-fixed co-ordinate system

Please refer to section 4.5 for further details on output co-ordinate systems and different options to redefine the output co-ordinate systems.

True North vs. Magnetic North

As defined above the output coordinate system of the MTi / MTx is with respect to local Magnetic North. The deviation between Magnetic North and True North (known as the magnetic declination) varies depending on your location on earth and can be roughly obtained from various models of the earth's magnetic field as a function of latitude and longitude. The MTi / MTx can accept a setting of the declination value. This is done by setting the "declination" in the MT Manager, SDK or by direct communication with the sensor. The output will then be offset by the declination and thus referenced to "local" true north.

4.1.3 North-East-Down optional aerospace co-ordinate system definitions

It is possible to change the default local tangent plane Euclidean coordinate system to a **North-East-Down (NED) convention coordinate system. This is often used in aerospace applications. Changing to the NED setting** will also change the body-fixed sensor coordinate system to a Z down coordinate system as indicated in the figure below.

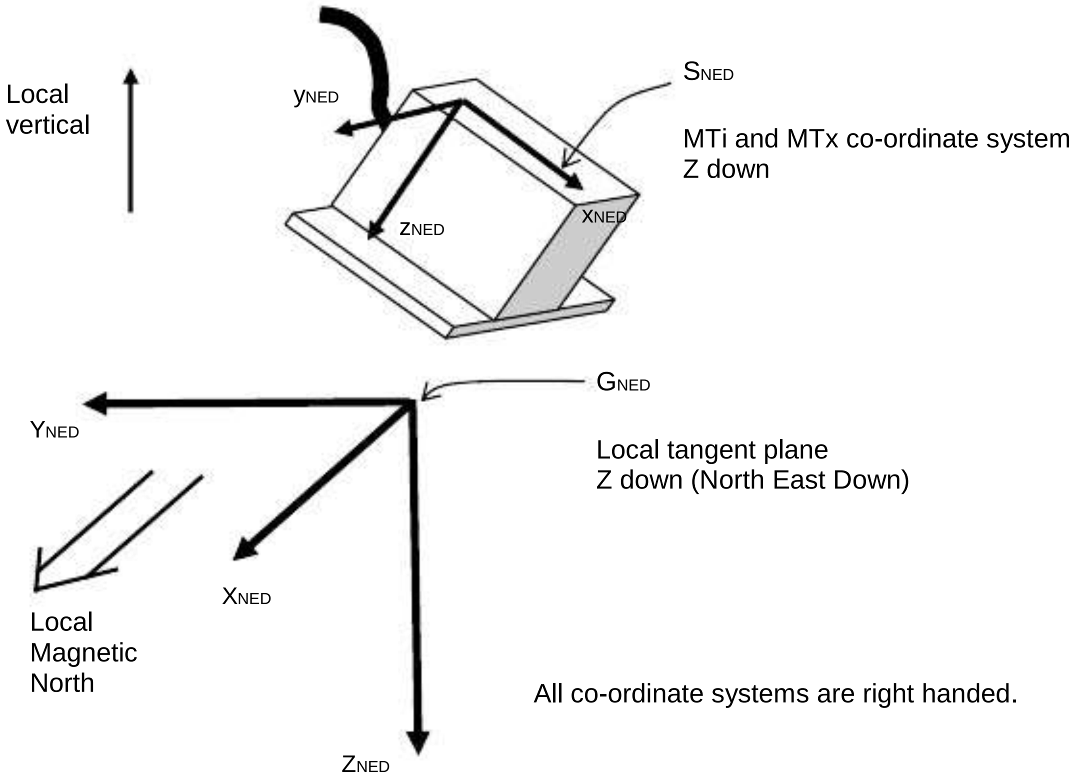


Figure 4: MT in a NED convention coordinate system

4.2 Orientation performance specification

Typical performance characteristics of MTi and MTx orientation output.

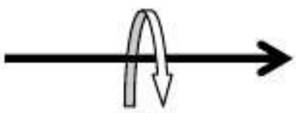
Dynamic Range:	all angles in 3D
Angular Resolution:	0.05° [3]
Repeatability:	0.2°
Static Accuracy (roll/pitch):	0.5°
Static Accuracy (heading)[4]:	1.0°
Dynamic Accuracy:	2° RMS [5]
Update Rate:	user settable, max 120 Hz [6]

4.3 Orientation output modes

The orientation as calculated by the MTi or MTx is the orientation of the sensor-fixed co-ordinate system (S) with respect to a Cartesian earth-fixed co-ordinate system (G). The output orientation can be presented in different parameterizations:

- Unit Quaternions (also known as Euler parameters)
- Euler angles [7] : roll, pitch, yaw (XYZ Earth fixed type, also known as Cardan or aerospace sequence)
- Rotation Matrix (directional cosine matrix)

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



NOTE: This section is intended to give detailed information on the definition of the various orientation output modes of the MTi and MTx. The output sequence of the elements in the vectors and matrices defined here holds for all interface options (RS-232/422/485, API, GUI). For more detailed information about the respective interfaces please refer to their specific documentation;

Direct MTi and MTx Low-level Communication Documentation
API MT Software Development Kit Documentation
GUI MT Manager

[3] 1σ standard deviation of zero-mean angular random walk

[4] in homogenous magnetic environment

[5] may depend on type of motion

[6] inertial data max update rate is 512 Hz, host PC processing allows 512 Hz orientation update rate

[7] Please note that due to the definition of Euler angles there is a mathematical singularity 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.

4.3.1 Quaternion orientation output mode

A unit quaternion vector can be interpreted to represents a rotation about a unit vector n through an angle α.

$$q_{GS} = (\cos(\frac{\alpha}{2}), n\sin(\frac{\alpha}{2}))$$

A unit quaternion itself has unit magnitude, and can be written in the following vector format;

$$q_{GS} = (q_0, q_1, q_2, q_3)$$

$$q = 1$$

Quaternions are an efficient, non-singular description of 3D orientation and a quaternion is unique up to sign:

$$q = -q$$

An alternative representation of a quaternion is as a vector with a complex part, the real component is the first one, q_0.

The inverse (q_{SG}) is defined by the complex conjugate (†) of q_{GS}. The complex conjugate is easily calculated;

$$q_{GS}^{\dagger} = (q_0, -q_1, -q_2, -q_3) = q_{SG}$$

As defined here q_{GS} rotates a vector in the sensor co-ordinate system (S) to the global reference co-ordinate system (G).

$$x_G = q_{GS} x_S q_{GS}^{\dagger} = q_{GS} x_S q_{SG}$$

Hence, q_{SG} rotates a vector in the global reference co-ordinate system (G) to the sensor co-ordinate system (S), where q_{SG} is the complex conjugate of q_{GS}.

The output definition in quaternion output mode is:

MTDataDATA =
MID 50 (0x32)

q0	q1	q2	q3

All data elements in DATA field are FLOATS (4 bytes) , unless specified otherwise by modifying the OutputSetting Data Format field.

4.3.2 Euler angles orientation output mode

The definition used for 'Euler-angles' here is equivalent to 'roll, pitch, yaw/heading' (also known as Cardan). The Euler-angles are of XYZ Earth fixed type (subsequent rotation around global X, Y and Z axis, also known as aerospace sequence).

- ϕ = roll [8] = rotation around X_G, defined from [-180°…180°]
- θ = pitch [9] = rotation around Y_G, defined from [-90°…90°]
- ψ = yaw [10] = rotation around Z_G, defined from [-180°…180°]

NOTE: Due to the definition of Euler angles there is a mathematical singularity when the sensor-fixed X-axis is pointing up or down in the earth-fixed reference frame (i.e. pitch approaches ±90°). This singularity is in no way present in the quaternion or rotation matrix output mode.

The Euler-angles can be interpreted in terms of the components of the rotation matrix, R_{GS}, or in terms of the unit quaternion, q_{GS};

$$\varphi_{GS} = \tan^{-1}\left(\frac{R_{32}}{R_{33}}\right) = \tan^{-1}\left(\frac{2q_2q_3 + 2q_0q_1}{2q_0^2 + 2q_3^2 - 1}\right)$$

$$\theta_{GS} = -\sin^{-1}(R_{31}) = -\sin^{-1}(2q_1q_3 - 2q_0q_2)$$

$$\psi_{GS} = \tan^{-1}\left(\frac{R_{21}}{R_{11}}\right) = \tan^{-1}\left(\frac{2q_1q_2 + 2q_0q_3}{2q_0^2 + 2q_1^2 - 1}\right)$$

Here, the arctangent ($\tan^{-1}$) is the four quadrant inverse tangent function.

NOTE: that the output is in degrees and not radians.

The output definition in Euler-angle output mode is:

MTDataDATA =
MID 50 (0x32)

roll	pitch	yaw

All data elements in DATA field are FLOATS (4 bytes) , unless specified otherwise by modifying the OutputSetting Data Format field.

[8] "roll" is also known as: "bank"

[9] "pitch" is also known as: "elevation" or "tilt"

[10] "yaw" is also known as: "heading", "pan" or "azimuth"

4.3.3 Rotation Matrix orientation output mode

The rotation matrix (also known as Direction Cosine Matrix, DCM) is a well-known, redundant and complete representation of orientation. The rotation matrix can be interpreted as the unit-vector components of the sensor coordinate system S expressed in G. For R_{GS} the unit vectors of S are found in the columns of the matrix, so col 1 is X_S expressed in G etc. A rotation matrix norm is always equal to one (1) and a rotation R_{GS} followed by the inverse rotation R_{SG} naturally yields the identity matrix I_3.

$$R_{GS} R_{SG} = I_3 \qquad |R| = 1$$

The rotation matrix, R_{GS}, can be interpreted in terms of quaternions;

$$R_{GS} = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2q_1q_2 - 2q_0q_3 & 2q_1q_3 + 2q_0q_2 \\ 2q_0q_3 + 2q_1q_2 & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2q_2q_3 - 2q_0q_1 \\ 2q_1q_3 - 2q_0q_2 & 2q_2q_3 + 2q_0q_1 & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

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

or in terms of Euler-angles;

$$R_{GS} = R_\psi^Z R_\theta^Y R_\varphi^X$$

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

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

As defined here R_{GS}, rotates a vector in the sensor co-ordinate system (S) to the global reference system (G):

$$x_G = R_{GS}\, x_S = (R_{SG})^T x_S$$

It follows naturally that, R_{SG} rotates a vector in the global reference co-ordinate system (G) to the sensor co-ordinate system (S).

For the rotation matrix (DCM) output mode it is defined that:

$$R_{GS} = \begin{bmatrix} a & d & g \\ b & e & h \\ c & f & i \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix}$$

$$R_{SG} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}$$

Here, also the row-order/col-order is defined.

The output definition in rotation matrix (DCM) output mode is:

MTDataDATA =
MID 50 (0x32)

a	b	c	d	e	f	g	h	i

All data elements in DATA field are FLOATS (4 bytes) , unless specified otherwise by modifying the OutputSetting Data Format field.

4.4 *Calibrated data performance specification*

	rate of turn	acceleration	magnetic field	temperature
Unit	[deg/s]	[m/s^2]	[mGauss]	[°C]
Dimensions	3 axes	3 axes	3 axes	-
Full Scale [units]	+/- 300*	+/- 50	+/- 750	-55...+125
Linearity [% of FS]	0.1	0.2	0.2	<1
Bias stability [units 1σ][11]	1	0.02	0.1	0.5 [12]
Scale factor stability [% 1σ][11]	-	0.03	0.5	-
Noise density [units /√Hz]	0.05 [13]	0.002	0.5 (1σ) [14]	-
Alignment error(15) [deg]	0.1	0.1	0.1	-
Bandwidth [Hz]	40	30	10	-
A/D resolution [bits]	16	16	16	12

*Table 1, calibrated data performance specification. These specifications are valid for an MTi and MTx with standard configuration. *) The standard configuration of the MTx is with a rate gyro with a range of 1200 deg/s.*

The following custom configurations are available, standard configuration highlighted in bold. If not specified otherwise the same performance specification as in table 1 is valid.

11 temperature compensated, deviation over operating temperature range (1σ)

12 minimal resolution of digital readout is 0.0625, absolute accuracy is ±0.5 °C

13 The following sensors MT-28xxxxxx DID<303800, MT-68xxxxxx DID<310200, MT-49xxxxxx ID<323800, MT-48xxxxxx ID<330200 have different specifications, see MTi and MTx User Manual version J.

14 magnetometer noise density can be susceptible to electro-magnetic radiation. For example, a 1 kHz amplitude modulated high frequency EM radiation of 80-1000 MHz of 10 V/m or higher may result in a noise density of 16 times the typical value

15 after compensation for non-orthogonality (calibration)

Accelerometer	Specification amendment
± 50 m/s2 (5 g) (default)	None, see table 1
± 17 m/s2 (1.7 g)	None, see table 1
± 180 m/s2 (18 g)	Noise density:0.004 m/s2/√Hz

Rate gyroscope	Specification amendment
± 1200 deg/s (MTx default)	Noise density: 0.1°/s/√Hz
± 300 deg/s (MTi default)	None, see table 1
± 150 deg/s	Noise density: 0.04°/s/√Hz

Specifications of custom units may vary.

4.5 Calibrated data output mode

NOTE: This section is intended to give detailed information on the definition of the calibrated inertial data output modes of the MTi and MTx. The output sequence of the elements of the vectors defined here holds for all interface levels (RS-232/422, API, GUI). For more detailed information about the respective interfaces please refer to their specific documentation;

Direct MTi and MTx Low-level communication Documentation
API **MT Software Development Kit Documentation**
GUI MT Manager

4.5.1 Physical sensor model

This section explains the basics of the individual calibration parameters of each MTi and MTx. This explains the values found on the MT Test and Calibration Certificate that comes with each MTi and MTx.

The physical sensors inside the MTi and MTx (accelerometers, gyroscopes and magnetometers) 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:

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

The model really used is more complicated and is continuously being developed further. From factory calibration each MTi / MTx has been assigned a unique gain matrix, K_T and the bias vector, b_T This calibration data is used to relate the sampled digital voltages, ***u,*** (unsigned integers from the 16 bit ADC's) from the sensors to the respective physical quantity, s.

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

$$A = \begin{bmatrix} a_{1,x} & a_{1,y} & a_{1,z} \\ a_{2,x} & a_{2,y} & a_{2,z} \\ a_{3,x} & a_{3,y} & a_{3,z} \end{bmatrix} \qquad G = \begin{bmatrix} G_1 & 0 & 0 \\ 0 & G_2 & 0 \\ 0 & 0 & G_3 \end{bmatrix}$$

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

With O representing higher order models and temperature modelling, g-sensitivity corrections, etc.

Each individual MTi and MTx is modeled for temperature dependence of both gain and bias for all sensors and other effects. This modeling is not represented in the simple model in the above equations, but is implemented in the firmware.

The basic indicative parameters in the above model of your individual MTi or MTx can be found on the MT Test **and Calibration Certificate.**

4.5.2 Calibrated inertial and magnetic data output mode

Output of calibrated 3D linear acceleration, 3D rate of turn (gyro) and 3D magnetic field data is in sensor-fixed coordinate system (S).

The units of the calibrated data output are as follows:

ctor Unit	
Acceleration	m/s^2
Angular velocity (rate of turn)	rad/s
Magnetic field	a.u. (arbitrary units) normalized to earth field strength

The calibrated data is "unprocessed", i.e. only the physical calibration model is applied to the 16-bit values retrieved from the AD-converters. There is no additional filtering, or other temporal processing applied to the data. The bandwidths of the signals are as stated in the datasheet and section 4.3.

The output definition in calibrated data output mode is:

MTDataDATA = MID 50 (0x32)

accX	accY	accZ	gyrX	gyrY	gyrZ	magX	magY	magZ

All data elements in DATA field are FLOATS (4 bytes) , unless specified otherwise by modifying the OutputSetting Data Format field.

The accelerometer / rate-of-turn / magnetometer data can be individually dis- or enabled. See SetOutputSettings message in section 5.3.3.

NOTE: The linear 3D accelerometers measure all accelerations, including the acceleration due to gravity. This is inherent to all accelerometers. Therefore, if you wish to use the 3D linear accelerations output by the MTi / MTx to estimate the "free" acceleration (i.e. 2nd derivative of position) gravity must first be subtracted.

4.5.3 Un-calibrated raw output mode

In un-calibrated raw output format the "raw" readings from the 16-bit AD-converters in the MTi / MTx are outputted. This means the physical calibration model described in the previous section is not applied. This gives you open access to the basic level of the sensor unit, but in most cases this level of use is not recommended. However, if your main purpose is for logging and post-processing, it may be advantageous as it is always possible to go back to the "source" of the signal. In this mode the device temperature is also outputted (housing ambient only).

NOTE: The data fields are 2 bytes (16 bits) as opposed to the 3 byte floats for the other output modes.

The output definition in un-calibrated RAW inertial data output mode is:

MTDataDATA =
MID 50 (0x32)

accX	accY	accZ	gyrX	gyrY	gyrZ	magX	magY	magZ	temp	

Each data element in DATA field is 2 bytes (16 bit) unsigned integers.
See below for reading the temperature data

Temperature output format

The 2 byte temperature data field in the un-calibrated raw output mode of the MTi / MTx can be interpreted as a 16 bits, 2-complement number. However, please note that the resolution of the temperature sensor is not actually 16-bit but 12-bit.

For example you can interpret the 2-byte temperature as follows:

00.00hex = 0.0 °C
00.80hex = +0.5 °C
FF.80hex = -0.5 °C
19.10hex = +25.0625°C
E6.F0hex = -25.0625 °C

The temperature-field is a 16-bit two-complement number of which the last byte represents the value behind the comma. To calculate the temperature value use the formula :

if $x \geq 2^{15}$ $T = (-2^{16} + x) / 256$
or $T = x / 256$ if $x < 2^{15}$, where x is the 16-bit value of the Temp field.

For example, the value 59120 (0xE6F0) corresponds with a temperature of -25.0625 °C.

4.6 Reset of output or reference co-ordinate systems

4.6.1 Output with respect to non-default coordinate frames

In some situations it may occur that the MT sensor axes are not exactly aligned with the axes of the object of which the orientation has to be recorded. It may be desired to output the orientation and/or calibrated inertial data in an object-fixed frame, as opposed to a sensor-fixed frame. Four methods have been added to the software to facilitate in obtaining the output in the desired coordinate frames, they are discussed below.

1. Setting an arbitrary rotation matrix to rotate S to the chosen object coordinate system O.

2. A heading reset that redefines the X-axis of the global coordinate frame while maintaining the Z-axis along the vertical (also known as "boresighting"). After the heading reset the orientation will be expressed with respect to the new global (earth fixed) reference frame.
3. An object reset that defines how the sensor is oriented with respect to the coordinate axes to which it is attached. After the object reset, both the orientation and the calibrated sensor data are expressed with respect to the axes of the object.
4. A combined object/heading reset, referred to as alignment.

NOTE: For all co-ordinate system reset functions it is important to remember that the housing of the MTx can not be considered an accurate reference. Placement and subsequent aligning must be done very carefully otherwise (alignment) errors may be induced.

4.6.2 Arbitrary alignment

If the measured kinematics is required in an object coordinate system (O) with a known orientation with respect to standard sensor coordinate frame (S), the object alignment matrix can also be set with an arbitrary but known orientation. This can be useful if for mechanical reasons the MTi / MTx can only be fastened in some specific orientation. The **MTi and MTx Low-level communication protocol** describes the message SetObjectAlignment that is required to set the matrix.

The object alignment matrix (R_{OS}) is applied to the output data (R_{GS}) according to the following equations. For 3D orientation data,

$$R_{GO} = R_{GS} (R_{OS})^T$$

and for inertial and magnetic data.

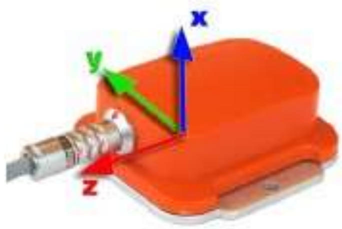
$$s_O = R_{OS}\, s_S$$

Example
The object alignment matrix is given by

$$R_{OS} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix}$$

Here ***O*** represents the object coordinate system and ***S*** the standard sensor coordinate system described in section 2.1.1. Once the object alignment matrix is set to R_{OS}, the sensor output will be expressed with respect to the object coordinate system drawn in following figure (b).

(a)



(b)

The MTi with the sensor coordinate frame (a) and the object coordinate frame (b).

4.6.3 Heading reset

Often it is important that the global Z-axis remains along the vertical (defined by local gravity vector), but the global X-axis has to be in a particular direction. In this case a heading reset may be used, this is also known as "bore sighting". When performing a heading reset, the new global reference frame is chosen such that the global X-axis points in the direction of the sensor while keeping the global Z-axis vertical (along gravity, pointing upwards). In other words: The new global frame has the Z axis along gravity, pointing upwards, the X-axis in the plane spanned by the vertical and the sensor X-axis, perpendicular to the global Z-axis and the Y-axis such that a right handed coordinate system is formed.

NOTE: After a heading reset, the yaw may not be exactly zero, this occurs especially when the X-axis is close to the vertical. This is caused by the definition of the yaw when using Euler angles, which becomes unstable when the pitch approaches ± 90 deg.

4.6.4 Object reset

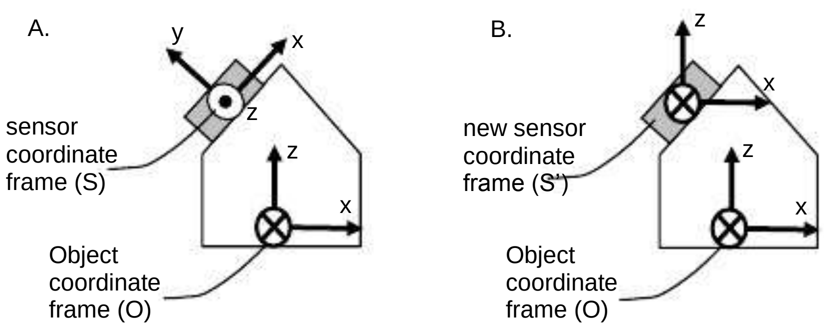
The object reset function aims to facilitate in aligning the MTi / MTx coordinate frame (S) with the coordinate frame of the object to which the sensor is attached (O). After an object reset, the ***S*** coordinate frame is changed to S' as follows:

- the S' Z-axis is the vertical (up) at time of reset
- the S' X-axis equals the S X-axis, but projected on the new horizontal plane.
- the S' Y-axis is chosen as to obtain a right handed coordinate frame.

NOTE: Once this object reset is conducted, both calibrated data and orientation will be output in the new coordinate frame (S').

The object reset can be used to set the MTi / MTx coordinate frame to that of the object to which it is attached (see figure below). **The sensor has to be attached in such a way that the *X-axis* is in the XZ-plane of the object coordinate frame (situation A), i.e. the MTi / MTx can be used to identify the X-axis of the object. To** preserve the global vertical, the object must be oriented such that the object z-axis is vertical. The object reset causes the new S' coordinate frame and the object coordinate frame to be aligned (situation B).

NOTE: Since the sensor X-axis is used to describe the direction of the object X-axis, the reset will not work if the sensor X-axis is aligned along the Z-axis of the object.



MTi or MTx coordinate frame before (A) and after (B) object reset. The new Z-axis of the sensor coordinate frame will be along the vertical. The new direction of the X-axis will be the old X–axis that is projected on the horizontal plane.

4.6.5 Alignment reset

The alignment reset simply combines the Object reset and the Heading reset at a single instant in time. This has the advantage that all co-ordinate systems can be aligned with a single action. Keep in mind that the new global reference x-axis (heading) is defined by the object X-axis (to which XZ-plane you have aligned the MTi / MTx).

NOTE: Once this alignment reset is conducted, both calibrated data and orientation will be output with respect to the new S' coordinate frame.

4.7 Timestamp output

Timestamp output can be enabled or disabled (using the SetOutputSettings message). The timestamp is always last in the data field of the MTData message.

Currently, there is one option for the timestamp output, the sample counter which is a 16 bit counter increasing with 1 with each MTData message sent. After reaching (2^16) -1= 65535 the sample counter will wrap to zero (0).

4.8 Test and Calibration Certificate

Each MTi and MTx is accompanied by an individual Test and Calibration Certificate. This certificate states the calibration values determined during the calibration of the MTi and MTx in Xsens' calibration facilities. The values are explained here in short:

The "Specifications" chapter contains the full ranges and bandwidths of the physical sensors inside.

The "Basic test results" describes the noise of the 3 sensor types and it contains residuals in orientation.

Noise	The noise on the individual sensor signals [16].
Static accuracy residual	The residual calibration error for static orientations at room temperature
Temperature residual	The residual calibration error for static orientations over the temperature range

"Calibration **data"** are the values that describe the conversion from the physical phenomenon to a digital output in an orthogonal coordinate system:

Gains (bits): Gains (or scale factor) describe the relation between the digital reading in bits and the measured physical signal.

Offsets (bits): Digital reading in bits of the sensor no physical signal is measured.

Alignment matrix: Non-orthogonality of the sensor triade. This includes non-orthogonality in the orientation

[16] The resolution of the sensor signals are always limited by the noise in the sensor signal, not by the accuracy or resolution of the analog to digial converter. Exceptions are the temperature and static pressure sensor where quantization can be significant.

of the sensitive system inside the MEMS sensor, the mounting of the sensors on the PCB of the MTi and MTx, the mounting of the PCB's and the misalignment of the OEM board in the MTi housing.

Next to the basic Test and Calibration values documented in the certificate, 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 [17]).

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

5 Basic communication

5.1 Introduction

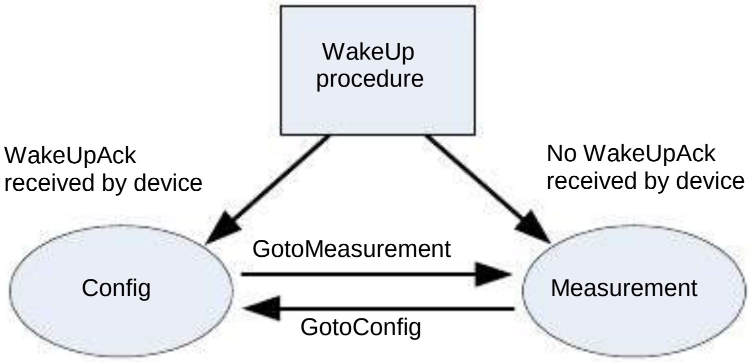
This section describes the basics of how to communicate with the MTi / MTx directly on low-level using RS-232/422/485 serial communication with or without the use of an Xsens USB-serial converter. For a detailed and complete list of all messages please refer to the MT Low-level Communication Documentation.

NOTE: You can skip this chapter if you plan to only interface with the device using Xsens' GUI software or SDK API.

The communication protocol, which is message based, enables the user to change the configuration of the MTi or MTx and to retrieve the data from the device. The communication protocol used for the MTi and MTx is compliant to the **MotionTracker communication protocol**[18]. The configuration is fully user-settable, e.g. sample frequency, in- & output synchronization, baudrate and data output modes, can all be changed to fit your requirements.

All configuration changes must be made while the device is in the so-called Config State. In this state the device accepts messages that set the output mode or changes to other settings. Whenever the preferred configuration is completed the user can set the device to Measurement State. In this state the device outputs data based the current configuration settings.

5.2 States



The MTi / MTx has two states, i.e. Config State and Measurement State. In the Config State various settings can be read and written. In the Measurement State the device will output its data message which contains data dependent on the current configuration.

There are two different ways to enter the Config State or the Measurement State. At power-up the device starts the WakeUp procedure, if no action is taken it will then enter Measurement State by default, using its latest stored configuration.

Prior to entering the Measurement State, the Configuration message is always sent to the host[19]. This is the configuration that is read from the internal non-volatile memory and will be used in the Measurement

[18] The MotionTracker-host protocol is a fully documented standard message based protocol developed by Xsens tailor made for the needs of inertial sensors.

[19] If the device is set to RAW OutputMode the device will send additional encrypted data to the host after sending the Configuration message. The encrypted data primarily contains the calibration values of the

State. The data in the Configuration message can always be used to determine the output mode and settings. It is also possible to enter the Config State at power-up, see WakeUp message description in the MTi **and MTx Low-Level Communication Document. Another way to enter the Config State or Measurement State** is to use the GoToConfig or GoToMeasurement messages.

The default configuration of the MTi / MTx is shown in the following table.

	Value
Output mode	Orientation output
Output settings	Orientation in quaternion mode
	Sample counter enabled
Sample frequency	100 Hz
Baudrate	115k2 bps
Output skip factor	0

With the default configuration the MTi / MTx outputs in Measurement State the MTData message at a frequency of 100Hz (based on its internal clock). The MTData message contains the orientation data in quaternions together with a sample counter.

If you want to retrieve the output data on request then set Output skip factor to value 65535 (0xFFFF) and send ReqMTData message to the device. For more information see MTi and MTx Low-Level Communication **Document.**

5.3 Messages

5.3.1 Message structure

The communication with the MTi and MTx is done by messages which are built according to a standard structure. The standard MT message can contain zero to 254 bytes of data and the total length is five to 259 bytes.

An MT message contains the following fields:

PRE	BID	MID	LEN	DATA	CS

Field	Field width	Description
PRE	1 byte	Preamble, indicator of start of packet 250 (0xFA)
BID	1 byte	Bus identifier / address 255 (0xFF)
MID	1 byte	Message identifier
LEN	1 byte	Value equals number of bytes in DATA field Maximum value is 254 (0xFE). Value 255 (0xFF) is reserved.
DATA	0 – 254 bytes	Data bytes (optional)
CS	1 byte	Checksum of message

device. This data is referred to as the eMTS data (extended Motion Tracker Specification data). This data is required to be able to later process the data by Xsens software to calculate calibrated inertial data values as well as estimating orientation etc.

Preamble (PRE)
Every message starts with the preamble. This field always contains the value 250 (=0xFA).

Bus identifier (BID) or Address
All messages used for the MTi and MTx use the address value 255 (0xFF) indicating a "master device". MT's used on the Xbus have other BID's.

Message Identifier (MID)
This message field identifies the kind of message. For a complete listing of all possible messages see MTi and **MTx Low-Level Communication Document.**

Length (LEN)
Specifies the number of data bytes in the DATA field. Value 255 (=0xFF) is reserved. This means that a message has a maximum payload of 254 bytes. If Length is zero no data field exists.

Data (DATA)
This field contains the data bytes and it has a variable length which is specified in the Length field. The interpretation of the data bytes are message specific, i.e. depending on the MID value the meaning of the data bytes is different. See the description of the specific message for more details about interpretation of the data bytes.

Checksum
This field is used for communication error-detection. If all message bytes excluding the preamble are summed and the lower byte value of the result equals zero, the message is valid and it may be processed. The checksum value of the message should be included in the summation.

5.3.2 Message usage

Generally, a message with a certain MID value will be replied with a message with a MID value that is increased by one, i.e. the acknowledge message. Depending on the type of message the acknowledge message has no or a certain number of data bytes. In some cases an error message will be returned (MID = 66 (0x42)). This occurs in case the previous message has invalid parameters, is not valid, or could not be successfully executed. An error message contains an error code in its data field.

Example
Requesting the device ID of an MTi / MTx:

Sending message:
ReqDID =0xFA 0xFF 0x00 0x00 0x01 (hexadecimal values)

Receiving message (= Acknowledge):
DeviceID =0xFA 0xFF 0x01 0x04 HH HL LH LL CS (hexadecimal values)

The requested Device ID is given in the acknowledged message DeviceID (here shown as: HH HL LH LL, the checksum is CS). As you can see the MID (Message ID) of the acknowledgement is increased by one in comparison with the sending message ReqDID.

Some messages have the same MID and depending on whether or not the message contains the data field the meaning differs. This is the case with all the messages that refer to changeable settings. For example, the MID of message requesting the output mode (ReqOutputMode) is the same as the message that sets the output mode (SetOutputMode). The difference between the two messages is that the Length field of ReqOutputMode is zero and non-zero for SetOutputMode.

Example
Request current output mode:
Sending message:
ReqOutputMode =0xFA 0xFF 0xD0 0x00 0x31 (hexadecimal values)
Receiving message (= Acknowledge):
ReqOutputModeAck =0xFA 0xFF 0xD1 0x02 MH ML CS (hexadecimal values)

ReqOutputModeAck contains data which represents the current mode (= MH & ML). CS stands for the checksum value. To change the output mode you must add the new mode in the data field of the sending message:

Set the output mode:
Sending message:
SetOutputMode =0xFA 0xFF 0xD0 0x02 MH ML CS (hexadecimal values)
Receiving message (= Acknowledge):
SetOutputModeAck =0xFA 0xFF 0xD1 0x00 0x30 (hexadecimal values)

5.3.3 Common messages

GoToConfig

MID	48 (0x30)
Data field	n/a
Direction	To MTi / MTx
Valid in	Measurement State & Config State

Switches the active state of the device from Measurement State to Config State. This message can also be used in Config State to confirm that Config State is currently the active state.

SetOutputMode

MID	208 (0xD0)
Data field	MODE (2 bytes)
Direction	To MTi / MTx
Valid in	Config State

Sets the output mode of the MTi / MTx. The output mode can be set to various output modes of which most of them can be combined, like for example calibrated sensor data and orientation data.
The un-calibrated raw inertial data output however can not be used together with any of the other outputs.

MODE

	R		R	R	R	R	R	R	R	R	R	R				
Bit #	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

MODE bits	Output mode
Bit 0	Temperature data
Bit 1	Calibrated data
Bit 2	Orientation data
Bit 3	Auxiliary data (see also SetOutputSettings)
Bit 14	Un-calibrated raw data (not in combination with calibrated sensor data and/or orientation data)

SetOutputSetings

MID	210 (0xD2)
Data field	SETTINGS (4 bytes)
Direction	To MTi / MTx
Valid in	Config State

Sets the output settings of the MTi / MTx.

SETTINGS

Bit #	31 - 24	23 - 16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	Reserved	Reserved	R	R	R	R	R				R							

SETTINGS bits	Settings
Bit 1-0	Timestamp output
	00 = No timestamp
	01 = Sample Counter
	Orientation Mode
Bit 3-2	00 = Quaternion
	01 = Euler angles
	10 = Matrix
	Calibration Mode
	Bit 4: 0 = Enable acceleration (XYZ) output
Bit 6-4	1 = Disable acceleration (XYZ) output
	Bit 5: 0 = Enable rate of turn (XYZ) output
	1 = Disable rate of turn (XYZ) output
	Bit 6: 0 = Enable magnetometer (XYZ) output
	1 = Disable magnetometer (XYZ) output
	Reserved
	Output Format
	00 = Float output
	01 = Fixed point Signed 12.20 format
Bit 7	Auxiliary Mode
Bit 9-8	Bit 10: 0 = Enable analog in #1 output
	1 = Disable analog in #1 output
	Bit 11: Reserved
	Bit 12: Reserved
	Bit 13: Reserved
Bit 13-10	Reserved
Bit 31-14	

GoToMeasurement

MID	16 (0x10)
Data field	n/a
Direction	To MTi / MTx
Valid in	Config State

Switches the active state of the device from Config State to Measurement State. The current configuration settings are used to start the measurement.

MTData

MID	50 (0x32)
Data field	DATA (length variable)
Direction	From MTi / MTx
Valid in	Measurement State

This message contains the output data depending on the current Output Mode and Output settings.
The data field can contain multiple data outputs but the order of outputs is always the same. The following order is used (disabled outputs must be omitted):

1. Temp
2. Calibrated data output
3. Orientation data output
4. Auxiliary data output
5. Status
6. Sample counter

Un-calibrated raw data output can not be used together with other outputs and is therefore not listed. The following text explains the data values of each output.

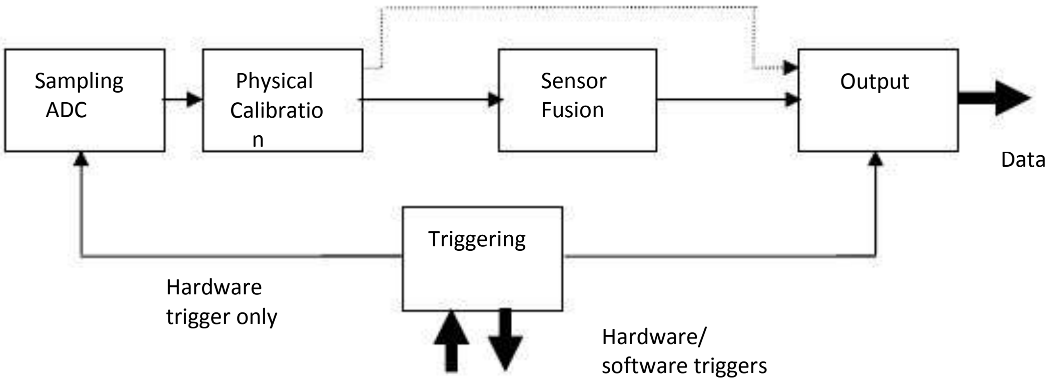
DATA
The data can contain multiple outputs. All the different outputs are not described separately here. If not specified otherwise each data value is 4 bytes long by default and corresponds with the single-precision floating-point value as defined in the IEEE 754 standard (= float). Other data formats are also supported.

NOTE: RAW inertial data output however can not be used together with any of the other outputs. It is therefore not listed above. Please refer to the **MT Low-Level Communication Document** for detailed information on the various DATA modes and options, interpretation of the values as well as a detailed discussion on the DATA fields.

The Communication MT (CMT) C++ class has easy to use member functions to retrieve the individual data fields. See MT SDK Documentation.

5.4 Communication Timing

For many applications it can be crucial to know exactly the various delays and latencies in a system. In this section it is described how the timing between physical events and the device output are related in the basic usage modes of the MTi and MTx.



When the MTi / MTx is in Measurement State, the internal DSP continuously runs a loop roughly according to the above diagram. The triggering can be generated by device internal sampling triggers, or by external software triggers (polling), or even hardware triggers (normally not recommended). For more information about triggering see section 5.5.

The time delay between a physical event (e.g. an orientation change or acceleration) is dictated by two factors;

1. Internal acquisition and calculation time
2. Serial transmission time

The internal acquisition and calculation time is dependent on the scenario and the output mode. The following table shows the internal acquisition and computation times of all scenarios and output modes. Since the Xsens Kalman Filter applies different calculations depending on the data available, the computation time is not constant. In the table below the longest (worst case) computation times are listed since these are usually of particular importance for control applications. Internal acquisition time of raw data is 0.19 ms.

acquisition and acquisition and computation time computation time		
[illegible]		
XKF-3 scenario – Machine 0.31 ms2.55 ms		
XKF-3 scenario – Machine_nomagfield 0.31 ms2.01 ms		
XKF-3 scenario – Marine0.31 ms2.55 ms		
There is no difference between the internal acquisition and computation time of orientation data and calibrated data/orientation data together.		

The serial transmission time can easily be calculated:

$$\frac{total\_bytes\_in\_message * 10bits/byte}{communication\_baudrate\ (bits/s)} = transmission\_time$$

These two factors will be discussed using the example of the two common output modes of the MTi and MTx.

The bytes in the message consist of the Preamble, BusID, MessageID, length indicator, data itself and the checksum:

PREAMBLE	BID	MID	LEN	DATA	CHECKSUM

The Preamble, BusID, MesssageID, length indicator and checksum together is always 5 bytes. The length of the various data messages is discussed in [LLCP].

Example 1: Calibrated data output mode at 100 Hz with a baud rate of 115200 bps.

Calibrated data is 36 bytes.

$$transmission\_time = \frac{(36+5) * 10 bits/byte}{115200 (bits/s)} = 3.56\ ms$$

Together with the internal acquisition and computation time (1.97 ms for machine_nomag scenario), the total time from acquisition of the data until the reception at the host is 5.53 ms.

Example 2: Quaternion orientation data output mode plus timestamp at 120 Hz with a baud rate of 921600 bps.

Quaternion orientation data is 16 bytes, timestamp is 2 bytes.

$$transmission\_time = \frac{(18+5) * 10 bits/byte}{921600 (bits/s)} = 0.25 ms$$

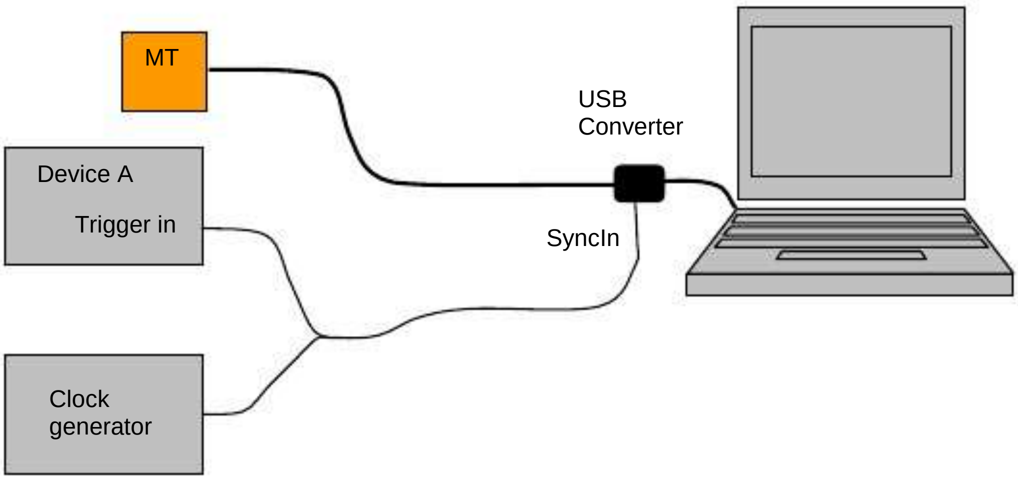
Together with the internal acquisition and computation time (1.97 ms for machine_nomag scenario), the total time from acquisition of the data until the reception at the host is 2.22 ms.

5.5 *Triggering & synchronization*

In case multiple systems are used during a measurement it is important to have the measurement data synchronized between the systems. Processing synchronised data is much easier because there is no need to resample the data to compensate for timing inaccuracies like clock drift and clock deviations. Synchronization using multiple systems involves 2 important issues: starting the measurement at the same time and having a fixed time relationship of the sampling instances. This section will explain how the MTi / MTx must be setup when using multiple measurement systems.
The MTi / MTx have capabilities to be triggered by external devices or trigger external devices. These two scenarios are explained in the following subsections.

5.5.1 External device triggers MTi / MTx

In the following figure, a possible configuration is shown where a Motion Tracker and Device A are synchronised. In this example, a clock generator triggers device A and a MTi / MTx ensuring that the two devices are synchronized with each other.



The output of the clock generator can be directly connected to the MTi / MTx or to the spare header of the USB converter as shown in the figure above. More information about this can be found in section 6.4.1.

NOTE: Always check if the SyncIn specification matches with the trigger signal. See section 6.4.

The following MTi / MTx devices support SyncIn, MTi-28A##G## (MTi RS-232), MTi-48A##G## (MTi RS-485), MTi-68A##G## (MTi RS-422) and MTx-28A##G## (MTx RS-232).

The SyncIn signal can either trigger the transmission of the latest data or the internal sensor sampling. The first SyncIn mode is highly recommended in situations where the clock signal is not reliable and/or accurate. More information is given in the next two sections. For more information about the SyncIn modes and settings see **MTi and MTx Low-Level Communication Document.**

Transmission of the latest data
In this SyncIn mode the internal clock and the stored sample frequency determine when the sampling of the sensor signals start. The data is transmitted only if a trigger is detected on the SyncIn line. This means that the trigger instance will not coincide with the sampling instance of the transmitted data. Because two different clocks are used the time difference between the trigger instance and the sampling instance may also vary during the measurement and at most with a time equal to the used sampling period. Nevertheless this mode is preferred if the clock generator is not that accurate as the internal clock of the MTi / MTx. In this mode a SyncIn trigger will always transmit the latest data available.

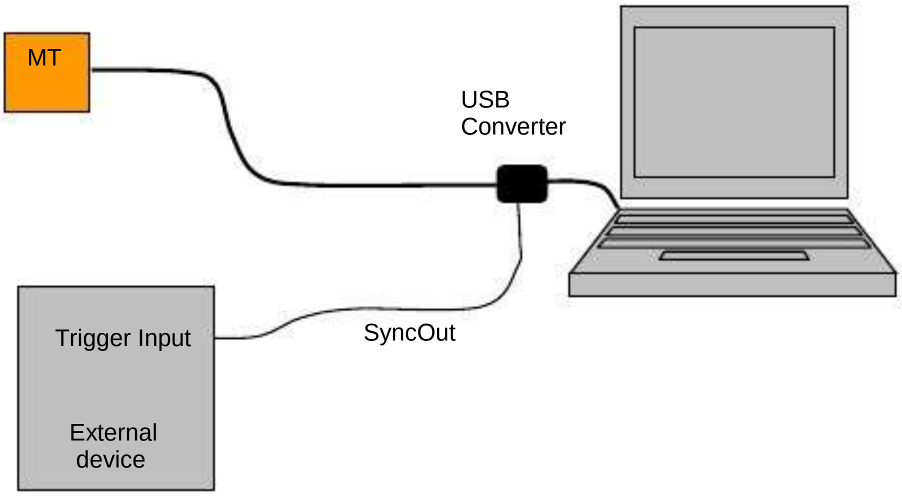
Trigger the sampling of the internal sensors
In this SyncIn mode the external signal connected to the SyncIn line of the MTi / MTx starts the sampling (AD conversion) of the sensor signals, i.e. accelerations, rate-of-turn, magnetic field and temperature. Next, depending on the OutputMode, the physical calibration and the sensor fusion (XKF) are started. If all data is processed it will be transmitted at a rate depending on the OutputSkipFactor (see **MTi and MTx Low-Level Communication Document).**

In this SyncIn mode it is important to set the MTi / MTx sample frequency to the same frequency as the trigger signal. Furthermore the trigger signal should have at least the same accuracy as the internal clock of the MTi / MTx (see section 5.6). This is because the stored sample frequency is used in the sensor fusion calculations and is not corrected by deviations in the trigger signal. If the accuracy is not high enough or the sample frequency cannot be accurately matched you must choose the first SyncIn mode (transmission of latest data).Moreover, a sample frequency below 100 Hz is not supported by the MTi / MTx since it would compromise total accuracy, so the trigger frequency must be at least 100 Hz. Note that the output frequencies lower than 100 Hz are supported.

5.5.2 MTi / MTx triggers external devices

In case the clock specification of the MTi / MTx is accurate enough for the measurement, the MTi / MTx can provide a sync pulse which is generated based on its internal clock. For more details on clock accuracy see section 5.6. The sync pulse or SyncOut signal will mark the time instance at which the MTi /MTx starts sampling the internal sensors[20] and continue doing this while the MTi / MTx is in measurement state and with the frequency related to the current sample frequency. The signal can be set to either pulse or toggle mode and in case of pulse mode the polarity can be set to negative or positive. For more information about enabling SyncOut and its settings see MTi and MTx Low-Level Communication Document.

To connect the SyncOut signal to an external device you can either make a custom cable that wires the SyncOut pin (see section 6.4) directly from the MTi / MTx or in case you use the USB-serial data and power cable you can use a spare header in the USB converter for a connection to the SyncOut line (see section 6.4.1). This configuration is shown in the next figure.



NOTE: Always check if the input voltage levels and the input impedance of the external device matches the SyncOut specifications (see section 6.4).

The following MTi devices support SyncOut: MTi-28A##G## (MTi RS-232) and MTi-48A##G## (MTi RS-485).

[20] Provided that the SyncOut offset setting is zero.

5.6 Internal clock accuracy

The internal clock jitter of the MTi and MTx is less than 25ns.

The internal clock of the MTi and MTx which generates the sample timing based on the set sample period is accurate to ±30 ppm over the temperature operating range. In practice this means that the worst case deviation after a 1 hour log is ± 0.108 seconds (= 3600 s · 30 ppm) or 10 sample counts in 360,000 at 100 Hz sample rate (± 0.3 µs/sample @ 100 Hz).

NOTE: For long logging times that require synchronization with external clocks or events, means of synchronization with a high-precision external clock should be considered.

5.7 Default Serial Connection Settings

Setting	Default Value
Bits/second (bps):	**115200**
Data bits:	**8**
Parity:	**none**
Stop bits:	**1** (21)
Flow control:	**none**

These settings are the same for the RS-232 as the RS-422 versions. The baudrate (bps) setting can be changed by the user. The maximum is 921600 bps and the minimum 9600 bps. Please refer to the MTi and MTx Low-**level Communication Documentation for details.**

5.7.1 General definitions for binary data

All binary data communication is done in big-endian format.

Example:

Un-calibrated 16 bits accelerometer output
1275 (decimal) = 0x04FB (hexadecimal)
Transmission order of bytes = 0x04 0xFB

Calibrated accelerometer output (float, 4 bytes)
9.81 (decimal) = 0x411CF5C3 (hexadecimal)
Transmission order of bytes = 0x41 0x1C 0xF5 0xC3

The bit-order in a byte is always:

[MSB…LSB] [bit 7 …bit 0]

[21] Two stop bits are needed for devices produced earlier than January 1st 2008 in order to allow correct frame-timing. One stop bit is always possible in receive-only mode. For devices produced since January 1st 2008 one stop bit can be used in any mode.

6 Physical Specifications

6.1 Physical sensor overview

MTi and MTx Sensor Fact Table	
Accelerometers	MEMS solid state, capacitative readout
Rate of turn sensor (rate gyroscope)	MEMS solid state, monolithic, beam structure, capacitative readout
Magnetometer	Thin film magnetoresistive

Further, the MTi and MTx have several onboard temperature sensors to allow compensation for temperature dependency of the various sensors.

6.2 Physical properties overview

6.2.1 MTi overview

	MTi-28A##G##	MTi-48A##G##	MTi-68A##G##
Communication interface:	Serial digital (RS-232)	Serial digital (RS-485)	Serial digital (RS-422)
Additional interfaces:	SyncIn SyncOut Analog In	SyncIn SyncOut	SyncIn
Operating voltage [22]:	4.5-30 V	4.5-30 V	4.5-30 V
Power consumption [23]: (AHRS/3D orientation mode)	350 mW	350 mW	350 mW
Temperature Operating Range:	-20°C - 55°C	-20°C - 55°C	-20°C - 55°C
Specified performance Operating Range:	0°C - 55°C	0°C - 55°C	0°C - 55°C
Outline Dimensions:	58 x 58 x 22 mm (W x L x H)	58 x 58 x 22 mm (W x L x H)	58 x 58 x 22 mm (W x L x H)
Weight:	50 g	50 g	50 g

6.2.2 MTx overview

	MTx-28A##G##	MTx-48A##G##	MTx-49A##G##
Communication Interface:	Serial digital (RS-232)	Serial digital (RS-485)	Serial digital (RS-485, Xbus)
Additional Interfaces:	SyncIn	-	Analog Input
Operating Voltage[22]:	4.5-30 V	4.5-30 V	4.5-30 V
Power consumption[23]: (AHRS/3D orientation mode)	350 mW	350 mW	350 mW
Temperature Operating Range:	-20°C - 55°C	-20°C - 55°C	-20°C - 55°C
Specified performance Operating Range:	0°C - 55°C	0°C - 55°C	0°C - 55°C
Outline Dimensions:	38 x 53 x 21 mm (W x L x H)	38 x 53 x 21 mm (W x L x H)	38 x 53 x 21 mm (W x L x H)
Weight:	30 g	30 g	30 g

---

22 The previous revision of the Motion Tracker has a maximum input voltage of 15V instead of 30V. It also has no reverse voltage protection. These Motion Trackers have serial numbers lower than 2000 (last 4 digits only).

23 Power consumption at 5V DC The following sensors MT-28xxxxxx DID<303800, MT-68xxxxxx DID<310200, MT-49xxxxxx ID<323800, MT-48xxxxxx ID<330200 have different specifications, power consumption will be approximately 90mA@5V = 450mW when using firmware 2.2 or higher. Increasing baudrate from 115k2 to 460k8 will decrease 10% in power consumption for all configurations. Please note that efficiency of the power input stage will decrease with increasing supply voltage. At 5...6 V DC the efficiency is optimal, at 30V DC the efficiency is around 75%.

6.3 Power supply

The nominal power supply of the MTi and MTx is 5V DC.

The minimum operating supply voltage is >4.5V and the absolute maximum is <30V.

- The sensor works at a power supply of >4.5-30V [24]. Use only SELV (Separated or Safety extra-low voltage) power supplies (double isolated) that are short-circuit proof.
- The average operating power consumption is 350mW (~70 mA @ 5V) for the MTi and MTx. The average power consumption may vary slightly with usage mode (DSP load). Please note that efficiency of the power input stage will decrease with increasing supply voltage. At 5…6 V DC the efficiency is optimal, at 30V DC the efficiency is around 75%.
- The peak current at startup (power on) can be up to 200mA [25].
- When operated in room temperature the temperature inside the sensor will be 33-40°C in normal conditions.

6.4 Physical interface specifications

6.4.1 USB-serial data and power cables overview

RS-232 MTi cable (CA-USB2)
RS-485 MTi cable (CA-USB4)
RS-422 MTi cable (CA-USB6)

RS-232 MTx cable (CA-USB2x)
RS-485 MTx cable (CA-USB4x)

[24] The previous revision of the Motion Tracker has an absolute maximum input voltage of 15V instead of 30V. These Motion Trackers have a serial number lower than 2000 (last four digits only).

[25] If an alternative power supply is used check if it can supply these peak currents. Do not use a power supply if the peak supply current is lower than stated.

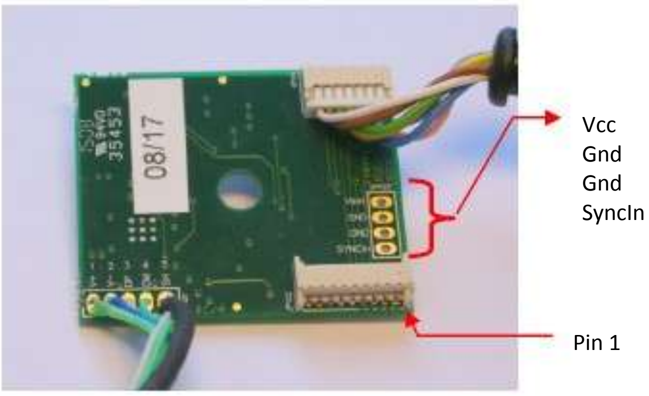
The USB-serial data and power cable delivered with the MTi and MTx Development Kit is compatible with USB 1.1 and higher. Make sure your PC USB outlet is rated to deliver 100 mA or more (all USB compliant outlets should be).

The RS-422 MTi cable (CA-USB6) is compatible with the RS-422 version of the MTi. Blue cable markers are located at the connector and the casing for visual distinction between the RS-232 MTi cable. The MTx can not be ordered with RS-422 interface therefore no RS-422 MTx cable is available. The RS-485 MTi / MTx cable has yellow cable markers to indicate RS-485 interface instead of RS-232.

The USB-serial data and power cable provides easy access to the individual pins of the Motion Tracker. Inside the housing there is a free connector that can for example be used for synchronization purposes. The following photo shows the location of the connector.

It is a 9-pins Molex header type 53048-0910 and it mates with the Molex crimp housing type 51021-0900 (Farnell InOne code 615122). Farnell also offers crimp leads for these housings, e.g. Farnell InOne code 889570.

The 7 pins Molex header is type 53047-0710 (Farnell InOne code 9732870) and mates with Molex crimp housing type 51021-0700 (Farnell InOne code 615110).



The first 5 or 7 pin definitions are the same as the pin definitions of the connected Motion Tracker, i.e. pins one to seven for MTi and pins one to five for MTx. Check the following sections for the pin definitions of your MTi/MTx. Pin 8 is always ground and pin 9 is reserved (do not use this pin).

ex pin MTi RS-232 MTi RS-485MTi RS-422
Pin 1 VCC VCCVCC
Pin 2 GND GNDGND
Pin 3 Analog IN Y / ATX+ / A1 (sensor)
Pin 4 TX (sensor) Z / BTX- / B1 (sensor)
Pin 5 RX (sensor) ReservedRX+ / A2 (sensor)
Pin 6 SyncOut SyncOutRX- / B2 (sensor)
Pin 7 SyncIn SyncInSyncIn

Pin 1 VCC VCC
Pin 2 GND GND

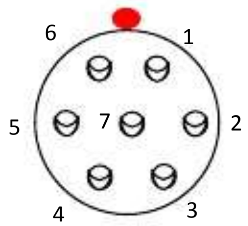
Pin 3	Reserved	Z / B
Pin 4	TX (sensor)	Y / A
Pin 5	RX (sensor)	Reserved
Pin 6	Reserved	Reserved
Pin 7	SyncIn	Reserved

For definition of wire colors see next sections.

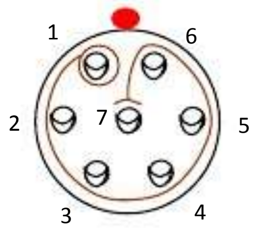
The operating temperature of the USB-serial data and power cable (CA-USB) is 0 °C - 40°C.

The MTi and MTx are designed to be used with the power supply supplied by Xsens (integrated in the RS-232/422/485 to USB cable). It is possible to use other power supplies; however this must be done with care. For safety and EMC any power supply used with the device must comply with the Electromagnetic Compatibility directive.

6.4.2 Pin and wire color definitions MTi-28A##G## (MTi RS-232, standard version)



MTi housing socket
ODU L-series 7 pin female socket (receptacle) back view (solder bucket view)
ODU product code: GL0L0C-T07LCC0-000



MTi USB-serial cable plug (CA-USB2)
ODU L-series 7 pin male connector (plug) back view (solder bucket view)
Solder contact for AWG 28 wire
ODU product code: S10L0C-T07MCC0-5200

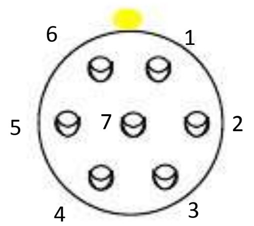
Pin definitions MTi plug/socket and wire color

Signal	ODU pin
VCC	Pin 1
GND	Pin 2
Analog IN	Pin 3

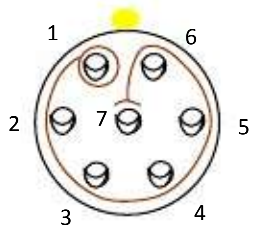
TX (sensor)	Pin 4
RX (sensor)	Pin 5
SyncOut	Pin 6
SyncIn	Pin 7

ODU pin	Unitronic	Elitronic
Pin 1	Yellow	White
Pin 2	Yellow-green	Brown
Pin 3	Black	Green
Pin 4	Beige	Yellow
Pin 5	Brown	Grey
Pin 6	Green	Pink
Pin 7	Blue	Blue

6.4.3 Pin and wire color definitions MTi-48A##G## (MTi RS-485)



MTi housing socket
ODU L-series 7 pin female socket (receptacle) back view (solder bucket view)
ODU product code: GL0L0C-T07LCC0-000



MTi USB-serial cable plug (CA-USB4)
ODU L-series 7 pin male connector (plug) back view (solder bucket view)
Solder contact for AWG 28 wire
ODU product code: S10L0C-T07MCC0-5200
Cable has a yellow marker at the connector side

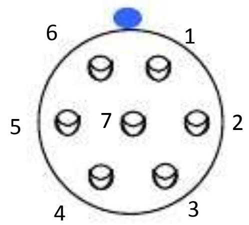
Pin definitions MTi plug/socket and wire color

pin	
VCC Pin 1	
GND Pin 2	
Y / A Pin 3	
Z / B Pin 4	

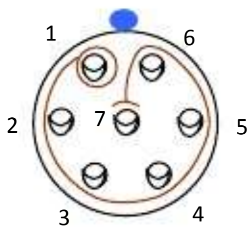
Reserved	Pin 5
SyncOut	Pin 6
SyncIn	Pin 7

ODU pin	Unitronic cable	Elitronic cable
Pin 1	Yellow	White
Pin 2	Yellow-green	Brown
Pin 3	Black	Green
Pin 4	Beige	Yellow
Pin 5	Brown	Grey
Pin 6	Green	Pink
Pin 7	Blue	Blue

6.4.4 Pin and wire color definitions MTi-68A##G## (MTi RS-422)



MTi housing socket
ODU L-series 7 pin female socket (receptacle) back view (solder bucket view)
ODU product code: GL0L0C-T07LCC0-000



MTi USB-serial cable plug (CA-USB6)
ODU L-series 7 pin male connector (plug) back view (solder bucket view)
Solder contact for AWG 28 wire
ODU product code: S10L0C-T07MCC0-5200
Cable has a blue marker at the connector side

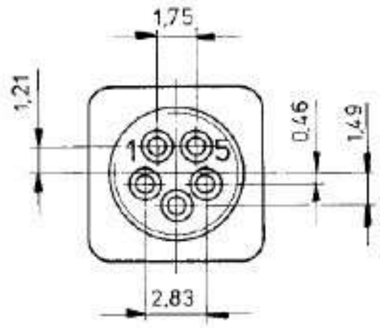
Pin definitions MTi plug/socket and wire color

Signal	ODU pin
VCC	Pin 1
GND	Pin 2
TX+ / A1 (sensor)	Pin 3

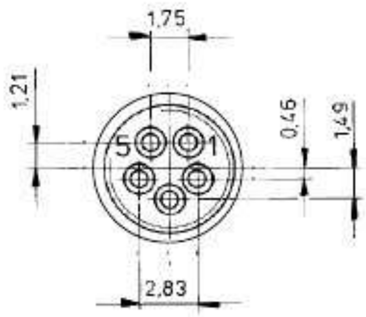
TX- / B1 (sensor)	Pin 4
RX+ / A2 (sensor)	Pin 5
RX- / B2 (sensor)	Pin 6
SyncIn	Pin 7

ODU pin	**Unitronic cable**	**Elitronic cable**
Pin 1	Yellow	White
Pin 2	Yellow-green	Brown
Pin 3	Black	Green
Pin 4	Beige	Yellow
Pin 5	Brown	Grey
Pin 6	Green	Pink
Pin 7	Blue	Blue

6.4.5 Pin and wire color definitions MTx-28A##G## (MTx RS-232, standard version)



MTx housing socket
Binder **female** 719 socket (receptacle), **back view** (solder bucket view)
ridge on upper side



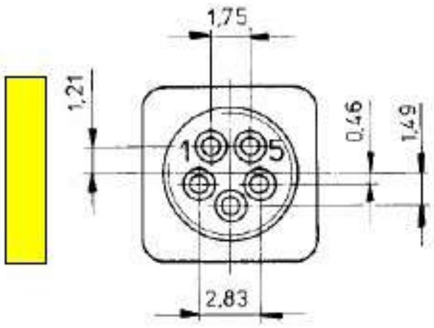
MTx USB-serial cable plug (CA-USB2x)
Binder 719 male connector, back view (solder bucket view)
Ridge on upper side

Pin definitions MTx plug/socket and wire color

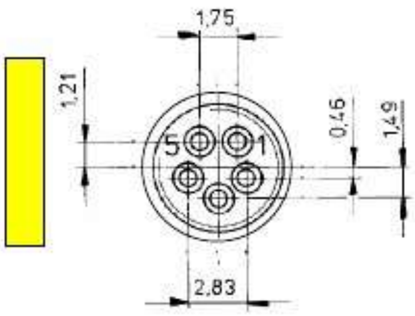
Binder pinUnitronic cable			**Elitronic cable**

VCC	Pin 2	Black	Brown
GND	Pin 4	Yellow-green	Yellow
TX (sensor)	Pin 1	Beige	White
RX (sensor)	Pin 5	Brown	Grey
SyncIn	Pin 3	Blue	Green

6.4.6 Pin and wire color definitions MTx-48A##G## (MTx RS-485 standalone)



MTx housing socket
Binder **female** 719 socket (receptacle), **back view** (solder bucket view)
ridge on upper side



MTx USB-serial cable plug (CA-USB4x)
Binder 719 male connector, back view (solder bucket view)
Ridge on upper side

Pin definitions MTx plug/socket and wire color

VCC P			Elitronic cable
GND Pin 4 Yellow-green			Brown
Z / B Pin 1 Beige			Yellow
Y / A Pin 5 Brown			White
Do not use Pin 3 Blue			Grey
			Green

6.4.7 Pin and wire color definitions MTx-49A##G## (MTx Xbus)

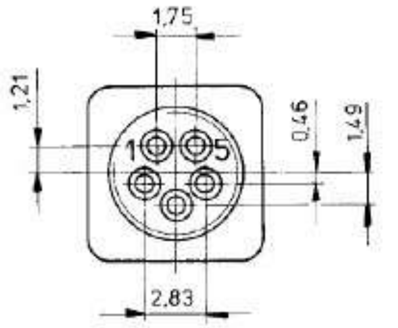
Pin definitions MTx socket and wire color

Signal	Binder pin	Grey Unitronic	Grey Elitronic	Black cable
VCC	Pin 2	Black	Yellow	Red
GND	Pin 4	Yellow-green	Grey	Black
Z / B	Pin 1	Beige	White	White
Y / A	Pin 5	Brown	Green	Green
Analog IN	Pin 3	Blue	Brown	Blue

MTx housing socket

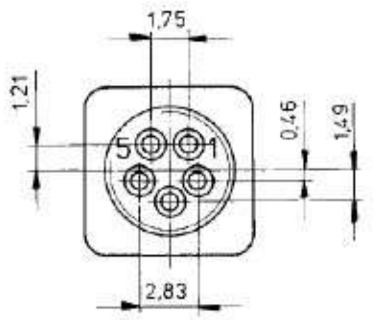
Binder 719 female, back view (solder bucket view)

ridge on upper side



Signal	Binder pin	Grey Unitronic	Grey Elitronic	Black cable
VCC	Pin 2	Black	Yellow	Red
GND	Pin 4	Yellow-green	Grey	Black
Z / B	Pin 1	Beige	White	White
Y / A	Pin 5	Brown	Green	Green
Analog IN	Pin 3	Blue	Brown	Blue

MTx housing plug
Binder 719 male (receptacle) connector, back view
(solder bucket view) ridge on upper side



6.4.8 Additional interface specifications

The MTi & MTx has additional interface lines for synchronization and/or analog input support. Which features are supported depends on the type of device. See pin definitions of the device.

Analog IN

This line supports in 16 bit sampling of an external analog signal of voltage range 0 to 5V at the sampling frequency used by the MTi / MTx. A data field is added to the data message which contains the 16-bit representation of the analog voltage. To enable this functionality use the SetOutputMode and SetOutputSettings messages with the proper parameters as defined in section 5.3.3.

Input volt [redacted]	
Input capacitance	150 pF
ADC resolution	16 bit

Analog IN is supported by MTi RS-232 (MTi-28A##G##) and MTx Xbus (MTx-49A##G##). For best performance, connect the Analog IN signal as close to the ODU connector as possible. Dismantle the cable carefully and read the connection instructions in section 6.4.

NOTE: Please do not hesitate to contact Xsens (support@xsens.com) if you have problems to get Analog IN to work as expected.

SyncIn

This digital input can be used to trigger the MTi / MTx for synchronization purposes. The MTi / MTx can wait until a valid trigger is detected and it either starts sampling or sends the latest calculated data. For more information about the SyncIn settings (timing, polarity) see the MT Low-level Communication Documentation.

The signal specifications are listed in the next table.

Input range high voltage	3.0 to 20V
Input range low voltage	0.0 to 0.5V
Input re [redacted]	
Latency [redacted]	
Latency (offset > 0, not including)	12.2 us
Jitter	500ns@115k2, 104ns@921k6

The recommended duty cycle is <10%. = 1ms @ 100Hz sample frequency.

Supported by MTi RS-232 (MTi-28A##G##), MTi-68A##G## (MTi RS-422) and MTx-28A##G## (MTx RS-232, standard version).

NOTE: Please do not hesitate to contact Xsens (support@xsens.com) if you have problems to get SyncIN to work as expected.

SyncOut

This is an output signal that can trigger other device(s) for synchronization purposes. The triggering instance is related to the sampling instance of the MTi. The signal parameters like type, offset, skipfactor or width can be customized using the SyncOut settings. See the MT Low-level Communication Documentation.

The signal specifications are listed in the next table.

	Value
Output high voltage	3.0-3.3V
Output low voltage	0.0V
Minimum ohmic value of load	10 kOhm
Latency (offset = 0)	-1.1us
Latency (offset > 0)	+5.4us
Jitter	40ns

Supported by MTi RS-232 (MTi-28A##G##)

6.5 Housing mechanical specifications

The plastic parts of the housing are made of polyamide (PA6.6). The MTi bottom plate is made of anodized aluminum (6082). The housing is dust-proof but not water-proof. The MTi connector socket and housing assembly features rubber o-ring sealing and is generally more robust to harsh environments than the MTx.

6.5.1 Environmental protection of the housing

MTi

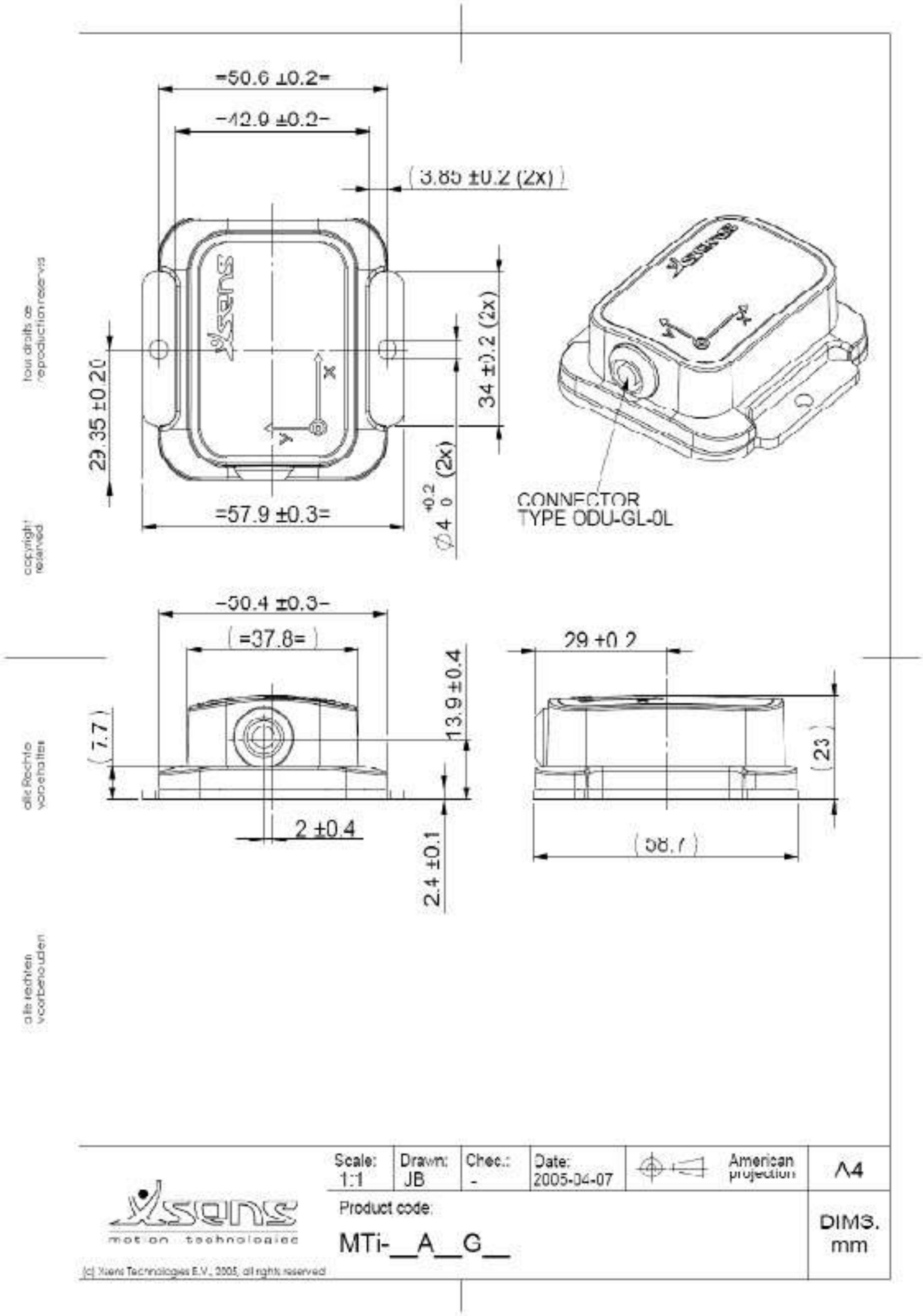
The MTi casing is designed to withstand usage in application where dust and occasional water splashing can be expected. Xsens in house testing has confirmed that the casing and connector can withstand temporary environmental circumstances equivalent to Protection Classification IP 66 (sealed against dust, protection against powerful water jet). Please note that the MTi housing connector is water proof, but the supplied connector is not water proof.

MTx

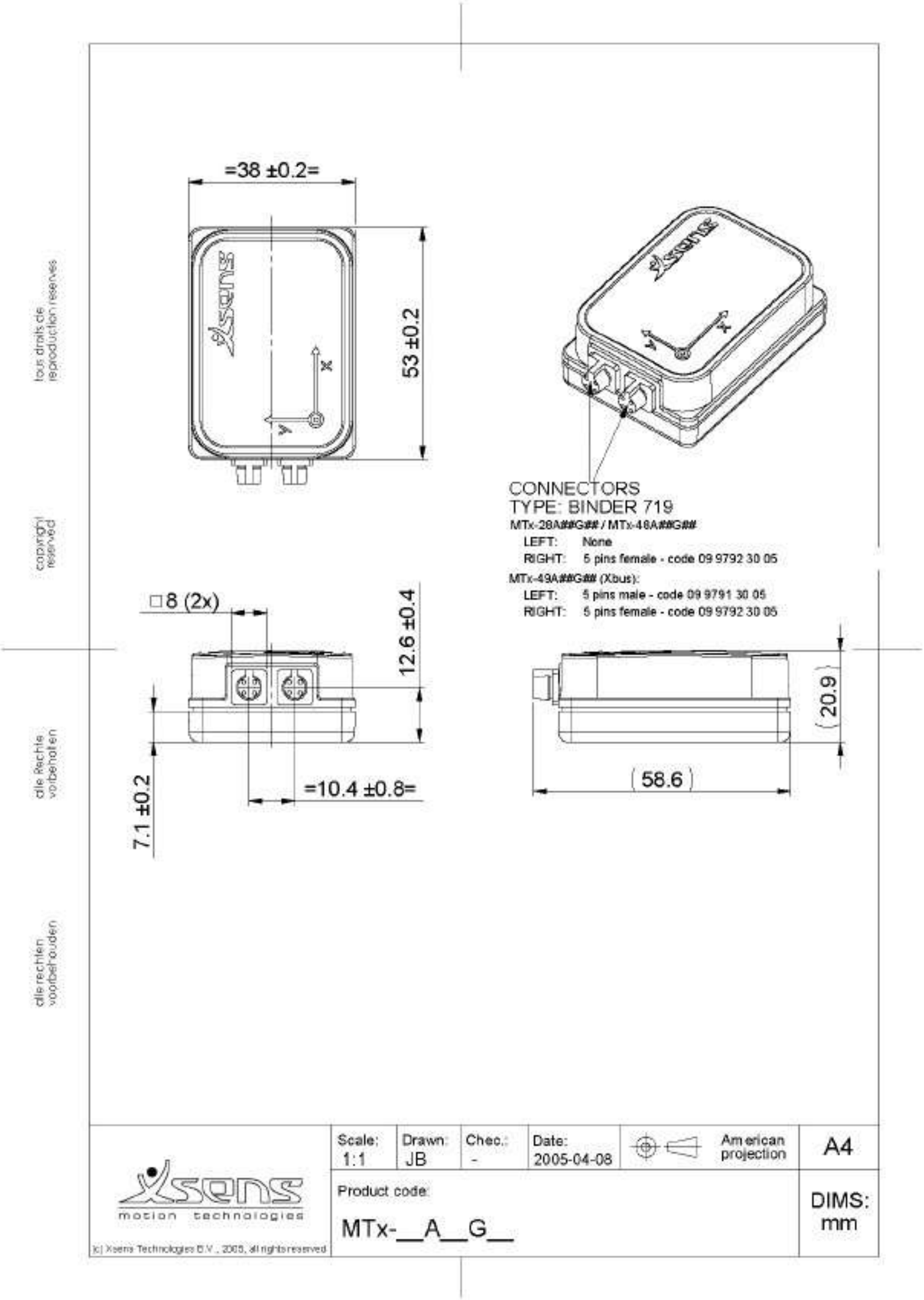
The MTx casing is designed to be as light weight as possible, and to be friendly for use on a human body. It does not employ protecting O-rings etc and does therefore not provide protection against water and large amounts of moisture. The housing is dust resistant.

The plastic material used for both MTi and MTx have UL94 V2 classification.

6.5.2 Dimensions MTi



6.5.3 Dimensions MTx

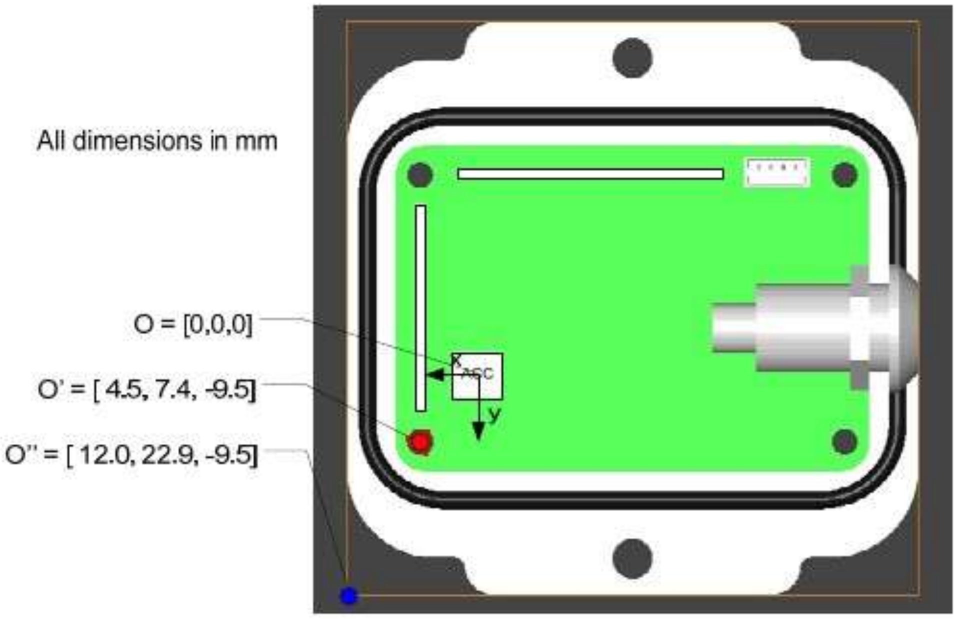


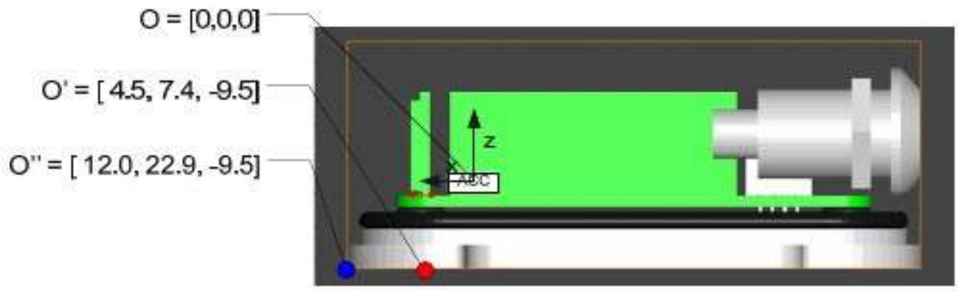
6.6 *Physical location of Origin*

The MTi and MTx is primarily an orientation sensor and as such it is not important where its internal origin is situated, i.e. the orientation is the same for all positions of the MT as it can be considered a rigid body. However, for applications where accelerations are measured it is important to know the true Origin of the MT, which is defined by the physical location of the accelerometer [26].

Below you can find the translation vector between the origin O of the MT and some convenient external point ***O'(a screw hole) or O'' (the intersection between the sides of the MTi) on the outside of the casing.***

6.6.1 MTi

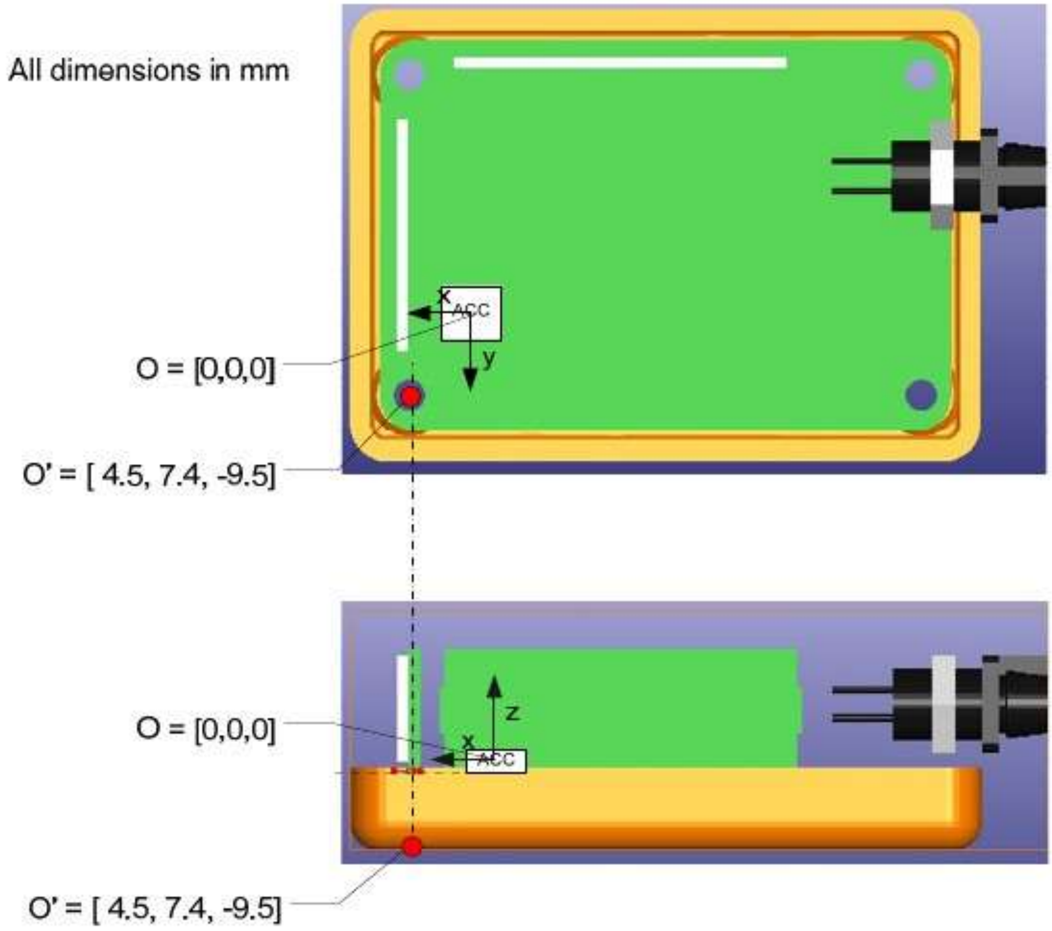




---

26 Keep in mind that the accelerometer itself can not be considered to be "point accelerometer", i.e. it has a finite size. This means the exact physical location for the different axes may deviate by the finite size of the accelerometer, which is a few millimetres. This effect is neglected here.

6.6.2 MTx



7 Operating Guidelines

7.1 Normal operating procedure

NOTE: Please also refer to the Quick Setup Sheet that came in your Development Kit package.

1. Power-on the device
2. *Optional: check the device is using the settings you need*
3. Allow electronics to warm up for about 15 minutes for optimal performance
4. Start measurements
5. Stop measurements
6. Power off device

7.2 Placement considerations

7.2.1 Transient accelerations

The 3D linear accelerometers in the MTi and MTx are primarily used to estimate the direction of gravity to obtain a reference for attitude (pitch/roll). During long periods (more than a few seconds) of transient "free" accelerations (i.e. 2nd derivative of position) the observation of gravity cannot be made. The XKF sensor fusion algorithms take these effects into account, but nonetheless it is impossible to estimate true vertical without added information.

The impact of transient accelerations can be minimized when you take into account a few things when positioning the device.

If you want to use the MTi or MTx to measure the dynamics of a moving vehicle/craft it is best to position the measurement device at a position where you expect the least (smallest) transient accelerations. This is typically close to the centre of gravity (CG) of the vehicle/craft since any rotations around the centre of gravity translate into centripetal accelerations at any point outside the point of rotation, which is usually close to the CG. The acceleration of the vehicle as a whole can of course not be taken into account.

7.2.2 Vibrations

For best performance the MTi or MTx should be mechanically isolated from vibrations as much as possible. Vibrations are measured directly by the accelerometers. This is not necessarily a problem, but two conditions can make the readings from the accelerometers invalid;

1. The magnitude of the vibration is larger than the 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 in the 3D orientation estimates 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).

7.2.3 Magnetic materials and magnets

When an MTi or MTx is placed close or on an object that contains ferromagnetic materials, or that is magnetic by itself, the measured magnetic field is distorted (warped) and causes an error in measured yaw/heading. The earth magnetic field is altered by ferromagnetic materials, permanent magnets or very strong currents (several amperes). In practice, the distance to the object and the amount of ferromagnetic material determines the

amount of disturbance. Errors in yaw/heading due to such distortions can be quite large, since the earth magnetic field is very weak in comparison to the magnitude of many sources of distortion.

Whether or not an object is ferromagnetic should preferably be checked by using the MTi's or MTx's magnetometers. It can also be checked with a small magnet, but be careful, you can easily magnetize hard **ferromagnetic materials, causing even larger errors.** If you find that some object is magnetized (hard iron effect), this is often the case with for example stainless steels that are normally not magnetic, it may be possible to "degauss[27]" the object.

In most cases when the disturbance of the magnetic field caused by placement of the MTi or MTx on a ferromagnetic object can be corrected for using a specialized calibration procedure commonly known as a "hard- and soft iron calibration". The calibration procedure can be executed in a few minutes and yields a new set of calibration parameters that can be written to the MTi / MTx non-volatile memory.

This calibration procedure is implemented in the software module "Magnetic Field Mapper" that comes with the SDK. The method used in this software is unique in the sense that it allows a user chosen measurement sequence (within certain constraints), and that it allows for full 3D mapping. 3D mapping is important in applications, where the object is rotating through a substantial range of orientations (e.g. a camera). Normal 2D mapping is suitable in applications where the object moves more or less in a single plane (e.g. a car or boat).

Disturbance caused by objects in the environment near the MTi or MTx, like file cabinets or vehicles, that move ***independently,*** with respect to the device cause a type of distortion that can not be calibrated for[28]. However, the amount of ***error*** caused by the disturbance is significantly by XKF and this works best if the correct XKF Scenario is selected for your application.

8 Important notices

8.1 Environmental Operating Conditions

The recommended operating temperature of the MTi / MTx hardware is between 0°C and 55°C ambient temperature. If operated outside this temperature range performance may decrease or the device might be damaged. Absolute maximum ratings are between -20°C and 55°C. Fast transient temperature fluctuations may cause significant temperature gradients across the device. Such gradients cannot be properly modelled by temperature compensation and may therefore decrease performance. For optimal performance the ambient temperature should remain constant as much as possible during the measurement.

NOTE: Never expose the MTi or the MTx to strong magnetic fields. The MTi and MTx contain the absolute possible minimum of ferromagnetic materials ("hard" and "soft" magnetic materials). Nonetheless, some minor components can be magnetized permanently by exposure to strong magnetic fields. This will not damage the unit but will render the calibration of the magnetometers useless, typically observed as a (large) deviation in heading. For mild magnetization it may be possible to compensate for the magnetization of the device by a re-calibration (magnetic field mapping). Taking care not to expose the MTi or the MTx to strong magnetic fields, such as close proximity of permanent magnets, speakers, electromotor, etc. will make sure magnetization does not occur.

---

[27] Degaussing is a procedure to apply strong alternating magnetic fields with decreasing magnitude in random direction to an object that has been magnetized. The effect of the strong alternating fields is to remove any magnetized (aligned) domains in the object. If you degauss, please make sure the MTi or MTx is not anymore on the object!

[28] This type of disturbance is non-deterministic.

The MTi and MTx hardware must be kept dry at all times. Condense may damage the internal electronics.

The MTi and MTx hardware should be protected from electro static discharges or sources of radiation, as exposure to such source will damage the internal electronics.

The MTi and MTx hardware should be protected from violent handling such as drops on hard surfaces. Excessive shocks or violent handling may damage the motion sensors.

The MTi and MTx hardware should be protected from strong vibrations. Excessive and continuous vibration may damage the device. Please contact support@xsens.com for more detailed information.

8.2 FCC specific operating instructions

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

1. Reorient or relocate the receiving antenna
2. Increase the separation between the equipment and receiver
3. Connect the equipment into an outlet on a circuit different from that to which the receiver is connected
4. Consult the dealer or an experienced radio/TV technician for help

8.3 Safety instructions

CAUTION

- Read these instructions
- Do not place the MTi or MTx near strong magnetic fields.
- Do not use cables or connectors other than described in this manual.

8.4 Absolute maximum ratings

Stresses above Absolute Maximum Ratings may cause permanent damage to the device.

Shock (any axis): 20000 m/s2 (2000 g) 0.5 ms (half-sine)
Input Voltage: -0.3 V … 30 V [29]
Interface inputs: -25 V … 25 V (RX, A and B inputs)
Analog IN: -0.3 V … 5.3 V or 30 mA, whichever comes first
Sync IN: -0.3 V … 20 V
Operating Temperature: -20 °C … 55 °C
Storage Temperature: -20 °C … 55 °C
Humidity: 95% max (non condensing)

Stresses beyond those listed here may cause permanent damage to the device. These are stress ratings only, and functional operation of the MTi / MTx at these or any other conditions beyond those indicated in section 6 of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

NOTE: Drops onto hard surfaces can cause shocks of greater than 20000 m/s^2 (2000 g) exceed the absolute maximum rating of the device. Care should be taken when handling to avoid damage. Drops causing shock greater than absolute maximum ratings may not destroy the device but will permanently alter the properties of the physical motion sensors, which may cause the device to become inaccurate.

8.5 Maintenance

The MTi and MTx will not require any maintenance if properly used (see also section 8.1 and 8.4). However, if the Motion Tracker is not functioning according to the specifications please contact Xsens Technologies B.V. (support@xsens.com).

8.5.1 Cleaning

Disconnect the MTi or MTx from the power supply and computer. Wipe the case with a damp cloth and mild detergent. Do not use abrasives, isopropyl alcohol, or solvents to clean the case.

8.6 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 1 year 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 support@xsens.com 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.

[29] The previous revision of the Motion Tracker has an absolute maximum input voltage of 15V instead of 30V. These Motion Trackers have a serial number lower than 2000 (last four digits only).

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.

8.7 *CE Declaration of Conformity for the MT devices*

We, Xsens Technologies BV, of
Pantheon 6a
7521 PR Enschede
The Netherlands

declare under our sole responsibility that our products:

MT#-##A53G35 (MTx-28A53G35, MTx-48A53G35, MTx-49A53G35, MTi-28A53G35, MTi-48A53G35, MTi-68A53G35),
MT#-##A33G35 (MTx-28A33G35, MTx-48A33G35, MTx-49A33G35, MTi-28A33G35, MTi-48A33G35, MTi-68A33G35),
MT#-##A83G35 (MTx-28A83G35, MTx-48A83G35, MTx-49A83G35, MTi-28A83G35, MTi-48A83G35, MTi-68A83G35),
MT#-##A53G15 (MTx-28A53G15, MTx-48A53G15, MTx-49A53G15, MTi-28A53G15, MTi-48A53G15, MTi-68A53G15),
MT#-##A33G15 (MTx-28A33G15, MTx-48A33G15, MTx-49A33G15, MTi-28A33G15, MTi-48A33G15, MTi-68A33G15),
MT#-##A83G15 (MTx-28A83G15, MTx-48A83G15, MTx-49A83G15, MTi-28A83G15, MTi-48A83G15, MTi-68A83G15),
MT#-##A53G25 (MTx-28A53G25, MTx-48A53G25, MTx-49A53G25, MTx-49A53G25-LX, MTi-28A53G25, MTi-48A53G25, MTi-68A53G25),
MT#-##A33G25 (MTx-28A33G25, MTx-48A33G25, MTx-49A33G25, MTi-28A33G25, MTi-48A33G25, MTi-68A33G25),
MT#-##A83G25 (MTx-28A83G25, MTx-48A83G25, MTx-49A83G25, MTi-28A83G25, MTi-48A83G25, MTi-68A83G25),

to which this declaration relates, are in conformity with the essential requirements of the
EMC Directive: 89/336/EEC and the following Standards and other Normative Documents:

EMC Directive: 89/336/EEC
EN 61326-1 (2006)
EN 61000-3-2 (2006)
EN 61000-3-3 (1995) + A1 (2001) + A2 (2005)

Environment to be used is light industrial / laboratory

Class of emission is B and performance criterion B.

Test results are summarized in the Electromagnetic Compatibility Test Report with the following document numbers 07C00496RPT02, 08C00494RPT01 and 08C00546RPT01

July 1st 2008 Enschede, the Netherlands

Per Slycke
CTO
Xsens Technologies BV

8.8 *FCC Declaration of Conformity for the MT devices*

We, Xsens Technologies BV, of
Pantheon 6a
7521 PR Enschede
The Netherlands

declare under our sole responsibility that our products:

MT#-##A53G35 (MTx-28A53G35, MTx-48A53G35, MTx-49A53G35, MTi-28A53G35, MTi-48A53G35, MTi-68A53G35),
MT#-##A33G35 (MTx-28A33G35, MTx-48A33G35, MTx-49A33G35, MTi-28A33G35, MTi-48A33G35, MTi-68A33G35),
MT#-##A83G35 (MTx-28A83G35, MTx-48A83G35, MTx-49A83G35, MTi-28A83G35, MTi-48A83G35, MTi-68A83G35),
MT#-##A53G15 (MTx-28A53G15, MTx-48A53G15, MTx-49A53G15, MTi-28A53G15, MTi-48A53G15, MTi-68A53G15),
MT#-##A33G15 (MTx-28A33G15, MTx-48A33G15, MTx-49A33G15, MTi-28A33G15, MTi-48A33G15, MTi-68A33G15),
MT#-##A83G15 (MTx-28A83G15, MTx-48A83G15, MTx-49A83G15, MTi-28A83G15, MTi-48A83G15, MTi-68A83G15),
MT#-##A53G25 (MTx-28A53G25, MTx-48A53G25, MTx-49A53G25, MTx-49A53G25-LX, MTi-28A53G25, MTi-48A53G25, MTi-68A53G25),
MT#-##A33G25 (MTx-28A33G25, MTx-48A33G25, MTx-49A33G25, MTi-28A33G25, MTi-48A33G25, MTi-68A33G25),
MT#-##A83G25 (MTx-28A83G25, MTx-48A83G25, MTx-49A13G25, MTi-28A83G25, MTi-48A83G25, MTi-68A83G25),

to which this declaration relates, have been tested and found to comply with the limits for a Unintentional Radiator as described in 47 CFR 15 (2007 May, 04 Edition) Class B Digital Device, pursuant to Part 15 of the FCC Rules.

Operation is subject to the following two conditions:

1. This device may not cause harmful interference, and
2. This device must accept any interference received, including interference that may cause undesired operation.

Test results are summarized in the Electromagnetic Compatibility Test Report with the following document numbers 08C00494RPT01, 08C00546RPT01 and 07C00496RPT02.

July 1st 2008 Enschede, the Netherlands

Per Slycke
CTO
Xsens Technologies BV

8.9 CE Declaration of Conformity for the USB converters

We, Xsens Technologies BV, of
Pantheon 6a
7521 PR Enschede
The Netherlands

declare under our sole responsibility that our products:

CA-USB2# RS232 (CA-USB2, CA-USB2x, CA-USB2G)

CA-USB4# RS485 (CA-USB4, CA-USB4x)

CA-USB6# RS422 (CA-USB6, CA-USB6x)

CA-USBXM RS232

to which this declaration relates, are in conformity with the essential requirements of the
EMC Directive: 89/336/EEC and the following Standards and other Normative Documents:

EMC Directive: 89/336/EEC
EN 61326-1 (2006)
EN 61000-3-2 (2006)
EN 61000-3-3 (1995) + A1 (2001) + A2 (2005)

Environment to be used is light industrial / laboratory

Class of emission is B and performance criterion B.

Test results are summarized in the Electromagnetic Compatibility Test Report with the following document number 08C00497RPT01

September 23 2008 Enschede, the Netherlands

Per Slycke
CTO
Xsens Technologies BV

8.10 FCC Declaration of Conformity for the USB converters

We, Xsens Technologies BV, of
Pantheon 6a
7521 PR Enschede
The Netherlands

declare under our sole responsibility that our products:

CA-USB2# RS232 (CA-USB2, CA-USB2x, CA-USB2G)

CA-USB4# RS485 (CA-USB4, CA-USB4x)

CA-USB6# RS422 (CA-USB6, CA-USB6x)

CA-USBXM RS232

to which this declaration relates, have been tested and found to comply with the limits for a Unintentional Radiator as described in 47 CFR 15 (2007 May, 04 Edition) Class B Digital Device, pursuant to Part 15 of the FCC Rules.

Operation is subject to the following two conditions:

1. This device may not cause harmful interference, and
2. This device must accept any interference received, including interference that may cause undesired operation.

Test results are summarized in the Electromagnetic Compatibility Test Report with the following document number 08C00497RPT01

September 23 2008 Enschede, the Netherlands

Per Slycke
CTO
Xsens Technologies BV

8.11 Customer Support

Xsens Technologies B.V. is glad to help you with any questions you may have about the MTi or MTx, or about the use of the technology for your application. Please contact Xsens Customer Support:

by e-mail: support@xsens.com
telephone: +31(0)88-9736700

To be able to help you, please mention your Motion Tracker **Device ID** (on the back of the device) and **software license registration number in your e-mail.**