Magnetic Field Mapper Documentation

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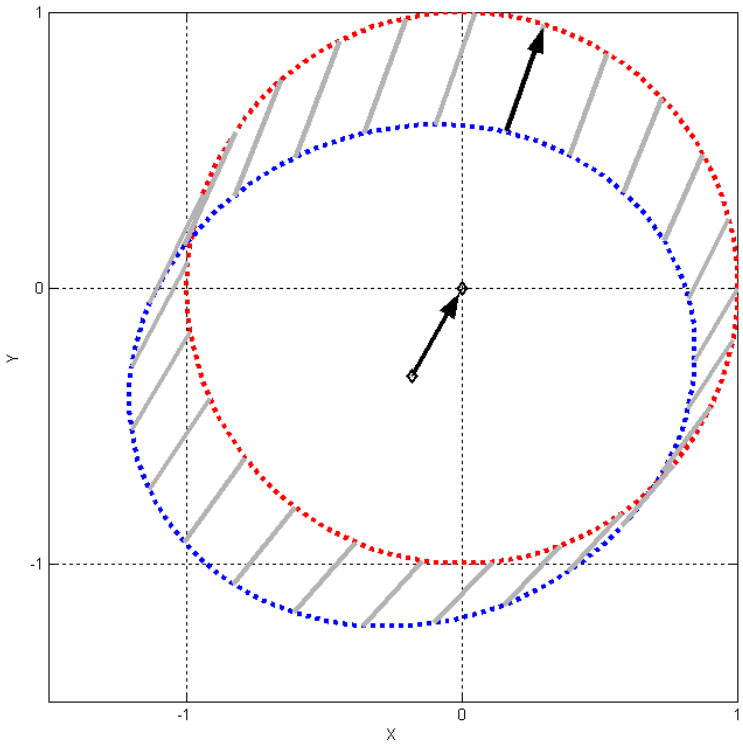

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Revisions

Revision	Date	By	Changes
A	June 29, 2005	PSL	First version
B	January 29, 2007	SSM	Revision for latest software Added section 4 which include off-line calibration.
C	November 2, 2007	PSL	Minor updates for MTi-G release.
D	April 1, 2008	MMI	Minor updates for MT SDK 3.0.1 release
E	May 27, 2009	MHA	Minor updates and new corporate design
F	Oct 15, 2010	MHA	Added clarification on offline procedure and factory settings

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1 Introduction

An MTi-G, MTi or MTx motion tracker (MT) can be used to easily and accurately record 3D orientation. When an MT is mounted to an object that contains ferromagnetic materials, the measured (Earth) magnetic field is distorted (warped) and causes an error in measured orientation if the magnetometers are used to estimate orientation. This is not the case in all XKF Scenarios. Please refer to the product User Manual for details.

However, the disturbance of the magnetic field caused by mounting the MT on a ferromagnetic object can be corrected for using a specialized calibration procedure that is described in this document. The calibration procedure can be executed in a few minutes and yields a new set of electronic datasheet values (extended Motion Tracker Specification (eMTS) data) that can be written to the MT non-volatile memory. Once written to the eMTS-data, the orientation data calculated by the MT, will be accurate even when mounted on the ferromagnetic object.

The calibration procedure is suitable for both 3D applications, where the object is rotating through a substantial range of orientations (e.g. a camera), and 2D applications where the object moves more or less in one plane (e.g. a car or boat).

An accurate calibration is obtained by recording the MT signals while rotating the object, with the MT mounted on it, in a space without other, nearby, ferromagnetic materials. Once the object is rotated over a sufficiently large amount of orientations, the MagField Mapper add-on can then calculate new calibration parameters that can immediately be used in the MT.

The calibration has only to be performed once during the period in which the MT is mounted on the same location on the object. If properly carried out, the resulting accuracy will be comparable to the accuracy experienced with the MT without any ferromagnetic materials nearby.

2 Theory of Operation

2.1 Background

The direction of the measured earth magnetic field is used as a (3D) compass to determine the direction of the north (heading or yaw), used as an absolute reference in the calculation of 3D orientation.

A locally disturbed (warped) magnetic field causes an error in orientation that can be quite substantial. The earth magnetic field is altered by ferromagnetic materials, permanent magnets or very strong currents (several amperes). Whether or not an object is ferromagnetic should preferably be checked by using the motion tracker's magnetometers. It can also be checked with a small magnet, **but be careful, you can easily *magnetize*** some 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[1]" the object.

***NOTE:* Never expose the MT to strong magnetic fields.** The MT contains 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 MT to strong magnetic fields, such as close proximity of permanent magnets, speakers, electromotor, etc. will make sure magnetization does not occur.

In practice, the distance to the object and the amount of ferromagnetic material determines the amount of disturbance.

The disturbance of the earth magnetic field can be divided into two kinds of effects:

1. Disturbance caused by objects in the environment near the motion tracker, like file cabinets or vehicles that move ***independently***, with respect to the MT. This type of disturbance is ***non-deterministic***, and cannot be fully compensated for. However, the amount of ***error*** caused by the disturbance can be ***reduced*** by optimally using the available sensor information and valid assumptions about the application. This is the task of the Xsens Kalman Filter (XKF) running in the DSP.

2. Disturbance caused by mounting the MT to an object of which the motion is to be recorded (the MT moves with the object). The error in magnetic field only depends on the orientation, and can therefore be predicted (i.e., it is deterministic) and taken into account during motion tracking. Using a mapping of the disturbance (warping) of the magnetic field the errors caused by this type of disturbance can in theory be reduced to zero. The calculations and methodology required to achieve this is supplied by the MagField Mapper add-on and this documentation. This type of correction is commonly known as compensation for hard and soft iron effects.

2.2 Method

In a non-disturbed magnetic field, the 3D measured magnetic field vector has a magnitude of one and therefore all measured points lay on the circumference of a sphere with the centre at zero. In the case of a disturbed magnetic field, this sphere is both shifted and warped. The calibration procedure described in this documents

[1] 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 MT is not anymore mounted on the object!

aims to derive a function that maps the measured magnetic field vector to a sphere. This function is then implemented in new eMTS data, stored in non-volatile memory in your MT.

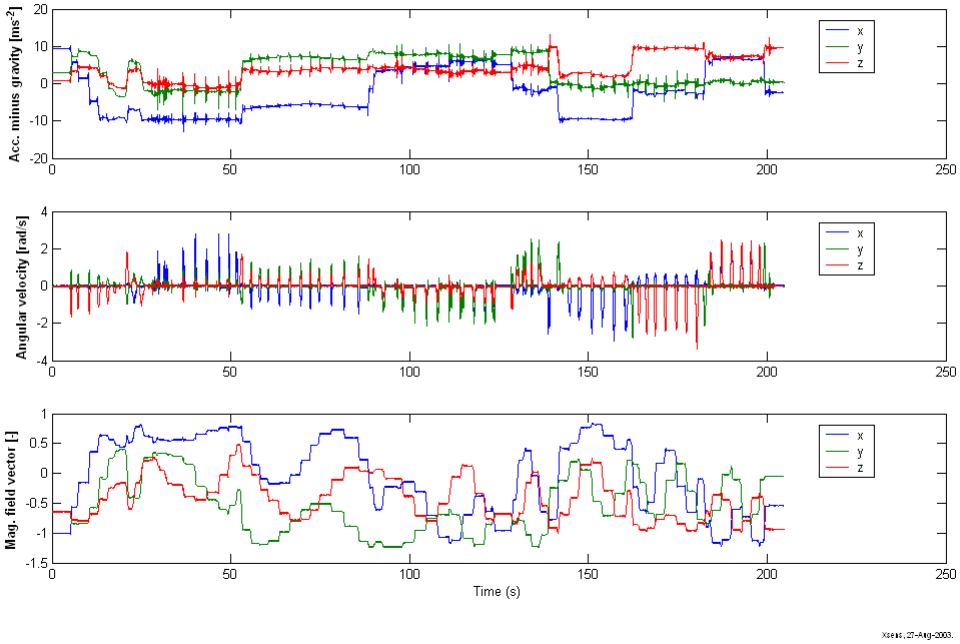


Figure 1: Example of time sequence of MT data used for 3D magnetic field mapping. The accelerometer, rate gyro and magnetometer signals with respect to the three sensor axes are plotted. Note the many different orientations where the MT is briefly held still.

The calibration procedure requires the inclination, which is obtained using accelerometers. Accuracy of inclination is influenced by linear accelerations. Large accelerations will have a large effect on the accuracy of the calibration results. Therefore it is **very important to move the object as slowly as possible** during the measurement, or alternatively to hold the object briefly still in many different directions.

The Magnetic Field Mapper add-on is designed to disregard periods with large accelerations and reduce any errors, therefore you can move fast without causing errors, but there must be sufficient periods of “stillness”. This requirement is only applicable for a 3D calibration measurement since e.g. a boat can not be held still. For details see next section about the Calibration Procedure.

Since the MagField Mapper algorithm can not distinguish between an external disturbed magnetic field and a disturbance caused by the object on which the motion tracker is attached, it is extremely important that the ***measurement is carried out in a homogeneous magnetic field***. As a rule of thumb there should be no ferromagnetic objects within *at least* three meters from the place in which the measurement is carried out. Keep in mind that the structure of the building you are in (floor and ceiling) is likely to contain magnetic materials.

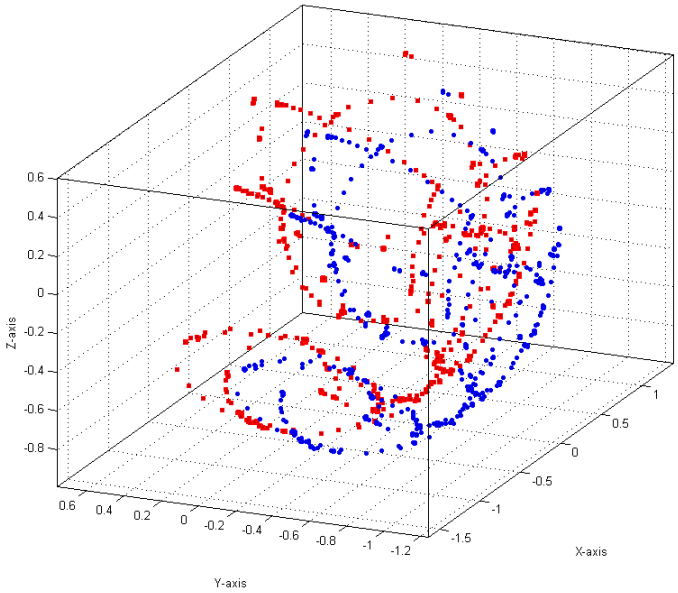


Figure 2: 3D representation of magnetic field vector before (blue) and after (red) compensation using magnetic field mapping.

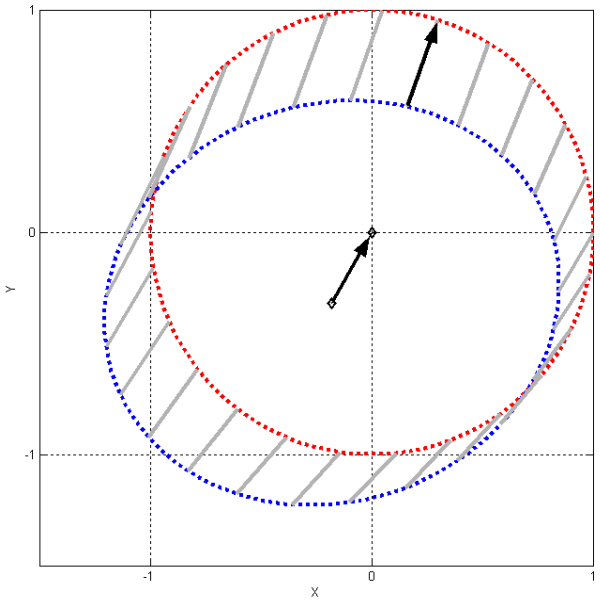


Figure 3: 2D representation of magnetic field vector (projected on X-Y plane) vector before (blue) and after (red) compensation using magnetic field mapping. The arrows represent the "transformation" applied.

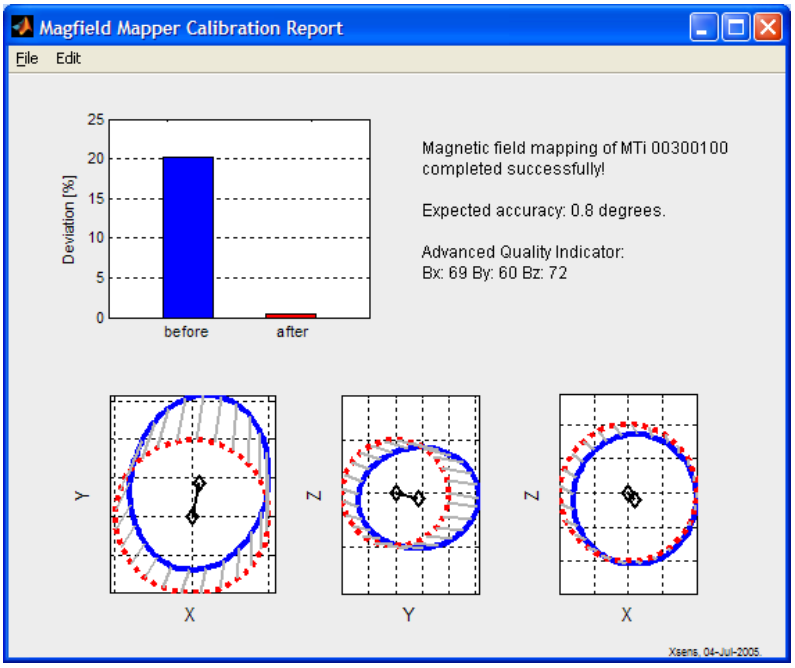


Figure 4: Calibration report, including a projection of the obtained fit in three planes.

3 Magnetic field mapping Procedure

The magnetic field mapping procedure consists of the following steps:

1. Mounting of MT
2. Recording of calibration measurement using MagField Mapper software or other logging software
3. Processing of measurement data by MagField Mapper software
4. Writing the results to Motion Tracker using MagField Mapper software or by transmitting a specialized message to the Motion Tracker which is generated by the MagField Mapper software.

In the case that after mounting the MT can not be directly connected to a PC that runs the MagField Mapper software it is possible to perform magnetic field mapping off-line. This is described in section 4.2. The standard procedure is described in the following sections.

3.1 Mounting of MT

The MT is attached to the object for which the magnetic field mapping procedure is carried out. Make sure that wherever the MT is placed, it can not move with respect to the object.

There are ***no*** specific requirements in terms of mounting orientation of the MT on the object.

Remarks:

- ➔ Every time the sensor is temporarily removed from the object, it is advised to repeat the calibration procedure.
- ➔ If the geometry of the object is significantly altered, e.g. the geometry is changed or components are added or removed, it is advised to repeat the calibration procedure.
- ➔ The calibration procedure is more accurate for smaller disturbances. If possible, try to position the sensor one to a few centimetres/inches away from ferromagnetic materials. The MagField Mapper will automatically warn you if the magnetic field sensors in the MT become saturated.

3.2 How to perform a calibration measurement

During a 3D calibration measurement, the object to which the sensor is attached has to be rotated through as **many different orientations as possible,** it may help to think about 'scanning' the surface of a sphere with the MT x-axis. Not only is it important to cover many orientations, the object also has to be moving sufficiently slow. **The best is to keep the object still for a few seconds in at least 12 significantly different orientations, preferably more.**
In case of a 2D calibration measurement, the object has to be rotated through at least a full 360° circle. It is recommended to do this with constant speed. Note that large errors can occur when a 2D Magnetic Field Mapping is performed and the Motion Trackers are used outside the horizontal envelope.

The MagField Mapper plug-in will tell you if the measurement was OK.

Limited angles
The calibration procedure works best if the MT is rotated through a large amount of possible orientations. If this is difficult for the object for which the MT has to be calibrated, the procedure might still give accurate results with mild magnetic disturbances. It should be noted that orientations that are recorded with a calibration file that is generated with a limited set of orientations will only be accurate for that particular range of orientations (rotation range).

Calibration remarks:

- A longer calibration measurement is generally better. As a rule of thumb, a calibration trial of around 3 minutes should suffice, provided that the object is rotated over a sufficiently large angle and held sufficiently still. If one of these requirements is not met, a longer calibration trial may prove to be useful.
- For a 2D calibration measurement it is recommended that the object moves through a full 360° circle.
- It is extremely important to perform the calibration in a magnetic homogeneous field. Try to conduct the measurement *at least* 3 meters from large ferromagnetic objects such as radiators and iron desks.
- During the calibration trial, the accelerometers are used for inclination measurement, much like a water dial (spirit level). This means that the inclination accuracy will be less when the sensor is accelerated. Especially centripetal accelerations that occur e.g. during swinging result in a large inclination error, since centripetal acceleration error do generally not average out.
- In 3D mode, the algorithm only uses periods with low activity to perform the calculation. Therefore it is more important to keep the object still for a few seconds in every orientation than to slowly rotate the object during the entire calibration.

Advanced Quality Indicators

The quality indicators that are presented if the calibration is succeeded give a measure on how well the measured signals could be mapped and results in an estimate of the remaining orientation error. A higher value means a better mapping. This number is displayed in the Magnetic Field Mapper dialog window.

A very low number of samples will always yield low residuals. This is much like a line fitted through two measurements can always be fitted perfectly, in contrary to three or more points. The more samples the bigger the chance is that not all measurement points can be perfectly corrected and a more realistic error measure is obtained. The MagField Mapper software will warn you if the useful part of the captured data is too small. It will give a warning not to use the measurement or even not allowing you to use the measurement.

The quality indicators can only check the accuracy of the range of orientations that the object was held during the calibration measurement (the rotation range). This will not cause any problems as long as the orientations during use of the MT are not very different from the orientations during calibration.

3.3 Performing the calibration measurement

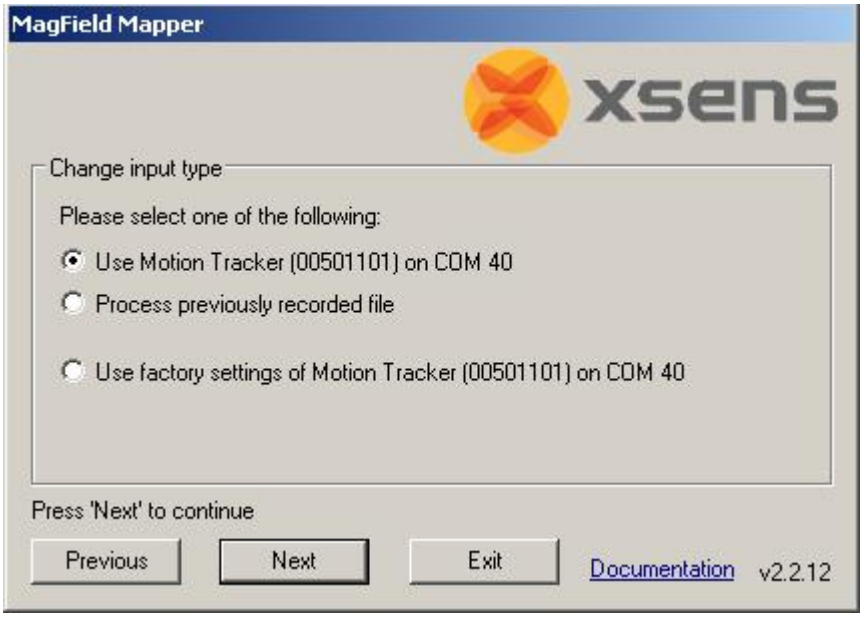
If the MT can be directly connected to a PC the MagField Mapper software can be used to record the calibration measurement data. If this is not the case read also section 4.2 to setup the off-line procedure.

1. To start the recording of the calibration measurement, start the MagField Mapper plug-in from the MT Manager. Use the Tools menu.

2. The MagField Mapper software will now start-up. Choose the ‘Write results to MotionTracker non-volatile memory’ option if the MotionTracker is directly connected to the PC running the MagField Mapper software.

Make sure you select the current baud rate of the MotionTracker in the dropdown box and connect at maximum **one** MT to the PC.

3. Press “Scan” to scan for the connected MT. If the MT is found the following dialog is shown.



4. Click “Next” and select the location where the software stores the log file of the calibration measurement.

5. Click “Next” to select the required mapping mode. Select 2D or 3D and optionally check the graphical representation of results.

6. The software is now ready to start the calibration measurement. Reread section 3.2 for more information about how to perform the measurement. Click “Start” to begin the measurement.

7. When the sequence of rotations is completed press “Stop” to end the measurement and to start the analysis of the data.

8. If the measurement is succeeded you can store the calibration results in the non-volatile memory of the MT. Check the optional warnings and review the quality indicators (see also section 3.2). If you are satisfied with the results click “Write” to store the new calibration parameters in the MT memory.

NOTE: If you remove the MT from the object, please remember to **restore the extended Motion Tracker Specification data (eMTS data) to factory settings**!

Use the “eMTS” Tool  in the MT Manager, select “Revert” to revert to Factory.

3.4 Error causes

If the calibration procedure is not giving the desired results, it may be caused by one of the following error sources:

Cause	Explanation
Non homogeneous magnetic field in measurement volume	The effect of a non homogeneous measurement field shows in large residuals even though you follow procedure. To remedy this problem, try to perform the calibration measurement in a different place or remove nearby metal objects.
Saturation	The disturbance of the magnetic field can be so extreme that the magnetometers are saturated. In this case, a warning will be given. Reposition the MT on the object, away from the ferromagnetic material and not close to sharp edges, to remedy this problem.
Large accelerations	If the object is accelerated too much during calibration this will cause an error. If large accelerations can not be avoided contact the Xsens support team at http://www.xsens.com/support.
Limited rotation.	The calibration procedure is designed to process measurements in which the MT is rotated through a large amount of possible orientations even though measurements with a limited range of motion will most likely give good results as well.
Extreme disturbance of magnetic field	It can be that the disturbance of the magnetic field is so extreme that the program can not find any function to correct the disturbance. This could occur more easily when one of the other error causes play a significant role. The result of such an error will become apparent in very high residuals or an error message.
Wrong mapping mode (2D/3D)	If the wrong mode is selected, the calibration will most likely result in a non-optimal fit or even give an error message.

4 Non-default calibration procedures

This section describes other than the default procedure to calibrate the MT for magnetic disturbances.

4.1 Use a previously recorded measurement

For every calibration the MagField Mapper software process a log file which contains the sensor data logged during measurement. The location of these log files is set prior to the measurement in one of the MagField Mapper dialog. These log files have the following name:

MT_data_XXXXXXXX_SSS.bin

where the X stands for the device ID or serial number of the MT and S is a sequence / simple file counter.

If it is necessary to use the results of a previously recorded measurement, the MagField Mapper can process a previously recorded log file. Use the following procedure to accomplish this:

1. Start the MagField Mapper software
2. Select 'Write results to MotionTracker non-volatile memory', choose the correct baud rate and press 'Scan'.
3. In the Change Input type dialog choose 'Process previously recorded file' and press 'Next'.
4. The rest of the procedure is identical to the default one, see section 3.3.

4.2 Off-line procedure

If the Motion Tracker can not be directly connected to a PC for an on-line measurement it is possible to 'manually' generate a log file with measurement data. This log file can be processed off-line by the MagField Mapper software. Because the calibration results can not directly stored in the MT the MagField Mapper can generate a binary result file. This file contains a custom MT message that updates the calibration data of the MT if the message if transmitted to the MT.

Generate a log file

To generate a valid MagField Mapper log file follow these instructions. **NOTE: the firmware of MT needs to be version 1.2.2 or higher.**

1. Set the MT in un-calibrated raw data output mode and set the output settings to enable the sample counter. Status byte should be disabled.
2. Send a Reset message or power cycle the MT
3. Start recording all the data received after sending the Reset message or at power up.
4. While recording the incoming data into a file perform the measurement. See section 3.2 for more information about how to perform the measurement.

Process the log file

After generating the log file the MagField Mapper software can process this and generate a result file. Follow these steps to generate a MFM result file:

1. Copy the log file to a system on which the MagField Mapper is installed (or check if it available using the network).
2. Start the MagField Mapper software
3. Select 'Write results to MFM result file' and press 'Next'
4. Select 'Load' to browse for the log file and select 'Next'.
5. Select the required mapping mode, either 2D or 3D and optionally check the graphical representation of results.
6. Check the results and if you are satisfied click 'Write' to generate the MFM results file. This file stored in the same folder as the MagField Mapper executable, in most cases the following folder: C:\Program Files\Xsens\MT Manager\MagField Mapper.

   The filename of the MFM results file is:
   mfm_Results_XXXXXXXX.bin and X is the deviceID/serial number

Write calibration results to MT

The MFM results file contains a message that contains the calibration results. If this message is sent to the MT it will update the non-volatile memory which holds the calibration values. Follow the next instructions to update the calibration parameters:

1. Copy the MFM results file to the system that has a direct connection to the MT.
2. Ensure that the MT is powered
3. Make sure that the MT is in **Config** state
4. Write the binary data message in the MFM results file to the sensor, using binary communication

4.3 Using factory setting for calibration

Normally the calibration procedure uses the latest stored calibration parameters of the MT. These can be already updated several times by multiple MagField Mapper procedures. This could result in a non-optimal solution for the calibration parameters. In this case you can perform the calibration procedure using the factory default calibration parameters and not to use the current parameters. You can do this as follows:

1. Start the MagField Mapper software
2. Select “Write results to MotionTracker non-volatile memory”, select the correct baud rate and press ‘Scan’.
3. If the MT is found you can select ‘Use factory settings of Motion Tracker’ and press “Next” to continue. The rest of the procedure is the same as the default procedure (see section 3.3).

Note: to revert to the factory calibration (without any Magfield Mapper results applied), use the Revert command in the MT Manager.

Customer Support

Please, contact us if you have any questions regarding the use of Magnetic Field Mapper, its performance for your specific application, or any other questions.

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