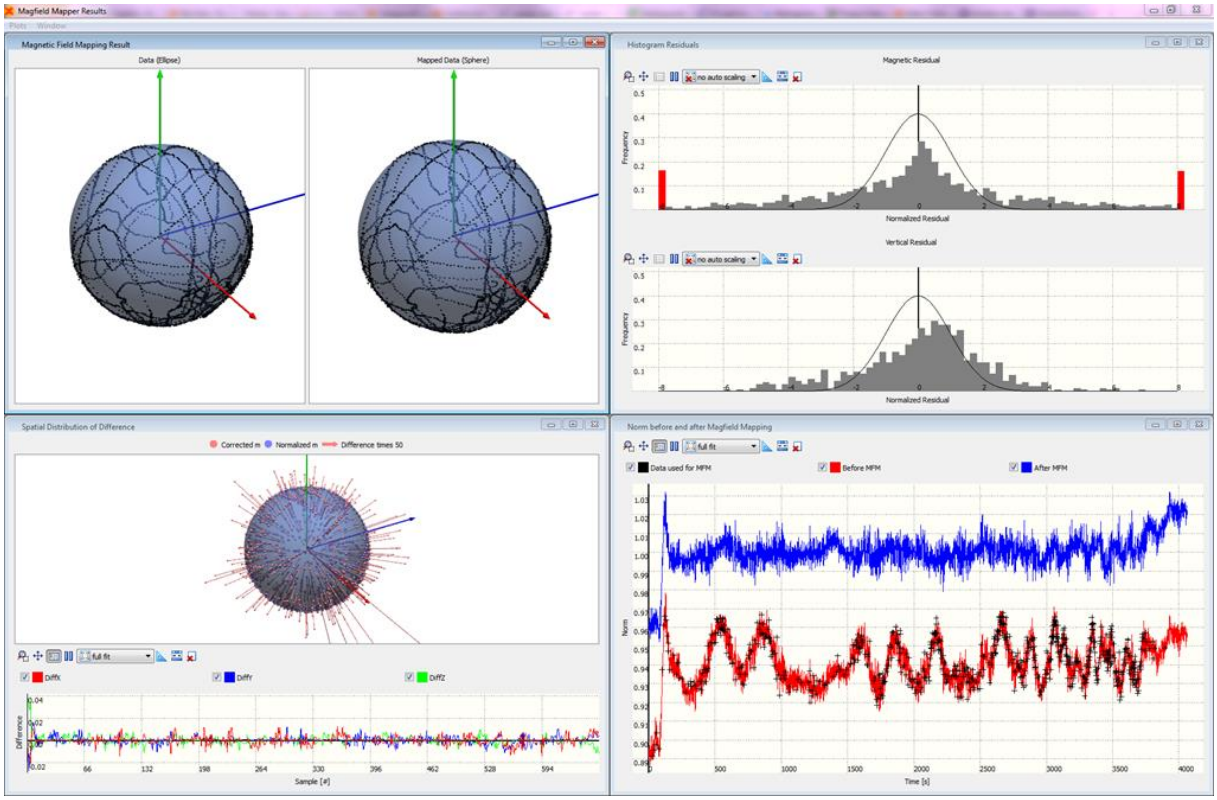
Magnetic Field Mapper Documentation

Document MT0202P, Revision J, 28 October 2013



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Revisions

Revision	Date	By	Changes
A	June 29 2005	PSL	Initial release
…	….	…	…
G	Sept 26 2012	MHA	Release 4.0; MFM 2.1
H	Dec 18 2012	MHA	Release 4.1
I	2 May 2013	MHA	Release 4.1.5 (new template)
J	28 October 2013	MHA	Release 4.2 (MFM 2.1 without MATLAB Component Runtime)

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1 Introduction

An MTi/MTw 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 filter profiles. 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 MTi, 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 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.

NOTE:
This manual discusses the Magnetic Field Mapper version 2.1 for MTi 10-series, MTi 100-series and MTw. For the Magnetic Field Mapper for Magnetic Field Mapper versions that support legacy devices, please refer to version F of this document.

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.

[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!

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 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.

The calibration procedure requires the inclination. Accuracy of inclination is influenced by linear accelerations. Large accelerations will have a large effect on the accuracy of the calibration results.

Since the MagField Mapper algorithm cannot 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.

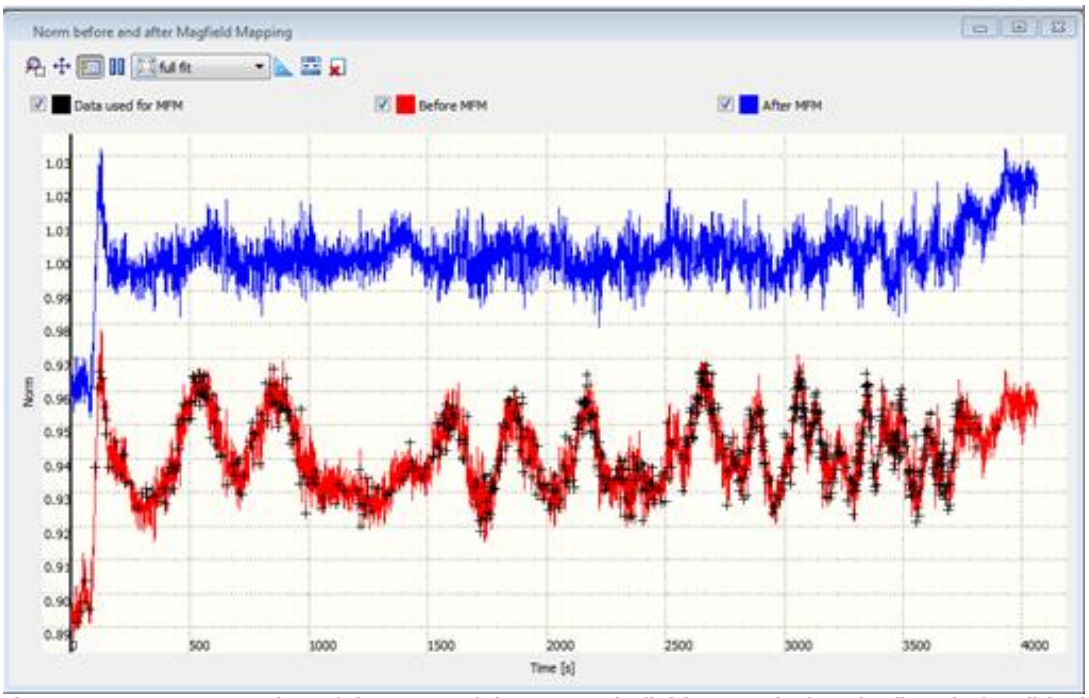


Figure 1: 3D representation of the norm of the magnetic field vector before (red) and after (blue) compensation using magnetic field mapping. The black dots represent the measurements used by the MFM algorithm.

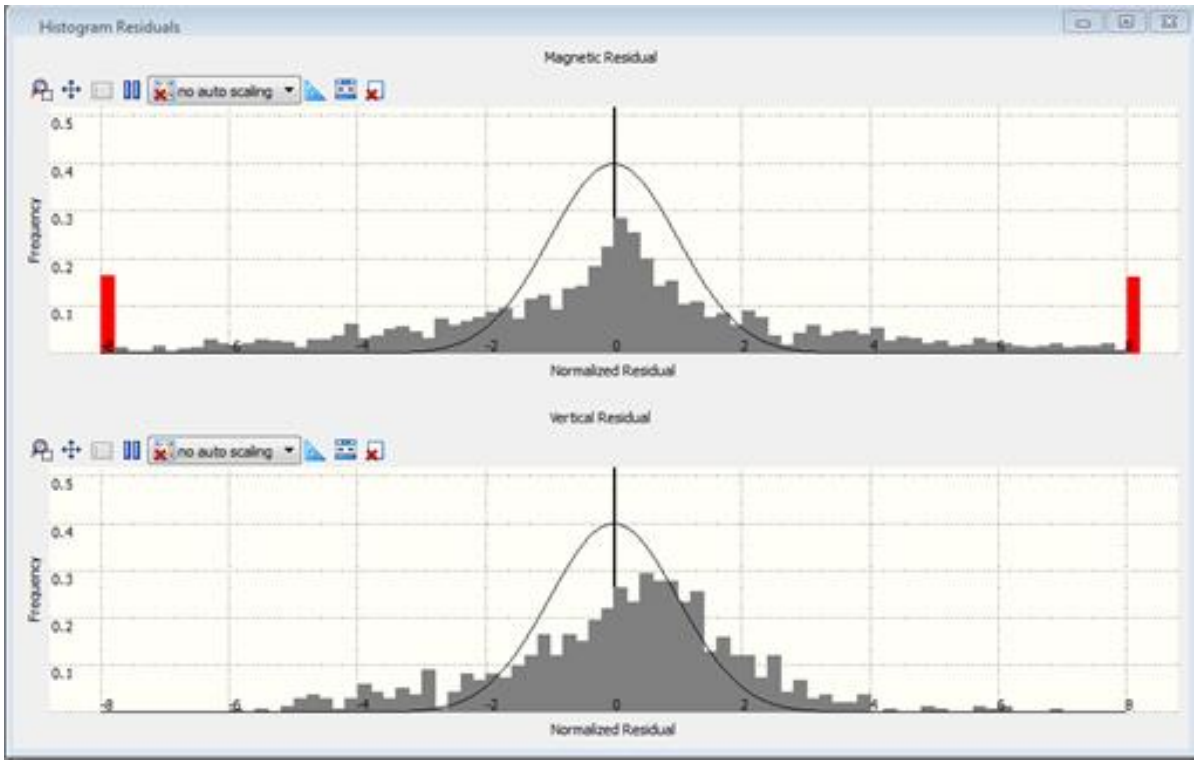


Figure 2: Part of calibration report, showing the distribution of the residuals after an MFM procedure

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 cannot 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 cannot 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. It is important to cover as many orientations as possible, at least that many that will cover the envelope of motion of your application.
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 and low (<15 km/h) speed.

Note: The MFM algorithm will always try to find a solution, even if there is only a partial capture. This means that when the MFM has been performed in the orientations of the intended application only, the heading will be accurate in those orientations, but possibly not outside that captured envelope.

The Magnetic Field Mapper 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:

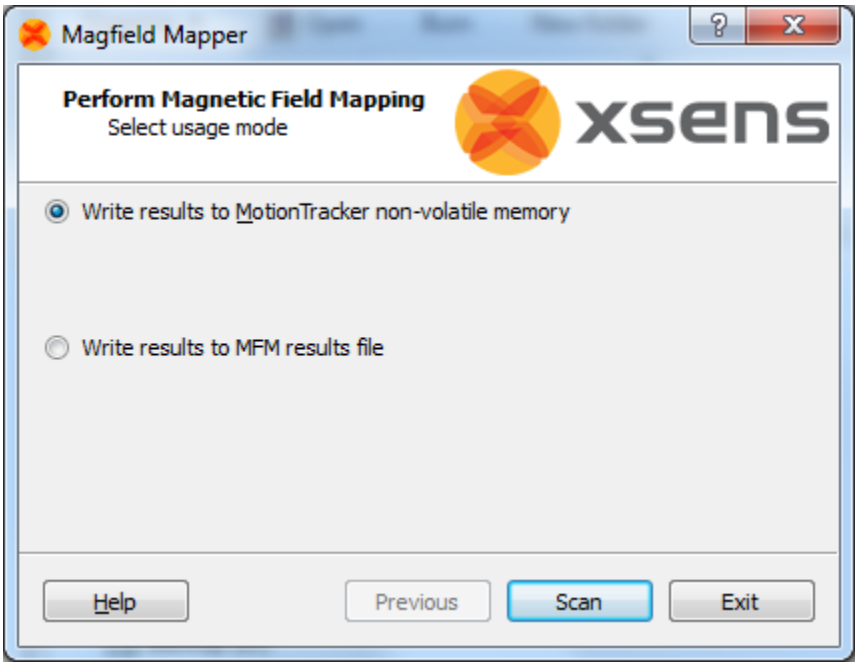
- It is required to hold the MTi in as many different orientations as possible. To reach all points, as can be seen in Figure 3, as a rule of thumb a calibration trial of around 3 minutes should suffice, provided that the object is rotated over a sufficiently large angle and held sufficiently still. 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, Xsens filter is used for inclination measurement. 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.

3.3 Performing the calibration measurement

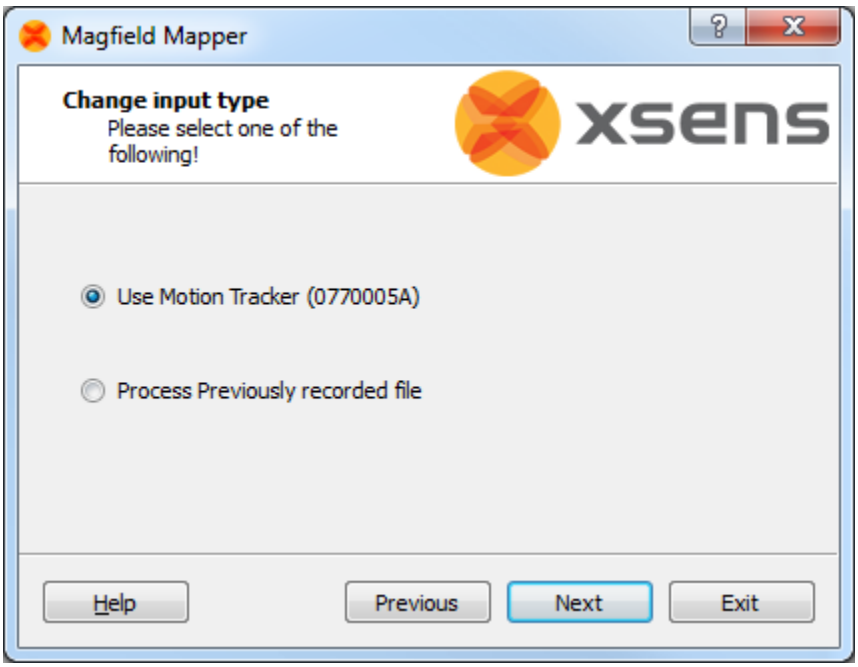
If the MT can be directly connected to a PC the MagField Mapper software can be used to record the calibration measurement data. If this is not the case read also section 4.2 to setup the off-line procedure.

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. For MTw, first establish a wireless connection using the MT Manager (100 Hz).



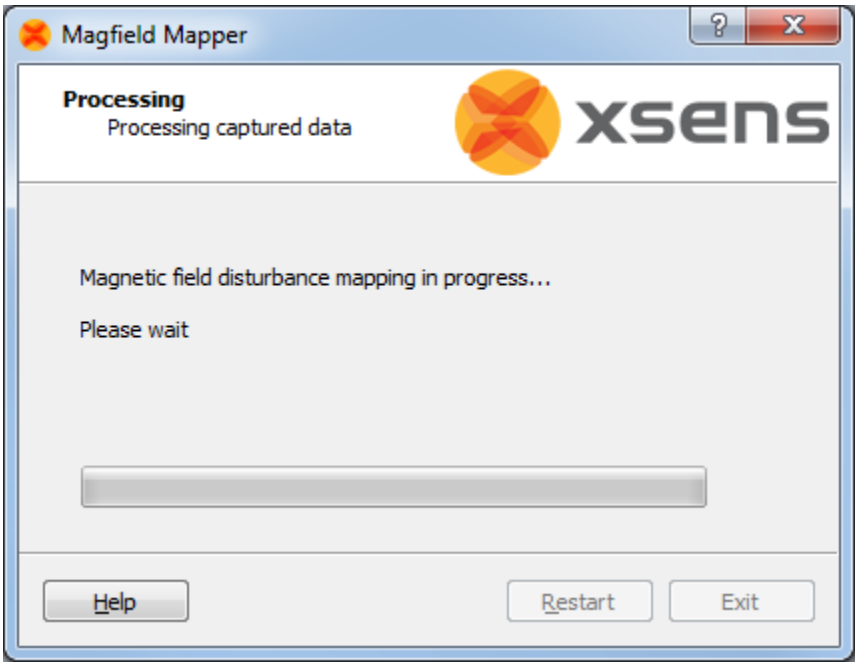
3. Press “Scan” to scan for the connected MT. If the MT is found the following dialog is shown.



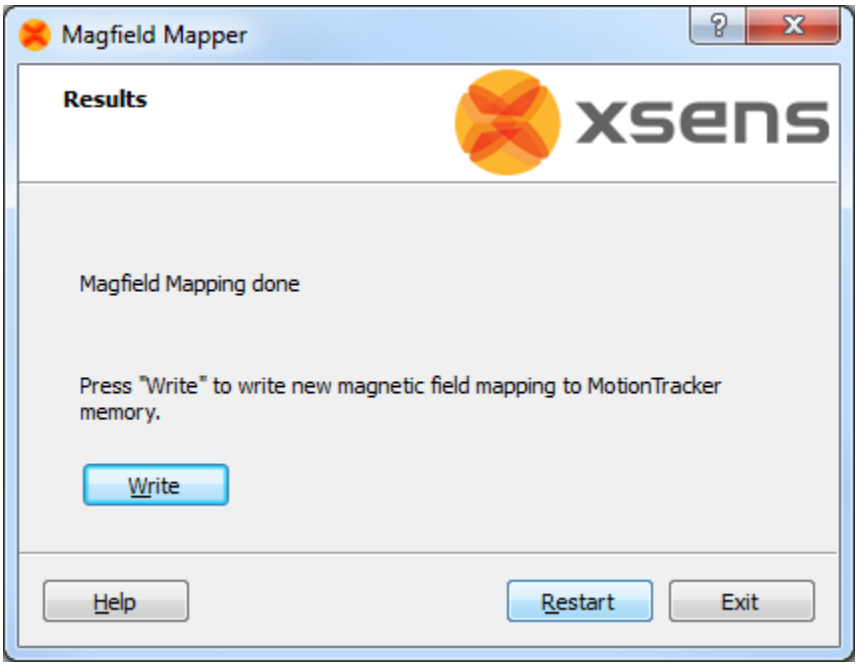
4. Click “Next” and select the location where the software stores the log file of the calibration measurement.

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

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



7. 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.



3.4 Explanation of the reports

The Magnetic Field Mapper generates several reports, that are discussed below.

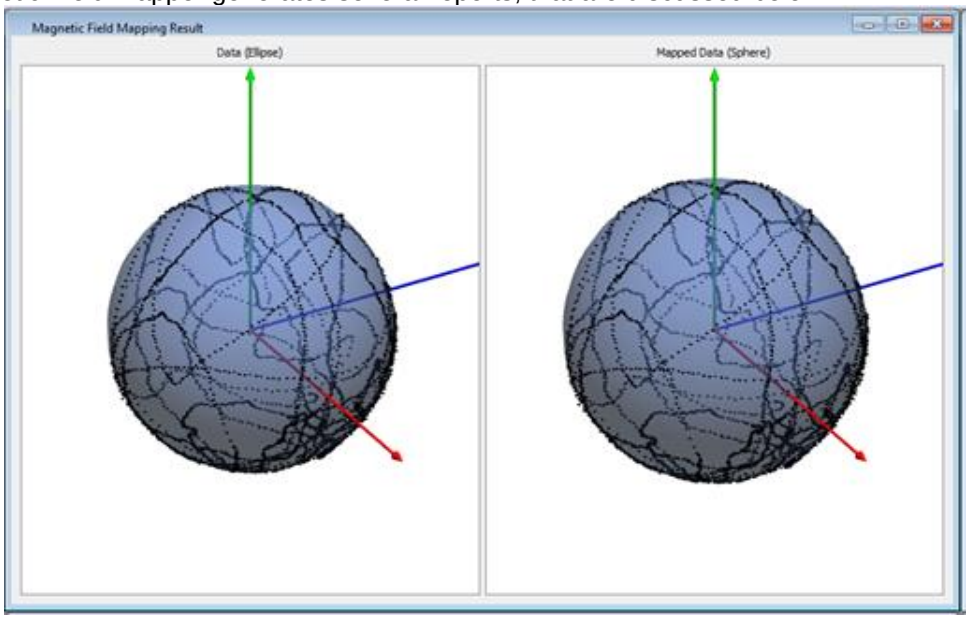


Figure 3: In the results, this figure shows the total movement of the MTi over all directions of an imaginary sphere. In the left image, the original magnetic field readings are shown, the right shows the magnetic field readings after the MFM procedure. The rounder this sphere is, the better the MFM results are

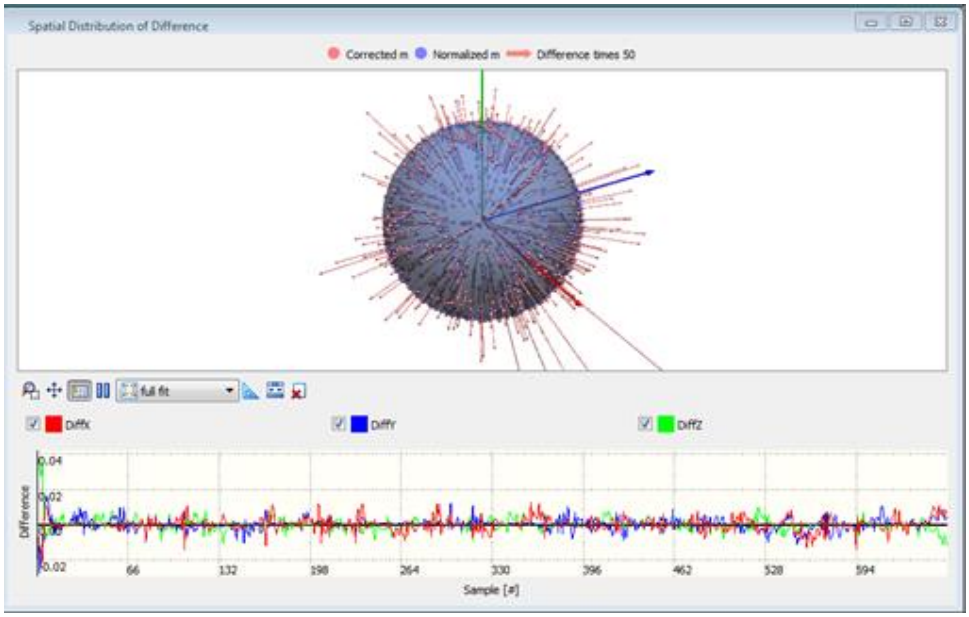


Figure 4: In the results, this figure shows if the MFM was able to apply the new magnetic field model to all corrected magnetic field measurements of the file or measurement When large spikes are visible, the data set used for the MFM had errors, which may result in a magnetic field model of lesser quality.

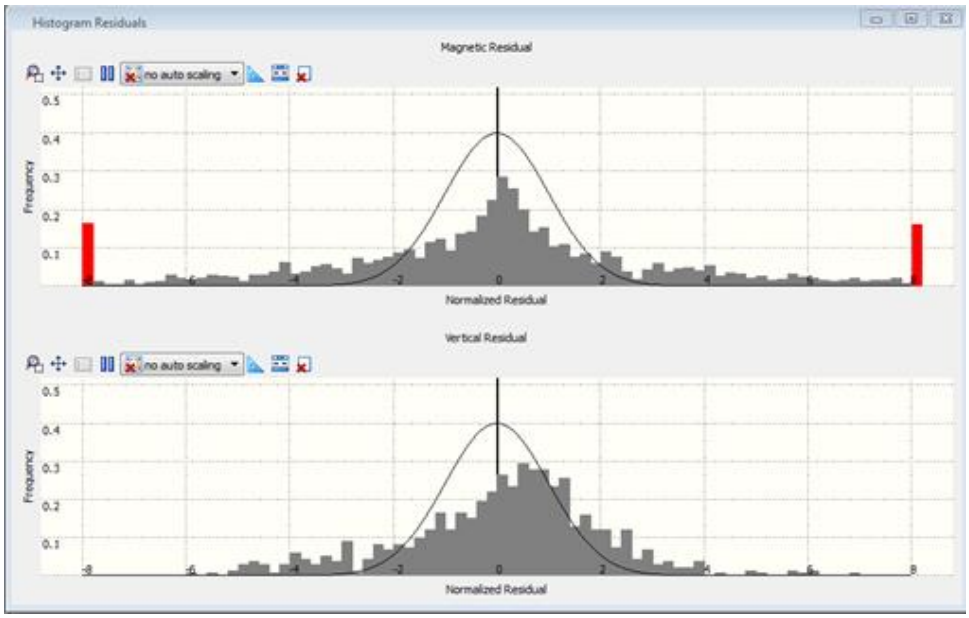


Figure 5: the results, this figure shows the residuals of the corrected magnetic field vector of the file or measurement with respect to the new magnetic field model. When measurements are visible outside Gaussian distribution, the data set used for the MFM had errors, which may result in a magnetic field model of lesser quality.

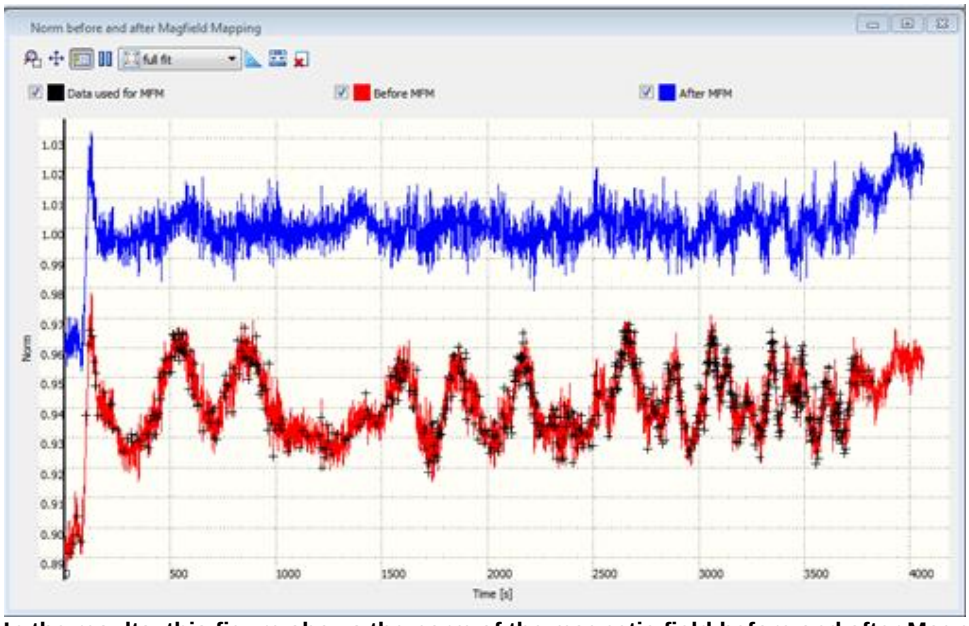


Figure 6: In the results, this figure shows the norm of the magnetic field before and after Magnetic Field Mapping. It also shows which data points were used for the Magnetic Field Mapping. The more flat the red line is (and the closer to 1.0), the better the Magfield Mapping

3.5 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 cannot 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 cannot 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.

3.5.1 Example reports of erroneous results

The MagField Mapper algorithm will always try to produce a result. Only when the MagField Mapper algorithm internal results are unrealistic, the MagField Mapper will not output the results.

This chapter provides several example reports in order to be able to recognize disturbances.

Correct MagFieldMapping

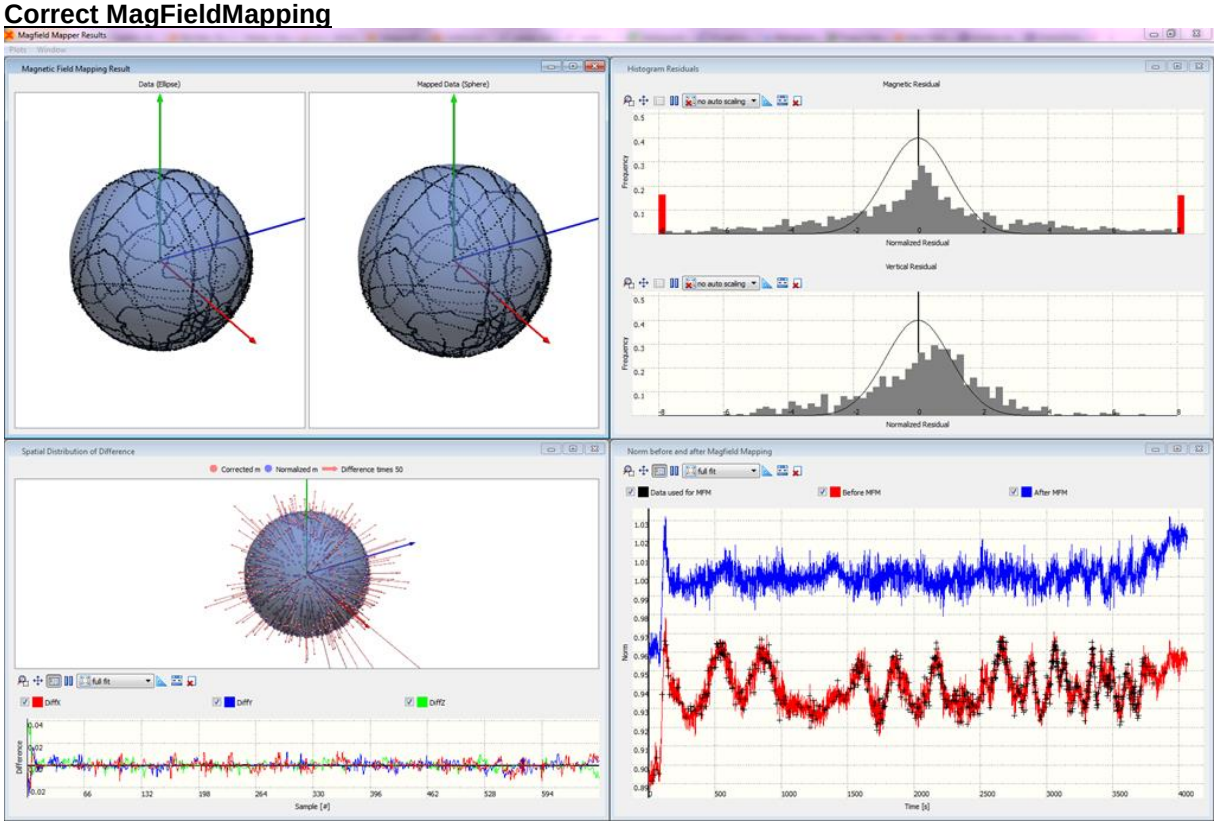


Figure 7: This report has an even distribution of points on the sphere, has a normal distribution of residuals (fit within the gaussian model), has small residuals in all directions and a norm after MFM of close to 1.

Too much magnetic disturbance

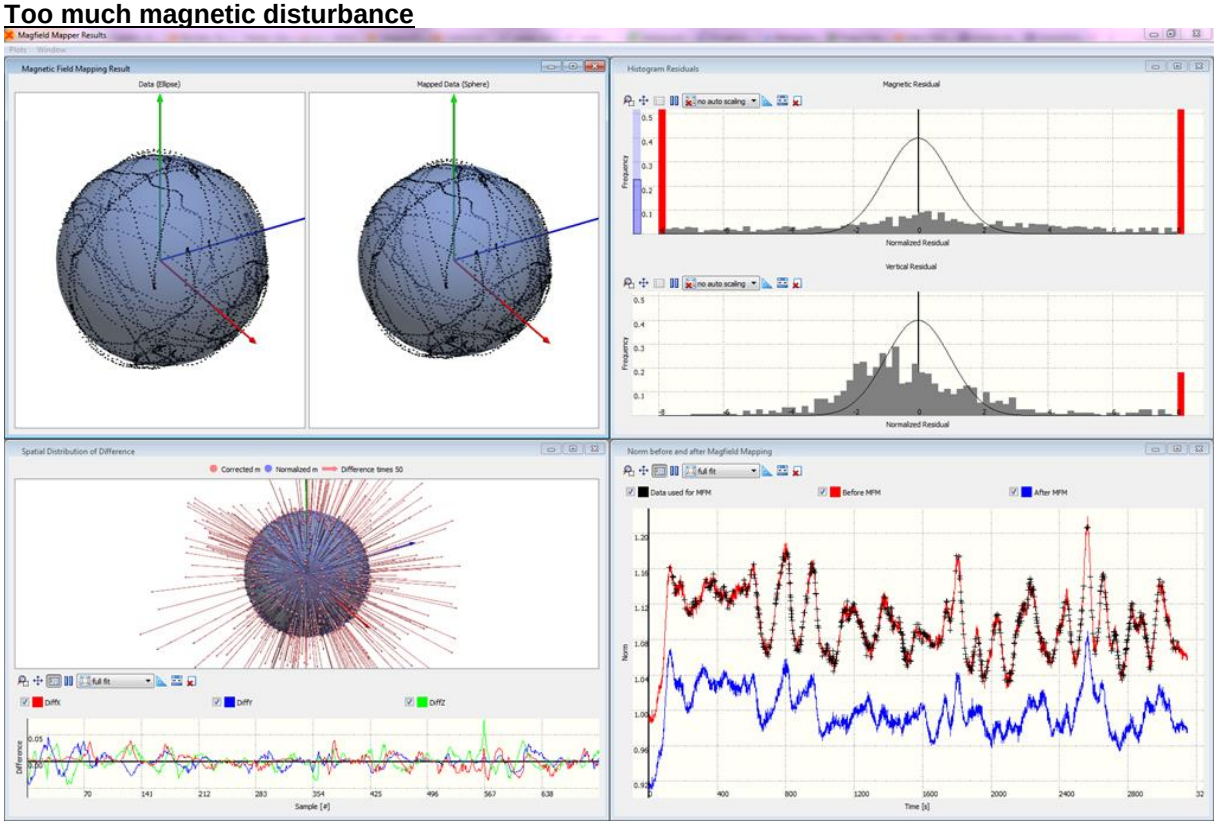


Figure 8: The points in the right sphere hover just above the surface of the model, the points do not fit to the model (and many points even fall outside the graph, see the red bars), residuals are large and the norm is not straight and/or close to 1.

Moving too fast

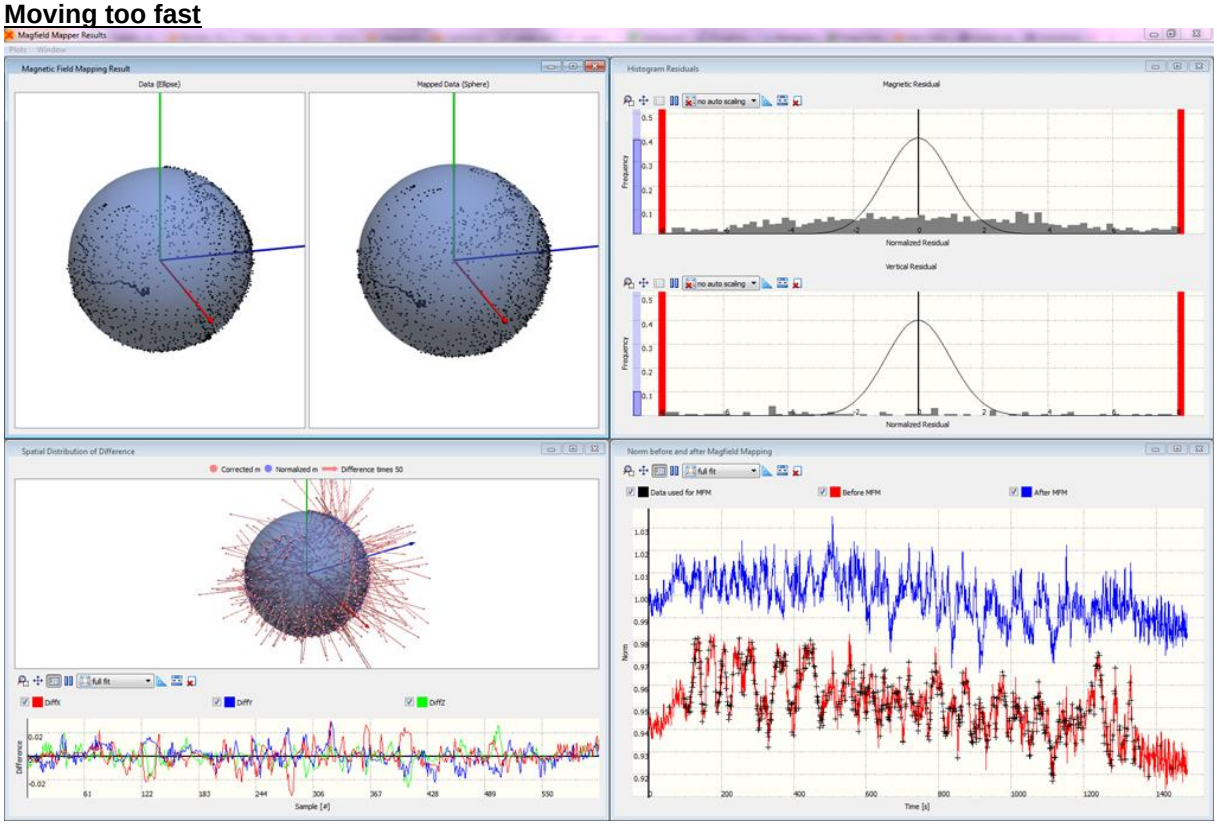


Figure 9: The points in the sphere do not form solid lines, almost all points are outside the graph in the gaussian model plot, the residuals are huge in all directions and the norm after MFM is not 1.

Not enough points

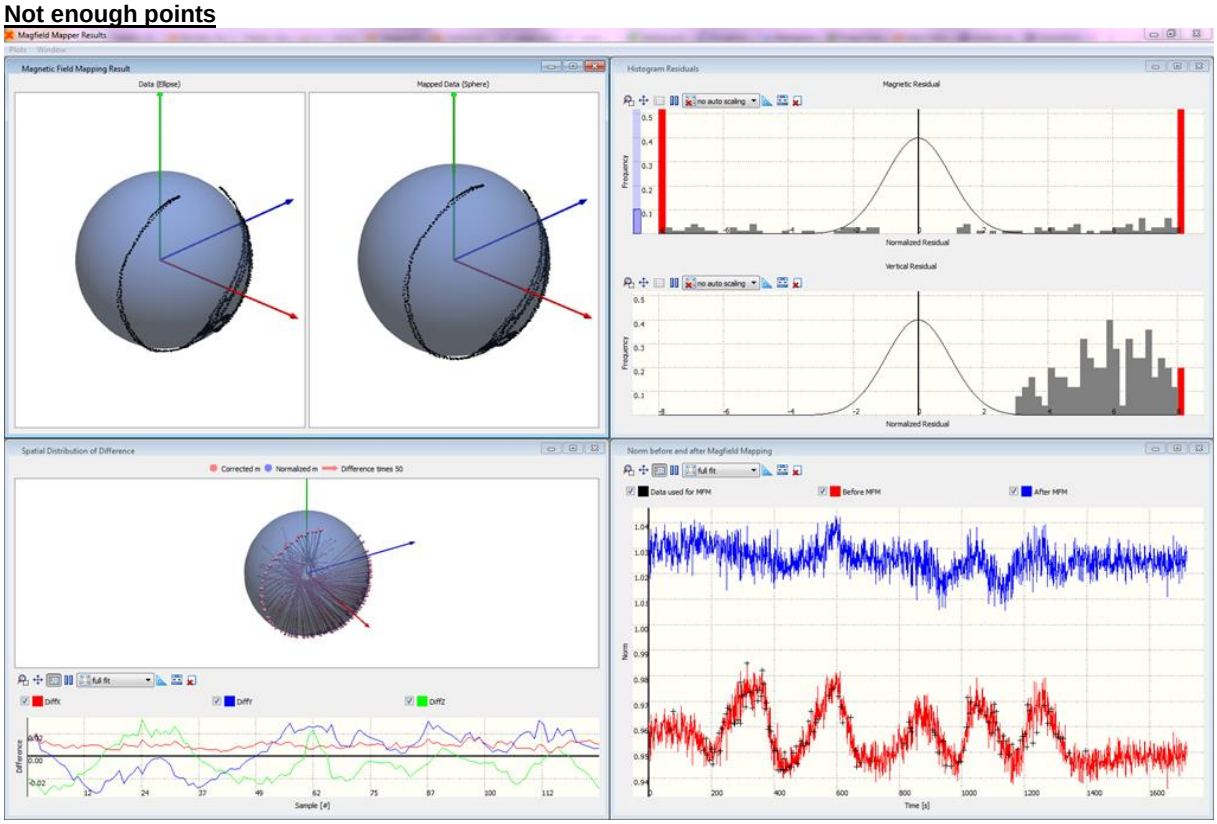


Figure 10: The spheres show hardly any points and are poorly distributed, resulting in large residuals. The norm after the MFM procedure is not close to 1.

Points too concentrated

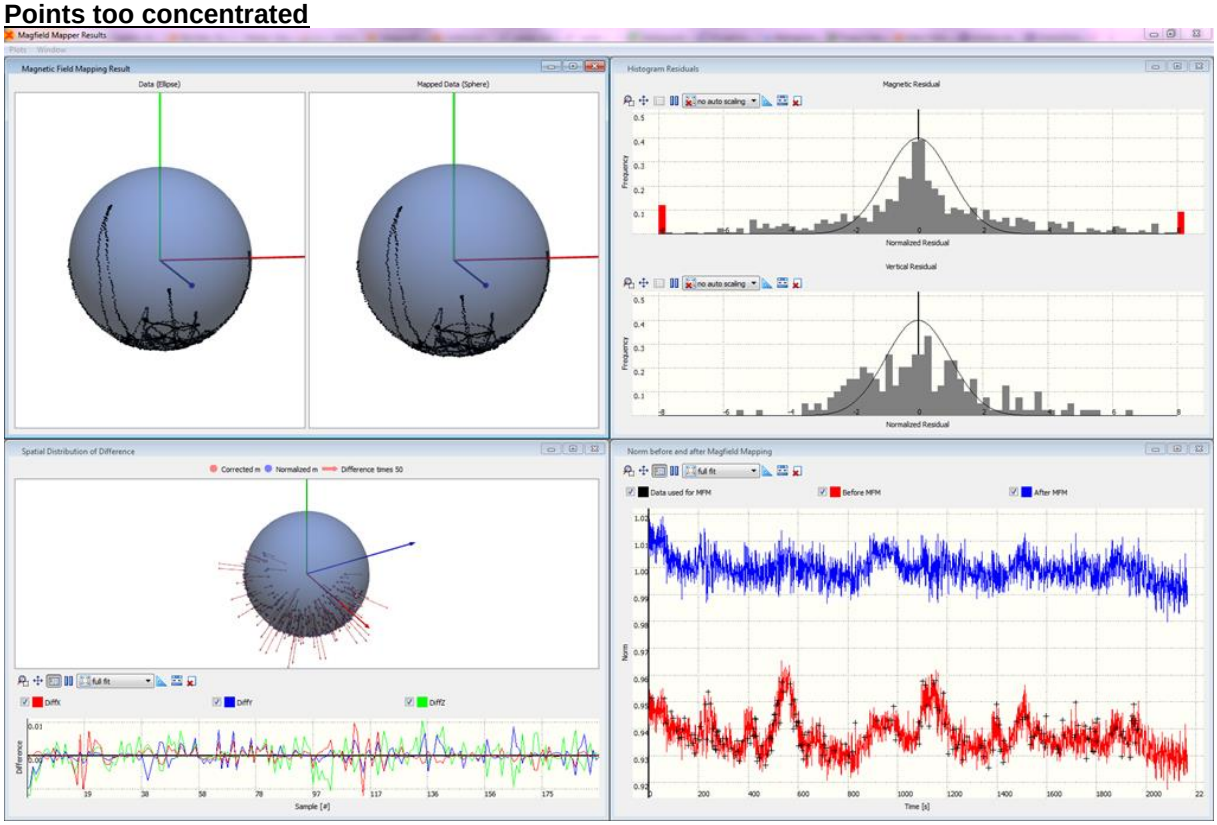


Figure 11: One of the advantages of the MagField Mapper is that mapping can be done with a small envelope of motion. Though there are only a few points, the distribution of these points on the sphere is adequate for a good observability of the MFM calibration parameters. The calibration parameters determined is valid for MFM motion envelope, but may be incorrect beyond the mapped area.

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 cannot 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. As the calibration results cannot be directly stored in the MT the MagField Mapper generates 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.

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. Check the results and if you are satisfied click 'Write' to generate the MFM results file. This file is stored in the same folder as the MagField Mapper executable, in most cases the following folder: C:\Program Files (86)\Xsens\Magnetic Field 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:

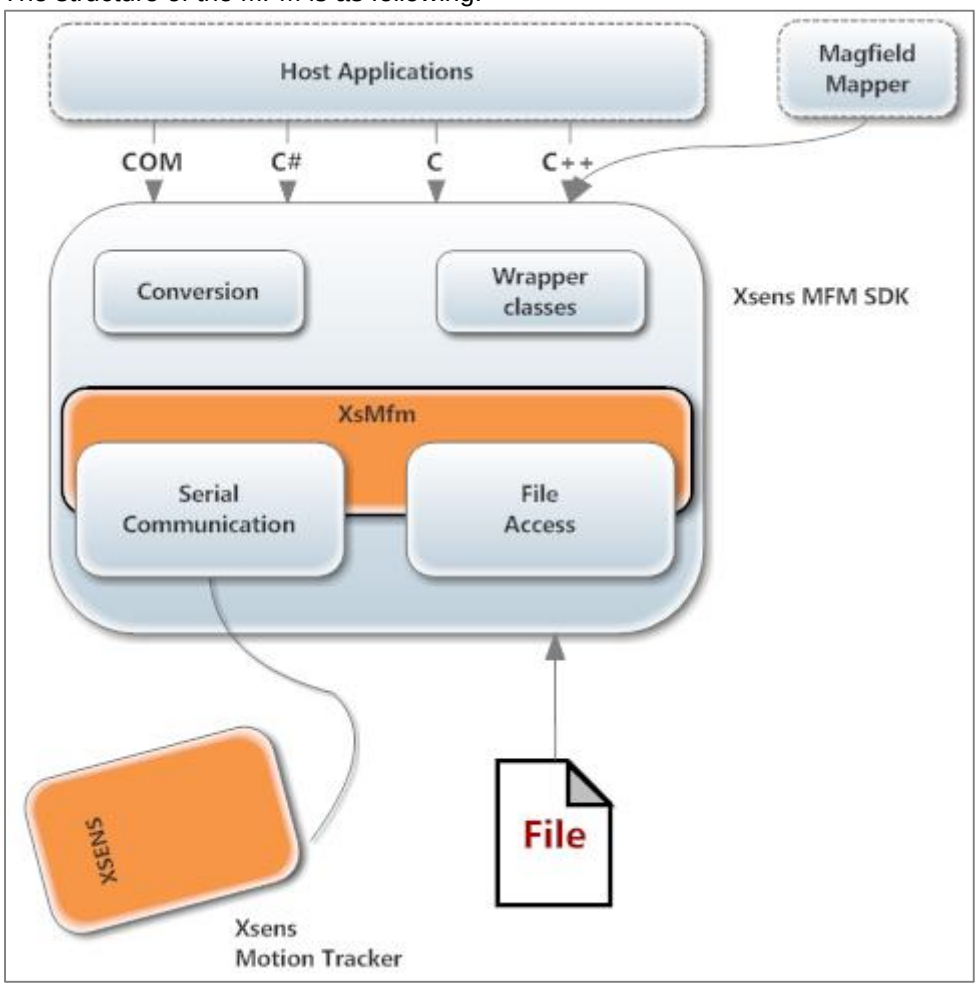
1. Copy the MFM results file to the system that has a direct connection to the MT.
2. Ensure that the MT is powered
3. Make sure that the MT is in **Config** state
4. Write the binary data message in the MFM results file to the sensor, using binary communication

4.3 Magnetic Field Mapping SDK

The Magnetic Field Mapping algorithm is also available in the Software Development Kit. This makes it possible to embed the Magnetic Field Mapping in 3rd party programs or to use MATLAB or C/C++/C#. The MFM SDK has the following components:

- DLL and .so that return MFM parameters and data for visualizations
- Examples for C#, MATLAB, C++

The structure of the MFM is as following:



Note: Extensive HTML documentation for the MFM SDK is included in the SDK. See the Xsens folder (e.g. C:\Program Files (x86)\Xsens\MT Software Suite 4.2\Documentation\Magfieldmapper)

5 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.

WWW: http://www.xsens.com/support
Phone: +31-(0) 88-9736700