Manual for the MREG Data Reconstruction Tool

Thimo Hugger and Jakob Assländer, updated by Antonia Barghoorn
University Medical Center Freiburg, Department of Radiology, Medical Physics

16 December 2024

Introduction

The interested reader can find additional background information on the topic of reconstructing MREG data in the following dissertations by Thimo Hugger (in German): http://www.freidok.uni-freiburg.de/volltexte/8081/ and Jakob Assländer: https://freidok.uni-freiburg.de/data/9756.

Contact: antonia.barghoorn@uniklinik-freiburg.de

1 Top Elements

1.1 Push Button: Set Working Dir

Selects a directory as the default for saving data. An additional folder is created in this directory for reconstructed data. The active working directory is displayed next to the push button.

1.2 Push Button: Export Settings

Saves all current settings in a `.mat` file for reuse.

2 Raw Data

2.1 Push Button: Load RawData

Selects a `.dat` file measured with the MREG-sequence. Header information is read and data is loaded on-demand during reconstruction.

3 Reference

3.1 Push Button: Load Reference

Allows selecting reference data as a `.dat` or `.mat` file. Sensitivity maps are computed using:

- **sos**: Sum of squares.

- **adapt**: Optimized combination of all coil images.
- **lowres**: Strongly low-pass filtered coil images.

3.2 Popup Menu: Select View

Options include:

- Coil Profiles: Reference images of each coil.
- Coil Sensitivities: The computed coil sensitivities
- Off-resonance Map: A map of the estimated off-resonances due to B_0 field inhomogeneities in radians per second

4 Trajectory

4.1 Push Button: Load Trajectory

Loads trajectories from `.dat`, `.mat`, or `.grad` files. For trajectory calibration, three `.dat` files are required.

4.2 Select Range

Allows you to select only part of the trajectory. Most of the time one will want to discard points in the beginning and at the end of the data that corresponds to parts of the trajectory that are either unimportant or might affect the reconstruction quality negatively (e.g. parts where the trajectory does not change). Usually the optimal range is already read from the header of the .grad or the .dat file, so no further selection is necessary. If the button is pressed, a window will pop up, showing the length of the k-spaces point versus the index, as guidance for the selection. One can then click on two positions in the graph and the range between these two points will be used, while the rest will be discarded. The process will repeat in case there is more than one interleaf.

4.3 Push Button: Save and View

Saves the trajectory to a `.mat` file and displays it in a plot.

5 Reconstruction Parameters

5.1 Editbox: CG-Tolerance

Specifies the tolerance for the conjugate gradient (CG) algorithm (e.g., 1×10^{-5}).

5.2 Editbox: Max. Iterations

Sets the maximum number of iterations for CG algorithms. Default values:

- L2-norm: 40 iterations.
- L1-norm: 200 iterations.

5.3 Editbox: Recon Size

The array size of the reconstruction can be adjusted here. This option as well as the next (Voxel Size) will only be enabled once the reference and the trajectory are loaded. Using a smaller reconstruction size can greatly benefit the reconstruction time since a smaller array size speeds up the internal operations like e.g. the FFT. Please note that this will not affect the resolution, that means reducing the array size leads to a reduction of the field of view. One therefore needs to make sure that the object still fits into the reduced field of view, otherwise aliasing will occur.

5.4 Editbox: Voxel Size

If really necessary the effective voxel size in the reconstruction can be changed here. Internally this will lead to the application of scaling factors to the k-space trajectory. This can be used e.g. to reduce the array size of the reconstruction beyond the point where the object would be larger than the field of view, by enlarging the voxel size.

5.5 Push Button: Adjust

In case the trajectory and the reference have different size and resolution and in case the Recon Size or the Voxel Size are changed, one has to adjust the reference data to the new settings. Internally the coil sensitivities, the coil profiles and the off-resonance map are resized. The callback mainly executes the function imresize3D to do that. If correctly adjusted, the color of the button will change to green.

6 Reconstruction Options

6.1 Popup Menu: Reconstruction Type

This option allows setting the reconstruction method in case of an interleaved acquisition. If the acquisition was interleaved, the methods **Sliding Window** or **KWIC** need to be used to get consistent results within timeframes. Otherwise, the **Standard** option is usually the correct choice.

1. **Standard**: Reconstructs each timeframe separately using the corresponding interleaf of that timeframe.

2. **Sliding Window**: If N_i interleaves are used, and timeframe n is to be reconstructed, the neighboring timeframes are combined and treated as the current timeframe. The timeframe range for reconstruction is:

$$n - \left\lfloor \frac{N_i}{2} + 1 \right\rfloor + 1 \ldots n + N_i - \left\lfloor \frac{N_i}{2} + 1 \right\rfloor$$

   If the neighboring timeframes exceed the range of the available timeframes, the reconstruction of the current timeframe is set to zero.

3. **KWIC (K-space Weighted Interpolation and Combination)**: This method is similar to the Sliding Window approach, but less data is used from interleaves further away from the current timeframe. The timeframes used are given by:

$$n \ldots n + N_i - 1$$

This option is most sensible when the so-called **bit-reversed ordering** is used for the interleaves.

Note on Interleaved Acquisition If $k = 1 \ldots N_i$ different trajectories were used for data acquisition, this typically means that in timeframe with index n, k is equal to:

$$k = \mathrm{rem}(n, N_i)$$

where `rem` represents the remainder operation.

The choice of reconstruction type depends on the specific application and acquisition scheme.

6.2 Checkbox: Off-resonance Correction

Incorporates off-resonance effects into the image reconstruction. If this option is checked the reconstruction time per timeframe is prolonged approximately by a factor 10.

6.3 Checkbox: z0

When z0 is chosen, one image in the middle of the time series is reconstructed. This image is then used as the starting point for the conjugate gradient. The number of steps necessary for convergence should be smaller than when using zero as starting point (default). But this option should be handled with care, since too few steps could give you a image, that corresponds more to the initial guess than to the image at that particular time frame. This could result in a meaningless time series.

6.4 Checkbox: DORK

"Dynamic off-resonance in k-space" is a method by Josef Pfeuffer et al. (MRM, 2002), that corrects for B0 changes due to scanner drifts, respiration etc. They way it works: If the frequency is off-center, the phase of the FID develops over time. If the the change of phase changes over the time series, the global off-resonance frequency can be calculated for the particular time frame and multiplied to the raw data. But it assumes, that the first time frame is on resonance. So I highly recommend to adjust the frequency before every MREG scan (Options-Adjustments in the exam task of the scanner). The computational costs are mainly a couple of seconds when turning on the mode. This is when the frequency drift is calculated. For the reconstruction itself the costs are negligible. Therefore I highly recommend to use the option. It seems to work very well for the drift of the B0 field, making sure, that last image is not shifted compared to the first and is of reasonable quality. The respiration induced artifacts seem to change not that much, even though they are clearly visible in the frequency (have a look in recon$_{\mathrm{d}}$etails.dork$_{\mathrm{f}}$requency stored by the grid engine; just set a breakpoint and plot the vector). The reason, why the respiration artifacts are not reduced by that much are higher spatial order components of the frequency (see Magnetic Resonance Encephalography Reconstruction with Magnetic Field Monitoring, F. Testud et al., ISMRM 2012).

6.5 Global off-resonance

Global means in this case "4D-global". So, if you forgot to adjust the frequency before the MREG scan, the frequency can be wrong right from the beginning of the time series, which cannot be corrected by DORK. This will result in crappy images with lots of shading all over the brain. If that is the case, you can try to find a frequency that improves the image. Just try some values, usually between -100/s and 100/s and see which one fits best. There is no, automatic or systematic way for that, sorry.

6.6 Checkbox: Use GridEngine

If the Sun GridEngine (http://wikis.sun.com/display/GridEngine/Home) is available to you and you want to reconstruct a lot of timeframes, this option can be checked to split up the reconstruction task into jobs and distribute them among the available slots on the GridEngine. Depending on the available resources this can tremendously speed things up. The option will be grayed out if the GridEngine is not found on your system.

6.7 Editbox: Frames per job

If the GridEngine option is checked, one can specify here the number of timeframes that will comprise one GridEngine job.

6.8 Editbox: Timeframe Range

Here you can specify the timeframes that you would like to reconstruct. Any vector of timeframes is acceptable as long as each timeframe is within the boundaries given by the data. Standard Matlab syntax can be used in this editbox, like for example:

$$[101 : 2 : 200].$$

Please note that unless the data is saved to files during the reconstruction (see 6.10), the resulting 4D-array will contain no information about the timeframes that were used.

6.9 Push button: Start Recon

Performs the Reconstruction either locally or submits jobs to the GridEngine depending on the option 6.6.

6.10 Checkbox: Save during recon

If this option is checked, the data is saved to the current working directory (section 1.1) in a folder with the name given by the option **Where** (6.12). If no name is specified or the field is empty, a default folder will be created containing the current timestamp to avoid overwriting previous reconstructions. This option will become unavailable if **Use GridEngine** (6.6) is checked, since in that case each job saves the data during reconstruction by default.

6.11 Popup menu: Save as ...

Sets the file format for the saved reconstructions. Each frame will be saved in a separate file. The filename will contain the timeframe of the reconstruction in the file. Options are:

1. **mat**: Standard Matlab mat-file. Contains no additional information about the reconstruction at this point.
2. **nifti**: NIFTI file format. The header of the resulting `.nii`-file contains some information about the reconstruction. Please note that SPM is needed in order to save to this file format.

6.12 Push button: Where

Provides an optional possibility to name the folder inside the working directory (1.1) where the data will be saved. This is useful in case you want to open several `mreg_recon_tools` to split up a local reconstruction task into several smaller tasks and ensure they are all saved in the same folder. If this field is empty, a default folder will be created containing a timestamp.

6.13 Push button: Save File

If **Save during recon.** was not checked and a reconstruction was performed, the data will be viewable only inside the `mreg_recon_tool`. This option allows saving the data to a file in the file format specified in 6.11.

6.14 Push button: Save WS

Sometimes one might want to analyze the reconstruction inside the Matlab workspace. Use this option to export the data to the current Matlab workspace. A window will then pop up, where you can name the variable.

6.15 Push button: View

If reconstructed data is available, this button opens the `viewer3d_tool` to view it.

7 Penalties

7.1 Push buttons: Add & Delete

Adds and deletes penalties in the cost function. The default cost function always consists of the fidelity term. If A is the encoding operator, ρ is the unknown image, and b is the measured data, then the cost function has the form:

$$f(\rho) = \|A\rho - b\|_2^2.$$

Adding a penalty (pressing the push button **Add**) really just adds the specified penalty mathematically to the fidelity term. With, for example, a regularization parameter λ, the L1-norm, and an operator W, the resulting cost function would be equal to:

$$f(\rho) = \|A\rho - b\|_2^2 + \lambda\|W\rho\|_1.$$

7.2 Editbox: lambda

The regularization parameter for this penalty.

7.3 Popup menu: Select norm

The norm for the penalty can be selected here. It can either be:

- **L1-norm**
- **L2-norm**

7.4 Popup menu: Select operator

An operator can be selected that is applied to ρ before measuring the norm of it.