StimFit 1.0

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A MATLAB Toolbox for
T_2 Relaxometry with Stimulated Echo Compensation

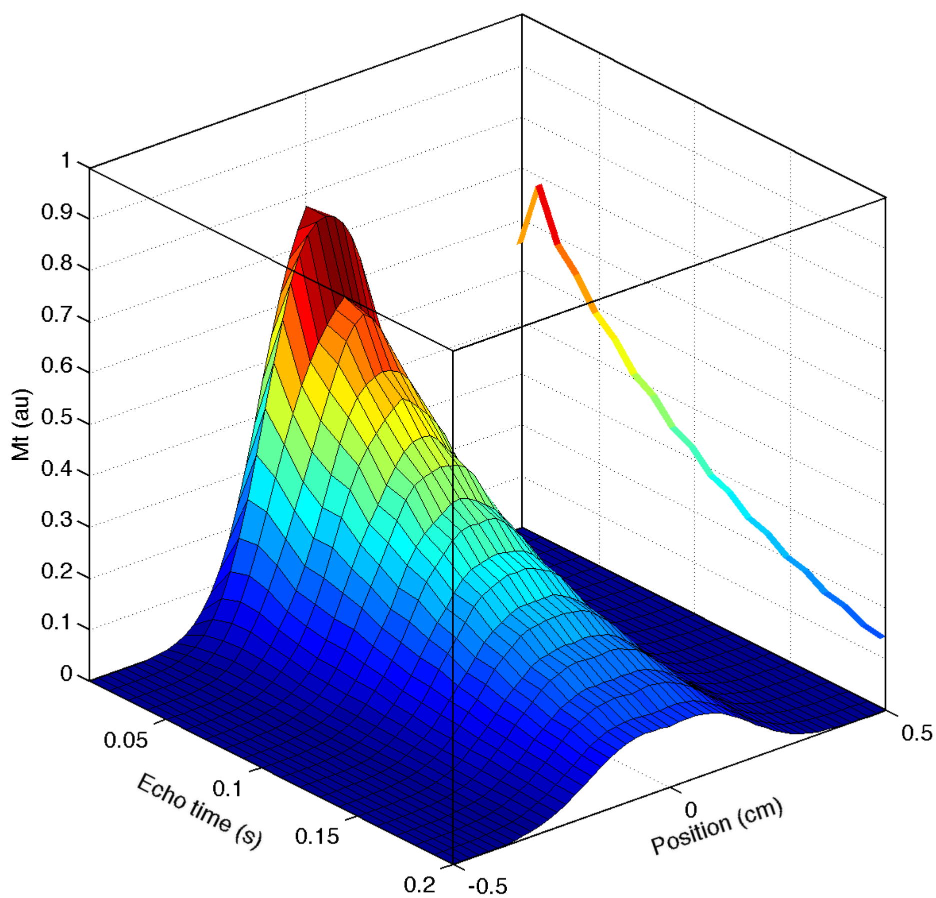

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Table of Contents

Introduction

About

This software package contains a MATLAB implementation of the method for transverse relaxometry with stimulated echo correction [1]. It estimates T_2 and the relative (and approximate) B_1^+ field from multi-echo spin echo data. While based on the original publication, there are several important differences — hopefully improvements! — these include:

- support for both single- and multiple-component fitting.
- support for finite T_1 values.

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This software has been tested on 64 bit versions of OSX and Ubuntu Linux; it is likely to work on other platforms.

Installation

Add the 'StimFit' directory and all subdirectories to the MATLAB path. If necessary, compile mex files:

```
>> mex Engine/epgMEX.c
>> mex RF_Tools/pulse_simMEX.c
```

Instructions

Demos

Two demonstration scripts and a data set are provided. A single-component fit can be run via 'demo_lsq_voxel.m'; a multi-component fit with 'demo_nnls_voxel.m'.

Basic Use

The following step-by-step instructions explain the basic functionality of the StimFit package.

1. Load image data. No tool is provided to do this.
   - The image should be of size NP×NV×NS×NE, where NP, NV, NS are spatial dimensions and NE is the number of echoes.
   - The image should be real valued, and (ideally) have zero-mean noise.
2. Load default fitting options into the 'opt' structure (refer to the section on fitting options, page 8, for details):
   - >> opt = StimFit_optset;
3. Modify crucial fields of 'opt' to reflect specific acquisition parameters:
   - opt.Dz Start and end positions for the slice profile simulation (cm)
   - opt.esp Interecho spacing (sec.)
   - opt.etl Echo train length
   - opt.RFe.tau RF pulse duration (excitation) (sec.)
   - opt.RFe.G Slice select amplitude (excitation) (G/cm)
   - opt.RFr.tau RF pulse duration (refocusing) (sec.)
   - opt.RFr.G Slice select amplitude (refocusing) (G/cm)
4. [optional] Enable debugging for graphical output (see Fig 1):
   - >> opt.debug = 1;
5. Run the fitting routine:
   - >> [T2, B1, amp, opt] = StimFitImg(img, opt);
6. When prompted, select the RF waveform files for excitation, then for refocusing.

7. Adjust image threshold, Fig 2.
8. If in debug mode, verify that the simulation bounds chosen in step 1 cover a sufficient portion of the slice profile, Fig 1.

Fitting will proceed without further input and the progress will be updated in the command window. Typical processing times are on the order of ~20 minutes per slice. The output variables are:

- T_2: map of the transverse relaxation rate (size: NP×NV×NS) (sec.)
- B_1: approximate map the fractional transmit field (size: NP×NV×NS) (a.u.)
- amp: map of scaling factors accounting for proton density, coil sensitivity, and global scaling factors (size: NP×NV×NS) (a.u.)
- opt: a modified version of the options structure containing detailed information about the RF pulses

Relevant variables are automatically saved in the working directory as 'StimFit.mat'.

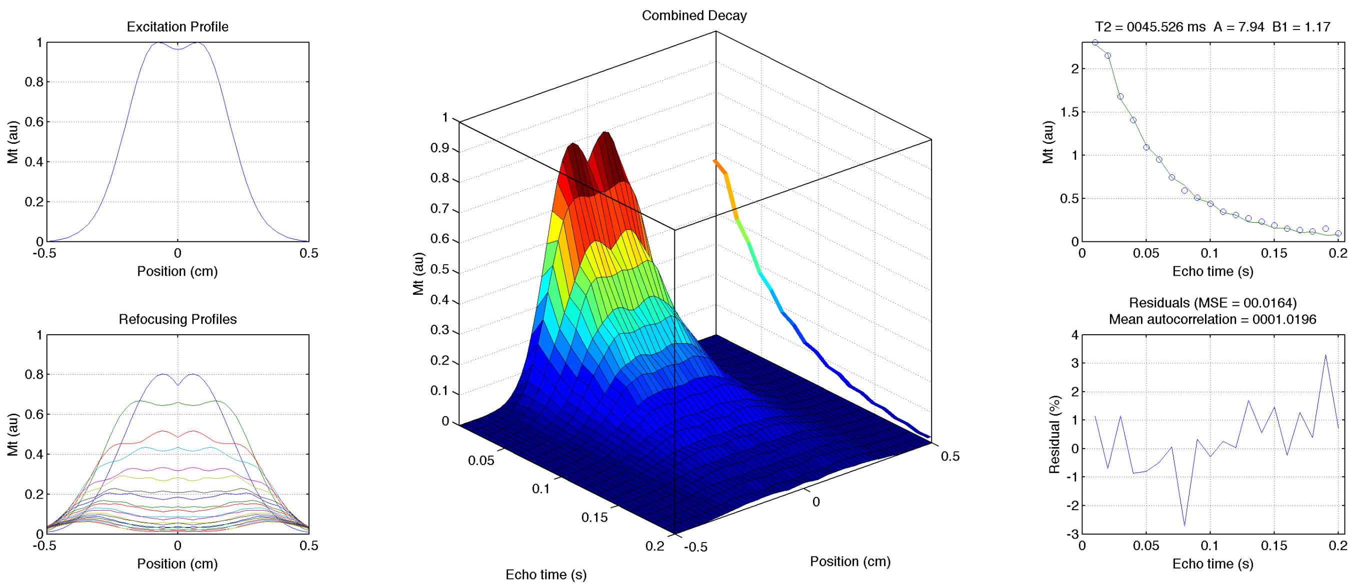

Figure 1: Graphical output in debug mode. Plots on the left column show the transverse magnetization following excitation (top) and following all refocusing pulses, assuming uniform excitation, (bottom) as functions of slice position. It is important to verify that the simulation width (specified in 'opt.Dz') spans the excited magnetization. The transverse magnetization due to both excitation and refocusing is plotted in the central frame versus the slice profile and echo time; the net magnetization — the integral across the slice position axis — is projected on the 'Position' axis. The data points, the three parameter fit, and the residuals are shown in the right column.

Advanced Use

StimFit allows multiple component T_2 fitting; there are two approaches for multi-component fitting:

- Bounded non-linear least squares with 2 or 3 independent T_2 parameters with non-overlapping domains.
- Pseudo-continuous T_2 fitting with regularized non-negative least squares [2, 3].

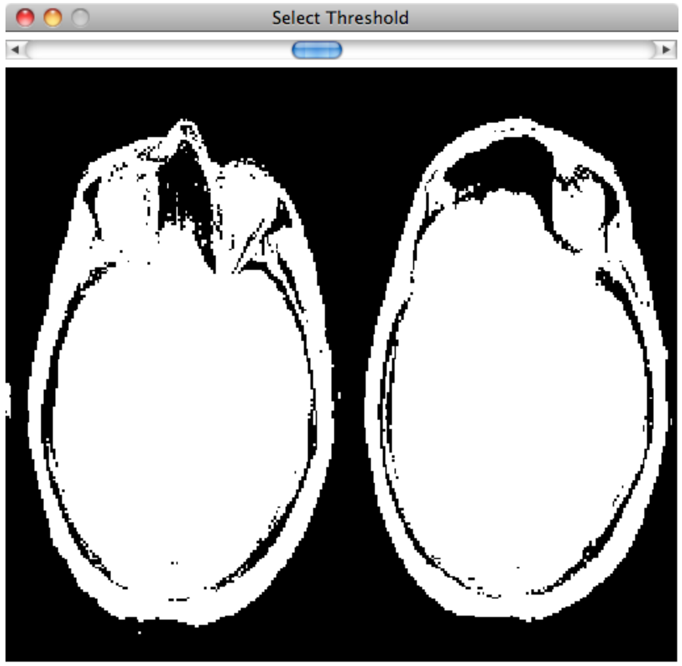

Figure 2: Image thresholding tool. Adjust the slider to constrain the fitting procedure. Close the window to accept the threshold.

In both cases, a single B_1 parameter is fit to the data. The type of fitting is controlled by 'opt.FitType': use 'lsq' for non-linear least squares and 'nnls' for regularized non-negative least squares. Additional fitting options are documented in 'StimFit_optset.m' and described below.

Fitting Options

Fitting options are defined in a MATLAB structure, typically called 'opt'; a default set can be obtained with the command:

```
>> opt = SimFit_optset;
```

Many of the default options are applicable to most scenarios; however, several crucial fields should be modified to reflect specific acquisition parameters. The fields are defined as follows.

General Options

opt.mode	Defines slice-selective or non-selective refocusing. Use 's' for 2D acquisitions with slice selective refocusing; use 'n' for 2D with non-selective refocusing and all 3D cases.
opt.debug	Plotting flag. 0 for none; 1 for one voxel only; 2 for all voxels.
opt.Dz	Spatial bounds of the simulation in the slice select direction. Input as [min max] (cm).
opt.Nz	Number of discrete positions to simulate across the slice select direction.
opt.Nrf	Number of resampled points in the RF waveform.
opt.esp	Inter-echo spacing (sec.).
opt.etl	Echo train length.
opt.T1	Assumed T_1 value (sec.). Must be provided as a function handle.
opt.FitType	String specifying the type of fitting to perform. Must be either 'lsq' for non-linear least squares or 'nnls' for non-negative least squares.
opt.th	Noise threshold for image masking (# of standard deviations). Set to '0' for manual selection. This option only applies when fitting an image.
opt.th_te	Array of echo times that must satisfy the threshold to be considered for fitting. This option only applies when fitting an image.

Excitation Pulse Options

opt.RFe.path	Path to excitation waveform. Provide an empty string for a graphical interface.
opt.RFe.RF	Placeholder for RF waveform. If empty, the waveform will be read from opt.RFe.path then scaled according to opt.RFe.angle.
opt.RFe.tau	Duration of excitation pulse (sec.).
opt.RFe.G	Slice select gradient during excitation (G/cm).
opt.RFe.phase	Relative phase (0 in CPMG) (degrees).
opt.RFe.angle	Prescribed excitation pulse angle, typically 90 (degrees).
opt.RFe.ref	Rephasing gradient fraction, times two. Near unity for excite.
opt.RFe.alpha	Actual tip angle distribution across the slice (degrees). If empty, will be automatically computed.

Refocusing Pulse Options

opt.RFr.path	Path to refocusing waveform. Provide an empty string for a graphical interface.
opt.RFr.RF	Placeholder for RF waveform. If empty, the waveform will be read from opt.RFr.path then scaled according to opt.RFr.angle.
opt.RFr.tau	Duration of refocusing pulse (sec.).
opt.RFr.G	Slice select gradient during refocusing (G/cm).
opt.RFr.phase	Relative phase (90 in CPMG) (degrees).
opt.RFr.angle	Prescribed refocusing pulse angle, typically 180 (degrees).
opt.RFr.ref	Rephasing gradient fraction, times two. Zero for refocus.
opt.RFr.alpha	Actual refocusing angle distribution across the slice (degrees). If empty, will be automatically computed.

Non-Linear Least Squares Options

opt.lsq.Ncomp	Number of components to fit. Currently 1, 2, or 3 components are supported.
opt.lsq.Icomp.X0	Starting point for fitting (1 component). Specified as a 1×3 array: [T_2 amp B_1].
opt.lsq.Icomp.XU	Upper parameter bounds (1 component). As above.
opt.lsq.Icomp.XL	Lower parameter bounds (1 component). As above.
opt.lsq.IIcomp.X0	Starting point for iterative fitting (2 components). Specified as a 1×5 array: [$T_2^{(a)}$ amp$^{(a)}$ $T_2^{(b)}$ amp$^{(b)}$ B_1].
opt.lsq.IIcomp.XU	Upper parameter bounds (2 components). As above.
opt.lsq.IIcomp.XL	Lower parameter bounds (2 components). As above.
opt.lsq.IIIcomp.X0	Starting point for iterative fitting (3 components). Specified as a 1×7 array: [$T_2^{(a)}$ amp$^{(a)}$ $T_2^{(b)}$ amp$^{(b)}$ $T_2^{(c)}$ amp$^{(c)}$ B_1].
opt.lsq.IIIcomp.XU	Upper parameter bounds (3 components). As above.
opt.lsq.IIIcomp.XL	Lower parameter bounds (3 components). As above.
opt.lsq.fopt	Options for non-linear least squares fit using 'lsqnonlin'. Typically defined with 'optimset'.

Non-Negative Least Squares Options

opt.nnls.T2range	Minimum and maximum T_2 values (sec.). Specified as [$T_2^{(min)}$ $T_2^{(max)}$].
opt.nnls.NT2	Number of T_2 values to model.
opt.nnls.B1range	Range of B_1 values to consider. Specified as [$B_1^{(min)}$ $B_1^{(max)}$].
opt.nnls.NB1	Number of B_1 values to model.
opt.nnls.A	Placeholder for the solution space (size: opt.etl x opt.nnls.NT2 x opt.nnls.NB1). If empty, computed in StimFitNNLS.m.
opt.nnls.lambda	Regularizer defining the fractional misfit.

Function List

/demo_lsq_voxel.m	Demonstration of a single voxel non-linear least squares fit.
/demo_nnls_voxel.m	Demonstration of a single voxel non-negative least squares fit.
/StimFit_optset.m	Defines default fitting options.
/StimFit.m	Non-linear least squares fitting routine for a single signal vector.
/StimFitImg.m	Looping function to fit an entire image volume using StimFit.m.
/StimFitNNLS.m	Non-negative least squares fitting routine for a single signal vector.
/StimFitImgNNLS.m	Looping function to fit an entire image volume using StimFitNNLS.m.
/Bloch_Tools/bloch_sim.m	Bloch simulator for CPMG sequences (alternative to the EPG method, not actually used in the StimFit package).
/Engine/epgMEX[.m, .c, .mex*]	Extended phase graph routine to compute echo amplitudes.
/Engine/FSEsig.m	Computes and integrates the echo amplitude using known tip angle distributions.
/Miscellaneous/get_threshold.m	Graphical interface for image thresholding.
/RF_Tools/calcflipRF.m	Computes the spatial distribution of tip angles from the RF waveform.
/RF_Tools/getRF.m	Populates an RF waveform structure (as defined and initialized in StimFit_optset.m) with crucial information.
/RF_Tools/pulse_sim.m	Bloch simulator for RF pulses.
/RF_Tools/puse_simMEX[.c, .mex*]	Bloch simulator for RF pulses.
/RF_Tools/readRF_GE	Import filter for GE .rho files.
/RF_Tools/readRF_Siemens	Import filter for Siemens .pta files.
/RF_Tools/readRF_Varian	Import filter for Varian .RF files.
/RF_Tools/readRF.m	Vendor neutral graphical interface for importing RF waveforms.
/RF_Tools/scaleRF.m	Scales RF waveforms for the desired tip angle.

Bibliography

[1] Lebel RM, Wilman AH. Transverse relaxometry with stimulated echo compensation. Magn Reson Med 2010;64(4):1005–14.

[2] MacKay A, Whittall K, Adler J, Li D, Paty D, Graeb D. In vivo visualization of myelin water in brain by magnetic resonance. Magn Reson Med 1994;31(6):673–7.

[3] Whittall KP, MacKay AL, Graeb DA, Nugent RA, Li DK, Paty DW. In vivo measurement of T2 distributions and water contents in normal human brain. Magn Reson Med 1997;37(1):34–43.