Example of performing IMPULSED fitting

This example shows how to (1) how to synthesize dMRI signals based on the IMPULSED method; and (2) how to fit the IMPULSED model to dMRI data to extract microstructural parameters such as mean cell size d, apparent intracellular volume fraction v_{in}, intra- and extra-cellular diffusion coefficients D_{in} and D_{ex}.

Contents

Reference

The main reference that should be cited when using the code in this script is

1. Jiang X, et al. Quantification of cell size using temporal diffusion spectroscopy. Magn Reson Med. 2016;75(3):1076-85. PubMed PMID: 25845851.
2. Xu J, et al. Magnetic resonance imaging of mean cell size in human breast tumors. Magn Reson Med. 2020;83(6):2002-14. PubMed PMID: 31765494.

Preliminary

```
clear variables ; clear obj ;
```

Generate DiffusionPulseSequence objects

Create a trapezoidal cosine OGSE pulse sequence object for all OGSE acquisitions

```
Nacq = 9 ;          % total number of acquisition points
pulse_tcos = mati.DiffusionPulseSequence(Nacq,...
    'TE',              110,...                 % echo time [ms]
    'delta',           40,...                  % gradient duration [ms]
    'Delta',           45,...                  % separation of two gradients [ms]
    'b',                 [0.1,0.2,0.3, 0.4, 0.2,0.4,0.6,0.8,1.0], ...      % b value [ms/um^2]
    'n',                 [2,2,2, 2, 1,1,1,1,1],...            % number of oscillating cycles
    'shape',         "tcos",...                % gradient waveform shape
    'gdir',            [0 0 1],...              % gradient directions. It should be a Nx3 matrix
    'trise',           0.9) ;                  % gradient rise time [ms]

% Create a trapezoidal PGSE pulse sequence object for all PGSE acquisitions
Nacq = 9 ;
pulse_tpgse = mati.DiffusionPulseSequence(Nacq, ...
    'TE',              110,...
    'delta',           12, ...
    'Delta',           74, ...
    'b',                 [0.2:0.2:1.8], ...
    'shape',         "tpgse",...
    'gdir',            [0 0 1],...
    'trise',            0.9) ;

% Combine OGSE and PGSE pulse sequence objects
pulse = mati.PulseSequence.cat(pulse_tcos, pulse_tpgse) ;

% An example of choosing a subset of PulseSequence object to meet e.g., hardware limitations
pulse = pulse(pulse.G<80e-5) ;      % 80mT/m = 80 x 10^(-5) gauss/um

% Display the PulseSequence object
pulse.disp(pulse)
```

```
<a href="">Note: PulseSequence properties should be column vectors. They are shown as row vectors here for visualization purpose only
</a>
ans =
```

```
  struct with fields:

    delta: [40 40 40 40 40 40 40 12 12 12 12 12 12 12 12 12]
    Delta: [45 45 45 45 45 45 45 74 74 74 74 74 74 74 74 74]
    shape: [1×16 string]
        b: [1×16 double]
        G: [1×16 double]
        n: [2 2 1 1 1 1 1 0 0 0 0 0 0 0 0 0]
    trise: [1×16 double]
     gdir: [3×16 double]
        f: [1×16 double]
        w: [1×16 double]
        T: [20 20 40 40 40 40 40 0 0 0 0 0 0 0 0 0]
       tp: [1×16 double]
    tdiff: [5 5 10 10 10 10 10 70 70 70 70 70 70 70 70 70]
    gamma: 26.7500
     Nacq: 16
       TR: []
       TE: [110 110 110 110 110 110 110 110 110 110 110 110 110 110 110 110]
       B0: []
       df: []
```

Generate IMPULSED model object

Choose which specific model to use. Note that IMPULSED can fit up to five parameters, i..e, d, v_{in}, D_{in}, D_{ex0}, and β_{ex}. Individual parameters could be fixed during fitting to enhance the fitting precision of other parameters.

```
nmodel = 3 ;
switch nmodel
    case 1, structure.modelName = '1compt' ; structure.geometry = 'sphere' ;
    case 2, structure.modelName = 'impulsed_vin_d_Dex' ; structure.Din = 2 ; structure.betaex = 0 ; structure.geometry = 'sphere';
    case 3, structure.modelName = 'impulsed_vin_d_Dex_Din' ; %structure.betaex = 0 ; structure.geometry = 'sphere';
    case 4, structure.modelName = 'impulsed_vin_d_Dex_Din_betaex' ; %structure.geometry = 'sphere';
end

% Create an IMPULSED model object
impulsed = mati.IMPULSED(structure, pulse) ;
```

Example of synthesize dMRI signals based on the IMPULSED model

This is for computer simulations studies to synthesize dMRI signals based on the IMPULSED model. The ground-truth microstructural parameter are determined below. NOTE:

1. parms_sim is a cell array that contains all microstructual parameters for dMRI signal synthesis
2. variables (*_sim) indicate ground-truth microstructural parameters used in the simulations.

```
switch nmodel
    case 1      % [d, Din]
        d = [10:15] ; Din = [1.56 3] ;
        parms_sim = {d, Din};    [d,Din]=meshgrid(d,Din) ;
        d_sim = d(:)' ; Din_sim = Din(:)' ;
    case 2      % [vin, d, Dex]
        vin = [0.6] ; d = [10:15] ; Dex = [1.56 3] ;
        parms_sim = {vin, d, Dex};   [vin, d,Dex] = meshgrid(vin, d,Dex) ;
        d_sim = d(:)' ; vin_sim = vin(:)' ; Dex_sim = Dex(:)' ;
    case 3      % [vin, d, Dex, Din]
        vin = [0.6] ; d = [10:15] ; Dex = [1.56 3] ; Din = [1.56] ;
        parms_sim = {vin, d, Dex, Din};   [vin, d,Dex,Din] = ndgrid(vin, d,Dex,Din) ;
        d_sim = d(:)' ; vin_sim = vin(:)' ; Dex_sim = Dex(:)' ; Din_sim = Din(:)' ;
    case 4      % [vin, d, Dex, Din, betaex]
        vin = [0.6] ; d = [8:2:16] ; Dex = [2] ; Din = [1.56] ; betaex = [5] ;
        parms_sim = {vin, d, Dex, Din, betaex};   [vin, d,Dex,Din,betaex] = ndgrid(vin, d,Dex,Din,betaex) ;
        d_sim = d(:)' ; vin_sim = vin(:)' ; Dex_sim = Dex(:)' ; Din_sim = Din(:)' ; betaex_sim = betaex(:)' ;
end

% Synthesize IMPULSED signals based on the microstructural parameters determined above
signal_sim = impulsed.FcnSignal(parms_sim, impulsed) ;

% Add Rician noise to synthesized signals
sigma_noise = 0.025 ;         % standard deviation of Gaussian noise in the real and the imaginary images assuming to be equal
```

```
signal_sim = mati.Physics.AddRicianNoise(signal_sim, sigma_noise) ;

% Create an ImageData object
[Npulse, Nparms] = size(signal_sim) ;
data = mati.ImageData(reshape(signal_sim',[Nparms, 1, 1, Npulse]), sigma_noise) ;
```

Fit IMPULSED model to dMRI signals

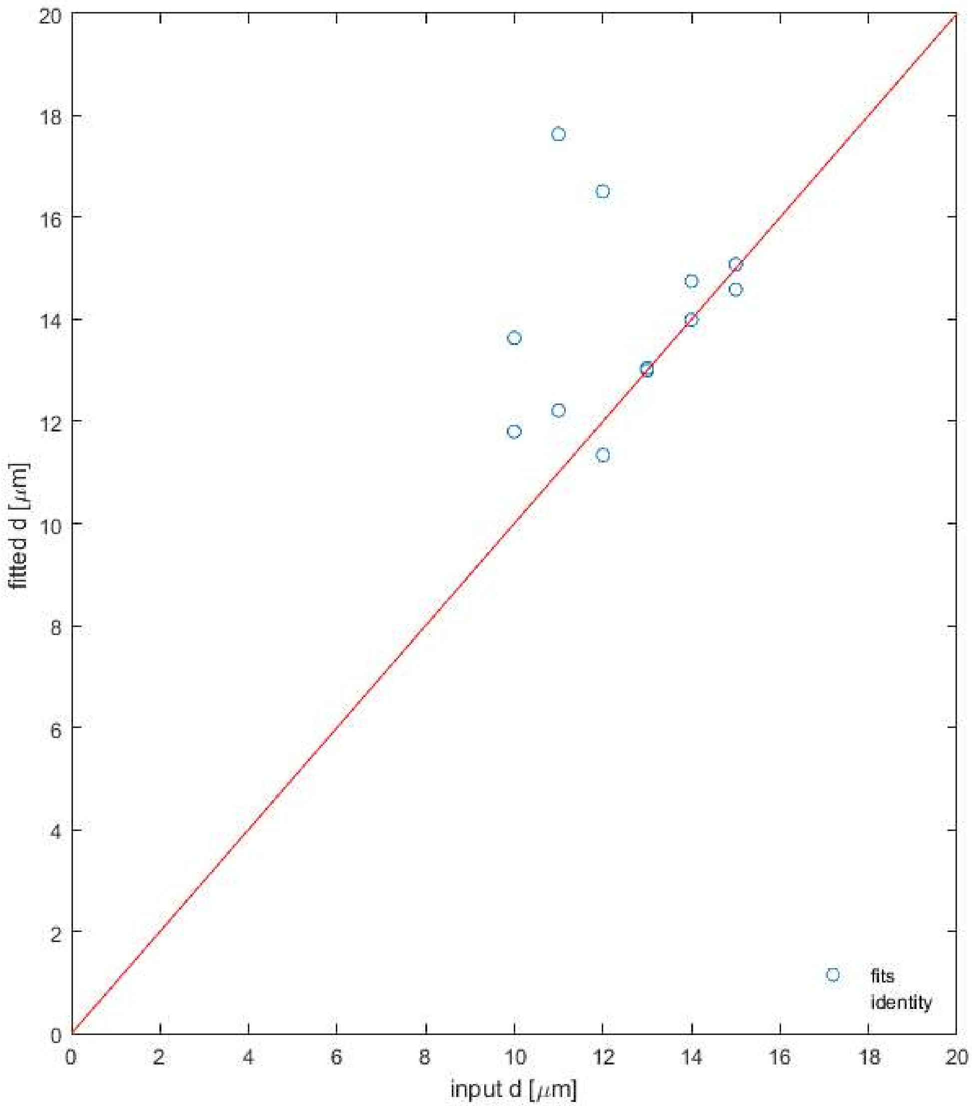
Create a Fit object

```
fitopts.solverName = 'lsqnonlin'; % {'lsqcurvefit' , 'lsqnonlin' , 'fmincon'}
fitopts.options = optimoptions(fitopts.solverName,'Display','off') ;
fitopts.noiseModel = 'standard' ; %{'none','standard';'logLikelihood'}
fitopts.flag.parfor = 'y' ;              % If use parallel computing with parfor
fitopts.flag.deivim = 'n' ;             % if remove IVIM influence
fitopts.flag.multistart = 'y' ;         % If try fittings multiple times with different initial conditions
fitopts.NumStarts = 5 ;              % if try multistart=='y', try how many times of different initial conditions?

% Create a data fitting object
fitpars = mati.FitPars(impulsed, fitopts) ;
warning off ;

% Fit model to data
fitout = fitpars.Fit(data) ;
```

Check fitted results

Show the comparison of IMPULSED fitted and ground-truth mean cell size

```
figure(1) ; clf ; hold on ;
plot(d_sim, fitout.d, 'o') ;
plot([0 20],[0 20],'r') ; box on ;
xlabel('input d [\mum]') ; ylabel('fitted d [\mum]') ; xlim([0 20]) ; ylim([0 20]) ;
legend('fits', 'identity', 'Location','Southeast') ;
```



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