SimuBloch v0.3 User Guide

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Chapter 1

Introduction

The simulator package *SimuBloch* is made for a fast simulation of image sequences based on Bloch equations, which can be run directly from VIP Portal: `http://vip.creatis.insa-lyon.fr`. The current version is v0.3.

The simulator allows to construct 6 different MR pulse sequences:

1. *SimuBlochSE*: Simulation of spin echo sequences.
2. *SimuBlochGRE*: Simulation of gradient echo sequences.
3. *SimuBlochIR-SE*: Simulation of inversion recovery spin echo sequences.
4. *SimuBlochIR-GRE*: Simulation of inversion recovery gradient echo sequences.
5. *SimuBlochSP-GRE*: Simulation of spoiled gradient echo sequences.
6. *SimuBlochCoherentGRE*: Simulation of coherent gradient echo sequences.

Chapter 2

SimuBlochSE

2.1 Description

The executable *SimuBlochSE* allows to simulate the **Spin Echo** sequence using the following function:

$$S = M_0[1 - \exp(-TR/T_1)] \cdot \exp(-TE/T_2) \tag{2.1}$$

The simulator is given in Fig. 2.1.

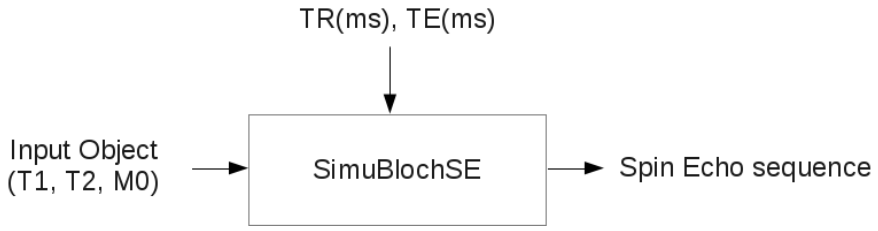

Figure 2.1: Construction of the Spin Echo sequence with the simulator *SimuBlochSE*.

2.2 Inputs & Output

- Input image files (Mandatory)
  - T_1: Longitudinal (or spin-lattice) relaxation time (ms).
  - T_2: Transverse (or spin-spin) relaxation time (ms).
  - M_0: Equilibrium magnetization, which is proportional to proton density ρ.

The dimensions and sizes of the input images should be equal. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with input images of 3D nifti format.

- Input parameters
  - TR: Repetition time (ms). The value should be ≥ 0. The default value is 500ms.
  - TE: Echo time (ms). The value should be ≥ 0. The default value is 8.4ms.

  If the parameters are not set as input, the simulator uses the default values to calculate the sequence.

- Output image file (Mandatory)
  - S: Spin Echo sequence. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with output image of 3D nifti format.

2.3 Usages

From a 3D virtual object with parameters T_1, T_2 and M_0, we can compute the Spin Echo sequence using the simulator for 3 basic MRI scans. Examples are given for humain brain imaging at 3T.

- T_1-weighted: Short TR, short TE.
  For example, $TR = 500ms$, $TE = 8.4ms$.

- T_2-weighted: Long TR, long TE.
  For example, $TR = 6530ms$, $TE = 84ms$.

- PD-weighted: Long TR, short TE.
  For example, $TR = 6530ms$, $TE = 9.4ms$.

We can also generate the T_1 and T_2 relaxometry images.

- T_1 relaxometry: Short TE, multiple TR (both short and long, $TR < 0.5T_1$, $TR > 2T_1$)
  For example, $TR = [80, 250, 400, 800, 1300, 4000]ms$, $TE = 8.4ms$.

- T_2 relaxometry: Long TR, multiple TE.
  For example, $TR = 4530ms$, $TE = [13.8, 27.6, 41.4, 55.2, 69.0, 82.8, 96.6]ms$.

The sample data can be found in the package *SimuBloch* v0.3.

Chapter 3

SimuBlochGRE

3.1 Description

The executable *SimuBlochGRE* allows to simulate the **Gradient Echo** sequence using the following function:

$$S = M_0[1 - \exp(-TR/T_1)] \cdot \exp(-TE/T_2^*) \tag{3.1}$$

The simulator is given in Fig. 3.1.

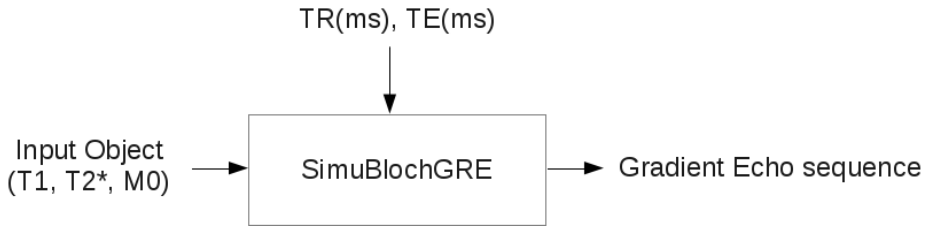

Figure 3.1: Construction of the Gradient Echo sequence with the simulator *SimuBlochGRE*.

3.2 Inputs & Output

- Input image files (Mandatory)
  - T_1: Longitudinal (or spin-lattice) relaxation time (ms).
  - T_2^*: A transverse relaxation time (ms) with extra dephasing effects included. T_2^* is always smaller than T_2.
  - M_0: Equilibrium magnetization, which is proportional to proton density ρ.

The dimensions and sizes of the input images should be equal. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with input images of 3D nifti format.

- Input parameters
  - TR: Repetition time (ms). The value should be ≥ 0. The default value is 120ms.
  - TE: Echo time (ms). The value should be ≥ 0. The default value is 8ms.

  If the parameters are not set as input, the simulator uses the default values to calculate the sequence.

- Output image file (Mandatory)
  - S: Gradient Echo sequence. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with output image of 3D nifti format.

3.3 Usages

From a 3D virtual object with parameters T_1, T_2^* and M_0, we can compute the Gradient Echo sequence using the simulator for the following MRI scans. Examples are given for humain brain imaging at 3T.

- T_1-weighted: Short TR, short TE.
  For example, $TR = 120ms$, $TE = 8ms$.

The sample data can be found in the package *SimuBloch* v0.3.

Chapter 4

SimuBlochIR-SE

4.1 Description

The executable *SimuBlochIR-SE* allows to simulate the **Inversion Recovery - Spin Echo** sequence using the following function:

$$S = M_0|1 - 2\exp(-TI/T_1) + \exp(-TR/T_1)| \cdot \exp(-TE/T_2) \tag{4.1}$$

The simulator is given in Fig. 4.1.

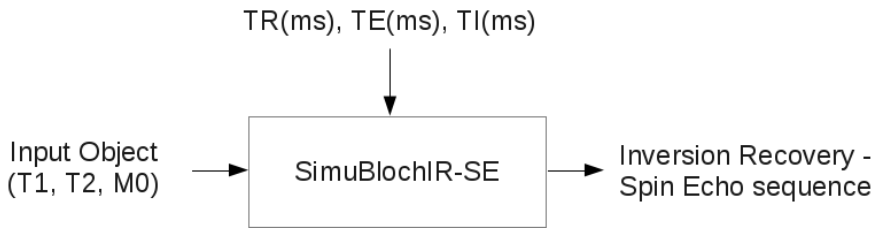

Figure 4.1: Construction of the Inversion Recovery - Spin Echo sequence with the simulator *SimuBlochIR-SE*.

4.2 Inputs & Output

- Input image files (Mandatory)
  - T_1: Longitudinal (or spin-lattice) relaxation time (ms).
  - T_2: Transverse (or spin-spin) relaxation time (ms).
  - M_0: Equilibrium magnetization, which is proportional to proton density ρ.

The dimensions and sizes of the input images should be equal. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with input images of 3D nifti format.

- Input parameters
  - TR: Repetition time (ms). The value should be ≥ 0. The default value is 2400ms.
  - TE: Echo time (ms). The value should be ≥ 0. The default value is 20ms.
  - TI: Inversion time (ms). The value should be ≥ 0. The default value is 1200ms.

  If the parameters are not set as input, the simulator uses the default values to calculate the sequence.

- Output image file (Mandatory)
  - S: Inversion Recovery - Spin Echo sequence. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with output image of 3D nifti format.

4.3 Usages

From a 3D virtual object with parameters T_1, T_2 and M_0, we can compute the Inversion Recovery - Spin Echo sequence using the simulator for the following MRI scans. Examples are given for humain brain imaging at 3T.

- T_1-weighted: $TE << T_2$, $TI \sim T_1$.
  For example, $TR = 2400ms$, $TE = 20ms$, $TI = 1200ms$.
- T_2-weighted: $TE \sim T_2$, $TI >> T_1$.
  For example, $TR = 2400ms$, $TE = 100ms$, $TI = 2000ms$.

The sample data can be found in the package *SimuBloch* v0.3.

Chapter 5

SimuBlochIR-GRE

5.1 Description

The executable *SimuBlochIR-GRE* allows to simulate the **Inversion Recovery - Gradient Echo** sequence using the following function:

$$S = M_0|1 - 2\exp(-TI/T_1) + \exp(-TR/T_1)| \cdot \exp(-TE/T_2^*) \tag{5.1}$$

The simulator is given in Fig. 5.1.

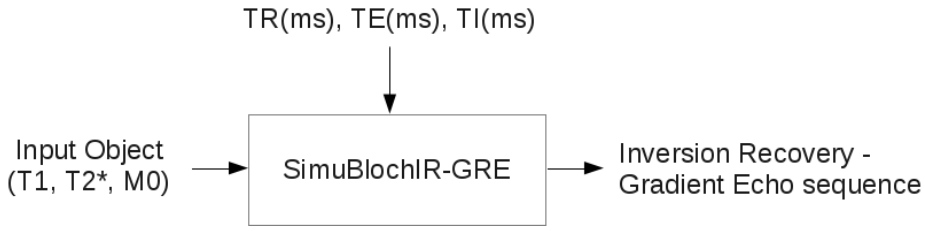

Figure 5.1: Construction of the Inversion Recovery - Gradient Echo sequence with the simulator *SimuBlochIR-GRE*.

5.2 Inputs & Output

- Input image files (Mandatory)
  - T_1: Longitudinal (or spin-lattice) relaxation time (ms).
  - T_2^*: A transverse relaxation time (ms) with extra dephasing effects included. T_2^* is always smaller than T_2.
  - M_0: Equilibrium magnetization, which is proportional to proton density ρ.

The dimensions and sizes of the input images should be equal. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with input images of 3D nifti format.

- Input parameters
  - TR: Repetition time (ms). The value should be ≥ 0. The default value is 1900ms.
  - TE: Echo time (ms). The value should be ≥ 0. The default value is 2.98ms.
  - TI: Inversion time (ms). The value should be ≥ 0. The default value is 900ms.

  If the parameters are not set as input, the simulator uses the default values to calculate the sequence.

- Output image file (Mandatory)
  - S: Inversion Recovery - Gradient Echo sequence. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with output image of 3D nifti format.

5.3 Usages

From a 3D virtual object with parameters T_1, T_2^* and M_0, we can compute the Inversion Recovery - Gradient Echo sequence using the simulator for the following MRI scans. Examples are given for humain brain imaging at 3T.

- **MPRAGE**: Magnetization Prepared Rapid Acquired Gradient Echo to produce high-resolution T_1-weighted images. TE has to be short.
  For example, $TR = 1900ms$, $TE = 2.98ms$, $TI = 900ms$.

The sample data can be found in the package *SimuBloch* v0.3.

Chapter 6

SimuBlochSP-GRE

6.1 Description

The executable *SimuBlochSP-GRE* allows to simulate the **Spoiled Gradient Echo** (possible called **SPGR**, **FLASH**, or **T1-FFE** on the scanner) sequence using the following function:

$$S = M_0 \frac{\sin FA \cdot [1 - \exp(-TR/T_1)] \cdot \exp(-TE/T_2^*)}{1 - \cos FA \cdot \exp(-TR/T_1)} \tag{6.1}$$

The simulator is given in Fig. 6.1.

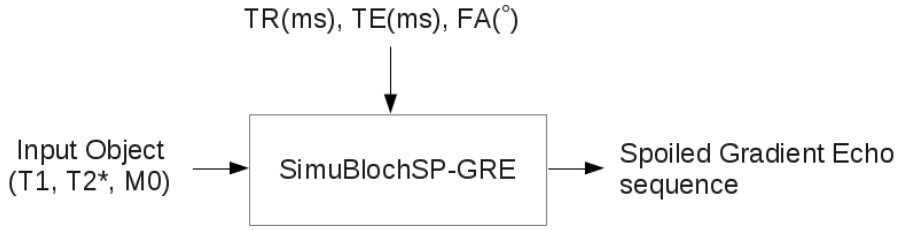

Figure 6.1: Construction of the Spoiled Gradient Echo sequence with the simulator *SimuBlochSP-GRE*.

6.2 Inputs & Output

- Input image files (Mandatory)
  - T_1: Longitudinal (or spin-lattice) relaxation time (ms).
  - T_2^*: A transverse relaxation time (ms) with extra dephasing effects included. T_2^* is always smaller than T_2.

  - M_0: Equilibrium magnetization, which is proportional to proton density ρ.

  The dimensions and sizes of the input images should be equal. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with input images of 3D nifti format.

- Input parameters
  - TR: Repetition time (ms). The value should be ≥ 0. The default value is 35ms.
  - TE: Echo time (ms). The value should be ≥ 0. The default value is 6ms.
  - FA: Flip angle (°). The value should be in the range of $[0°, 180°]$. The default value is 40°.

  If the parameters are not set as input, the simulator uses the default values to calculate the sequence.

- Output image file (Mandatory)
  - S: Spoiled Gradient Echo sequence. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with output image of 3D nifti format.

6.3 Usages

From a 3D virtual object with parameters T_1, T_2^* and M_0, we can compute the Spoiled Gradient Echo sequence using the simulator for the following MRI scans. Examples are given for humain brain imaging at 3T.

- T_1-weighted: Short TR, short TE, large FA.
  For example, $TR = 35ms$, $TE = 6ms$, $FA = 40°$.

- PD-weighted: Long TR, short TE, small FA.
  For example, $TR = 500ms$, $TE = 6ms$, $FA = 20°$.

- T_2^*-weighted: Long TR, long TE, small FA.
  For example, $TR = 500ms$, $TE = 40ms$, $FA = 20°$.

We can also generate the T_1 and T_2^* relaxometry images.

- T_1 relaxometry: Fixed TR, very short TE, multiple FA.
  For example, $TR = 15ms$, $TE = 1.54$, $FA = [5°, 30°]$.

- T_2^* relaxometry: Fixed TR, fixed FA, multiple TE.
  For example, $TR = 50ms$, $TE = [4.36, 11.9, 19.44, 26.98, 34.52]ms$, $FA = 17°$.

The sample data can be found in the package *SimuBloch* v0.3.

Chapter 7

SimuBlochCoherentGRE

7.1 Description

The executable *SimuBlochCoherentGRE* allows to simulate the **Coherent** or **Partially Refocused (Rewound) Gradient Echo** sequence (**FISP**, **GRASS**, **FFE**, **FAST**) using the following function:

$$S = M_0 \frac{\sin FA \cdot [1 - \exp(-TR/T_1)] \cdot \exp(-TE/T_2^*)}{1 - \cos FA \cdot \exp(-TR/T_1) - \exp(-TR/T_2) \cdot [\exp(-TR/T_1) - \cos FA]} \tag{7.1}$$

Coherent Gradient Echo sequences are used with very short TR, much less than T_1 and T_2. In this case, the equation is simplified to

$$S = M_0 \frac{\sin FA \cdot \exp(-TE/T_2^*)}{1 + T_1/T_2 - \cos FA \cdot (T_1/T_2 - 1)} \tag{7.2}$$

The simulator is given in Fig. 7.1.

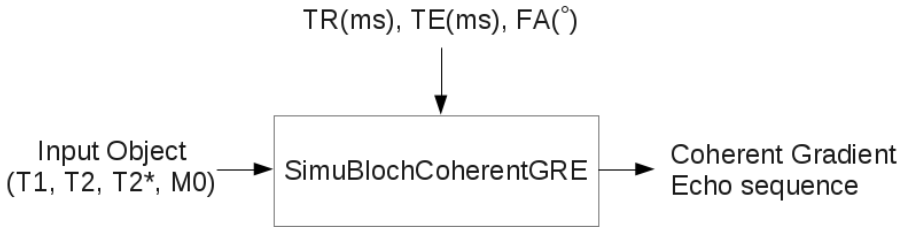

Figure 7.1: Construction of the Coherent Gradient Echo sequence with the simulator *SimuBlochCoherentGRE*.

7.2 Inputs & Output

- Input image files (Mandatory)

  - T_1: Longitudinal (or spin-lattice) relaxation time (ms).
  - T_2: Transverse (or spin-spin) relaxation time (ms).
  - T_2^*: A transverse relaxation time (ms) with extra dephasing effects included. T_2^* is always smaller than T_2.
  - M_0: Equilibrium magnetization, which is proportional to proton density ρ.

  The dimensions and sizes of the input images should be equal. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with input images of 3D nifti format.

- Input parameters
  - TR: Repetition time (ms). The value should be ≥ 0, and very short. The default value is 40ms.
  - TE: Echo time (ms). The value should be ≥ 0. The default value is 15ms.
  - FA: Flip angle (°). The value should be in the range of $[0°, 180°]$. The default value is 25°.

  If the parameters are not set as input, the simulator uses the default values to calculate the sequence.

- Output image file (Mandatory)
  - S: Coherent Gradient Echo sequence. The supported image formats are given in the ITK library. The dimension can be 1D, 2D or 3D. The simulator was tested with output image of 3D nifti format.

7.3 Usages

From a 3D virtual object with parameters T_1, T_2, T_2^* and M_0, we can compute the Coherent Gradient Echo sequence using the simulator for the following MRI scans. Examples are given for humain brain imaging at 3T.

- T_2^*-weighted: Short TR ($20ms \leq TR \leq 50ms$), long TE ($15ms \leq TE \leq 25ms$), small FA ($FA \leq 45°$).
  For example, $TR = 40ms$, $TE = 15ms$, $FA = 25°$.

The sample data can be found in the package *SimuBloch* v0.3.

Contact

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Sample Data

The sample data in SimuBloch v0.3 package were acquired on in vivo MR acquisitions performed on a 3T Siemens Verio (VB17) scanner with a 32-ch head coil as part of the USPIO-6 imaging protocol. The subject was one multiple sclerosis patient (Subject: 01002; Sex: Female; Birth Date: 1989/01/01) on Month 00, Day 1 (Creation Date: 2009/08/10). The images are 3D nifti with $192 \times 192 \times 44$ voxels. The voxel size is $1.3 \times 1.3 \times 3.0\text{mm}^3$.

- T_1 map: T1.nii.gz
- T_2 map: T2.nii.gz
- T_2^* map: T2s.nii.gz
- M_0 (PD map): M0.nii.gz