

Modelling FMRI Motion Artefacts using a Simulated Scanner

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Synopsis

A simulated scanner was implemented, based on solving the Bloch equations for a general pulse sequence in order to quantitatively model motion artefacts in FMRI. This simulation was run using an EPI sequence, allowing the precise amounts of within-scan blurring and spin history artefacts to be found for a model of the brain undergoing typical motions. The results show that spin history induces a change of similar magnitude to within-scan motion effects.

Introduction The presence of motion artefacts in functional MRI data is a confound for statistical analysis and often results in erroneous activations being reported, especially when the motion is correlated with the paradigm. Current methods of modelling and correcting for motion artefacts are often based purely on the temporal correlation with estimated motion parameters and cannot distinguish between motion-induced and activation-induced signal changes. Hence there is a need for realistic and complete modelling of motion-induced artefacts, such as within-scan motion and spin history, which will allow the accurate quantification of artefact levels. This is critical for the development and testing of motion artefact correction techniques.

Methods A general MRI simulator was constructed in C++ to solve the Bloch equations for each element of the object (small rectangular voxels). In order to model general motion of the object a rigid-body coordinate transform, $R(t)$, relating the object and scanner coordinate systems is specified as a function of time; i.e.

$\mathbf{x}_{sc} = R(t)\mathbf{x}_{ob}$. Motion parameters are specified at discrete time points via an input file and the transform is interpolated between these points. In addition, the RF timings and gradient waveforms are specified and interpolated from a second input file. Integrating the magnetisation vector in time for each tissue type separately in a voxel element in object space gives the MR signal as

$$S_{voxel}(t) = \iiint_{voxel} \rho M_0 \exp\left(-\frac{t}{T_2}\right) \exp\left(j\gamma \int_0^t \mathbf{G}_{sc}(\bar{t})R(\bar{t})\mathbf{x}d\bar{t}\right) \exp\left(j\gamma \int_0^t B_z(\bar{t})d\bar{t}\right) d\mathbf{x}$$

where M_0 is the transverse magnetisation following the last RF excitation, ρ is the average spin density of this tissue type in this voxel, $\mathbf{G}_{sc}(t)$ is the applied gradient vector (in the scanner coordinate frame) at time t , and $B_z(t)$ is the field (along the z direction) at the origin, which can include any inhomogeneities. This integral can be evaluated analytically over the voxel giving

$$S_{voxel}(t) = L_x L_y L_z \rho M_0 \exp\left(-\frac{t}{T_2}\right) \exp\left(j\gamma \int_0^t B_z(\bar{t})d\bar{t}\right) \text{sinc}(F_x) \text{sinc}(F_y) \text{sinc}(F_z)$$

where L_x is the length of the voxel in the x direction, $F_x = \frac{1}{2} \gamma L_x \int_0^t G_x(\bar{t})R(\bar{t})d\bar{t}$, and similarly for the y and z directions. RF excitations are modelled with a simple rotation of the magnetisation vector about the x axis. The total signal is then formed by summing the contributions from each voxel.

Results

A simulated image acquisition was performed using an EPI pulse sequence with trapezoidal gradient waveforms, 90° flip angle and crushers. The Brain Web partial volume tissue estimates [1] for CSF, Grey Matter and White Matter were used to model the object. Figure 1 shows a single axial slice without and with object motion (a 20 degree rotation during the acquisition) respectively. Intensity changes with time are shown in Figure 2 for no motion, demonstrating saturation effects, and Figure 4 for through-slice translation (shown in Figure 3), demonstrating changes due to spin history effects. The relative magnitude of spin-history changes in this case are approximately 3%, similar to those associated with within scan motion but less than the main saturation effects. The effect of a timing mis-specification in the readout gradient is shown in Figure 5, demonstrating the typical N/2 ghost.

Conclusion

We have quantitatively simulated motion artefacts using the Bloch equations for a realistic brain object and motion parameters. This differs from existing simulators [1],[2],[3] due to the inclusion of within-scan motion. As very large amounts of calculation are involved, significant optimisation and pre-computation was required in order to reduce the computational time down to feasible times (hours) on a standard modern Linux workstation (Athlon 2200). It is intended to include the effects of chemical shift and B0-inhomogeneities next, using a theoretical model for the B0 changes [4]. The quantification of the relative strengths of B0-motion interaction versus spin-history effects for different motions and brain regions is important in understanding, modelling and eventually correcting for such artefacts in FMRI. In addition, it is possible to extend this simulation framework to include time varying signals of a physiological nature (e.g. varying $T2^*$ with time to model BOLD) which would provide a realistic method of generating simulated data with known ground truth for testing and validation of statistical analysis methods, even in the presence of stimulus-correlated motion artefacts.

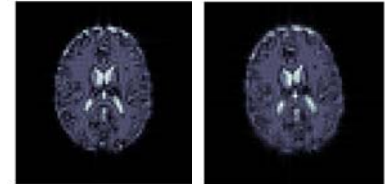


Figure 1: EPI images without and with motion (a 20 degree rotation).



Figure 2: Saturation effects in acquisition of 3 volumes with $TR=3s$.

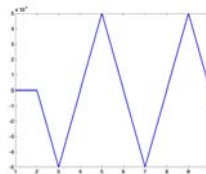


Figure 3: Translation in z

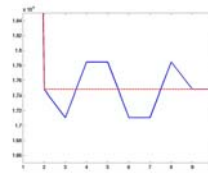


Figure 4: Spin history effects

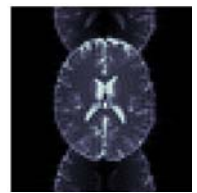


Figure 5: N/2 ghost

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References

[1] R.K.S. Kwan, A.C. Evans and G.B. Pike, IEEE TMI 1999, 18(11). [2] A. Stenger, et al, HBM 2003, poster 951. [3] D. Yoder, et al, SPIE Medical Imaging 2002. [4] M. Jenkinson, J. Wilson and P. Jezzard, ISMRM 2002