FMRI Simulator: Development and Applications

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Hilary Term, 2007

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and

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To my family

Mami, tati, bati, seki, baki, deki i ujki ...

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Abstract

Functional Magnetic Resonance Imaging (FMRI) is a non-invasive method of imaging brain function in-vivo. However, images produced in FMRI experiment almost invariably contain imperfections, known as artifacts. These artifacts can result from, for example, rigid-body motion of the head, magnetic field inhomogeneities, chemical shift and eddy currents.

To investigate these artifacts, with the eventual aim of minimising or removing them completely, a computational model of the FMR image acquisition process was built which can simulate all of the above mentioned artifacts. The simulator uses a geometric definition of the object (brain), Bloch equations (to model the behaviour of the magnetisation) and a model for the Blood Oxygen Level Dependent (BOLD) activations. Furthermore, it simulates rigid-body motion of the object by solving Bloch equations for an object moving continuously in time (as opposed to assuming movement only between the acquisition of consecutive images). This is a novel approach in the area of MRI computer simulations. With this approach it is possible, in a controlled and precise way, to simulate the full effects of various rigid-body motion artifacts in FMRI data (e.g. spin-history effects, B_0-motion interaction and within-scan motion blurring) and therefore formulate and test algorithms for their reduction. This thesis presents the development of the model for the simulator, its numerical implementation and solutions for the computational issues, and the validation of the simulator by comparing its outputs with existing theoretical and experimental results.

Finally, the simulator is applied in a number of diverse applications. These applications include: comparing different acquisition techniques for eddy-current compensation; reproducing and extending experiments in neuronal current imaging; quantifying the performance of motion correction software; quantitatively evaluating the impact of stimulus correlated motion artifacts; and investigating the performance of Independent Component Analysis (ICA) as a tool for quantifying motion-related artifacts.

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BOLD	Blood Oxygenation Level Dependant
CSF	Cerebro-Spinal Fluid
DWI	Diffusion-Weighted Imaging
EPI	Echo Planar Imaging
FID	Free Induction Decay
FLASH	Fast Low-Angle SHot
FLIRT	FMRIB Linear Image Registration Technique
FMRI	Functional Magnetic Resonance Imaging
FMRIB	Oxford centre for fMRI of the Brain
FSL	FMRIB software library
FOV	Field Of View
FT	Fourier Transform
GE	Gradient-Echo
GM	Grey Matter
ICA	Independent Component Analysis
MCFLIRT	Motion Correction using FLIRT
MIDAS	MR Imaging Data Acquisition Simulator
MRI	Magnetic Resonance Imaging
NMR	Nuclear Magnetic Resonance
POSSUM	Physics Oriented Scanner Simulator Utility for MRI
RF	Radio-Frequency
ROI	Region-Of-Interest
SCM	Stimulus Correlated Motion
SE	Spin-Echo
SNR	Signal-to-Noise Ratio
TE	Echo Time
TR	Repetition Time
WM	White Matter