Preface

This book is about how to analyze perfusion-weighted imaging (PWI), functional MRI (fMRI), diffusion-weighted imaging (DWI), and structural MRI (sMRI) data for investigating brain functions. Broadly speaking, there are two approaches to study brain function in vivo: one is bolus injection method and the other is noninvasive (no injections) method, e.g., blood-oxygen-level-dependent (BOLD) contrast method. For the tracer injection method, we will introduce dynamic susceptibility contrast imaging (DSC-MRI), which we focus on the Dirac delta function (impulse function) as an input for studying the brain blood flow system. The basic indicator theory is explained in details. Both linear and nonlinear regression methods are employed to smooth the DSC-MRI concentration time course. To solve the ill-posed problem for the residual function estimation, weighted damping method, i.e., Levenberg–Marquardt (LM) algorithm is introduced to solve Toeplitz matrix regularization problem. Cerebral blood flow parameters are then estimated based on the indicator theory.

BOLD-fMRI processing is the main part of this book; this includes both activation detection (segmentation view of the brain) and effective connectivity study (integration view of the brain). We begin with the first-level activation detection analysis, and we introduced the generalized linear model with autoregression model for error correction in activation detection. The threshold correction for the activation map using false discovery rate (FDR) and family-wise error (FWE) is introduced subsequently. Then mixed model is presented for the second-level analysis. To calculate the regression parameters, i.e., variance in the mixed effect model, Newton–Raphson (NR), LM, and trust region methods are given in Chap. 3.

In recent years, there has been increasing interest in studying effective connectivity using fMRI method. Generally speaking, there are three methods to study effective connectivity from the viewpoint of system identification, i.e., black-box, gray-box, and white-box methods. Since the black-box method is model free and easy to apply, we concentrate on introducing this method. This includes model selection for first-level and robust regression for second-level effective connectivity analysis. We also apply this method for resting-state fMRI study.

The third part of this book is about processing diffusion-weighted imaging (DWI). The basic principle of MRI diffusion imaging is to study the motion of water molecules. The first concept is the apparent diffusion coefficient (ADC) which quantifies the magnitude of the water diffusion on one dimension. Because water diffusion is really 3D processing, diffusion tensor imaging (DTI) is introduced to describe this motion. Based on this information, we can infer the fiber directions in the human brain. But DTI method cannot resolve the problem of crossing fiber issue; to circumvent this limitation, high angle resolution diffusion imaging (HARDI) was proposed, and Q-ball imaging (QBI) and diffusion spectrum imaging (DSI) have been developed for studying diffusion orientation map. To estimate orientation distribution function (ODF) from QBI/DSI, regularization methods need to be adopted. We introduce the commonly used method, i.e., generalized cross validation (GCV) method for ODF regularization.

Finally, sMRI data analysis method is presented. Instead of concentrating on sMRI image segmentation and registration, we present voxel-based morphometry (VBM) method and its application to Alzheimer's disease (AD) study. To begin with, we give the processing steps for VBM analysis based on cross-sectional study, and then we provided longitudinal VBM for sMRI data analysis. Furthermore, as an example, we apply this method to AD study to demonstrate how to use this method. Based on longitudinal VBM, we investigate the causality relationship between different brain regions at different stages of disease progression.

I assume the reader has a certain background in computer programming, numerical analysis, statistics, and medical image analysis. This book can be used for graduate students who are interested in studying medical image analysis, particularly fMRI image analysis. It can also be used as a reference book for radiologists, psychologists, neurologists, medical image physicists, computer scientists, and biomedical engineers for studying MRI image processing.

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