Bioengineering 248: Magnetic Resonance Imaging

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Course: http://www.its.caltech.edu/~jmt/Mike_Tyszka_Research/BE248.html

Summary

The aim of this course is to provide a graduate level introduction to magnetic resonance imaging of biological systems with special emphasis on the human brain. The theory, engineering and practice of magnetic resonance imaging are covered in detail. The course takes the student from the underlying NMR phenomenon to practical MR image acquisition and is illustrated throughout with real-world examples and current research topics.

Units: 9 (3-0-6) (Lecture-Lab-Homework)

Weekly schedule: Tue, Thu 1:30pm – 3:00pm (First lecture Tue Sep 30th, 2008)
Homework: Assigned problems each week. Some Matlab programming. One paper over final two-weeks.

Requirements:

Undergraduate level physical sciences, biological sciences or engineering are recommended. Vector algebra, basic differential calculus, signal and imaging processing background are helpful but not essential.

Course Books:

Liang Z-P and Lauterbur PC. Principles of Magnetic Resonance Imaging: A Signal Processing Perspective. Wiley-IEEE Press, 1st Edition 1999. ISBN 0780347234.

Optional: Haacke EM et al. Magnetic Resonance Imaging: Physical Principles and Sequence Design. Wiley-LISS, 1st Edition 1999. ISBN 0471351288.

Optional: Bernstein MA et al. Handbook of MRI Pulse Sequences. Academic Press, 2004. ISBN 0120928612.

Optional: Buxton RB. Introduction to Functional Magnetic Resonance Imaging: Principles and Techniques. Cambridge University Press, 2001. ISBN 0521581133.

Lecture Syllabus (30 hours formal lecture):

This is a draft syllabus and is open to revision during the course.

1. Basic NMR
   a. A Brief History of NMR and MRI
   b. Magnetism and Magnetic Materials
   c. The Zeeman effect and nuclear spin polarization
   d. The Larmor relation
   e. Nuclear shielding and chemical shift
   f. The Semi-classical Vector Model
   g. The Rotating Frame
   h. Radiofrequency Interaction with the nuclear spin system
   i. Basic Pulse Sequences and Sequence Diagrams
   j. Relaxation and Contrast
2. Image Formation in MRI
   a. Spatial frequency encoding
   b. Volume selection
   c. The gradient echo
   d. The spin echo
   e. k-space
   f. Gradient waveforms and k-space trajectories
   g. 2D multi-slice imaging
   h. 3D volumetric imaging
3. Contrast Manipulation in MRI
   a. Magnetization preparation
   b. Steady-state Free Precession
   c. Multiple-echo imaging
   d. Echo planar and spiral imaging
   e. Image artifacts
4. Motion and Dynamic Imaging
   a. Flow detection by MRI
   b. Motion in a gradient
   c. Gradient moments and phase accumulation
   d. Velocity phase contrast
   e. Time-of-flight
   f. Cardiac Imaging
   g. Angiography
5. Diffusion
   a. Molecular Self Diffusion
   b. Stejskal-Tanner Experiment
   c. Apparent diffusion
   d. Restricted and Hindered Diffusion in Biological Tissues
   e. The diffusion tensor model
   f. High angular resolution diffusion imaging (HARDI)
   g. Q-space
   h. Diffusion spectrum imaging and the orientation density function
   i. Deterministic and probabilistic fiber tractography
6. Contrast Manipulation
   a. Relaxivity
   b. Water coordination
   c. T1 and T2 contrast agents
   d. Cell labeling
   e. Functional contrast agents

7. Hardware and Safety
    a. Hardware overview
    b. Main field solenoids and shimming
    c. Gradient coils
    d. RF coil design
    e. Pulse control
    f. RF transmitter and receiver electronics
    g. Bioeffects of MRI
        i. Static Field Exposure
        ii. Acceleration and Torque in Ferromagnetic Materials
        iii. Radiofrequency Power Deposition and SAR
        iv. Rapid Gradient Switching and Nerve Stimulation
        v. Acoustic Noise
        vi. Claustrophobia
        vii. Safety Screening and Human Subjects Protection
8. Signal Processing for MRI
    a. Sampling theory
    b. Filter design
    c. Digital signal processing
    d. Integral Transforms
    e. The Fourier Transform
    f. Properties of the DFT
    g. Related transforms: DST, DCT and Hilbert
    h. Fourier-domain filtering
    i. Sparse Method, Compressed Sensing and Wavelet MRI
9. Image Processing
    a. Denoising with linear and nonlinear filters
    b. Spatial interpolation
    c. Quantitative image analysis
    d. Image coregistration
    e. Bias Correction
    f. Tissue Segmentation
10. Functional MRI
    a. Neurovascular coupling
    b. The hemodynamic response
    c. BOLD Contrast
    d. Experimental Design
    e. fMRI Statistical Image Processing
    f. Non-BOLD fMRI