Syllabus

Version: 5.16.2017

FALL 2017

Magnetic Resonance Imaging and Spectroscopy: Physical Principles and Applications

Short Title: MR Imaging and Spectroscopy

PHYC 581-003 - ECE595 – CS591 – BME598

The course will be cross-listed Physics and Astronomy, Electrical and Computer Engineering, and Computer Science. It will also be open to students in Chemistry, Bioengineering, Nuclear Engineering, Medical Physics and interested students in the School of Medicine.

Instructor:

Stefan Posse, PhD
Office Hours: Monday 3-5:30pm
Office: Department of Neurology, BRF, G23H
Email: sposse@unm.edu
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Guest lecturers:
Natalie Adolphi, PhD (UNM – Biochemistry)
Vincent Calhoun, PhD (UNM – ECE)
Arvind Caprihan, PhD (Mind Research Network)
Mark Conradi, PhD (Wash U)
Eiichi Fukushima, PhD (ABQMR)
Per Magnelind, PhD (LANL)
Ricardo Otazo, PhD (NYU Medical Center)
Laurel Sillerud, PhD (UNM - Biochemistry)

Location: PandA 4

Class schedule:
Tuesday 3-5 pm

COURSE OVERVIEW

GOALS:

- This interdisciplinary course introduces the physics and engineering aspects of magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (MRS), including pulse sequence design, and describe selected applications in neuroscience and clinical research.
- Students will learn the principles of MR physics as a basis for future research in method development and for clinical research and neuroscience applications.
- Topics include recent advances in ultra-fast MRI techniques, functional MRI methodology, the role of MRI and MRS in the context of multimodal imaging.
- This course will be of interest for students and fellows in engineering, physics, computer science, chemistry and related fields.

OBJECTIVES:

Learn to assess the contrast properties and sensitivity limitations of MR techniques for studying normal and diseased organ function. This course provides a basis for students who want to choose in vivo MRI and MRS as a field of research.

PREREQUISITES

Standard engineering, physics and mathematics core courses. Introductory courses to signal and image processing are required. The following would be useful but are not mandatory: differential equations, complex variables, statistics, electronics laboratory, and electromagnetism.

LECTURES

Lectures will sometimes cover material that is not contained in textbooks. In addition, it is not possible to cover all the material contained in the assigned reading during lectures. Students are responsible for all material covered in the lectures as well as that in the assigned text chapters. Students should do the assigned reading prior to lecture to avoid falling behind.

TEXTS USED IN THIS COURSE

- *"Magnetic Resonance Imaging: Physical Principles and Sequence Design",* E. M. Haacke, R.W. Brown, M.R. Thompson and R. Venkatesan, 1st edition, Wiley, 1999 (available electronically via EReserves – see below)
- *"Functional Magnetic Resonance Imaging"* by Huettel, Song & McCarthy, Sunderland MA: Sinauer Associates, Inc., 2004.

- **Additional reading:**
  - *"Handbook of MRI Pulse Sequences"*, Matt A. Bernstein, Kevin F. King, Xiaohong Joe Zhou, Academic Press; 1 edition (September 21, 2004)
  - *"Clinical MR Neuroimaging: Physiological and Functional Techniques"*, Jonathan H. Gillard, Adam D. Waldman, Peter B. Barker, Cambridge University Press; 2 edition (December 21, 2009)
  - *"In vivo NMR spectroscopy",* Robin A. de Graaf, John Wiley &Sons, Ltd, 2nd edition (2nd edition, December 18, 2007)

- *"Clinical MR Spectroscopy: Techniques and Applications"*, Peter B. Barker, Alberto Bizzi, Nicola De Stefano, Rao Gullapalli, Doris D. M. Lin, Cambridge University Press; 1 edition (December 14, 2009)
- *"Magnetic Resonance Imaging of Diffusion and Perfusion: Applications to Functional Imaging".* Le Bihan D, Editor. Lippincott-Raven Press, New York, 1995.

- **Reference books:**
  - *High Resolution NMR - Theory and Chemical Applications*, E.D. Becker, Academic Press (1980)
  - *Principles of Nuclear Magnetism*, A.Abragam, Oxford University Press (1996)
  - *Principles of Nuclear Magnetic Resonance in One and Two Dimensions*, R.R. Ernst, G. Bodenhausen and A. Wokaun, Clarendon Press (1990)
  - *Principles of Magnetic Resonance*, C. P. Slichter, Harper (1963)
  - *NMR and its applications to living systems*, D.G. Gadian, Oxford University Press (1995)
  - *Nuclear Magnetic Resonance Spectroscopy - A Physicochemical View*, R.K. Harris, Longman Scientific & Technical (1994)
  - *NMR Imaging in Biomedicine*, P. Mansfield, P.G. Morris, Academic Press (1982)
  - *Biomedical Magnetic Resonance Imaging: Principles, Methodology and Applications*, F.W. Wehrli, D. Shaw, J.B. Kneeland, VCH Publishers, Inc. (1988)

EXAMINATIONS AND ASSIGNMENTS

Grading will be based on the quizzes (50 %) and a term paper (50 %). The term paper is an assignment to read literature on a selected MR method and to either critically review the method or to explore a small modification of the method under guidance. The topic will be assigned after lecture #5. Students are welcome to propose topics. Draft papers are due for comments on November 13. Students will present their term papers during the final week of November and the first week of December. Final papers are due December 4. There is no final exam. Instead, there will be a hands-on workshop at the Mind Research Network Imaging Center during the week of December 9, which everybody shall attend. The date will be decided during the first weeks.

WEB-BASED LEARNING

The syllabus, the slides from the course, the weekly quizzes, selected book chapters and other readings will be placed on the web.

READING ASSIGNMENTS

Students are expected to read the textbook chapters made available on the web to understand the background of the material presented during the lectures.

INTERNET WEBSITES

- **Research Institutes**

- **Martinos MNR Center – MGH: http://www.nmr.mgh.harvard.edu**
- **Center for Magnetic Resonance Research: http://www.cmrr.umn.edu/**
- **Mind Research Network: http://dev.lrri.org/**

- **Professional Society (ISMRM)**
  - **http://www.ismrm.org/**
- **MR teaching**
  - **http://www.cis.rit.edu/htbooks/mri/**
- **Literature Search:**
  - **http://www.ncbi.nlm.nih.gov/PubMed/**

CLASS SCHEDULE (16 weeks)

1) Aug. 22, 2017 - Introduction and spin physics (Stefan Posse)
- Course overview and targets
- History of MR
- Introduction of basic concepts: Larmor equation, relaxation, image encoding concepts, spectroscopy, fMRI, other imaging techniques
- Spins, quantum and classical picture; Boltzmann distribution.
- Bloch equation and the rotating frame.

2) Aug. 29, 2017 - Relaxation and data acquisition (Stefan Posse)
- T1, T1rho, T2, T2*: Definition and characterization
- Relaxation mechanisms and molecular movement: dipol-dipol, paramagnetic ions, magnetization transfer, diffusion, static dephasing
- Magnetic properties of tissues
- Bloch equations with relaxation
- Radiofrequency pulses
- Data acquisition methods: Free Induction Decay, Steady State Free Precession, Inversion Recovery, Spin Echo, Stimulated echo, Gradient Echo.
- The Fourier transform
- Signal digitization – sampling theorem

3) Sept. 5, 2017 - Principles of imaging, k-space and fast imaging (Stefan Posse)
- Projection imaging
- Phase encoding
- Slice selection and radiofrequency pulses
- Spin-warp imaging
- K-space
- Point spread function and Gibb's ringing
- Filtering and image resolution
- FLASH and steady state free precession
- TSE, TGSE, EPI, Spiral, BURST
- Image resolution
- Signal to noise
- Contrast to noise

4) Sept. 12, 2017 – MR hardware (Eiichi Fukushima)
- Radiofrequency coils
    - Biot-Savart
    - Reciprocity, and signal to noise ratio.
    - Solenoid
    - Surface coil
    - Birdcage resonator
    - Array coils
- Magnets
- Gradient coils

5) Sept. 19, 2017 – Accelerated MRI (Ricardo Otazo)
- RF coil arrays

- Parallel MRI: SENSE, GRAPPA
- Compressed Sensing
- Superresolution reconstruction
- Inverse imaging

6) Sept. 29, 2017 - Image artifacts and functional MRI (Stefan Posse)
- Magnetic field inhomogeneity effects and T2* dephasing
- Signal losses and compensation
- Artifacts: movement, drifts, etc.
- Functional MRI
    - Contrast mechanism
    - Image acquisition techniques
    - Recent advances in ultra-fast imaging
    - Model and data driven analysis
    - Neuroscience and clinical research applications

7) Oct. 3, 2017 - Flow, diffusion and perfusion (Arvind Caprihan)
- Phase contrast and time-of-flight angiography
- Brownian motion and diffusion
- Restricted diffusion
- Acquisition methods: Carr-Purcell, Meiboom-Gill
- Torrey-Bloch Equation
- Diffusion sensitive MRI: spin-echo, stimulated echo
- Diffusion tensor imaging and fiber tracking
- Q-space imaging
- Perfusion imaging using bolus injection of contrast agents
- Perfusion imaging using arterial spin labeling

8) Oct. 10, 2017 - Introduction to MR spectroscopy (Laurel Sillerud)
- NMR-visible nuclei
- Chemical shift
- J-coupling
- Multiplet patterns and chemical structure
- Spectral editing
- High-resolution spectroscopy (magic angle spinning, molecular structure by multi-dimensional MRS)
- Spectral quantification
- Prostate cancer
- Liver metabolism

9) Oct. 17, 2017 - Spectroscopic localization and imaging (Stefan Posse)
- Single voxel localization: PRESS, STEAM, ISIS
- Spectroscopic imaging using phase encoding
- Acceleration using parallel imaging
- High-speed spectroscopic imaging
    - Interleaved 1D- and 2D-Spatial - Spectral Encoding: EPSI, SPIRAL
    - Echo-time-shifted encoding: (Spectroscopic RARE, GRASE,…)
    - Advanced Concepts (SENSE-SI, SLIM, SLOOP, SSFP)

- Clinical applications and
- Dynamic metabolite imaging and hyperpolarized MRI

9) Oct. 24, 2017 – Ultra-low field MRI and MEG (Per Magnelind)
- Integration of MRI and MEG
- Hardware: field generation, detectors, gradients
- Pulse sequences
- Applications

11) Oct. 31, 2017 – Specialty topics (Natalie Adolphi)
- Part 1: Post-Mortem MRI for Evaluating Cause and Time of Death
- Part 2: MR Hardware Revisited -- MR Safety and Common Image Artifacts

12) Nov. 7, 2017 – NMR in solids and hyperpolarized MRI (Mark Conradi)
- Methodology of NMR in solids
- Applications
- Hyperpolarized lung imaging

13) Nov. 14, 2017 – Principles and roles of contrast agents on MRI (Laurel Sillerud)
- What are contrast agents
- What are the physical principles of MRI contrast agents
- Different classes of MRI contrast agents: Passive vs active
- Magnetic Nanoparticle Detection
- Examples of various contrast agents
- Physiological and safety requirements of contrast agents
- Targeted contrast agents

14) Nov. 21, 2017 – Advanced topics in fMRI analysis (Vince Calhoun)

15) Nov. 28, 2017 - Student Presentations

15) Dec. 5, 2017 - Student Presentations

16) Dec.12, 2017 - Workshop at MRN (Domenici Hall)
- Real-time functional MRI
- MR spectroscopy and spectroscopic imaging
- Diffusion MRI