Syllabus
Principles of Magnetic Resonance Imaging (BMENE4430)
Spring 2020

Date/Time: Thursdays, 4:10-6:40 PM
Location: 253 Engineering Terrace

Instructor: Christoph Juchem, Ph.D.
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Prerequisites: (PHYS UN1403) and (APMA E2101) or PHYS C1403 and APAM E2101
                      or instructors' permission

Credits: 3 points

Course Description
Topics include the fundamental principles of Magnetic Resonance Imaging (MRI) and the physics and mathematics of image formation with an emphasis on the application of MRI to scientific research and clinical diagnostics. The course will examine both theory and experimental design techniques.

Course Objectives
At the end of the course, attendees should
- be familiar with the concepts of MRI
- understand the basic magnetic resonance scanner and hardware architecture
- have a basic overview of the various MRI techniques
- recognize the spectrum of research and clinical MRI applications
- be able to describe the potential, limitations and pitfalls of MRI
- be able to discuss MRI aspects before an audience of peers
- be able to provide some critique of MRI projects and manuscripts

Suggested Textbooks

1. *Magnetic Resonance Imaging : Physical Principles and Sequence Design*, Robert W. Brown, Yu-Chung N. Cheng, E. Mark Haacke, Michael R. Thompson, Ramesh Venkatesan, ISBN 9780471720850, https://clio.columbia.edu/catalog/10873044

2. *Magnetic Resonance Imaging Handbook*, edited by Luca Saba, ISBN 9781482216202, https://clio.columbia.edu/catalog/12583458

3. *Principles of Magnetic Resonance Imaging: A Signal Processing Perspective*, Zhi-Pei Liang, Paul C. Lauterbur, ISBN 0780347234, https://clio.columbia.edu/catalog/12461127

4. *MRI: Basic Principles and Applications*, Brian M. Dale, Mark A. Brown, and Richard C. Semelka, ISBN 9781119013037, https://clio.columbia.edu/catalog/11720594

5. *The Mathematics of Medical Imaging: A Beginner's Guide*, Timothy G. Feeman, ISBN 9783319226651, https://clio.columbia.edu/catalog/11685941

6. *MRI: Essentials for Innovative Technologies*, Giuseppe Placidi, ISBN 9781439840405, https://clio.columbia.edu/catalog/9586884

Note that electronic versions of all books are available through Columbia's online library free of charge

Grading Criteria
11 problem sets at 3% each:	33%
Midterm exam:	32%
Final exam:	35%

Policies
The course follows Columbia University policies, including those describing the Rights and Responsibilities of its members. Also, please note the Faculty Statement on Academic Integrity.

Homework Assignments
All homework is due at the beginning of the next class and to be submitted via CourseWorks (courseworks2.columbia.edu).

Make Up Exams
Only students with legitimate reasons will be allowed to postpone examinations or make up for missed ones. Note that
1) students are expected to present appropriate documentation, e.g. a doctor's note
2) all make-up exams will be oral - no exceptions.

Additional
All aspects of this syllabus are subject to change.
Suggestions and feedback are welcome.

Detailed Course Schedule
(next page)

Week	Date	Lecture	Topics	Assignments
1	1/23/2020	1	**Basics of Magnetic Resonance (253 Eng Terrace)** spin, magnetic resonance, Boltzmann distribution, excitation, Larmor condition, sensitivity, FID, basic experiment	HW1 out, due 1/30/2020
2	1/30/2020	2	**MR Scanner Architecture (253 Eng Terrace)** scanner architecture, field gradients, radio-frequency pulses, signal detection, signal demodulation, laboratory/rotating frame	HW2 out, due 2/6/2020
3	2/6/2020	3	**Basic Sequences and Bloch Equations (253 Eng Terrace)** relaxation, T1, T2, T2*, Bloch equations, spin echo, Ernst angle, sequence diagram, saturation-recovery, inversion-recovery	HW3 out, due 2/13/2020
4	**2/11/2020**	4	**Image Formation (343 Eng Terrace, Multipurpose Room)** spatial selection, spatial encoding, field-of-view, k-space, slice orientation, multi-slice 2D, 3D, gradient-echo, spin-echo, point-spread function, spatial resolution, filtering, signal-to-noise, contrast-to-noise	HW4 out, due 2/20/2020
5	**2/18/2020**	5	**k-Space Sampling Strategies (343 Eng Terrace, Multipurpose Room)** Fourier transform, shift theorem, convolution theorem, Nyquist theorem, radial MRI, scan time, echo-planar imaging, spiral imaging, turbo-spin-echo, partial k-space, sparse sampling	HW5 out, due 2/27/2020
6	2/27/2020	6	**Challenges and Solutions (253 Eng Terrace)** gradient eddy currents and preemphasis, flow artifacts/compensation, respiratory motion, cardiac motion, voluntary movement, water/fat separation, Gibbs ringing, phase aliasing, chemical shift, corrupted data	HW6 out, due 3/5/2020
7	3/5/2020	7	**B0 Hardware, Fields and Safety (253 Eng Terrace)** scanner B0 field/coil, field strength, gradient fields/coils, PNS, spherical harmonics, region-of-interest, B0 homogeneity, B0 shimming, active/passive, static/dynamic, real-time, multi-coil approach, DYNAMITE	
8	3/12/2020	-	**Midterm Exam (253 Eng Terrace)**	
9	3/19/2020	-	**Spring Recess**	
10	3/26/2020	8	**MRI Techniques and Applications (253 Eng Terrace)** T1/T2/T2*/PD-weighting, diffusion weighted imaging, DTI, perfusion, susceptibility weighted imaging, susceptibility mapping, flow imaging, angiography, aterial spin labeling	HW7 out, due 4/2/2020
11	4/2/2020	9	**Radio-Frequency Coils, Pulses and Safety (253 Eng Terrace)** radio-frequency, sensitivity, RF pulse, selective/non-selective, resonance circuit, detector design, surface/quadrature/phased-array coil, B1 homogeneity/shimming, SAR, power dissipation, tissue heating	HW8 out, due 4/9/2020
12	4/9/2020	10	**Contrast Agents and Functional MRI (253 Eng Terrace)** hyperpolarized gas, MION, manganese, gadolinium, functional MRI, blood oxygen level dependence, cerebral blood flow, cerebral blood volume, baloon model	HW9 out, due 4/16/2020
13	4/16/2020	11	**Fast and Parallel MRI (253 Eng Terrace)** scan time, fast spin-echo, fast gradient-echo, TSE, SSFP, partial k-space, sparse sampling, parallel imaging, g-factor, SMASH, SENSE, GRAPPA, GRASP, multislice MRI	HW10 out, due 4/23/2020
14	4/23/2020	12	**Hot Topics and Future Directions (253 Eng Terrace)** MR fingerprinting, non-Cartesian encoding, future scanner architecture, low-field MRI, high-temperature magnets, deep learning	HW11 out, due 4/30/2020
15	4/30/2020	13	**MRI in Action** (Field Trip, Location TBA)	
16	5/7/2020	-	**Study Days**	
17	5/14/2020	-	**Final Exam (Location???)**	