ELEC4820 Medical Imaging

Time: Mondays for self learning
and Fridays 10:30-11:50AM discussions in the classroom
ClassRoom: Room 5620
Instructor: Yu, Weichuan

Course overview:

This course introduces medical imaging methods to senior undergraduate and graduate students. It covers the following topics: radiation, radiography, computer tomography, radioisotope imaging, diagnostic ultrasound imaging, magnetic resonance imaging, and applications of different imaging modalities.

This course requires basic knowledge of linear algebra, calculus, and geometry. Familiarity with a programming language such as MATLAB is needed.

Prerequisite: ELEC2100

Course Text Book:

Medical Imaging: Signals and Systems, by Jerry Prince and Jonathan Links,
Pearson Prentice Hall, ISBN 0-13-065353-5

Additional Course Resources:

1. The Essential physics of Medical Imaging, 2nd Edition
   J. T. Bushberg, J. A. Seibert, E. M. Leidholdt, and J. M. Boone,
   Lippencott Williams & Wilkins, 2002
2. The physics of Medical Imaging
   Steve Webb (ed.), Institute of physics publishing, 1988
3. The Basics of MRI --- online book with many video clips
   Joseph P. Hornak http://www.cis.rit.edu/htbooks/mri/
4. Diagnostic Ultrasound Imaging: Inside Out
   Thomas L. Szabo, Elsevier Science, 2004

Course Intended Learning Outcomes

ELEC4820 is about five common imaging modalities. By the end of the course, learners will be able to:

- Explain the differences of five common imaging modalities, namely X-ray imaging, computer tomography, nuclear medicine imaging, ultrasound imaging and MRI, in terms of application setting and targets of measurement.
- Calculate radiation and attenuation of X-ray in body and explain the working principle of X-ray imaging.
- Carry out Fourier transform and Radon transform to objects with different geometric shapes (such as circle and ellipse), and apply Fourier slice theorem and filtered back projection to reconstruct the CT images of objects from parallel projection and fan projection.
- Calculate the mass defect and the corresponding energy, explain the radioactive decay law, and describe the image formation process of nuclear imaging using mathematical formula.
- Solve the plane wave equation and the spherical wave equation, and mathematically describe the ultrasound imaging process.
- Explain the nuclear magnetic resonance (NMR) at both microscopic level and macroscopic level, describe the key difference between NMR and magnetic resonance imaging (MRI), draw the timing diagram of MRI pulse sequences (such as 90-free induction decay (FID) pulse sequence, spin-echo pulse sequence, and inversion-recovery sequence) and describe the principles of controlling gradients (such as slice selection gradient, frequency encoding gradient, and phase encoding gradient).

Assessments and Grading

Assessment	Format	Weighting (%)
Homework on five imaging modalities	Hand in hard copies after discussions in the classroom. The students will carry out imaging-related calculation in these homework.	10%
Online quizzes after watching video clips	Weekly online quizzes in the format of multiple choices.	10%
Classroom discussion	Attendance and participation of classroom discussion. Attendance will be recorded. Students who actively participate the discussions (such as voluntarily explaining the solutions) will be given bonus points.	10%
Midterm	Open-book exam consisting of multiple-choice questions, calculation questions, and proof questions related to X-ray imaging and computer tomography imaging.	30%
Final exam	Open-book exam consisting of multiple-choice questions, calculation questions, and proof questions related to nuclear medicine imaging, ultrasound imaging and MRI.	40%
	Total:	**100%**
	Passing Score:	**60%**

Detailed Course Outline

The plan is to replace one lecture (80 minutes) per week with **on-line activities** and **self-preparation**:

- The on-line activities include: watching video clips from online sources, detailed PPT with narration about mathematical deductions, and reading online books with interactive components.
- The students will be asked to prepare the solutions to the discussion/calculation questions released online BEFORE the in-class meeting. In addition to the online sources, we will also put summary and reference files in PDF format on Canvas for students to better prepare the solutions.

The face-to-face meeting in the classroom will focus on solving the discussion/calculation questions with an interactive setting. For each question, one student will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have questions. In order to encourage students get involved, we will give bonus points to volunteers who lead the discussions.

Week	Weekly Objectives	Module Titles, Learning Activities and Sequence	Assessments
1	By the end of this week, you will be able to: • Explain the application settings of five imaging modalities. • Explain the quantitative measure of imaging quality.	**Course Introduction and Imaging Basics** **In-class: 80 minutes** • Overview of course content, blended Learning style, and expectation from students. • explanation of week-by-week learning content arrangement in the Canvas system. • Brief introduction of five imaging modalities.	
		Online Video: • Introduction to X-ray imaging • Introduction to CT imaging • Introduction to Nuclear medicine imaging • Introduction to Ultrasound imaging • Introduction to MRI imaging • Imaging basics and quality measure	• Online quiz (5 multiple-choice questions)
2	By the end of this week, you will be able to:	**X-Ray Imaging** **Online Video:**	• Online quiz (5 multiple-choice questions)

	• Use the x-ray imaging formation equation to describe the X-ray imaging process. • Carry out Fourier transform of commonly used functions.	• The history and physics of X-ray • X-ray hardware components • X-ray image formation • Applications of X-ray imaging **Preparation for in-class discussion:** • Study the five questions regarding X-ray physics, X-ray imaging, and Fourier transform. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	
		In-class: • Interactive discussion of five questions. For each question, one student will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues. • Explanation of online content for the next week	• Release Homework 1 assignment after the class. Individual-based submission in the next week
3	By the end of this week, you will be able to: • Calculate the Radon transform an object with regular geometric shape. • Prove the rotation property of the Fourier transform.	**CT-Imaging: Hardware and mathematical background** **Online Video:** • Overview of CT-imaging • Hardware of CT-imaging • Definition of Radon transform • Radon transform of a circle • Radon transform of an ellipse • Rotation property of the Fourier transform **Preparation for in-class discussion:** Study the discussion questions regarding the Radon transform of objects with regular geometric shape. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)
		In-class: • Interactive discussion of Radon transform and Fourier transform. Go through the discussion questions on the whiteboard. For each question, one student (volunteer will be encouraged and be given bonus points) will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues. • Explanation of online content for the next week.	• Release Homework 2 assignment.
4	By the end of this week, you will be able to: • derive the Radon transform and the Fourier slice theorem. • Calculate the filtered back project to imaging examples. • Derive the equations	**CT-Imaging: Reconstruction algorithms.** **Online Video:** • Deduction of the Fourier Slice Theorem. • Filtered back projection algorithm • Image reconstruction from parallel projection • Image reconstruction from fan projection **Preparation for in-class discussion:** • Study the discussion questions regarding the filtered back projection and the image reconstruction. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)

	needed for reconstructing images from the parallel projection.	In-class: • Interactive discussion of questions released online. For each question, one student will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues. • Discussion of Homework 2.	• Individual-based submission of HW2 in the next week
5	By the end of this week, you will be able to: • Explain the concepts of atomic number, mass number, isotope, mass defect, and binding energy. • Calculate the binding energy for a given mass defect.	**Nuclear Medicine Imaging: Physics of radioactive particles.** **Online video:** • three types of nuclear medicine imaging • atomic number, mass number, nuclide, and radionuclide. • Isotopes, isobars, isotones, and isomers • mass defect and binding energy with example • Radioactive decay law **Preparation for in-class discussion:** • Study the questions on atomic number, mass defect, binding energy, and radioactive decay law. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)
		In-class: • Interactive discussion of the questions. For each question, one student will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues. • Explanation of online content for the next week	• Release HW3
6	By the end of this week, you will be able to: • Explain the image formation using the Anger camera. • Explain the difference among planar scintigraphy, SPECT imaging and PET imaging.	**Nuclear Medicine Imaging: three imaging modalities.** **Online video:** • Components of Anger camera: collimator and scintillation detector. • Components of Anger camera: photomultiplier tubes and position logic circuit. • Components of Anger camera: pulse height analyzer and gating circuit. • Image formation using Anger camera. • Image quality of Anger camera. • SPECT imaging • PET imaging **Preparation for in-class discussion:** • Study the questions on hardware of Anger camera, image formation using Anger camera, SPECT imaging, and PET imaging. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)
		In-class: • Interactive discussion of questions. For each question, one student (volunteer will be encouraged and be given bonus points) will lead the discussion to solve	• Individual-based submission of HW3 in the next week

		the question on the whiteboard. Other students may interrupt the leading students when they have issues. • Discussion of Homework 3.	
7		**Midterm review and exam** **In-class:** • Review key concepts of the first two imaging modalities (i.e. X-ray and CT imaging). The modality of nuclear medicine imaging will be tested in the final exam. • Q & A	
		In-class: • Mid-term exam	
8	By the end of this week, you will be able to: • Derive the acoustic wave equation. • Explain the physical meaning of Euler force equation	**Ultrasound Imaging: Physics of ultrasound** **Online video:** • Basics of ultrasound • Acoustic propagation speed. • The spring model • Plane wave equation • Spherical wave equation **Preparation for in-class discussion:** • Study the questions on ultrasound physics and different wave equations and acoustic propagation model. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)
		In-class: • Interactive discussion of questions. For each question, one student will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues.	
9	By the end of this week, you will be able to: • Explain the wave propagation equation. • Explain the Doppler effect and calculate the frequency shift.	**Ultrasound Imaging: wave propagation, Doppler effect, and wave approximation.** **Online video:** • Wave propagation • Doppler effect • Pulse-echo mode • Beam forming and focusing **Preparation for in-class discussion:** • Study the questions on wave propagation, Doppler effect, beam forming and focusing. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)
		In-class: • Interactive discussion of questions. For each question, one student (volunteer will be encouraged and be given bonus points) will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues.	• Release HW4
10	By the end of this week, you will be able to: • Explain the working principle	**Ultrasound Imaging: Imaging hardware and scan setting.** **Online video:** • Ultrasound imaging system block diagram • A-mode, M-mode, and B-mode scan • Pulse-echo imaging and dynamic focusing. **Preparation for in-class discussion:**	• Online quiz (5 multiple-choice questions)

	of the transducer. • Mathematically explain the ultrasound imaging principle	• Study the questions on hardware of ultrasound imaging system, different modes of imaging, and imaging principle. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	
		In-class: • Interactive discussion of questions. For each question, one student will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues. • Discussion of Homework 4.	• Individual-based submission of HW4 in the next week
11	By the end of this week, you will be able to: • Explain the spin at the microscopic level and at the macroscopic level. • Describe the rotating frame of reference, spin relaxation. • Use the Block equation to calculate the spin position in an external magnetic field.	**MRI: Spin Physics** **Online video:** • Spin Physics (1) Microscopic level (a) Properties of spin (b) Energy level and transitions (c) Continuous wave NMR experiment (2) Macroscopic level (a) Boltzmann statistics (b) Spin packets (c) T1 process (d) Precession (e) T2 process (3) Rotating frame of reference (4) Pulsed magnetic fields (5) Spin relaxation (6) Bloch equation **Preparation for in-class discussion:** • Study the questions on spin physics, rotating frame of reference, spin relaxation and Bloch equation. Submission is not mandatory, students who submit answers to these questions before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)
		In-class: • Interactive discussion of questions. For each question, one student (volunteer will be encouraged and be given bonus points) will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues.	• Release HW5
12	By the end of this week, you will be able to: • Explain the working principle of NMR spectroscopy. • Describe the differences of different sequences.	**MRI: NMR and imaging principle** **Online video:** • NMR Spectroscopy (1) Time-domain NMR signal (2) The 90-FID sequence (3) The spin-echo sequence (4) The inversion recovery sequence (5) Chemical shift • Imaging principle (1) Magnetic field gradient (2) Frequency encoding gradient (3) Back projection imaging **Preparation for in-class discussion:** • Study the questions on NMR spectroscopy, different gradients, and back projection imaging. Submission is not mandatory, students who submit answers to	• Online quiz (5 multiple-choice questions)

		these questions before the next class will be awarded with bonus points.	
		In-class: • Interactive discussion of questions. For each question, one student will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues.	• Release HW5
13	By the end of this week, you will be able to: • Explain the principle and differences of different encoding gradients. • Describe typical imaging setting.	**MRI: Imaging setting and hardware** **Online video:** • Principle of Fourier Transform Imaging (1) Phase encoding gradient (2) Fourier transform tomographic imaging (3) Examples • Basic Imaging Techniques (1) Multi-slice imaging (2) Oblique imaging (3) Spin-echo imaging (4) Inversion recovery imaging (5) Gradient recalled echo imaging • Imaging Hardware **Preparation for in-class discussion:** • Study the questions on Fourier transform imaging, basic imaging technique, and hardware of MRI imaging system. Submission is not mandatory, students who submit answers before the next class will be awarded with bonus points.	• Online quiz (5 multiple-choice questions)
		Final review **In-class:** • Interactive discussion of questions. For each question, one student (volunteer will be encouraged and be given bonus points) will lead the discussion to solve the question on the whiteboard. Other students may interrupt the leading students when they have issues. • Discussion of HW5. • Final review of three imaging modalities.	• Individual-based submission of HW5 after the class.