ECE 4786
Medical Imaging Systems: Physics, Engineering, and Applications

Catalog Description

Introduce major biomedical and clinical imaging modalities including X-ray radiography, computed tomography (CT), nuclear medicine (SPECT and PET), magnetic resonance imaging (MRI), and ultrasound (US).

Prerequisites:

See course description (below).

Other Prerequisites:

Desire to learn, common sense, being able to enjoy challenges, ability to work alone and in a team, curiosity, and, finally, some knowledge of digital signal processing and programming in MATLAB.

Course Objectives:

Overall objective:

Upon successful completion of this course, the student should be able to:
Describe and implement the processes used by medical imaging systems to form images by applying fundamental mathematical and engineering principles to X-ray, CT, PET/SPECT, MRI, and US imaging.

Specific learning objectives:

Upon successful completion of this course, students should be able to:

- Apply fundamental mathematical and engineering principles (sampling, Fourier transform, linear systems) in the development of imaging systems and image acquisition.
- Describe the interactions between electromagnetic, acoustic, or other forms of energy and biological tissues and apply these principles to imaging system design.
- Apply underlying principles of imaging system physics and instrumentation to design systems or subsystems for specific applications for X-ray, CT, PET/SPECT, MRI, and US imaging.
- Utilize understanding of imaging physics and imaging systems engineering principles in order to reconstruct acquired raw data into images.
- Quantitatively compare imaging performance and tradeoffs within and across imaging modalities using criteria including contrast, spatial resolution, contrast-to-noise ratio, and signal-to-noise ratio.

Course Description:

This course is an introduction to imaging systems. The main objective of this course is to gain understanding of the process used by medical imaging systems and to implement the image formation strategy used by each imaging modality. For each imaging modality, the following approach is used: 1) describe basic physics; 2) develop a system model of the imaging system; 3) derive imaging equations; 4) describe hardware and software; 5) analyze signal, noise (sources), contrast, and primary artifacts; 6) discuss biomedical and clinical applications.

The course will be divided into three modules. The first module will cover X-ray imaging and nuclear medicine including computed tomography (CT), single photon emission computed tomography (SPECT), and positron emission tomography (PET). In the second part of the course, we will focus on nuclear magnetic resonance (NMR), including magnetic resonance imaging (MRI) and MR spectroscopy (briefly). In the final part of the course, ultrasound (US) imaging will be introduced. Overall, fundamental similarities between the imaging equations of the different modalities will be emphasized, and vital differences between different modalities will be discussed.

Topics Covered:

1. X-ray imaging and computed tomography
2. Nuclear medicine imaging (PET, SPECT)
3. Magnetic resonance imaging (MRI)
4. Ultrasound (US) imaging

Textbooks

Required:

Textbooks: none

Extensive lecture notes, review papers, tutorials, software, and other materials are available on the class web site: http://canvas.gatech.edu/

Supplemental/Optional:

Introduction to Medical Imaging: Physics, Engineering and Clinical Applications, N.B. Smith and A.G. Webb. December 2002, Wiley-IEEE Press

The Essential Physics of Medical Imaging (4th Edition), J.T. Bushberg, J.A. Seibert , E.M. Leidholdt Jr., J.M. Boone. November 4, 2020, Lippincott Williams & Wilkins (LWW)

Medical Imaging Signals and Systems, 2nd Edition, J.L. Prince and J. Links, Prentice Hall, 2014

Imaging Systems for Medical Diagnostics: Fundamentals, Technical Solutions and Applications for Systems Applying Ionizing Radiation, Nuclear Magnetic Resonance and Ultrasound, Arnulf Oppelt (Ed.) 2006, John Wiley & Sons Inc

Online resources:

Provided during the class, available at http://canvas.gatech.edu/

Teaching Approach

The students will attend two lectures per week (3 hours). There will be 4 homework assignments (2 in the first module and 1 each in the second and third modules) and 3 projects (1 each module) covering all imaging modalities. In addition, there will be three midterm exams covering the three modules of the course. Exams will be administered in person during regular class times.

Attendance Policy

Attendance is required for lectures.

This course is designated as an in person course per Georgia Tech policy. Students should plan to attend lectures to realize maximum learning. Classes will not be recorded.

Per Georgia Tech policy, if you are sick and experiencing any symptoms, please do not attend class or participate in any in-person class activities.

Accommodations for Students with Disabilities

If you are a student with learning needs that require special accommodation, contact the Office of Disability Services at (404) 894-2563 or http://disabilityservices.gatech.edu/ as soon as possible to make an appointment to discuss your special needs and to obtain an accommodations letter.

The Office of Disability Services will then communicate with the instructors. This could include any health-related accommodations (e.g. high-risk health condition, etc.).

Grading & Evaluation

The course grade will be determined by homework (25%), class projects (30% total, 10% each), and three midterm/final examinations (45% total, 15% each). The third exam will be held during the campus final exam period, which is scheduled by the registrar according to the final exam matrix.

Homework assignments (4)	25% (total)
Projects (3)	30% (total)
Exams (3)	45% (total)

In most cases, exams are not curved. However, instructors may decide to curve individual exams upward, which will be announced when grades for these assignments are released.

Final grades

A	90% and above
B	80% to 89.99%
C	70% to 79.99%
D	60% to 69.99%
F	Below 60%

There are no extra assignments available for extra credit.

If you have concerns about your grade or grading of an assignment, please discuss with the instructor for the specific module

Class Web site:

All materials for the class (announcements, schedule/changes, lecture notes, homework assignments, etc.) will be distributed electronically via course web site: http://canvas.gatech.edu/
You will be responsible for checking the course website regularly for class work and announcements. *All assignments and projects are submitted electronically via Canvas.* This is the only way to submit your assignment (no hard copies will be accepted). If you fail to submit before the deadline, the site will lock and you will receive a zero. If there is a technical problem with the site, you need to email the assignment to the instructor *before* the deadline. The time stamp on the email must be prior to the due date/time.

Student-Faculty Expectations

At Georgia Tech, we believe that it is important to strive for an atmosphere of mutual respect, acknowledgement, and responsibility between faculty members and the student body. The Student-Faculty Expectations articulate some basic expectations that students can have of the instructors and that instructors have of the students. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, students are encouraged to remain committed to the ideals of Georgia Tech while in this class.

Use of E-mail

In this course, e-mail will be used as a means of communication with students. You will be responsible for checking your e-mail regularly for class work and announcements.
All students should become familiar with the Georgia Tech's official e-mail student notification policy. It is the student's responsibility to keep the Institute informed as to changes in his or her e-mail address. Students are expected to check e-mail on a frequent and regular basis in order to stay current with Institute-related communications, recognizing that certain communications may be time-critical. It is recommended that e-mail be checked daily, but at a minimum, twice per week.

Use of Artificial Intelligence

While artificial intelligence may be useful tool for finding relevant sources such as research papers, student submissions for homework assignments and projects must be completed by the student and may not be done by artificial intelligence. If an assignment is found to be completed using artificial intelligence, the student will receive a zero on that assignment. Exams are completed in class without computer access, thus there will be no use of artificial intelligence during exams.

Late Policy

The student must notify the instructor in advance before the due date or deadline has passed. Late assignments may not be accepted and documentation of the reason for the late assignment may be requested. Missing the deadline without communication prior to the missed deadline will result in a grade of zero for the missed assignment.

Academic Integrity

Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. Review the Student Code of Conduct and the Academic Honor Code, especially Appendix A: Graduate Addendum to the Academic Honor Code.
Students are expected to perform research in an ethical and responsible manner.
Any student suspected of cheating or plagiarizing on a quiz, exam, or assignment will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations.
Allegations of scientific or scholarly misconduct are handled in accordance with the procedures outlined by the Policy for Responding to Allegations of Scientific or Other Scholarly Misconduct.

Mental Health

Your instructors, and the corresponding schools/departments, care about student mental health. We want to make sure you are aware of the formal resources for receiving mental health assistance in BME/ECE and at GT. More information about these resources can be found here: https://mentalhealth.gatech.edu/

- **Mental Health Care & Resources** – The Center for Mental Health Care and Resources (CMHCR) is the best place to engage with mental health care at GT. They are found in the Smithgall Student Services Building and can also be reached at **404-894-2575**. Their normal hours of operation are

8am to 5pm Monday through Friday. CMHCR can connect you with services including individual or group counseling, academic or personal support services, assessment and testing for learning disabilities, and other mental health providers. They can help you find the right resources for a crisis, an acute issue, or a longer-term concern.

- **BME Satellite Counselor** – In addition to the Center for Mental Health Care's centralized services, BME hosts a counselor, Kate Silverio, in Room 1105 of the Whitaker Building (in the back of the academic office). The Satellite Counselor offers 15 min appointments (in-person or virtual) during which students can discuss a brief or specific, non-emergency concern, and/or learn about mental health resources on campus. To schedule with the Satellite Counselor, please email her (**kate.silverio@studentlife.gatech.edu**).
- **Crisis Services -** If you require immediate support for mental health difficulties you have several options:
  During business hours (8 a.m.-5 p.m.). Call **404-894-2575** or go to Suite 238 in the Smithgall Student Services Building.
  Outside of business hours, call **404-894-2575** and select the option for the after-hours counselor.
  In an emergency, call Georgia Tech Campus Police at **404-894-2500** on campus or **911**.

List of Topics

Introduction

Overview of imaging modalities, differences and similarities, general image characteristics
Math preliminaries/refresher

Part 1

X-ray Imaging
- Physics of X-rays; X-ray production, detection, hardware/instrumentation
- Projection radiography; Mammography; Fluoroscopy
- Digital angiography, mammography and fluoroscopy

Computed tomography (CT)
- Spiral/helical and multi-slice CT; Detectors; Image reconstruction

X-ray Imaging and Computed Tomography
- Radiation dose; Contrast agents; Clinical applications

Nuclear Medicine
- Radioactivity and radiotracer half-life; Generators
- Gamma camera; SPECT and SPECT/CT; PET and PET/CT
- Applications

Part 2

Magnetic Resonance Imaging (MRI)
- Spins in a strong magnetic field
- Radiofrequency pulse, Faraday induction and free induction decay
- Longitudinal and transverse magnetization relaxation
- RF pulse excitation and MR signal
- MR instrumentation
- Basic imaging sequences
- The k-space formalism and image reconstruction
- MRI contrast agents
- Applications

Part 3

Ultrasound Imaging
- Wave propagation, acoustic impedance, reflection/refraction, absorption and attenuation
- Scattering and ultrasound field
- Ultrasound speckle
- Array transducers and image formation
- Imaging system and modes
- Doppler ultrasound
- Applications