BIOE 580: Foundations of Imaging Science

Meeting Time: 3:00 PM – 4:50 PM MW (110 min)

Location: 4039 Campus Instructional Facility

Credit Hours: 4

Semester: Spring

Prerequisites: BIOE 205, MATH 241, BIOE 210/MATH 415, STAT 400, ECE/BIOE 380, or permission of the instructor

Instructor Information

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Course Description

The course will provide a comprehensive understanding of the fundamental principles of image formation and quality assessment, essential for the principled application of artificial intelligence in biomedical imaging. Imaging systems will be analyzed using both a deterministic framework, employing linear operator theory, and a statistical framework, introducing stochastic models for objects and images. Methodologies for the objective assessment of image quality (OAIQ) will be introduced, which will address classification tasks, receiver operator characteristic (ROC) analysis, numerical observers, and estimation theory.

Textbook and Reading Materials

There are no required textbooks, however, the following references will likely be helpful:
- Foundations of Imaging Science by Barrett and Myers (optional)
- Foundations of Computational Imaging by Charles Bouman (optional)

Additional Requirements

Access to a modern computer capable of running the latest versions of Python and the NumPy, SciPy, Matplotlib, Pillow, and Numba libraries is expected in order to complete the homework assignments. ImageJ (or Fiji), which is free and standard in the industry, likely will be helpful for viewing example images.

Course Objectives

- Appreciate the differences between objects and images of objects
- Apply linear vector concepts and linear operator theory to describe imaging systems
- Understand how to compute the singular value decomposition of linear imaging operators
- Understand how to characterize the null space of a linear imaging operator
- Understand representation error in discrete or semi-discrete imaging models
- Understand how to describe objects and images in stochastic terms
- Elucidate the possible sources of randomness in measured image data
- Understand the critical role of OAIQ in medical imaging

- Understand how to apply signal detection theory and estimation theory to quantify the OAIQ
- Understand the role of numerical observers in OAIQ
- Understand how to optimize the performance of a biomedical imaging system

Course Policies

Lectures

- Class meetings will consist primarily of lectures (see schedule and attendance policies, below).
- The mid-term exam and final exam will take place during normal class hours.

Homework

- There are 4-6 total assignments, each comprising 3-4 multi-part exercises. The assignments will consist of some "by hand" computation, some computation/coding in Python, and some short-answer questions. Real and synthetic biomedical image data will be discussed and analyzed.

Exams

- Two in-class, pencil-and-paper exams will be given. These will comprise several short-answer and short-calculation problems covering key concepts from imaging science.

Attendance & Participation

- Students are expected to attend at least 80% of the classroom lectures.
- Students are expected to meaningfully participate in class.
- Very brief quizzes/polls may be given in class or online via Canvas; these will not be graded beyond simple attendance/participation.

Additional Policies

- In general, no make-up exams will be given, and homework deadlines are firm. Special circumstances regarding absence or forbearance will be handled on a case-by-case basis at the discretion of the instructor. Please inform the instructor promptly if additional consideration is required.

Grading & Assessment

The overall course grade will comprise 67% homework and 33% exams. This grade is given on an absolute scale and will not be curved. Final course grades will be rounded to the nearest whole number. Concerns about individual assignments or grades should be expressed to the instructor promptly.

Grade scale (%)

A+ [97, 100]	**B+** [87, 90)	**C+** [77, 80)	**D+** [67, 70)	**F** [0, 60)
A [93, 97)	**B** [83, 87)	**C** [73, 77)	**D** [63, 67)	
A- [90, 93)	**B-** [80, 83)	**C-** [70, 73)	**D-** [60, 63)	

Tentative Schedule

Lecture	Spring 2024	Topic	Note
1	January 17	Introduction to imaging science in medicine	
2	January 22	Vector spaces in imaging	
3	January 24	Products, projections, and key subspaces	
4	January 29	Adjoints and mappings between spaces	
5	January 31	Integral transforms and the discretized adjoint	HW 1 due
6	February 5	Using generalized functions as imaging operators	
7	February 7	Case study: Computed Fresnel propagation of X-rays	
8	February 12	The Radon transform in tomography	
9	February 14	Eigenvalues, spectral decomposition, and the commutation operator	
10	February 19	Singular value decomposition of imaging operators	HW 2 due
11	February 21	Pseudoinverses and inverse filtering	
12	February 26	Model-based image reconstruction	
13	February 28	The Moore-Penrose pseudoinverse in iterative image reconstruction	
14	March 4	Review of Lectures 1-13: Hallucinations in image reconstruction	
15	March 6	*Mid-term exam*	HW 3 due
	March 9-17	*Spring break*	No class
16	March 18	Discretization operators and representation error	
17	March 20	Linear shift-invariant imaging operators and the point-spread function	
18	March 25	Objective measures of image quality and sources of variance	
19	March 27	Random variables in imaging	HW 4 due
20	April 1	The covariance matrix of an ensemble of images	
21	April 3	Maximum a priori estimates in imaging	
22	April 8	The likelihood ratio and numerical observers	
23	April 10	Stochastic object models in imaging trials	
24	April 15	Learning the channelized Hotelling observer	HW 5 due
25	April 17	Task-based measures of image quality and ROC curves	
26	April 22	Experimental design and comparing imaging systems	
27	April 24	Course review: A virtual imaging trial to optimize an imaging system	
28	April 29	*Final exam*	HW 6 due