ILLINOIS
Bioengineering
GRAINGER COLLEGE OF ENGINEERING

# BIOE 580: Foundations of Imaging Science

**Meeting Time**: 3:00 PM – 4:50 PM MW (110 min)
**Location**: 3018 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

Seonyeong Park, Ph.D.
Research Assistant Professor of Bioengineering
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Office Location: 3146H Everitt Laboratory
Office Hours: TBD

## 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 Image 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.

## 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 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

- Midterm Exam: The midterm will be an in-class written exam consisting of short-answer and short-calculation problems. These will focus on key concepts from imaging science covered in the course.
- Final Project: The final assessment will be a coding project. Students will implement a project design provided by the instructor, applying the concepts learned throughout the course. Students will analyze and discuss their results in a detailed written report.

### 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 (%)

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|---|---|---|---|---|
| **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 2025 | Topic | Note |
|---|---|---|---|
| 1 | January 22 | Introduction to imaging science in medicine | |
| 2 | January 27 | Vector spaces in imaging | |
| 3 | January 29 | Basis vectors, subspaces, and products | |
| 4 | February 3 | Mappings between spaces | |
| 5 | February 5 | Inverse, adjoint, and projection operators | HW 1 due |
| 6 | February 10 | Using generalized functions as imaging operators | |
| 7 | February 12 | Case study: Computed Fresnel propagation of X-rays | |
| 8 | February 17 | The Radon transform in tomography | |
| 9 | February 19 | Eigenvalues, spectral decomposition, and the commutation operator | |
| 10 | February 24 | Singular value decomposition of imaging operators | HW 2 due |
| 11 | February 26 | Pseudoinverses and inverse filtering | |
| 12 | March 3 | Model-based image reconstruction | |
| 13 | March 5 | The Moore-Penrose pseudoinverse in iterative image reconstruction | |
| 14 | March 10 | Review of Lectures 1-13: Hallucinations in image reconstruction | |
| 15 | March 12 | ***Mid-term exam*** | HW 3 due |
| | March 15-23 | ***Spring break*** | No class |
| 16 | March 24 | Discretization operators and representation error | |
| 17 | March 26 | Linear shift-invariant imaging operators and the point-spread function | |
| 18 | March 31 | Objective measures of image quality and sources of variance | |
| 19 | April 2 | Random variables in imaging | HW 4 due |
| 20 | April 7 | The covariance matrix of an ensemble of images | |
| 21 | April 9 | Maximum a priori estimates in imaging | |
| 22 | April 14 | The likelihood ratio and numerical observers | |
| 23 | April 16 | Stochastic object models in imaging trials | |
| 24 | April 21 | Learning the channelized Hotelling observer | HW 5 due |
| 25 | April 23 | Task-based measures of image quality and ROC curves | |
| 26 | April 28 | Experimental design and comparing imaging systems | |
| 27 | April 30 | Course review: A virtual imaging trial to optimize an imaging system | |
| 28 | May 5 | ***Final exam*** | HW 6 due |