BMEN 509 / BMEN 623

Introduction to Biomedical Imaging

Deliverable 1

Radiation Physics, Image Processing & Quality

Due Date:	Monday, February 9, 2026 at 11:59 PM
Weight:	6% of final grade
Submission:	D2L Dropbox (.ipynb + .pdf)

1 Overview

In this deliverable, you will apply the concepts from Weeks 2–5 (Chapters 1, 2, and 4) to design and implement computational tools for radiation physics and image quality analysis. This is not a fill-in-the-blank exercise—you are expected to **design algorithms**, **make engineering decisions**, and **justify your approaches** with physical reasoning.

Learning Objectives Assessed

- **CLO1:** Demonstrate knowledge of fundamental physics underlying biomedical imaging
- **CLO2:** Predict and evaluate image quality based on standardized criteria
- **CLO3:** Choose and apply appropriate algorithms for image processing and analysis
- **CLO5:** Explain the physics and algorithms used in image formation

2 Materials

Download the starter notebook and data files from the course GitHub repository:

Repository:
`https://github.com/[INSTRUCTOR]/bmen509-deliverable-01`
Click "Code" → "Download ZIP" or clone using Git

The repository contains:

- `deliverable-01-starter.ipynb` – Jupyter Notebook template with section headers
- `data/xray_spectra.csv` – Simulated X-ray tube spectra (80, 100, 120 kVp)
- `data/attenuation_coefficients.csv` – Mass attenuation data for common materials
- `data/edge_phantom_*.npy` – Edge phantom images for MTF analysis
- `data/phantom_generator.py` – Helper functions for lesion phantom generation

3 Deliverable Structure

This deliverable consists of three design challenges plus a synthesis component. **Estimated time: 6 hours.**

3.1 Part 1: X-ray Spectrum Analysis & Attenuation Simulator (30%)

Scenario: You are tasked with designing optimal X-ray beam filtration for a pediatric imaging protocol. Given raw X-ray spectra, you must build a computational pipeline to simulate beam hardening and evaluate filtration strategies.

Your tasks:

1. Design an algorithm to apply Beer-Lambert attenuation across an *entire energy spectrum*
2. Implement calculations for mean energy, effective energy, and half-value layer (HVL)
3. Evaluate multiple filtration strategies (combinations of Al, Cu, tissue-equivalent materials)
4. Develop and justify an optimization approach to balance dose reduction with image quality
5. Present your recommended filtration with quantitative justification

What we're looking for: Creative algorithm design, sound physical reasoning, clear optimization strategy, and professional presentation of results.

3.2 Part 2: MTF Measurement Pipeline (30%)

Scenario: Two competing digital radiography detectors need to be evaluated for spatial resolution performance. You have edge phantom images from each detector and must develop a complete MTF measurement pipeline.

Your tasks:

1. Develop an edge detection and localization algorithm
2. Extract the Edge Spread Function (ESF) with appropriate sampling/binning
3. Design a differentiation strategy that handles noise (ESF $\rightarrow$ LSF)
4. Implement Fourier transform to obtain MTF with appropriate windowing
5. Compare Detector A vs. Detector B and interpret results clinically

What we're looking for: Robust algorithm design, thoughtful noise handling, proper signal processing techniques, and meaningful interpretation.

3.3 Part 3: Detection Task & SNR Analysis (30%)

Scenario: You will design and execute a computational experiment to determine minimum detectable lesion size as a function of contrast and noise—essentially deriving your own detection limits from first principles.

Your tasks:

1. Design an experimental methodology with clear independent/dependent variables
2. Develop a computational "detection algorithm" (your design choice)
3. Collect sufficient data with appropriate statistical rigor
4. Create visualizations of detection performance (e.g., detection maps, curves)
5. Critically compare your empirical results to Rose criterion predictions

What we're looking for: Rigorous experimental design, creative detection approach, proper statistical analysis, and critical scientific thinking.

3.4 Part 4: Integration & Synthesis (10%)

Write a **one-page technical memo** (within the notebook) that synthesizes your findings from Parts 1–3. Given the clinical scenario of screening mammography in young women, recommend imaging parameters and justify your choices using quantitative evidence from your analyses.

4 Submission Requirements

You must submit TWO files to D2L:

1. **Jupyter Notebook** (`.ipynb`): Your completed notebook with all code, outputs, and written analysis. All cells must be executed in order.
2. **PDF Export** (`.pdf`): Export your notebook to PDF (File → Export as PDF, or print to PDF). Verify all figures and equations render correctly.

File naming convention: `LastName_FirstName_Deliverable1.ipynb` and `.pdf`

5 Grading

This deliverable is graded using a **qualitative rubric** that rewards thoughtful design, creativity, and sound reasoning—not just correct answers. Each component is evaluated on a 7-level scale:

Level	Description	Approximate %
Outstanding	Exceptional work; exceeds expectations significantly	95–100%
Excellent	High quality; demonstrates mastery	85–94%
Good	Solid work; meets expectations well	75–84%
Satisfactory	Adequate; meets basic expectations	65–74%
Poor	Below expectations; significant gaps	50–64%
Very Poor	Major deficiencies; minimal understanding shown	25–49%
Incomplete	Missing or not attempted	0–24%

Complex questions have **multiple rubric components** (e.g., algorithm design, physical reasoning, interpretation). See the detailed rubric on D2L.

6 Academic Integrity

- You may discuss general concepts with classmates, but all code and written analysis must be your own work.
- You may use course materials, textbooks, and documentation (NumPy, SciPy, etc.).
- You may use AI tools (e.g., GitHub Copilot, ChatGPT) as a *learning aid*, but you must understand and be able to explain every line of code you submit. Blindly copying AI-generated code without understanding is a violation of academic integrity.
- Cite any external resources beyond course materials.

7 Late Policy

Per the course syllabus: Late submissions are penalized 10% per day (including weekends). Submissions more than 5 days late will not be accepted without prior arrangement or documentation of extenuating circumstances.

8 Getting Help

- **Office Hours:** See syllabus for times and locations
- **D2L Discussion Board:** Post questions (no code solutions in public posts)
- **Email:** For private matters only; use discussion board for content questions

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This deliverable is designed to challenge you. Start early, think creatively, and enjoy the process of designing your own solutions!