BMEN 509 / BMEN 623
Introduction to Biomedical Imaging
Deliverable 2
X-ray Projection & CT Imaging

Due Date: Monday, March 2, 2026 at 11:59 PM
Weight: 6% of final grade
Submission: D2L Dropbox (.ipynb + .pdf)

1 Overview

In this deliverable, you will apply concepts from Lectures 13–18 (Weeks 6–7) covering X-ray imaging and computed tomography. You will explore X-ray tube design and production, projection radiography geometry, contrast, and scatter reduction, digital X-ray detectors and image formation, CT acquisition, reconstruction, image quality, and dose metrics, as well as protocol design and optimization for clinical goals. Through conceptual questions and coding exercises, you will analyze and simulate X-ray and CT imaging systems, interpret image quality trade-offs, and apply quantitative reasoning to real-world clinical scenarios.

Learning Objectives Assessed

- **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 from the course GitHub repository:

Repository: github.com/EthanMacDonald/BMEN509-623_Deliverable_2
Click "Code" → "Download ZIP" or clone using Git

The repository contains:

- `README.md` – Assignment overview and quick-start instructions
- `deliverable-02-instructions.pdf` – This document
- `deliverable-02-starter.ipynb` – Jupyter Notebook with questions and coding exercises
- `data/Brain_CT.png` – CT brain image for analysis
- `data/Xray_Chest.png` – Chest X-ray image for analysis

3 Deliverable Structure

This deliverable consists of seven parts with conceptual questions and coding exercises. **Estimated time: 6 hours.**

3.1 Part 1: X-ray Production and Spectrum

- X-ray tube physics: bremsstrahlung and characteristic radiation
- Tube voltage (kVp), tube current (mA), and their effects
- Filtration and anode material selection
- Question Q1, Coding Exercise 1

3.2 Part 2: CT Simulation, Error Analysis & Design

- Shepp-Logan phantom and sinogram simulation
- Image reconstruction using filtered backprojection
- Error and artifact identification and mitigation
- CT protocol design and optimization
- Coding Exercise 2, Question Q2, Coding Exercise 3, Question Q3

3.3 Part 3: Projection Radiography & Image Quality

- Scatter radiation and contrast degradation
- Geometric unsharpness
- Scatter reduction techniques and grid optimization
- Question Q4, Coding Exercise 4, Question Q5, Coding Exercise 5

3.4 Part 4: X-ray Detectors & Quantum Efficiency

- Quantum efficiency and detective quantum efficiency (DQE)
- Detector selection trade-offs
- Image contrast and brightness adjustment
- Question Q6, Coding Exercises 6–7

3.5 Part 5: CT Principles & Image Reconstruction

- Hounsfield units and tissue contrast
- CT projections and sinogram formation
- Question Q7, Coding Exercise 8

3.6 Part 6: CT Image Quality, Artifacts & Dose Optimization

- Streak artifacts: causes and mitigation strategies
- Noise and dose relationships
- Question Q8, Coding Exercise 9

3.7 Part 7: Quantitative Analysis of CT Image Quality

- Signal-to-noise ratio (SNR) and RMSE metrics
- Denoising and filtering techniques
- Coding Exercise 10

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.

Important: All answers must be completed directly in the Jupyter notebook.

File naming convention: `LastName_FirstName_Deliverable2.ipynb` and `.pdf`

5 Grading

This deliverable is graded using a **qualitative rubric** with a 7-level scale for each question:

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, Matplotlib).
- 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.
- Cite any external resources beyond course materials.

7 Late Policy

Per the course syllabus, late submissions are penalized as follows:

Days Late	Penalty
0–24 hours	25% deduction
24–48 hours	50% deduction
48–72 hours	75% deduction
More than 72 hours	Not accepted (0%)

Extensions may be granted for documented extenuating circumstances if requested before the deadline.

This deliverable is designed to challenge you. Start early, think creatively, and enjoy the process!