OPTI 636 Syllabus:

Development of mathematical tools for describing stochastic processes in single optical detectors and complex imaging systems; understanding the effect of image processing and reconstruction algorithms on image noise; development of a quantitative approach to assessing and optimizing image quality.

This course is a companion to OPTI 637, Principles of Image Science, but neither is a prerequisite to the other.

Grading

Homework will be assigned every other week. You have two weeks to turn in the assignments. There will also be a final project of your choosing. Please talk to me before beginning this final project. The project writeups are due the final day of classes. Homework will account for 50% of your grade and the final project will count for 50%.

Content

UNIT I: Basic Probability Laws (Mainly review of course 508)
- Gaussian random variables: Univariate and multivariate normal distributions, central-limit theorem, and Wishart distributions.
- Complex random variables: Rayleigh and Rician statistics.
- Discrete random variables: Bernoulli trials and binomial statistics; Poisson statistics.

UNIT II: Random Sequences and Random Processes
- Definitions of a random process and basic properties; integrals and derivatives.
- Correlation, stationarity and ergodicity, Karhunen-Loeve expansion.
- Fourier analysis of random processes; Wiener-Khinchin theorem.
- Filtering of random processes.
- Random sequences: Definitions, stationarity, covariance matrices.
- Random impulses: Autocorrelation and power spectrum, Poisson impulses, filtering.

UNIT III: Statistical Decision Theory
- Kinds of decisions: estimation vs. classification.
- Approaches to decision-making: Randomized vs. nonrandomized, hard vs. fuzzy, one hypothesis vs. two or more; costs and utility.
- Performance measures: receiver operating characteristics.
- Signal detection: White vs. colored noise, Gaussian vs. non-Gaussian noise, random signals.
- Estimation theory: Nonrandom parameters, properties of estimators, Cramer-Rao bound and Fisher information; random parameters and Bayesian estimation.

UNIT IV: Noise in Radiation Detectors
- Basic concepts: taxonomy of detectors, survey of devices, noise sources.
- Noise descriptions for single-element detectors, arrays of detectors, continuous detectors.
- Thermal noise, fluctuation-dissipation theorem, Fokker-Planck equation.

- Other electronic noise: l/f, generation-recombination, kTC, quantization noise.
- Photon counting: Photon statistics, photoelectron statistics, Poisson vs. non-Poisson source.
- Detectors with gain: Photomultipliers and APDs, moment-generating functions, continuous vs. discrete gain stages, scintillation detectors, image amplifiers.
- Photographic film.
- Noise propagation through processing algorithms: continuous and discrete formulations.

UNIT V: Image Quality

- Task-based assessment of image quality: estimation vs. classification tasks; figures of merit.
- Psychophysical studies and ROC analysis.
- Model observers for classification tasks: ideal observers and linear discriminants; statistical pattern recognition.
- Image quality in direct imaging.
- Image quality in indirect imaging.