APPLIED PHYSICAL SCIENCES

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

APPL 460

Optical instrumentation for scientists and engineers

Spring 2020

Introduction	This course introduces fundamental principles of optical system design, covering a broad variety of imaging and microscopy instruments. The material will span beyond physical optics to include computational methods for optical signal processing, as well as basic principles governing light-matter interactions. The course will include theory, hands-on experience to implement and test methods on inexpensive hardware. We will discuss recent publications and state-of-the-art optical systems which are task-driven, controlled by computers, tailored to specific applications, and optimized to monitor or manipulate complex systems such as biological tissue with extreme temporal and spatial resolution.
Methods	The course is divided in three parts of about equal size : 1 – Lectures with pencil and paper problem sets to establish a common ground 2 – Simulations with pre-written Matlab code . Students are encouraged to install Matlab (with the Image acquisition toolbox add-on): https://software.sites.unc.edu/software/matlab/ 3 – A hands-on project on inexpensive optical system design. Students are encouraged to enroll for trainings at BEAM (3D printing, and Laser Cutting) during the first month of lectures.
Results	By the end of this course, students should be able to do the following: • Understand the design and capabilities of most commercial optical systems. • Identify the bottlenecks limiting performance in any specific application. • Implement optical system design methods to tailor software and hardware for a given task, and improve performance in efficient and cost effective ways. • Process optically encoded information using computer simulation. • Propose better optical instrumentation for research, medical or industrial applications that currently rely on suboptimal technologies.
Discussion	This course will give students opportunities to build expertise in optical engineering, the technical material will provide you with a valuable skillset and can be further completed with additional coursework in wave theory for or in biology. The course will value creative input in device fabrication, optical information processing algorithms, electronics, and applications in biology. The project can be individualized to best fit the student's long term goals.
Engineering Student Outcomes	By the end of this course, students will gain experience in the following engineering student outcomes: • Identify, formulate, and solve complex engineering problems by applying principles of optical engineering, computer science, and life sciences to execute a well-defined task. • Apply engineering design to produce solutions that meet specified needs with consideration of needs, cost, and user-specified constraints. • Recognize ethical and professional responsibilities in developing instrumentation and imaging systems that will directly impact safety, health outcomes, and society. • Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives in a

	time-limited setting (Deadlines are generous but strictly enforced). • Develop communication skills by producing reports and preparing for a presentation. • Demonstrate constant curiosity by exploring tailored optical designs that best responds to the needs of our changing world. • Persist through and learn from failure.

Class Essentials

CONTACT INFORMATION

Prof. Pegard	Teaching assistants
Office Location Caudill 154 **Email** pegard@unc.edu **Phone** N/A	N/A

LOGISTICS

Class meeting times
See online information

Class meeting location
See online information

Office Hours
by appointment

Required Texts & Software

- **Matlab**
- **Fundamentals of Photonics, by Bahaa E. A. Saleh, Malvin Carl Teich (ISBN: 978-0-471-35832-9).**

Pre-requisites

- Math 383 or permission of the instructor

Course content

COURSE TOPICS

- Ray optics and lens-based optical systems
  - Snell's laws, ray tracing rules, thin lenses and lens equations, Ray transform matrices, and image-forming systems.
- Wave optics, image processing algorithms and computational optics.
  - Wave properties, interferences, diffraction, computer generated holography (With lab demos and computational MATLAB simulation homework sets.)
- Quantitative optics, and advanced optical instrumentation.
  - Sensors and low light detections, non-linear light matter interactions, lasers, super-resolution microscopy. Instrumentation for biology and neurosciences.

Course Schedule

W1 Thin lenses: Descartes (Snell)'s law. Lens equations, image-forming systems.
W2 Sampling the Light field: Ray Transfer matrices and applications to linear optical system design.
W3 Processing the Light field: Plenoptic imaging, digital refocusing for 3D image reconstruction.
W4 Optical waves: phase, coherence, interferences.
W5 Wave propagation and simulation. Phase Imaging and Computer-Generated Holography.
W6 Optics at the microscopic scale: Diffraction, resolution limits.
W7 Dielectric Interfaces: Optics through thin films, optical filters.
W8 MIDTERM
W9 Scattering & aberrations: Optics in biological tissue.
W10 Simple models for light-matter interactions: Absorption & fluorescence.
W11 High power optics: Nonlinearity and multiphoton processes.
W12 Lasers & sculpted light: A brief introduction to light sources and structured illumination.
W13 Noise in optical systems: Cameras, detectors, signal processing & image enhancing methods.
W14 Super resolution. Beyond Abbe's resolution limits.
W15 Computational imaging & optical instrumentation. A review of the newest technologies, and future research.

To help you succeed

Course Expectations and Policies

- Participate in class discussions and problem-solving activities.
- During class time, do not use your phone or computer for something unrelated to class; research shows that this is distracting to other students in the class. If there is an urgent situation, then you can leave the classroom to use your phone or computer.
- Come to every scheduled class and lab session and let me know ahead of time if you cannot attend.
- Assignments will be handed out with plenty of advance to allow students flexibility in organizing their schedule. In return, students are expected to start projects and attend office hours early on, and should plan to deliver their assignments before the deadline. Assignments will not be accepted after the deadline.

Student Resources

SEE, SAY, DO SOMETHING

We're happy you are here and eager to learn. Despite our best intentions to follow a plan, life may throw us a curve ball. If you or someone you know is experiencing some distress or you are concerned about the well-being of a student, please report it here: https://deanofstudents.unc.edu/carereport. It is important to support one another. If you see something, say, and do something.

ACCESSIBILITY RESOURCES

UNC-CH provides accommodations for any students with documented disabilities. If you have a disability and believe you require accommodations, please contact the Department of Accessibility Resources at http://accessibility.unc.edu. Please contact me early in the semester so we can make any necessary arrangements and discuss the learning checks.

Assignments & Evaluation

➢ Your Course Grade

25%: Homework and quizzes	Up to one homework set per week, due within two weeks
25%: Midterm exam	In class, closed book
25%: Final exam	In class, open book
25%: Final project	Preparation, Project abstract and final report, Presentation and participation
100%: total	

➢ Grade Interpretation & Honor Code

Your final course grade will be determined from a standard scale:

A	93+
A-	90.0 - 92.9
B+	87.0 - 89.9
B	83.0 - 86.9
B-	80.0 - 82.9
C+	77 - 79.9
C	73 - 76.9
C-	70 - 72.9
D+	67 - 69.9
D	60 - 66.9
F	<60

ACADEMIC HONESTY

There will be clear communication if assignments are individual or group. For individual assignments, while I encourage collaboration, it is a violation of the honor code if a student duplicates work or obtains solutions from another student and submits it on their own. Please reference the honor code: http://honor.unc.edu.

➢ Major Course Due Dates

Midterm	In class, end of scheduled class time
Final exam	In class, end of scheduled class time
Final Project	Report due a week before scheduled presentation

I reserve to right to make changes to the syllabus, including project due dates and test dates (excluding the officially scheduled final examination), when unforeseen circumstances occur. These changes will be announced as early as possible so that students can adjust their schedules.