APPLIED PHYSICAL SCIENCES

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

APPL 430

Optical instrumentation for Scientists and Engineers

Spring 2024

Introduction	This course explores how optoelectronic materials can be turned into optoelectronic devices to build high performance optical instruments. At the intersection between electrical engineering, optics, and computer science, the course includes hands-on activities in which students will learn optics and electronics. Hands-on projects and activities include testing sensors operating under low light and high noise conditions, custom optical system design, imaging, holography systems, as well as computational imaging techniques using MATLAB or python (basic programming experience in any language is sufficient), camera control, and integrated hardware-software designs.
Methods	The course is divided in three parts of about equal size: 1 – Lectures and problem sets to establish a common ground. 2 – Computer simulations with MATLAB or python. We invite students to use ChatGPT to develop their code and rapidly fix their syntax. 3 – Hands-on projects. This includes Lab activities and personal projects. 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 operation of common scientific imaging systems. • Identify the bottlenecks limiting performance of image acquisition capabilities. • Process optically encoded information using computer simulation. • Propose better optical instrumentation for research, medical or industrial applications that currently rely on suboptimal technologies. • Customize optical systems to perform on-demand interactions with light.
Discussion	This course will give students a foundational skillset in optical engineering, and practical training in experimental optics. The course easily complements theoretical coursework (e.g. EM wave theory, physical optics) or biosciences backgrounds (e.g. neuroscience / biology / chemistry) for students who are interested in expanding their expertise towards experimental sciences, and for experimentalists who wish to rely on advanced optical instrumentation and benefit from better understanding how they operate. 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 personal 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 • Oral and Written presentation skills

Class Essentials

➢ CONTACT INFORMATION

Prof. Nicolas Pégard		Teaching assistants
Office Location.	Caudill 154	N/A
Email	pegard@unc.edu	
Phone.	Use Slack	

➢ LOGISTICS

Class meeting times

See online information

Class meeting location

See online information

Office Hours

by appointment and via slack

Required Texts & Software

- **Matlab**
- **We will use materials from Fundamentals of Photonics, by Bahaa E. A. Saleh, Malvin Carl Teich (ISBN: 978-0-471-35832-9).**
  Please inquire on SLACK before purchasing textbook as we have copies availiable to borrow.

Pre-requisites

- Math 383, or an equivalent course in Physics, BME, CS, or with permission from 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-L1 : Descartes (Snell)'s law, thin lens equations, introduction to ray tracing optics.
W1-L2 : Ray transfer Matrices.
W2-L3 : Light Fields. Plenoptic imaging systems, a light field model of the confocal microscope.
W2-L4 : Wave optics : Fresnel propagation through free space and thin lenses (with Matlab simulations).
W3-L1 : In-class activity with Matlab tutorial : Visualizing phase-objects with out-of-focus imaging.
W3-L2 : Computer Generated Holography, Iterative algorithms with Matlab-based simulation
W4-L1 : In class activity : Wave diffraction (Slit and double slit aperture model) – a proxy for resolution.
W4-L2 : An introduction to light detectors, cameras, and scientific digital imaging.
W5-L1 : Noise in imaging systems : Thermal noise, read noise, shot noise.
W5-L2 : In-class activity : Digital holography for phase imaging.
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.
- **ChatGPT policy:** We support the use of ChatGPT to facilitate and accelerate the writing of Matlab & Python code. The course (projects and assignments) has been revised to integrate these novel tools. ChatGPT usage remains prohibited for the preparation of written reports. A lecture will clearly discuss and explain what constitutes a fair use of ChatGPT. Students are expected to be able to explain the meaning of any code they submit, even if it is based on scripts generated by ChatGPT.

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.

Resources

Lecture slides

Lectures slides, code, and materials will be shared with class participants, please do not re-share them without permission from the instructor.

Attendance.

While in person attendance is expected, I will make Zoom attendance whenever possible for students who need this option due to illness, COVID exposure, or other extenuating circumstances.

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. CAPS is strongly committed to addressing the mental health needs of a diverse student body through timely access to consultation and connection to clinically appropriate services, whether for short or long-term needs. Go to their website: https://caps.unc.edu/ or visit their facilities on the third floor of the Campus Health Services building for a walk-in evaluation to learn more. *(source: Student Safety and Wellness Proposal for EPC, Sep 2018)*

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

The University of North Carolina at Chapel Hill facilitates the implementation of reasonable accommodations, including resources and services, for students with disabilities, chronic medical conditions, a temporary disability or pregnancy complications resulting in barriers to fully accessing University courses, programs and activities.

Accommodations are determined through the Office of Accessibility Resources and Service (ARS) for individuals with documented qualifying disabilities in accordance with applicable state and federal laws. See the ARS Website for contact information: https://ars.unc.edu or email ars@unc.edu.

Title IX Resources

Any student who is impacted by discrimination, harassment, interpersonal (relationship) violence, sexual violence, sexual exploitation, or stalking is encouraged to seek resources on campus or in the community. Please contact the Director of Title IX Compliance (Adrienne Allison – Adrienne.allison@unc.edu), Report and Response Coordinators in the Equal Opportunity and Compliance Office (reportandresponse@unc.edu), Counseling and Psychological Services (confidential), or the Gender Violence Services Coordinators (gvsc@unc.edu; confidential) to discuss your specific needs. Additional resources are available at safe.unc.edu.