OPTI 519L Computational Wave Optics Lab

Course Description:
This course teaches students how to set up and execute computational wave optics simulations in MATLAB, Python, or Julia. Topics covered include foundations of scalar diffraction theory, digital Fourier transforms, simple computations using digital Fourier transforms, Fraunhofer diffraction and lenses, imaging systems and aberrations, Fresnel diffraction in vacuum, sampling requirements for Fresnel diffraction, relaxed sampling constraints with partial propagations, and propagation through atmospheric turbulence.

Prerequisites:
Background in Fourier optics

Location and Times:
Meinel 307, F: 1100-1150 MST
D2L site: https://d2l.arizona.edu/d2l/home/1781285

Instructor:
Prof. Mark Spencer
spencerm@arizona.edu
(520) 621-2927
Office hours: F 1200-1300 MST in Meinel 737 or by appointment

TA:
N/A

Learning Outcomes:
- Understand how to apply digital Fourier transforms to wave optics simulations
- Simulate Fraunhofer diffraction, Fourier-transforming properties of lenses, isoplanatic aberrations, and both incoherent and coherent imaging systems
- Apply Fresnel diffraction with multiple steps and proper sampling in simulations
- Model propagation through atmospheric turbulence in simulation

Required Texts:
Jason D. Schmidt, *Numerical Simulation of Optical Wave Propagation with Examples in MATLAB,* (SPIE Press, 2010).

The full text will be available for download on the D2L website.

References:
- Paul H. Merritt and Mark F. Spencer, *Beam Control for Laser Systems*, 2nd ed. (Directed Energy Professional Society, 2018).
- David G. Voelz, *Computational Fourier Optics: A Matlab Tutorial*, 1st ed. (SPIE Press, 2011).
- Larry C. Andrews and Ronald L. Phillips, *Laser Beam Propagation Through Random Media*, 2nd ed. (SPIE Press, 2005).

Schedule:

Week 1

1. Foundations of scalar diffraction theory (Schmidt ch. 1)

   Lab 1 assigned

Week 2

2. Digital Fourier transforms (Schmidt ch. 2)

   Lab 2 assigned; Lab 1 due

Week 3

3. Simple computations using digital Fourier transforms (Schmidt ch. 3)

   Lab 3 assigned; Lab 2 due

Week 4

4. Fraunhofer diffraction and lenses (Schmidt ch. 4)

   Lab 4 assigned; Lab 3 due

Week 5

5. Imaging systems and aberrations (Schmidt ch. 5)

   Lab 5 assigned; Lab 4 due

Week 6

6. Fresnel diffraction in vacuum 1 (Schmidt ch. 6)

   Lab 6 assigned; Lab 5 due

Week 7

7. Fresnel diffraction in vacuum 2 (Schmidt ch. 6)

   Lab 7 assigned; Lab 6 due

Week 8

8. Sampling requirements for Fresnel diffraction (Schmidt ch. 7)

   Lab 8 assigned; Lab 7 due

Week 9

9. Relaxed sampling constraints with partial propagations (Schmidt ch. 8)

   Lab 9 assigned; Lab 8 due

Week 10

10. Propagation through atmospheric turbulence 1 (Schmidt ch. 9)

    Lab 10 assigned; Lab 9 due

Week 11

11. Propagation through atmospheric turbulence 2 (Schmidt ch. 9)

    Lab 11 assigned; Lab 10 due

Week 12

12. Propagation through atmospheric turbulence 3 (Schmidt ch. 9)

    Lab 12 assigned; Lab 11 due

Week 13

13. Introduction to final project

    Final project abstract, poster, and paper assigned; Lab 12 due

Week 14

Thanksgiving

Final project abstract due

Week 15

No class – work on your final project

Finals Week

Final project paper due; Final project poster session

Grading:

Labs	60 points
Class participation	5 points
Final project abstract	5 points
Final project paper	15 points
Final project poster	15 points

As scheduled above, there will be 12 graded labs worth 5 points each. These labs will prepare you to complete a final project. Class participation (i.e., class attendance, asking questions, study groups, etc.) will also prepare you for this project. You are encouraged to pick a topic that helps you make progress on your thesis/dissertation research. This is also an opportunity to practice scientific proposing, writing, and presenting with feedback from a professor.

Final projects should be similar in scope to the assigned labs in terms of time spent. Analogous to an Optica conference proceeding, the final project paper (two pages max) and poster should include a concise statement of the problem, a diagram of the setup, a description of the simulation, a summary of the results, and a listing of the computer code used (in an appendix).

Below is a list of suggested project topics. This list is not exhaustive, so feel free to propose (via an abstract) your own topic. This course will not cover propagation through atmospheric turbulence until late in the semester, but do not let that deter you from picking a topic that requires turbulence. Students can make significant progress earlier in the semester with vacuum simulations, sampling analysis, and basic models of a sensor, a rough object, a fiber, or whatever the project requires. Vacuum simulations are an important part of every turbulent simulation.

- Propagation through turbulence:
  - show that the log-amplitude variance saturates as scintillation strength increases
  - estimate turbulence parameters from noisy measurements
  - model a simple wavefront sensor
  - model a simple directed-energy, laser-comm, or lidar system
  - model a coherent imaging system with anisoplanatic conditions
  - model an incoherent imaging system with anisoplanatic conditions
  - simulate propagation of multiple beams and observe irradiance fluctuations
- Propagation of laser-beam modes other than TEM00
- Simulation of an incoherent source/object (see Voelz ch. 9)
- Propagation through an integrated optical device
- Propagation after interaction with a grating
- Propagation after interaction with a spatial light modulator
- Simulation of coupling light into an optical fiber
- Simulation of light emerging from an optical fiber
- Comparison of Hankel transform calculations with discrete Fourier transforms

There are 100 points possible in the class (plus extra credit – see below). As the course progresses and you lose points on the graded labs, you should immediately know where your grade stands relative to the following rubric.

A, >89.5 points; B, > 79.5 points; C, >69.5 points; D, >59.5 points; E, 59.5 points or lower

If there is still doubt about your grade at any time during the course, then please do not hesitate to ask for clarification. Lastly, if you miss one (or more) of the graded labs, then you will forfeit all class participation points.

Extra Credit:
Mistakes found in the lectures or course materials will result in half a point of extra credit. Please email me with your findings if they are not pointed out in class. A thoughtful suggestion on how to improve the course material will result in 1 point of extra credit. Each student will be limited to 5 points of extra credit during the semester.

Academic Integrity:
You may refer to notes from other versions of this course (previous offerings at UA and other universities), and you may use solutions from outside this course. Students may collaborate on solving the labs, but each student must submit his/her own copy of their solutions for each lab. In my view, directly copying another student's solution or using generative AI without supplying your own effort to solve any steps in the problem is cheating.

The final project paper and poster will be completed by yourself without the help of your fellow classmates. Keep in mind that if you do somehow cheat on these items (e.g., blindly using generative AI), then you will not be prepared for questions during the poster session.

Cheating of any kind will be prosecuted and may result in any or all of the following:

- Reduction of grade
- Failing grade
- Referral to the Dean of Students for consideration of additional penalty

Accessibility and Accommodations
At the University of Arizona, we strive to make learning experiences as accessible as possible. If you anticipate or experience barriers based on disability or pregnancy, please contact the Disability Resource Center (520-621-3268, https://drc.arizona.edu/) to establish reasonable accommodations.

Subject to Change Notice
The information contained in the course syllabus, other than the grade and absence policies, may be subject to change with reasonable advance notice, as deemed appropriate by the instructor.