Fourier Optics Lab

Center for Adaptive Optics Summer School

August 4–8, 2008

1 Introduction

The Fourier Optics activity is designed to enable you to observe and experiment with the diffraction of light. This activity uses a tabletop optical setup consisting of a computer-controlled detector illuminated by a laser source. You will work in small groups to investigate the relationships between the shape of the limiting aperture and the resulting far-field diffraction pattern. You will be able to directly examine how phase errors in the pupil affect the point spread function, as well as how they alter the signal received by a Shack-Hartmann sensor. The computer can be used to quantitatively examine the point spread function, and software tools are provided for comparing your experimental results with simulations.

This activity is conducted in two stages. In the first stage (§2), you will investigate a series of optical phenomena that are present in the laboratory setup. In the later stage (§3), you will perform an investigation of a problem (or problems) of your choosing.

1.1 Optical Setup

The layout of the optical bench is shown in Figure 1. A 632 nm laser provides a reference point source, which is collimated by a lens. An iris is used as a limiting aperture — you may also place your own apertures in the collimated beam. A second lens then causes the beam to converge on a detector. The detector is a 480×640 array with 13 μm pixels. The lenses' focal lengths vary from station to station. Additional equipment includes a lenslet array, which can be used to simulate a Shack-Hartmann wavefront sensor. These lenslets have a 1 mm pitch and a 24 mm focal length.

A computer is connected to the detector and provides an interface to the CCD data. Note that "ghost" artifacts may be present in the image obtained by the detector. These are caused by internal reflections within the CCD chip and optical system, and should be ignored. Examples of such ghosts are shown in Figure 2.

You are free to modify the system as you see fit, including altering the positions of optical components. If you need a different piece of equipment for your investigation, feel free to ask your instructor.

Note: Please handle the lenses carefully. Also avoid touching the surface of the lenses as smudges from fingerprints or scratches on the lenses will affect the quality of the resulting images. Please use the lens paper when you need to put the lenses on some surface.

1.2 Materials

The materials for this activity include:

- cardboard, razor blades (for cutting apertures)

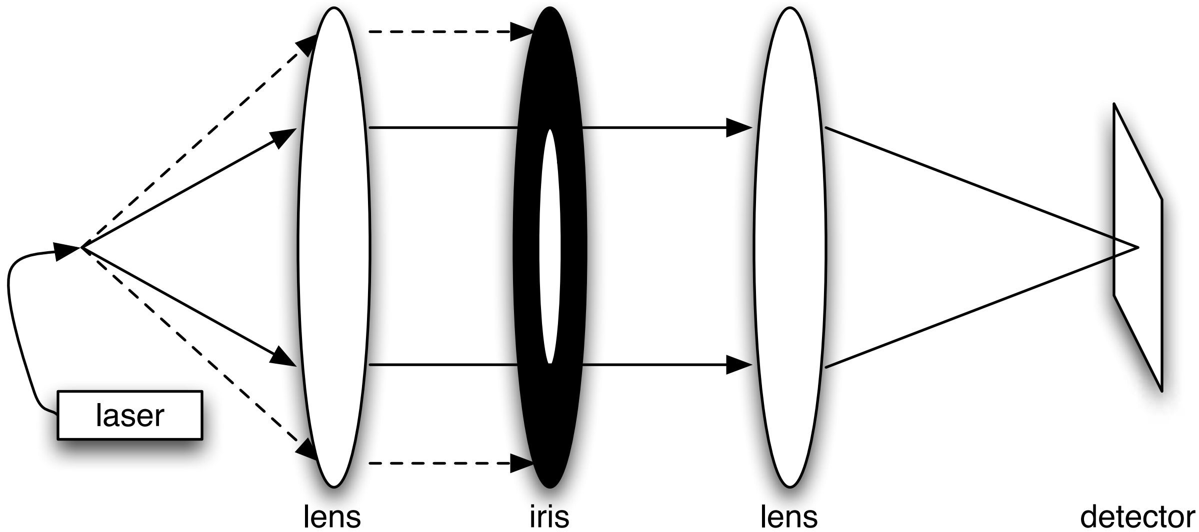

Figure 1: Layout of the Fourier Optics bench.

- pins (for making pinholes)
- plastic (for phase aberrations)
- trial lenses (for phase aberrations)
- transparency paper (for printing masks)

1.3 Software

Detector Interface The detector is controlled by a program called `Astro IIDC`. The interface in Figure 3 can be used to control the appearance of the pattern on the detector. Important controls are the *gamma*, *brightness*, and *exposure time*. The gamma is the index of a power-law stretch applied to the data values read from the CCD. A gamma of one represents a linear stretch. The brightness control amplifies the image (by applying a gain). The exposure time controls how long the detector integrates before being read out. All of these can be adjusted to bring out faint features in the diffraction pattern on the displayed image, though the brightness control can introduce noise at high settings. The 'Camera' menu item has functions for zooming in. Documentation of additional controls can be accessed via the software Help function.

Fourier Simulation An IDL computer program is provided to help in your investigations of diffractive phenomena. The primary purpose of this program is to simulate the far field diffraction pattern of several simple apertures with and without phase aberrations. Two different methods of introducing phase aberrations are available: a simulated phase screen with a Kolmogorov model of turbulence and aberrations decomposed into Zernike polynomials. For example, you can use the program to compare the effect of introducing an aberration like astigmatism to the optical system to the theoretical calculations. This program is available on the same computer that you are using to take images. Please feel free to ask for help using this program.

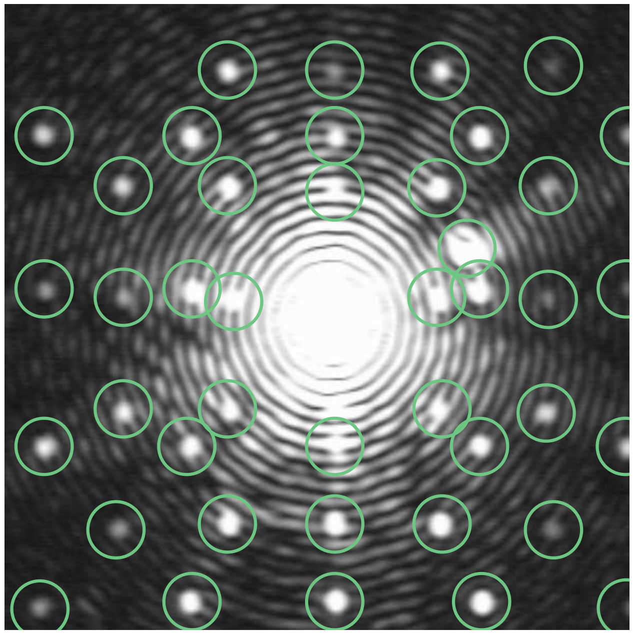

Figure 2: Location of ghost artifacts in an example CCD image.

The IDL language used for this graphical program can also be used for analyzing images and whatever data you see fit.

Drawing and Graphic Conversion The `Graphic Converter` software can be used to process images captured by the `Astro IIDC` software. It can also be used as a drawing program, where you can create aperture masks to be used in the optical setup. When printing a mask, be sure to select the appropriate paper feed for transparencies.

It is also possible to take screenshots of the detector display by using Apple+Shift+4, and dragging a box over the region of interest. Images will appear as: Picture 1, 2, 3 ... on the desktop.

2 Initial Investigation

1. Trace the propagation of light through the system using a white piece of paper. Can you identify any diffraction effects? What is the purpose of the final lens?

2. Try using the iris to expand and contract the pupil. What is the relationship between the overall size of the aperture and the corresponding scale of the resulting far-field diffraction pattern?

3. Introduce an edge, such as a razor, into the iris. How does the presence of an edge in the aperture affect the point spread function (PSF)? How about the orientation of the edge? What PSF structure do you expect with a triangular aperture?

4. What is the relationship between the shape of an aperture and the far-field diffraction pattern?

5. Phase errors, such as those caused by atmosphere, can degrade the imaging performance of an optical system. Phase errors can be introduced in to the optical setup by inserting a piece

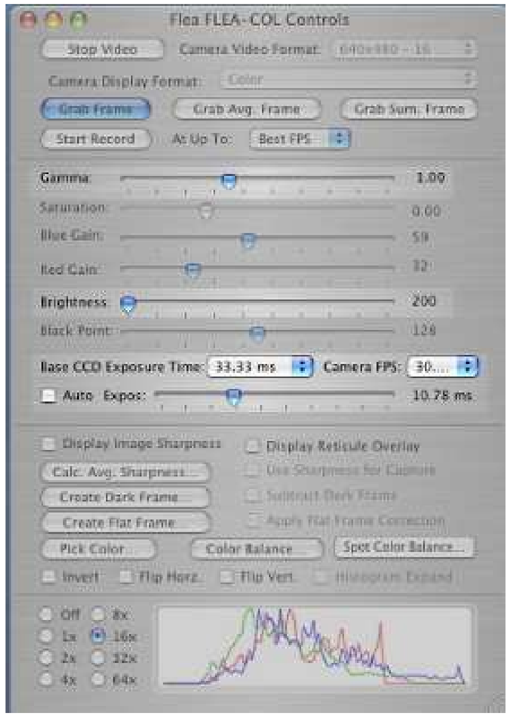

Figure 3: Interface to the detector through the Astro IIDC software.

of plastic at the pupil. How do various phase errors affect the PSF? What is the relationship between the phase errors and the resolution achievable by the system? To introduce a specific aberration such as astigmatism, ask for a trial lens.

6. *Optional:* Alter the optical setup to image the pupil of the system on the detector. You can use this configuration to compare the wavefront in the pupil with the resulting far-field pattern. What happens when aberrations are not introduced in a pupil, but in a separate plane?

3 Avenues for Exploration

1. A critical need for some astronomical observations is the ability to detect faint sources of light next to a bright one (e.g. a planet orbiting a distant star). Can you quantify what contrast levels are achievable by the system? What can you do to improve contrast limits?

2. Investigate how a Shack-Hartman wavefront sensor works: construct a WFS by adding the lenslet array to the optical setup. What are the spots and how do they give information about the wavefront? What would happen with a different number of lenslets? Predict what a simple aberration like defocus or astigmatism will do to the spots, and try to introduce such an error into the system. How would you use the information from the lenslets to remove the aberrations?

3. You are free to design an investigation of Fourier optical phenomena of your choosing. Define a problem and design a series of experiments to enhance your understanding. Feel free to consult an instructor for guidance.