OPTICS AND LASER PHYSICS LAB #5

CONVENTIONAL IMAGING AND SPATIAL FILTERING

with Jennifer Malos

The goal of this laboratory experiment is to familiarize students with basic lens properties, demagnification and magnification of images, and simple spatial filtering. Apparatus includes a laser, some converging lenses, a spatial resolution chart, a iris diagram aperture, and a gold painted spot (1 mm diameter). A software package, NIH Image, is used with Macintosh computers for simulating the spatial filtering and then analyzing the actual experimental data. Finally, a CCD camera sends images directly into the PowerMac 8500 for viewing and analyzing.

Imaging with Convex Lenses

Let's explore the fundamental imaging equation $\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$ where f is the focal length of the lens, o is the object distance from the lens, and i is the image distance from the lens. Set up an optical system that will pass light through the resolution chart, through a lens, and then onto a screen. Draw a diagram of your apparatus including distances, focal lengths and other optics placement. Place the screen far enough onto the table for the CCD camera to fit behind it.

Q1. At what distance from the lens is the image found? How does this image distance compare to the calculated value?

Vary the distance between lens, chart, and screen and check image.

Q2. What is the difference between the focal length and the image plane?

Q3. Is it upright or inverted?

Create a magnified image and then measure your image magnification using the resolution chart's known spatial frequencies and the CCD camera on monitor. Then calculate the magnification of the image you should have produced for comparison. Remember that the CCD camera has an active area of around 1 cm x 1 cm. With the CCD camera attached to the computer, a program called Image 1.59 is opened. Place sufficient neutral density filters in front of the camera for protection. By selecting **start capture** from the SPECIAL menu, the "full-sized" screen (456 x 556 pixels) opens to display the image sent from the camera. To grab a frame from the live image, click the mouse button when the cursor is over the image. This image can be saved for later manipulation of the image or to print it out by selecting **save as** from the FILE menu. The pixel size on "full screen" setting is 6.94 μm.

CONVENTIONAL IMAGING AND SPATIAL FILTERING

Q4. In your present set-up, (i.e. with the resolution chart and convex lens position kept the same), what focal length lens would you require to magnify the image 20 times? and how far should the screen be placed to do so? Could you produce a 40 times magnification with the same lens as you used for 20 time? What would you have to change in order for this to be possible?

Q5. With your lens, could you produce a de-magnified image? How?
Q6. What happens to the quality of the image if your image-bearing beams does not go through the center of the lens?
Q7. What happens to the image if you block half the lens? The other half? Can you predict this behavior with a series of rays going through the lenses. Draw the schematic. (Hint: Are the rays coming into the lens parallel now?)

Spatial Filtering -- One Form of Image Processing

Spatial filtering is accomplished in the Fourier Transform plane of a lens. This occurs in the focal plane of the lens. Light that passes through a lens, will form the Fourier Transform of the spatial information in the beam at the focal plane. This means that the spatial information is moved into a new pattern in which low frequency components are near the center of the new beam and higher frequency components produce spots leading away from the central dot at angles reflecting the position of the higher spatial frequencies. Mathematically, we can show that the Fourier Transform of a spatially varying image is equivalent to the far field diffraction pattern of an aperture that has the same spatial variation. For instance, 2 vertical lines placed in the beam would create a Fourier Transform with a central dot and several dots decreasing in size and separation to the right and left on a screen in the focal plane which is the diffraction pattern of 2 slits placed in a beam.
Q8. Based on the above information, how would you expect the Fourier Transform of a triangle placed in the beam to appear in the focal plane?

Spatial filtering terminology is as follows. The term "_high or low_" frequency filtering means that the filter blocks the specified frequency range and the term "high or low" pass filter means that the specified frequency range is allowed to pass through the filter. For example, low spatial frequency filtering can be used to enhance high spatial frequencies, producing what is called an edge enhanced image in the image plane by blocking low spatial frequencies in the Fourier plane. Whereas a low pass filter produces a blurry image by blocking high frequency components in the Fourier plane and allowing low frequency components to pass.

OPTICS AND LASER PHYSICS LABORATORY #5

CONVENTIONAL IMAGING AND SPATIAL FILTERING

Computer Simulation of Optical Processing

Let's predict our experimental results by utilizing the software package, Image 1.2. (on the PowerMac Image 1.59) Open Image (double click), Select **New** under FILE, and a blank screen will come up on the computer [PowerMac choose Width: **512** and Height: **512**, Then click on **OK**]. Use the tool bar to draw a pattern on the screen that we envision our beam passing through. This can be accomplished by creating circles, squares, etc. with the Tool Bar and then using **Fill** under EDIT to blacken the inside of the selected portion of the picture. Next choose **Select All** under EDIT to encircle the pattern and choose **FFT** (fast Fourier transform) from the FFT bar on the menu [PowerMac go under PROCESS and choose **FFT**]. After a brief calculation, the FFT will appear on a new screen. Now check to see if it has the high frequency components that you would expect from your drawing (in general).

Then using the tool bar place a spatial filter on the FFT (it can be a low or high pass filter). This allows you to box in certain areas of your FFT with symmetrically placed circles or quadrangles. By choosing **Filter** (which blocks the inside of selected area) or **Pass** (which keeps only the information within the selected area) under FFT on menu the filtering is accomplished. [PowerMac users must use Tool Bar to filter with squares or circles and then push **Delete** button on keyboard to remove selected space and produce filter. Selection of center or edges of FFT produce high or low pass filtering.] Lastly have the computer take the **Inverse FFT** of the spatially filtered FFT of the image under FFT on menu [or under PROCESSES, then FFT for PowerMac]. The resulting image is what you would expect to observe on the screen in the image plane with the particular type of filter you created.

You can use a box from the Tool Bar to draw a line through the picture. Under ANALYZE choose **Column Average Plot** [**Plot Profile** on PowerMac] to see how clean the edges are before and after spatial filtering.

Try several patterns and types of spatial filters in the simulation. Include the following:

a) You have a file with Lincoln's picture named ABE. Choose a particular set of features to either sharpen or dull. Predict where in the FFT you need to filter to achieve desired results. Try it and store finished product.

Q.9 Were you successful at first? What did you have to change and why?

b) You also have a file with the resolution chart. Note: The experimental apparatus you have available is an Air Force Resolution Chart. Create high and low frequency filtering of this image. Use the line on plot profile to check profile for edge sharpness before and after filtering.

CONVENTIONAL IMAGING AND SPATIAL FILTERING

Q.10 What do you note about low versus high frequency filtering? How do the plot profiles look?

Store one of each on the computer in a file with your group's name on it.

Experimental Optical Filtering

With the optics and spatial filtering devices available, set-up and explore the following optical filtering systems.

a) Low frequency filtering.
b) High frequency filtering of a single orientation of line (vertical, horizontal, +45 degree).
c) High frequency filtering of all orientations. Here place the diaphragm fully open in the Fourier plane and observe the amount of filtering you produce. Record.
d) Study how close to the Fourier plane you must be to produce filtering.
Q.11 Why is it or is it not possible to filter anywhere but in the focal plane? Discuss limitations.

Using the CCD camera and PowerMac or monitor. Observe and record your resolution capabilities with the two types of filtering.

Record images into Image 1.59 using VIDEO window and **Capture**. Then use Image's Tool Box to draw a straight line through the recorded images and check on edge sharpness. Compare to the images you simulated.
Q.12 Does the simulation actually predict results?
Q.13 How does the size of the spatial filter you chose in the simulation effect the results?