<u>Core Concepts</u>

The Diffraction Pattern

Diffraction occurs when a wave travels through a slit of a width similar to its wavelength. If the slit is much larger than the wavelength, we may see some diffraction around the edges, but we won't see a noticeable effect for most of the light. If the slit is much smaller than the wavelength, we don't see a clear wave pattern. Because light is a transverse electromagnetic wave, we can observe it diffract. When light diffracts through a single slit, it travels outward in a semicircular pattern, maintaining its wavelength. This occurs because different parts of the same wave are hitting the edges of the slit and reflecting off of them at different angles. Since the new waves are travelling at different angles, they are also travelling different distances, so they arrive at the CCD out of phase. Because of this, we see interference patterns even though we have only one light source. This gives us a sinusoidal pattern in terms of the light's intensity, where the absolute maximum occurs directly in front of the slit and the maxima grow smaller and smaller as we move further away from the center. From this pattern, we can determine the angle θ between the slit and a given pixel at a minimum point:

$$\frac{D}{2}\sin\theta = \frac{\lambda}{2}$$

Where D is the diameter of the slit and λ is the wavelength. We can relate this geometrically to the distance from the slit to the CCD to calculate pixel size:

$$\frac{ns}{d} = \sin\theta$$

Where *n* is the number of pixels between the given pixel and the central pixel, *d* is the distance between the laser and the CCD, and *s* is the pixel size. In our case, we have a far field, in which

$$F = \frac{R^2}{D\lambda} \ll 1$$

For an aperture of radius R. This means that our diffraction pattern should be the same shape as long as we stay in a far field. In a near field ($F \geq 1$), this is not necessarily the case, and we get much more complex situations.

Equipment

CCDs

CCDs, or charge-coupled devices, measure the intensities of different wavelengths of light. The device contains an array of electrodes which measure the intensity of incoming light, then maps this to pixel data. Each pixel corresponds to a particular position which is relative to multiple electrodes; these electrodes are positioned above a piece of silicon. Each pixel has multiple values, each of which corresponds to a different color. These different colors are recorded by different electrodes. In our case, the CCD we used was a webcam with the lens removed, so there were three colors – red, green, and blue – but some CCDs can read into the infrared or ultraviolet ranges. When light strikes the detector, a positive current is run through it, creating a potential well which attracts electrons. The greater this potential well becomes, the more electrons it attracts; the more electrons are attracted to the well, the greater the saved intensity data is. Because we used a webcam, it likely had a relatively low quantum efficiency. This means that the camera doesn't register all incident light; instead, it reads and records a smaller percentage. The device's accuracy can be further reduced by physical damage; because of this, we measured the distance to the CCD externally around the webcam. It is also possible for noise to interfere with data; for example, thermal noise can cause false positives on the electrodes.

Data Analysis

Determining the angles of the diffracted light without damaging the CCD.

There are two ways to determine the angles of diffracted light. The method that seems simpler at first glance is to do so geometrically. If we know the horizontal distance from the slit to the CCD and the distance from the center of the beam to the pixel we are trying to analyze, we can use the geometry of a right triangle to determine the angle between of that wave to the CCD. Unfortunately, to do this, we need to know the pixel size, which we can't accurately or precisely measure directly without removing the CCD from its casing and touching it with whatever our measuring device is; both run a high risk of damaging the CCD in the process. So, we can instead take an image of the beam and convert it to RGB intensity data. In doing so, we should get a roughly sinusoidal function in which the center peak represents the center of our beam and the peaks going in either direction become shorter. By finding the local maxima or minima, we can calculate the angle of the wave from the slit to the CCD without risking damaging the CCD using:

$$\frac{ns}{d} = \sin\theta$$

To solve for θ. By calculating the angle this way, we were able to reverse-engineer the pixel size from the geometric definition of the angle.

References

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