Constructing a Simple Beam Profiler

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Abstract

It is possible to construct a simple beam profiler for qualitative analysis using a standard off-the-shelf webcam. The following is a description of one such set-up. This set-up is quick and useful, but has certain limitations.

1 Equipment

The tools necessary to image a beam are as follows:

- A CCD-based Camera
- A Lens
- Neutral Density Filters
- Software for CCD Image Capture
- Software for Image Analysis

The CCD camera we used was an USB GE EasyCam. This was bundled with the software Arcsoft PhotoImpression 3 for image capture. Due to the limitations of this software we used different software, ImageJ, for analyzing the beam images. ImageJ is free and can be found at http://rsb.info.nih.gov/ij/.

Any lens may be used; along with the desired magnification this will determine the geometry of the apparatus. We used a lens with a focal length $f = 50mm$, coupled with a magnification of $M = 0.5$. This set the lens-to-camera distance. Lastly, neutral density filters are necessary to reduce the overall beam power incident on the camera. These types of CCDs do not have a large dynamic range, thus detail is lost if the beam intensity is too high.

2 Procedure

First there will be a description of the *Calibration Procedure* to determine the pixel size of a CCD camera. Once the pixel size is known, the camera can be used in conjunction with a lens and neutral density filters to capture images of

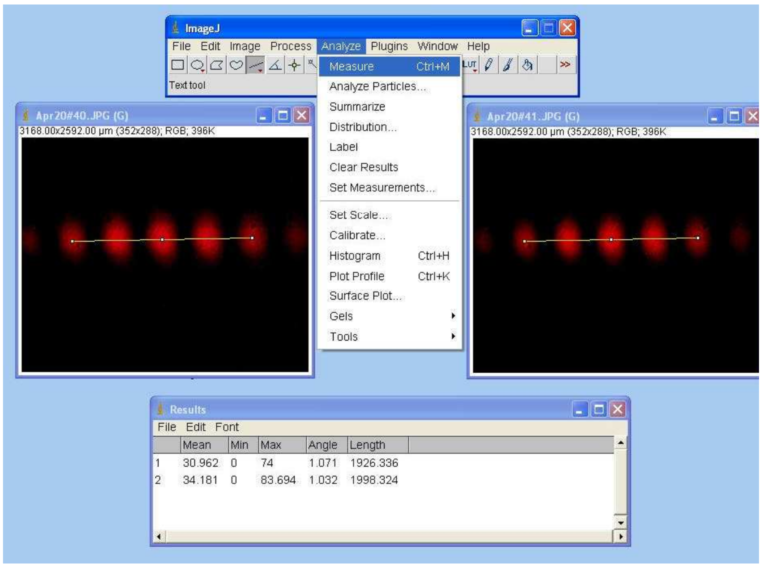

Figure 1: Measure Dialogue in ImageJ

a beam. This is the *Apparatus Procedure* described below. Then those images can be analyzed using imaging software to obtain information on the shape and size using the *Image Analysis Procedure*.

2.1 Calibration Procedure

In order to use the CCD camera to measure the size of a beam the effective size of the pixels must be known. This was obtained by using a laser and a double-slit slide to create an interference pattern. The double-slits were placed on translation slide so that the distance from the slits to the camera could be varied and reliably measured. The width w between maxima is then well-known for a sufficiently large slit-to-camera distance d by the formula:

$$w = \frac{\lambda d}{a} \tag{1}$$

where λ is the wavelength of the laser, and a is the distance between the two slits. Two images of different distances d were captured, and the difference Δd was recorded.

Next the captured images were loaded in ImageJ. For each a straight line segment was drawn from the center of one maximum across the central maximum to the maximum of the same order on the other side (Figure 1). Then the option *Analyze > Measurement* was performed on each image. The length in pixels was read off the *Measurements* window, divided by the number of minima crossed, and subtracted from each other to get a difference in maxima distance Δw_{pixels} measured in pixels.

Using the recorded Δd and Eq. 1, a difference in maxima distance $\Delta w_{microns}$ was obtained. Comparing these two values, $\Delta w_{pixels} = \Delta w_{microns}$, yielded a pixel-to-micron conversion. This is the effective pixel size. For the GE EasyCam we found an effective pixel size of approximately $9\mu m$.

2.2 Apparatus Procedure

Once the pixel size was known, we set up the camera to image a beam that was being used in another experiment. A beam splitter sent part of the beam out of the experiment, through a neutral density filter, a $50mm$ lens, another neutral density filter, and into the CCD camera. Initially a circular aperture was placed after the beam splitter, at an appropriate distance from the lens. The image taken by the CCD was to be of a magnified circle, so that we knew what to expect.

$$\frac{1}{f} = \frac{1}{Z_1} + \frac{1}{Z_2} \tag{2}$$

$$M = -\frac{Z_2}{Z_1} \tag{3}$$

Specifically, we designed the apparatus for a magnification of $M = 0.5$ using standard lens equations. We chose a lens of focal length $f = 50mm$. This set the lens-to-camera distance $Z_1 = 75mm$. Neutral density filters were then placed between the camera and the lens. It was necessary to put them as close to the camera as possible to reduce the ambient light. Other filters were placed in front of the lens to reduce the beam power further. Overall reduction by the filters was on the order of 80%.

The aperture was placed at a distance of $Z_2 = 150mm$ from the lens. The aperture used was a circular hole drilled to be approximately $600\mu m$ in diameter. Thus the image captured by the camera was expected to be of a circle with a diameter of approximately $300\mu m$. We took images both with and without the aperture.

2.3 Image Analysis Procedure

Once the camera and lens are aligned for a desired image, PhotoImpression 3 was used to save it. PhotoImpression 3 captures images in JPEG format, but does not have the necessary tools to analyze them. For this we opened the images in ImageJ.

First, with an image open, we selected *Analyze > Set Scale*, and set *Distance in Pixels* to 1 and *Known Distance* to 9 since our pixel to micron conversion was 1 : 9. We also changed *Unit of Length* from *cm* to *um* (for μm), and checked the *Global* box (Figure 2).

Next we used the *Straight Line Sections* tool to create a line of interest in our image. Selecting The *Analyze > Plot Profile* produced a plot of "gray value" vs. x-y distance. "Gray value" is essentially a measure of intensity (Figure 3).

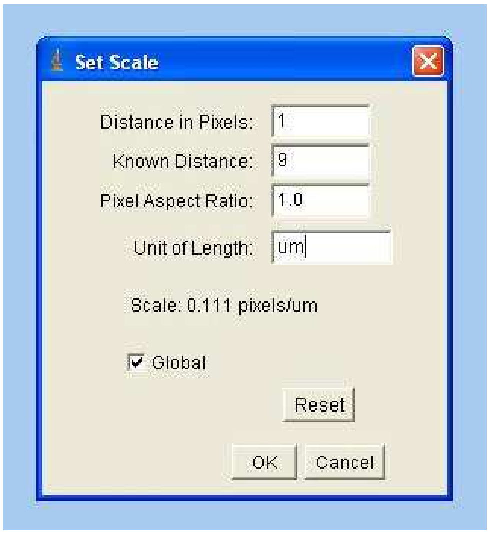

Figure 2: Set Scale Dialogue

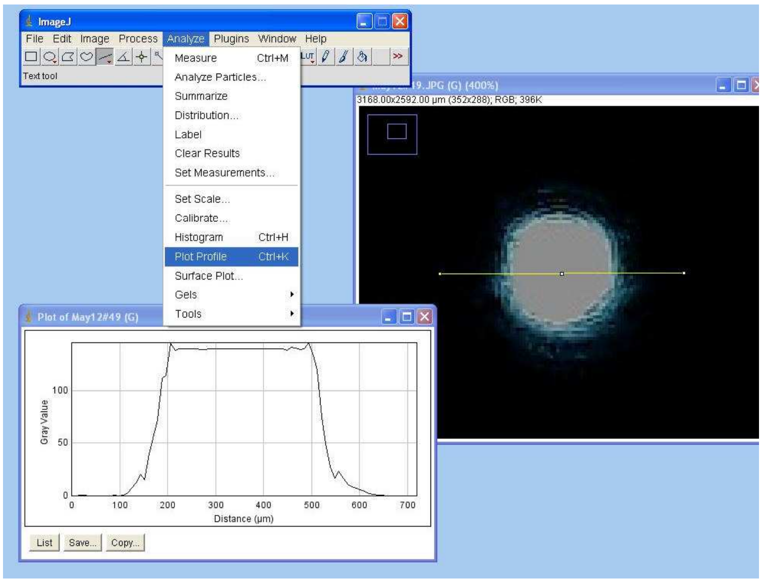

Figure 3: Plot Profile Window in ImageJ

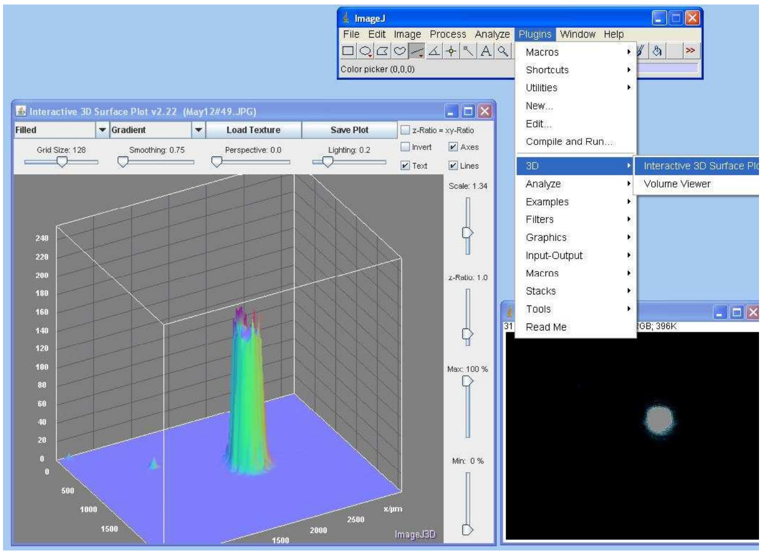

Figure 4: 3D Interactive Plot Feature in ImageJ

For a more interesting visualization, we used the *Rectangular Sections* tool to create a region of interest, and then selected *Plugins > 3D > Interactive 3D Surface Plot* (Figure 4). This made a 3D plot with the "gray value" on the *Z*-axis. Various types of color schemes and types of fills could be chosen. *Smoothing* was kept close to zero, since it distorts the qualitative features that we were interested in viewing. The plot was saved by choosing *Save Plot* and then selecting *File > Save As* from the main menu.

3 Limitations

This method has two significant limitations. While it allows for a quantitative analysis of beam profiles, there is significant uncertainty when using this apparatus for measurements. Uncertainty in pixel size is the main cause. The pixel measurement gives an effective pixel size, and does not account for possible dead space between pixels.[1] This is largely overshadowed by the uncertainty in the pixel size measurement, however. Error in pixel size can be made arbitrarily small by precisely measuring the quantities from the right hand side of Eq 1.

Another limitation is the small dynamic range of the CCD. The beams being imaged are typically too intense to capture without filtering. This causes the pixels to register the maximum intensity value for parts of the beam that are not the most intense. The amount of filtering depends on the laser intensity. An interesting extension to this project could explore the maximum intensity the CCD can register, and look at techniques for improving dynamic range.

References

[1] F. Cignoli, S. D. Iuliis, and G. Zizak, Appl. Spectrosc. **58**, 1372 (2004).