LIGO SURF Progress Report 1: Particle Imaging and Analysis for Advanced LIGO

Sabrina Waller

Mentor: Calum Torrie

July 14, 2014

1. Introduction

The design for LIGO (Laser Interferometer Gravitational Wave Observatory) centers around the use of high intensity lasers aimed at a series of optics to detect gravitational waves. However, when the laser beams hit the optics, particulate contamination on the surface of the optics results in interference with the beam and damage to the optics. As of yet, there is no efficient and cost effective way for engineers on sight to accurately identify the contamination level of the optics within Advanced LIGO. Additionally, the program currently being used to process images and count the particles on them forces the user to go through every step of processing the image by hand, and the information it provides about the size of the particles is in pixels, its equivalent in meters based on the camera used, making it necessary to first calculate the resolution of the camera before converting the pixels to meters, a time consuming and lengthy process. The development of a straightforward, automated process is essential for enabling quick, on-site determinations of what optics need cleaning and if there is an unacceptable level of contamination remaining after cleaning.   I am developing a process where a Nikon D7100 with an AF Micro Nikkor 200mm 1:4 D lens can be remotely controlled to take images of the optics, which are then processed in MATLAB using code that utilizes MATLAB's Image Processing Toolbox. The program will count the number of particles and measure their various sizes, providing accurate and immediate information about the contamination on the optics.

2. Progress

Having limited prior experience with high quality digital cameras, I began by familiarizing myself with first the Nikon D40 and then the more powerful Nikon D7100 once it arrived. I explored the various functions available with the camera and researched photography techniques and tips, especially focusing on those important for macrophotography. I also looked into how to run ControlMyNikon, which is software that can be used to remotely operate the camera. Once I understood the system, I began taking test images of a 3 inch radius optic surrounded by a ring of green LEDs, illuminating the dust on the surface of the optic, all of which is inside a chamber. This set-up mimics the shooting conditions on site. I took over a hundred test shots varying aperture, shutter speed, ISO (the camera's sensitivity to light), White Balance, Image Quality, and the brightness of the surrounding LEDs. In the beginning I used the camera's autofocus, but the resulting images were not clear, so I did some research and found that Autofocus does not function properly when working on such a small scale and that in order to take a clear image, one has to focus the camera manually for each shot. This means that the camera cannot be completely remote operated as remote focusing relies on the Autofocus function. This introduces a certain level of human error into the process as manual focusing is based on the

operator's judgment. However, I found that opening live view and zooming in as far as possible before focusing allows the operator to focus the camera consistently and accurately, thus making any human error in focusing so slight as to be negligible, a conclusion I later confirmed when I processed the hand focused images using ToupView, the computer processing and particle counting program currently in use, and found the same particles and measurements for the particles on both images. After comparing all my test images I discovered that the best, most consistent setting is as follows:

Aperture: f-stop 5

Shutter Speed: 1/80

ISO: 200

White Balance: Fluorescent

Image Quality: Fine

Picture Control: Vivid

Green LEDs: Anywhere within a 25.4 to 30.9 Volt bracket

I practiced using ToupView to convert the images to binary and count the particles on the image. I then checked to see if the software could successfully stitch together multiple images of the optic to allow a larger area of the optic to be analyzed and found that it could not. I discovered that this was for multiple reasons. The first was a barrel-roll distortion on the image which I corrected by turning on the camera's auto-distortion function, the second was a glare on the surface of the optic which was caused by the ring of LEDs being not centered properly, and the final cause was the slight variation in angle and distance made by moving the tripod over to take the next picture. The only way to fix this problem would be to mount the camera on remote controlled XZ translation stages.

We were working off of the assumption that it would take multiple images stitched together to create a single image that fully encompasses the maximum desired area of 75 mm x 75 mm of the optic's surface. However, as I was working with stitching the images I observed that one image appeared to capture a large portion of the optic, even greater than the 75 mm x 75 mm area we are looking to capture. I tested my theory by taping a ruler to a white wall and taking pictures of it from a 40 inch distance to accurately recreate the distance the camera will be from the optic when actually on site. I checked the images and found that a single image covers an area of 103 mm x 74 mm, which means that we would not need to buy a translation stage, but also calls into question if the camera can resolve small enough particles to provide accurate information about the contamination on the surface of the optic.

I proceeded to calculate the resolution of the camera by drawing objects of known size on a post it note, putting it on the wall next to the ruler, and taking a picture. I opened the image in ToupView, which allowed me to draw a line across a section of the ruler in the image and then told me how many pixels that distance was. I could see from the image that the actual length of the selected portion was 18 mm, which ToupView informed me was 963.301 pixels, and from there was able to calculate the Resolution as 53544 Pixels/Meter. I tested this resolution on the hand drawn circles and ended up with the following results:

Area (Pixels)	Perimeter (Pixels)	Hand Measured Diameter (mm)	ToupView Calculated Diameter (mm)	Hand Measured Area (mm^2)	ToupView Calculated Area (mm^2)
3672	302	1	1.277009192	0.785398	1.28079
11150	514	2	2.225262706	3.14159	3.88913
21494	720	3	3.089575516	7.06858	7.497
40859	1000	4	4.259818917	12.56637	14.25188
70489	1274	5	5.595062155	19.63495	24.58667
80262	1344	6	5.999999588	27.9955	28.27433
142723	1822	8	7.999999804	49.782	50.26548

While the smaller ones seem highly inaccurate, the circles were hand drawn and on such a small scale, there is a large margin for human error. Additionally, when I measured the 5 mm circle and the 4 mm circle again, the calculated diameters were more accurate than my previous measurements due to the paper soaking up and spreading the ink from the pen. In this case, the 6 mm and 8 mm circle data yield the most accurate results due to the decreased human error and higher precision from their increased size. The difference between the diameter and area calculated using the pixel/meter ratio and the known diameter and area calculated based on hand measurements is so slight to be negligible, thus confirming that 53544 pixel/meter ratio for the Nikon D7100 with an AF Micro Nikkor 200mm 1:4 D lens 40 inches away from the optic.

For further confirmation, I had my supervisor place a ruler inside the chamber and measure the width of a circle etched on the face of the optic as somewhere between 27 and 28 millimeters. I then took a picture of the optic from 40 inches away, focusing on the circle. I opened the image in ToupView, which measured the circle to be 1468 pixels, and used the 53544 Pixels/Meter ratio to calculate the circle at 27.4 mm across, which confirms that the pixel to meter ratio is accurate.

I then took a picture of the optic, processed it using ToupView and used this ratio to calculate the size of all of the particles on the optic. The full data sheet of the particles and the full size graph of the results can be found in the following document: LIGO-T1400467-v1.
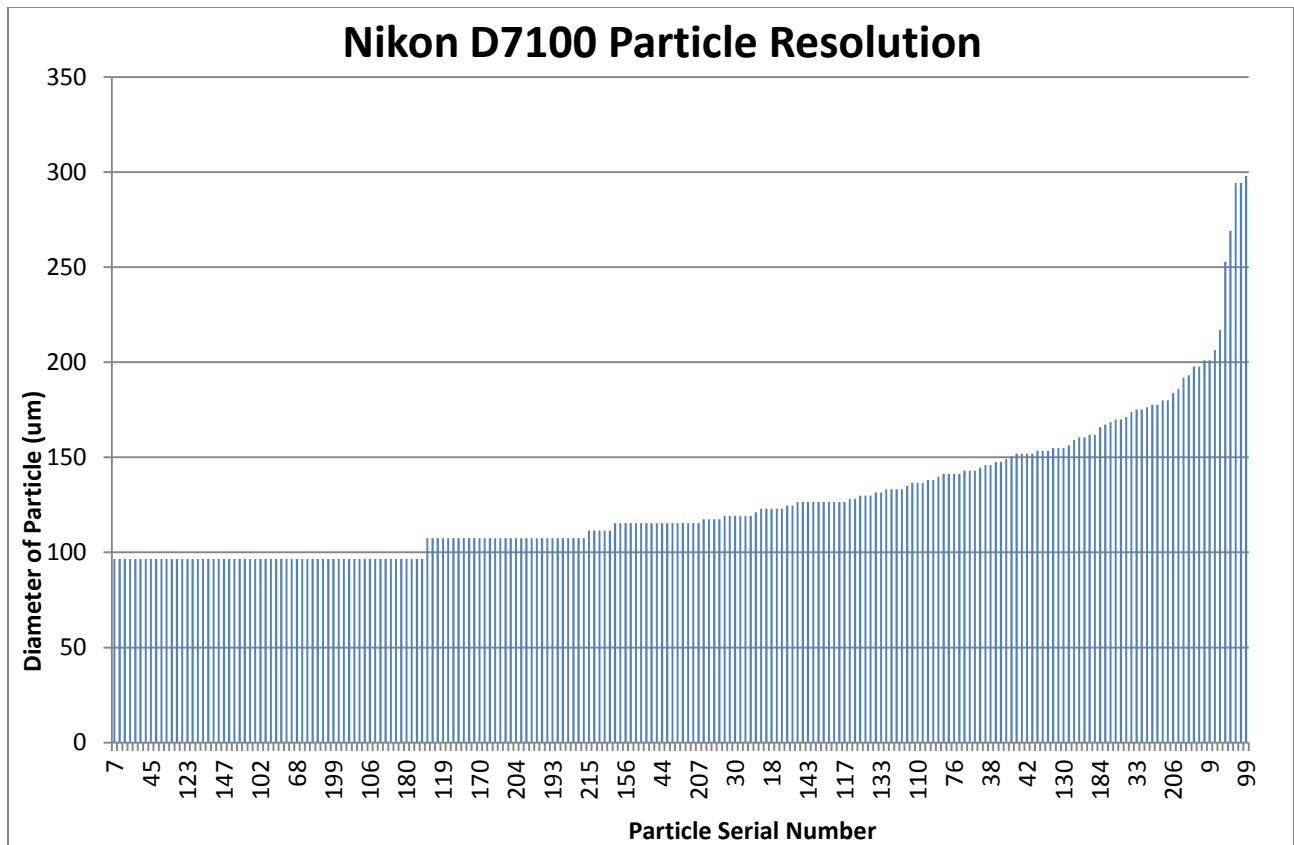
As is evident from the data, the particles did not actually begin resolving until around 130 microns; everything smaller than that simply appeared as the same size.

While this is a high resolution, it is evident from the graph that almost half of the particles were below this resolution threshold. Therefore, we are currently looking into purchasing a Nikon TC-200 or TC-201 teleconverter which will increase the magnification even further, which will in turn, increase the resolution of the image.

Looking Forward:

Once I receive the teleconverter, I will calculate the new resolution and determine the smallest particle the camera with teleconverter can resolve. With that information, I will determine whether or not further measures need to be taken to increase the resolution. However, in the mean time I will begin experimenting with MATLAB's image processing toolbox to explore what it is capable of and to establish which functions will be useful when later putting together a program to process the images and count the particles.