EE 475/575
Digital Image Processing
Project 6
Camera Calibration

Instructor: Dr. Helder

Date: 12/13/2019

Written By: Harsh Dubey

Partners: Lin and Gagan

The purpose of this project is to perform a camera calibration similar to what is done for precision imaging programs such as microscopy and satellite remote sensing. We will assume that our camera has a linear response with respect to radiance. That is, the camera output in digital numbers, or DN, is a linear function of the input radiance, L_λ, to the camera as follows

$$DN = b_{i,j} + g_{i,j}L_\lambda$$

where $b_{i,j}$ is the bias level of detector i, j with no input and $g_{i,j}$ is the gain of detector i, j. Thus, the task at hand is to estimate the gain and bias of every detector in the focal plane of the camera. In our case, that will include three spectral bands—red, green, and blue. You are to perform the following tasks:

1. Obtain the test camera and go to the SDSU Optics Lab. Set up the camera on the optical bench with the integrating sphere. Obtain at least three images with the lens cover on the camera; these will be used to estimate bias. Follow standard laboratory procedures to use the integrating sphere. Increase the output of the integrating sphere until detectors in the camera are operating at the upper end of their dynamic range without saturating (this can be estimated from the histogram of the image as displayed by the camera). Obtain at least three images at this intensity level; these will be used to estimate the gain of the detectors.

   Five images of the integrating sphere were obtained for bias and illumination level. Image label: 4917-4921, is the bias and from 4922-4926, is illumination.

   Table 1: Radiance scaler based on spectral band wavelength

Wavelength (nm)	**Radiance scale**
Red, 420-510	1.048
Green, 480-580	1.525
Blue, 570-640	1.947

2. Use the bias images to estimate the bias level of each detector, and the noise of each detector, for each spectral band. To get an understanding of the distribution of these values, histogram the detector bias levels and noise levels for each spectral band. From these, find the location and value of the noisiest and quietest detector in each band, as well as the average bias and noise levels.

   The noisiest and the quietest detector was found by using find() and min/max() function on the std. deviation of the 5 images. Furthermore, the average bias level of each detector was computed by calculating the average of each pixel's location over the 5 images obtained. Noise was estimated by calculating the standard deviation of each pixel location over the 5 obtained images.
   Below are the histograms for each band with average bias levels, Fig.1,2,3 and histogram of noise at each band, Fig. 4,5,6.

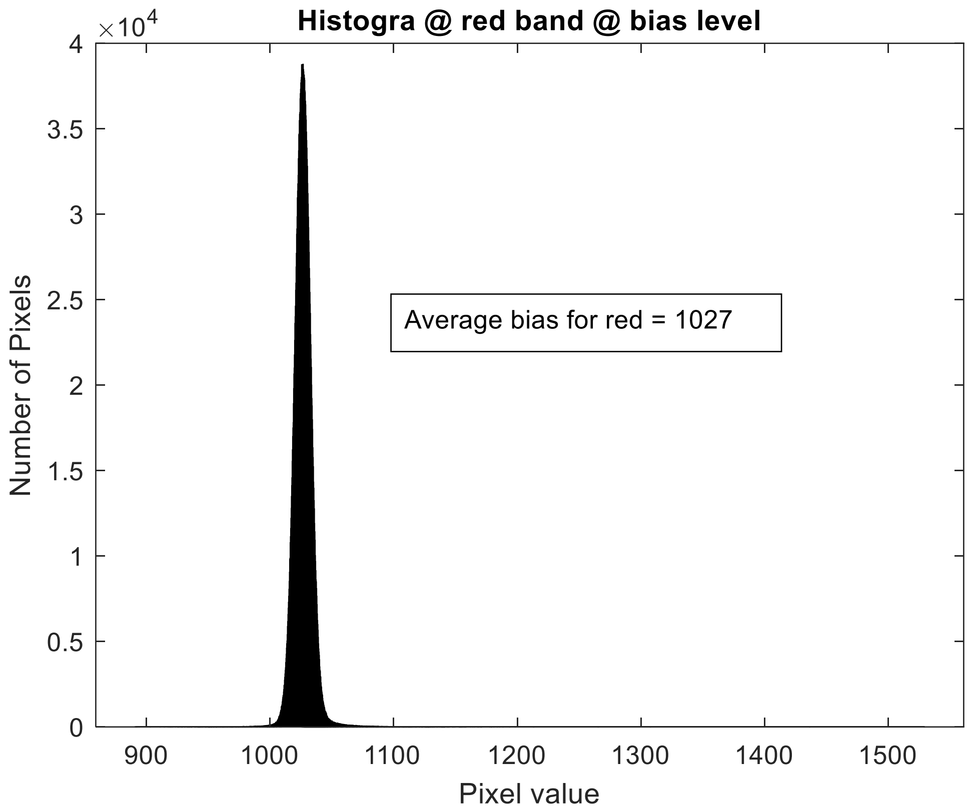

Figure 1: Histogram for red band @ bias level

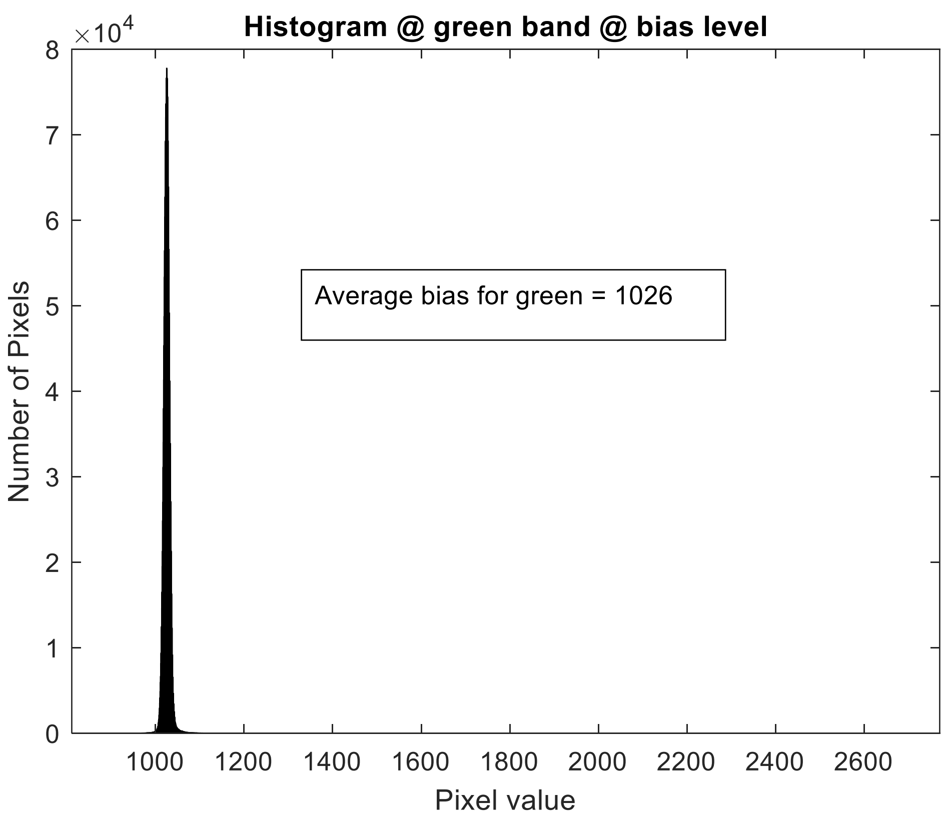

Figure 2: Histogram for green band @ bias level

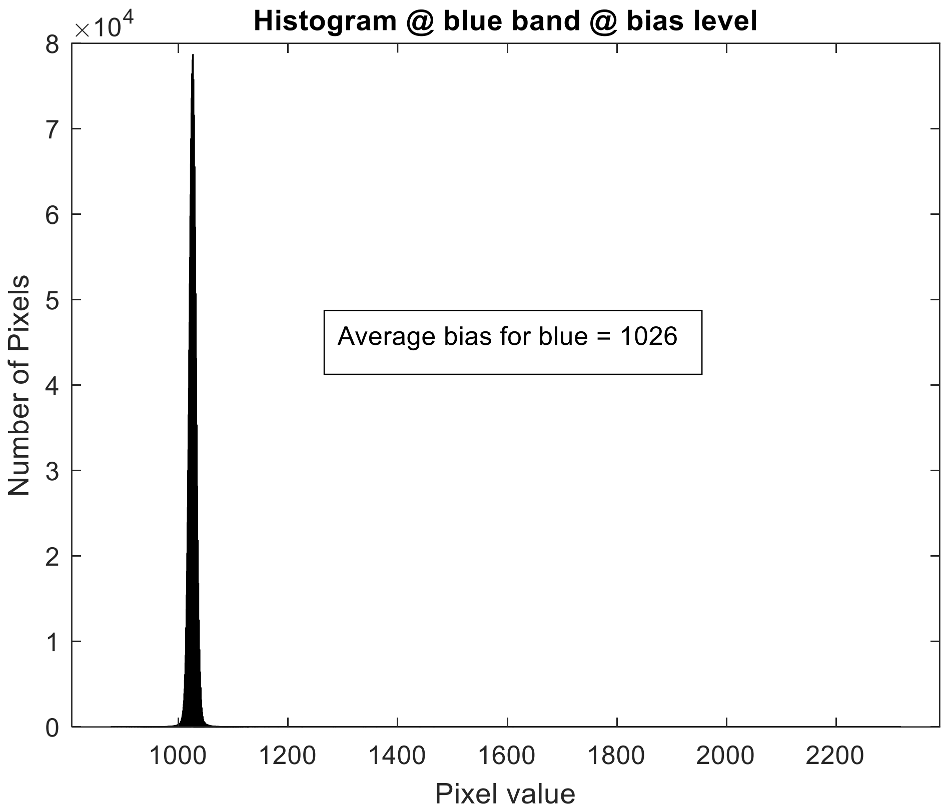

Figure 3: Histogram for blue band @ bias level

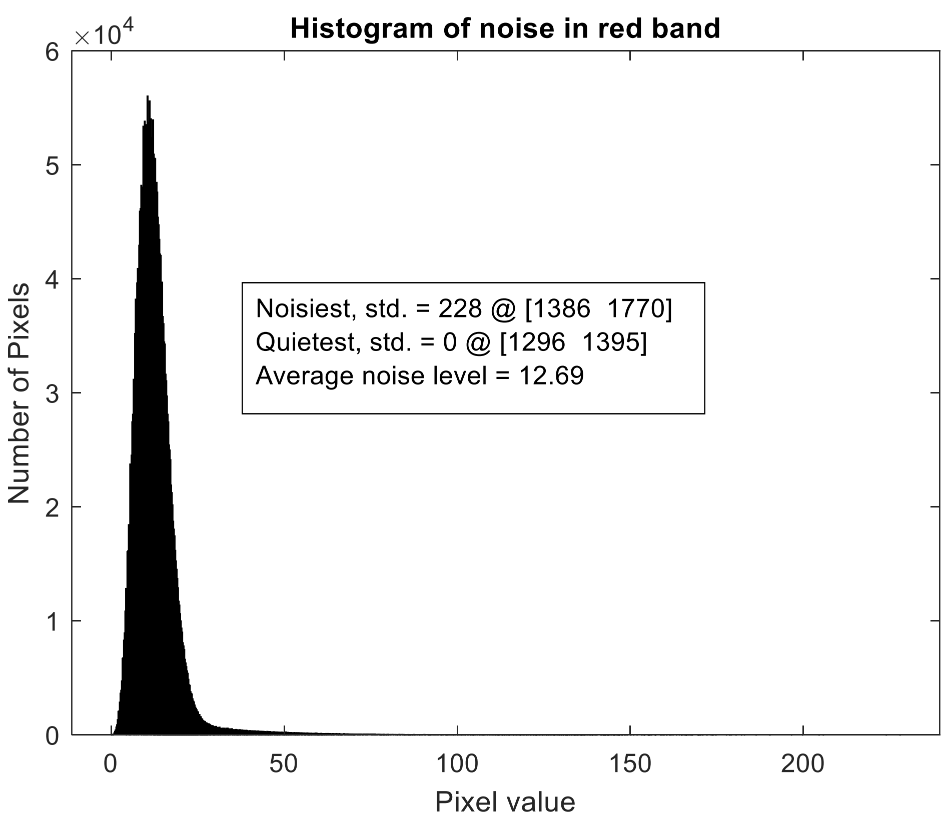

Figure 4: Histogram of noise @ bias in red band

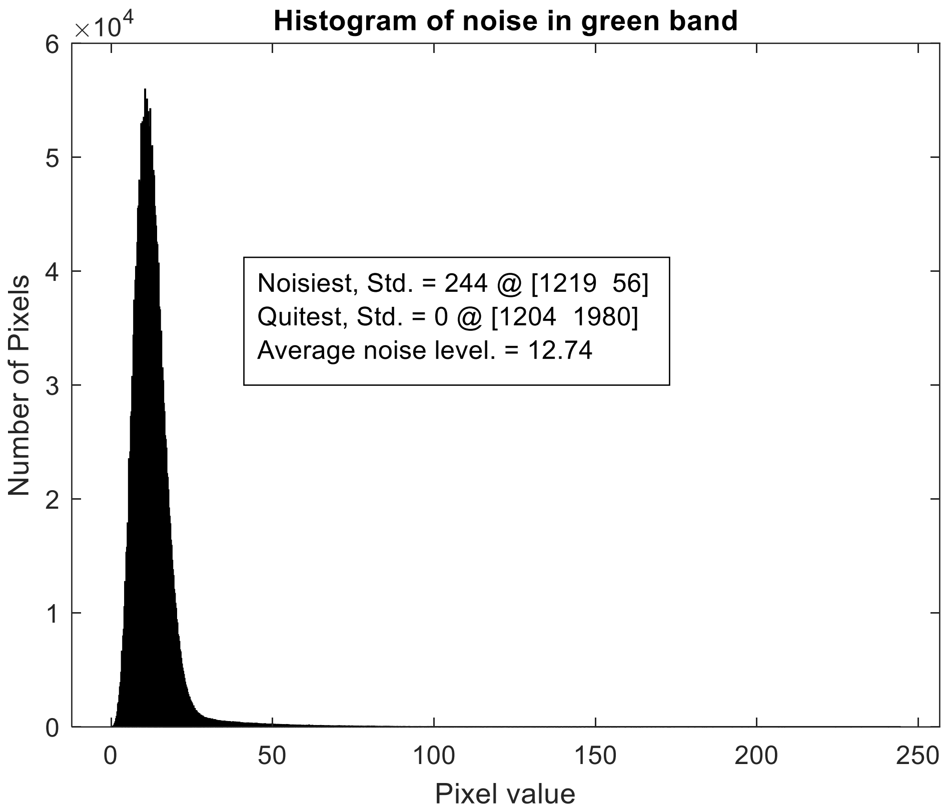

Figure 5: Histogram of noise @ bias in green band

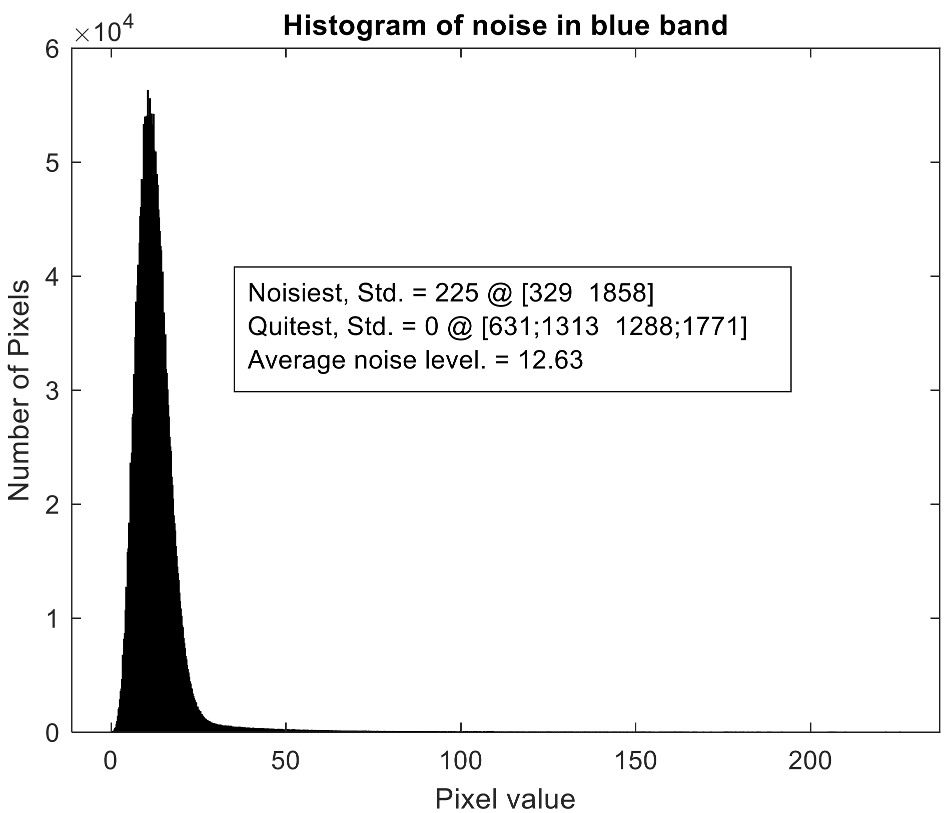

Figure 6: Histogram of noise @ bias in blue band

3. Use the integrating sphere images to estimate the gain of each detector, and the noise level of each detector, for each spectral band. To get an understanding of the distribution of these values, histogram the detector gains and noise levels (expressed as % of signal level; bias removed) for each spectral band. From these, find the location and value of the noisiest and quietest detector in each band as well as the highest and lowest gain detector in each band. What is the accuracy and precision of your calibration?

   The gain of each detector was estimated by calculating the average value of each pixel location from the 5 obtained images. Noise estimation with respect to signal percentage, was calculated by dividing the standard deviation of the image with the signal level. Signal level was obtained by subtracting the offset at bias from the mean at illuminated level.

   In this project, precision is how our image data remains on the approximately around similar values but has a + or - offset from the mean value. Example, a gunshot is scattered around the aim. In our project, it can be described by the average of standard deviation of each image. Accuracy is how our experiment result suffice with an institutional measurement, in our case is the NIST calibration transfer uncertainty from the integrating sphere. Also, the uncertainty can be caused by lens edges i.e. the lens edge will be less bright than the center and the distance of lens from the sphere will also cause uncertainty. However, NIST information is a huge factor in accuracy because the radiance scaler came directly from the integrating sphere measurement.

   Measurement was done at 500 nm, the uncertainty of radiance at this wavelength is ±1.7 %. Our accuracy cannot be smaller than this value. Also, the noise in the image must be accounted for, which will increase the uncertainty and affect the accuracy.

   Precision was calculated by finding the mean of the noise in each band. In red band precision was found out to be 3.15%, in green band it was found out to be 2.99% and for blue band it was found out to be 5.35%.

   Below is the highest and lowest detector output at illumination and the histogram in each band, Fig. 7,8,9. Also noise histogram and noisiest and quietest detector at illumination, Fig. 10,11,12.

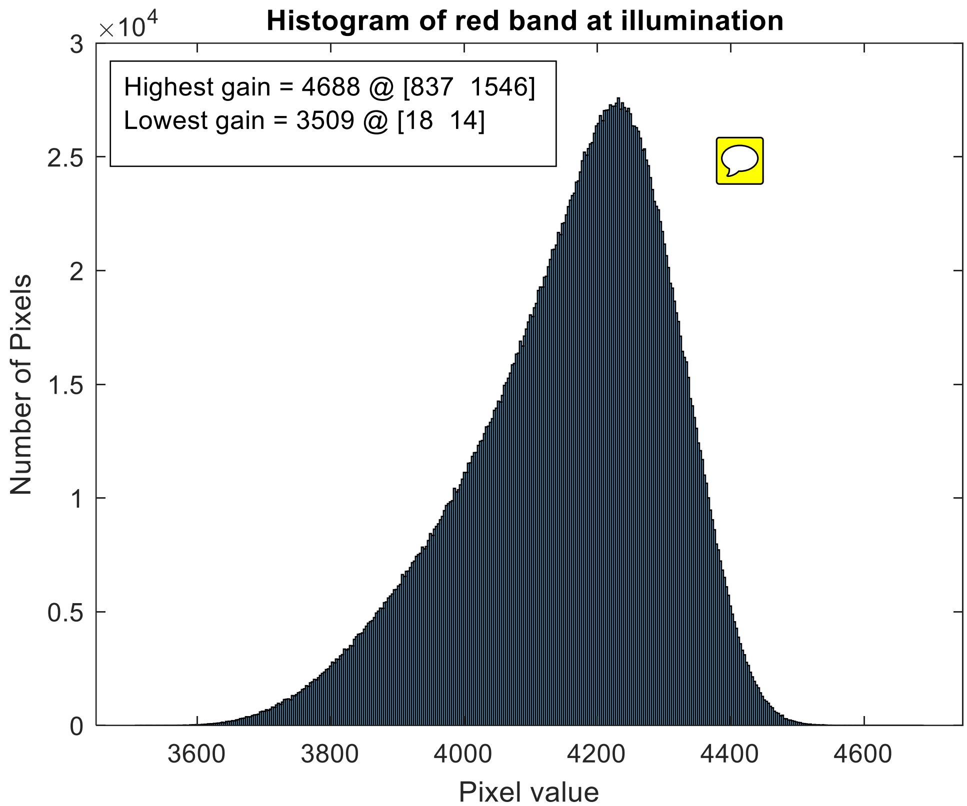

Figure 7: Histogram of red band at illumination

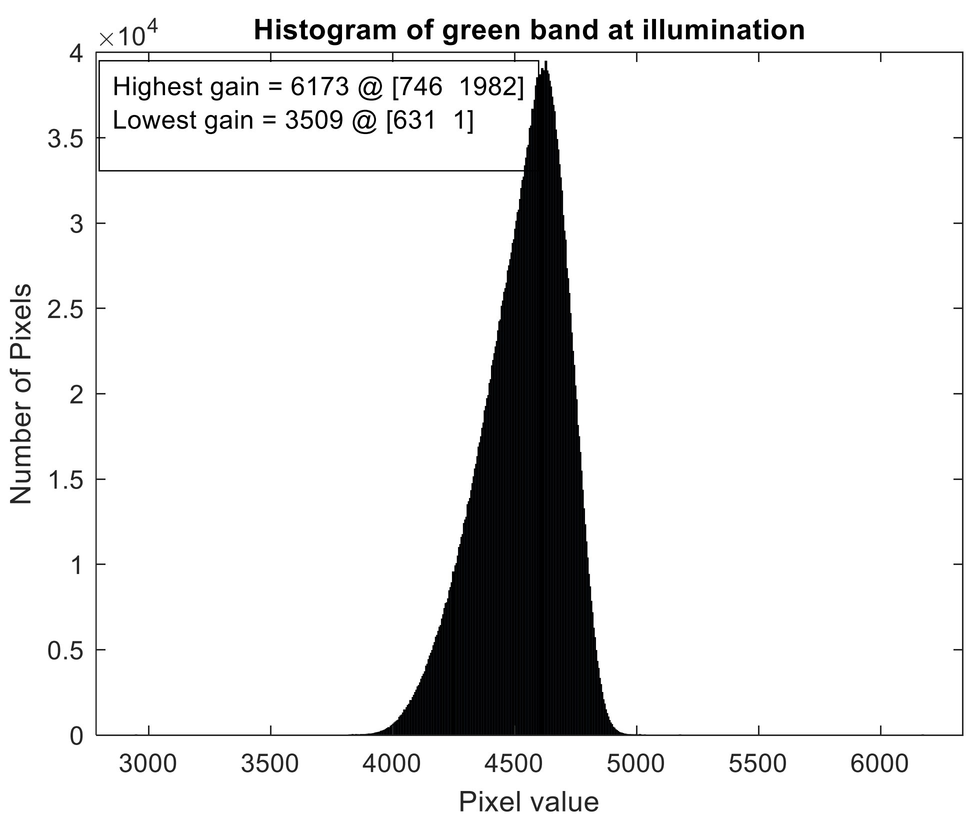

Figure 8: Histogram of green band at illumination

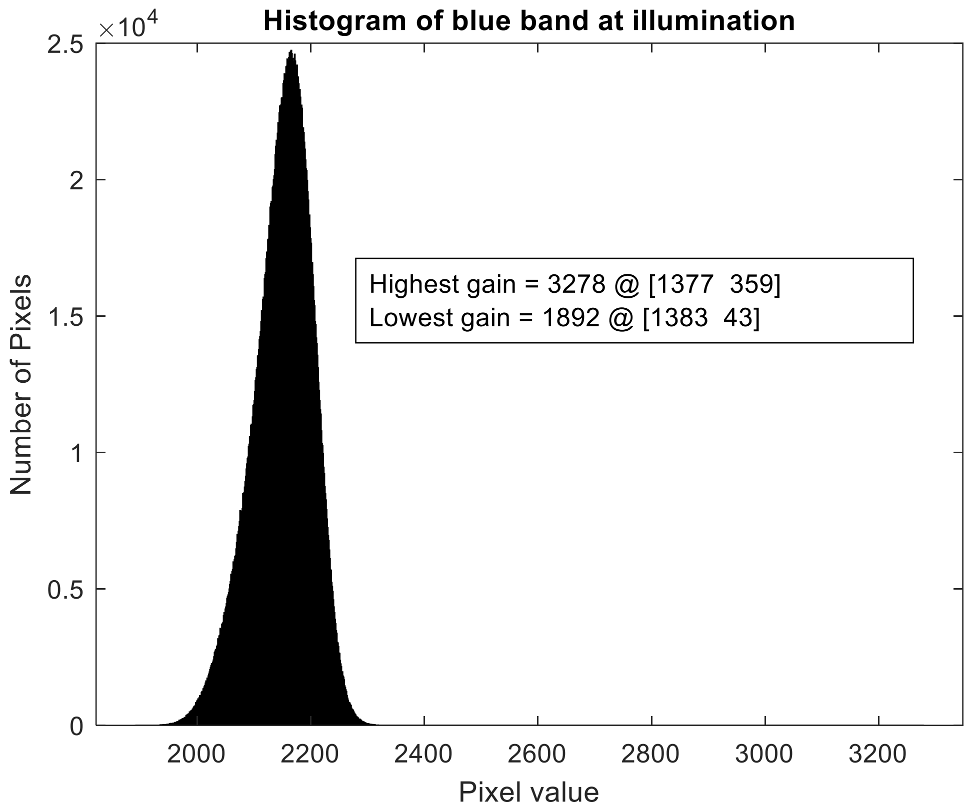

Figure 9: Histogram of blue band at illumination

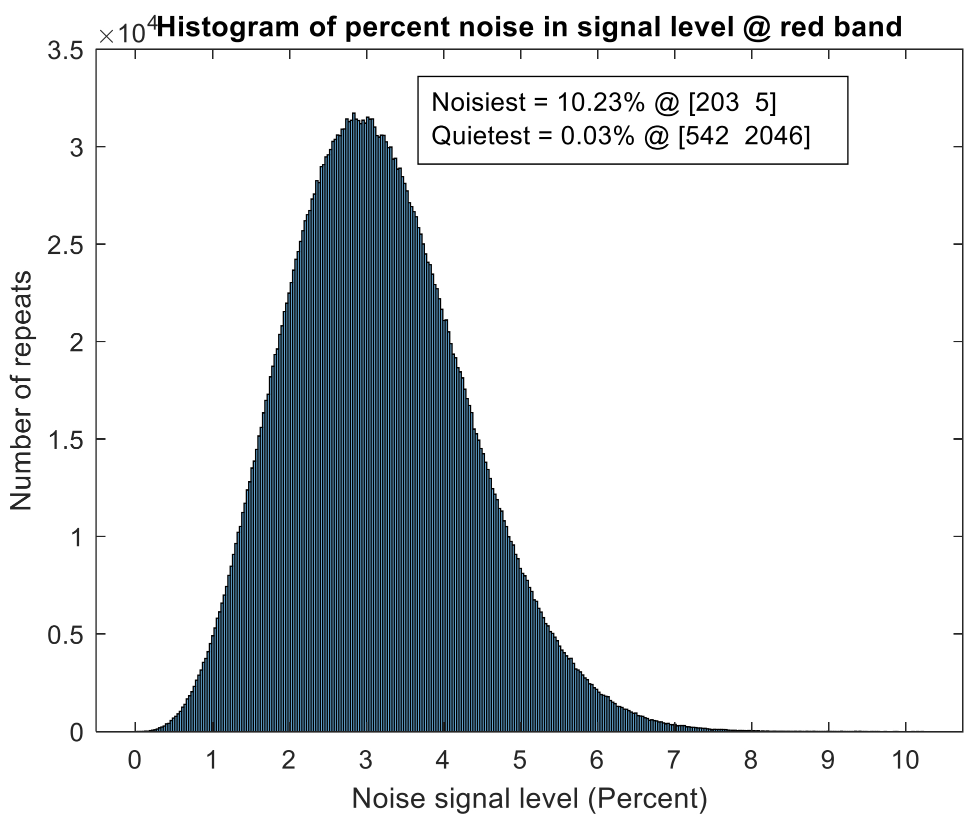

Figure 10: Histogram of percent noise in signal level @ red band

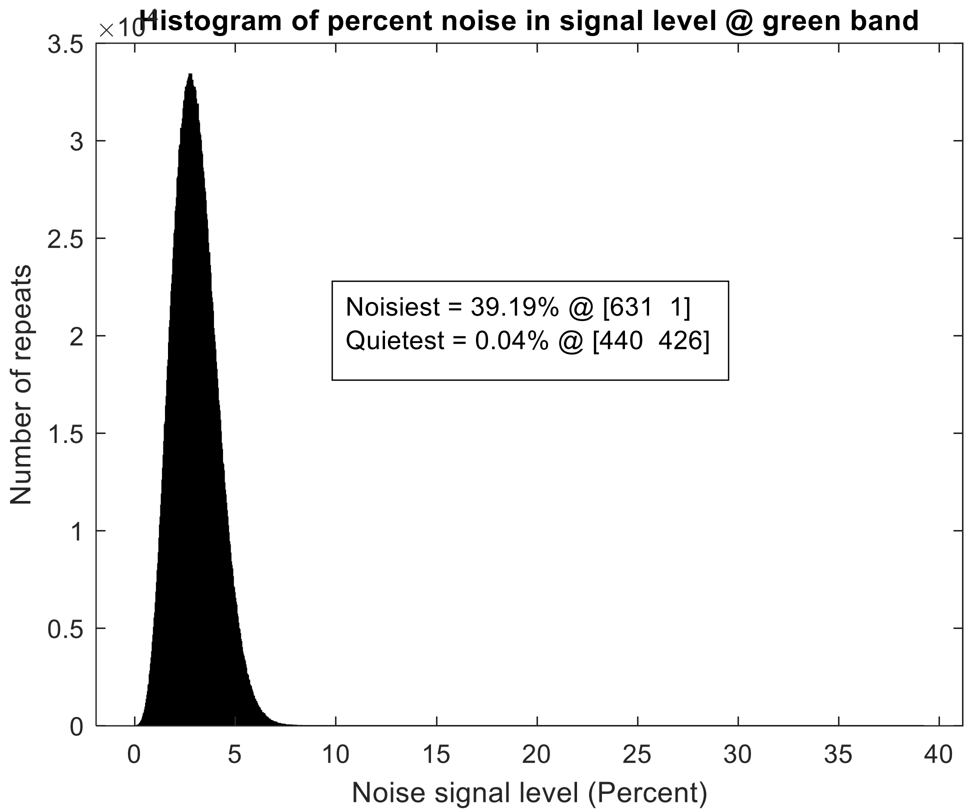

Figure 11: Histogram of percent noise in signal level @ green band

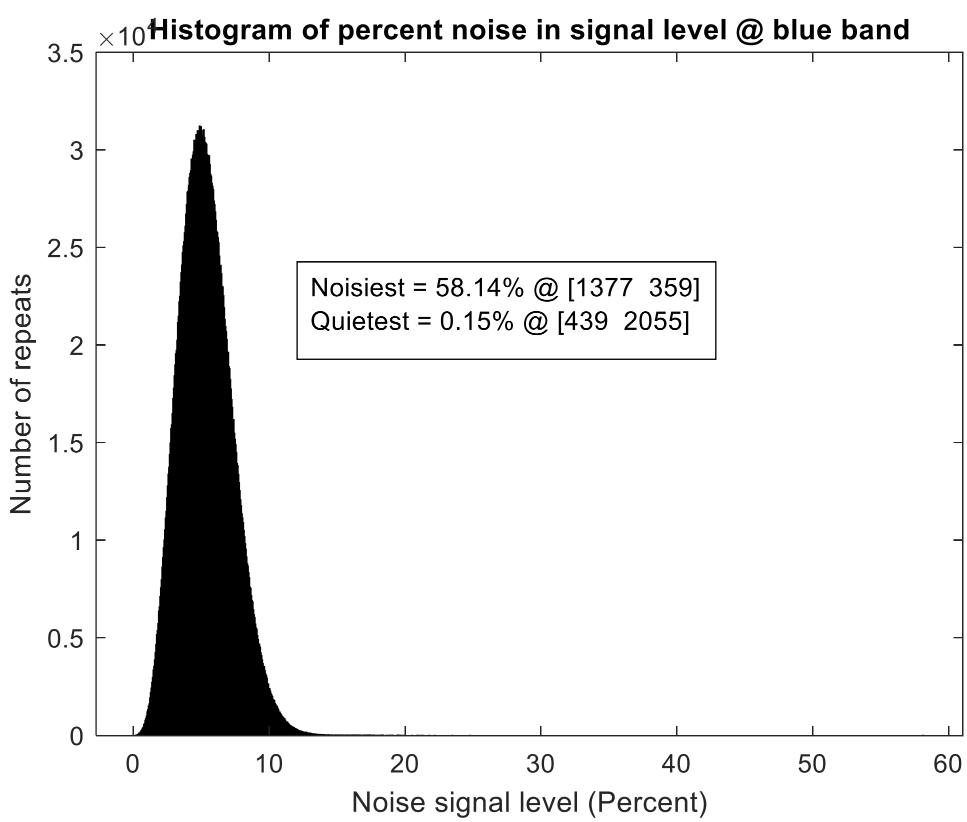

Figure 12: Histogram of percent noise in signal level @ blue band

4. Once you have obtained your camera calibration model, apply it to the test image provided for this project. In this case, use the scaled radiance values chosen in class. Show the uncalibrated and calibrated images next to each other (make sure they are scaled similarly) and describe the improvement in a qualitative manner. Estimate the noise level in each band before and after calibration. Did calibration reduce the noise level?

   Hint: Be sure to look at the calibration images. Stretch them appropriately so you can see the details.

   Using data from table 1, average of all detectors' bias and gain and eq. 1, eq.2 and eq.3 the uncalibrated image is calibrated assuming linear response for all detectors. The unit of calibrated image is in radiance.

   DN = g*radiance_scale+b; b=bias (1)

   g = (mean(detector_gain)-mean(detector_bias)) ./ radiance_scale; (2)

   Calibrated_radiance = (DN_Uncalibrated - b) ./ g; (3)

The uncalibrated image of Chris has a higher gain in green band as compare to the red and the blue band.

After calibration, the original color image which was in digital number was later redistributed to radiance unit in the form of floating-point numbers. The color bands of the image were then cross-calibrated because now all the three bands are in the similar scale. Our computer uses 4 bytes to store float and 2 bytes to store. For the purpose of using less memory, the unit was scaled by 2000 to save the pixel dynamic ranges in integer.

The noise level before and after calibration for each color band was computed by cropping a smooth homogenous region on the image. Later the standard deviation was obtained of the region of interest. A region on the checkerboard was selected for this calculation.

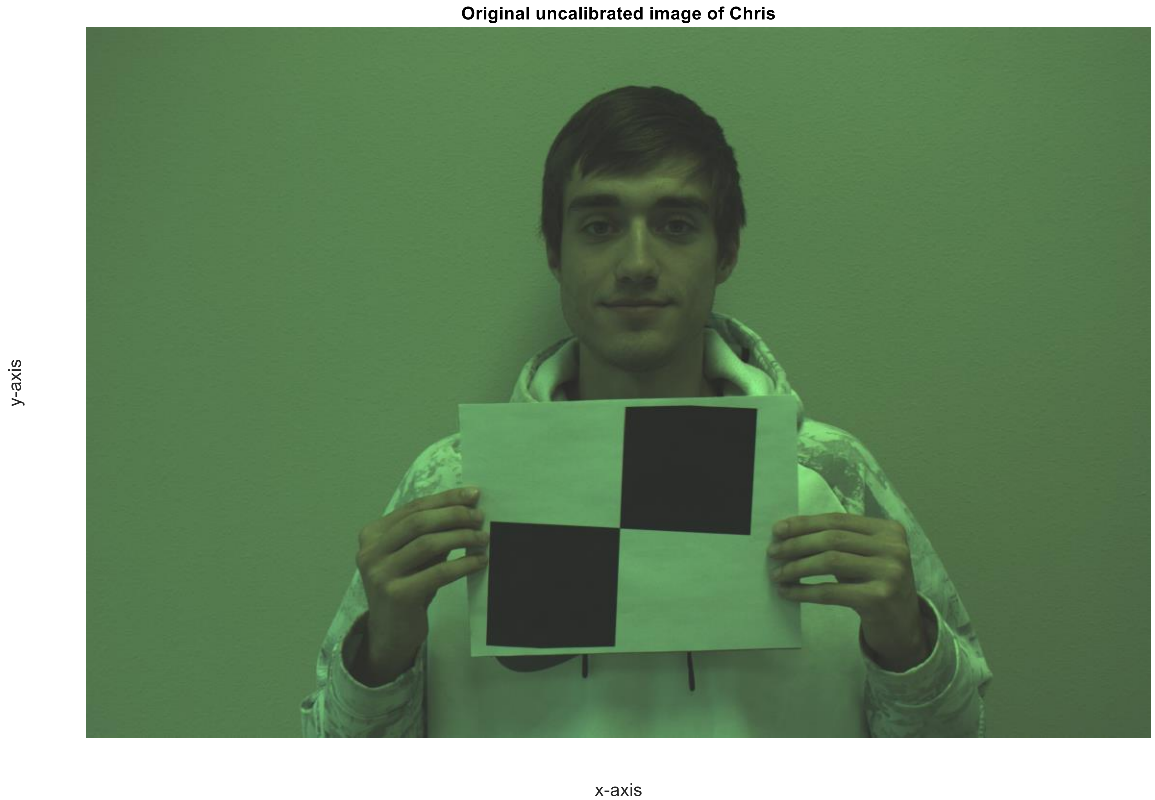

Figure 13: Original uncalibrated image of Chris

Figure 14: Calibrated image of Chris

Table 2: Noise estimation before and after calibration

Standard deviation before		**Standard deviation after calibration and scaled by 2000**	
Red	315.53	Red	223.72
Green	498.32	Green	305.84
Blue	315.99	Blue	339.26

The noise in the red bad and the green band was reduced by calibration but not in blue band.