2d Lt Aaron Bonner

Non-Linear Photodetector Calibration

1. Prompt

Use the 1000ms and 2000ms sky calibration data together with the 1ms moon data (looking away from the moon to find pixels where only the offset is present) to provide the necessary data to use the NLS NUC algorithm. Also implement the SANUC algorithm and compare the values for the 1 second photocount per pixel. This is the radiation that is falling on the aperture and getting focused into each cell so take the number of photons per second and divide by the area of the aperture to arrive at a radiant power in terms of watts per square meter. How does this compare to the rough value of 1000 watts per square meter delivered by the sun?

2. Data Used

The data used for this module was provided and is broken down into three major sets. The first two datasets consisted of calibration data captured with an exposure time of $1000ms$ and $2000ms$. The $1000ms$ dataset contained 102 images of resolution 2000x2000, and the $2000ms$ dataset contained 135 images of the same resolution. The first frames of each dataset are shown in Figure 1.

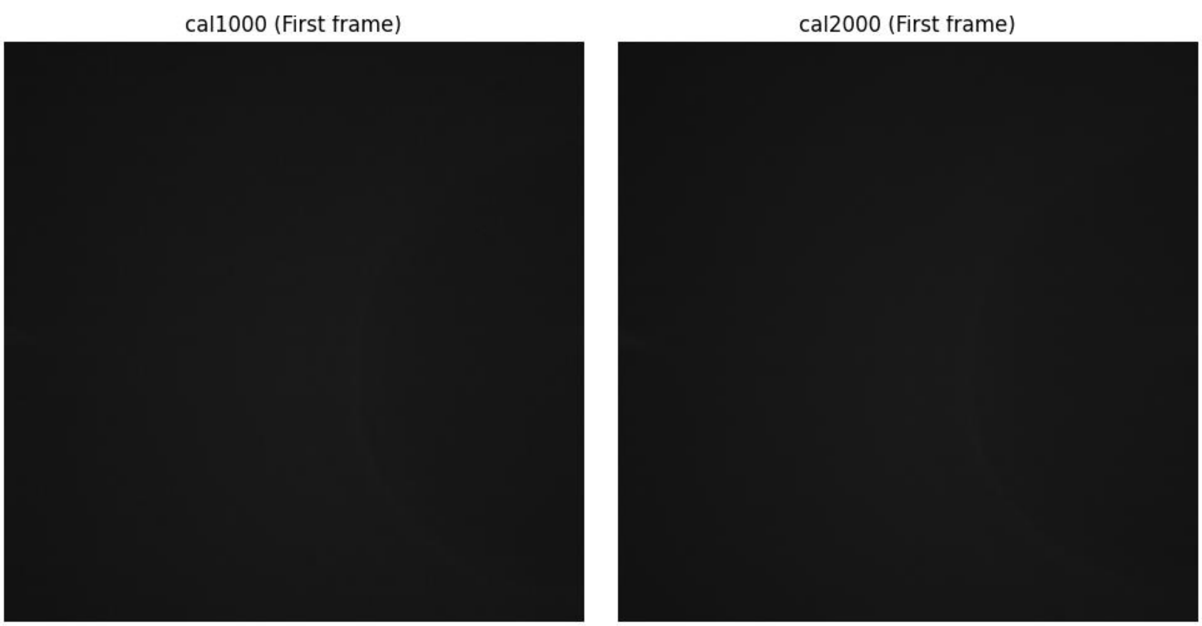

Figure 1. First frame of the two calibration datasets.

The third dataset provided contained images of the moon with a $1ms$ exposure time. This dataset consisted of 135 images with a resolution 2000x2000. The first frame of the moon dataset is shown in Figure 2, with the red box indicated the area used to calculate the offset value in later calibration.

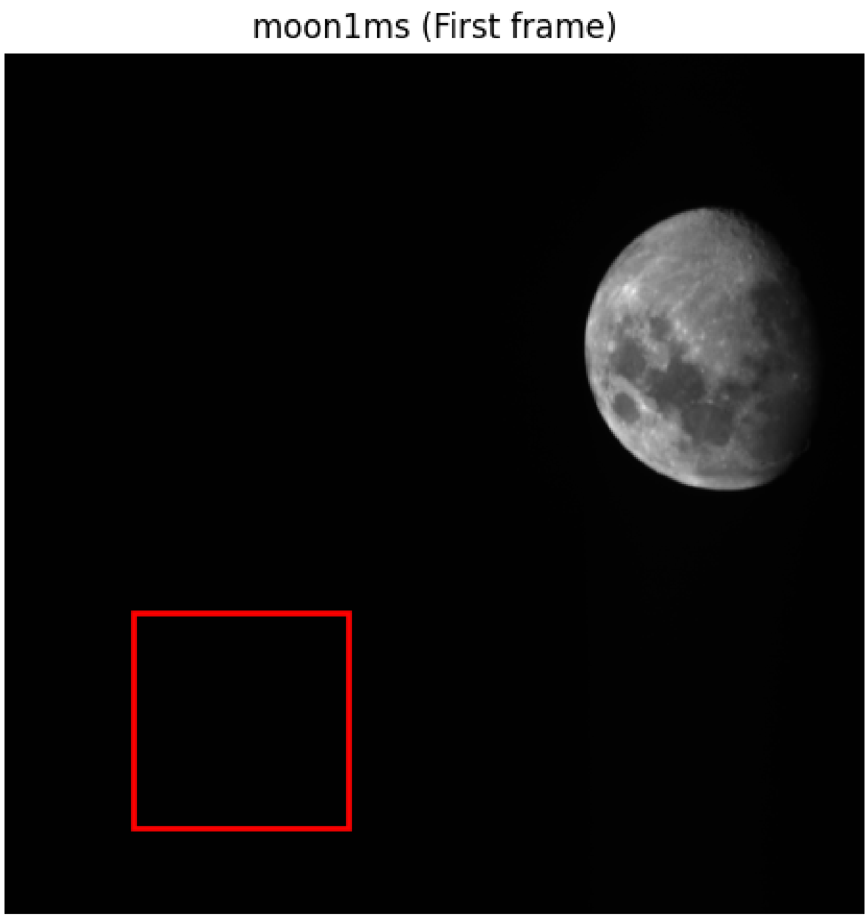

Figure 2. The first frame of the moon data used for offset calculation.

3. NLS NUC Calibration

To start the NLS NUC calibration process, first the offset was found in the moon data by taking the mean of the region show in the red box found in Figure 2. This resulted in a calculated offset of 53.547 digital counts for the photodetector. Then, the next steps required for NLS NUC algorithm are followed according to the process described in the paper "Non-linear Statistical Photocalibration of Photodetectors without Calibrated Light Sources" by Dr. Stephen Cain. Following the calculations of the means of the two calibration datasets, the estimate $\hat{g}$ was calculated. This estimate is defined by the parameter g, which is show in Equation (3.1).

$$g(x,y) = \alpha(x,y)K(x,y) \tag{3.1}$$

Where $\alpha(x,y)$ is the non-linear gain factor of a given pixel and $K(x,y)$ is the number of photons at a given pixel. Solving for the estimate results in Equation (3.2).

$$\hat{g}(x,y) = \arg\min\left(\frac{E[D_2(x,y)-O]}{E[D_1(x,y)-O]} = \frac{(1-e^{-2g(x,y)})}{(1-e^{-g(x,y)})}\right)^2 \tag{3.2}$$

Where the left side of the internal equation is the ratio of the means of the two datasets, and the right side is the Moment Generating Function of a Poisson random variable. For the programmatic implementation of this calculation, the total number of values required to calculate was four million, and so the process was broken into chunks of ten thousand to prevent computational overload. Following the calculation of $\hat{g}$, the saturation $C(x,y)$ was calculated using Equation (3.3).

$$C(x,y) = \frac{D_1(x,y)-O}{(1-e^{-g(x,y)})} \tag{3.3}$$

Next, the data was converted from a linear format to a non-linear format using the equations show in Equation (3.4).

$$\begin{aligned} H_1 &= -\log(1-(D_1(x,y)-O/C(x,y)) \\ H_2 &= -\log(1-(D_2(x,y)-O/C(x,y)) \end{aligned} \tag{3.4}$$

From the new datasets H_1 and H_2 the means and variances were calculated and the value of $\alpha(x,y)$ was calculated using Equation (3.5).

$$\alpha(x,y) = \frac{\sigma_{H_2}^2(x,y) - \sigma_{H_1}^2(x,y)}{\bar{H}_2(x,y) - \bar{H}_1(x,y)} \tag{3.5}$$

Following the calculation of $\alpha(x,y)$, the estimate for the number of photons in the $1000ms$ dataset was found using Equation (3.6).

$$K(x,y) = \frac{H_1(x,y)}{\alpha(x,y)} \tag{3.6}$$

The values of $K(x,y)$ where then summed, resulting in a calculated photon count of $1.780 * 10^8$ photons for the NLS NUC Algorithm.

4. SANUC Calibration

Starting again with the raw datasets, the SANUC Calibration algorithm was implemented. First, the mean of the two datasets was calculated with the offset subtracted. Then, the variance was calculated. Next, the linear gain of the detector was calculated with Equation (4.1).

$$G(x,y)=\frac{\sigma_{D_2}^2(x,y)-\sigma_{D_1}^2(x,y)}{\bar{D}_2(x,y)-\bar{D}_1(x,y)} \tag{4.1}$$

The value of K was then found using Equation (4.2) and the median of $G(x,y)$.

$$K(x,y)=\frac{\bar{D}_1(x,y)-\bar{D}_2(x,y)}{G(x,y)} \tag{4.2}$$

Similar to the NLS NUC algorithm, the values of $K(x,y)$ were then summed resulting in a photon count of $1.403 * 10^8$ for the SANUC Algorithm.

5. Power Comparison to Direct Sunlight

With the number of photons calculated using each photo calibration algorithm, the next step was to calculate the total power on the detector. For this optical system, the size of the aperture was given as $7cm$ and the size of each pixel being $3.5\mu m$. To convert from photons to power, Equation (5.1) was used.

$$E=\frac{hc}{\lambda} \tag{5.1}$$

Where h is Plank's Constant and c is the speed of light. The wavelength of $500nm$ was used to approximate the emission spectrum of the sun. Following the calculation of the power, it was then divided by the area of the aperture to convert the units into Watts per meter squared. For the NLS NUC algorithm, a power density of $1.449 * 10^{-8}\frac{W}{m^2}$ was calculated, and for the SANUC algorithm a power density of $1.839 * 10^{-8}\ \frac{W}{m^2}$ was found. Although these values are far from approximately $1000\frac{W}{m^2}$ at the Earth's surface under direct sunlight, keeping in mind that these values are from $1000ms$ sky data, the low value makes sense.