JMAPS Technical Memoranda 10-04

Non-Linearity Centroiding Error Analysis

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ABSTRACT

We analyze the effect of a non-linear detector response on JMAPS centroiding error. By varying the simulated quantum efficiency in JSIM as a function of photon counts, we can determine the centroiding error as a function of the standard deviation of the difference in photon counts between a linear and non-linear responses. We calculate the x, y, and overall centroiding error as function of magnitude, as well as the centroiding error caused by non-linearity by averaging results from 72 simulated observations of stars in random sub-pixel locations for each magnitude. To further examine the effects of sub-pixel location on centroiding error and non-linearity, we simulate centroiding errors with non-linearity as a function of magnitude for four distinct sub-pixel locations.

1. Methodology and Data

1.1. Method 1

Understanding non-linearity in the JMAPS detector is critical for JMAPS error analyses. Using JSIM, we create a parabolic curve for the quantum efficiency (QE) of the detector as a function of photon counts. We vary the maximum QE from 0.0 to 1.5 with 100 iterations. Figure 1 shows an example of these curves with a maximum QE of 1.2. We then compare the simulated non-linear response curve to a linear response curve, an example of which is shown in Figure 2. Then, subtracting the linear response from the non-linear response, we are left with the photon count difference as a function of photon counts, as shown in Figure 3. Finally, using JSIM, we calculate the centroiding error on a 20s exposure for an F5 star, and plot the resulting errors as a function of the standard deviation of the photon count difference for each iteration, shown in Figure 4. The centroiding error as a function of the standard deviation of the photon count difference tends to be a linear relationship, varying slightly from simulation to simulation.

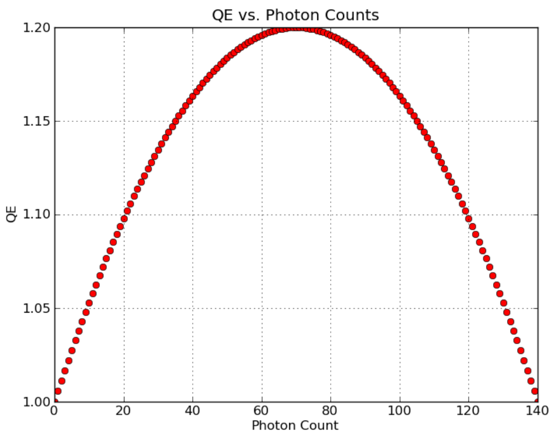

Figure 1

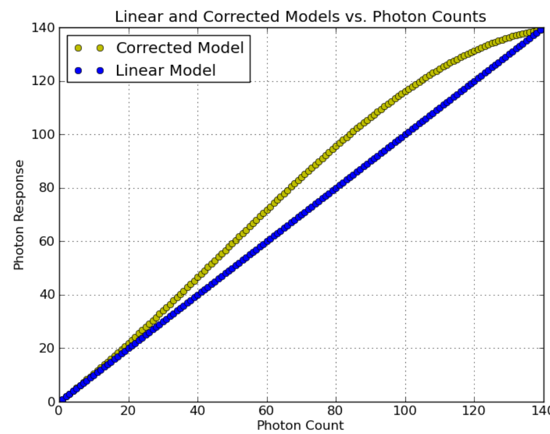

Figure 2

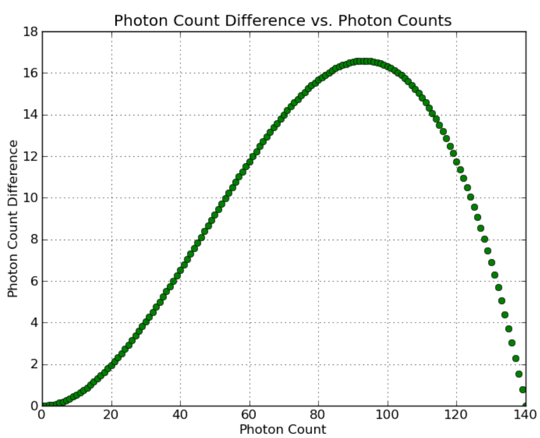

Figure 3

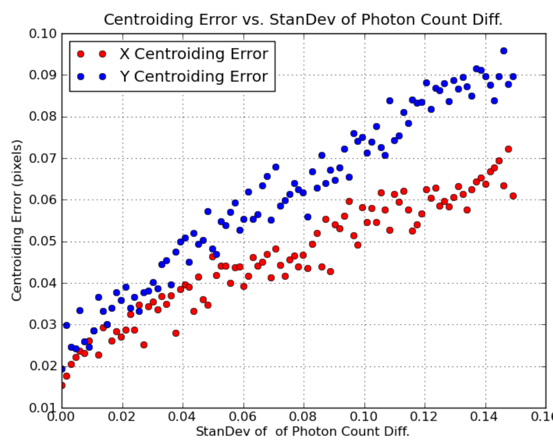

Figure 4

1.2. Method 2

To further understand the effects of magnitude and non-linearity, more simulations were conducted using a parabolic QE function, like the one shown in Figure 1, only over 500,000 photons, which is the top of the dynamic range for stars before saturation. The centroiding error caused by non-linearity is determined by subtracting the centroided x and y values with a linear response from the x and y centroided values with a non-linear response. For linear responses as well as non-linear responses with maximum QE's of 1.01, 1.1, and 1.3, 72 observations of a single star with a random sub-pixel location were simulated for magnitudes 8-13 in 0.2 magnitude increments. The mean x and y centroiding errors as a function of magnitude are shown in Figures 5 and 6. The mean total centroiding error with non-linearity as a function of magnitude and the mean centroiding error resulting only from the non-linearity as a function of magnitude are shown in Figures 7 and 8. The x-y mean centroiding error scatter plot as a function of magnitude is shown in Figure 9. To more clearly show the smaller features, Figures 7-9 are replotted with different limits in Figures 10-12.

To further examine the role of sub pixel location in the relationship between magnitude and centroiding error, more simulations still were conducted. The centroiding error resulting from non-linearity as well as the x y centroiding scatter plots as a function of magnitude for both maximum QE's are shown in Figures 13-16. These plots show the errors for four distinct sub pixel locations in (x,y) coordinates: (0,0), (0,0.5), (0.5,0), and (0.5,0.5).

2. Analysis

That centroiding error caused by non-linearity decreases as magnitudes become dimmer agrees with the manner in which the non-linearity was applied. The effect of the non-linear response diminishes with fewer photons, and thus stars with dimmer magnitudes generating fewer photons will cause less centroiding error from the non-linearity. The hump in the middle of the centroiding plots can also be explained by the application of the non-linearity. At the highest and lowest photon counts, the effects of non-linearity are minimal. Thus, for brighter stars with higher photon counts, the non-linearity will cause less centroiding error than for slightly dimmer stars with fewer photon counts where the effects of non-linearity are the greatest. The spike at the very brightest magnitudes can be explained by sub-pixel locations, as shown in Figures 13 and 14. Depending on the sub-pixel location, photons may or may not fall into nearby pixels, changing the effect of non-linearity on the pixel in question as well as on adjacent pixels. Figures 13 and 14 show that for some sub-pixel locations, the brightest magnitudes do not generate more non-linear centroiding error, while for other sub-

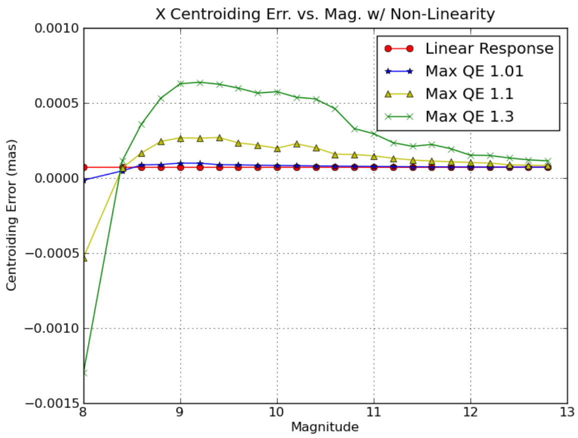

Figure 5

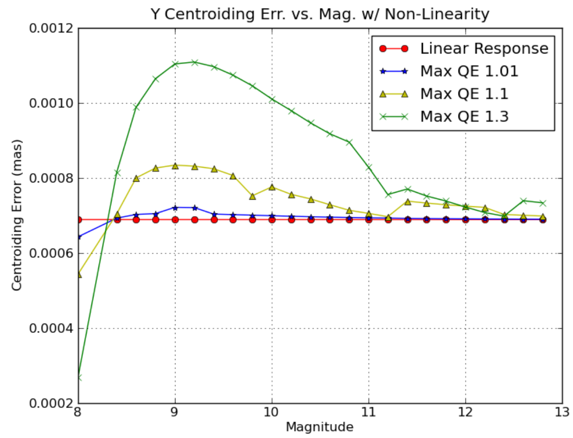

Figure 6

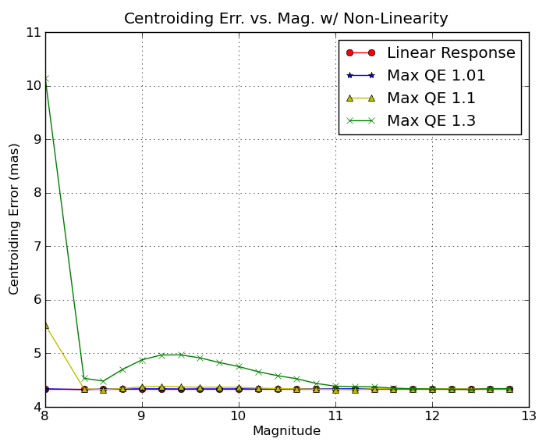

Figure 7

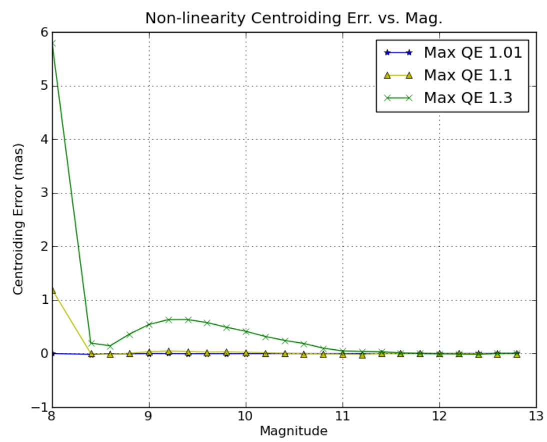

Figure 8

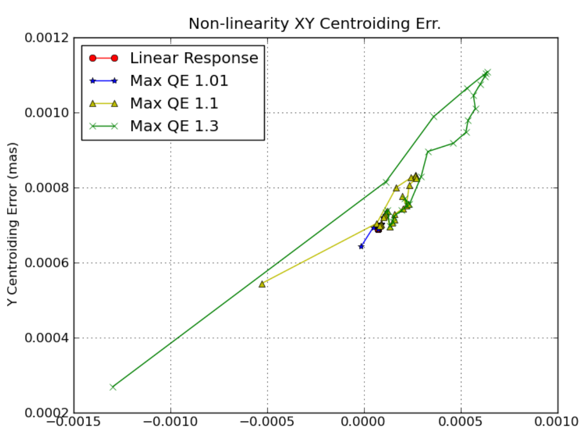

Figure 9

Note: Each point represents data from the average of 72 random sub pixel locations for a given magnitude from 8-13 in 0.2 magnitude increments.

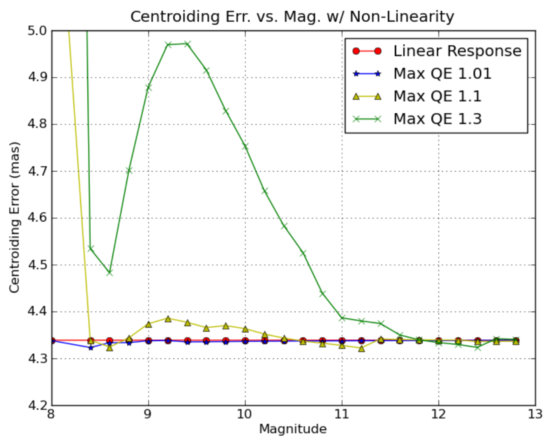

Figure 10

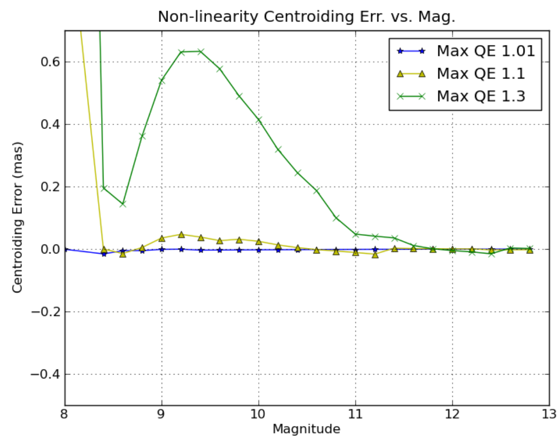

Figure 11

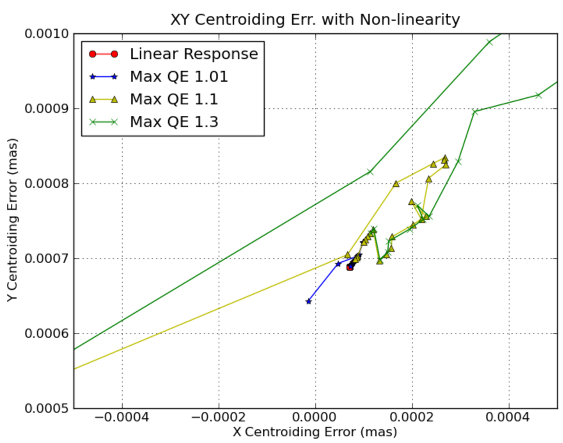

Figure 12

Note: Each point represents data from the average of 72 random sub pixel locations for a given magnitude from 8-13 in 0.2 magnitude increments.

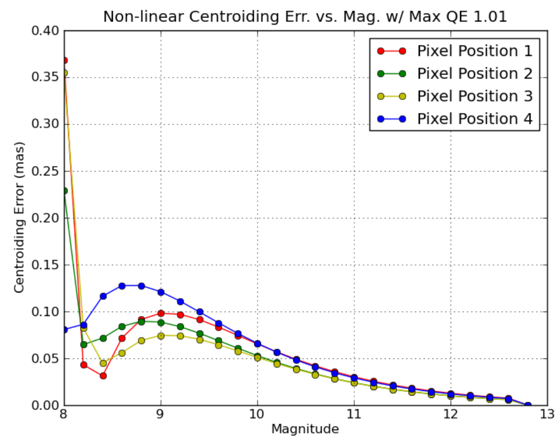

Figure 13

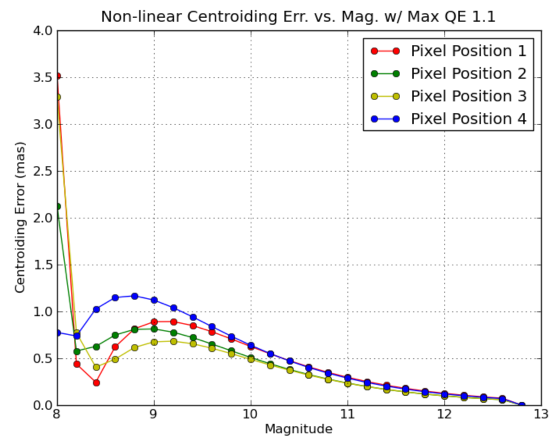

Figure 14

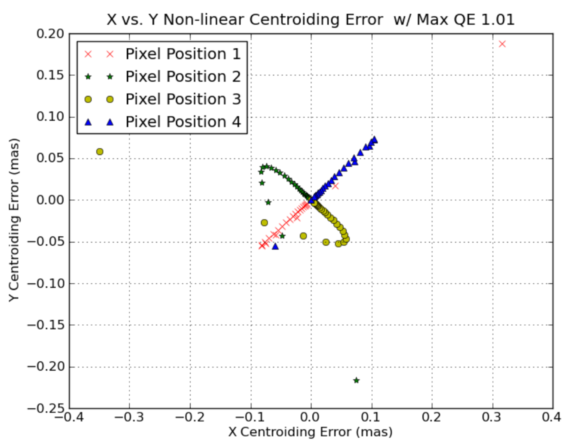

Figure 15

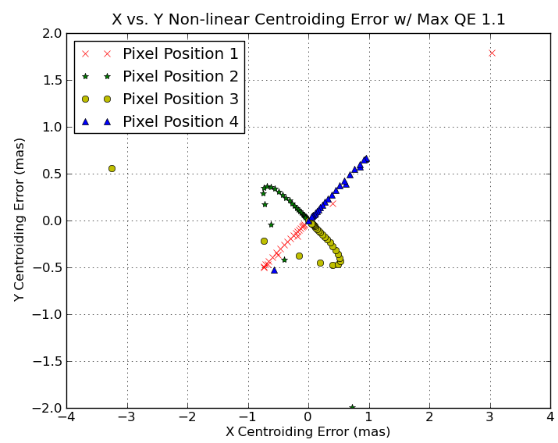

Figure 16

Note: The sub-pixel locations for the above Figures are (0,0), (0,0.5), (0.5,0), and (0.5,0.5) for Pixel Positions 1-4 respectively. In Figures 7 and 8, each mark represents a magnitude from 8-13 in 0.2 magnitude increments.

pixel locations, they do. Pixel position 4 is (0.5,0.5) in pixels, i.e. at the center of a pixel. As the photon counts increase, the detector response becomes closer to linear and the effects of non-linearity on centroiding decrease. However, the other pixel locations, (0, 0), (0.5, 0), and (0, 0.5), all border other pixels, causing the center of the applied PSF to land on surrounding pixels. This spread over a few pixels decreases the high photon counts at bright magnitudes per pixel, increasing the effects of non-linearity and corresponding centroiding error.

3. Summary and Conclusions

We simulate non-linearity by varying QE in JSIM. We find that even a simulated QE function with a maximum of 1.3 only causes an maximum additional centroiding error of approximately 0.6 milliarcseconds.

4. References

Dugan, Z. JMAPS TM 10-03

Veillette, D. 2009, JSIM.