Cross Correlation Test and Preliminary Aperture Photometry Result

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1 SUMMARY

1. Using cross correlation images can be with the precision of ~ 0.01 pixels, which is far better than the precision of IDL `cntrd.pro` and `gcntrd.pro` routines. According to the patterns on PSF subtracted images, cross correlation has better performance tan WCS alignment.

2. Aperture photometry for secondary object in ABPIC system is carried out with a fixed aperture radius of 5 pixels. The light curves are very similar to Glenn's measurement. The light curves for two filters, F125W and F160W have better agreement in my measurement.

3. Considering only statistical uncertainty (counting error) and fluctuations in the background, a rough estimate gives an relative uncertainty of 0.3% for one photometry measurement.

2 IMAGE ALIGNMENT

2.1 ALIGNMENT PRECISION TEST

The performance of image registration is quantified by how precise the method can measure the shift from two different images. In practice, I choose one image, shift this image with a specific distance with `fshift.pro`, measure the shift, and calculate the offset of the measured shift and real shift. With above procedure, I tested the performance of 3 image alignment method. I listed the results as Figure 2.1.

The offsets for cntrd and gcntrd methods can be as large as 0.2 - 0.3 pixels. However cross correlation method can limit the offset within 0.06 pixels. It is surprising that none of the three distributions of offsets has a Gaussian like profile. For cross correlation, I plotted the offset against the real shift distance. It turned out that the offset oscillates with shift distance with a period of exact 1 pixel and an amplitude of 0.05 pixels. I do not know clearly why they have such a relationship.

According to the test result, cross correlation has a much better performance on registration images.

2.2 MODIFICATION OF CROSS CORRELATION

The general idea of cross correlation method is that it calculate cross correlation matrix of one image and one reference image. The coordinate of the maximum in cross correlation matrix then can be converted to the shifts in x and y direction of the image relative to the reference image. To locate the peak in cross correlation matrix is one key factor of the accuracy of this method. The original `crosscorr.pro` routine use `polyfit2d.pro` to find the maximum, which uses a polynomial function (default order is 4) to fit the an area around the maximum value (default is a (5 pixel)^2 square) and find the peak. I tried to fit either with a higher order or larger area, the result turned to be unstable. Especially, when I kept on using an order of 4 polynomial function to fit a (10 pixel)^2 square around the peak, the program got stuck and returned error.

Therefore, I tried `mpfit2dpeak.pro` routine which fits either Gaussian, Lorentz or Moffat function to find the peak. It turned out that mpfit could improve the accuracy of cross correlation for nearly an order of magnitude. With mpfit, the offset for measured shift and real shift can be limited within 0.008 pixels. However, the weird oscillation still exists.

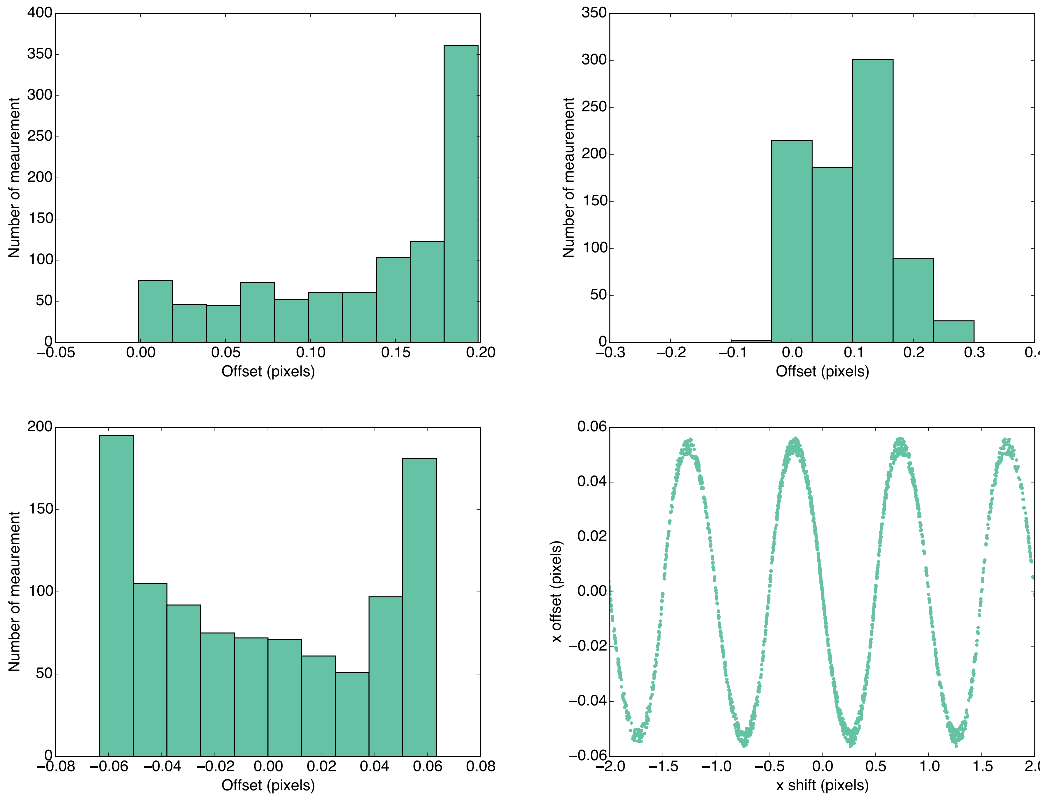

Figure 2.1: Measured shifts minus real shifts histogram in x direction measured by IDL `cntrd.pro` IDL `gcntrd.pro` and cross correlation

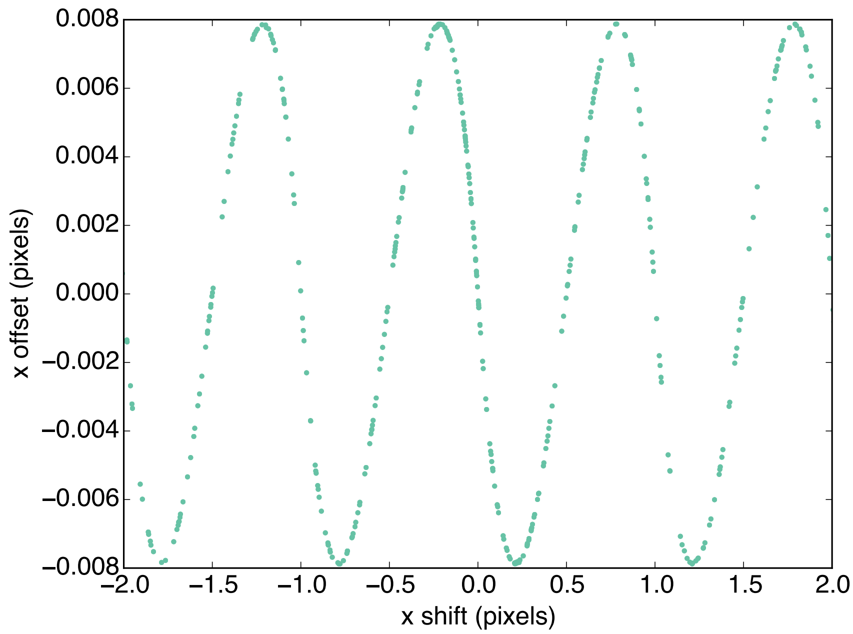

Figure 2.2: offset for measured shift and real shift. The shift is measured by cross correlation with mpfit.

2.3 TEST WITH NOISE ADDING IN

Primary star image is subtracted with a PSF image that has a different rolling angle. Thus it is important to know the accuracy in the scenario where only the primary star image stays the same, other objects rolled to a specific angle. To simulate rolling, I add 5 fake star images in random positions to both original image and shifted image and then use cross correlation to measure the shift. As shown in figure 2.3, noise star images does not affect the accuracy too much.

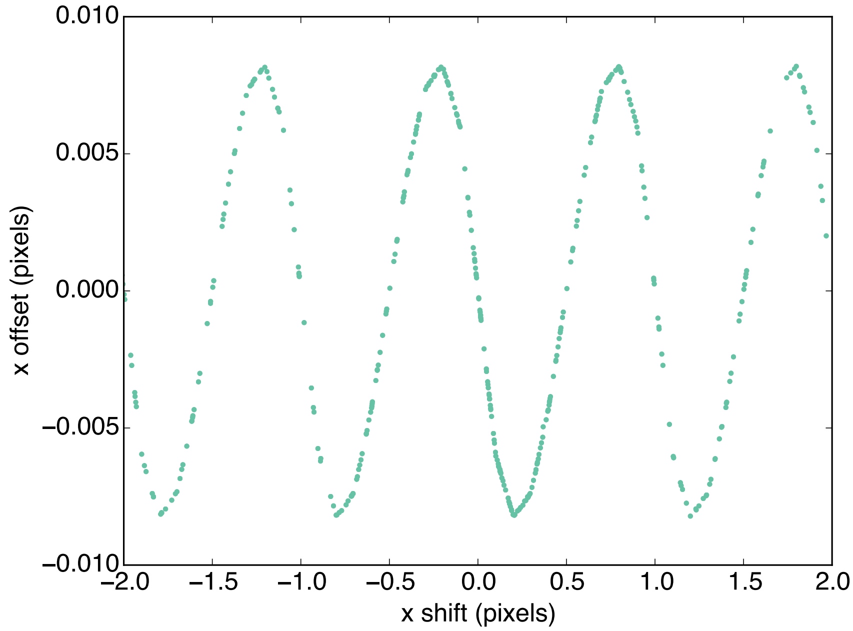

Figure 2.3: offset for measured shift and real shift. Original image and shifted iamge were both added with 5 fake star in random poistions.

3 PSF SUBTRACTION RESULT

Using cross correlation and World Coordinate System to register images, two set of data were compiled. I carried out the PSF subtraction with both data set.

For one specific image(img_0), every other image(img_i) that was taken with the same filter and different rolling angle were selected to be subtracted. With equation 3.1:

$$res = \sum (img_0 - c \cdot img_i)^2 \tag{3.1}$$

tunable scale factor c is calculated with minimum least square fitting. The PSF is chosen with the criterion of least residual.

Figure 3.1 illustrate the difference of PSF subtraction results between cross correlation and WCS registration. It is clearly shown that cross correlation gives a better alignment that the residual image is much more even. WCS aligned PSF is clearly offset to downright direction.

The background fluctuation of the region around secondary is ~ 1.0 counts/s.

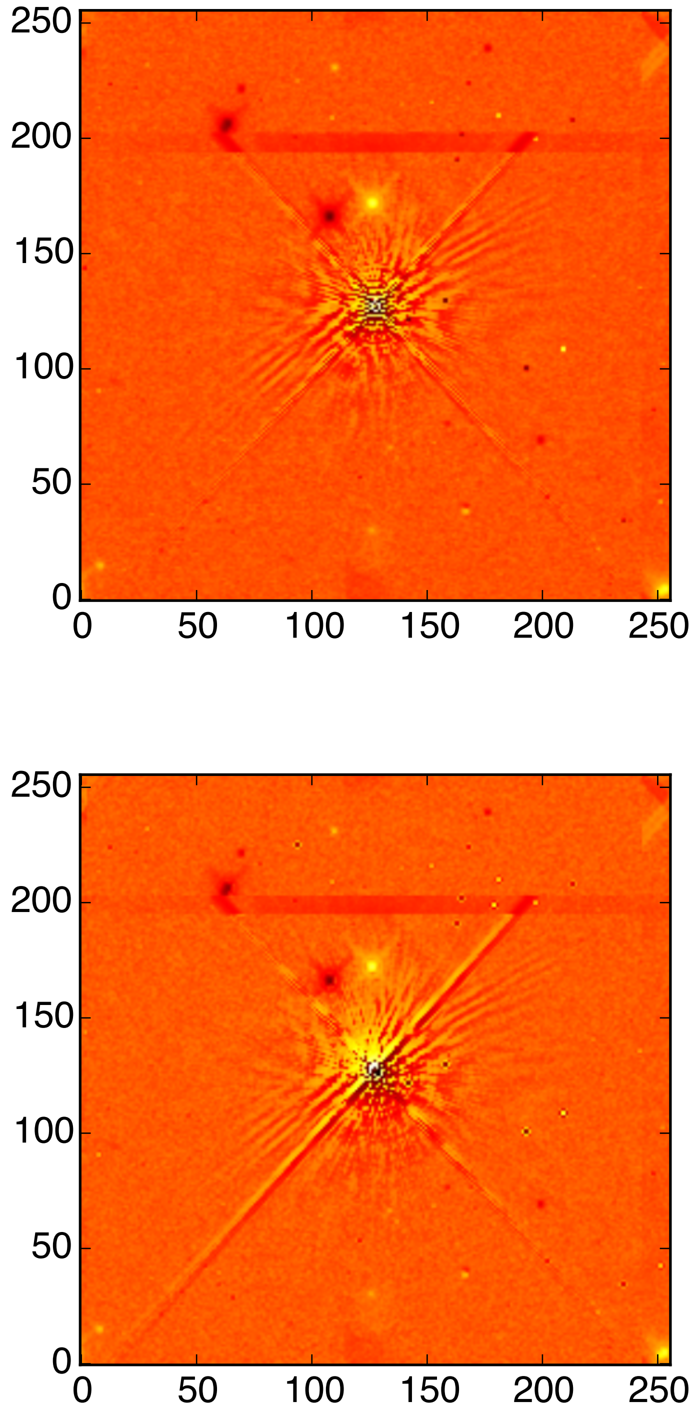

Figure 3.1: PSF subtraction comparison. Above: cross correlation. Below: WCS

4 Aperture Photometry Result

4.1 Light Curves

The light curve measurements for both absolute fluxes and relative fluxes are shown in Figure 4.1. Figure 4.2 is Glenn's preliminary measurements. The lower plot in figure 4.1 is very similar to figure 4.2. However, in figure 4.2, the light curves for F125W and F160W show considerable discrepancies in 5th and 6th orbits. However in my measurement, the two curves agree better. Apart from this, the most prominent features are shown in both light curves, e.g. the light curves are lower in 2nd orbit and the discrepancy at start of the 3rd orbit.

4.2 Error Estimation

Considering statistical uncertainty and fluctuation of background sky, the relative error for one aperture photometry measurement is below 0.3% according to my estimation. The error estimation procedure is explained as following.

Statistical uncertainty:

$$\sigma_{\text{stat}}^2 = f\, t_{\text{expo}} \tag{4.1}$$

Background fluctuation:

$$\sigma_{\text{sky}}^2 = N\sigma_{\text{sky},0}^2\, t_{expo} \tag{4.2}$$

Total error are the combination of these two parts:

$$\sigma^2 = \sigma_{\text{stat}}^2 + \sigma_{\text{sky}}^2 = f\, t_{\text{expo}} + N\sigma_{\text{sky},0}^2\, t_{expo} \tag{4.3}$$

Relative uncertainty:

$$\frac{\sigma}{\text{Flux}} = \frac{\sqrt{f\, t_{\text{expo}} + N\sigma_{\text{sky},0}^2\, t_{expo}}}{f\, t_{\text{expo}}} \tag{4.4}$$

The exposure time are 30s for F125W images and 15s for F160W images. Here I adopt 15s for a upper limit estimation. The flux intensity for the exoplanet is ~ 8000 counts per second. The standard deviation for background is ~ 1 counts per second. Plugin those numbers, I estimated a relative uncertainty for 0.3%.

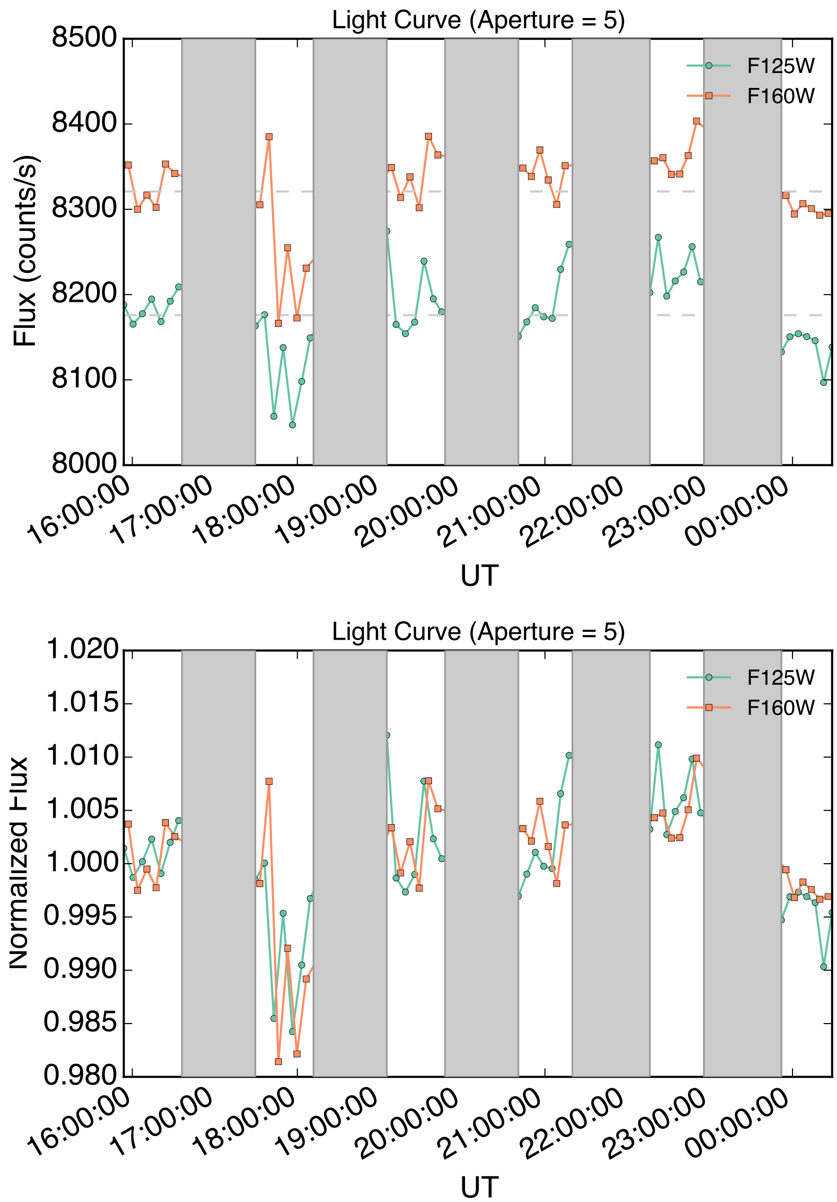

Figure 4.1: Filter F125W and F160W light curves. Upper images shows the curve for absolute flux (count per second) changing with time. The mean values for both light curves are plotted with gray dashed lines. In the lower image, two light curves are normalized with the mean value of itself.

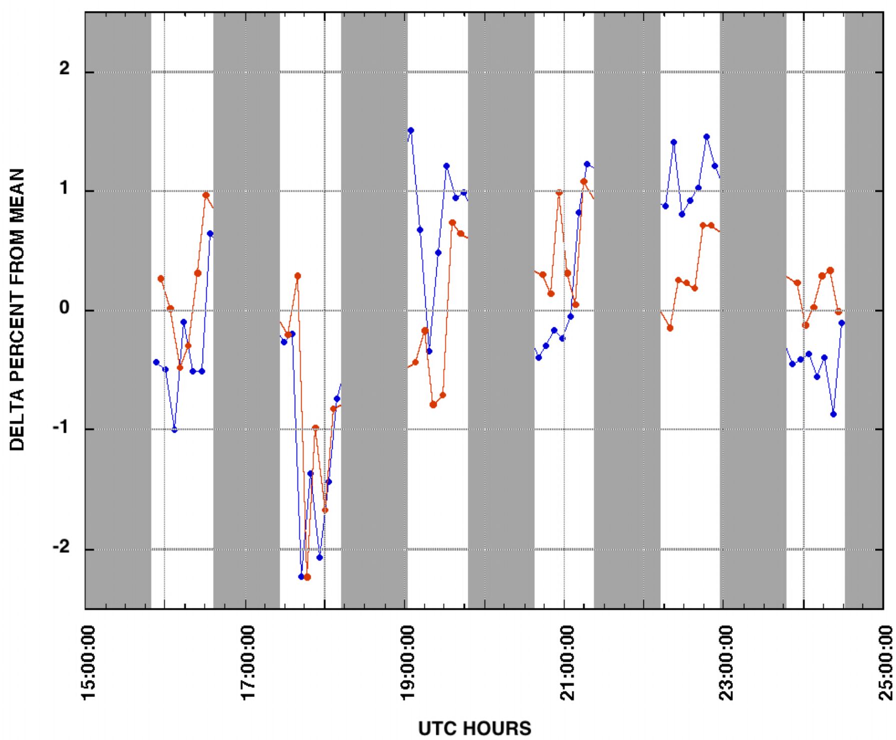

Figure 4.2: Glenn's preliminary measurement