Cross Correlation Test and Preliminary Aperture Photometry Result

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1 SUMMARY

1. Using cross correlation, images can be aligned with precision of ~ 0.01 pixels, which is far better than the precision that IDL `cntrd.pro` and `gcntrd.pro` routines can provide. According to the patterns on PSF subtracted images, cross correlation has better performance than 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. Taking only statistical uncertainty (counting error) and background fluctuations into account, a rough estimation gives an relative uncertainty of 0.3% for one photometry measurement.

2 Image Registration

2.1 Image Registration Precision Test

The performance of image registration method is valuated by the accuracy of the measurement for shift between two images. In practice, I choose one image, shift it for a specific distance with `fshift.pro`, measure the shift with various methods, and calculate the difference of the measured shift and real shift. With above procedure, I tested the performances of 3 image registration methods. Results are demonstrated in figure 2.1.

The difference of measured shift and real shift for cntrd and gcntrd methods can be as large as 0.2 - 0.3 pixels. In contrast, 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 shaped 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 ~0.06 pixels. I do not know clearly why they have such a relationship.

Nevertheless, according to the test result, cross correlation has a better performance on registration images.

2.2 Modification of Cross correlation

The general idea of cross correlation registration is to use the position of peak in cross correlation matrix calculated with two images to determine how they shift from each other. To locate the peak in cross correlation matrix is one key factor of the accuracy of this method. The original `crosscorr.pro` routine uses `polyfit2d.pro` to find the maximum, which fits a polynomial function (default order is 4) to 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, but 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 profile 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.

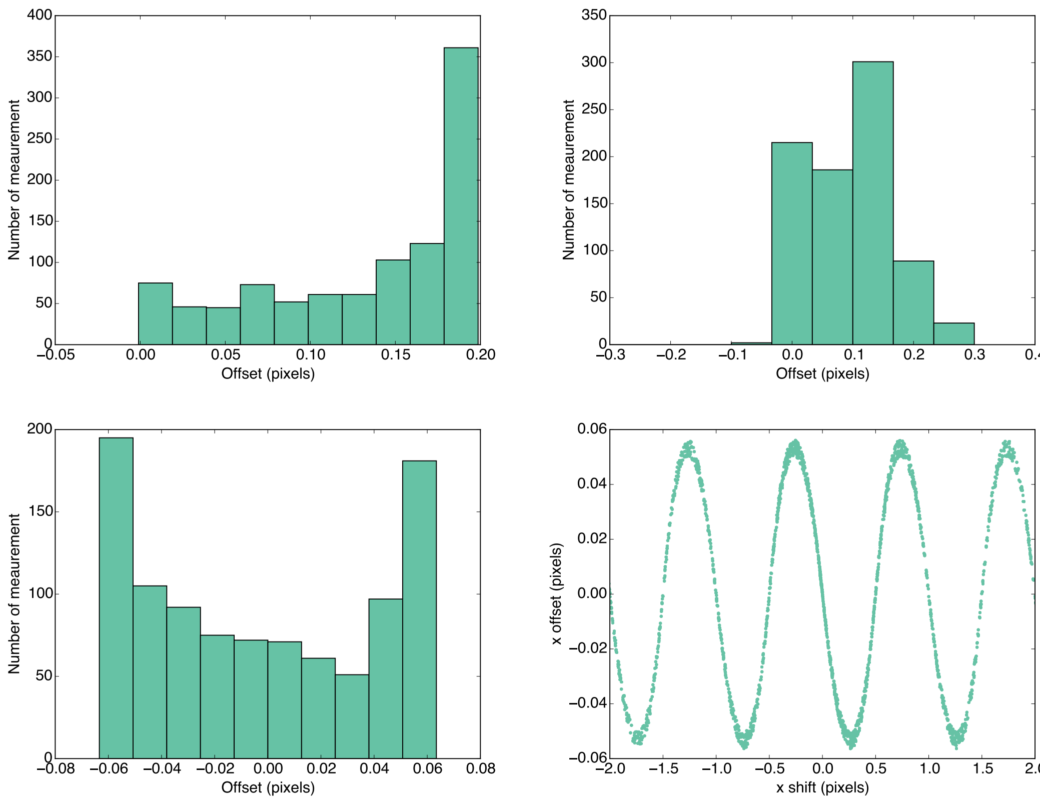

Figure 2.1: Measured shifts minus real shifts histogram in x direction measured by IDL `cntrd.pro` IDL `gcntrd.pro` and cross correlation

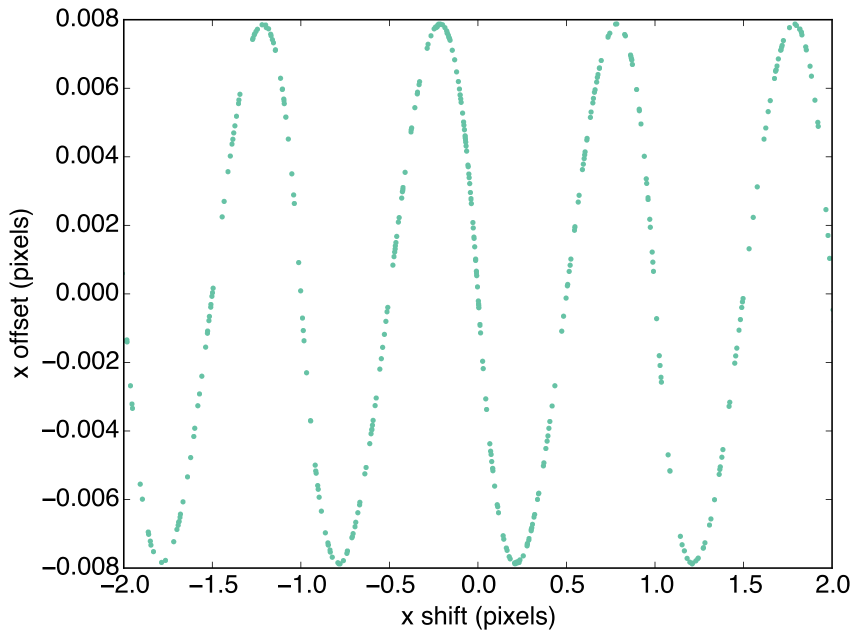

Figure 2.2: offset for measured shift and real shift. The shift is measured by cross correlation with mpfit.

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 added 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, fake star images does not affect the accuracy too much.

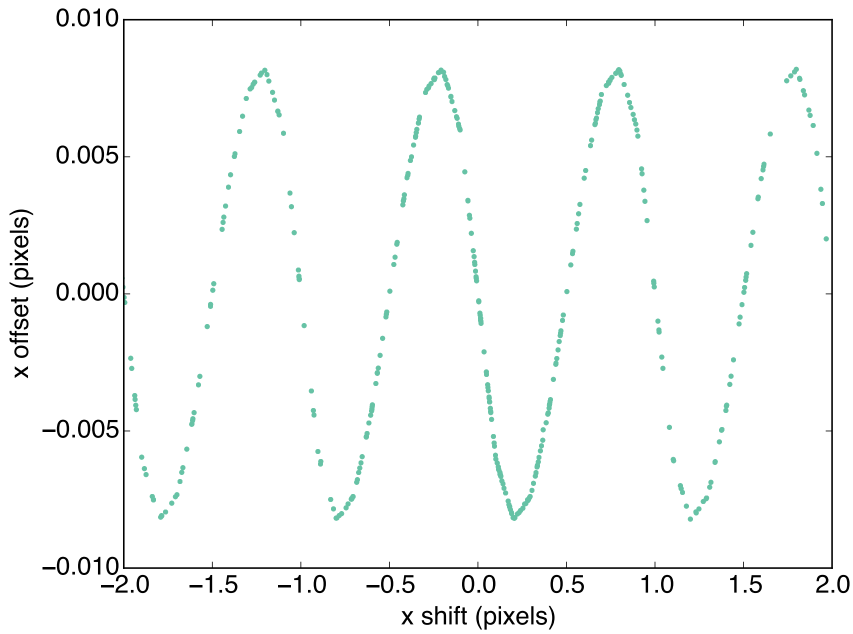

Figure 2.3: offset for measured shift and real shift. Original image and shifted iamge were both added with 5 fake star in random positions.

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 from img_0. 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 an example of the difference of PSF subtraction results between cross correlation and WCS registration. It is clearly shown that cross correlation gives a better alignment. The residual image is more even with cross correlation registration. WCS aligned PSF is clearly offset to downright direction.

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

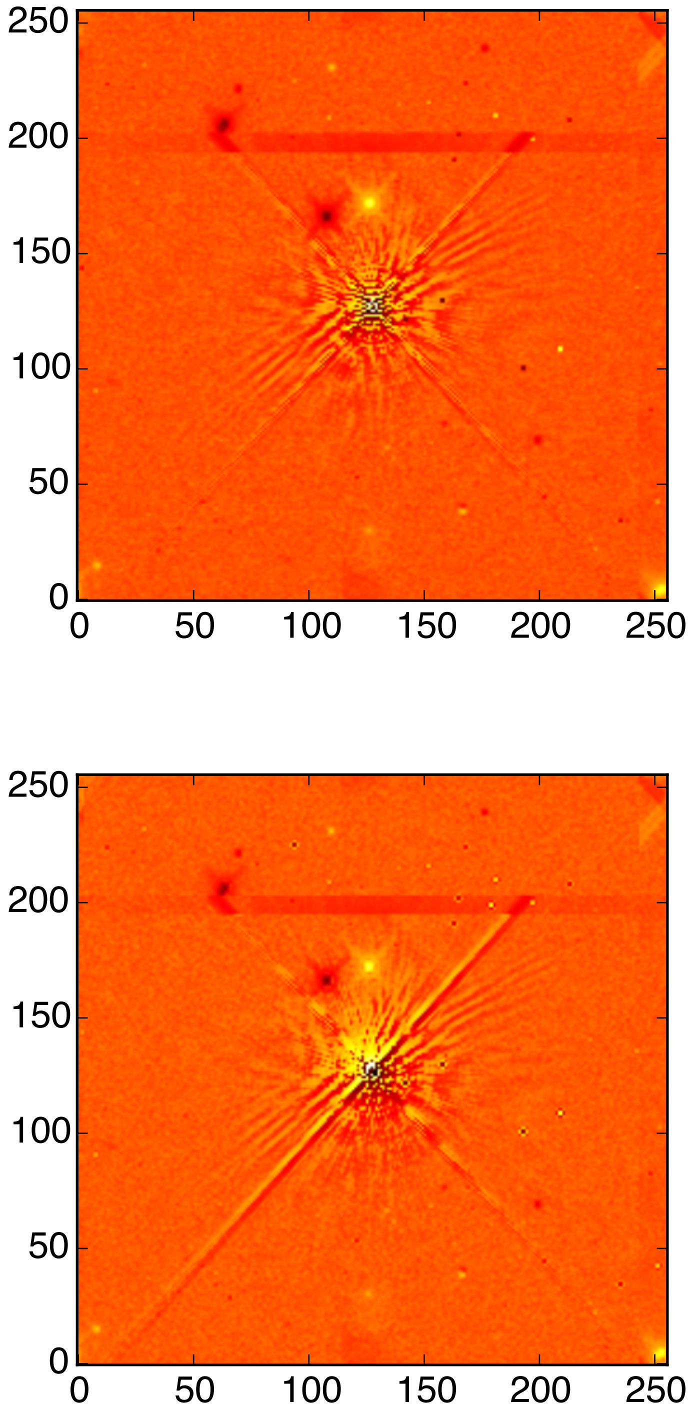

Figure 3.1: PSF subtraction comparison. Above: cross correlation. Below: WCS

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. In my measurement, the two curves seemed to 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 there is a discrepancy of two curves 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:

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

Background fluctuation:

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

Total error are the combination of these two parts:

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

Relative uncertainty:

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

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%.

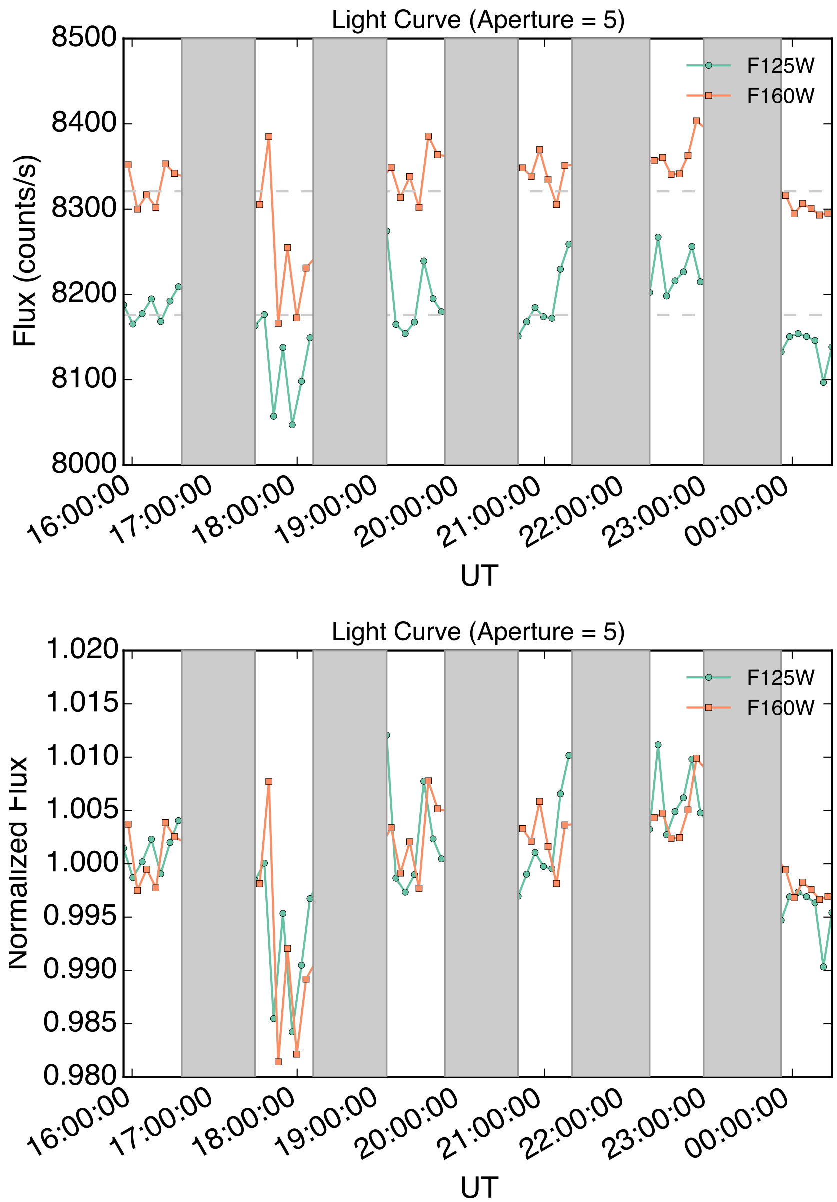

Figure 4.1: Filter F125W and F160W light curves. Upper images shows the curve for absolute flux (count per second) changing with time. The mean values for both light curves are plotted with gray dashed lines. In the lower image, two light curves are normalized with the mean value of itself.

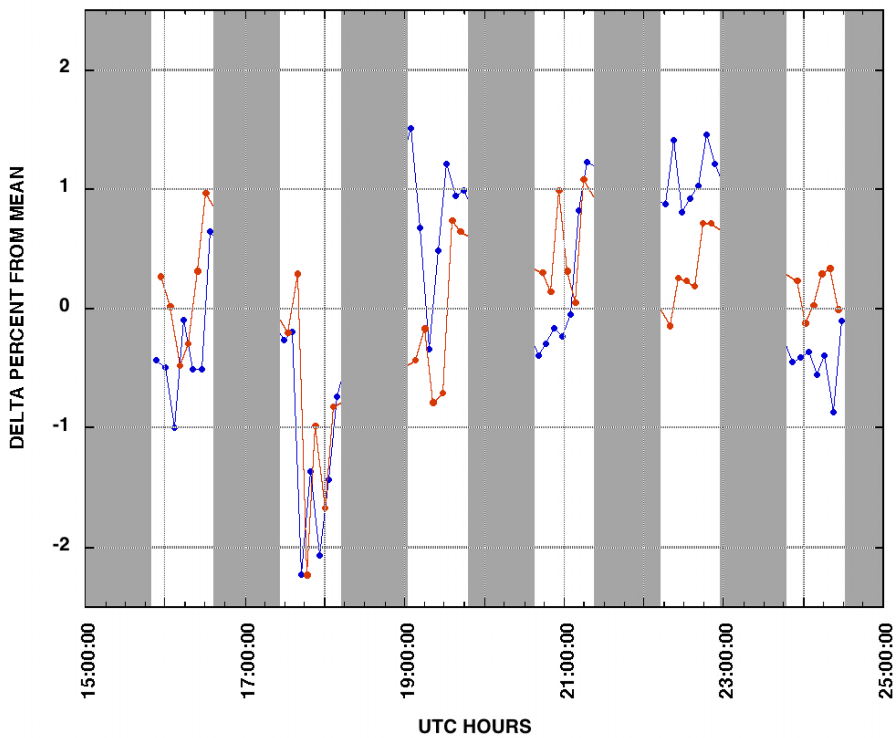

Figure 4.2: Glenn's preliminary measurement