AN042

Slope Inaccuracy for Pupil Intensity Variations When the Detector is not in the Focal Plane

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1 Introduction

Shack-Hartmann wavefront sensors are nominally insensitive to variations in the pupil plane intensity when the imaging sensor is in the exact focal plane of the lens array. Unfortunately, manufacturing a Shack-Hartmann wavefront sensor cannot typically achieve this exact position. This application note investigates the slope estimation inaccuracy when the imaging sensor is not in the exact focal plane.

2 Centroid Inaccuracy with 50% Duty Cycle Pupil Intensity for Varying Distance from the Focal Plane

We considered a 6.7mm focal length 150 micron diameter lens as is commonly used in our Shack-Hartmann wavefront sensors. We evaluated the centroid (first moment) after a 5% threshold (subtraction then zero). For this study, we considered two cases: a uniform pupil plane intensity and the case of a 50% blocking of the uniform intensity. Figure 1 shows the two pupil plane intensities.

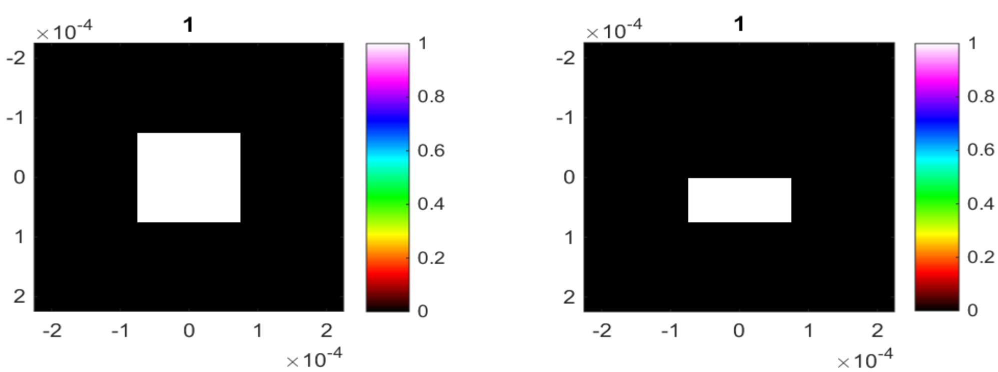

Figure 1: The Two Evaluated Pupil Plane Intensities

We used wave-optics to propagate the focusing beam to the detector plane while varying the distance from the detector plane to the pupil plane. Figure 2 shows an example intensity profile for the two different pupil plane intensities. We maintained a flat wavefront in the pupil plane in each of these cases any only varied the separation from the detector to the pupil plane.

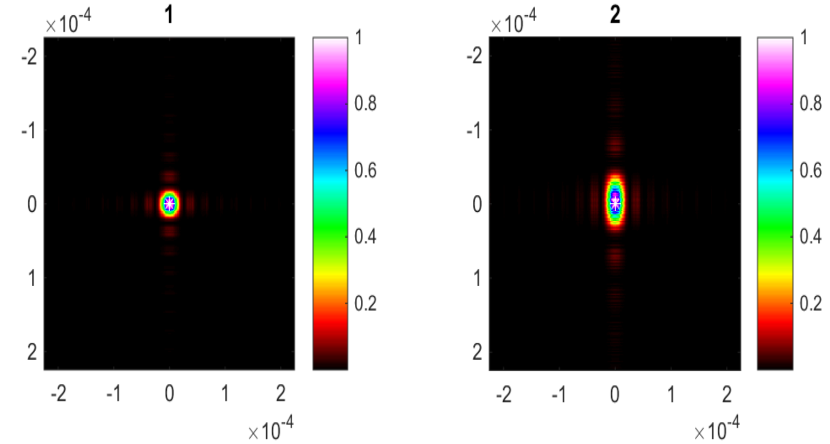

Figure 2: Detector Plane Intensities for the full-aperture intensity (left) and the half-aperture intensity (right).

Based on this analysis, we determined the error in the centroid position relative to the uniform intensity case. Figure 3 shows the centroid position error with respect to distance from the detector to the focal plane. We observed a linear variation in the centroid position with respect to distance from the focal plane. Based on this, we calculated a gain factor relating the centroid inaccuracy to the distance from the focal plane. For the wave-optics calculation, we measured a 2.55e-3 gain factor. Using ray optics, we would expect a gain factor that is equal to one quarter of the diameter over the focal distance, or 5.6e-3 for this case. The wave-optics showed more than a factor of 2 reduction in the error over the ray-optics solution. Figure 3 also shows the approximate centroid error for a 5.5-micron pixel pitch camera. Each point on the graph indicates a quarter turn of a 40 thread per inch mount. The worst mounting inaccuracy would produce half of a quarter rotation of the threading, which creates a centroid error of less than the typical 1/20th pixel centroid RMS error of a pixelated detector.

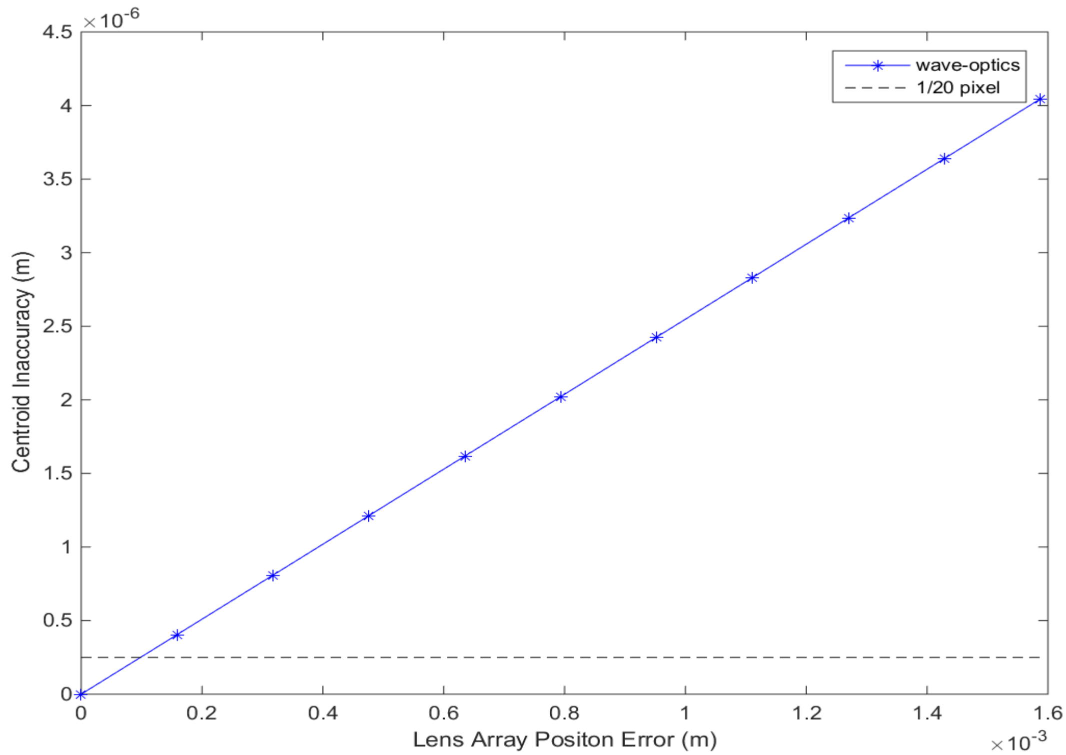

Figure 3: Centroid Error with Respect to Error in the Lens Array Position

3 Conclusion

We have shown using high fidelity wave-optics modeling that the centroid inaccuracy due to a 50% occultation of the pupil plane intensity. The wave-optics simulation predicted a 50% less error in centroid accuracy than the ray optics estimate. For the considered lens array and camera, the centroid inaccuracy due to 50% occultation was less than the typical 1/20th pixel typical RMS centroid accuracy from a Shack-Hartmann wavefront sensor when the lens array position was within an eighth turn of a 40 thread per inch mounting mechanism. It is also important to note that if the intensity variation over the aperture does not change, the fixed offset can be calibrated out of the system.