AN001

Hartmann Wavefront Sensor Calibration

Author: Justin D. Mansell, Ph.D.
Active Optical Systems, LLC
Revision: 10/10/07

The most critical measured parameter of a Hartmann wavefront sensor (HWFS) is the spacing between the Hartmann aperture array and the camera. In this application note we describe how we make this measurement.

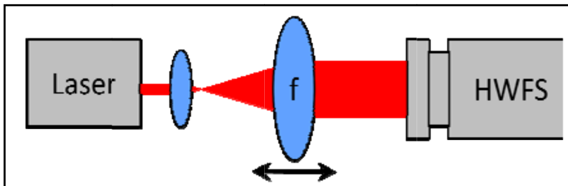

Figure 1 - Optical Setup for Hartmann wavefront sensor calibration

Figure 1 shows the optical setup used when making this measurement. First laser light is expanded from in a two lens telescope, often with a pinhole at the focus of the first lens, so that the beam is much larger than the HWFS input aperture. Expanding the beam creates a fairly uniform intensity profile at the HWFS input aperture. The second lens in the telescope is placed on a translation stage so that the distance between the lens and the focus (or pinhole) can be varied.

To begin the calibration process, a separation is assumed in the AOS HWFS software. Then a reference is taken with the wavefront impinging on the HWFS nearly collimated. This collimation can be tested using a shear plate or simply by allowing the light from the telescope to propagate a long distance and seeing if the beam size changes during this propagation. To complete the calibration, a series of measurements of the wavefront curvature are made at different positions of the second lens using a planar fitting of the measured slopes. This measurement is typically made with 20 or more frames of averaging turned on to maximize the accuracy of the measurement. We typically use a 500 mm focal length lens and make measurements in 2.5 mm steps over 25 mm.

Ray optics analysis tells us that the effective output curvature of the wavefront after the beam transmits through the second lens can be given by,

$$\frac{1}{f} = \frac{1}{f_{eff}} + \frac{1}{f+\Delta}$$

$$f_{eff} = \frac{f\left(f+\Delta\right)}{\Delta}$$

where f_{eff} is the effective focal length of the output wavefront, f is the focal length of the second lens, and Δ is the motion of the second lens from its nominal collimated position. This function is difficult to fit with a linear function, so we often use the approximation that f is much greater than Δ, which yields a much simpler form given by,

$$\frac{1}{f_{eff}} = \frac{1}{f\left(f+\Delta\right)}\Delta \approx \frac{1}{f^2}\Delta$$

The measured data can be then fit to a line and the slope compared to the expected $1/f^2$. The ratio of the measured slope of this line to the expected slope is then multiplied by the separation that was assumed in the software to yield the actual distance between the Hartmann aperture array and the camera.

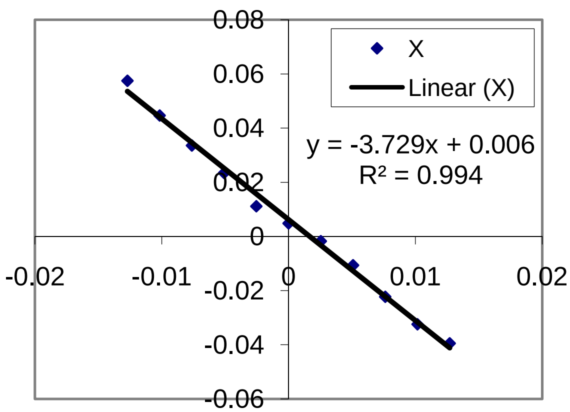

Figure 2 - Example HWFS calibration data (meters of lens displacement (Δ) vs. focal power in diopters (1/m)).

Figure 2 shows example HWFS calibration data. In this experiment a 332 µm sub-aperture spacing Hartmann array was being used. The assumed separation was 7 mm. In this setup, a 500-mm focal length lens was used for the calibration and steps of 2.5 mm. The expected line slope was -4.0. (The sign of the slope is inverted relative to the equation because the sign of the displacements (Δ) were inverted). The ratio of the measured slope to the expected slope was 0.9325. The resulting measurement of the actual distance is 6.53 mm.

Appendix A: Alternative Rapid Calibration Method

Another less accurate but more rapid way of calibrating a HWFS is to place the sensor into a collimated beam of light and create a reference with an assumed separation. Then place a lens with a known focal length into the beam and measure its focal length by again fitting the slopes to a plane. The assumed separation multiplied by the ratio of the measured focal length to the actual focal length is a good estimate of the actual separation between the Hartman array and the camera. This technique is difficult to get very accurate results from because the propagation distance between the lens and the Hartmann array needs to be taken into account and it relies heavily on the knowledge of the lens focal length.