# A Laboratory Verification Sensor

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Channan, Nelson and Mast [1] described the use of a variant of the Hartmann test proposed by R. Shack [2] to sense the co-alignment of the 36 primary mirror segments of the Keck 10-meter Telescope. The Shack-Hartmann alignment camera, illustrated schematically in FIGURE 1, is a surface-tilt-error-sensing device,operable with high sensitivity over a wide range of tilt errors. An interferometer, on the other hand, is a surface-height-error-sensing device. In general, if the surface height error exceeds a few wavelengths of the incident illumination, an interferogram is difficult to interpret and loses utility. The Shack-Hartmann alignment camera is, therefore, likely to be attractive as a development tool for segmented mirror telescopes, particularly at early stages of development in which the surface quality of developmental segments may be too poor to justify interferometric testing.

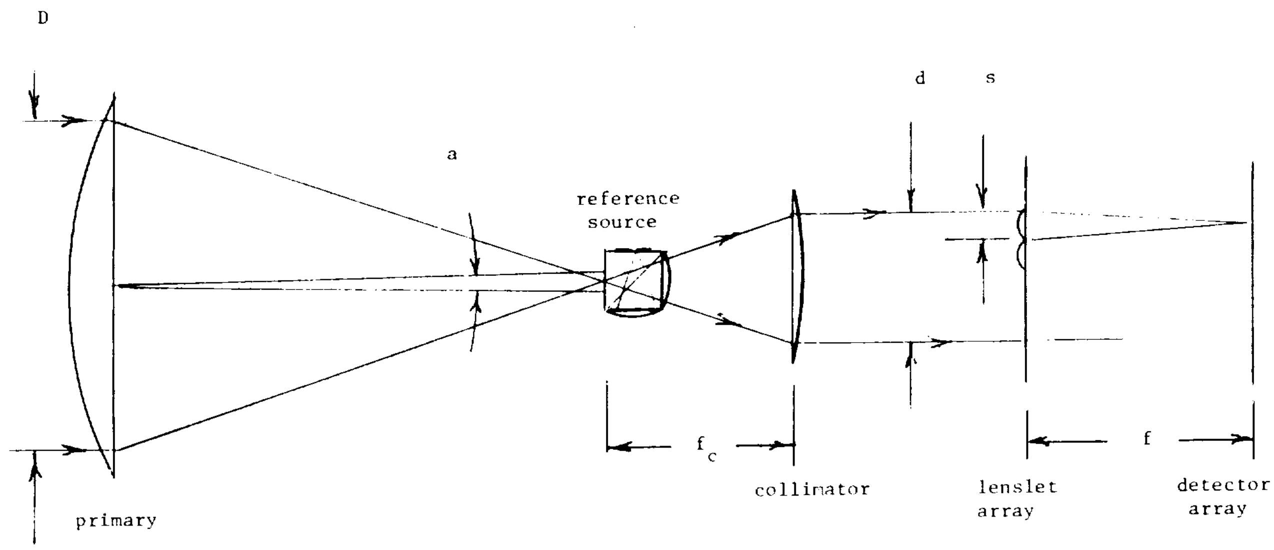


FIGURE 1. Parameters of a Hartmann-Shack Alignment Camera

The purpose of this discussion is to examine the constraints that would define the first-order properties of a Shack-Hartmann alignment camera and to investigate the precision and range of measurement one could expect to achieve with it. For this discussion it is sufficient to assume that the camera will be used as a focal-plane instrument and illuminated by starlight from the telescope. As shown in FIGURE 1, the starlight is allowed to fall on a collimating lens, L, which forms an image of the telescope primary mirror on the surface of a two-dimensional array of small lenses (lenslets). Each of these lenslets in turn forms an image of the star in a final image plane where a detector array is located. Since the lenslet array is at an image of the mirror, each lenslet samples the wavefront from a specific subarea of the mirror. If that area suffers a tilt error, the star image formed by the corresponding lenslet will be displaced. A reference wavefront can be introduced by means of a beam splitting cube in such a way as to sample the camera optics identically, so that a measurement of the displacement between the star image formed by the same lenslet will be independent of errors inherent in the camera optics.

If the alignment camera is to be used with a segmented mirror consisting of hexagonal segments, it might be natural to arrange the lenslets in a hexagonal array. In this case, it can be shown that the segments of the mirror will be sampled uniformly if the number of lenslets per segment is 6N+1 (N=0,1,2...). Hence if the mirror contains 36 segments, one finds the following possibilities:

| Samples per Segment | Samples Across Aperture | Total Samples |
|---|---|---|
| 1 | 7 | 36 |
| 7 | 21 | 252 |
| 19 | 35 | 684 |
| 25 | 49 | 900 |
| etc. | ... | ... |

However, considerations might arise in which other sampling schemes are advantageous, so that such "quantization" is not necessarily a fundamental issue.

Fundamental constraints do arise, however, from consideration of (1) geometrical imaging, (2) diffraction, and (3) the density of sampling of images at the detector array. Geometrical imagining determines the linear size of the image, and depends on the primary mirror diameter and the f-number of a lenslet. Diffraction is another constraint; it depends on the lenslet aperture. Finally, the sampling density at the detector array is important since the number of pixels in the image determines how accurately the centroid of the image can be measured. When these factors are considered under realistic assumptions (for example, 1-2 arcsecond seeing conditions), it is apparent that the first order design of a Shack-Hartmann alignment camera is completely determined by the first-order constraints considered, and that in the case of a 20-meter telescope with seeing-limited imaging, such a camera, used with a suitable detector array, will achieve useful precision.

References:


1. Chanan, G.A., Nelson, J.E, and Mast, T.S. (1987), Alignment Camera Preliminary Design, W.M.Keck Observatory Report No. 168.
2. Shack, R. (1976), Private communication to A.H. Vaughan.