Application of Phase Retrieval to Precision Optical Metrology

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Phase retrieval is a non-interferometric technique for measuring a wavefront. Its main distinguishing characteristic is the simplicity of the apparatus required to make a measurement <96> only a known illuminating field, an optical surface or system under test, and a detector array are required. The detector array measures intensity patterns in one or more near-focus planes formed by the illuminating field after it has interacted with the surface or system under test and no additional optics are required. Phase retrieval is vibration-tolerant and capable of measuring aspheric wavefronts without having to account for retrace errors that occur in interferometry, simply because there are no optics through which the deviated rays must travel.

The complexity of the technique lies in the phase retrieval algorithms used to determine the wavefront in the exit pupil from these intensity patterns. They are iterative in nature and must accurately model the physical optics propagation from the exit pupil to the measurement planes.

The technique has been used previously in wavefront sensing for adaptive optics [1], to determine the fabrication errors in the Hubble Space Telescope [2], and will be used for fine phasing of the segmented primary mirror of the James Webb Space Telescope. However, using phase retrieval in the manufacture of precision optics is a demanding new application.

Modeling results, including the effects of realistic detector noise, have shown that phase retrieval can achieve accuracies of better than λ/200 (RMS) using two measurement planes and of λ/1000 using a larger number of planes. We anticipate that real-world effects may degrade this extreme accuracy. The limits on accuracy and how to surpass them are a major topic in our research.

Accurate positioning of the detector is important, but a refinement in the algorithm can greatly reduce this requirement. This is an example of a situation where complexity in an experimental arrangement can be eliminated by increasing the complexity of the phase retrieval algorithm.

We have also begun to explore the limits of the capabilities of phase retrieval to measure different types of surfaces and system. The speed of the beam (NA or f-number) incident on the detector is limited by the detector pixel spacing. The slope of the deviation of the wavefront from spherical, which limits the asphericity that can be measured, is limited by the number of pixels in the detector. A promising technique for extending the range of optics that can be measured is to make undersampled measurements of the intensity patterns [3], although determining the uniqueness and accuracy of the wavefront estimate under that circumstance requires further work.

REFERENCES:

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