Optical test alignment using computer generated holograms

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Abstract:
Measurement systems for optical surfaces that lack axisymmetry are notoriously difficult to align and have limited accuracy. This paper describes a technique that uses a single CGH to act as null lens for measuring the aspheric surface, at the same time as it projects alignment marks into space that can be used for aligning the test. By providing reference features and the surface shape on the same hologram, we ensure accurate alignment. This method can also be used for aligning systems with multiple surfaces.

OCIS Codes: 220.4840 Optical testing, 050.1970 Diffractive optics

Creation of multiple images used for alignment

The computer generated hologram CGH provides a well known tool for controlling light for interferometric measurement of aspheric surfaces. The CGH can create a wavefront with arbitrary shape using diffraction from a pattern that is written using equipment developed for integrated circuit fabrication. Also, similar holograms optimized for efficiency, usually called diffractive optics or binary optics are used as special types of lenses in optical systems for imaging, laser projections, etc.

We are combining aspects of CGH metrology and diffractive optics to create holograms that produce multiple wavefronts that have accurate registration. Using a combination of interferometry and direct imaging, the light projected from a CGH can be used not only to determine the shape of an optical surface, but also simultaneously determine the position of this surface. This technique can be extended to control the relative positions of multiple surfaces. The basic idea is shown below in Figure 1, where the CGH creates multiple images. The relative positions of these images is controlled to great accuracy by the hologram. These images are located using detector arrays and the coordinates are transferred to a mechanical system.

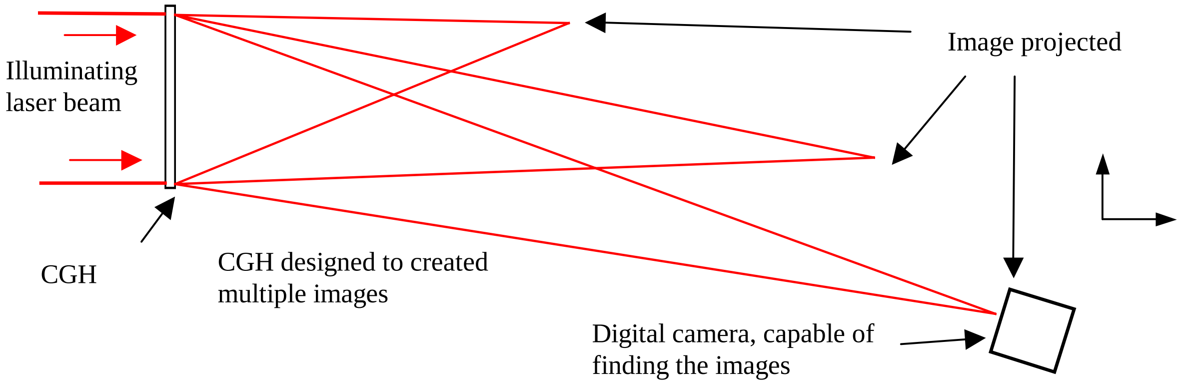

Figure 1. The CGH uses diffraction to simultaneously create multiple beams that each project a sharp image of a feature such as a crosshair. The relative position of these images are controlled to very high accuracy in the *x* and *y* directions. A calibrated digital camera is used to locate these features in space, then coordinates are transferred mechanically from the camera to reference features.

The CGH is designed so that the projected images appear as a crosshair patterns that can be easily found, with a sharp central lobe that can be located with high precision. Figure 2 shows a simulated image from such a hologram, 55 mm across. The central lobe of has FWHM about 100 µm at a distance of 15240 mm from the CGH. (In angle this is 7.1 µrad.) By imaging this with a CCD camera and finding the centroid, it is easy to find this image to a few microns.

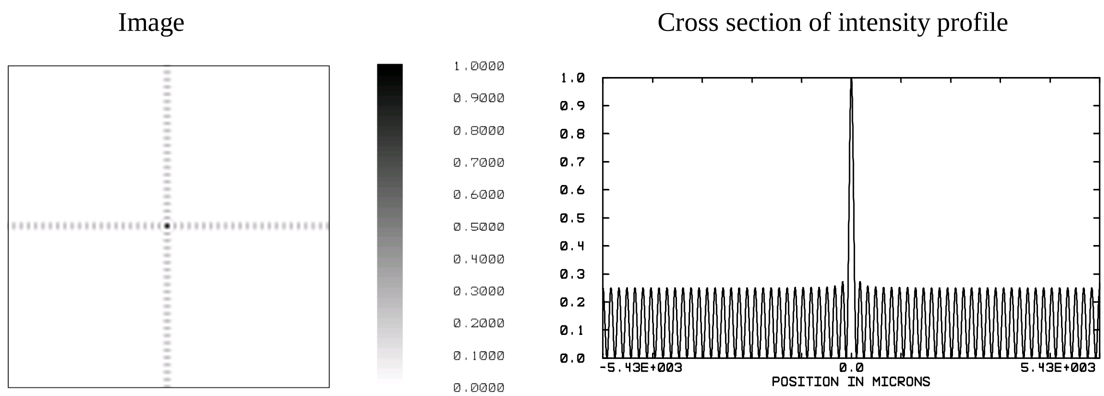

Figure 2. Image created from a 55 mm CGH, a distance 15 meters away. The hologram was optimized to give the crosshair pattern with a sharp lobe at the center. The width of the lobe is about 100 µm, or 7 µrad from the CGH.

Alignment of interferometric tests

We couple this powerful ability of creating reference marks in space with interferometric surface measurements. By manufacturing a CGH null lens on the same substrate as a set of holograms that create fiducials, we are assured of accurate registration between the test wavefront and the projected cross-hair images. This allows a simple test for non-axisymmetric aspheres, as shown in Fig. 3. This method was successfully used to support manufacturing of a set of off axis parabolas at the University of Arizona.

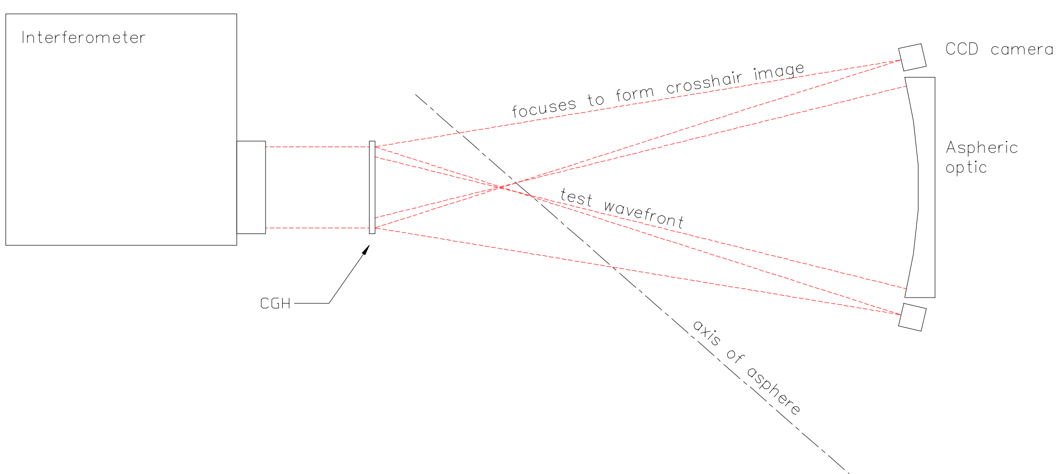

Figure 3. A single substrate contains the CGH for testing the aspheric surface, and for aligning the test. The alignment marks are picked up by CCD cameras and are used to define the coordinates of the optic. The surface is measured using the test wavefront created by the CGH. The registration between these insures that the true axis of the asphere is controlled, even though it is never directly measured.

Optical system alignment using computer generated holograms

The technique of projecting numerous alignment marks can be used to align other complicated optical systems. This builds on some early work in this field where we used a computer generated hologram to provide the wavefront correction and alignment for an optical system that was built for testing the adaptive secondary mirror for the 6.5-m telescope.[1] The CGH used for this purpose is shown in Fig. 4.

A concept for using the CGH for alignment is shown in Figure 5. A single hologram creates multiple images, that occur in multiple spaces. By making direct measurement of the image positions, a true coordinate frame can be established and the optics can be aligned with respect to this. The holograms can be designed to compensate for any aberration that would come from the optics so that the projected features are always sharp.

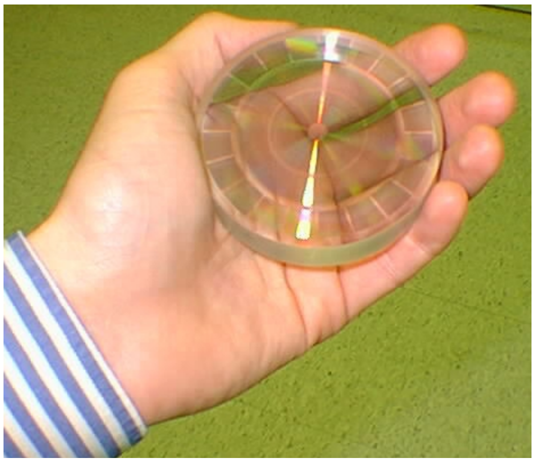

Figure 4. The hologram was used for simultaneous two wavelength correction and 5 DOF alignment for the optical system that tested the 64 cm adaptive secondary mirror for the MMT.

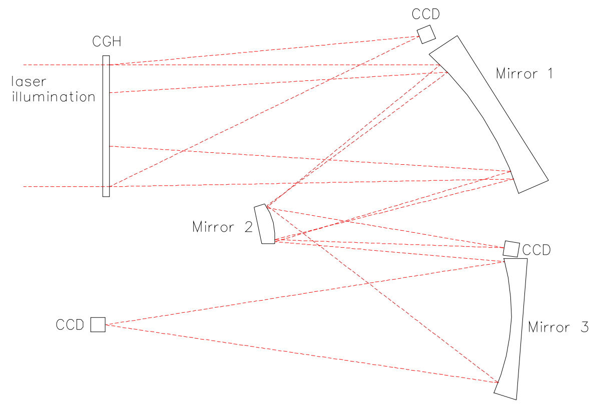

Figure 5. A CGH can be used to create multiple images that define a coordinate frame for a complicated optical system.

The holograms can create images that are used not only for registration, but are used for low order wavefront sensing. Particular images that have characteristic signatures for different aberrations can be used to determine alignment. One simple example would be a pair of images with a small amount of defocus between them. The combination of these two images can be used real time to determine aberrations in the optical system. These can provide feedback for the system alignment. It is clear that the basic technique has enormous power and flexibility that should be explored.

Conclusion

Computer generated holograms can be used not only to create accurate wavefronts that are used for optical tests, but also to accurately project shape images that provide information for optical alignment. We have explored some early designs and have done some testing in the laboratory, but the power of this method has not yet been exploited.

References

[1] R. J. Sarlot and J. H. Burge, “Optical system for closed-loop testing of adaptive optic convex mirror,” in *Novel Optical Systems and Large-Aperture Imaging*, K. Bell, *et al.* Eds. Proc. SPIE **3430**, 126-135 (1998).