A holographic dual-channel interferometer

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Optical interferometry is used for various kinds of optical test studies, including temperature, refractive index and wavefront measurements. The conventional optical interferometers generally use precise custom-made bulky optics, which is expensive. These interferometers also suffer from disadvantages of systematic error. The systematic error is due to the aberration of the lenses and surface imperfections of the mirrors in the interferometer. Holographic optical elements (HOEs) offer several advantages over conventional interferometers as holographic optical elements offer several attractive features like light weight, compactness, ease of fabrication and multiple optical functions in the single element. Use of HOEs in various types of interferometers allows simplification of the optical arrangements with improved functionality and also eliminates the aberrations of the optical system under certain conditions. Applications of HOEs have been reported largely in the area of shearing and two-beam interferometers.

However, most of existing interferometers can perform optical test studies with one object at a time and therefore are not suitable for the study of two or more phase objects simultaneously. This note aims to present a simple yet versatile holographic interferometer in which two different phase objects can be studied simultaneously and independently. Further, single object could be studied simultaneously in two different modes (e.g. finite and infinite fringe states). For quantitative evaluation, simultaneous phase shifts in both interferograms can be given through in-built elements. The optical configuration of the proposed interferometer is such that it utilizes only two optical components: the HOE and a diffraction grating.

The compound HOE is formed on a recording plate H by capturing two diffracted orders O_1 and O_2, derived from diffraction grating G when illuminated by collimated beam R, in conjunction with two independent collimated beams O_3 and O_4 respectively, as shown in Figure 1. Accordingly, two spatially separated HOEs (H_11 and H_12) are constructed in the form of holographic diffraction gratings on plate H. The grating G and the processed plate H, when precisely repositioned and illuminated by the same collimated beams R, O_1 and O_3 serve as a holographic dual-channel interferometer. At H_11, illuminating beam O_1 provides diffracted beam O'_1 which is superimposed on the undiffracted beam O_1 resulting in an interference pattern. Likewise at H_12, undiffracted beam O_3 overlaps on the diffracted beam O'_2 (due to O_2) and produces another independent interference pattern. It may be noted that two more spatially separated interference patterns caused by O_1, O'_1 (due to O_2) and O_2, O'_2 (due to O_3) will also be formed. However, we are not considering these, as earlier described interference patterns are sufficient for our study. Two different phase objects S = exp[\phi_i] and P = exp[\phi_i] can now be studied simultaneously by inserting them in beams O_3 and O_4 respectively. It is easy to understand that the intensity distribution at P_1 and P_2:

\[ i_1 = |O_3S + O'_1|^2 = A + B \cos \phi_1, \]  
\[ i_2 = |O_3P + O'_2|^2 = C + D \cos \phi_2, \]

where A, B, C and D are constants. It may be noted that the proposed scheme is suitable for phase-shifting interferometry to study the two objects without using any external device. Here, it is possible to acquire a series of simultaneous phase shifts in both interferograms simply by transverse displacing of the grating G in a direction perpendicular to its grooves. The transverse displacement \( \Delta x \) introduces a phase shift of \( \pm 2\pi \Delta x d / d \) in the diffracted beams O_1 and O_2, where d is the period of the grating. Accordingly, the intensity distribution would be:

\[ I_{1,i} = A + B \cos (\phi_1 + \alpha_i), \]  
\[ I_{2,i} = C + D \cos (\phi_2 - \alpha_i), \]

where \( i = 1, 2, 3 \ldots \) are the number of steps (displacements) given to the grating.

![Figure 1. Schematic of the holographic dual-channel interferometer. BE, Beam expander; OPM, Off-axis parabolic mirror; G, Diffraction grating; H, Compound holographic optical element containing two HOEs, H_11 and H_12.](image-url)
The phase profiles in the respective interferograms can then be measured using well-known standard algorithms.

In our experiment H is formed using the upper, lower and middle portions of a large collimated beam (labelled as O₁, O₂ and R respectively) from an off-axis parabolic mirror (diameter 150 mm). The distance between observation plane OP and HOE H (Figure 1) was 300 mm to separate the two interferograms (e.g. O₁ + O₁′ and O₂ + O₂′). In an ideal situation the grating hologram should be linear, have low noise and high diffraction efficiency, so that high contrast of the fringes is obtained. The diffraction efficiency that can actually be obtained is limited by the nonlinearities of the recording medium, resulting in distortion of the profile of the fringes. In our case, standard Kodak D-19 developer and R-9 bleach bath solutions were used with Slavich PFG-01 plates (having spatial resolution power of more than 3000 mm⁻¹), giving sufficiently higher diffraction efficiency and low noise. Figure 2 shows simultaneous study of two different phase objects (burning candle and glass plate) in an infinite fringe mode. These interferograms can also be set in finite fringe mode by slightly misaligning H. To demonstrate the feasibility of simultaneous phase shifts in both finite fringe mode interferograms, the grating is given a series of transverse displacement (e.g. \( \Delta x_0 = d/3 \), \( d = 0.005 \text{ mm} \), resulting in phase shifts of \( 2\pi/3 \)). Figure 3 shows typical results (phase shifted by \( 2\pi/3 \), 0 and \(-2\pi/3\)) for two different phase objects (glass plates of different sizes). It may be noted that the method can easily be modified for study of single object simultaneously in two different modes (i.e. finite and infinite fringe modes) by recording H₁₁ and H₁₂ on two separate holographic plates. The phase object is inserted in beam R, and the plates H₁₁ and H₁₂ are adjusted in a manner that finite and infinite fringe modes are obtained. Figure 4 shows simultaneous typical results of a burning candle in finite and infinite fringe mode.

Generally two-beam interferometers have disadvantage of instability, which comes from vibration and atmospheric disturbances when the interfering beams have different paths in the interferometer. The described compact geometry of the interferometer has an added advantage of inherent stability against (thermal and mechanical) fluctuations, as all the reference and test beams are derived from the
same collimating optics. Additionally, the interferometer is free from optical aberrations as wavefront distortions caused due to emulsion shrinkage/swelling and substrate, etc. get cancelled, since all the interfering beams pass through the same respective portions of the HOE. Further, the geometry of the interferometer as well as formation and alignment of HOE is rather simpler in nature and could be realized with relative ease.

We have described a simple, compact and stable holographic optics-based interferometer with an in-built phase-shifting element, which is suitable for performing optical test studies on two different phase objects simultaneously and independently. Further, the interferometer can be modified to study single object in finite and infinite fringe mode simultaneously. Simultaneous study of two different phase objects may have application for comparison-type studies and also it can be used for performing two interferometric experiments with a single instrument.


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