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Comparison of Laplacian Differential Reconstruction of In-line Holograms Recorded at Two Different Wavelengths and Distances

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Abstract: We record two holograms using two different illuminating wavelengths. Subtracting these holograms, the resulting reconstruction is an approximation to the second order Laplacian differentiation of the object wave.

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1. Introduction

Digital Holography (DH) is the process where two coherent wavefields interfere resulting in an interference pattern which is captured using a light sensitive opto-electronic detector array such as a CCD or CMOS camera. From this hologram, the object wavefield is reconstructed numerically.

A recent method has recently been reported where the object wavefield is reconstructed from two in-line holograms captured at distances ‘z’ and ‘z+dz’[1] A variation to this method has also been reported in the literature [2]. By subtracting the captured holograms which are recorded at two different planes, the reconstructed object wavefield is an approximation to the Laplacian second order differentiation of the object wavefield [3].

In this paper, we compare the current method of reconstructing the object wave from multiple intensity recordings at different planes with using different illuminating wavelengths at a single distance. Once clear advantage of using different illuminating wavelengths is that there is no requirement to mechanically move the digital capture device. This method could also be used for edge enhancement in digital holography.

2. Principle

Direct numerical processing of the Fresnel-Kirchhoff integral is computationally time consuming. For this reason, equivalent formulation of this integral is used to determine whole field information from a single hologram based. The diffraction formula is a superposition integral of the object \( o(x,y) \) and reference \( r(x,y) \) wave (the hologram) as well as a term describing diffraction of light in free space\[4\]. The whole field information at the object plane is given by;

\[
\Gamma(\xi,\eta) = \frac{1}{\lambda} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} h(x,y) g(\xi,\eta,x,y) dx dy,
\]

where \( h(x,y) \) is the hologram, while the impulse response of the optical system propagating a distance ‘d’ given by

\[
g(\xi,\eta,x,y) = \frac{1}{\lambda} \exp \left\{ -i \frac{2\pi}{\lambda} \sqrt{(x-\xi)^2 + (y-\eta)^2 + d^2} \right\}.
\]

With the impulse response of the system characterised by \( g(\xi,\eta,x,y) = g(\xi-x,\eta,-y) \), its space-invariance results in a convolution of the terms in Eqn. 1 of the superposition integral. Employing the convolution theorem, and aided by the fast Fourier transform (FFT) algorithm, the reconstructed complex image at the image plane is obtained as follows; The Fourier transform is applied to the hologram and impulse response terms in Eqn. 1.
The ensuing matrices of complex data are then point-wise multiplied, with the inverse Fourier transform algorithm being applied to the resultant complex matrix yielding a matrix of complex data representing the field at the image plane,

$$\Gamma(\xi, \eta) = \mathfrak{F}^{-1}\{\mathfrak{F}[h(x, y)] \times \mathfrak{F}[g(\xi, \eta)]\}. \quad (2)$$

An approximation to second order Laplacian differentiation[3] of the object wave by propagating the difference of two holograms recorded at two different planes $z_1$ and $z_2$ is given by;

$$\Gamma_{\Lambda_1 \Delta z}(\xi, \eta) = \mathfrak{F}^{-1}\{\mathfrak{F}[h_{z_1}(x, y) - h_{z_2}(x, y)] \times \mathfrak{F}[g(\xi, \eta)]\} \approx \frac{j\lambda_1 \Delta z}{4\pi} r^+(x, y) \nabla^2 o(x, y). \quad (3)$$

In this paper, we present equivalent results for Laplacian differential reconstruction using two illuminating wavelengths. We then proceed to use two different illuminating wavelengths equivalent to Eqn. 3. This method does not require mechanical movement of the camera and our initial results agree with those of the two plane method.

3. Experimental Setup
Our inline system, as shown in Fig. 1, contains two laser sources, a HeNe laser of wavelength $\lambda_1 = 632.8$ nm and a laser diode with a wavelength of $\lambda_2 = 652.5$ nm. Emitted radiation from both lasers is combined using a beamsplitter before spatial filtering and collimation occurs. The source illumination is controlled by shutters permits illumination by the wanted laser. The specimen is placed in the path of the collimated beam. Light which is scattered by the object is the diffracted object beam, while unscattered light acts as the reference beam. The interference of these two beams is captured digitally at a distance ‘$z_1 = 225$ mm’ away from the object. By shifting the camera a distance, ‘$\Delta z = z_2 - z_1 = 1$ mm’ holograms at the second plane are recorded.

![Figure 1: Schematic of the experimental setup showing both laser sources, shutters (S1 and S2), beamsplitter (BS), mirror (M), microscopic objective (MO), spatial filter (SF) collimating lens (CL), specimen (SP) and digital capture device (camera).](image)
4.1 Results

We present a comparison between the two plane and the two wavelength method. The first set of results in Fig. 2 (i) come from the two plane setup. The difference of the two holograms recorded at \( z_1 = 225 \) mm and \( z_2 = 224 \) mm and resultant second order Laplacian differentiation of the object wave is displayed for \( \lambda_1 = 632.8 \) nm in (a) and (b) with (c) and (d) obtained with \( \lambda_2 = 652.5 \) nm.

The second set of results presented here, in Fig. 2 (ii) were obtained using the two wavelength method. The difference of the two holograms recorded with wavelength at \( \lambda_1 \) and \( \lambda_2 \) and resultant second order Laplacian differentiation of the object wave is displayed at \( z_1 = 225 \) mm in (a) and (b) with (c) and (d) obtained with at a distance \( z_2 = 224 \) mm from the camera face.

![ Figure 2: (i) shows the two plane difference holograms (a) and (c) and resulting Laplacian differential reconstruction (b) and (d) at \( z = 225 \) mm from the two plane experiment for \( \lambda = 632.8 \) nm (a) and (b) and for \( \lambda = 652.5 \) nm (c) and (d). (ii) shows the the 2 wavelength difference hologram and resulting Laplacian differential reconstruction (b) and (d) at \( z = 225 \) mm (a) and (b) and \( z = 224 \) mm (c) and (d). The dimensions on the x- and y- axis are in mm. ]

5. Summary of Results

The results presented so far provide an enhanced edge of the object imaged using the in-line holographic technique which approximates second order Laplacian differentiation of the object wave. The two plane method yields a clearly definable object edge. This experiment was repeated using a different wavelength with comparable results.

The two wavelength method does provide a defined object edge without the requirement to mechanically move the capture device. The results are equivalent to those for the two plane method which approximate second order Laplacian differentiation of the object wave.

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7. References


