Digital Holographic Imaging of Microstructured and Biological Objects

J.A. Dominguez-Caballero, J.H. Milgram, G. Barbastathis
Sponsorship: MIT Sea Grant

Digital Holographic Imaging (DHI) is a powerful technique that allows three-dimensional imaging by recording the optical-wave field using a CCD array. This recording is followed by a numerical reconstruction of the image field. The DHI is being employed to characterize micro-structured and biological objects at distances relatively far from the CCD with high lateral resolution. The amplitude and phase information can be retrieved from the reconstructed field, allowing us to obtain a more complete description of the sampled object.

The digital hologram is created by capturing the interference between the wavefronts scattered by an illuminated object and a reference beam. The intensity registered at the CCD plane is given by:

\[ I_{\text{CCD}} = \left| r + o \right|^2 \]

where \( r \) is the reference field and \( o \) is the Fresnel diffracted-object field. The recorded intensity is then multiplied by the digitally generated version of the reference beam \( r_{\text{D}} \) in order to recover the virtual image. The next step is to reconstruct the object in the image plane by using the diffraction integral. The reconstruction is achieved using the convolution approach:

\[ T_o = F^{-1} [F(I_{\text{CCD}} \cdot r_{\text{D}}) \cdot F(h)] \]

where \( T_o \) is the reconstructed field in the image plane; the operators \( F() \) and \( F^{-1}() \) are the forward and inverse Fourier Transforms, respectively, and \( h \) is the diffractive kernel. The reconstruction is optimized by using the Fast Fourier Transform algorithms.

Experiments using an in-line configuration reconstructed a USAF 1951 resolution target and a live brine shrimp. The recordings were made using a He-Ne Laser with \( \lambda = 632.8 \text{nm} \). The beam was expanded and split into two paths of equal length, forming a Mach-Zehnder Interferometer. The sampled object was placed in one of the paths and the other path was left clear to form the reference wave. Neutral Density Filters were used to control the relative intensity between the object and reference beams. The hologram was captured using a CCD array of 4096x4096 pixels with a pixel size of 9µm and a fill factor of 100%. Figure 1 shows the reconstruction made for the USAF 1951 resolution target located 15mm away from the CCD array. Figure 2 shows the reconstruction made for the live brine shrimp located at a distance of 167mm. The length of the brine shrimp is, approximately, 5mm.

Figure 1: Reconstruction of a USAF 1951 resolution target: \( z = 15\text{mm} \).
Figure 2: Reconstruction of a live brine shrimp: \( z = 167\text{mm} \).