An Inverse Imaging Approach to Sectional Image Reconstruction in Optical Scanning Holography

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Abstract: Inverse imaging is proposed to reconstruct the sectional images in a hologram by optical scanning holography. The methodology is based on formulating the reconstruction as an inverse problem, which is ill-posed and requires regularization. Experiments on multiple-section holograms demonstrate the efficacy of the approach in sectional image reconstruction with suppression of the defocus noise.

Keywords: Optical scanning holography, inverse imaging

1. **Introduction**

Optical scanning holography (OSH) is a technique which records the holographic information of a three-dimensional (3-D) object on a two-dimensional (2-D) hologram by lateral scanning [1]. Nowadays, it covers a great number of application areas, such as holographic fluorescence microscopy, remote sensing and biological microscopy [2, 3, 4, 5, 6]. The first system was designed by Poon in 1985 [7]. Using optical scanning, multiple sections of an object are recorded on a 2-D hologram [8, 9]. Generally, the hologram is complex-valued and contains information from all sections. Our goal is to design a flexible image reconstruction technique that can obtain sectional images from OSH. We achieve this by formulating the imaging using a matrix approach, resulting in an inverse imaging problem for the sectioning of the hologram. To cope with the ill-posed nature of the imaging, regularization is used, together with an iterative approach for the successive computations.

2. Imaging model

Optical Scanning Holography (OSH) records the holographic information of a 3-D object by optical heterodyne scanning. It was designed by Poon in 1985 [7]. Mathematical analysis of the OSH system has been conducted by Poon [10] and Swoger et al. [11] in details. Its spatial impulse response is

$$h(x,y;z)\,|_{\text{osh}} = -j\frac{k_0}{2\pi z}\,\text{esp}\left\{\frac{jk_0(x^2+y^2)}{2z}\right\}. \tag{1}$$

Then, the hologram can be represented by a summation,

$$g_c(x,y) = \sum_{i=1}^{n}\left\{\left|\phi(x,y;z_i\right|^2 * h(x,y;z_i)\right\}, \tag{2}$$

where * denotes the convolution operation. In practice, z is sampled at a series of positions, denoted by z_1, z_2, $\cdots$, z_n. Suppose the focused plane is located at z_1. A reconstruction of the sectional image means to recover $\left|\phi(x,y;z_i)\right|$ from a hologram $g_c(x, y)$. When an object has two sections as an example,

$$g_c(x,y) = \left|\phi(x,y;z_1\right|^2 * h(x,y;z_1) + \left|\phi(x,y;z_2\right|^2 * h(x,y;z_2). \tag{3}$$

Because OSH is a linear space-invariant system, convolution with $h_1(x, y)$ and $h_2(x, y)$ can be replaced by the multiplication operation expressed as follows

$$\gamma_c = H_1\psi_1 + H_2\psi_2 = [H_1 \quad H_2]\begin{bmatrix}\psi_1\\ \psi_2\end{bmatrix} = H\psi. \tag{4}$$

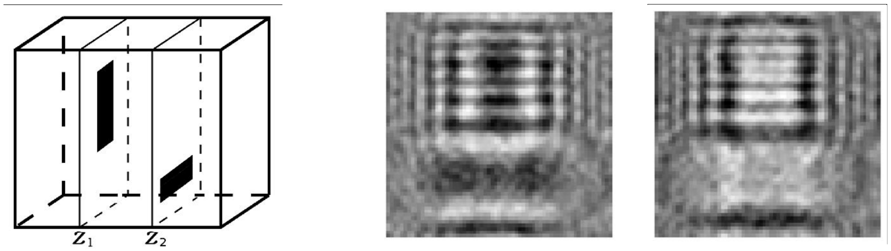
We can only find an approximation of ψ in the equation above because of the ill-posed nature of the inverse imaging problem. The regularization method is employed to reach the solution. We formulate the image reconstruction as a minimization problem

$$\text{minimize}_{\psi} \quad f(\psi) = \left\|A\psi - \beta_c\right\|^2 + \lambda\left\|C\psi\right\|^2, \tag{5}$$

where $\left\|\cdot\right\|^2$ denotes the L_2 norm, C stands for the Laplacian operator, and λ is the regularization parameter.

3. Results

The first experiment is performed on an object drawn in Fig. 1a and containing two elements in two distinct sections, z_1 and z_2 away from the scanner of OSH system. We suppose the object is illuminated by a HeNe laser, whose wavelength is 0.63mm and that two sections including individual element in each are located at z_1=10mm and z_2=11mm. The two sections are scanned to generate a hologram. During the scanning, the hologram is further contaminated by additive white Gaussian noise with zero mean and 0.01 variance.



(a) (b)

Fig.1 The object and holograms. Shown in Fig. 1a is the object and 1b are the cosine Fresnel zone plate (FZP) hologram and sine-FZP hologram, respectively.

Optical scanning technique produces the complex hologram of the object. The real part of the hologram is referred to as the sine-FZP hologram, the imaginary part as the cosine-FZP hologram [10]. Fig. 1b present the two kinds of holograms. An observation directly on them is hard to figure out any intensity distribution information of the two sections. The inverse imaging method is used to reconstruct the sectional images and suppress the defocus noise. The reconstructed images are shown in Fig. 2.

(a) (b)

Fig.2 Reconstructed sectional images. Shown in Fig.2a and Fig.2b are the reconstructed sections at z_1 and z_2.

As is presented, each reconstructed section is barely influenced by the defocus noise as well as the element in each is clearly recovered. Signal-to-noise ratio (SNR) between the original sections and the recovered ones are 29.93 dB at z_1 and 28.85 dB at z_2. The experiment demonstrates that the reconstruction recovers sectional images without visible influence of defocus noise, and with efficient suppression of additive white Gaussian noise.

4. Conclusions

In the paper, we propose a novel model to reformulate the scanning technique, in which matrix multiplication replaces the convolution operation to express a hologram. The reconstruction is equivalent to solving an ill-posed inverse problem. Then the regularization method is used to yield the reconstructed sections. Our results demonstrate that our method can achieve reconstructions with good image quality.

5. References

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