Efficient Autofocusing in Optical Scanning Holography

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Abstract

For the optical scanning holography (OSH) system, obtaining the distance parameters, known as autofocusing, is a key preprocessing step in sectional image reconstruction. In this paper, we discuss an efficient analytic autofocusing technique, which is applicable to the reconstruction of single-section objects from their complex holograms, without the need for axial scanning or blind estimation.

1. Mathematical Principles

The OSH imaging system [1,2] is modeled as a linear space-invariant (LSI) system. The optical transfer function (OTF) is given by

$$H\left(k_x,k_y;z\right)=\exp\left\{-j\frac{z}{2z_0}\left(k_x^2+k_y^2\right)\right\}, \tag{1}$$

where k_x and k_y are the transverse spatial frequency coordinates, and k_0 is the wavenumber ($k_0=\frac{2\pi}{\lambda}$). Correspondingly, the spatial impulse response is the inverse Fourier transform

$$h(x,y;z)=-j\frac{k_0}{2\pi z}\left\{j\frac{k_0}{2z}\left(x^2+y^2\right)\right\}. \tag{2}$$

The hologram generated by OSH of a single-section object located at distance z is

$$g(x,y)=|o(x,y;z)|^2*h(x,y;z), \tag{3}$$

where $|o(x,y;z)|^2$ is the complex light field of the object and "$*$" denotes 2-D convolution. The hologram in frequency domain is

$$G\left(k_x,k_y;z\right)=I\left(k_x,k_y;z\right)H\left(k_x,k_y;z\right). \tag{4}$$

If we look at the phase, then

$$\varphi_G\left(k_x,k_y;z\right)=\varphi_I\left(k_x,k_y;z\right)+\varphi_H\left(k_x,k_y;z\right). \tag{5}$$

Since $|o(x,y;z)|^2$ is real while $h(x,y;z)$ is symmetric about its center, as given above, it is seen that

$$\varphi_I\left(k_x,k_y;z\right)=-\varphi_I\left(-k_x,-k_y;z\right); \tag{6}$$

$$\varphi_H\left(k_x,k_y;z\right)=\varphi_H\left(-k_x,-k_y;z\right). \tag{7}$$

For Eq.(7), which is a 2-D function, we examine the lines across the origin. In other words, we set $k_y=ak_x$, where a is a constant. By flipping $\varphi_G\left(k_x,k_y;z\right)$ and taking average, $\varphi_H\left(k_x,k_y;z\right)$ is obtained, where

$$\begin{aligned}\varphi_H(k_x;z)&=\frac{1}{2}\left[\varphi_G(k_x;z)+\varphi_G(-k_x;z)\right]\\&=-\frac{z}{2k_0}\left(1+a^2\right)k_x.\end{aligned} \tag{8}$$

By assigning certain values to a and k_x, z can be derived.

2. Simulation

To test the autofocusing technique, six thin objects are imaged by the OSH system to generate the corresponding holograms, where we have also added some random noise, which is distributed randomly along the z-axis. The accuracy of this autofocusing technique is illustrated in Figure I.

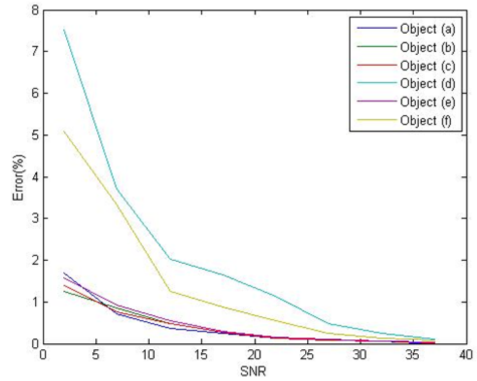

Figure I　Relative errors changing with SNR.

The typical SNR of the OSH imaging system ranges from 20dB to 40dB. According to Figure I, in that particular range, the error is less than 2%.

After obtaining the distance parameter, the objects are reconstructed using the conventional reconstruction method [1]. Reconstructed objects (a) and (f) are displayed in Figure II. SNR is around 32dB in these cases.

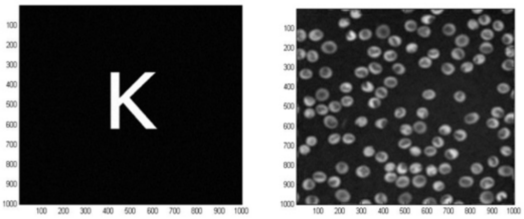

Figure II　Two reconstructed objects with SNR = 32dB.

3. Conclusions

An efficient autofocusing technique for OSH is proposed, implemented and tested. The performance is accurate and fast. The application is limited to single-section objects at present.

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