

OpenHolo Algorithm Guide

(Hologram Core Processing ::

Extraction of distance parameter

using axis transformation)

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1. Introduction

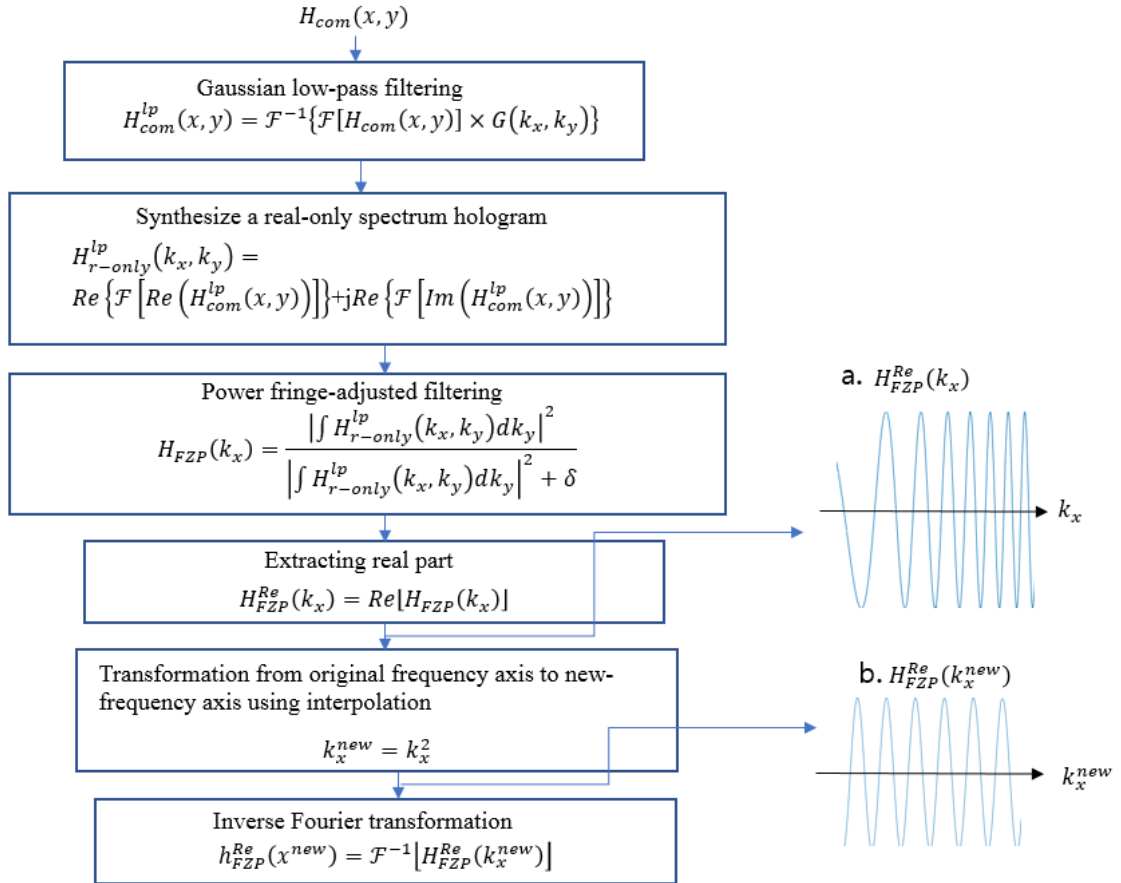
OSH is reconstructed digitally by convolving the complex conjugate of Fresnel zone plate (FZP) with the hologram. This is the same as conventional digital holography, in which the FZP's distance parameter is set according to the depth location of the objects. However, since the depth location of the objects is unknown, digital reconstructions with different distance parameters are required until we get a focused image.

Unfortunately, this searching process is time consuming and requires a manual process. Recently several numerical techniques that extract the distance parameter directly from the hologram without reconstructions have been proposed [1-3]; however, these involve a search algorithm [2,3] or a tracking process [1]. Most recently, an auto-focusing technique based on the Wigner distribution analysis of a hologram has been proposed [4].

In the proposed technique, we extract the distance parameter directly from the hologram without any searching or tracking process. However, a manual process that measures the slope of the Wigner distribution output is required in order to determine the distance parameter. Therefore, we propose to extract the distance parameter directly from the hologram using axis transformation without any manual processes.

2. Algorithm

2.1. Extraction of distance parameter using axis transformation method



[Fig. 1] Algorithm 2.1 Flow Chart

First, the complex hologram is filtered by a Gaussian low-pass filter with transfer function. The Gaussian low-pass filtered hologram is given by the following equation:

$$\begin{aligned}
 H_{com}^{lp}(x, y) &= \mathcal{F}^{-1}\{\mathcal{F}[H_{com}(x, y)] \times G(k_x, k_y)\} \\
 &= \int_{z_0 - \frac{1}{2}\delta z}^{z_0 + \frac{1}{2}\delta z} I_o(x, y, z) \otimes \frac{j}{\lambda z} \exp\left[\left(\frac{-\pi}{a_{lp}(z)^2} - j\frac{\pi}{\lambda z}\right)(x^2 + y^2)\right] dz \\
 G(k_x, k_y) &= \exp\left\{-\pi\left[\frac{\lambda}{2\pi NA_g}\right]^2(k_x^2 + k_y^2)\right\}
 \end{aligned} \tag{1}$$

Where $\mathcal{F}\{\cdot\}$ represents the Fourier transform operator, $a_{lp}(z) = NA_g NA / \sqrt{NA^2 + NA_g^2} \times z$ determines the radius of the Gaussian low pass filtered hologram. Hence, the Reyleigh range of the Gaussian low-pass filtered hologram evolves into the following equation:

$$\Delta z = 2\lambda z^2 / (a_{lp}(z)^2 \pi) = 2\lambda / \pi \times (NA^2 + NA_g^2) / (NA_g NA)^2$$

In Gaussian low pass filtering, we set NA_g such that the Rayleigh range of the FZP is larger than the depth range of the object, i.e. $\Delta z \geq \delta z$. The radius of the scanning beam pattern is approximately constant within the depth range of the object. This makes the phase of the Gaussian low pass filtered hologram stationary within the depth range of the specimen [4, 5]; thus, we can extract the FZP which contains the information only about the distance parameter from the hologram.

Second, a real-only spectrum hologram in the frequency domain is synthesized and is given by the following:

$$H_{r-only}^{lp}(k_x, k_y) = \text{Re} \left\{ \mathcal{F} \left[\text{Re} \left(H_{com}^{lp}(x, y) \right) \right] \right\} + j \text{Re} \left\{ \mathcal{F} \left[\text{Im} \left(H_{com}^{lp}(x, y) \right) \right] \right\} \quad (2)$$

After projecting the real-only spectrum hologram onto the k_y direction, we filter the square of the projected real-only spectrum hologram by a power-fringe-adjusted filter [6-9]. The power-fringe-adjusted filtered output is given by:

$$H_{FZP}(k_x) = \frac{\left| \int H_{r-only}^{lp}(k_x, k_y) dk_y \right|^2}{\left| \int H_{r-only}^{lp}(k_x, k_y) dk_y \right|^2 + \delta} \approx \exp \left(j \frac{\lambda z_0}{2\pi} k_x^2 \right) \quad (3)$$

Eq. (3), the filtered output is a chirping signal whose chirping rate is determined by the distance parameter. Note that the filtered output is the one-dimensional FZP with the distance parameter.

Third, the real part of Eq. (3) is extracted and is given by the following: .

$$H_{FZP}^{Re}(k_x) = \text{Re}[H_{FZP}(k_x)] \approx \cos \left(\frac{\lambda z_0}{2\pi} k_x^2 \right) \quad (4)$$

$H_{FZP}^{Re}(k_x)$ shown as fig.1-a.

Fourth, the transformation from original frequency axis to new-frequency axis using interpolation.

$$k_x^{new} = k_x^2, \quad H_{FZP}^{Re}(k_x^{new}) \approx \cos \left(\frac{\lambda z_0}{2\pi} k_x^{new} \right) \quad (5)$$

Note that this sinusoidal signal has a single frequency and the frequency of the signal is directly proportional to the distance parameter. Hence, the inverse Fourier transformation of Eq.(5) expresses the delta function pair in the new spatial axis:

$$h_{FZP}^{Re}(x^{new}) = \mathcal{F}^{-1}\{H_{FZP}^{Re}(k_x^{new})\} \approx \frac{1}{2} \delta\left(x^{new} - \frac{\lambda z_0}{2\pi}\right) + \frac{1}{2} \delta\left(x^{new} + \frac{\lambda z_0}{2\pi}\right) \quad (6)$$

Note that the location of the delta function pair gives the distance parameter. This can be extracted directly by detecting the location of the maximum value of Eq. (6).

Extraction a Distance Parameter	
Input	<ul style="list-style-type: none"> • data.mat : Input hologram data
Output	<ul style="list-style-type: none"> • max : weight of distance parameter , max_loc : Distance parameter
<pre> clear load data %Gaussian filter generation unit radius=900; %Radius of Gaussian filter in arbitrary unit L=1*10^-2; %Length of frequency axis in arbitrary unit for r=1:1024, for c=1:1024, %compute Gaussian filter Kx(r)=L/(255*4)*(r-1)-L/2; Ky(c)=L/(255*4)*(c-1)-L/2; G(r,c)=exp(-radius*4*(Kx(r).^2+Ky(c).^2)); end end %Real-only hologram generation stage %Extracting real and imaginary parts of the complex hologram FIR=real(fft2(real(h))); FII=real(fft2(imag(h))); %Synthesize the real-only hologram Hsyn=FIR+j*FII; %Gaussian low-pass filtering Hsyn=Hsyn.*G; %Power fringe-adjusted filtering Fo=(Hsyn.*Hsyn)./(abs(Hsyn).*abs(Hsyn)+10^-300); Fo=fftshift(Fo); %Axis transformation t=linspace(0,1,129); tn=t.^0.5; Fon=real(Fo(512,512:512+128)); yn=interp1(t,Fon,tn); %location extraction Ab_yn=abs(fft(yn)); [max max_loc] = max(Ab_yn(65:129)) Save max max </pre>	

	Save max_loc max_loc
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Code 1. Algorithm 2.1 Pseudo Code

3. Implementation S/W

Type	Source File	S/W	Description
Matlab	axis_trans.m		Load hologram data and extraction of a distance parameter using axis transformation

4. Reference

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- [9] P. Klysubun, G. Indebetouw, T. Kim, and T.-C. Poon, "Accuracy of three-dimensional remote target location using scanning holographic correlation," *Opt. Comm.* **184**, 357 -366 (2000).
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