OpenHolo Algorithm Guide

(Hologram Core Processing ::

Chromatic Aberration Compensation Filter)

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Contents

1. Introduction

Recording holographic information of a real object as a form of electric signal has a long history [1,2]. Optical scanning holography (OSH) proposed to record a hologram of a real object using heterodyne scanning [3,4]. Twin-image noise in OSH was eliminated by recording a complex hologram using in-phase and quadrature(Q) -phase heterodyne detection scheme [5]. speckle-free recording of a complex hologram using OSH has been demonstrated [6]. Recently full-color OSH has been proposed and shows that the full-color complex hologram of a real object can be recorded by two dimensional (2D) scanning [7].

Meanwhile, digital holography has been intensively investigated for recording a hologram of a real object for a three-dimensional (3D) imaging system as well as industrial metrology applications [8,9]. Recently, color digital holography has been proposed and chromatic aberration compensation techniques are investigated [11-16]. As in color digital holography, the chromatic aberration issue has also been emerged in full-color OSH. In this paper, I will investigate the chromatic aberration issue of full-color OSH and propose a digital filtering technique that compensates the chromatic aberration.

2. Algorithm

2.1. CHROMATIC ABERRATION OF FULL-COLOR OPTICALSCANNING HOLOGRAPHY

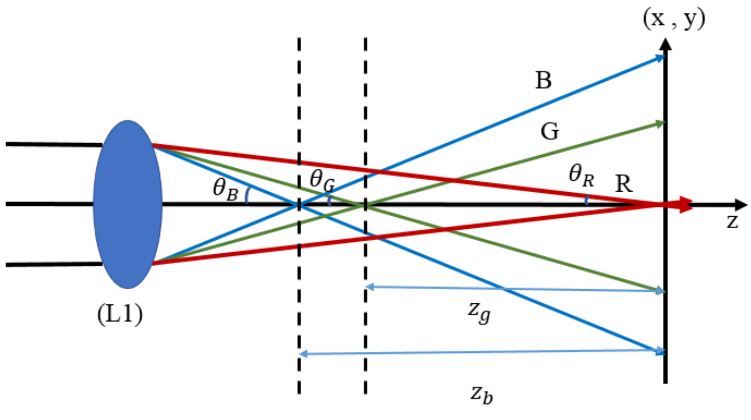
The complex RGB holograms that are encoded pattern between RGB FZPs and object's RGB reflectances are given by [7]:

$$H_n(x,y) = \int I_n\,(x,y,z) \otimes \frac{j}{\lambda_n z_n} exp\left\{\left(\frac{-\pi}{{NA_n}^2{z_n}^2} + j\frac{\pi}{\lambda_n z_n}\right)(x^2+y^2)\right\} dz$$

$$\text{n}=\{R,G,B\} \tag{1}$$

$\otimes$ represents 2D convolution operation, $I_n(\text{x},\text{y},\text{z})$ are the RGB reflectances of the object, λ_n are the wave length of RGB beams, z_n are the distance between the focal points of RGB spherical waves to the object's RGB reflectances distributions and NA_n represent the numerical apertures defined as the sine of the half-cone angle subtended by RGB spherical waves.

Full-color OSH has chromatic aberration issue. Figure 1 represents the RGB spherical waves generated by L1 where L1 is made of conventional material whose refractive index decreases as wavelength increases in visible range. Since the refractive index of the material depends on the wavelength, the location of the focal points of the RGB spherical waves are different as shown in fig. 1.



[Fig. 1] RGB spherical waves generated by the lens L1.

The focal length of a conventional bi-convex lens is given by :

$$\text{f} = \frac{1}{(n_l - 1)\left[\frac{2}{R} - \frac{(n_l - 1)d}{n_l R^2}\right]} \qquad (2)$$

where n_l is the refractive index of the lens L1, R is the front and back radii of curvature and d is the center thickness of the lens L1. As shown in Eq (1), the RGB holograms are encoded patterns between the spatial distribution of the object's RGB reflectances and RGB FZPs. We note that the focal lengths of the RGB spherical waves are different according the Eq (2). This makes the distances (Z_n) from the focal points of the RGB spherical waves to the object's RGB reflectances distributions, and the numerical apertures ($NA_n = \mathrm{Sin}(\theta_n)$) of the RGB FZPs depend on the wavelengths of RGB beams. Since the Z_n and the NA_n of the RGB FZPs are different according to the RGB beams, the recorded RGB holograms are reconstructed at different depth locations with different divergence angles. This causes chromatic aberration as in the conventional imaging system.

2.2. NUMERICAL COMPENSATION OF CHROMATIC ABERRATION OF FULL-COLOR OPTICAL SCANNING HOLOGRAPHY

We need to match the NAs and focal lengths of RGB FZPs each other. Because focals length and NAs of the RGB FZPs in recorded RGB holograms are different according to the wavelengths. Chromatic aberration compensation filter (CAC) matches the NAs and focal lengths of the RGB FZPs of the recorded RGB hologram. The fig. 2 shows the CAC filter that matches the NAs and focal lengths of the GB FZPs in the GB holograms to those of the R FZP in the R hologram, where (k_x, k_y) is the spatial frequencies, G_n are the extents of the CAC filter and z_n are the focal length differences as shown in fig. 1.

The extent of CAC filter G_n match the NAs of the GB FZPs to the NA of the R hologram. The fringes of the CAC filter determined by $\lambda_n z_n$ match the focal lengths of GB FZPs to the focal length of the R FZP.

$$H_n(x,y)$$

Transfer function

$$\boldsymbol{G_n}(k_x,k_y)=\exp\left\{\left[-\frac{1}{4\pi}\left(\frac{\lambda}{\mathrm{G_n}}\right)^2-\frac{j\lambda_n z_n}{4\pi}\right]\left(k_x{}^2+k_y{}^2\right)\right\}$$

$$where\ G_n=\frac{NA_R NA_n}{\sqrt{NA_n^2-NA_R^2}},n=\{B,G\}$$

$$H_n^{Comp.}(x,y)=\int I_o(x,y,z)\otimes\frac{j}{\lambda_n z}\exp\left\{\left(\frac{-\pi}{NA_n^2 z^2}+j\frac{\pi}{\lambda_n z}\right)\left(x^2+y^2\right)\right\}dz$$

$$where\ n=\{B,G\}$$

[Fig. 2] Algorithm 2.2 Flow Chart.

Chromatic Aberration Compensation Filter	
Input	• data1.mat : Input R,G,B hologram data
Output	• fzp_r : Red hologram • fzpb_com_holo : Chromatic aberration compensated Green hologram • fzpb_com_holo: Chromatic aberration compensated Blue hologram

```
clear,clc

%% Hologram input

load(data1.mat)     %%Input R,G,B hologram data

z=11.05;
lr=633*10^-9;lg=532*10^-9;lb=488*10^-9;     %%R,G,B Wavelength


ky=-0.075;
for r=1:1024
   kx=-0.075;
   for c=1:1024

        FZP_R(r,c)=exp(j./(z*lr)*kx*kx+j./(z*lr)*ky*ky);
        kx=kx+ 1.4648e-04;
        end
   ky=ky+ 1.4648e-04;
end



kyy=-0.075;
for r2=1:1024
   kxx=-0.075;
   for c2=1:1024

        FZP_G(r2,c2)=exp(j./(z*lg)*kxx*kxx+j./(z*lg)*kyy*kyy);
        kxx=kxx+ 1.4648e-04;
        end
   kyy=kyy+ 1.4648e-04;
end


kyyy=-0.075;
for r3=1:1024
   kxxx=-0.075;
   for c3=1:1024

        FZP_B(r3,c3)=exp(j./(z*lb)*kxxx*kxxx+j./(z*lb)*kyyy*kyyy);
        kxxx=kxxx+ 1.4648e-04;
        end
   kyyy=kyyy+ 1.4648e-04;
```

```
end


%% CAC Filter

FZP_R=ifft2(FZP_R);
FZP_R=ifftshift(FZP_R);

FZPB_COM=FZP_B.*conj(FZP_R);   %% Blue Compensation Filter
FZPG_COM=FZP_G.*conj(FZP_R);   %% Grenn Compensation Filter

Holo_G=fft2(Holo_g); Holo_B=fft2(Holo_b);
Holo_G=fftshift(Holo_g); Holo_B=fftshift(Holo_b);

fzpb_com_holo=ifft2(Holo_B.*conj(FZPB_COM));
fzpb_com_holo=ifftshift(fzpb_com_holo);

fzpg_com_holo=ifft2(Holo_G.*conj(FZPG_COM));
fzpg_com_holo=ifftshift(fzpg_com_holo);


save FZP_R FZP_R
save fzpg_com_holo fzpg_com_holo
save fzpb_com_holo fzpb_com_holo
```

3. Implementation S/W

Type	Source File	S/W	Description
Matlab	*Chromatic_aberration.m*		Load R,G,B hologram data and compensate chromatic aberration using CAC filter.

4. Reference

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