Color Image Reconstruction Based On Digital Holography

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Abstract. In this paper, a color image reconstruction algorithm based on digital hologram is proposed. The color image is decomposed into three primary color images, and the corresponding hologram is generated in each channel using the four step phase shift method. Then the image of each channel is reconstructed using the inverse Fourier transform, the reconstructed graph of three channels is superimposed to obtain the final color reconstruction image. The reconstructed image overcomes the zero-order image and the straight-through bright spot generated during Fresnel digital holographic image generation in the coaxial recording mode.

1. Introduction:
When the eye receives the light information from the object, it can see the three-dimensional image of the object due to the parallax of the two eyes. The carrier, which can record the object's light wave on it and recreate it under a given light, is called a "hologram", in which one can see the three-dimensional image of the object in a given light [1]. This kind of imaging technique, which is completely different from traditional photography, is called optical holography. Digital holography is the use of photoelectric sensor components (such as CCD or CMOS) to replace the dry plate recording hologram, and then the hologram is stored in a computer, and computer holographic optical diffraction process is used to realize the holographic reproduction and processing of the recorded object. Compared with traditional optical holography, digital holography has the advantages of low fabrication cost, fast imaging speed, flexible recording and reappearance. In recent years, with the development of computer, especially high resolution CCD, digital holography technology and its application has been paid more and more attention, and its application scope has involved in many fields such as topography measurement, deformation measurement, particle field test, digital holography microscope, anti-counterfeiting, three-dimensional image recognition, medical diagnosis and so on. Combining the mathematical technique with the traditional optical holography technology, the CCD device is used as the holographic recording medium, and the digital.holography theory, method, technique and the application of digital holography in the particle field are studied in this paper [2].

Due to advances in computer and CCD detection technologies, CCDs have been used in place of traditional silver salt plates, digital holograms have been virtually reproduced with computerized light, diffraction is reproduced numerically to reproduce the propagation of object light, and finally, computer image display technology has been used. Digital holography, which reproduces images of objects, is making remarkable progress. This article uses four holograms to obtain the object light field that reaches the CCD, and then uses the diffraction inverse to reconstruct the object plane image [3]. In addition, the phase shift method overcomes the zero-order image and the straight-through bright spot generated when the Fresnel digital holographic image is generated in the coaxial recording mode.
Makes each channel’s reconstructed image look very good, and the synthesized color image is perfect in both sharpness and color.

2. True color image
According to the different interpretation methods of image data matrix, MATLAB divides the processed images into three categories: variable access image, grayscale image and true color image. True color refers to the composition of a color image in each pixel value, there is a r,g,b three base color components, each base component directly determines the base color of the display device, so that the resulting color is called true color. Different data types stored in MATLAB True Color images are classified into double (double) and integer (Unit 8 or Unit 16) data precision. When the data precision is double, the array size of the image matrix X is (m×n)×3, and the element value is a linear quantized floating-point number between [0,1], which directly determines the intensity of the color, and the required memory is 64×(m×n)×3; the color of the pixel pij has the following three colors: X(i,j,1) determines the red intensity, X(i,j,2) determines the green intensity, and X(i,j,3) determines the blue intensity.

According to the hologram of each base light recorded by CCD or color CCD, not only can we reconstruct all kinds of base shade wave fields from the object in the computer, but also can show the real color image of the object through the screen. Studying the different responses of objects to the three-base light can reveal the information of the object more fully.

3. Fresnel Integral
Based on the Fresnel diffraction reconstruction algorithm, the amplitude and phase information of the measured sample can be extracted from a hologram, and the original object image is reconstructed in real time [4]. Fresnel diffraction integral is the most widely used formula in applied research, and Fresnel diffraction integral is:

\[
U(x, y, z) = \frac{\exp(jkz)}{j\lambda z} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} U_0(x_0, y_0) \times 
\exp \left\{ \frac{jk}{2z} [(x - x_0)^2 + (y - y_0)^2] \right\} dx_0 dy_0
\]

in the formula, \(U_0(x_0, y_0)\) and \(U(x, y)\) are the complex amplitude of the light wave in the plane and the observation plane, respectively. \(Z\) is to observe the distance between the plane and the plane of the object. \(\lambda\) is the wavelength of light; \(k=2\pi/\lambda\) is wave number. The above formula can be used to calculate the diffraction of the diffracted field distribution, which is called Fresnel diffraction.

The Fourier transform on both sides of the (1) type and the use of the spatial convolution law are:

\[
F\{U(x, y)\} = F\{U_0(x_0, y_0)\} 
\]
\[
F \left\{ \frac{\exp(jkz)}{j\lambda z} \exp \left\{ \frac{jk}{2z} (x^2 + y^2) \right\} \right\} = F_{\mathcal{F}} \left\{ \frac{\exp(jkz)}{j\lambda z} \exp \left\{ \frac{jk}{2z} (x^2 + y^2) \right\} \right\}
\]

So \(f_x, f_y\) is a frequency domain coordinate, and the Fresnel diffraction transfer function can be defined:

\[
H_{\mathcal{F}}(f_x, f_y) = F \left\{ \frac{\exp(jkz)}{j\lambda z} \exp \left\{ \frac{jk}{2z} (x^2 + y^2) \right\} \right\}
\]

The Fresnel diffraction expression of Fourier transform and inverse transformation is obtained by the inverse Fourier transform on both sides of (2).

\[
U(x, y) = F^{-1} \{ F[U_0(x_0, y_0)]H_{\mathcal{F}}(f_x, f_y) \}
\]

It can be seen that the Fresnel diffraction process is equivalent to the process of passing the object plane light wave field through a linear space invariant system. The spectrum of the light wave field of the observed plane is the product of the spectrum of the plane light wave field and a Fresnel diffraction transfer function \(H_{\mathcal{F}}\).
4. Four-Step phase shift method

The basic principle of phase shift method is through the phase shifter of moving reference mirror in the interferometer, the optical path of the reference beam and the test beam difference, the fringe position will be the corresponding mobile, make a little arbitrary intensity in the interference field of a cosine curve, three images or images with different acquisition the phase of the interferogram with light sensitive electronic components CCD [5]. This can remove the interference of the zero-order image and the conjugate image. The coherent superposition of the reference light wave and the material light wave in the CCD, the intensity distribution of the interference field recorded by CCD is as follows:

\[
I(x, y) = \left| R(x, y) \exp(j\theta) + O(x, y) \exp(j\phi) \right|^2 = \left| R \right|^2 + \left| Q \right|^2 + R \cdot Q \exp(-j\phi) \exp(j\theta) + R \cdot Q \exp(-j\theta) \exp(j\phi) \]  

In the formula: \( \theta \) is the introduced stepped phase shift angle, \( R \) and \( O \) are the amplitudes of the plane wave and scattered light reaching the CCD of the recording medium, respectively, and \( \Phi \) is the angle between the original and the Z axis.

Four-step phase-shifting algorithm refers to the process of recording the hologram, according to a certain state of the object, using the phase shifter to the reference light to take 4 different phase shift value, is generally 0, \( \pi/2 \), \( \pi \), \( 3\pi/2 \), the recorded four maps of the intensity distribution by (5) can be:

\[
\begin{align*}
I(x, y, 0) &= |R_0|^2 + |Q_0|^2 + 2R_0Q_0 \cos \varphi \\
I(x, y, \pi/2) &= |R_0|^2 + |Q_0|^2 + 2R_0Q_0 \sin \varphi \\
I(x, y, \pi) &= |R_0|^2 + |Q_0|^2 - 2R_0Q_0 \cos \varphi \\
I(x, y, 3\pi/2) &= |R_0|^2 + |Q_0|^2 - 2R_0Q_0 \sin \varphi
\end{align*}
\]  

The complex amplitude distribution of the CCD wave can be obtained by the four-step phase shift algorithm:

\[
O(x, y) = \frac{1}{4R} \left\{ [I(x, y, 0) - I(x, y, \pi)] + j[I(x, y, \pi/2) - I(x, y, 3\pi/2)] \right\} \]  

Equation (7) above is the digital holographic reproduction formula that we need. This method can eliminate zero-order images and conjugate images, improve the signal-to-noise ratio of digital holograms, and improve the reproduction image quality.

5. Principles and steps

In this paper, a color image reconstruction based on coaxial digital holography is studied and designed. When it is generated, the true color image is read and decomposed, then the hologram is computed, and the four-step phase-shift method overcomes the zero-order images and the straight translucent spot produced by the Fresnel digital hologram when the coaxial recording mode is generated. In the display, the three-color hologram is reconstructed respectively to the corresponding gray-scale graph, and three images are synthesized to obtain the complete color image. The quality of the reconstructed image is ensured and the imaging is clearer. The specific steps are as follows:

1. Decomposing color images
   Read a true color image and decompose the color image into the gray scale of three channels of R, G and B.

2. Generate holograms
   using the four-step phase shift method, so that each channel to generate a corresponding hologram.

3. Rebuilding images
   Using the Fourier inverse transform, the generated hologram is used to reconstruct, and a gray-scale reconstruction diagram is restored in each channel.

4. Combining images
   Three reconstruction images are synthesized to obtain the color reconstruction image, and the color
reconstruction map is compared with the original color image, and the observation effect is observed.

6. Analysis of experimental results

Decompose the original image:

![Fig.6.1 Color image](image1)
![Fig.6.2 Red component](image2)
![Fig.6.3 Green component](image3)
![Fig.6.4 Blue component](image4)

The three channels generate the holograms, respectively:

![Fig.6.5 Hologram of the Red channel](image5)
![Fig.6.6 Hologram of the Green channel](image6)
Images reconstructed by three channels:

Fig.6.7 Hologram of the Blue channel

Fig.6.8 Image reconstruction of Red channel

Fig.6.9 Image reconstruction of Green channel

Fig.6.10 Image reconstruction of Blue channel

The synthesized color image is compared with the original image:
From the graphs, we can see that every channel has good reconstruction results, and the synthesized color reproduction map is not quite different from the original one. The effect is perfect no matter in color or clarity, so it proves the feasibility of this method.

7. Conclusion

Compared to the traditional holographic technique, digital holography eliminates the tedious steps of developing and fixing in the process of reproducing, but because of the lack of the resolution of CCD detector in digital holography, the small size of the effective aperture, the image quality of digital holography is poor, in order to improve some problems appearing in digital holography, the effective bandwidth of CCD is fully utilized, In general, phase-shifting technology and coaxial digital holography are combined to improve the reconstruction quality of digital holograms.

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