Visual Influence of Additive Color Mixture in Reconstructed Hologram Images using He-Cd Laser and Dichroic Mirrors

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A blue white beam of commercially available He-Cd laser can be divided into the three primary color beams of light, i.e., R/G/B beam components using a set of dichroic mirrors. The dichroic mirror is widely used for color TV cameras to separate the visual image into its three primary color components.

In this study, an influence of additive color mixture in two types of reconstructed hologram images is checked through the optical experiments using the He-Cd laser and dichroic mirrors. The visual appearances and deteriorations of reconstructed color images owing to the cross-talk called overlapped or ghost image are discussed as for the optical Fresnel hologram and computer generated FTH (Fourier Transform Hologram).

1. Introduction

Optical holography technology has found a remarkably wide range of applications such as color holography, holographic interferometry, holographic optical elements and computer-generated holograms, and has developed various lasers and recording materials [1].

An idea of a multicolor image with 3-D appearances with reality was first pointed out by Leith and Upatnieks [2]. The color hologram is recorded on a special panchromatic film or plate by means of multiple exposure. It looks like the conventional monochromatic hologram in appearance, but the optical process for making and reconstructing the hologram differs from the standard holography techniques [3]. Special coherent light of the commercially available He-Cd laser can be divided into three primary colors, i.e., R/G/B beam components, using a set of dichroic mirrors which is widely used for color TV cameras. A special laser such as a He-Cd laser and a unique recording material are used in the color holography. The resulting hologram are considered as incoherently superposed holograms. When the color hologram is suitably illuminated using the light with three different wavelengths, each of light for reconstructing the original object image is diffracted by the hologram.

The superposition of these three images results in a multicolor image under the limited condition. But, there are the several practical problems of light sources for color holography, recording materials, the deterioration of reconstructed color images etc., though an idea of the multicolor holography was demonstrated in the early 1960's.

On the other hand, the unique techniques for making quasi-color holograms have been studied by many researchers. These special holograms, for example, rainbow hologram, Lippmann hologram, image hologram, embossed hologram and so on can be simply reconstructed with general white light such as an incandescent lamp. Recently, the feasibility study for making electron-beam CGHs has been carried out by Hamano and Kitamura [4]. Reconstructed color images of the CGH can be observed under white light, and 3-D image CGHs fabricated by electron beam printing seem to be practical for future commercial use, especially in the optical security field.

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In this study, the influence of additive color mixture in reconstructed holograms is checked from in the optical experiments. Cross-talk problems owing to the two types of holograms, i.e., optical Fresnel hologram and computer generated FTH (Fourier Transform Hologram), are discussed in terms of the visual depth sensation and over-lapping deterioration of reconstructed color images.

2. He-Cd Laser and Dichroic Mirror

2.1 Overview of He-Cd Laser

A hollow cathode He-Cd laser with coherent blue-white light is developed by Koito Manufacturing Co., Ltd., and is now commercially available [5]. In contrast to the conventional He-Cd laser (only blue light) which uses the positive column plasma as the laser medium, this new laser uses the negative glow plasma. The negative glow plasma can be generated in the center of cathode pipe. Both the electron density and energy of the negative glow plasma become very high. In addition to the blue light, it is possible to obtain red and green beam components from a single laser tube. This laser beam can oscillate simultaneously at red (636.0 nm and 635.5 nm), green (537.8 nm and 533.8 nm), and blue (441.6 nm) in a single tube. The characteristics of output power of the blue-white light laser are mainly affected by He pressure, discharge current, Cd^{+} vapor pressure corresponding to an anode voltage. The vapor pressure of Cd is an important parameter which determines the output of the laser. To keep it constant, the outside of reservoir is surrounded by a heater so that the temperature of the Cd reservoir is controlled. The vapor pressure of Cd in the laser tube is 10 [Pa] (7.5×10^{-2} [Torr]). Total output power of the three colors is about 34 [mW] (red power: 6 mW, green power: 8 mW, and blue power: 20 mW) at specifications. The life time, to be specific, can now exceed more than 1,000 [h] without refilling of the He gas and Cd from the outside.

2.2 Role of dichroic mirror

There are many types of optical filters which are used for photography, TV camera, holography, and so on. A dichroic filter is a kind of special filter. The ordinary dichroic color filter is available for color separation and/or color contrast improvement. The dichroic filter transmits one region of wavelengths and reflects the rest, thus splitting a white beam into complementary colors. For example, the red dichroic filter transmits the red component only, and reflects the G and B components. On the other hand, a special filter called dichroic mirror is widely used for color TV camera to separate the visual image into the three components with R/G/B primary colors. This mirror is designed with the incident angle of 45 degrees. The specified color component can be obtained as the reflected beam. Since they absorb no light, light intensity is not lost unlike ordinary subtractive color filters. This lack of absorption makes the dichroic filter suitable for special flood lights, because they do not heat up.

Figure 1 shows an example f a set of wo dichroic mirrors and two reflecting mirrors for color TV cameras. It is important to discriminate between dichroic filters and dichroic mirrors in the use of optical elements. The blue dichroic mirror reflects only the blue color component, and the rest, i.e., R and G color components is transmitted. Generally, the dichroic mirror is used to separate one component of the coherent light radiated from He-Cd laser composed of R/G/B components, and

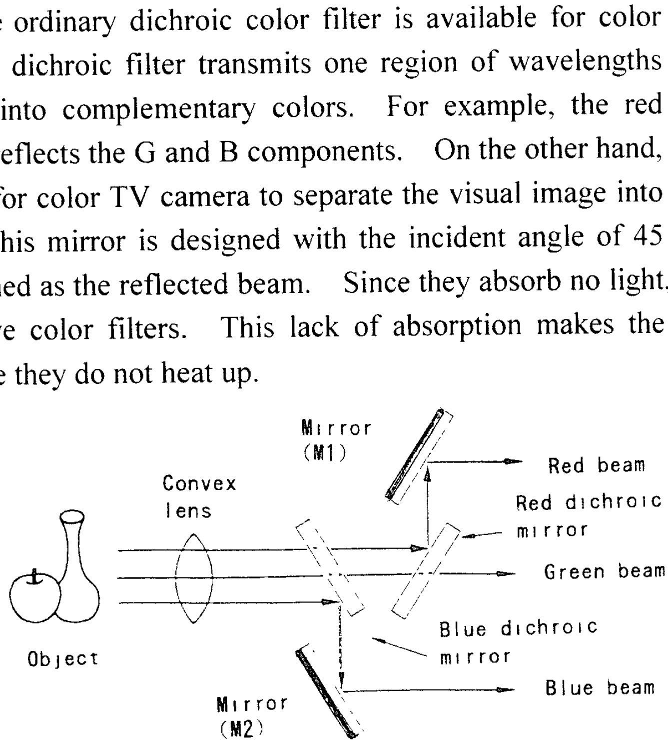
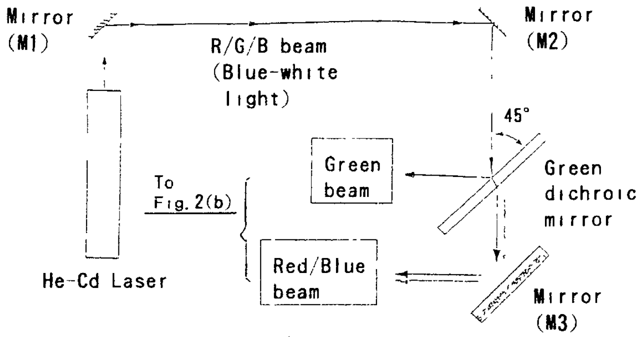


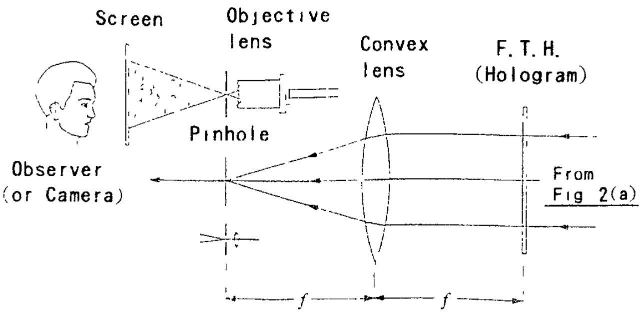
Fig. 1 RGB separation by two dichroic mirrors

to illuminate the hologram as a reference wave. In this study, two or three types of dichroic mirrors and ordinary reflective mirrors together with He-Cd laser are often used for observation of visual images reconstructed from optical holograms or computer generated holograms (CGHs) as the reference wave in the reconstruction process.

Figure 2 shows the separation techniques of primary colors and the optical setup for reconstructing FTH. In Fig.2 (a), the green dichroic mirror and three reflecting mirrors are used with He-Cd laser. The green beam and R/B beams can be simultaneously separated. In Fig.2 (b), the optical setup for reconstructing optical or computer generated FTH is shown with a convex lens, objective lens, translucent screen, etc. Note that the reference wave corresponding to a monochromatic coherent beam must be properly specified in advance.



(a) Separation of R/G/B beam components using dichroic mirror



(b) Optical setup for reconstructing FTH

Fig. 2 Separation of Green and Red/Blue beams and optical setup

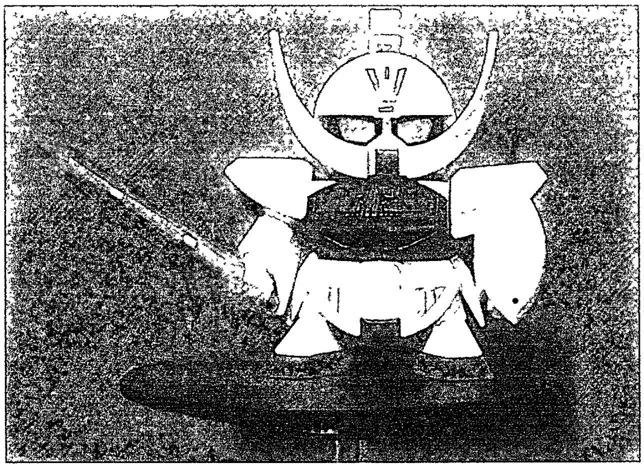
3. Optically reconstructed diffractive color images and visual appearance with cross-talk

Figure 3 shows the optically reconstructed color images using He-Cd laser with or without the dichroic mirror. Fig.3 (a) shows the object composed of color plastics. In Fig.3 (b)-(d), only one object is clearly displayed without cross-talk to all appearance. In Fig.3 (e), three visual images with depth sensation, i.e., one real virtual image and two virtual images with cross-talk, are separately demonstrated in three R/G/B primary colors, though there is only one object in the fabrication of optical hologram on visual appearance. Note that three beams of He-Cd laser are directly illuminated on the Fresnel hologram which is fabricated by the beam of R component only.

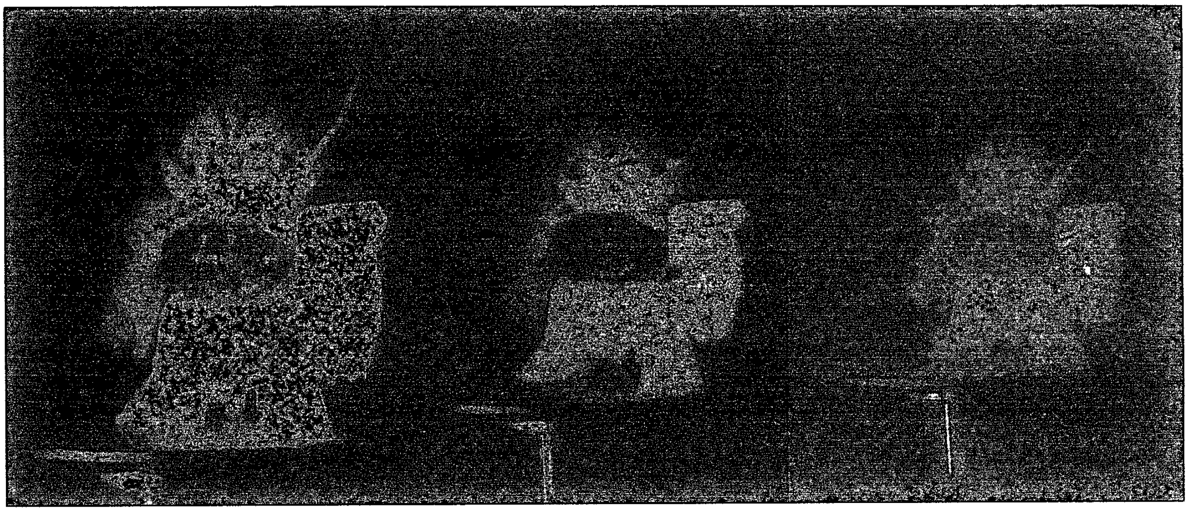
Generally, an optical hologram equivalent to binary CGHs/FTHs can be made with the optical setup and by photography techniques. A positive type hologram is simply displayed using monochromatic gray level or quasi-color on a standard color LCD/CRT. By means of the hard copy, (ex. plotter, printer, etc.) the positive type hologram is converted to the negative type hologram. It is possible to fabricate the transparency corresponding to the positive type hologram which is optically reduced in size, when using a negative film with high contrast. In this case, two different processes are necessary.

In the computer generated FTH, the amplitude component is proportional to the height and/or gray level/quasi-color level in the hologram cell. On the other hand, the phase component is proportional to the specified displacement from the center of a hologram cell in the case of Lomann type [6].

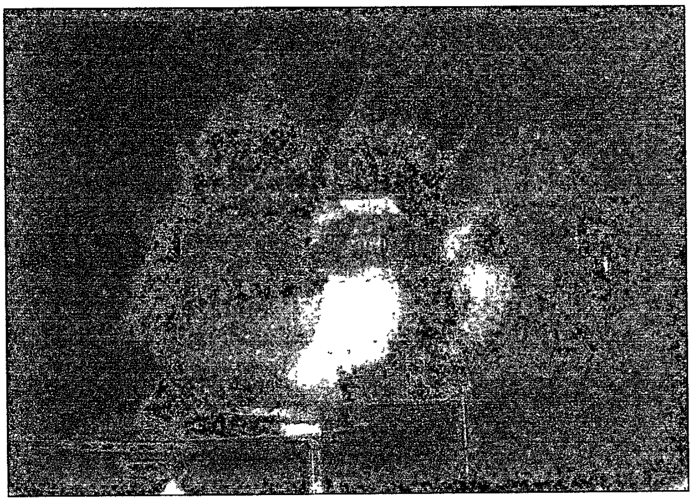
Figure 4 show an input data and a computer generated FTH. In Fig.4 (a), the original image, i.e., only one binary letter“光” in Japanese is shown with a uniform black level. The resolution is 128 × 128 pixels. Fig.4 (b) shows the computer generated FTH in binary level. Each hologram cell is composed of 8 × 8 pixels.



(a) Model composed of a set of color plastics

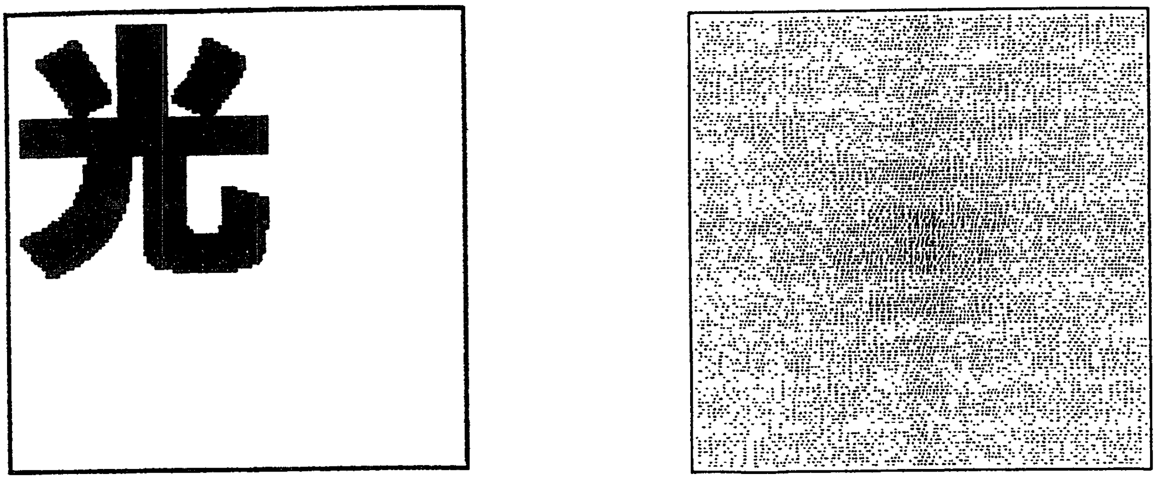


(b) Red image by R beam (c) Green image (d) Blue image



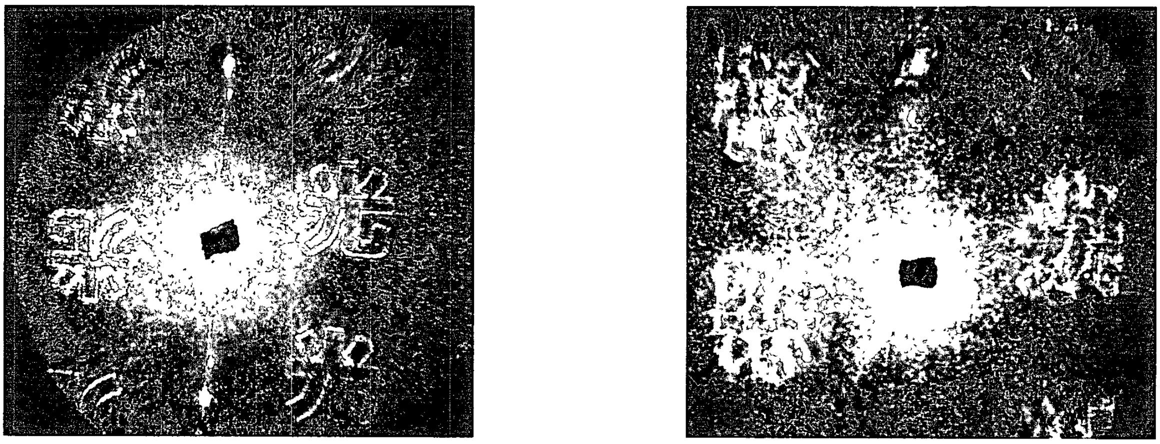
(e) Reconstructed color image by He-Cd laser (blue-white beam)

Fig.3 Original objects and virtual color images

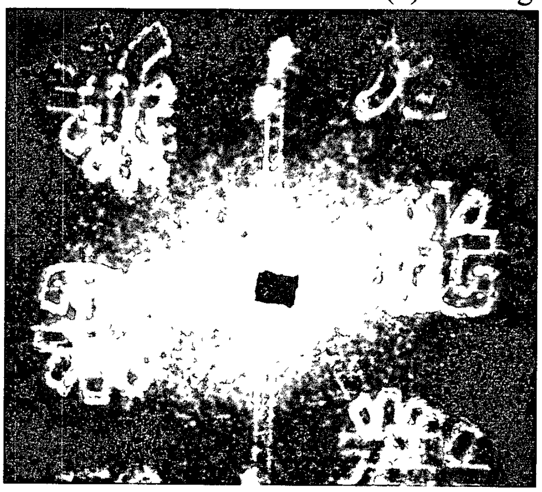


(a) Binary letter "光" in Japanese (b) FTH: 128 × 128 pixels

Fig.4 Input data and computer generated FTH with binary data



(a) Use of red and green dichroic mirrors (b) Use of green dichroic mirror only



(c) Use of green dichroic mirror and reflecting mirror

Fig.5 Optically reconstructed color images of FTH using He-Cd laser and dichroic mirror

Figure 5 shows optically diffractive color images which are reconstructed by means of the optical setup in Fig.2 (b). It is possible to observe a little different color images in quasi-color owing to the He-Cd laser and a combination of dichroic mirrors and standard mirrors.

In Fig.5 (a), a clear reconstructed green color image without overlapped image or ghost image called cross-talk is observed. Two dichroic mirrors: red and green components are used in this reconstruction.

On the other hand, three overlapped images are demonstrated in Fig.7 (b) and (c). In these cases, three R/G/B components are overlapped each other in the translucent screen in the order of R, G, and B, respectively. We must note the background color which looks like green and magenta (additive color mixture of R and B beamc omponents), respectively. It is difficult to discern the reconstructed color image which is in front or in rear, i.e., the order of R/G/B beam components, because three letters of "光" with different colors in various sizes exist on the same surface.

< Photography of Fourier transform hologram (FTH) >

It should be noted that photography techniques of the Fourier transform hologram (FTH) has an effect on the visual appearance and quality of optically reconstructed diffractive images. Two types of FTHs, i.e., positive and negative type displays are simply demonstrated on a color LCD/CRT. It is necessary for us to consider the following conditions

(a) A proper distance between the display surface and the camera position for fabricating the FTH less than 10mm×10mm in reduced size:

(b) A rational combination of the exposure time: T and stop: f for a negative film with high contrast or color reversal film:

(c) Adjustment of the screen luminance on a standard LCD/CRT in connection with photographic techniques:

When fabricating the computer generated FTH with binary type data, we must note that a negative film with the high contrast is exclusively used in place of a standard color reversal film. This film is commercially available as a minicopy film in Japan. On the other hand, the color reversal film is directly used for photo-reduction, when fabricating the computer generated FTH with the quasi-color and/or gray level.

<Cross-talk: overlapped images in reconstruction process>

Table 1 shows the aspects of diffracted color images from a single optical exposure hologram which is reconstructed using the specified wavelength in advance. In this table, three different R/G/B primary colors, i.e., the separated monochromatic coherent beams from He-Cd laser, are used for observing the reconstructed color images. If three wavelengths: λ_R , λ_G and λ_B are incident on the hologram which is fabricated using R beam component only, three different virtual images can be observed. The one virtual image without cross-talk and two cross-talk images are simultaneously reconstructed. In the case of only one object, three separated images are clearly reconstructed, though there are two cross-talk images on appearance. The symbol : $\lambda_R \Rightarrow \lambda_R$ means a real virtual image, and the symbols: $\lambda_G \Rightarrow \lambda_R$ and $\lambda_B \Rightarrow \lambda_R$ mean a cross-talk image, respectively. In general, a K beam hologram produces K^2 images in the reconstruction process. The K^2 - K images are undesirable. A three-color hologram after the three times of multiple exposure would produce nine images simultaneously, and six out of nine would unwanted. As a result, an observer sees a combination of the reconstructed color images with deterioration owing to overlapped (or ghost) images.

Table 1 Reconstructed color images from single exposure hologram

(a) Diffractive color images using three different reconstruction beams:	
Incident beams Hologram	<Real virtual image> Two different cross-talk images
$(\lambda_R + \lambda_G + \lambda_B) \times \lambda_R$	$\lambda_R \Rightarrow \lambda_R + \lambda_G \Rightarrow \lambda_R + \lambda_B \Rightarrow \lambda_R$
(b) Diffractive color images using two different reconstruction beams:	
	Green and blue images with cross-talk
$(\lambda_G + \lambda_B) \times \lambda_R$	$\lambda_G \Rightarrow \lambda_R + \lambda_B \Rightarrow \lambda_R$

The explanation of Table 1 can be extensively applied for reconstructing the computer generated FTH. The diffractive real images with overlapped cross-talk are demonstrated on the translucent screen in quasi-colors. The FTH corresponds to the single exposure hologram irrespective of the specified wavelength in advance.

4. Conclusions

We can simply observe the clear diffractive color images with no cross-talk by means of only one red beam component which is separated using the He-Cd laser and the specified dichroic mirror in the case of only one object. The cross-talk problems owing to two types of holograms such as the Fresnel hologram and the FTH with binary data are discussed from the viewpoint of the additive color mixture.

It is very difficult to carry out the practical reconstruction of full color images without the cross-talk image called overlapped or ghost image in the experiment with a few objects, even though a set of color holograms containing three RGB beam components can be recorded using the He-Cd laser, dichroic mirrors, suitable optical setup, and special holographic materials in principle.

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Appendix

< Magnification/Reduction Ratio of Reconstructed Color Images by Experimental Measurement Values >

The transverse and axial magnifications are formulated with 3-D image locations (Xi,Yi,Zi) as shown in Table A. Note that the transverse and axial magnifications are often called the longitudinal and lateral magnifications [a]-[c]. In the reconstruction process, the hologram is assumed to be illuminated by a spherical wave originating from a point source at coordinates (Xp,Yp,Zp). When the distance Zo = Zr = Zp holds good, two kinds of magnifications can be approximately evaluated as Mt≒Ma≒R.
In this experiment, we use three coherent beams separated using He-Cd laser and different color dichroic mirrors. When the three wavelengths: λ_R, λ_G and λ_B are fixed as 636 [nm], 534 [nm], and 442 [nm], respectively, two kinds of magnifications: M_t ; M_a of green and blue reconstructed hologram images may be calculated as 534/636 ≒ 0.84 and 442/636 ≒ 0.69 on the base of the Freanel hologram fabricated using only the red coherent beam. On the other hand, the reduction ratio of reconstructed hologram images becomes about 3.5/4.1 ≒ 0.85 ～ 5/6 ≒ 0.83 for Green/Red image size in cm , and about 3.0/4.1 ≒ 0.73 ～ 4.1/6 ≒ 0.68 for Blue/Red image. These values are estimated from the experimental measurements of lateral and/or longitudinal size of three different objects in the color photo which is demonstrated in Fig.3 (e). The values of reduction ratio corresponding to 3-D depth sensation are similar to the theoretical estimation values, as it appears.

Table A Transverse and axial magnifications of reconstructed hologram images

<Position of reconstructed image>

$$X_i = \mp(R \cdot Z_i/Zo)Xo \pm (R \cdot Z_i/Zo)Xr + (Z_i/Zp)Xp$$
$$Y_i = \mp(R \cdot Z_i/Zo)Yo \pm (R \cdot Z_i/Zo)Yr + (Z_i/Zp)Yp$$
$$Z_i = \{1/Zp \pm R/Zr \mp R/Zo\}^{-1}$$

<Transverse magnification>

$$M_t = |dXi/dXo| = |dYi/dYo|$$
$$= |R \cdot (Zi/Zo)|$$
$$= |1 - (Zo/Zr) \mp (1/R) \cdot (Zo/Zp)|^{-1}$$

<Axial magnification>

$$M_a = |dZi/dZo| = (1/R) \cdot M_t^2$$

where,
Xo, Yo, Zo; Xr, Yr, Zr; Xp, Yp, Zp: 3-D position of object wave, reference wave, reconstructing wave, respectively
Xi, Yi, Zi: 3-D position of reconstructed hologram image
$R = \lambda i / \lambda r$: Ratio of reconstructing wavelength λ_i to recording wavelength λ_r

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