Visual Appearance Effect of Reconstructed Hologram Color Images using He－Cd Laser and Modified Color Images using Digital Image Processing Techniques

M.Kariya[*1], S.Uehara[*2], M.Iizuka[*3], Y.Ookuma[*4], Y.Nakashima[*5] and M.Takamatsu[*6]

A blue white He-Cd laser composed of three R/G/B component beams is directly applied to fabricate the optical Fourier transform hologram (OFTH). The visual appearance of reconstructed hologram color images is discussed in contrast to that of an ordinary OFTH which is fabricated using a monochromatic He-Ne laser and diode-pumped solid state (Nd:YAG) laser. The characteristic of He-Cd laser is checked from the viewpoint of the visual size and its place in the OFTH, and the visual depth sensibility of overlapped color ghost images called cross talk in the reconstruction process of the Fresnel hologram. The visual appearance and effect of reconstructed hologram ghost image which can be digitally modified and emphasized by means of commercially available software are discussed through this study.

1. Introduction

Optical holography technology has found a wide range of applications such as color holography, holographic interferometry, holographic optical elements, matched pattern filtering, computer-generated holograms etc., and has developed various lasers and recording materials [1]. An idea of a multicolor image with 3-D real appearances was first pointed out by Leith and Upatonieks [2]. In this case, He-Ne laser (632.8 nm) and Ar laser (514.5 nm and 488 nm) are often used in color holography. 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 color hologram differs from the standard holography techniques. A commercially available He-Cd laser is very useful for many optical and technological fields. In general, the He-Cd laser looks like blue white color, because three primary color beams composed of R/G/B components radiate simultaneously on the same axis from a special laser tube. It is possible to divide into independent three primary beams using a kind of the special filter called dichroic mirror. As a result, the He-Cd laser can be used for color holography techniques together with panchromatic film or plate in place of the combination of He-Ne laser and Ar laser. In this study, the He-Cd laser instead of using He-Ne laser is directly applied to fabricate the OFTH together with the red sensitive silver halide material for holography. The characteristic of He-Cd laser is checked from the viewpoint of the visual appearance of reconstructed color ghost images called cross talk. The effect and influence of digital image processing are discussed through the visual image quality of modified and emphasized digital color images in contrast to original analog images.

[*1] Alumnus, Tokyo Institute of Polytechnics (Jemuko Co., Ltd.)
[*2] Alumnus, Tokyo Institute of Polytechnics (Meitec Co., Ltd.)
[*3] Professor, Tokyo Institute of Polytechnics
[*4] Research Associate, Tokyo Institute of Polytechnics
[*5] Professor, Toyama University
[*6] Lecturer, Toyama University
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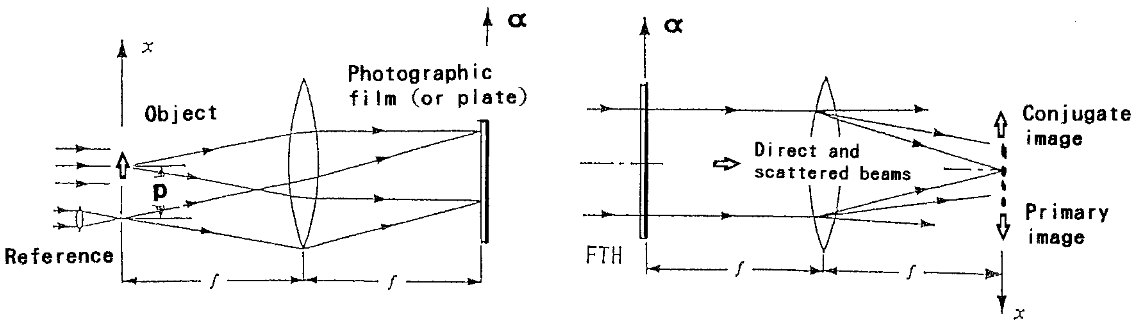
2. Formalization for Optical Fourier Transform Holography Techniques

An optical Fourier transform hologram (OFTH) can be fabricated by means of an inline optical setup using a monochromatic and coherent laser beam [3]. Reconstructed images have a pair of real images called $\pm 1^{st}$ order diffractive images on the translucent screen. The OFTH has a very important role as the complex amplitude spatial filter for optical matched filtering technology such as character and/or pattern recognition [4]-[5].

A simple inline optical setup for fabricating the OFHT is shown in Fig.1. The He-Ne laser, solid state (LD) laser, and He-Cd laser are applied to making and/or reconstructing the OFTH as a coherent light source. The two different beams called object and reference waves are used in this arrangement. In order to make a monochromatic type hologram, the red sensitive silver halide material is used in place of the panchromatic special plate or film for holography in this study.

A typical procedure for the optical Fourier transform holography techniques is formulated in Table 1. The procedure is composed of five steps. In Step 1 and Step 2, the object and reference waves are described using a definition of mathematical Fourier transform, respectively. Note that the reference wave (often called reference beam) is a collimated wave of a uniform intensity derived from the same source as that used to illuminate the object, i.e. transparency in Step 1. In Step 3 the interference of two waves can be described as an intensity distribution. In Step 4 the fabrication of OFTH after optical exposure is expressed as the complex amplitude. In Step 5, the complex amplitude in the back focal plane of the lens is the inverse Fourier transform of U(α, β) by using a reconstructing laser with the unit amplitude. The reconstructed images from OFTH which are composed of four terms are formulated by the inverse Fourier transform techniques.

The first and second terms are often called direct and scattered images, respectively. The former comes to a focus on the optical axis, while the latter forms a halo around it on the translucent screen. The third term produces a reconstructed image of the original object, shifted downward by a fixed distance p, while the fourth term gives rise to a conjugate image, inverted and shifted upwards by the same distance p. As a result, it is possible to observe the two real images called primary and conjugate images, i.e., a pair of reconstructed images, up & down or right & left in appearance at the translucent screen.



(a) Optical setup for recording FTH (b) Optical setup for reconstructing FTH

Fig.1 Optical holography setup for Fourier transform hologram (FTH)

Table 1 Procedure of optical Fourier transform holography

Step 1: Fourier transform of transparent object <Object wave>

$$O(\alpha, \beta) = F[o(x, y)]$$

Step 2: Fourier transform of point source <Reference wave>

$$R(\alpha, \beta) = F[C \times \delta(x-p, y)] = C \times \exp(-j2\pi\alpha p)$$

Step 3: Interference of two waves <Intensity>

$$I(\alpha, \beta) = | R(\alpha, \beta) + O(\alpha, \beta) |^2$$
$$= C^2 + | O(\alpha, \beta) |^2 + C \times O(\alpha, \beta)\exp(j2\pi\alpha p) + C \times O^*(\alpha, \beta)\exp(-j2\pi\alpha p)$$

Step 4: Fabrication of FTH after optical photography process

<Complex amplitude transmittance>

$$U(\alpha, \beta) = k \times I(\alpha, \beta)$$

Step 5: Reconstructed images from FTH <Diffractive patterns>

$$u(x, y) = F^{-1}[U(\alpha, \beta)]$$
$$= k \times C^2 \times \delta(x, y) + k \times o(x, y) \star o(x, y) + k \times C \times o(x-p, y) + k \times C \times o^*(-x+p, -y)$$

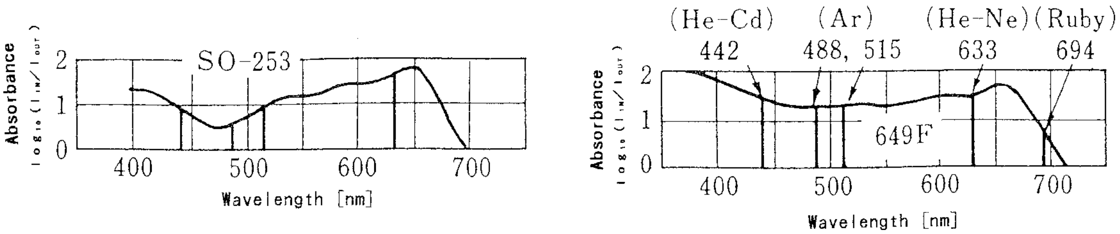
- List of symbols -

x, y : variables in real spatial coordinate
α, β : variables in spatial frequency coordinate
$F[\ —\ ]$: Fourier transform symbol
$F^{-1}[\ —\ ]$: inverse Fourier transform symbol
$\delta(x-p, y)$: delta function ; j : imaginary unit
p : position of point source ; C : constant ; k : constant
$|\ —\ |$: absolute symbol ; $*$: conjugate symbol ; $\star$: convolution symbol

3. Fabrication of Optical Fourier Transform Hologram by He-Cd Laser and Visual Modification of Reconstructed Images by Digital Image Processing Techniques

A hollow cathode He-Cd laser with coherent blue-white light is developed by Koito Manufacturing Co., Ltd. and is now commercially available [6]. In contrast to the conventional He-Cd laser (only blue ray: 441.6 nm and ultraviolet ray : 325.0 nm) which uses the positive column plasma as the laser medium, this new appearance tube uses the negative glow plasma and has a little complicated structure. In addition to the blue light, it is possible to obtain the red and green beam components from a single laser tube. This laser can oscillate simultaneously at red (636.0 nm and 635.5 nm), green (537.8 nm and 533.7 nm), and blue (441.6 nm) within the visible spectral region. The characteristics of output power of He-Cd laser are mainly affected by He pressure, discharge current, Cd vapor pressure corresponding to an anode voltage. To keep Cd vapor pressure constant, the outside reservoir is surrounded by a special heater so that the temperature of the Cd reservoir is controlled. The output power of three colors is about 25 - 30 mW (red power : 5-6 mW, green power : 5-6 mW, and blue power: 15-18 mW) in total.

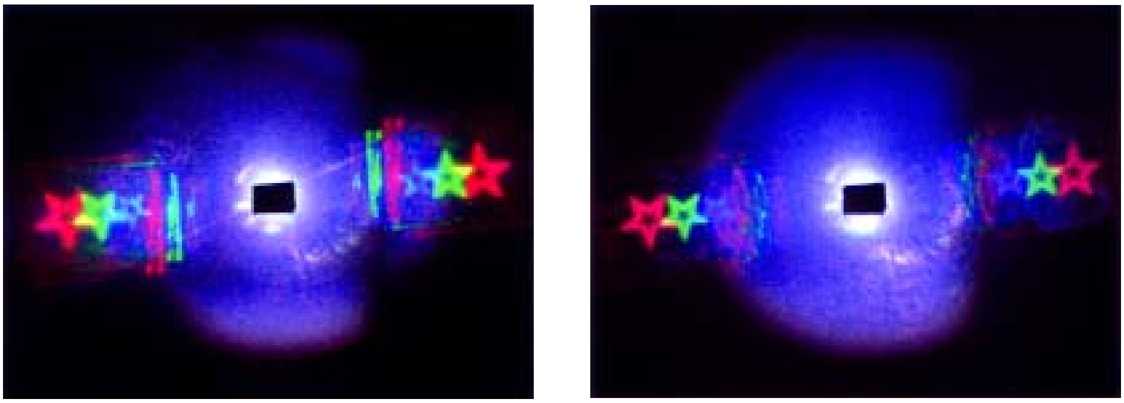
The two types of spectral characteristic curves for special holographic materials, i.e., silver halide materials for holography are shown in Fig.2. The axis of ordinate, often called the optical density, of characteristic curves represents a scale of common logarithm, and the red spectral sensitivity is high about 7-8 times against green and blue spectral domains as shown in Fig.2 (a). Most of these emulsions are available coated on glass plates or plastic films. The red sensitive film SO-253 is now on the market, but the panchromatic film 649F is not available because of the stop of production [7]-[10]. Note that Fig.2 (a) has a red sensitive characteristic, though Fig.2 (a) and Fig.2 (b) show the similar curves in the domain of green and blue wavelengths to same degree. On the other hand, Fig.2 (b) shows the panchromatic sensitive characteristics which are useful in a wide of visible wavelength domain. This film used to fabricate a kind of color hologram by means of multiple exposure techniques a long time ago.



(a) Red sensitive type emulsion

(b) Panchromatic type emulsion <Stop of production, at present>

Fig.2 Spectral characteristic curves of silver halide materaials for holography

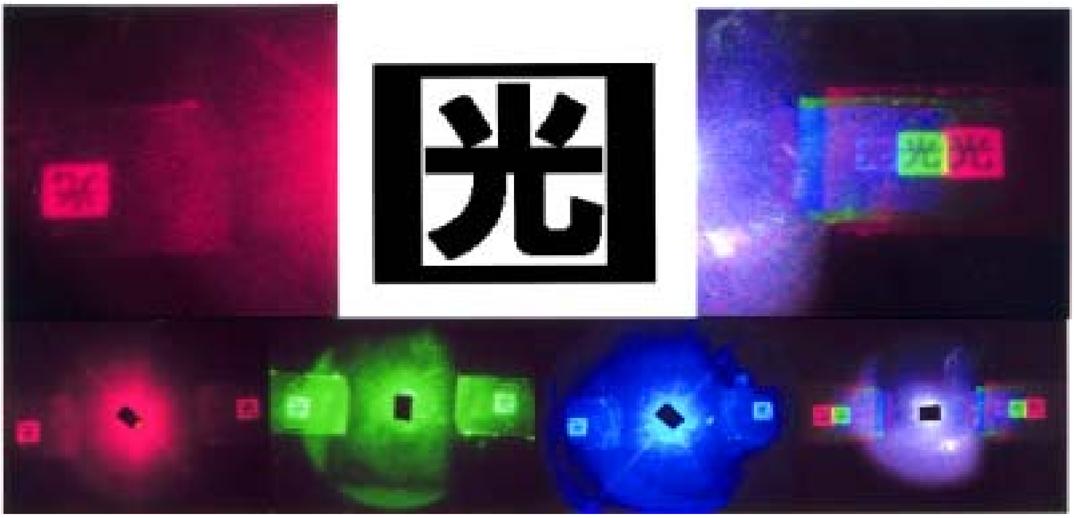


(a) Fabrication of OFTH by He-Ne laser

(b) Fabrication of OFTH by He-Cd laser

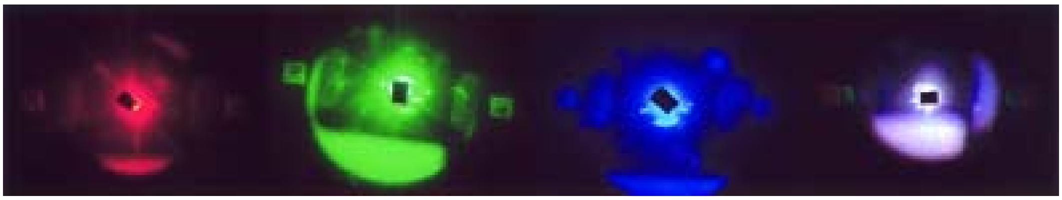
Fig.3 Reconstructed color images by He-Cd (R/G/B) laser

Fig.3 shows the color images reconstructed by He-Cd laser, after the optical Fourier transform hologram (OFTH) is fabricated by using He-Ne laser and He-Cd laser. A few ghost images called cross talk image are visually observed in reconstruction process of the OFTH. The ghost images are useful for the relative size or visual depth sensation of reconstructed hologram images in appearance. The transverse and axial magnifications are formulated by specifying the position of reference and object sources and that of recording film (hologram), and reconstruction geometries. The magnification (or reduction) ratio of reconstructed hologram images can be approximately calculated using the ratio MR which is defined as the reconstructing wavelength λ_i/the recording wavelength λ_r[11]. The relative size of two different color images corresponding to the MR, i.e., 534/636≑0.84 - 538/636≑0.85 for green image, 442/636≑0.69 for blue image, can be approximately estimated as the base of red wavelength (recording wavelength): λ_r =639 nm of He-Cd laser in the case of Fig.3.

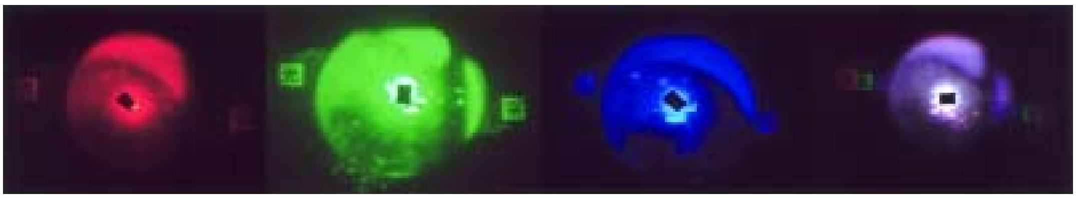


(1) He-Ne laser (2) LD green laser (3) LD blue laser (4) He-Cd laser

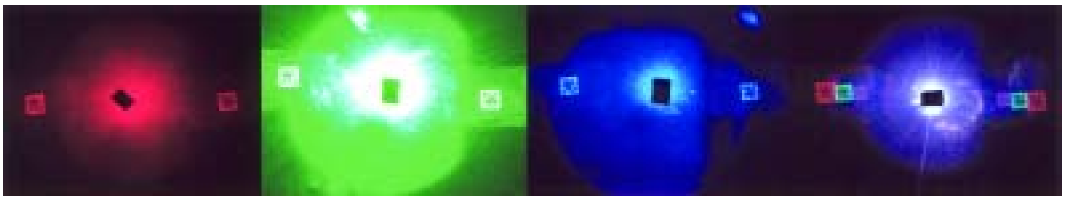
(a) Fabrication by He-Ne laser



(b) Fabrication by LD green laser



(c) Fabrication by LD blue laser

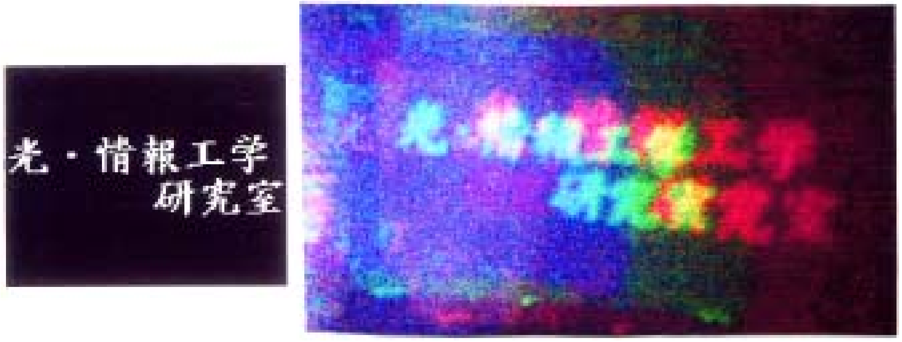


(1) He-Ne laser (2) LD green laser (3) LD blue laser (4) He-Cd laser

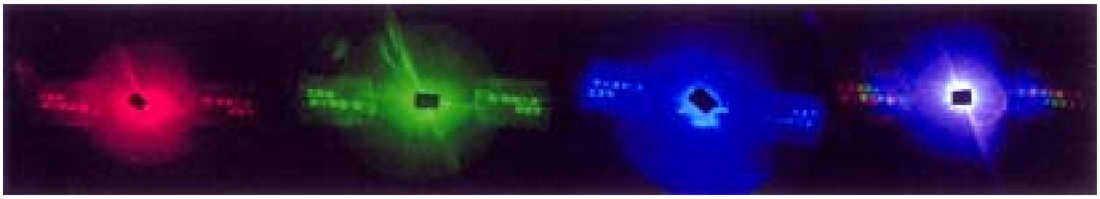
(d) Fabrication by He-Cd laser

Fig.4 Reconstructed color images by four different types of lasers in the case of OFTH

Fig.4 shows the four types of color images reconstructed by (1) He-Ne laser (10 mW : 632.8 nm), (2) solid state LD laser (50 mW: 532 nm), (3) solid state LD laser (30 mW: 473 nm), and (4) He-Cd laser, after the OFTH is fabricated by four types of lasers. A few ghost images called cross talk image are visually and clearly observed in Fig.4 (a) - (4) - and Fig.4. (d) - (4) -. Note that the transparent input data with negative type characters, i.e., black letters against the white background in 35 mm slide film is used in the fabrication of OHTH.

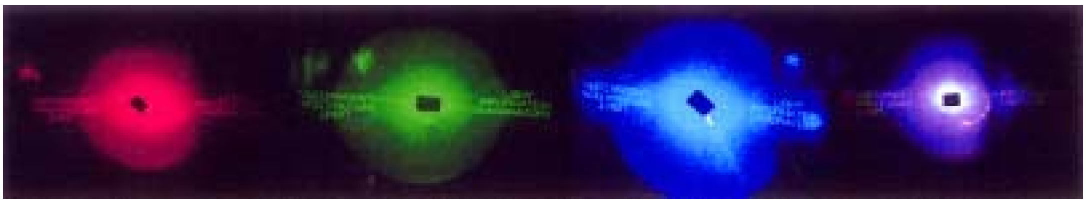


(a) Input : Japanese letters



(1) He-Ne laser (2) LD green laser (3) LD blue laser (4) He-Cd laser

(b) Input : English letters



(1) He-Ne laser (2) LD green laser (3) LD blue laser (4) He-Cd laser

Fig.5 Reconstructed color images by four different types of lasers<Fabrication of OFTH by He-Cd laser>

The blue beam of He-Cd laser is strong about three times in contrast to the red and green beams. However, we can directly fabricate the OFTH using He-Cd laser in place of using He-Ne laser on condition that the red sensitive material is used, because two kinds of green and blue beams in He-Cd laser do not almost contribute the red sensitive materials. The absorbance of characteristic curves as demonstrated in Fig.2 is represented using a scale of common logarithm. The red spectral sensitivity is high about 7-8 times against green and blue spectral domains in Fig.2 (a). On the other hand, LD green laser (50 mW) and LD blue laser (30 mW) contribute a little the red sensitive film from the result of Fig.4 (b) and (c), since the output power of two types of LD lasers is relatively strong in contrast to that of green and blue components of He-Cd laser. In the case of reconstruction using He-Cd laser as shown in Fig. 5 (4) as well as in Fig.3, it is possible to simply estimate the relative size, on the assumption that enlarged color images (hard copy print) may be prepared in advance.

Fig.5 shows the color images reconstructed by four types of lasers, after the optical Fourier transform hologram (OFTH) is directly fabricated by He-Cd laser with three R/G/B color beams. A few overlapped color images are intuitively observed by using He-Cd laser at reconstruction process of the OFTH, and the visual appearance of ghost images is rather complicated against the results of Fig.3 and Fig.4, because two kinds of input images contain a little long Japanese and English words in the specified 35 mm slide film (transparency).

A practical algorithm for converting from RGB to HSV (or HLS) color model, or from HSV (or HLS) to RGB color model has been proposed up to now in the field of computer graphics [12]-[13]. In this study, the commercially available software such as Micrograph PhotoMagic is used in order to invert the original color image (RGB color model) into the HSL color model corresponding to the above HLS color model (hue H, saturation S, and lightness L).

An original image and modified hologram color images by means of the software for digital image processing are depicted in Fig.6. In Fig.6 (a), we can clearly discern a combination of the overlapped images with two different color sizes. On the other hand, it is possible to modify the deteriorated images what is called cross-talk images to same degree in Fig.6 (b) and (c). After taking a photography (the use of a digital camera with 4M pixels) of the original color image reconstructed by He-Cd laser, the same software such as Micrograph PhotoMagic is used from the viewpoint of intuitive modification of overlapped image, i.e. the relative size and the visual depth sensation of reconstructed color images. Moreover, the negative/color conversion of HSL color model is applied in this case. In general, a human can intuitively recognize three basic attributes in the Munsell HV/C color model or three other attributes composed of hue H, saturation S, and intensity L (or I: intensity, V: value, B: brightness in place of the capital letter L).

As for the original color images of OFTH and Fresnel hologram, the red, green, and blue (RGB) colors have been used in color CRT and LCD monitors. The cyan, magenta, and yellow (CMY) colors and black are used for color hard copy. The RGB and CMY color models are hardware-oriented. On the other hand, the HSV and HSL color models are software- (or user-) oriented.

An original image and modified color images of Fresnel hologram type are demonstrated in Fig.7. It is difficult to find the front red image and back blue image in contrast to the middle green image in Fig.7 (a). We can recognize the front red image by modifying the red component only in Fig.7 (b). The negative conversion in the HSI color model is applied in Fig.7 (c) as well as in Fig.6 (c). As a result, a modified clear image is depicted with cross talk images. The effect of visual depth sensation of original color images is emphasized by means of digital image processing techniques, i.e. the use of the commercially available software.

(a) Reconstructed & modified image of OFTH using blue dichroic mirror and He-Cd laser

(b) Modified image using HSL color model

(c) Modified conversion image using HSL color model

Fig. 6 Reconstructed original and modified images by digital image processing in optical Fourier transform hologram (OFTH)

(a) Reconstructed original image (Fresnel hologram)

(b) Modified image (HSL color model)

(c) Modified conversion image (HSL color model)

Fig. 7 Reconstructed original image and modified images by digital image processing in Fresnel hologram

4. Conclusion

The blue beam of He-Cd laser is strong about three times in contrast to the red and green beams. It is possible to directly fabricate the optical Fourier transform hologram (OFTH) using the He-Cd laser composed of three R/G/B beams instead of the use of He-Ne laser, and the red sensitive silver halide material for holography. As a result, the red beams (636.0 nm and 635.5 nm) play an important role as the monochromatic and coherent beam in the fabrication of OFTH. On the other hand, a few ghost images called cross talk image are visually observed by using He-Cd laser in the reconstruction process of OFTH or the optical Fresnel hologram. The ghost images are often useful for the relative size and its place, and the visual depth sensibility of reconstructed hologram images on appearance. The visually deteriorated appearance of hologram ghost images can be digitally modified and emphasized by means of commercially available software, i.e., simple inversion processing of black & white and RGB & CMY (complementary color) against that of original hologram image.

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