Development of multicolor-holographic flip-books systems using lithium-niobate crystals (2)

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ABSTRACT

A multicolor holographic flip-books system using a white LED light source is presented. In this system, angle-multiplexed image plane holograms are recorded using an Fe-doped $LiNbO_3$ (LN) crystal as recording media with a 532-nm green laser. A white LED light source was then used to illuminate the recorded holograms. The flip-books animation can be played when the LN crystal was slowly rotated. The reconstructed flip-books can be observed directly with human eyes, and the image noise was drastically reduced due to an incoherent white-light source.

1. INTRODUCTION

We describe a multicolor-holographic flip-books system using Fe-doped $LiNbO_3$ (LN) crystals. By using the system, color animation can be observed by rotating the crystal.

Being different from the conventional hologram recorded on a thin recording material, volume hologram using a thick material allows the angle-multiplexed hologram recording [1~3]. Thus, volume hologram has proved to be very useful for optical memory due to the large storage capacity and fast transfer rate. Thanks to the angle-multiplexing property, it's interesting to use the LN crystal as a holographic recording material for recording multicolor flip-books.

Fourier-transform scheme has been usually used to record the hologram in LN crystals. However, Bragg-mismatch occurs when we use a light source with a different wavelength for hologram reconstruction, as a result, only a portion of the recorded image can be reconstructed. On the hand, an image hologram [3] can produces a whole image. We demonstrate the whole-image reconstructions from an image-plane volume hologram with a Fe-doped LN crystal. A LN volume hologram can record a number of multiplexed images with the rotation of a crystal [4].

2. THEORY AND OPTICAL SYSTEM

The concept of the proposed multicolor-holographic flip-books system [5,6] is schematically shown in Fig.1. The images forming the flip-books are multiply recorded on an LN crystal as holograms while the LN crystal is rotated by an angle of 1°. After that, we can observe a color animation by rotating the LN crystal under the illumination of a LED broad-spectral source [7].

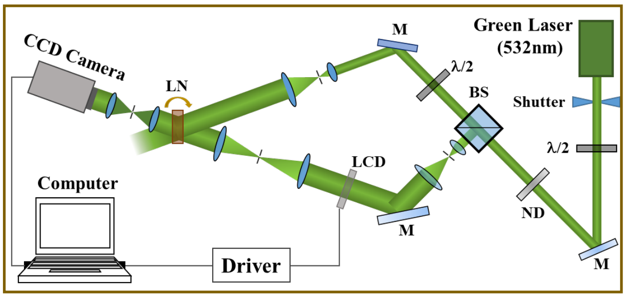

Fig. 3 Optical setup hologram recording

A diode-pumped solid-state (DPSS) laser (Coherent Compass 315M-100SL, 532nm, 100mW) is used for recording the holograms. The light beam from the DPSS laser is split using a Beam-split into two beams. One is used to illuminate a liquid-crystal device (LCD) on which the input images were displayed, and the light wave passing through the LCD was imaged with a *4-f* optical system onto the LN crystal as the object wave. The other beam is expanded and then used as a reference wave. The object and reference waves with a cross angle of 30° overlapped on the LN crystal and form an interference fringe patterns. In the bright region of the fringe patterns, the electrons of Fe level were excited, moved to dark region and finally formed a space-charge field that produces a space refractive index distribution via Pockels effect. In this way the input image was recorded on the LN crystal as a transparent image hologram. Because of the sharp Bragg condition, the next image can be recorded by slightly rotating the crystal.

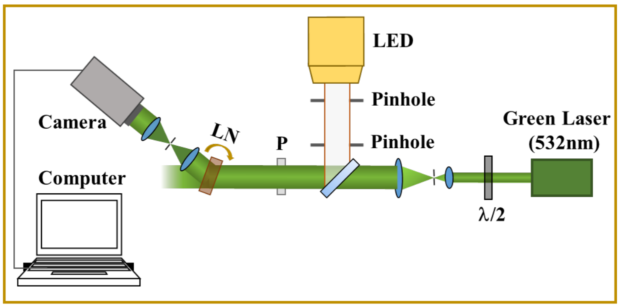

Fig. 2 Optical setup hologram reconstruction

In multi-color observation of the flip-books, a day light white LED Solis-3C (Thorabs Inc.) was use as a light source. Solis-3C covers a large spectrum range from 430nm to 750nm. The DPSS green laser was also used as light source for comparison. For reconstruction of image with different wavelength i.e. different color, the incident angle of the illumination beam should be set as $\theta_R = \sin^{-1}\left(\lambda_R / \lambda_G \cdot \sin\theta_G\right)$,and $\theta_B = \sin^{-1}\left(\lambda_B / \lambda_G \cdot \sin\theta_G\right)$ to match the Bragg condition due to the wavelength difference between the recording and readout lights.

3. EXPERIMENTAL RESULTS

3.1 Hologram reconstruction using the LED light

In our experiments, a Fe-doped LN crystal of 10-mm square and 4-mm thickness was used. In our previous study, we found that the p-polarization is better than s-polarization, therefore the p-polarization was used in hologram recording. An image hologram was recorded by use of the image shown in Fig.3(a). The angle between object and reference beams is 30°. The reconstructed image using the LED light source is shown in Fig.3 (b), and the reconstructed image using the green laser is also shown in Fig.3(c).

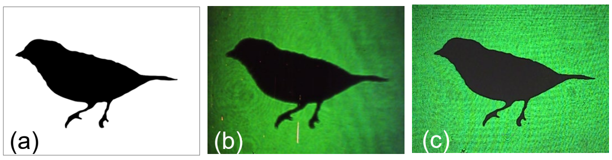

Fig. 3 Hologram reconstruction using LED and laser: (a) original image, (b) with LED, (c) using green laser.

3.2 The effect of the polarization

In order to check the effect of the polarization of illumination beam, reconstructed the hologram by use different LED light beam of different polarization states, and the experimental results are shown in Fig.4, (a) random, (b) p-polarization, and (c) s-polarization. From the results, we found s-polarized light does not make contribution and can be cut out using a polarizer.

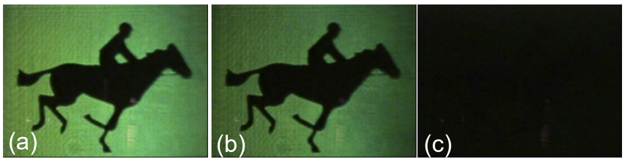

Fig. 4 Reconstruction image intensity at different polarization condition

3.3 Red image reconstructed using the LED light

Since we used a white LED light source for reconstruction, the images of different color can be reconstructed from the recorded hologram as shown in Fig.5. As an example, by setting the incident angle as17.94°, a red image corresponding to a central wavelength of 632.8nm was obtained.

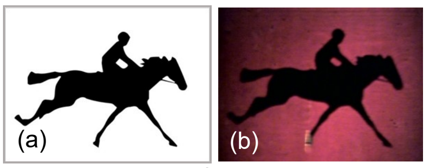

Fig. 5 Reconstruction of a red image with the LED: (a) original image, (b) reconstructed image.

4.4 Demonstration of flip-books using the LED

As a demonstration, flip-books was made using the LED light source. During the experiments, the original images was send to LCD one by one, and recorded with the reference beam, while the LN crystal was rotated by 1° between two adjacent images.

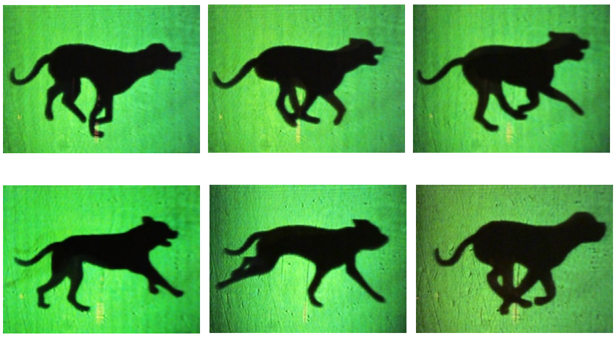

Fig. 6 Demonstration of a flip-books using the white LED as an illumination light source.

4. CONCLUSION

A multicolor holographic flip-boos system is presented. The original images were recorded on a rewritable photorefractive media, Fe-doped LN crystal, we can observe a color animation by slowly rotating the crystal with a white LED light source. By optimize the incident light polarization condition, the exposure-time reduction from hundreds to seconds enabled us to easily record a large amount of images into the crystal.

6. Acknowledgment

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7. REFERENCES

[1] K. Buse, A. Adibi and D. Psaltis, Nature, pp. 665- 668, Vol. 393(1998).

[2] R. Fujimura, T. Shimura, and K. Kuroda: Optics Express, pp. 1091-109818, Vol. 18 (2010).

[3] Y. Komori and Y. Ishii: Proc. of SPIE, pp. 1-7, Vol.778119 (2010).

[4] T. Sato, J. Chen, and Y. Ishii, Proc. of The Eleventh Finland-Japan Joint Symposium on Optics in Engineering, pp1-2 (2015).

[5] T. Hosono, S. Hikota, J. Chen, M. Toyoda, Y. Ishii, The 80th JSAP Autumn Meeting, 20a-PA1-1(2019).

[6] F. Shishido, Y. Okeya, J. Chen, M. Toyoda, Y. Ishii, Optics & Photonics Japan 2019, 3pP12 (2019).

[7] S. Nakadate, Y. Tokuyama, Y. Kume, M. Shibuya, J. Chen, Y. Azuma, T. Moriyama, Optical Review, PP.478-486, Vol.26, No.5, PP.478-486 (2019).