

A Dual-Depth Augmented-Reality Display System Based on Reflection Polarizer and Holographic Optical Element

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Abstract

A dual-depth augmented reality display system to enhance virtual-real combination experience is proposed. The system can produce a full color image and a single color image separately through reflection polarizer and holographic optical element to two different depths by temporal polarization multiplexing method, and the system has a compact size.

Author Keywords

Augmented reality, holographic optical element, dual-depth

1. Introduction

Augmented reality (AR) display technology has gained significant interest as it overlays digital content onto the physical world, enhancing our perception and becoming a burgeoning area of study [1].

However, AR display still has some problems such as poor virtual-real combination experience, small field of view, and insufficient depth. In recent years, researchers have proposed multi-depth AR display to solve the above problems. The technical schemes to realize multi-depth display mainly include geometric optics [2-3], dynamic zoom components [4], digital holography [5-6] and holographic optical element (HOE) [7-9]. Geometric optics can realize full color display, but some devices such as beam splitter and free-form surface optical elements, have the problem of large system size. For dynamic zoom component solutions, low image quality, small size and slow switching speed are the main limiting factors. Digital holographic technology also has many problems, such as low resolution, slow calculation speed, and is hard to achieve full color display. HOE has the advantages of high diffraction efficiency, good wavelength and angle selectivity, thin and light in the size, but its bandwidth is small, usually can only achieve monochromatic display.

We propose a dual-depth AR display system based on reflection polarizer and HOE. A full color image and a single color image are displayed to two depths by reflection polarizer and HOE by temporal polarization multiplexing method. Combing the advantages of geometric optics and HOE, the system can achieve dual-depth AR display and full color display in one of the two depths. Besides, the size of the system is compact.

2. System Configuration

The system configuration is shown in Fig. 1, including an LCD screen, a polarizer, a polarizer converter, a reflection polarizer and an HOE. The main principle is using temporal polarization multiplexing method to produce two sets of images separately through reflection polarizer and HOE to two different depths. In the proposed system, only *s*-polarized light from the LCD screen can pass the polarizer. And the LCD screen shows two sets of images in a time sequence. Then the polarizer converter changes the driving voltage also in the same time sequence synchronously to control the desired orthogonal linear polarization state of the incident light. The reflection polarizer which is stick together with the HOE shows different transmittance and reflectance to different orthogonal linear polarization light. The *p*-polarized

light will be reflected by the reflection polarizer, and form a full color image in the near depth. The distance between the full color image and the reflection polarizer equals the distance between the LCD screen and the reflection polarizer, because the reflection of the reflection polarizer is specular. The *s*-polarized light will pass through the reflection polarizer and be diffracted by the HOE, forming an enlarged single color image in the far depth. The distance between the single color image and the HOE can be calculated by the object image relationship of the HOE, which can be expressed by Gaussian formula. Meanwhile, all the reflection polarizer and the HOE have certain transmittance, so the observer can watch real objects through them.

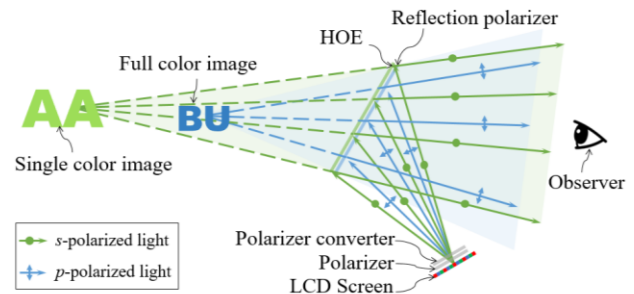


Figure 1. System configuration of the proposed dual-depth AR display system.

Fig. 2 shows the schematic diagram of the system parameters. The distance between the LCD screen and the HOE is *p*, equaling the distance between the full color image and the reflection polarizer, and is less than the focal length of the HOE represented by *f*. *q* refers to the distance between the single color image and the HOE, *l* refers to the distance between the observer and the HOE with the reflection polarizer, *a* is the size of imaging area of HOE and reflection polarizer, *x*₁ is the size of full color image and the LCD screen, and *x*₂ is the size of single color image. So the object image relationship of HOE is expressed by

$$\frac{1}{p} - \frac{1}{q} = \frac{1}{f} \quad (1)$$

Then *q* can be calculated by the formula (1) with

$$q = \frac{fp}{f-p} \quad (2)$$

The field of view of the system is *FOV*, which can be expressed as

$$FOV = 2 \arctan \left[\frac{x_1}{2(q+l)} \right] = 2 \arctan \frac{x_1(f-p)}{2(fp+fl-pl)} \quad (3)$$

And *EB* referring the eye box of the system is given by

$$EB = a \cdot \frac{q+l}{q} - x_2 \cdot \frac{l}{q} = a + al \cdot \frac{f-p}{fp} - x_1 \cdot \frac{l}{p} \quad (4)$$

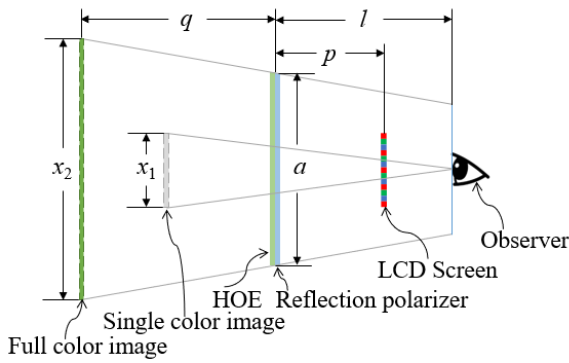


Figure 2. Schematic diagram of the system parameters.

To ensure the image diffracted by the HOE and the image reflected by the reflection polarizer can be seen together, the manufacture optical path of HOE is designed as Fig. 3. The spherical light and the parallel light interfered at the holographic material both in the angle of 60° with the holographic material. And the focal length is designed as 120 cm. The HOE is exposed on a $15\text{ cm} \times 20\text{ cm}$ silver halide holographic recording material attached to a 2 mm glass substrate by 532 nm laser. The diffraction efficiency of HOE is 64.4% at 532 nm, and the transmittance of ambient light is 60.5%.

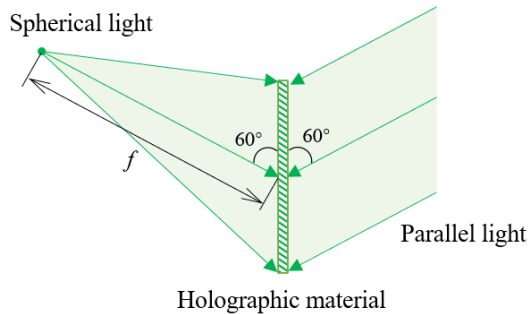


Figure 3. The manufacture optical path of the HOE.

3. Experiment and Result

The experimental setup of the proposed system is shown as Fig. 4. The system includes an LCD screen, a polarizer converter with a polarizer attached, a reflection polarizer and an HOE. The reflection polarizer and the HOE are glued together. The resolution of the LCD screen is 3840×2160 pixels. The switching cycle of the polarizer converter and the two images is 0.067 s, and the driving voltage of the polarizer converter is 5V. Two images displayed on the LCD screen are shown in Fig. 5.

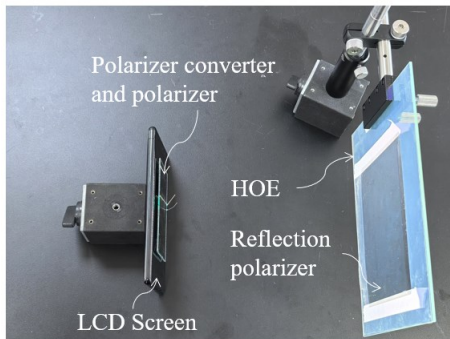


Figure 4. Experimental setup of the proposed system.



(a)



(b)

Figure 5. Two images displayed on the LCD screen. (a) The image for the near depth. (b) The image for the far depth.

The result is shown in Fig. 6. The LCD screen is located at 70 cm in front of the reflection polarizer and the HOE. The orange can is located at 70 cm behind the reflection polarizer and the HOE, and the “toy rabbit” is located at 170 cm behind the reflection polarizer and the HOE. When the camera focuses at the near depth which is 70 cm away from the reflection polarizer and the HOE, as Fig. 6(a) showed, the white letters “BU” and the “orange” can be seen clearly together, and the green letters “AA” and other real objects are also in the view, but are blurry. In Fig. 6(b), the camera focuses at the far depth which is 170 cm away from the reflection polarizer and the HOE, the green letters “AA” and the “toy rabbit” can be seen clearly together, and the white letters “BU” and other real objects are blurry in the view. The FOV and EB of the system are $4.8^\circ \times 2.4^\circ$ and $15\text{ cm} \times 8\text{ cm}$ respectively. The result shows that the proposed system can achieve a dual-depth display effect while implementing the AR functionality.



(a)



(b)

Figure 6. (a) Captured image when the camera focuses on the near depth of 70 cm. (b) Captured image when the camera focuses on the far depth of 170 cm.

In Fig. 6, we can see that there is a dim image of white letters “AA” at the same view area of the green letter in the near depth. That is because the reflectance of reflection polarizer to the *s*-polarized light is not zero but 18.4%, and the glass substrate which the holographic material attached on also reflects part of light. To reduce this dim image, we can use a low reflection glass substrate or replace the glass substrate by the reflection polarizer, and change a reflection polarizer with a superior performance.

4. Conclusion

A dual-depth AR display system based on reflection polarizer and HOE is proposed, using temporal polarization multiplexing method to produce two sets of images separately through reflection polarizer and HOE to two different depths. In the experiment, the system can display the full color image with the near depth of 70 cm and the green image with the far depth of 170 cm while implementing the AR functionality.

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6. References

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