# Demonstration of a large-size real-time full-color three-dimensional display

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A large-size and full-color three-dimensional (3D) display system without the need for special eyeglasses is demonstrated. With a specially fabricated holographic functional screen with a size of $1.8\times1.3$ m$^2$, the system including optimally designed camera-projector arrays and a video server can display the fully continuous, natural 3D scene with more than 1 m image depth in real time. We explain the operating principle and present experimental results. © 2009 Optical Society of America

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3D displays aim to provide vivid and natural scenes and natural-like 3D simulation environments as if they really existed, making them valuable tools for many applications, such as medical visualization, scientific research, entertainment, architecture design, media advertisement, 3D workstation, virtual reality system, industrial, and military areas [1,2]. Substantial recent efforts have been made to develop practicable 3D displays [1–13]. Stereoscopic displays based on binocular parallax often cause visual confusion and fatigue induced by inconstancies in the 3D visual information. Volume displays realize 3D images made up of light spots arranged in 3D space by optical scanning based on mechanical components, but they cannot provide a fully convincing 3D experience because of their limited color reproduction and lack of occlusions. Multi-view 3D imaging methods usually display 8–16 plane images seen at different viewing directions compromised with limited field of view and jumpy characteristics. The integral photography is capable of achieving real-time continuous imaging within a viewing angle under incoherent light and displaying moving 3D images using a single lens array in both the pickup and display stages. However, the display size, the lateral resolution, and the image depth are basic limitations of its applications [14]. Holography is a real 3D image recording and display method that has been considered the ideal method for 3D display. Currently available holographic 3D displays with conventional recording materials exhibit restricted applications for lack of image-updating capability. Recently, an updatable holographic 3D display based on photorefractive polymer was demonstrated [1]. Owing to limitations of recording materials, current holography is still hard to realize real time, large format, full-color 3D display for practical applications in the near future. Therefore, almost all the available 3D display technologies have some technical deficiencies. One main challenge is how to realize the real-time large size 3D display while maintaining full color and high resolution. In this Letter, we present the design, fabrication, and experiment of what is believed to the largest 3D display system with a holographic functional screen.

If the relative direction and intensity information of light beams originated from a 3D object are recorded, the 3D information of the object can be recovered by generating the beams with the same relative directions and intensities based on the recorded information. Figure 1 shows a schematic configuration of our 3D pickup and display system mainly made up of a video server, an optimally designed CCD camera array, and a projector array in specifically arranged configuration behind the holographic functional screen. We use 64 color CCD cameras with $640\times480$ pixels to pick up the information of 3D object at different view angles, and 64 color projectors to display the full-color 3D space information of the object through the planar holographic functional screen with the size of $1.8\times1.3$ m$^2$. Optical axes of all cameras in the array converge to a common point $R$. The light beams from projectors with their optical axes converging to a common point $R'$ are projected onto the holographic functional screen at various angles, which are determined by the geometry of the camera array. The magnification depends on the ratio between the geometry sizes of projector and camera arrays. Each camera is individually connected to a

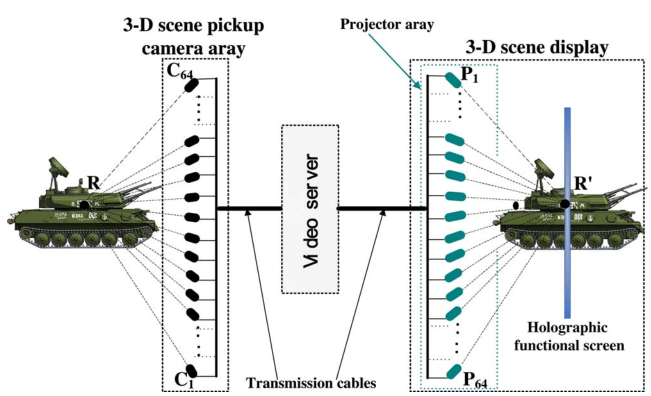



Fig. 1. (Color online) Schematic configuration for 3D scene pickup and display.

peripheral component interconnect card plugged into the video server. The video server is used to capture the images at 64 different view angles through the CCD camera array, correct image distortions, synchronize the image frames, and control the projector array to emit them onto the holographic functional screen. The precise synchronization is essential for real-time 3D display with a frame rate of 25 frames/second in the experiment.

All the projectors illuminate every point on the holographic functional screen. The point of the holographic functional screen emits multiple light beams of various intensities and colors in different directions in a controlled way, as if they were emitted from the point of the real 3D object at a fixed spatial position. For example shown in Fig. 2, if $M \times N$ projectors simultaneously project perspectives with object information onto one position $H_{ij}$ on the holographic functional screen with the specifically spreading function, the light beams are generated through projectors arranged in a specific geometry, and the holographic functional screen makes the necessary optical transformation. To recover the 3D information correctly, the key is to spread the light beams from the projectors with the right spatial angle $\omega_{mn}$, and the output light beams from $H_{ij}$ are the integral result as given in Eq. (1). All projectors contribute to each 3D scene view without sharp boundary between views. So the display provides continuous and smooth change at different view areas,

$$\Omega_{ij} = \sum_{n=1}^{N} \sum_{m=1}^{M} \omega_{mn}. \quad (1)$$

Our planar holographic functional screen is holographically printed with speckle patterns exposed on proper sensitive material [15]. It is easy to control the screen's diffused angle by controlling the shape and size of speckles through making the mask aperture to realize angular distributions of the light beams with the diffused angle close to $\omega_{mn}$. The fully random speckle structure is wavelength independent and without chromatic aberration, which enables high transmission efficiency. With this method, we can easily fabricate large size holographic functional screens.

In the experiment, horizontal-only-parallax imaging and real-time 3D display is confirmed to reduce the requirement of the number of cameras and projectors as shown in Fig. 1, which is an effective approximation to full-parallax 3D display [1], because humans perceive depth using horizontally offset eyes. This system exhibits a total horizontal view angle of 45° with uniform brightness and larger than 1 m clear depth. The picture of a 3D portrait display along with the real person of Prof. Tung H. Jeong at Lake Forest College in Fig. 3, where 64 images captured at different view angles are stored in the video server. We can see that the 3D image is higher than the real person. The displayed 3D image is very similar to the computer-generated hologram synthesized from multiple angular viewpoints [16] but the 3D display can easily realize large size, high brightness, and update without the limitations of the recording material. To compare them, the pictures of the computer-generated hologram and the 3D image in the display system with the same image data are shown in Fig. 4.

Several computer-generated full-color 3D animations and real-time pickup and display results were demonstrated and viewed successfully by attendees of the Eighth International Symposium on Display Holography on July 13–17, 2009 in Shenzhen, China.

The demonstrated 3D display corresponds to the horizontal-only-parallax capability. However, the display system can be extended to any directional parallax, such as an arched schematic configuration of an arched structure for the 360° desk-like 3D scene pickup and display, as shown in Fig. 5.

In summary, a large-size full-color 3D display system with an $1.8 \times 1.3\ m^2$ holographic functional screen has been demonstrated. We show that this method can realize fully continuous, natural 3D dis-

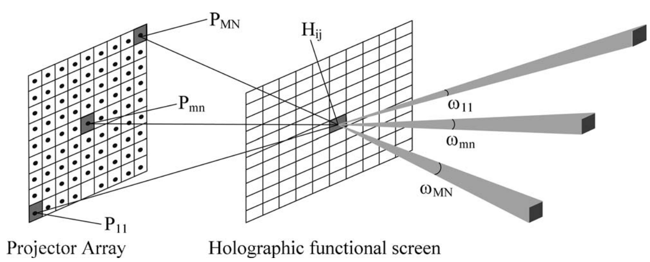
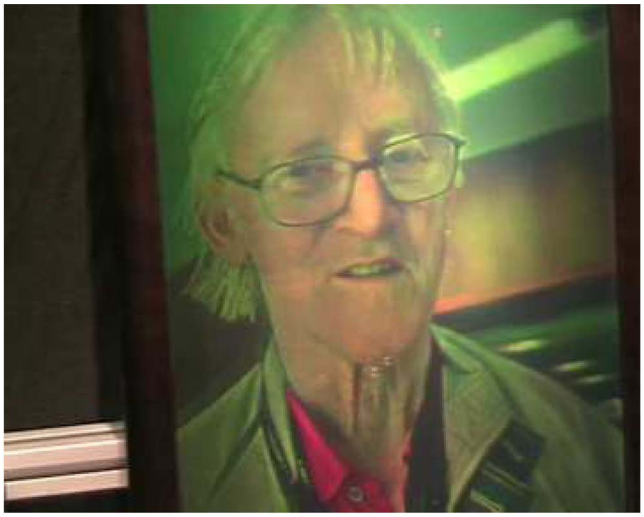
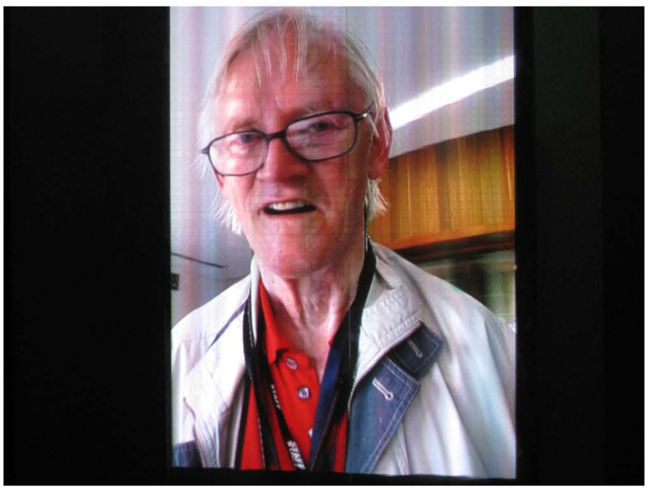



Fig. 2. Schematic diagram of the holographic functional screen to manipulate light beams.

Fig. 3. (Color online) The picture of a 3D portrait display along with the real person of Prof. Tung H. Jeong.



(a)



(b)

Fig. 4. (Color online) Pictures of (a) the computer-generated hologram and (b) the 3D display in the experiment with the same image data.

play without limitations of recording materials for conventional holography. We believe that the 3D display system will find many applications in medical, industrial, military, and advertising areas.

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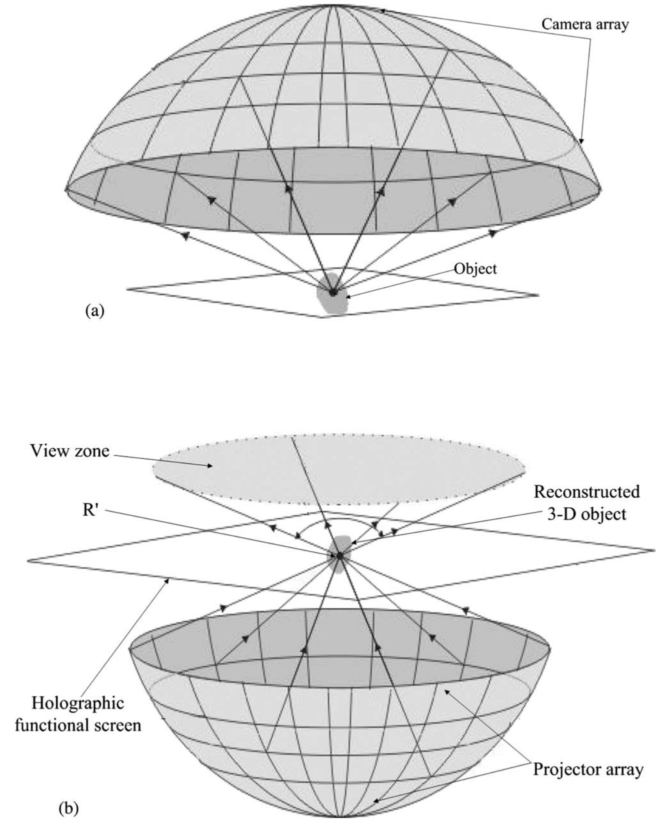


Fig. 5. Schematic configuration of an arched structure for the 360° desk-like 3D scene pickup and display. (a) Camera array for pickup a (b) projector array and the holographic functional screen for 3D display.

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