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3D TV Based on Spatial Imaging

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Abstract

We are studying a three-dimensional (3D) TV system based on a spatial imaging method for the development of a new type of broadcasting that delivers a strong sense of presence. This spatial imaging method can reproduce natural glasses-free 3D images in accordance with the viewer's position by faithfully reproducing light rays from an object. One challenge to overcome is that the 3D TV system based on spatial imaging requires a huge number of pixels to obtain high-quality 3D images. Therefore, we applied ultra-high-definition video technologies to a 3D TV system to improve the image quality. We developed a 3D camera system to capture multi-view images of large moving objects and calculate high-precision light rays for reproducing the 3D images. We also developed a 3D display using multiple high-definition display devices to reproduce light rays of high-resolution 3D images. The results show that our 3D display can display full-parallax 3D images with a resolution of more than 330,000 pixels.

Introduction

We are researching spatial imaging technologies for the creation of a three-dimensional (3D) TV that reproduces more natural 3D images and does not require viewers to wear special glasses. An integral 3D TV based on the integral photography method [1], which a type of spatial imaging technology, can reproduce natural 3D images in accordance with the viewing position by faithfully reproducing light rays from an object. One challenge to overcome in an integral 3D system is the requirement of a huge number of pixels to obtain high-quality 3D images. Therefore, we applied ultra-high definition (UHD) video technologies and multiple display devices to a 3D TV system to improve the image quality.

Integral 3D TV System

Principle of Integral Photography

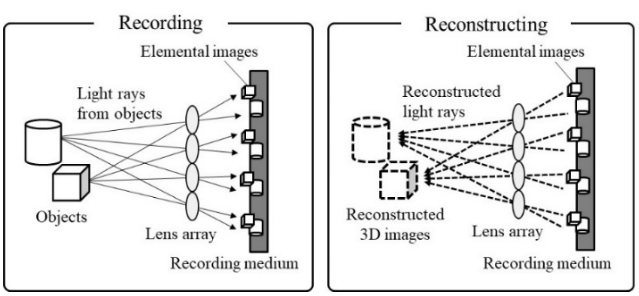


Figure 1. Principle of integral photography.

The integral photography method is a spatial imaging technique proposed by G. Lippmann in 1908 [1]. As shown in Fig. 1, this method uses a lens array to both record and reconstruct 3D images. Numerous small elemental images of objects are placed incident to the recording medium through the lens array. The light rays reconstructed from the elemental images on the recording medium behind the lens array converge at a point, thereby reconstructing the optical 3D images. One advantage of this method is that the 3D images are recorded and replayed under natural light without a coherent laser light. This spatial imaging method can display ideal 3D images that have motion parallax in both the horizontal and vertical directions. In addition, viewers do not require special glasses to see 3D images, which is important for practical TV broadcasting [2, 3].

Basic configuration of integral 3D TV

Three-dimensional TV based on the integral method has the potential to capture and display ideal natural-looking 3D images. However, an integral 3D method requires a large amount of image data to capture, transmit, and display images. Therefore, we constructed an integral 3D TV using an UHD video system [4-6].

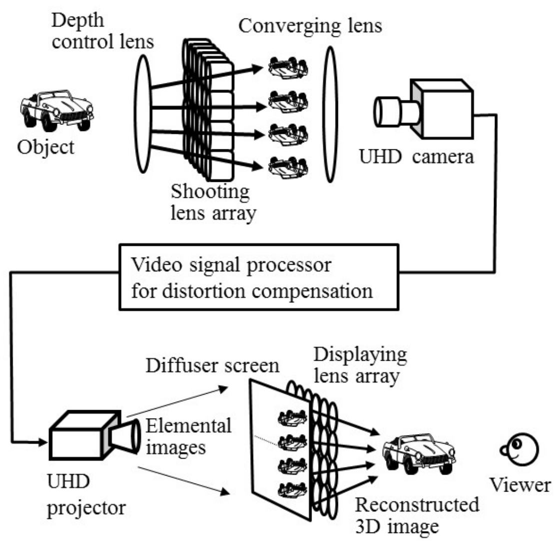
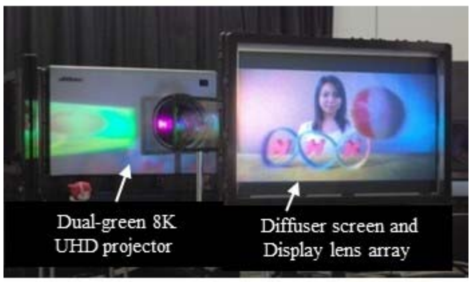


Figure 2. Integral 3D video system using UHD video devices.

Figure 2 shows the scheme of an integral 3D system using an UHD camera and display. During the capture stage, we use an UHD camera with a resolution equivalent to an 8K video image sensor by applying a pixel-offset method. The light rays of the objects are captured through a shooing lens array, which is constructed using a gradient-index elemental lens and a UHD camera. During the display stage, elemental images are projected using an UHD projector on a diffuser screen behind a displaying lens array, and 3D images are reconstructed in front of the viewers. The problem with a projection-type integral 3D system is that any geometric distortions present in the projection lens cause positional errors between the elemental images and elemental lens. Therefore, we developed a UHD video signal processor to compensate the distortion in elemental images with high accuracy for an integral 3D TV system [5].

Figure 3 shows a photograph of the integral 3D TV system using a dual-green 8K resolution pixel-offset camera and a display system. The reconstructed 3D images have a resolution of 182 (H) pixels × 140 (V) pixels and a viewing angle of 24.5° in the vertical and horizontal directions.

(a)



(b)

Figure 3. Integral 3D TV system using (a) UHD camera system and (b) UHD display.

We also developed a video system with a resolution equivalent to 8,000 scan lines [6]. We constructed a camera with a resolution equivalent to 8,000 scan lines by applying a pixel-offset imaging method to a 33-megapixel image sensor. The camera device uses a single complementary metal–oxide–semiconductor (CMOS) sensor for each of the red and blue signals and two CMOS sensors (G1 and G2) for the green signals. The two green sensors are diagonally offset from each other by half a pixel width to provide a resolution equivalent to 8,000 scan lines. In the UHD projector, a wobbling element is arranged to shift the positions at which the G1 and G2 signals are displayed by half a pixel diagonally every sixtieth of a second. Owing to the movement of the wobbling optical device, the green signal is displayed with a resolution equivalent to 8,000 scan lines at a rate of 30 fps. An integral 3D TV using the pixel-offset method can increase the depth range of 3D images to approximately twice that of a system without this method. The reconstructed 3D images have a resolution of 400 (H) pixels × 250 (V) pixels and a motion parallax in the horizontal and vertical directions.

3D display using high-pixel-density panel

With the goal of developing a compact direct-view 3D display, we adapted a high-density full-8K resolution direct-view panel for use in an integral 3D display. To build the prototype integral 3D display shown in Fig. 4, we display elemental images on a 13.3-inch organic light emitting diode (OLED) 8K display produced by Semiconductor Energy Laboratory Co., Ltd. [7], and use a designed optimum lens array for the pixel structure of the display. The specifications of the prototype are listed in Table 1. The prototype successfully displays 3D images with a resolution of 293 (H) pixels × 190 (V) pixels and a viewing-zone angle of 32°.

(a) (b)

Figure 4. Integral 3D display system using full-8K resolution OLED display panel: (a) OLED display panel (Semiconductor Energy Laboratory Co., Ltd.) and (b) displayed 3D image.

Table 1. Specifications of integral 3D display with 8K OLED.

8K OLED display panel	Resolution	7680 × 4320 pixels
	Pixel density	664 ppi (pixel per inch)
Lens array	Number of elemental lenses	293 × 193
	Focal length	1.74 mm
3D images	Resolution	293 × 193
	Frame rate	60 Hz

3D TV system using multiple devices

Multiple cameras and display devices

We plan to develop a 3D TV system using multiple cameras and displays to enhance the image quality of 3D images. It is difficult to capture large objects using only a single camera system because the field of view is too wide. To capture large objects in TV studios or theaters, we developed a dense camera array with 154 high-definition (HD) cameras without lenses, as shown in Fig. 5. Light-ray information for integral 3D images will be calculated from the captured multi-view images using image-based rendering.

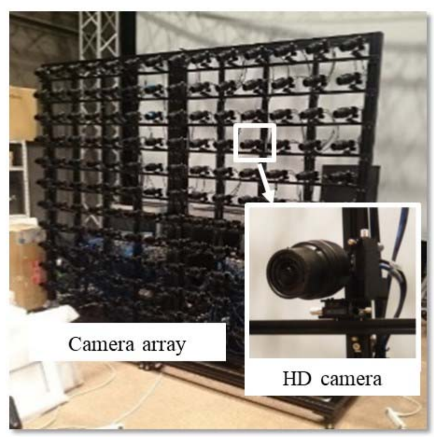


Figure 5. Camera array with HD cameras used to capture 3D spatial images.

For the display side, we plan to develop a 3D display using multiple display devices such as multiple flat-panel displays and multiple projector units, as shown in Fig. 6. We developed multi-flat-panel 3D displays for tablets or flat-screen displays with optics to magnify and combine the elemental or 3D images seamlessly on multiple displays (Fig.6 (a)). We also developed a projection-type display in which multi-directional elemental images are superimposed on the lens array using multiple projector units to enhance the resolution and enlarge the viewing angle of the 3D images (Fig. 6 (b)).

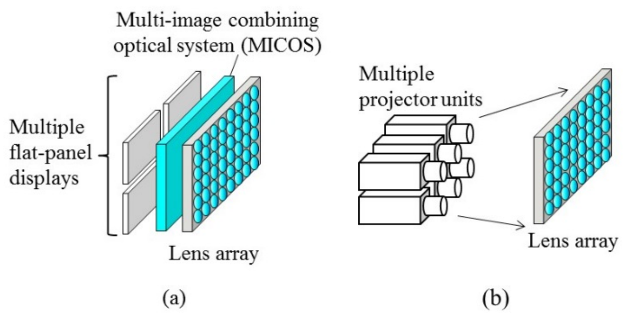


Figure 6. 3D display using multiple devices: (a) multi-flat-panel and (b) multi-projection 3D displays.

3D Display with multiple devices

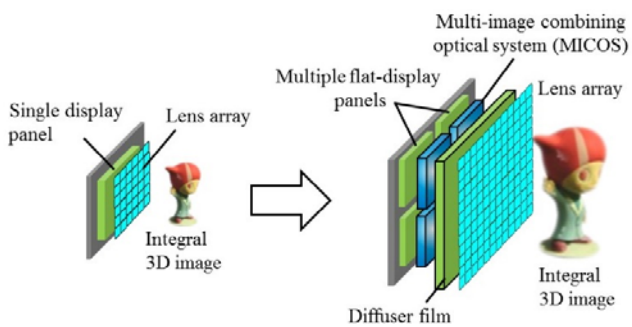


Figure 7. 3D display with multiple flat-display panels.

When we use a single display panel in a 3D display system, the size and resolution of the 3D image is limited by those of the panel. Therefore, we proposed several methods for combining the images of multiple flat-panel displays to improve the quality of integral 3D images [8, 9] (Fig. 7). These methods use a multi-image combining optical system (MICOS) to magnify and combine the images of multiple displays without gaps between the multiple display areas.

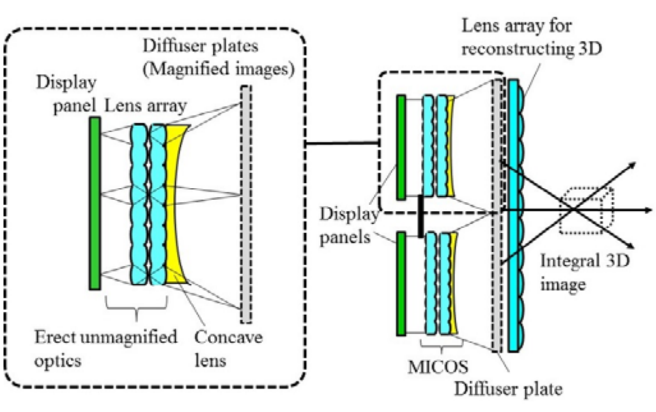


Figure 8. Multi-image combining optical system.

MICOS is composed of an erect unmagnified optical system and a concave lens. As shown in Fig. 8, the erect unmagnified optical system is composed of two sets of micro-lens arrays. To expand the light rays and create a magnified image, we combine the lens-array system and a concave lens. The unmagnified optical system is placed in front of each display panel, and each magnified display image is connected without a gap. Three-dimensional images are reconstructed from the synthesized elemental images on the diffuser plate through the lens array. It is possible to generate a 3D image that has more pixels than a single display panel.

In our prototype 3D display system, we use four 9.6-inch 8K dual green LCD panels, and a MICOS is placed in front of each LCD panel. Figure 9 shows the 3D images reconstructed using this prototype system. Only the dotted areas in the figures can be viewed when a single LCD panel is used. The use of four LCD panels makes it possible to enlarge the displayable image area by approximately 5.7 times because the magnification ratio of the MICOS is approximately 1.2.

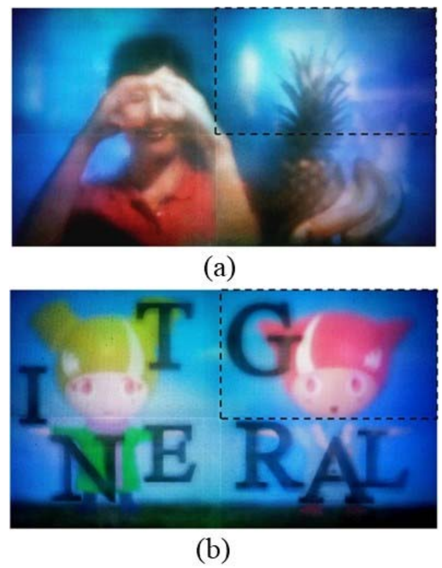


Figure 9. 3D images displayed using four LCD display panels and MICOS. Only the dotted parts in the figures can be viewed when a single LCD panel is applied: (a) real 3D objects and (b) 3D computer graphics.

The screen synthesis method, however, degrades the quality of the produced 3D images because it requires an optical system for the MICOS with a complex lens structure and a diffuser plate. We then improved the screen synthesis method for combing the 3D images of multiple flat-panel displays by using a simple and compact MICOS that eliminates the need for a diffuser plate [9]. The equipment displays 3D images with less noise and a higher resolution than those of the previous equipment applied. The depth of the display equipment using the new screen synthesis method is also reduced to less than 1/5 that of the previous prototype.

Multi-projection 3D display system

Many researchers have reported that integral 3D displays using multiple projectors effectively enhance the quality of 3D images [10-15]. We have also developed a projection-type integral 3D display system using multiple UHD projectors to enhance the viewing angle and resolution of 3D images [14, 15]. Figure 10 shows the basic configuration of the proposed display system. The display system consists of multiple projectors, a collimator lens, and a lens array. In our proposed display, the balance between enhancements of the viewing angle and resolution is controlled by installing multiple projectors at optimal positions and projecting elemental images onto the lens array at predetermined angles as collimated light beams [14]. In addition, for the prototype display system, we also developed methods for generating elemental images and compensating for distortions of the projection position of elemental images with high accuracy.

As shown in Fig. 11, the prototype display system consists of six compact UHD projectors with 4K resolution. The displayed 3D image (Fig. 12) has a viewing angle of over 30° in the horizontal direction while achieving a resolution of approximately 100,000 dots at the center view [15].

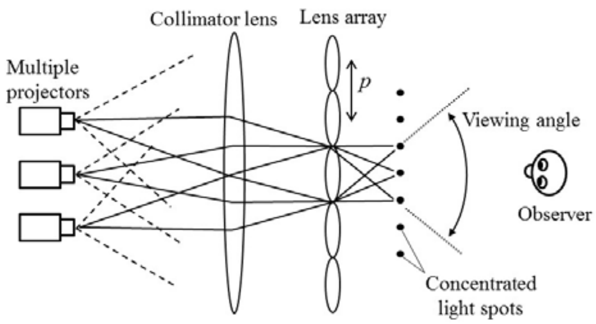


Figure 10. Proposed projection-type integral 3D display.

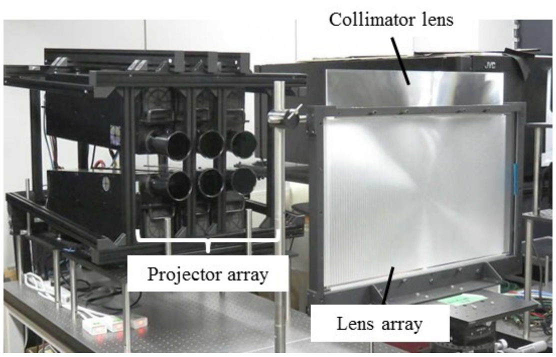


Figure 11. Prototype 3D display system with projector array.

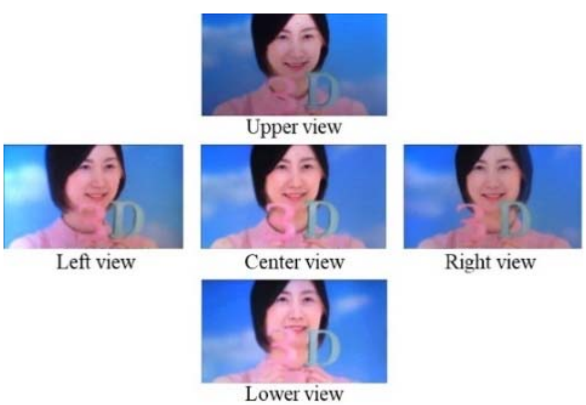


Figure 12. Displayed 3D images.

High-definition 3D display

We also developed a high-definition 3D display method using multiple projectors and a 3D screen with a narrow diffusion angle. Figure 13 shows the configuration of the developed 3D display system. The 14 projectors display 350 multi-view images on the 3D screen with top-hat diffusing characteristics to reduce crosstalk between the light rays. Therefore, the 3D images reproduced have a deeper depth representation than an ordinary 3D display system using a micro lens array. In addition, because the resolution of the displayed 3D image is equal to the multi-view resolution, with this method it is possible to easily improve the resolution of a 3D image by improving the resolution of a multi-view image. Figure 14 shows an example of a displayed 3D image. Our 3D display system can display 3D images of real moving objects at a frame rate of 30 fps. The reconstructed 3D images have approximately 330,000 pixels, which is three times as many as images as our previously developed 3D display system. Furthermore, a horizontal viewing angle of approximately 35° is obtained through the arrangement of multi-view images and the design of the display optics.

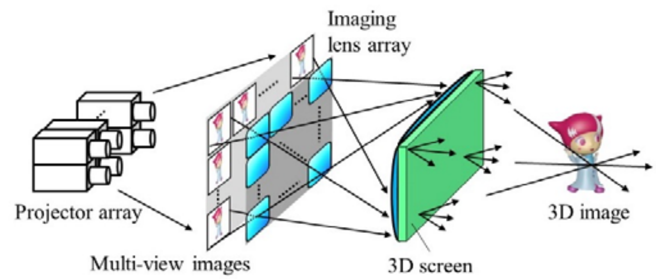


Figure 13. High-definition 3D display using projector array and 3D screen.

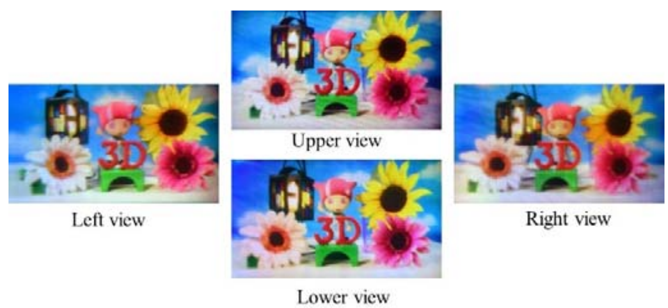


Figure 14. 3D images of high-definition 3D display.

Conclusion

Three-dimensional TV systems based on spatial imaging can present full-parallax 3D images without the need for special glasses. The challenges in constructing a practical 3D TV system are to develop technologies to efficiently capture and display enormous amounts of 3D information. Furthermore, highly efficient compression coding technologies for 3D information need to be developed for 3D TV systems.

Acknowledgements

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Masahiro Kawakita received his BS and MS degrees in physics from Kyushu University and his PhD in electronic engineering from the University of Tokyo in 1988, 1990, and 2005, respectively. In 1990, he joined the Japan Broadcasting Corporation (NHK), Tokyo. Since 1993, he has been at the Science & Technical Research Laboratories of NHK, where he has been researching applications of liquid crystal devices and optically addressed spatial modulators, three-dimensional TV cameras, and display systems.

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