Depth and viewing-angle enhanced 3D-2D convertible display system using multiple display devices and a lens array

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Abstract
An improved 3D-2D convertible display system with enhanced depth and viewing angle is proposed. By using the optical structure of an LCD panel, it is possible to enhance the performance of the system and realize the 3D-2D conversion. Some preliminary experimental results will also be provided.

1. Introduction
The three-dimensional (3D) display is a technique to display the image of the 3D object as if it really showed. Among them, the integral imaging (InIm), which is also called the integral photography [1], attracts much attention because of its advantages to provide full parallax color moving pictures without special glasses [2-4]. In these days, however, the mainstream of the display market is a two-dimensional flat panel displays (2D FPDs) while the 3D display systems are not ready to be commercialized yet. For that reason, the needs for the 3D-2D convertible display are increased and our group has proposed a 3D-2D convertible display system with two display devices [5]. However, since it is based on the InIm, the bottleneck of the InIm still remains in that 3D-2D convertible system. Therefore, we propose an improved method to enhance both the depth and viewing-angle of the 3D image while conserving the advantages of the previous system.

2. Principles
Since the proposed method is based on InIm, it is needed to review the basic principle of the InIm shown in Fig. 1. In Fig. 1, the InIm system is composed of a display device and a lens array with distance a. The location b of the central depth plane (CDP), which means the focal plane, is determined by the following lens equation.

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{f}. \qquad (1)$$

In the above equation, f means the focal length of the lens array.

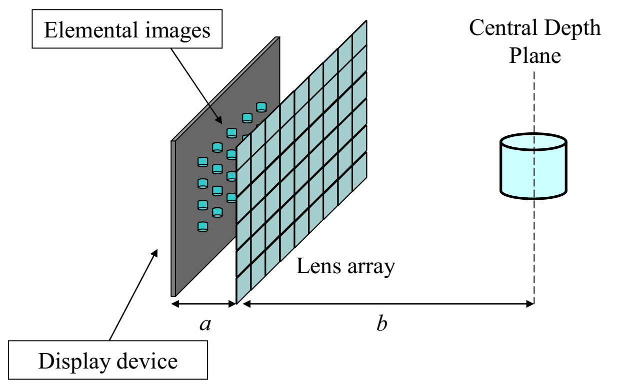


Fig. 1. The basic principle of the InIm.

If a is larger than f, b has a positive value and the 3D image is formed in front of the lens array. This is called a real InIm. If a is smaller than f, b has negative value and the location of the 3D image is behind the lens array. This is called a virtual InIm. Since the 3D image is integrated around the CDP, the expressible depth of the 3D image is restricted within few centimeters. Therefore, it is needed to increase the number of the CDP and to integrate the 3D image through the multiple CDPs for enhancing the total depth of the 3D images. There is a previously proposed method using this principle to overcome the depth limitation of the InIm [4]. In this paper, we combine the depth-enhancement InIm with the 3D-2D convertible InIm and realize a depth and viewing-angle enhanced 3D-2D convertible display system.

The proposed method uses the optical structure of a liquid crystal display (LCD) panel. The LCD panel is a transmission-type display device which shows an image by transmitting or blocking the light through it. Using this principle the previous method realizes a 3D-2D conversion electrically [5]. Additionally, the proposed method improves the previous method by increasing the numbers of the LCD panels. The structure of the proposed method is shown in Fig. 1.

The system is composed of lens array, two LCD panels and a display device. In Fig. 2, the focal length f of the lens array is located between the display device and the LCD panel 2. By this configuration, the proposed system can form a real and a virtual 3D images simultaneously and increase the total depth significantly.

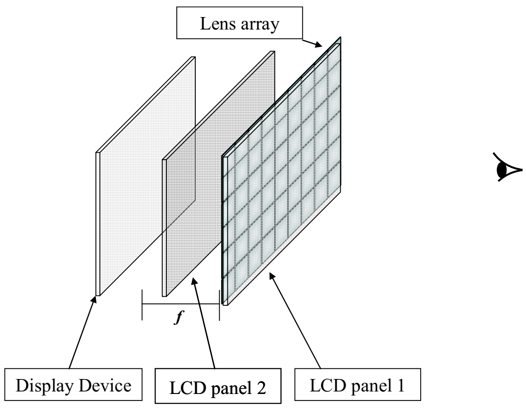


Fig. 2. The structure of the proposed method

In the 2D mode, the LCD panel 1 is the main display device while the others act as a backlight. For that purpose, the display device displays a white screen and the LCD panel 2 is set to be transparent. The LCD panel can be transparent by displaying a white screen because it has a maximum transmittance on that setup. Then, the LCD panel 1 receives the light from the other devices and displays 2D images by the principle of the LCD as shown in Fig. 3.

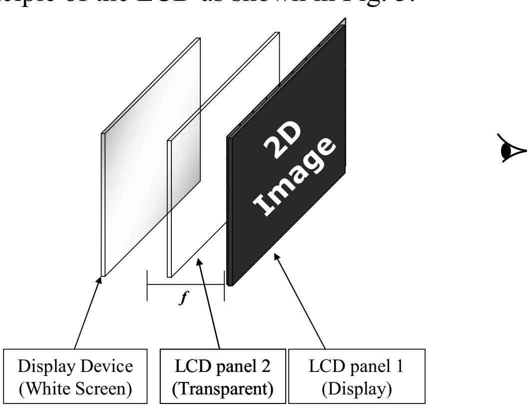


Fig. 3. The principle of the 2D mode

In the 3D mode, the LCD panel 1 displays two patterns of masks to enhance the viewing angle of the 3D image. Synchronized with the LCD panel 1, two sets of elemental images for the real and the virtual 3D images are displayed on the LCD panel 2 and the display device, respectively. As a result, the real and the virtual 3D images are displayed simultaneously and the depth of the 3D image is increased. The principles of the 3D mode are shown in Fig. 4.

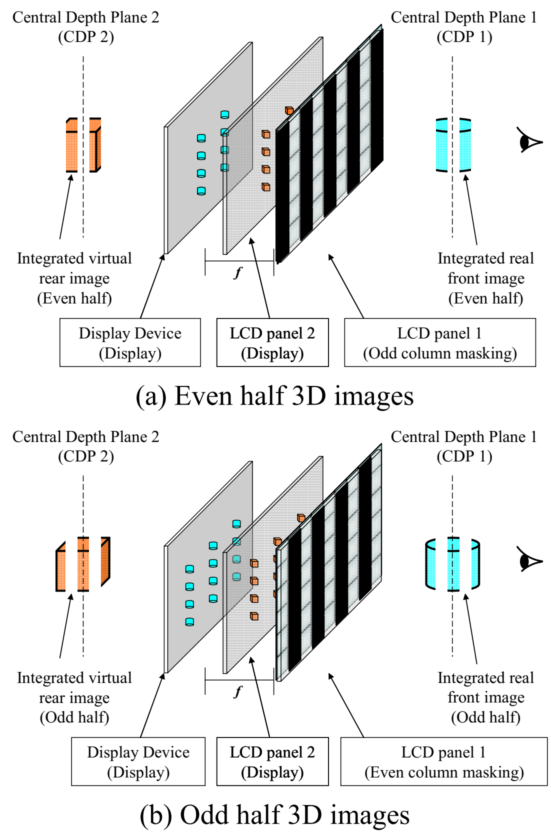
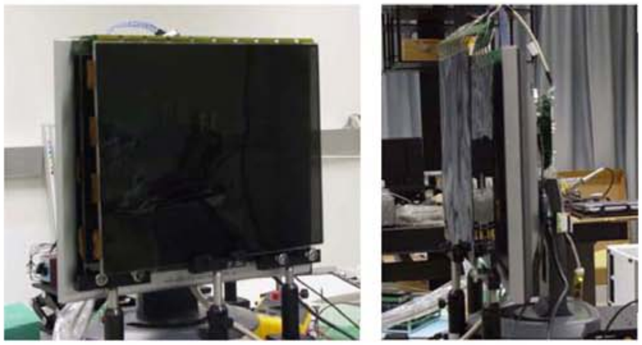


Fig. 4. The principles of the 3D mode

With the time-multiplexing to switch between the setup of Fig. 3(a) and (b) with speed enough to induce the afterimage effect, a whole depth and viewing-angle enhanced 3D images will be observed. Since there is no mechanical movement within this system, the system can be simple and has a comparable size with the conventional 2D FPDs.

3. Experimental Results

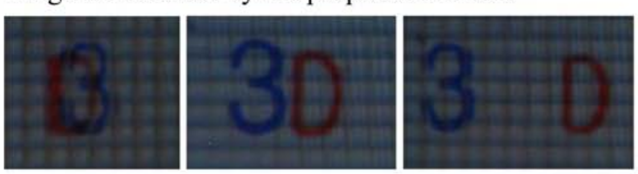
Some preliminary experiments were performed to prove the proposed method. In the experiment, one 17-inch LCD monitor and two 17-inch LCD panels are used for the display device and LCD panel 1 and 2, respectively. The LCD panels are acquired by disassembling the same model of LCD monitor which is used for the display device. As a result, three devices have same resolution of 1280 by 1024 pixels (SXGA) which have pitch of 0.263mm and same optical structure. The number of polarizer of the total system is minimized to acquire the maximum optical efficiency. The lens array is composed of 13 by 13 elemental lenses which have pitch of 10mm and focal length of 22mm. The picture of the experimental setup is shown in Fig. 4.



(a) Front view (b) Side view

Fig. 4. The experimental setup

In the 3D mode, two 3D images of '3' and 'D' are integrated at 80mm and -80mm from the lens array while the minus sign means the virtual image. A wide viewing angle technique is used to enhance the viewing angle of the 3D image. The experimental results of 3D mode are shown in Fig. 5. In Fig. 5, the 3D images are captured at various positions and it is easily recognized that the relative position of two images are changed with the viewpoints, which shows that the images have different depth positions and both the real and the virtual images are integrated without distortion. Therefore, the depth of the 3D image is increased by the proposed method.



(a) Left 14° (b) Center (c) Right 14°

Fig. 5. The experimental results of 3D mode

(a) Left 14° (b) Center (c) Right 14°

Fig. 6. The experimental results of 3D mode without wide viewing technique

The experimental results without the wide-viewing technique are shown in Fig. 6. In Fig. 6, the 3D images are severely distorted at the same view points and show that the viewing angle of 3D image is also enhanced using the proposed scheme.

In the 2D mode, the 2D images can be displayed in the LCD panel 1 with SXGA resolution. The experimental results of the 2D mode are shown in Fig. 7. In Fig. 7 (a) and (b), the image of flowers and sunset are shown clearly.

(a)

(b)

Fig. 7. The experimental results of 2D mode

In the 2D mode, the images are displayed with the full resolution of the LCD panel 1 and therefore it is suitable for the high-definition (HD) format because the LCD is one of the HD-qualified devices. However, in the proposed system, the lens array can be observed through the LCD panel 1 and degrades the 2D image quality. This problem is expected to be overcome to add an active diffuser such as a polymer-dispersed liquid crystal (PDLC) between the lens array and LCD panel 1. This improvement will be researched further for better performance.

4. Conclusion

An improved method is proposed to realize a 3D-2D convertible display system which can display 3D images with a large depth and wide viewing angle. Since the system uses an LCD panel as a 2D display device, the 2D image also has a high picture quality and also suitable for the HD format.

Acknowledgment

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