An improved 2D/3D convertible integral imaging with two parallel display devices

Heejin Choi, Jae-Hyeung Park, Joohwan Kim, Seong-Woo Cho, and Byoungho Lee
School of Electrical Engineering, Seoul National University, Seoul, Korea
byoungho@snu.ac.kr

Abstract

In this paper, a novel 2D/3D convertible display system based on integral imaging is proposed. Combining two liquid crystal display panels with integral imaging, it is possible to convert the display between two-dimensional mode and three-dimensional mode without mechanical movement. The proposed method is proven by preliminary experiments.

1. Introduction

A three-dimensional (3D) display is a method to provide a real-like image to the observer. Since 3D images contain more information of the original object than two-dimensional (2D) planar images, there are various applications of 3D display such as advertising, entertainments, scientific researches, medical treatments, and so on. For the various potential needs and researches, however, there are many problems to be solved and the 3D display system still needs some time before being fully commercialized. On the contrary, the field of recent 2D display is remarkably expanded due to the developments of the flat panel display (FPD) and the beginning of the high-definition (HD) broadcasting. Therefore, the needs for 2D/3D convertible display system are increased in 3D field [1]. In this paper, a 2D/3D convertible display system based on the principles of liquid crystal display (LCD) for 2D display and integral imaging for 3D display is proposed and proven by various preliminary experiments.

2. Basic Principles

The integral imaging (InIm), which is also called integral photography [2], is a method to display full parallax 3D images without special glasses. No need of the special 3D glasses is a major advantage of InIm because the observer needs nothing to view the 3D images. This means that InIm is suitable for home TVs, monitors, and even advertisements.

In the early days, InIm did not attract much attention due to the restriction of recording material and some major problems. Recently, various researches have been performed and it has been proven that it is useful to adopt a charge-coupled device (CCD) camera for recording device and a FPD for displaying device [3]. The principle of InIm is shown in Fig. 1.

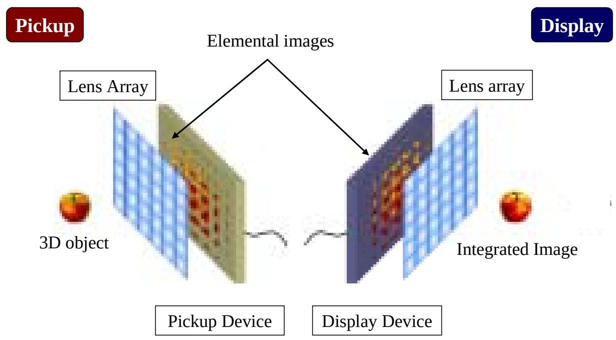


Figure 1. The principle of integral imaging

As shown in Fig. 1, InIm consists of two processes – pickup and display. In pickup process, the object is captured through the lens array into small 2D images, called elemental images. In display process, those elemental images are displayed on FPD such as LCD and integrated through the same lens array used in pickup. The integration of the elemental images forms a 3D image of original object. Although there are some bottlenecks in InIm, various researchers have overcome many of them [4-6]. In this paper, the 3D display mode of the proposed 2D/3D convertible display system is based on InIm.

The LCD, composed of two glasses and the liquid crystal which is located between them, is one of the most useful FPD devices. The LCD is basically a spatial light modulator which can transmit or block the light through it. From the principles of LCD, it is easily recognized that an LCD panel itself is transparent when the transmittance rate is maximized by displaying a white screen. Therefore, it is possible to observe an object implemented with the rear LCD through a white-displaying LCD panel (front LCD). This principle is one of the most important points in realizing the 3D mode of the proposed system.

3. Principles of the Proposed System

The structure of the proposed system is shown in Fig. 2. In Fig. 2, an LCD panel named as display device 2 is located in front of the lens array of the conventional InIm display system. With this structure, 2D/3D conversion is possible by converting the role of each display device.

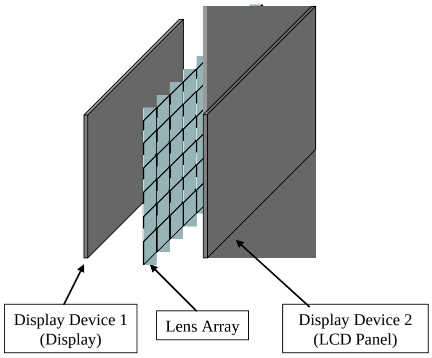


Figure 2. The structure of 2D/3D convertible system

3.1 Principles of the 3D display mode

The basic principles are the same as those of the conventional InIm in 3D display mode. The display device 2 basically has no role and is transparent. This is possible by displaying a white screen on display device 2 because the transmittance of an LCD panel is maximized. The elemental images are displayed on display device 1 and integrated by the lens array in central depth plane (CDP) and observed through display device 2 as shown in Fig. 3.

The location of CDP can be acquired from the following equation called lens's law:

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

In the above equation, *a* means the distance between the display device 1 and the lens array and *b* is the location of the CDP measured from the lens array. Since the basic principles are the same as those of InIm, the proposed system can provide all the advantages of InIm perfectly and be easily improved by the advanced recent technologies of InIm.

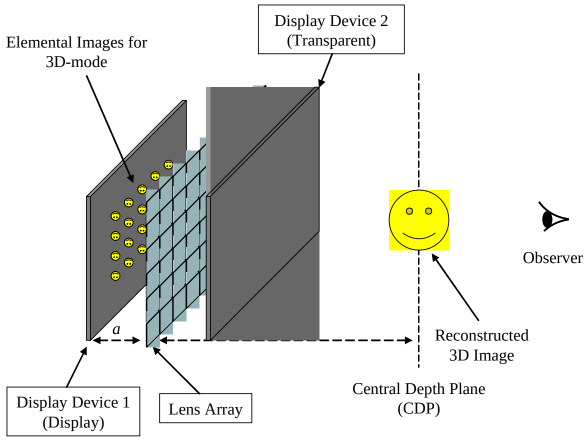


Figure 3. Principle of the 3D display mode

3.2 Principles of the 2D display mode

On the contrary to the 3D display mode, the display device 2 shows 2D images while the display device 1 and the lens array execute the role of backlight unit of LCD. In other words, the display device 1 displays a white screen and the display device 2 modulates the white light emitted from display device 1. Consequently the 2D images are displayed. These principles are described in Fig. 4.

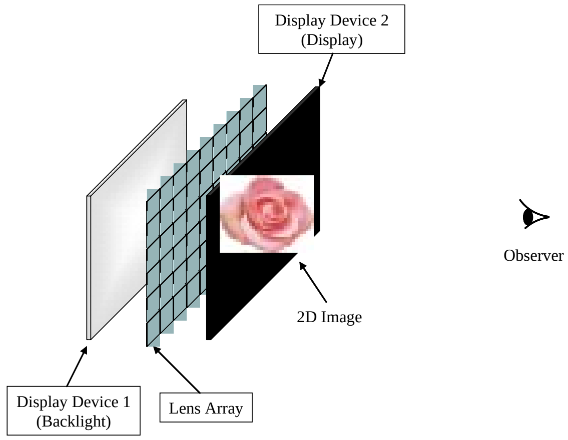


Figure 4. Principle of the 2D display mode

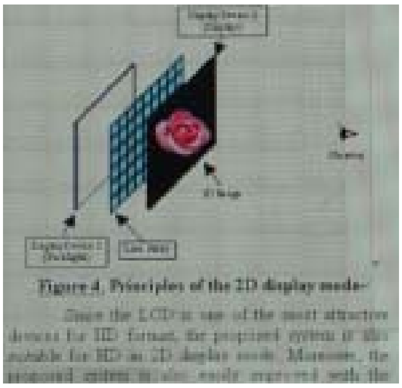
Since the LCD is one of the most attractive devices for HD format, the proposed system is also suitable for HD in 2D display mode. Moreover, the proposed system is also easily improved with the advances of LCD technologies.

4. Experimental Results

Various preliminary experiments were performed to prove the proposed method. In experiments, a 17-inch

LCD monitor with pixel size of 0.27mm is used as the display device 1. An LCD panel is obtained from the same kind of LCD monitor as display device 1 and used as display device 2. The direction of polarizer of display device 2 is adjusted to minimize the optical loss. The lens array consists of 13 by 13 elemental lenses with pitch of 10mm and focal length of 22mm.

4.1 Experimental Results for 2D Display



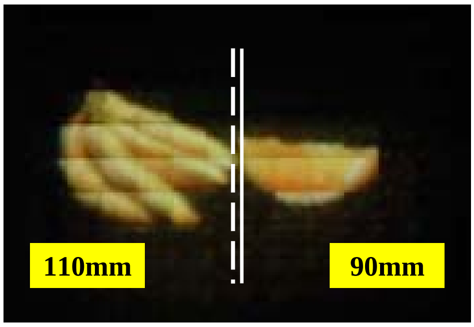
(a)

(b)

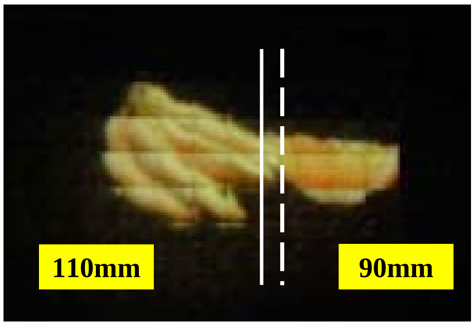
Figure 5. Experimental results of the 2D display mode : (a) texts and images, (b) image of rose

In the 2D display mode, there are many methods to measure the quality of the display system. In this paper, two samples of texts and image are displayed on the system and captured by CCD camera. The text samples are used because they are composed of small number of pixels and any distortion on them can be observed more significantly than the images. The experimental results for 2D display mode are shown in Fig. 5(a) and (b). In Fig. 5(a), part of this paper, which contains both texts and images, is displayed. It is easily observed that both images and texts are displayed clearly and easily recognized. An image of rose is also displayed and captured as shown in Fig. 5(b). From the experimental results, it can be proven that the proposed 2D/3D convertible system is almost as good as the conventional LCD display for displaying the 2D images and texts.

4.2 Experimental Results for 3D display



(a)



(b)

Figure 6. Experimental results of the 3D display mode : (a) Right viewpoint, (b) Left viewpoint

In the 3D display mode, two 3D images are reconstructed at 110mm and 90mm in front of the lens array. An image of banana is located at 110mm and an image of orange is located at 90mm. Although each image is planar image, the difference of location between them is 20mm and they are 3D images with total depth of 20mm. Since the purpose of these experiments is to prove the validity of the proposed method, the 3D images are integrated by basic InIm. However, the qualities of the 3D images can be improved by adapting the advanced technologies on it. The advanced 3D display mode will be researched further. The experimental results are shown in Fig. 6(a) and (b). The 3D images are captured in right and left viewpoints to show that they are located in different location – 110mm and 90mm from the lens array. The dotted-line indicates the right edge of the banana image, and the solid line indicates the left edge of the apple image. As shown in Fig. 6(a), the dotted-line is at the left side of the solid line, while it is at the right side of the solid line in Fig. 6(b). Therefore, the relative positions of the two images are changed, which proves that the reconstructed images are 3D images with different depth.

5. Conclusion

A novel method to construct a 2D/3D convertible display system based on principles of InIm and LCD is proposed and proven by preliminary experiments. The proposed system is suitable for HD format and can be easily improved by advanced technologies of the LCD and the InIm. The proposed system can be helpful in realizing a 2D/3D convertible HD display system.

Acknowledgment

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