3D/2D convertible color display based on modified integral imaging

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Abstract

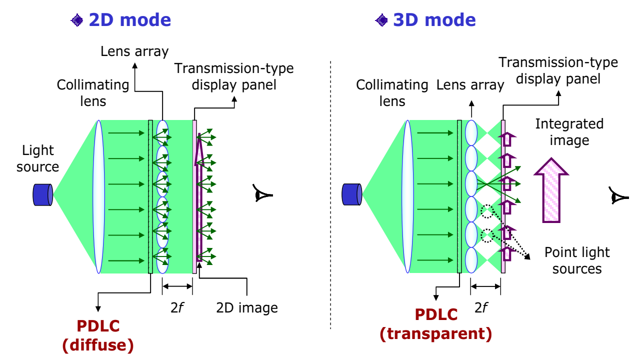
We describe the 3D/2D convertible color display based on modified integral imaging. In the proposed method a color liquid crystal display panel is used as a transmission-type display panel and enables a color 3D/2D convertible display system. The principle of the proposed method will be explained and methods to overcome the color dispersion problem will be discussed also.

1. Introduction

Integral imaging (II) is one of the promising three-dimensional (3D) display techniques. II was first proposed by Lipmann in 1908 [1]. Recently II attracts much attention as an autostereoscopic 3D display technique for its many advantages. II provides continuous viewpoints within the viewing angle and has full parallax. Recently it became possible to display real-time full-color 3D images owing to the advancement of electronic devices like charge coupled device (CCD) and liquid crystal display (LCD). However, the configuration of II that locates a lens array in front of a display device prevents the II system from displaying a two-dimensional (2D) image. This can be a significant obstacle to commercialize a 3D display based on II.

To solve this problem, a 3D/2D convertible display based on II is proposed recently [2, 3]. Schematic diagrams of the method are shown in Fig. 1. It uses a lens array and a display panel like conventional II method. However, it locates the lens array at the back of the display panel and uses a polymer-dispersed liquid crystal (PDLC).

In the 2D mode, the PDLC located just behind the lens array is electrically controlled to be diffuse. The illuminating light is scattered by the PDLC and relayed by the lens array to illuminate the transmission-type display panel. The observer can see the 2D image displayed in the transmission-type display panel. In the 3D mode, PDLC is set to be transparent. The collimated light is focused by the lens array to form a point-light source array at the focal plane of the lens array. A transmission-type display panel modulates the intensity of the light rays and a 3D image is displayed. This method made the system 3D/2D convertible. However, it uses a spatial light modulator (SLM) as the transmission-type display panel and displays black-and-white images only.



(a) **(b)**

Figure 1. Schematics of the 2D/3D convertible display (a) in 2D mode (b) in 3D mode

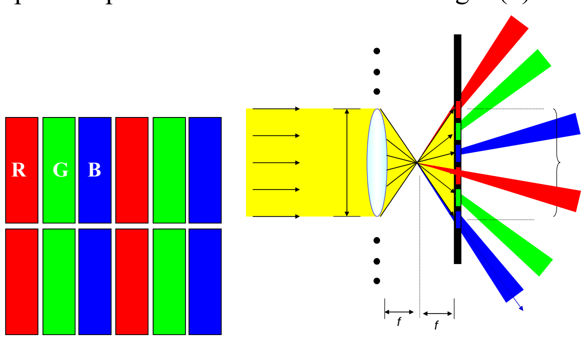
In this paper, we propose a 3D/2D convertible color display based on modified II. A color liquid crystal (LC) display panel is adopted as a transmission-type display panel instead of SLM and enables a color display. It is easy and simple to display color images using the proposed method. However, a color dispersion problem occurs in 3D mode in the boundary of 3D images. We will explain why the color dispersion occurs and propose some methods to overcome the color dispersion problem.

2. Principle of the proposed method

If a color LCD is used instead of SLM, the observer can see a color image because the LCD can express color with RGB color filter. Generally in TFT-LCD each color square pixel is composed of three rectangular sub pixels that are filtered to pass red, green and blue light. The arrangement of sub pixels is usually stripe-type as shown in Fig. 2(a).

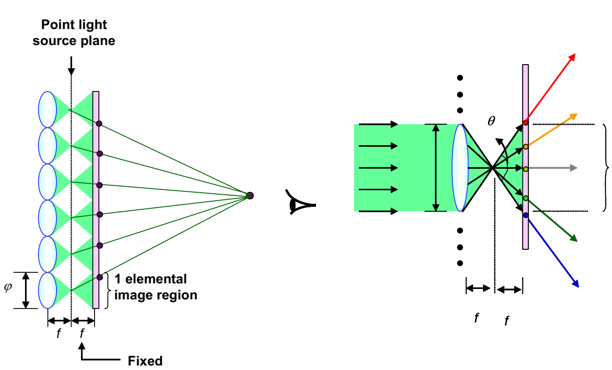
In the 2D mode, the observer can see the 2D color image displayed in the LCD. For 3D mode, elemental images should be calculated at first. Figure 3 shows the 3D image formation and calculation of elemental image points. The elemental image region that corresponds to each point-light source is defined as the extent of the diverging rays falling on the display panel from the point-light source. The elemental image point of 3D object is calculated by using ray optics and displayed in the transmission-type display panel. To display a real 3D image point as shown in Fig. 3(a), we display the elemental image points where the lines that join the point and the point-light sources meet the display panel.

Since the elemental image points are angularly sampled, different elemental image points are observed as the viewing direction changes and observer can recognize a 3D image. However, in the proposed method if the LCD of which pixel size is large compared with the lens size and the arrangement of sub pixel is stripe-type, observer may see only one color in a certain direction. As a result, the color dispersion problem occurs as shown in Fig. 2(b).



(a) (b)

Figure 2. (a) Stripe arrangement of R, G, B in color filter and (b) expected color dispersion in 3D mode



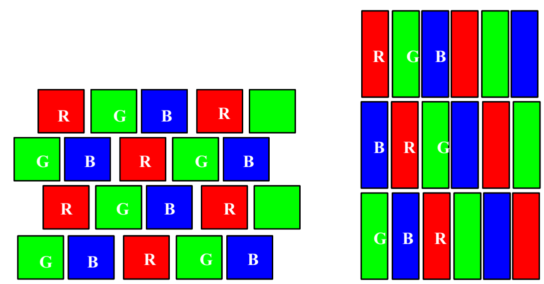
(a) (b)

Figure 3. (a) 3D image formation (b) each point of 3D image through angular sampling

Since the angular color division shown in Fig. 2(b) causes the dispersion, the color dispersion becomes distinct as the size of pixel pitch increases. Thus the dispersion can be reduced by using high-density color transmission-type display panel although it is not on commercial use yet.

The more fundamental reason of the color dispersion is the stripe-type sub pixel arrangement in color filter. The stripe-type sub pixel arrangement limits the expressible angular region according to the color as shown in Fig. 2(b). The regular division of color can be alleviated using mosaic or delta-type color filter where RGB sub pixels are mingled well. Taken as a whole image, the color dispersion can be reduced.

However, the most fundamental cause is spatial multiplexing of R, G, B. For expressing color, if time-multiplexing of R, G, B are used, the color dispersion problem can be solved easily.



(a) (b)

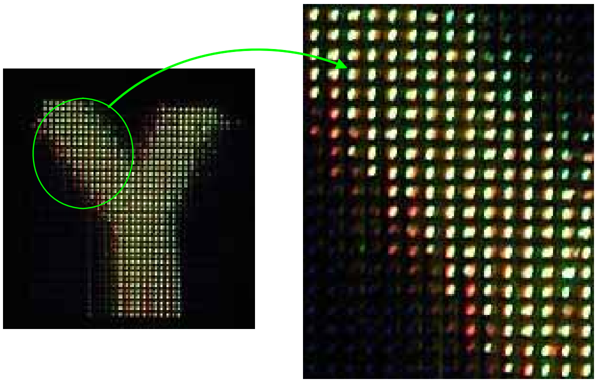
Figure 4. Color filter (a) delta-type (b) mosaic-type

3. Experimental results

3.1 Using LCD panel

In an experiment, a lens array used consists of 50 by 50 square elemental lenses of 3.3mm focal length and 1mm pitch. The pixel pitch of the color LCD is 0.254(H) by 0.254(V) mm and the arrangement of sub pixel is stripe-type. Pinhole array can be used instead of a lens array to make point light sources in 3D mode. The distance between the pinhole is 1 mm and the pinhole array consists of 50 by 50 pinholes. As a light source a LCD backlight is used.

Figure 5 shows the integrated image. The color character of 'Y' is displayed at 40mm in front of the display panel. The color of the image is yellow as shown in Fig. 5. However, in Fig. 5(b), the enlarged photo, the color dispersion is observed distinctly around the boundary of the image.

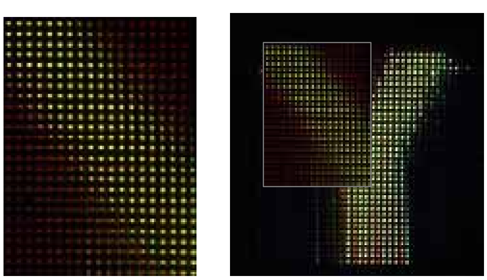


(a) (b)

Figure 5. (a) Integrated color image (b) enlarged photo

In the left side of the image red pixels are observed and in the right side of image green pixels are observed. As shown in Fig. 5(b), each sub pixel is piled up one on another and makes a color pixel in the inside of the image, while the dispersion usually occurs in the boundary of 3D image.

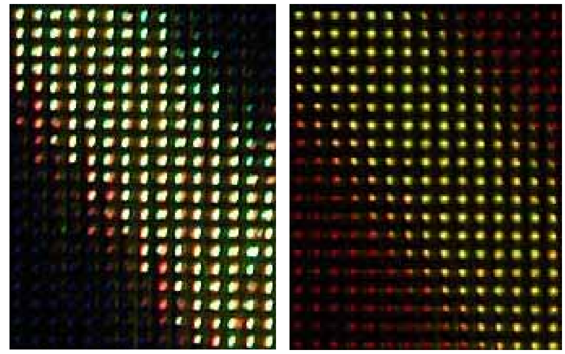
For reducing the color dispersion, we also experiment for the same 3D image using a small pixel pitch LCD. The resolution is 240(H) by 320(V) and the pixel pitch is 0.076 mm that is about a third of the 0.264 mm. Figure 6 shows the results. We can display only a portion of the image as shown in Fig. 6(b) because the size of the LCD panel of which pixel pitch is 0.076 mm is so small, 18 mm (H) by 25 mm (V). For comparison, we locate the result image using small pixel LCD at the corresponding location on the image using pixel pitch 0.264 mm.



(a) (b)

Figure 6. (a) Integrated image when the pixel pitch is 0.076 mm (b) corresponding location of the image on the image of pixel pitch 0.264 mm

As shown in Fig. 6, the color dispersion is reduced and it is difficult to recognize the color dispersion in the boundary of image. Figure 7 shows the difference between the two integrated images in detail. We can see that the color dispersion is reduced by using small pixel LCD.



(a) (b)

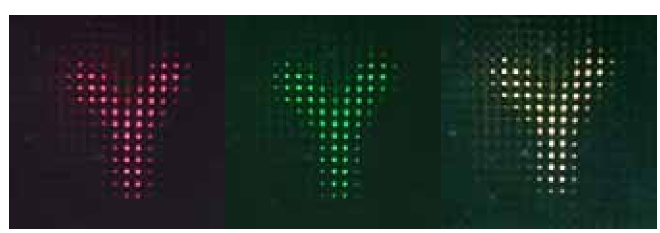
Figure 7. Image when (a) pixel pitch is 0.264 mm (b) pixel pitch is 0.076 mm

3.2 Using time-multiplexing method

As mentioned above, the fundamental reason of color dispersion is the spatially multiplexed RGB color filter. For solving this problem we express the color using time-multiplexing method.

In experiment the same pinhole and the backlight are used. In this method, a black-and-white SLM are used instead of a color LCD and R, G, B cellophane papers are used in front of the backlight for implementing a color filter. The pixel pitch of the SLM is 0.036 mm. The same image is used. However, the image size is reduced because of the resolution difference between the SLM and the LCD.

Figure 8 shows the experimental results. Figure 8(a) shows the integrated image when the backlight is covered by the red cellophane paper and Fig. 8(b) shows the image when the backlight is green. Since the image is yellow, no light is transmitted when the backlight is blue. Figure 8(c) shows the image by composition with Fig. 8(a) and Fig. 8(b).



(a) (b) (c)

Figure 8. Integrated color image using time-multiplexing method (a) when backlight is red (b) when backlight is green (c) result by composition

If RGB time-multiplexing is so fast that after-image effect can occurs, the observer can see the image shown in Fig. 8(c). As expected, using time-multiplexing will solve the color dispersion problem fundamentally, and we can observe a good quality color 3D images without any color dispersion.

4. Conclusion

A color 3D/2D convertible display based on modified II is proposed. A color liquid crystal display panel is used as a transmission-type display panel and enables a color 3D/2D convertible display system. In this case, if the size of LCD pixel pitch increases, the color dispersion problem occurs. This can be alleviated using a high-definition color display panel or some specific arrangement of color filter. As a fundamental solution, if RGB time-multiplexing method is used, good quality color 3D images can be observed without the color dispersion.

5. Acknowledgment

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6. References

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