Integral Photography Using Color Electronic Paper

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Abstract

A new 3D display using color electronic paper is presented. The system consists of a FLEPia, which is a commercially available color e-paper mobile terminal made by Fujitsu Frontech Ltd, and a commercially available hexagonal fly's eye lens. Not only horizontal but also vertical parallax is obtained because the extended fractional view method, which is a kind of integral photography, is adopted. Since the color cholesteric liquid crystal display of FLEPia is essentially reflective, it can display a clear image without backlight, and it does not consume the electric power except when the image is updated. Moreover, it is suitable for integral photography because an unsightly moire is hard to occur; there are no color subpixels that might be interfered with the fly's eye lens. Experiments revealed that a good full color image with the sense of depth was observed under appropriate lighting conditions.

Introduction

Electronic paper is a media of the next generation that has properties of both hard and soft copies. Electronic paper is thin and light, and it has the advantages that it does not need a backlight because it uses reflected light and does not consume power except when the displayed content is updated. The recent progress of electronic paper is marvelous, and it is being applied to electronic books and digital signage. Although practically used electronic paper is mostly black and white, a mobile terminal using color electronic paper has already been commercialized[1].

On the other hand, display systems are gradually evolving from 2D to 3D. Though special glasses are currently used in movie theaters and for television at home, there are autostereoscopic systems in which no special glasses are needed. Among them, integral photography (IP), shown in Figure 1, is an ideal method because not only horizontal but also vertical parallax is obtained unlike other methods except holography. Nevertheless, it is not so widespread probably because a very high-resolution flat panel display (FPD) and a very expensive fly's eye lens, designed and manufactured in accordance with the dimensions of each display device, is needed.

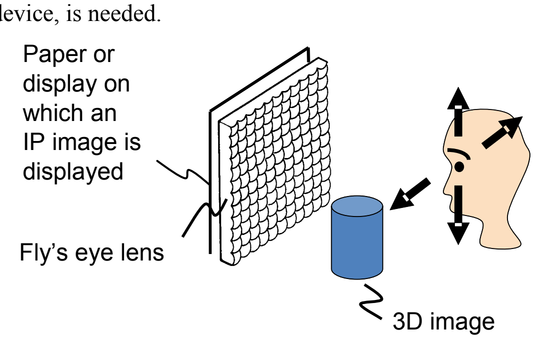


***Figure 1**. Simple IP system*

However, the extended fractional view (EFV) method[2][4][6]-[10], proposed by one of the authors of this paper as an extension of the fractional view method[11] toward IP, has enabled a wide range of FPDs to be freely combined with relatively inexpensive fly's eye lenses available on the market, thereby producing an IP system. In our previous study[8], the EFV method was applied to monochrome electronic paper. Although sufficient sense of depth was obtained from the previous system, it was also understood that colorization was necessary for richer representation. Therefore, we developed a new IP system that used color electronic paper.

Colorizing electronic paper

Among various electronic papers the electrophoretic display, each dot of which is basically black and white, is considered to be the most popular. It has already been used in a lot of electronic books such as Amazon Kindle and Sony Reader. And the great demand for such products has already been proven. If looking back on the technological history, it is understood that everything including the print, the photograph, the movie, the television, and the electrophotography has evolved from black and white to color. Therefore it is a natural idea that color electronic paper has great demands.

A simple way to colorize the electrophoretic electronic paper is that adjacent three pixels are grouped, and each of them is covered by the differently colored filter, where each color is one of the three primary colors of red, green, and blue. Although this idea has already been adopted in common color LCDs for common TV sets and computer displays, it is also applicable to the electrophoretic display in which each dot is either black or white. However the color that penetrates the color filter is only one of three primary colors. This is the reason that the efficiency of light is said to be one third or less when the color filter is used. In the case of common LCDs the three dots looks pure white when they become transparent and they are illuminated with a backlight. To the contrary, the three dots of the electrophoretic display look gray when all of them turn to white and they are observed through the color filter, because no more than one third of the light are used. Although intensive research and development is being performed so as to improve the brightness and saturation of color electrophoretic displays, a perfect solution has not been found yet.

Therefore we used a different type color electronic paper which uses ChLCD (Cholestic Liruid Crystal Display) technology which is free from color filter in this study. Figure 2 shows the principle of the color ChCLD.

Cholesteric Liquid Crystal Display

Comparizon with Typical LCD:

In typical LCDs which have already been used for common TV sets and computer displays, each pixel consists of a layer of molecules aligned between two transparent electrodes, and two polarizing filters. By changing the voltage applied between the electrodes, the twist of the molecules which causes the rotation of the light is controlled. When the angle of the rotation is coincident to the angle between the two polarizing filters, the incident light can pass through, and the device becomes transparent. Otherwise, the device becomes opaque.

Cholesteric Liquid Crystal:

On the other hand, A cholesteric liquid crystal has the character to reflect light of only specific wavelength. It is transmissive to lights of other wavelength. Therefore a color ChCLD is possible by piling up three cholesteric liquid crystal layers corresponding to the three primary colors of red, green, and blue[12]. The structure of the ChCLD is somewhat similar to that of a color film in which there are three layers, each corresponds to each of the three primary colors as shown in Figure 2. An important difference is that the ChCLD is reflective while the color film is transmissive. ChCLD reflects only the light of a specific color from the three primary colors of red, green, and blue. Other lights are transmitted. Therefore, it can display color images without using a color filter. This is a great advantage in IP.

When sunlight or the light of the fluorescent lamp enter the liquid crystal, either of red, green, or blue light may be reflected. When all the colors are reflected, it looks white to our eyes. When none of the lights are reflected, it looks black since only the light-absorbing layer at the bottom is seen.

The shape of each liquid crystal molecule is spiral. It is stable in two states, one of which is that the spiral axial direction is horizontal and the other is that it is vertical. It is possible to change the states by applying an appropriate voltage between the transparent electrodes. If no voltage is applied, the direction of the liquid crystal is maintained almost permanently. Therefore electric power is needed only when it is rewritten. Owing to the characteristics the super-low power consumption has been achieved. Another advantage is that eyes hardly become tired because the device is inherently free from flicker. ChLCD is thin and light because polarizing filters, a color filter, a backlight and a reflector are not needed any more.

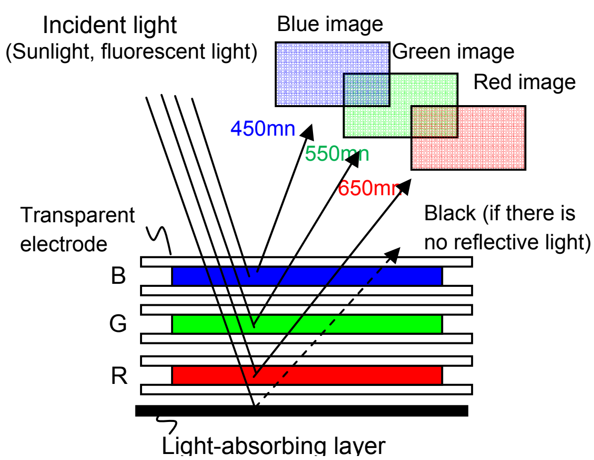


***Figure 2**. Structure of a color ChLCD.*

Synthesis of IP Image

The method to synthesize IP images by using CG is basically the same as what we have presented[4][6]-[11], and it consists of a modeling stage, a multi-viewpoint rendering stage, and a synthesis stage. The modeling stage is essentially the same as the usual 3D CG. In the rendering stage a scene is rendered from n × n viewpoints as shown in Figure 3, whereas a scene is rendered from a single viewpoint in the case of ordinary CG. Here n is typically 32, and the resolution of each rendered image is typically 360 × 360. In the synthesis stage, it is calculated which direction the ray, which is emitted from each pixel of the display device, goes to and which pixel of which camera captures the ray, as shown in Figure 4. As a result the n × n still images are integrated with our original software written in C language into an IP image to be displayed on the screen.

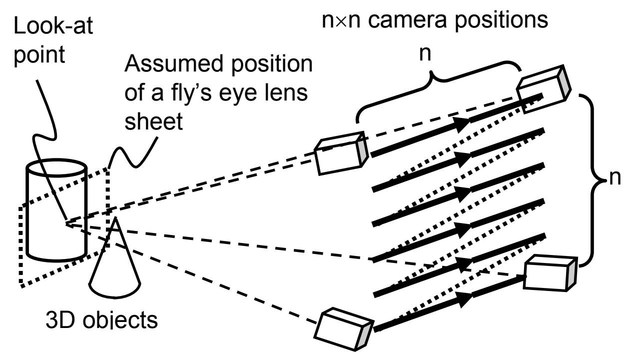


***Figure 3**. Multi-viewpoint rendering.*

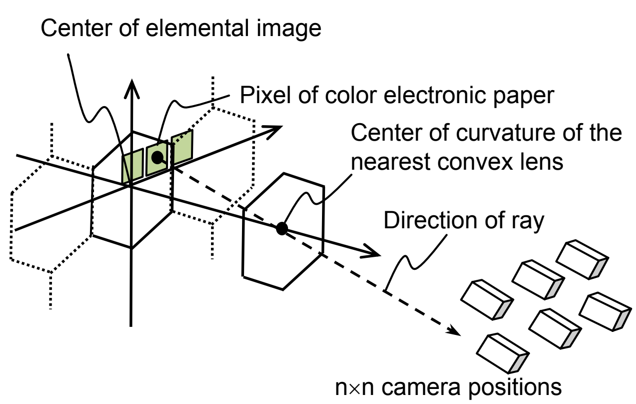


***Figure 4 Rendering stage**.*

Experiment

Specification of Color Electronic Paper:

The system consisted of a FLEPia, which is a commercially available color e-paper mobile terminal made by Fujitsu Frontech Ltd. The FLEPia has a 8-inch color electronic paper display that was developed by Fujitsu Laboratories. The electronic paper has approximately 158 dpi resolution ieach pixel can display 262144 colors. Brief specification of the display part is shown in Table 1. The dimensions for the display are given in Figure 5.

Table 1. Brief specification of the display part of FLEPia

Display size	8 inch 123.6(W) × 164.8(H)mm
Number of dots	768 × 1024
Number of colors	64colours (One scan) 4096 colors(Two scans) 262144 colors (Three scans)
Rewrite time (Standard mode)	1.8 sec. (One scan) 5 sec (Two scans) 8 sec (Three scans)

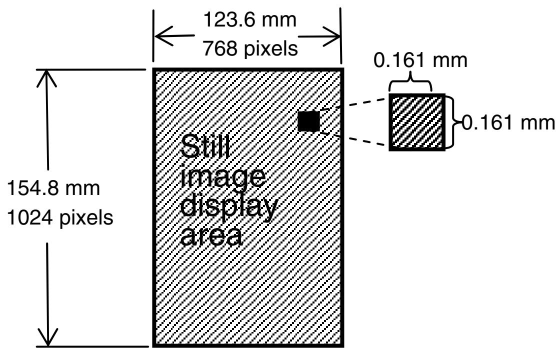
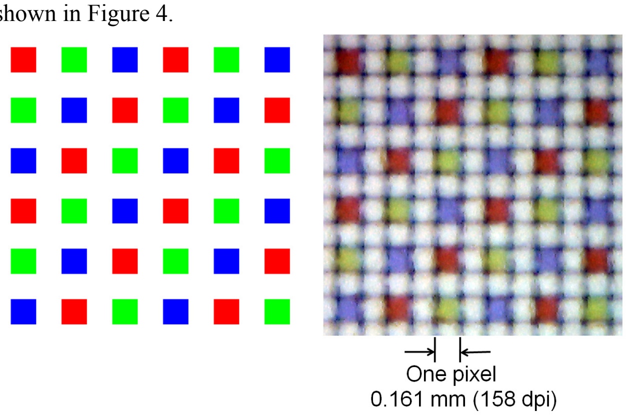


***Figure 5**. Dimensions for display of FLEPia*

Unlike many electronic books in which electrophoretic displays are used, FLEPia has a cholesteric liquid crystal display (ChLCD), which is also essentially reflective and able to retain an eight-inch color image consisting of 1024 x 768 pixels and up to 4096K colors per pixel without power. In most color LCDs, a pixel consists of three subpixels of red, green, and blue, and the positions of the subpixels are slightly horizontally different. Though it is possible to increase the number of effective horizontal views by using this property, complex processing is necessary. Moreover, it is highly probable that colored moiré patterns appear. In the case of ChLCDs, however, these annoying problems are not caused because there are no subpixels and a pixel is the smallest unit of color. Even isolated color dots can be displayed clearly as shown in Figure 4.



(a)Test pattern (b) Display image of test pattern

***Figure 6**. T The dimensions of the fly's eye lens*

Fly's Eye Lens:

A commercially available fly's eye lens made by Fresnel Technologies, Inc., the dimensions of which is shown in Figure 7, was cut so that it matched the size of the display of the FLEPia.

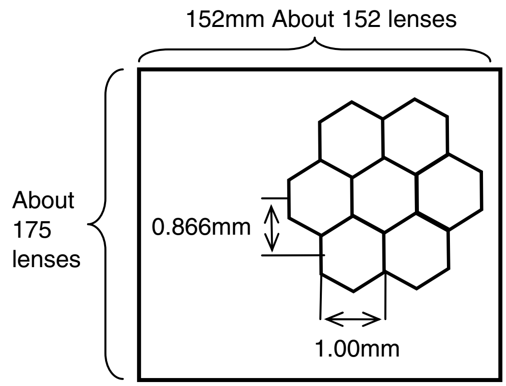


***Figure 7**. T The dimensions of the fly's eye lens*

Result:

In the experiment, IP images were synthesized and displayed on the screen of a FLEPia on which a fly's eye lens was placed. When the screen of the FLEPia was observed under appropriate lighting conditions, a good full color 3D image with both horizontal and vertical parallax was observed as shown in Figure 8.

***Figure 8**. 3D image displayed on the screen covered with a fly's eye lens..*

Discussion

In our previous studys[9][10] using common LCD, a pixel of the LCD consisted of three subpixels each of which corresponds to the three primary colors of RGB. Therefore it was highly probable that the moire which was caused by the interference between the subpixels and the fly's eye lens became visible. In order to avoid the moire the focal point of each convex lens was intentionally moved slightly from the surface of the electronic paper to prevent a moiré pattern from being generated, at the risk of the image degradation. To the contrary the color ChCLD has an advantage in displaying clearer 3D images without moiré because it does not have subpixels.

ChCLD of FLEPia has brightness and the contrast sufficient for usual use as a portable terminal. However appropriate lighting condition is desirable to obtain good 3D images when it is used for a 3D display system, because part of the incoming light is lost by the absorption and the reflection at the fly's eye lens. Fujitsu Laboratories and Fujitsu Frontech announced on May 7, 2010 that they had greatly improved the performance of the color electronic paper [12]. According to the announcement, they had achieved brighter display, higher contrast ratio of 7:1 which is three times as high as the conventional product, and more rapid rewriting speed which is two times as much as the conventional product. The new product is expected to have brightness and the contrast that overcomes the absorption and the reflection of light with fly's eye lens. They also announced that the new color electronic paper is scheduled to be commercialized by Fujitsu Frontech in October 2010. When their new color electronic paper product will become available to us, the image quality of 3D image would be improved further.

Conclusion

A new 3D display system that consists of color electronic paper and a fly's eye lens was developed, and experiments revealed that excellent stereoscopic views were possible. Not only horizontal but also vertical parallax were observed without having to wear special glasses because it was a kind of IP. Moreover, existing electronic paper and an existing fly's eye lens could be combined because the EFV method was introduced. 3D images were clearly displayed even in a sunny outdoor environment. Therefore, it may be possible to apply this technology to outdoor digital signage. 3D digital books are another promising field of application. In both cases, the system will become more attractive through the introduction of color 3D display technology.

At present appropriate lighting condition is required to display good 3D images because the display device is not illuminated with a backlight and the loss of light at the fly's eye lens is not negligibly small. However, this issue is expected to be solved soon by the progress of ChCLD technology.

Meanwhile developments of color electronic paper other than ChCLD are also in progress. We would like to make them 3D when they become available for us, since the EFV method can be applied to a wide range of display devices. We expect that our study can contribute to the early spread of both electronic paper and 3D displays.

Acknowledgement

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Author Biography

Kazuhisa Yanaka received his B.E. in electronic engineering in 1977, and M.E. and D.E. in electrical engineering in 1979 and 1982 respectively, all from the University of Tokyo. He joined the Electrical Communication Laboratories of NTT in 1982. He joined the Kanagawa Institute of Technology, Japan, in 1997 where he is currently a professor. For over 30 years, he has been researching various aspects of images such as image processing, image communication, and image input/output systems in which 3D image displays and printing are included.