Integral Photography Using Electronic Paper

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Abstract

Electronic paper has many advantages. First, no power is needed to maintain static images. Second, no backlighting is necessary, and it can be viewed even in direct sunlight. However, the primary benefit is that it is as legible as real paper because the characters and the figures can be clearly displayed at high resolution. These features indicate the potential of electronic paper as an ideal device if it is applied to 3D displays. Integral photography is one of the best of the various methods of 3D display because not only horizontal but also vertical parallax are obtained without having to wear special glasses. Researchers previously believed that a very expensive fly's eye lens had to be custom designed based on the size of the pixels on the display. However, the extended fractional view (EFV) method, proposed by one of the authors, changed this situation. This method has enabled us to combine a wide range of display devices and several fly's eye lenses on the market with almost no restrictions because the ratio between the lens pitch and dot pitch is no longer restricted to integer numbers. We describe a new 3D display system using electronic paper in which an existing fly's eye lens was placed on the electronic paper of an electronic book (Sony PRS505), and elemental images synthesized with the EFV method were displayed. Our experiments revealed that excellent binocular vision was possible.

Introduction

Paper, which is believed to have been invented by Cai Lun in China in approximately the 2nd century, has many advantages. Paper is thin, flexible, and inexpensive. It is an ideal material for writing on with pens and pencils and being printed on with printers. The only drawback is that the displayed content cannot be electronically updated.

Electronic paper is an advanced electronically rewritable medium that imitates many of the excellent features of ordinary paper. Unlike conventional flat-panel displays, in which backlights are necessary to illuminate the pixels, electronic paper reflects light like ordinary paper and it can hold text and images almost indefinitely without consuming power; yet, it allows the displayed images to be redrawn later. An electrophoretic display is a representative example of the various kinds of electronic paper because its appearance is similar to ordinary paper and it has already been widely commercialized. Visible images are formed in electrophoretic displays by rearranging charged pigment particles using an applied voltage amid two plates between which the particles are sandwiched.

However, electronic paper is not only excellent when used as 2D displays. It also has great potential to be applied to 3D displays. Integral photography (IP) is one of the best of the various 3D display techniques because not only horizontal but also vertical parallax can be obtained without the need to wear special glasses. This feature of IP is common with that of electronic holography, which is thought to be the ultimate 3D display. Moreover, IP is easier to handle because laser technology is not used. A simple IP system consists of paper covered with a fly's eye lens, which is a two dimensional array of tiny convex lenses, as shown in Fig. 1. Here, part of the image, which corresponds to each minute convex lens, is called an "elemental image" and the entire image, which corresponds to the entire fly's eye lens is called an "IP image. " It is widely known that a liquid crystal display (LCD) can be used instead of paper. Therefore, it is highly probable that conventional paper will be replaced by electronic paper. If this occurs, the various advantages of electronic paper will be inherited by 3D displays. As a result, new applications such as 3D digital picture books and 3D digital signage that can be viewed in daylight will appear.

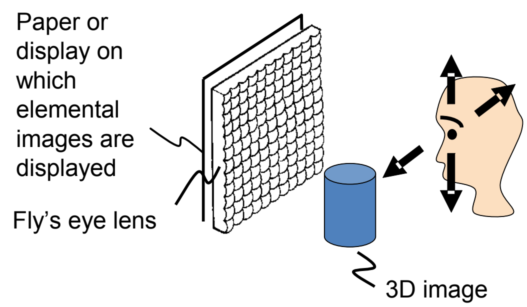

***Figure 1**. Simple IP system*

Adaptability of electronic paper to IP

Table 1 summarizes the main differences between ordinary paper, electronic paper, and liquid crystal displays (LCDs).

Table1: Comparison of ordinary paper, electronic paper, and LCDs

	Ordinary paper	Electronic paper	LCDs
Diffused surface	Yes	Yes	No
Refresh	No	No	Yes
Backlight	Unnecessary	Unnecessary	Necessary
Power to hold still images	Unnecessary	Unnecessary	Necessary
Gray levels per dot per color	Basically two	About 4–8	256 or more
Resolution (dpi)	1000 or more	About 167	About 100

The similarity of electronic paper to ordinary paper in that they have almost perfectly-diffused surfaces is considered to be related to the good legibility of electronic paper. This feature is also preferable for IP because it enables users to see 3D objects from arbitrary directions. Backlighting and electric power are related to usability in outdoor environments where strong sunlight might be present and the power supply might be limited. The various advantages of electronic paper can be exploited by using electronic paper in 3D display systems.

The last two items in the table, i.e., gray levels and resolution, should be considered when IP is achieved with electronic paper. It was previously believed that ultra-high-density displays were necessary for IP. This situation changed due to the emergence of the extended fractional view (EFV) method, which we will describe later. If the EFV method is used, IP can be accomplished even on the displays of conventional notebook PCs. Another issue that needs to be considered is that the number of gray levels per pixel is relatively small in electronic paper. This issue will also be discussed later.

EFV Method

The EFV method [1][3][5][6] is a variation of IP, and it was proposed by one of the authors. It is an extension of Ishii's fractional view approach [7] to IP. The differences between the existing and EFV methods are conceptualized in Figures 2 and 3.

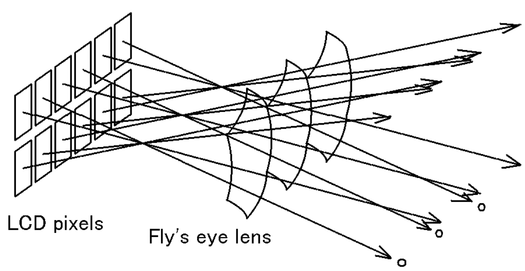

***Figure 2**. Existing IP*

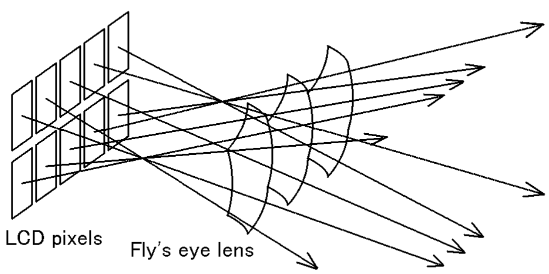

***Figure 3**. IP using EFV method*

As seen in Figure 2, the directions of the rays are aligned, and each bundle of rays corresponds to each view. The three encircled rays in this figure form a bundle of rays, and four bundles have been indicated here. Therefore, there are four views, which are equal to the number of LCD pixels per small convex lens on the fly's eye lens. This imposes conditions on the ratio of the size of the lens and the size of the pixels in the LCD. Therefore, it is necessary to custom order the fly's eye lens based on the LCD specifications. The high cost of the metal mold that is needed to manufacture fly's eye lenses has seriously discouraged the spread of IP up until now.

The EFV method solves this issue because the number of LCD pixels per small convex lens on the fly's eye lens is not limited to integers, as shown in Figure 3. Actually, any real number is acceptable. This means that the ratio between the lens pitch and dot pitch is no longer restricted to integer numbers. Therefore, a wide range of LCDs, normal PCs, and several fly's eye lenses available on the market can be quite freely combined, making considerable cost reductions possible.

Another advantage of the EFV method is that the directions of the rays are seemingly random. As a result, the effect obtained by improving image quality is similar to that obtained by increasing the number of views with existing methods.

Synthesis of Elemental Images

The method we used to synthesize the elemental images from CG data is basically same as that described in the previous papers [1–4]. Figure 4 outlines the capture of multi-viewpoint images that are necessary for synthesizing elemental images. Here, n × n images are being taken from different camera positions. The typical value of n is 32.

The captured n × n images are then synthesized together by using our program, and an IP image, which is a set of elemental images, is generated. The elemental images are then displayed on an LCD and observed through the fly's eye lens, as shown in Figure 1.

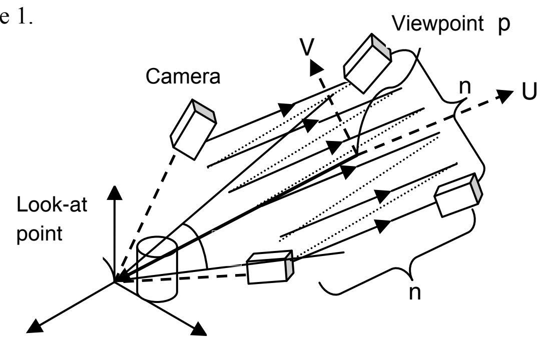

***Figure 4**. Multi-viewpoint rendering*

Experiments

Electronic book

A commercially available electronic book, the Sony Reader PRS-505 shown in Figure 5, was used in the experiment.

***Figure 5**. Sony Reader PRS-505 (left)and fly's eye lens (right)*

The PRS-505 has a 6-inch monochrome electronic paper display that was developed by E Ink Corporation. The electronic paper has approximately 167 dpi resolution and an 8-level gray scale. The dimensions for the display are given in Figure 6.

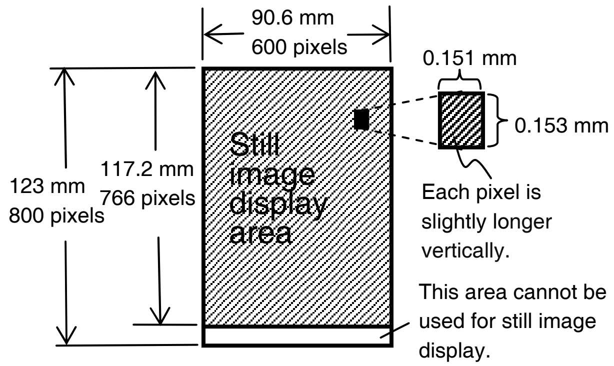

***Figure 6**. Dimensions for display of Sony PRS-505*

Fly's Eye Lens

The commercially available fly's eye lens in Figure 7 was cut so that it matched the size of the display of the PRS-505. A transparent acrylic board 3mm in thickness was attached to make the focal point of each convex lens close to the surface of the electronic paper. That is, the focus was intentionally shifted slightly from the display's surface to prevent a moiré pattern from being generated.

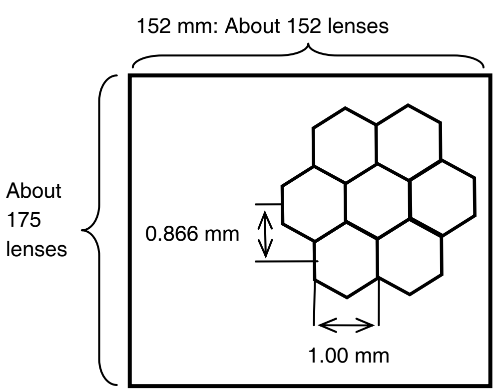

***Figure 7**. Dimensions of fly's eye lens*

Results

Excellent 3D images with both horizontal and vertical parallax are displayed on the electronic paper portion of the electronic book. The book becomes very thick and heavy if a fly's eye lens is attached to each page of a conventional book. In contrast, just piling up fly's eye lenses on the display of an electronic book is sufficient because the displayed content is rewritable. Figure 8 shows that clear 3D images can be displayed outdoors even during the day.

***Figure 8**. 3D display in outdoor environment*

Gray Level Representation

Despite the fact that the electronic book, PRS-505, can only display eight gray levels, it does appear to have the ability to display continuous tone images such as those in ordinary photos. This is because halftoning technology is used. The grounds for this are as follows. Textures similar to error diffusion appeared when various test patterns generated artificially with a PC were displayed. However, the displayed image was completely flat and no texture was visible for eight gray levels, i.e.,

0 (black), 33. 66. 99. 132. 165, 198 and 255 (white).

Therefore, we concluded that multi-level error diffusion was probably used internally in the PRS-505. If this is correct, these eight gray levels must correspond to the native gray levels of the electronic paper. We subsequently conducted the following experiment. After the IP image had been quantized to these eight gray levels with a PC, the IP image was transferred to the electronic book and displayed on the electronic paper. Even though we had predicted a great decrease in image quality, there was actually little decrease. This was probably because the quantization error that occurred at each pixel of the IP image was averaged at the fly's eye lens. At any rate, we concluded that the small number of gray levels per pixel of the electronic paper scarcely affected the quality of the 3D image we obtained.

Application to 3D Electronic Picture Books

A promising field of application of electronic paper other than in digital signage is electronic books. One of the authors of this paper therefore produced an experimental 3D book based on impressions from a fairy tale accessible to the public on the Web. The title of the fairy tale was "Poka poka no fuyu no kaze" (Warm winter wind), which won an outstanding performance award in the 30th Jomo fairy tale contest [8]. The author of the tale is Yoko Maejima.

All scenes for the 3D display were produced with Shade 10 and Poser 7. Shade 10 is a popular commercial CG application for modeling and rendering 3D scenes. The backgrounds and gadgetry in this experiment were created with Shade 10. Poser 7 is a commercial 3D rendering software for posing human and animal figures.

The characters were imported from "Modetan", which is a commercial 3D data collection of cartoon characters for the Poser series.

***Figure 9**. IP images produced for 3D electronic picture book*

The character data modeled with Poser 7 were then imported to Shade 10, and they were merged together with the backgrounds and gadgetry. The procedure after this is the same as that previously described. There are examples of the synthesized IP images in Figure 9. Finally, these IP images were merged with the text, and displayed on the PRS-505's electronic paper. Since only the 3D portion was covered with the fly's eye lens because a smaller fly's eye lens was used, users could read the text portion the same as they usually did.

A 3D book would become too thick and heavy if fly's eye lenses were attached to each page of a conventional book. In contrast, just piling up fly's eye lenses on the display is sufficient because the displayed content varies in electronic books. Therefore, it seemed to be easier to introduce 3D display technology to an electronic book than to introduce it to a hardbound book.

Conclusion

A new 3D display system that consists of 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 EFV 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 for electronic paper. We produced a 3D electronic book based on a fairy tale to evaluate it. As a result, we felt that the electronic picture book had become more attractive through the introduction of 3D display technology. Although we only used monochrome electronic paper, electronic books should become more attractive if colored electronic paper can be used in the future.

The method described in this paper can immediately be put to practical use, because existing technologies were used. Therefore, we expect that this study can contribute to the early spread of both electronic paper and 3D displays.

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Author Biography

Kazuhisa Yanaka received his B.E., M.E., and D.E. from the University of Tokyo in 1977, 1979, and 1982. 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.

Miho Kijima received her B.E. from the Kanagawa Institute of Technology in 2009, where she was engaged in the study of 3D image displays.