

# Imitating micro-lens array for integral imaging

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Integral imaging is a true, three-dimensional (3D) display technology that captures and reconstructs 3D scenes using two-dimensional (2D) micro-lens arrays. The manufacturing technique of micro-lens arrays is complicated and expensive, thus limiting the application of the technology. An imitating micro-lens array for integral imaging is presented in this letter. Imitating micro-lens array is composed of a cheap lenticular lens and a parallax barrier. The relationship of the parameters of the imitating micro-lens array is analyzed and the parameter formulae are deduced. The arrangement of pixels under a cell of the imitating micro-lens array is presented. The imitating micro-lens array is simulated using ASAP software, and the results prove that the designed imitating micro-lens array is effective. A 3D scene is reconstructed on a 3D display that consists of the imitating micro-lens array and a 17-inch flat panel display.

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Integral imaging, derived from integral photography, was first proposed by Lippmann in 1908<sup>[1]</sup>. Integral imaging uses micro-lens arrays to capture and reconstruct three-dimensional (3D) scenes. Among various 3D display methods<sup>[2,3]</sup>, integral imaging is a promising 3D display technique because it provides viewers continuous, full-parallax, and full-color stereoscopic images over a very wide angle without requiring special viewing devices<sup>[4]</sup>. Integral imaging records 3D scene information on two-dimensional (2D) images, which makes it possible to apply conventional processing and transmission techniques to integral imaging.

In the process of capture, a micro-lens array is typically used to capture rays of light emanating from the 3D scenes in different directions while recording elemental 2D images, each with their own perspective of the 3D scenes. In the process of reconstruction, the recorded 2D image is placed at the focal plane of an identical micro-lens array, and the diffused rays from the 2D image reconstruct the 3D scene in the space<sup>[5]</sup>.

Owing to complicated manufacturing techniques and high costs, the applications of integral imaging are limited. However, manufacturing techniques of the lenticular lens and parallax barrier are well developed, and the costs are low. Generally speaking, the lenticular lens and parallax barrier can only separate the rays emanating from 3D scenes in horizontal direction, and can only provide the viewers with horizontal parallax. Integral imaging using 2D micro-lens array captures and reconstructs 3D scenes not only with horizontal parallax, but vertical one as well. In view of all these, an imitating micro-lens array composed of a lenticular lens and a parallax barrier, and the corresponding arrangement of pixels, are proposed in this letter.

As shown in Fig. 1, the proposed imitating micro-lens array is composed of a parallax barrier and a lenticular lens, with the parallax barrier vertically stuck on the back surface of the lenticular lens. The imitating micro-lens array is placed on the front surface of a flat panel display. The lenticular lens separates the rays emanating from the flat panel display horizontally, while the parallax barrier

separates the rays emanating from the flat panel display vertically<sup>[6]</sup>. As a result, the imitating micro-lens array can obtain full parallax in the same manner as a real micro-lens array does.

Figure 1 shows a cell of the imitating micro-lens array, the parameter formulae of which are shown as<sup>[7,8]</sup>,

$$L_1 = \frac{(E + W_1) \cdot D}{W_1}, \quad (1)$$

$$L_2 = f \cdot \frac{E}{W_2}, \quad (2)$$

where  $L_1$  and  $L_2$  are the optimal viewing distances of the 3D display based on the parallax barrier and lenticular lens as shown in Fig. 2;  $D$  is the distance between the imitating micro-lens array and the flat panel display;  $W_1$  and  $W_2$  are the vertical and horizontal pixel sizes of the 3D display based on the parallax barrier and lenticular lens, respectively;  $E$  is the interpupillary distance (usually 65 mm);  $f$  is the focal length of the lenticular lens.

The optimal viewing distance of the parallax barrier must be equal to that of the lenticular lens as

$$L_1 = L_2. \quad (3)$$

From Eqs. (1)–(3), the relationship between  $f$  and  $D$  can be deduced as

$$f = W_2 \cdot D \cdot \frac{(E + W_1)}{E \cdot W_1}. \quad (4)$$

Figure 3 shows the relationship between the focal length and thickness of the lenticular cell, where  $F$  and  $H$  are the focus and cardinal point of the lenticular lens. The focal length of the lenticular lens  $f$  can be obtained by

$$f = D + \frac{d}{n}, \quad (5)$$

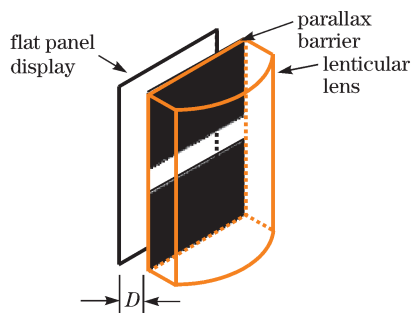


Fig. 1. Structure of a cell of the imitating micro-lens array.

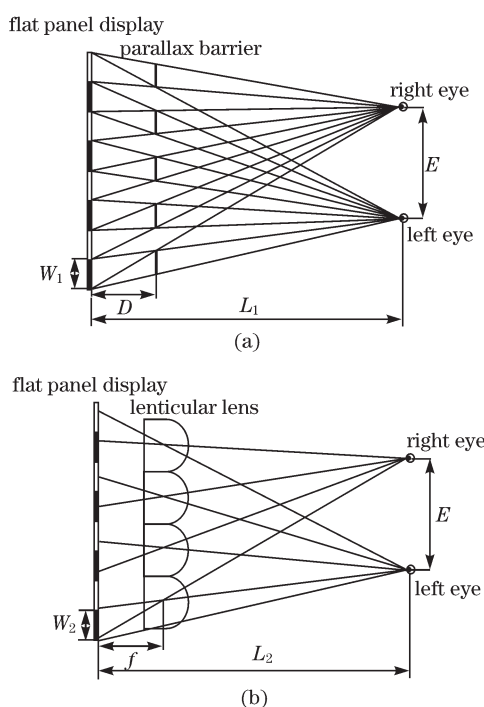


Fig. 2. Structure of 3D display based on (a) parallax barrier and (b) lenticular lens.

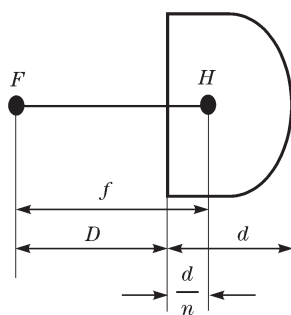


Fig. 3. Relationship between focal length and thickness of the lenticular lens.

where  $d$  is the thickness of the lenticular lens, and  $n$  is the refractive index of the lenticular lens.

From Eqs. (4) and (5), the relationship between  $d$  and  $D$  can be deduced as

$$\frac{D}{d} = \frac{E}{n} \cdot \frac{W_1}{E \cdot (W_2 - W_1) + W_1 \cdot W_2}. \quad (6)$$

Since the parallax barrier and lenticular lens are combined to form the imitating micro-lens array, the rela-

tionship exists as

$$W_1 = W_2 = W_p, \quad (7)$$

where  $W_p$  is the pixel size of the flat panel display. For the typical values  $W_p = 0.2976$ ,  $n = 1.4880$ , and thus

$$D/d = 147. \quad (8)$$

Obviously, the value  $D/d = 147$  for the lenticular lens is unreasonable.  $W_1$  cannot be equal to  $W_2$ . However, pixel size is fixed, thus, two pixels are combined into an imitating pixel shown as

$$2W_1 = W_2 = 2W_p. \quad (9)$$

Then

$$D/d = 0.669. \quad (10)$$

The value  $D/d = 0.669$  for the lenticular lens is reasonable and available. According to Eq. (9), two adjacent and horizontal pixels should be combined into an imitating one for the imitating micro-lens array. Practically, a cell of imitating micro-lens array covers a number of imitating pixels. For simplicity, four imitating pixels are taken in an elemental image as an example (Fig. 4). The two pixels in an imitating pixel are identical.

As an example, optical software ASAP was used to simulate an imitating micro-lens array for a 3D display using a 17-inch flat panel display. Their parameters are shown in Table 1, where  $W_b$  and  $W_1$  are the pitches of parallax barrier and lenticular lens, respectively;  $r$  is the radius of curvature of lenticular lens;  $L$  is the optimal viewing distance of 3D display based on the imitating micro-lens

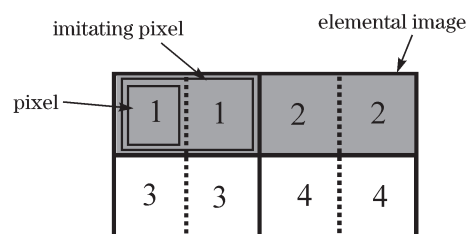


Fig. 4. Arrangement of pixels under a cell of the imitating micro-lens array.

**Table 1. Parameters of the 3D Display Using Imitating Micro-Lens Array**

Component	Parameter	Value
Flat Panel Display	Size (inch)	17
	Resolution (pixel)	1024×768
	$W_p$ (mm)	0.2976
Lenticular Lens	$W_1$ (mm)	1.1796
	$r$ (mm)	4.4688
	$f$ (mm)	9.1573
	$d$ (mm)	6.8443
	$n$	1.4880
Parallax Barrier	$W_b$ (mm)	0.5925
	$D$ (mm)	4.5576
3D Display	$L$ (mm)	1000
	$K$	4

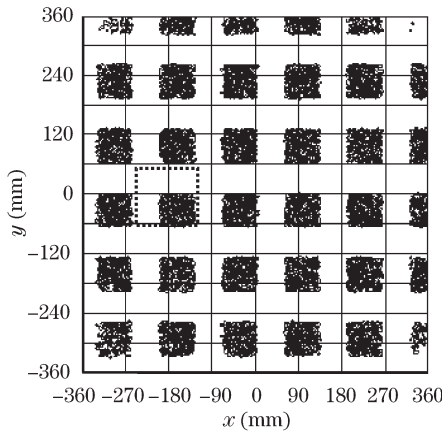


Fig. 5. Ray distribution on a receiving screen when light emanates from the flat panel display and transmits through the imitating micro-lens array.

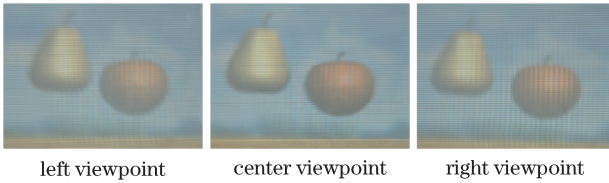


Fig. 6. Different perspectives of the reconstructed 3D scene.

array;  $K$  is the number of imitating pixels in an elemental image.

Several point light sources are set to simulate the pixels of the flat panel display. The rays emanating from the flat panel display are projected to the record plane through the imitating micro-lens array. The distribution of the image intensity in a receiving screen is shown in Fig. 5, where the origin is the center of the flat panel display,  $x$  and  $y$  axes indicate the horizontal and vertical directions of the flat panel display, respectively. The shadow areas indicate the places where rays are received. From Fig. 5, the imitating micro-lens array separates the rays emanating from the flat panel display horizontally and vertically. Thus, the imitating micro-lens array can be used for integral imaging.

A 3D display is developed using the imitating micro-

lens array and a 17-inch flat panel display. The integral image of a 3D scene consists of  $128 \times 100$  elemental images, and each elemental image has  $10 \times 10$  pixels. The 3D display presents the integral image allowing viewers to see a vivid 3D effect. Figure 6 shows different perspectives of the reconstructed 3D scene.

In conclusion, the imitating micro-lens array for integral imaging is proposed as a substitute for 3D display. The imitating micro-lens array is composed of a cheap lenticular lens and a parallax barrier. The relationship of the parameters of the imitating micro-lens array is analyzed and the parameter formulae of the imitating micro-lens array are deduced. The arrangement of pixels under a cell of the imitating micro-lens array is presented. The imitating micro-lens array is simulated using ASAP software, and the results prove that the designed imitating micro-lens array is effective. A 3D scene is reconstructed on a 3D display that consists of the imitating micro-lens array and a 17-inch flat panel display.

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