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1D integral imaging based on parallax images' virtual reconstruction

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One-dimensional (1D) integral imaging based on parallax images' virtual reconstruction is proposed. The 1D integral imaging contains parallax images' capture process, parallax images' virtual reconstruction process, and 1D elemental image array's generation process. A pixel mapping algorithm is deduced to implement the last two processes; a 1D elemental image array is generated by the mapping of pixels on the parallax images obtained using a 1D camera array. The proposed 1D integral imaging can capture the 1D elemental image array of a real three-dimensional (3D) scene.

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The three-dimensional (3D) display based on integral imaging (II) is one of the most attractive 3D displays[1]. In II 3D display, the observers' viewpoints that are light ray converging points and an important design parameter in the multi-view display need not be predetermined[2]. Compared with other 3D display, II has several advantages, such as arbitrary viewing position (independent of interpupillary distance), viewing comfort (no visual fatigue), continuous motion parallax, and full color information in continuous viewpoints without special glasses and coherent light[2−6].

Some of the problems encountered with II include the difficulty in capturing high-quality elemental image array (EIA) and low 3D resolution of II display. In the initial pure optical capture process, the image quality of the EIA is poor because of lens aberration, muddiness of the emulsion, and pseudoscopic captured EIA. Thus, a modification of a one-step II capture setup based on additional imaging lens has been proposed[7]. The modified setup allows depth control and orthoscopic captured EIA. In the recent years, researchers have focused on some electrical capture methods. A television camera is used to shoot numerous elemental images[8]. A capture setup including a micro-lens array, depth control lens, imaging lens, and a charge coupled device (CCD) has been proposed[9,10]. These electrical capture methods require an ultrahigh-resolution CCD sensor and a precise micro-lens array. In our previous study a two-dimensional (2D) camera array instead of a micro-lens array was used to shoot a 3D model in a computer[11]. Each camera performs the same role as a micro-lens, and tens of thousands of cameras are needed. Therefore, capturing a real 3D scene is complicated. In the multi-view capture process, parallax images are shot using a one-dimensional camera array (1DCA), in which each camera captures more information than that of a micro-lens in conventional 2D II; only a few cameras are needed to capture multi-view images. However, the multi-view 3D display causes visual fatigue[12]. One dimensional II (1DII), which has horizontal disparity and without vertical disparity is a practical solution foe low-cost, easy-viewable 3D display[2]. The main difference between 1DII and multi-view 3D display lies in the image arrangement in each unit image cell, the basic unit of composing the image display panel[13].

In this letter, we propose a 1DII based on parallax images' virtual reconstruction,and the 3D resolution of 1DII is pretty higher than conventional 2D II. In the capture process, we need only a few cameras to obtain parallax images like the multi-view capture method does, and a model for the pixel mapping is built up which is quite different from the pixel mapping in multi-view method. A 1D EIA (1DEIA) is generated using our proposed pixel mapping algorithm; good 3D display characteristics and higher 3D resolution are obtained, then in the 1DII display.

The proposed 1DII based on parallax images' virtual reconstruction contains three processes, namely, capture of parallax images, virtual reconstruction of parallax images, and capture of 1DEIA.

In the capture of parallax images, a real 3D scene is shot by a 1DCA whose number of cameras is much less than the number of 1DEIA, as shown in Fig. 1(a). The parallax images' virtual reconstruction is an inverse process of the capture of parallax images, as shown in Fig. 1(b). Pixels on parallax images are transmitted by a parallax barrier. The pitch of the parallax barrier is equal to d, the distance between the adjacent cameras in the 1DCA. Each slit of the parallax barrier aligns to the center of its corresponding parallax image. The distance between the parallax barrier and the parallax images is equal to f_1, the focal length of the 1DCA. Therefore, a virtual 3D scene similar to the original real 3D scene is reconstructed.

In the 1DEIA's capture process, a lenticular sheet is used to pick up the reconstructed virtual 3D scene,

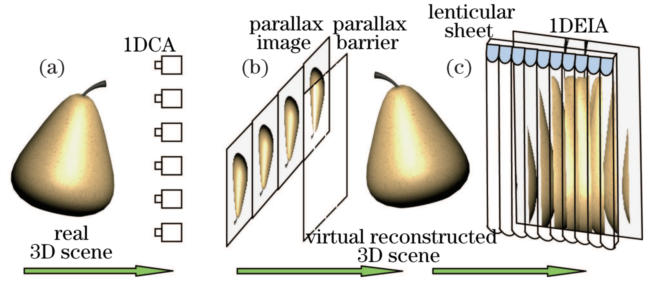

Fig. 1. Schematic of proposed 1DII. (a) Parallax images' capture process, (b) parallax images' virtual reconstruction process, and (c) 1DEIA's capture process.

as shown in Fig. 1(c); each lenticular lens has its own perspective to the virtual 3D scene and a 1DEIA is obtained on the focal plane of the lenticular sheet. The distance between the parallax barrier and the lenticular sheet is L. The pitch and focal length of the lenticular lens are p and f_2, respectively. The numbers of lenticular lenses in the lenticular sheet is equal to H, which is the horizontal resolution of a parallax image.

However, the parallax images' virtual reconstruction and the 1DEIA's capture practically need not be accomplished, because a pixel mapping algorithm is deduced to implement them in a computer. Figure 2 shows the geometric relationships of the pixel mapping algorithm. According to the light propagation theory in Fig. 2, the rays, emitted from the pixels $I_{i,j}$ on the jth row of the ith parallax image, are transmitted by the ith slit of the parallax barrier. The rays are then refracted by the jth lenticular lens of the lenticular sheet and arrive at the pixels $I'_{j,k}$ on the kth row of the jth 1D elemental image (1DEI). In short, the pixels $I_{i,j}$ on the parallax images are mapped to the pixels $I'_{j,k}$ on the 1DEIA. Thus, we can obtain

$$I'_{j,k} = I_{i,j}. \tag{1}$$

Based on the geometric relationships in Fig. 2, the value of k in Eq. (1) can be obtained as

$$k = \mathrm{round}\Big\{r/2 + \frac{r\cdot f_2\cdot(N/2+0.5-i)\cdot d}{L\cdot p} - \frac{r\cdot f_2\cdot(H/2+0.5-j)}{L} + \frac{r\cdot f_2}{2L}\Big\}, \tag{2}$$

where r is the horizontal 1DEI resolution, and the function round means rounding towards the nearest integer. When the calculated k is larger than r, these pixels should be abandoned to eliminate overlapping between adjacent 1DEIs. Loop i from 1 to N, where N is the number of the parallax images, and j from 1 to H. The pixels $I_{i,j}$ are mapped to the pixels $I'_{j,k}$ according to Eqs. (1) and (2), as shown in Fig. 3. All the pixels on the parallax images are mapped and form the 1DEIA.

The pitch of the 1DEI is p, and the number of 1DEIs in the 1DEIA is H. The depth of the displayed 3D scene can be adjusted by changing the distance L between the parallax barrier and the lenticular sheet in the pixel mapping algorithm. Assume that the distance between 3D object and camera is l. When $l = L$, the 3D object will be displayed on a screen, if $l > L$ (or $l < L$), the 3D object will be displayed behind of (or in front of) a screen.

In our experiments, a camera is moved along with a guide rail while shooting a real 3D scene, which function as a 1DCA, as shown in Fig. 4. The foreground "cup" and a background "bag" are 740 and 890 mm away from the camera, respectively. The parameters of the experiment are shown in Table 1. The number of parallax images N is much less than that of 1DEIs H. Figures 5(a) and (b) are the 5th and 25th parallax images shot by the camera, respectively. The 1DEIA is generated using the pixel mapping algorithm illustrated above, as shown in Fig. 6.

Optical II display is carried out. The displayed 3D scene does not suffer from pseudoscopic problem, and no visual fatigue is observed when viewers see it. The object "cup" appears in front of the display screen; the object "bag" appears behind of the display screen. Figures 7(a)

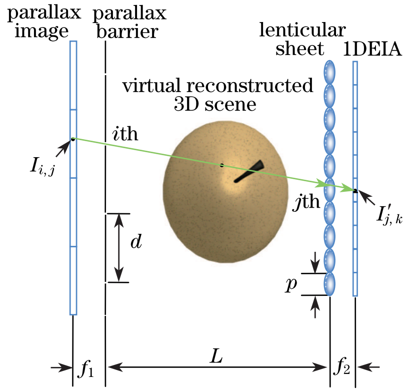

Fig. 2. Geometric relationships of the pixel mapping algorithm.

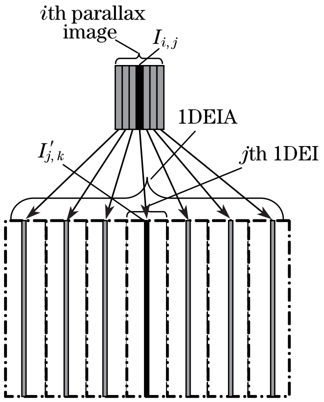

Fig. 3. Schematic of pixel mapping in 1DII.

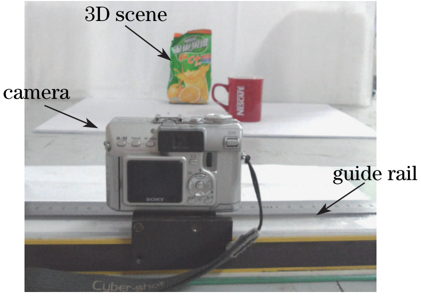

Fig. 4. Capture setup of a real 3D scene.

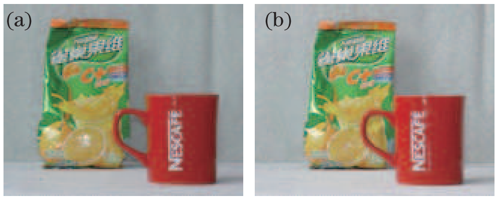

Fig. 5. (a) 5th and (b) 25th parallax images.

Fig. 6. 1DEIA generated by the pixel mapping algorithm.

Table 1. Parameters of the Experiment

N	f_1 (mm)	D (mm)	L (mm)	H	f_2 (mm)	r (pixel)
32	2.8	17	800	160	3	20

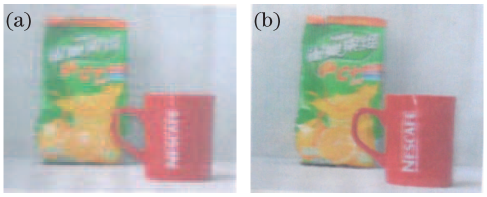

Fig. 7. (a) Left and (b) right views of optically displayed 3D scene.

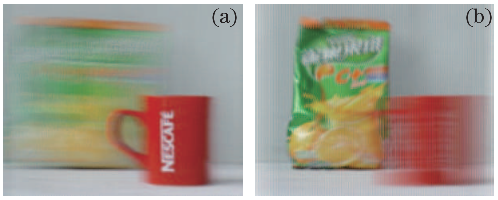

Fig. 8. Plane images obtained at (a) 60 and (b) –90 mm.

and (b) are the optically displayed 3D scene at different angles, which correspond to the 5th and 25th parallax images in Figs. 5(a) and (b), respectively.

Unlike the multi-view 3D display where the distance between adjacent cameras in the capture process affects the depth of the 3D image, 1DII reconstructs the 3D image with its original depth. 1DEIA is used for computational II display to testify the depth of the displayed 3D scene[14]. The plane images are obtained at different depths. The objects "cup" and "bag" are clearly imaged at the depth of 60 and –90 mm, respectively as shown in Figs. 8(a) and (b). This result demonstrates that the proposed 1DII generates a 1DEIA for a real 3D scene with its original size and depth similar to that of the conventional II.

In conclusion, a 1DII based on parallax images' virtual reconstruction is proposed. The parallax images are obtained using a 1DCA, which is very mature in the multi-view 3D capture technique. The 1DEIA is generated by a computer using our proposed pixel mapping algorithm. The proposed 1DII is much simpler than the conventional II, and no image degradation is observed. The displayed 3D scene does not suffer from pseudoscopic and visual fatigue problems. The depth of the displayed 3D scene is adjusted by changing the distance between the parallax barrier and the lenticular sheet in the pixel mapping algorithm. The experimental results demonstrate that the displayed 3D scene restores its original size and depth similar to that of the conventional II. Therefore, the proposed 1DII has great potential as a good candidate for practical application.

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