Realization of Smooth Motion Parallax by Coarse Integral Imaging with Interleaved Elemental Fresnel Lenses

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ABSTRACT

This paper applies a lens array composed of interleaved elemental lenses to coarse integral imaging. The interleaved lenses consist of elemental prisms whose slope angle corresponds to two adjacent convex lenses, where the width of each prism changes gradually. Smooth motion parallax is realized as a result.

1 Introduction

Integral imaging [1] is one of the most well-known three-dimensional display systems that do not force a viewer to wear special stereoscopic goggles. The feature of integral imaging is its reproduction of light-ray space, providing parallax both in the horizontal and vertical directions. There have been some trials to combine integral imaging and volumetric imaging where multilayer screens or panels are placed behind a lens array [2-6].

Kakeya proposed coarse integral imaging (CII) [7] and coarse integral volumetric imaging (CIVI) [8], where a coarse elemental lens array was used to generate a real image or a virtual image of the screen. Field curvature of image and barrel distortion were corrected by using texture mapping technique to show undistorted images [9,10]. Generation of real image with parallax in the air is suitable for interactive systems because of small vergence-accommodation conflict [11,12]. CIVI has also been modified to expand the viewing zone [13], to increase spatial resolution [14], and to erase pseudo images [15].

One of the greatest drawbacks of CII and CIVI is the distinct seam of elemental images in the horizontal and vertical directions, which is caused by the coarse lens array. To solve this problem, Kakeya et al. proposed insertion of an additional weak diffuser [16], which makes the system bulky and the presented image blurred, however. Kakeya et al. also proposed an interleaved Fresnel lens to be placed in the seam of the elemental lenses to smooth the edges [17], which has not attained images smooth enough.

Recently, a new type of interleaved Fresnel lens has been proposed [18] to realize uniform luminance in an autostereoscopic display with time-division directional backlight [19-22]. The feature of this lens is the gradual change of width in the elemental prisms.

This paper proposes to apply the above interleaved lenses to CII for realization of smooth stereoscopic image.

2 Conventional Study

Integral imaging is composed of an image screen (an electronic display panel in case of an electronic display) and a fly-eye lens whose elemental lens covers multiple pixels of the screen, which needs to have a higher spatial resolution than the lens array. When the interval between the display panel and the fly-eye lens is the same as the focal distance of the elemental lens, parallel light is emitted from each elemental lens. Since the pixel pitch of the screen is finer than the lens array, integral imaging can express many directional light rays. In reality, however, the pixel pitch of electronic displays is not usually fine enough to reproduce dense light-ray space.

One way to express deep space with a display panel with relatively low spatial resolution is to layer the panels to show volumetric elemental images. When each display panel is not thin enough, however, the resolutions and the viewing angles of the observed images from the front layer panel and the back layer panel become quite different from each other.

To solve this problem, the size of the elemental lens is enlarged in CIVI. To increase spatial resolution of the presented image, the elemental lens should be set so that multiple pixels may be observed through each elemental lens. Volumetric images viewed from different angles are aligned behind each elemental lens. In this setting, real images or virtual images are formed with the lenses. When the distance between the display panel and the lens array is the same as the focal distance of the elemental lens, an additional large aperture Fresnel lens generates a real image in the air as shown in Fig. 1, which enables a stereoscopic system to interact with images within the hand's reach.

The main problem of CII and CIVI is the distinct seam of lenses due to the coarse fly-eye lens. To make the discontinuity among the elemental images indistinct, elemental lenses with interleaved grooves were proposed as shown in Fig. 2. In the proposed elemental lenses, the grooves of two lenses are interleaved so that the adjacent elemental images may be mixed in the boundary. The optical rays in the CIVI system using an interleaved lens array are shown in Fig. 3.

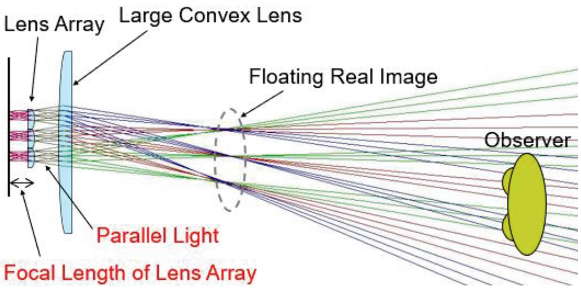

Fig. 1 Principle of coarse integral imaging.

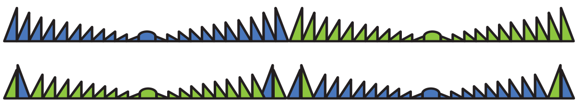

Fig. 2 Conventional elemental lenses (above) and the elemental lenses with interleaved grooves (below).

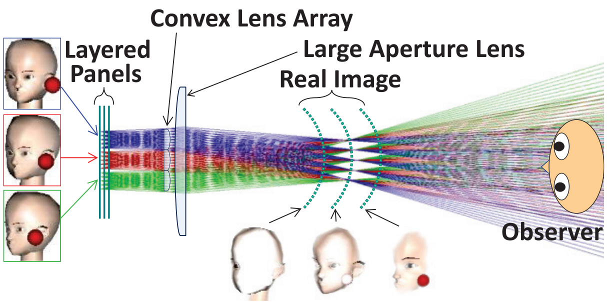

Fig. 3 Optical rays in the CIVI system with interleaved elemental lenses.

To realize the interleaved boundary both in the horizontal and the vertical directions, two layers of linear Fresnel lenses with interleaved boundary are stacked, one aligned in the horizontal direction and the other in the vertical direction. The images presented with the conventional lens array and the interleaved lens array are compared in Fig. 4.

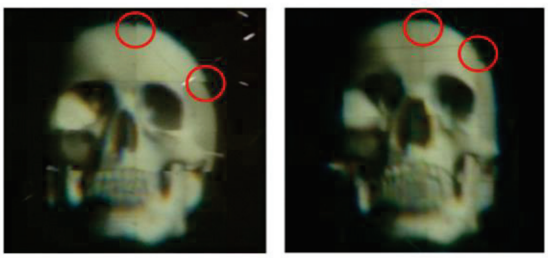

Fig. 4 The images observed with the conventional system and the system composed of interleaved elemental lenses.

3 Proposed System

3.1 Interleaved Lens with Gradual Width Change

To realize uniform luminance in an autostereoscopic display with time-division multiplexing directional backlight [19-22], a new type of interleaved Fresnel lens has been proposed, where the whole lens area is interleaved [18]. The feature of this lens is the gradual change of width in the elemental prisms, as shown in Fig. 5.

Fig. 5 Interleaved Fresnel lens with gradual width change.

The detailed design of the interleaved lens is shown in Fig. 6. Here the width of the prism whose tilt angle α_l is smaller than the other (α_r) in a prism pair is wider than the other and is decided based on two tilt angles. The width ratios of prisms to the total width of prism pair are designed so that the width of a steeper prism becomes shorter.

The width of each prism segment is easily calculated. Let the total width of prism pairs be w, the tilt angles of each prism be α_l and α_r respectively. Then the widths of two elemental prisms w_l and w_r are given by

$$w_l = \frac{h}{\tan \alpha_l}, \tag{1}$$

$$w_r = \frac{h}{\tan \alpha_r}, \tag{2}$$

where h is the height of the elemental prism. Since $w = w_l + w_r$ holds, h is given by

$$h = \frac{w \tan \alpha_l \tan \alpha_r}{\tan \alpha_l + \tan \alpha_r}. \tag{3}$$

By substituting eqn. (3) into eqns. (1) and (2), we obtain

$$w_l = \frac{w \tan \alpha_r}{\tan \alpha_l + \tan \alpha_r}, \tag{4}$$

$$w_r = \frac{w \tan \alpha_l}{\tan \alpha_l + \tan \alpha_r}. \tag{5}$$

Thus, the ratio of w_l to w_r is given by

$$\frac{w_l}{w_r} = \frac{\tan \alpha_r}{\tan \alpha_l}. \tag{6}$$

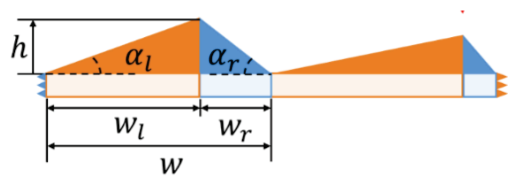

Fig. 6 Design of elemental prism in the interleaved Fresnel lens.

3.2 Prototype System

We made a prototype CII system using the interleaved lens explained in the previous section. The design of the lens we used is shown in Fig. 7, where the elemental lens was 30 mm wide and its focal length was 100 mm. The width of the elemental prism pair was 0.6 mm.

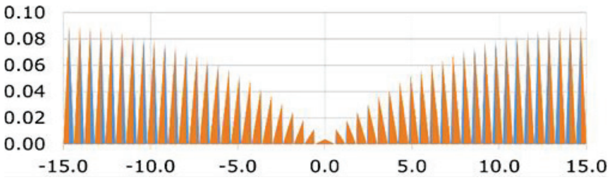

Fig. 7 Design of the elemental interleaved lens used in the prototype system [mm].

The display panel used here was KEIAN KIPD4K156, which had a 15.6 inch screen with the resolution of 3840 x 2160. The number of elemental lenses was 11 x 6, where each elemental image had the resolution of 381 x 381. The display panel was 100 mm behind the lens array. A large aperture Fresnel lens whose focal distance was 275 mm was placed on top of the lens array. The pictures of the prototype system are shown in Fig. 8.

Figure 9 shows the images presented by the prototype system observed from different viewpoints. As shown in the figure, smooth motion parallax is reproduced due to gradual mixing of images for adjacent viewpoints.

It is known that continuous change of motion parallax is important to let the viewer perceive precise depth [23]. Further study is needed to evaluate the effectiveness of the proposed method for precise depth perception.

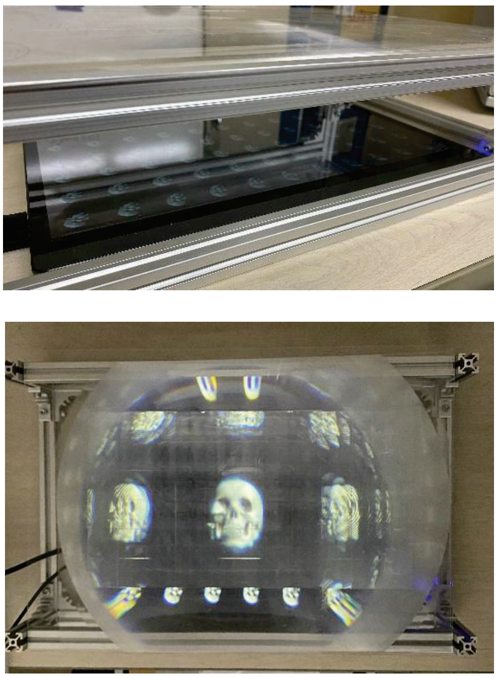

Fig. 8 Pictures of the prototype system.

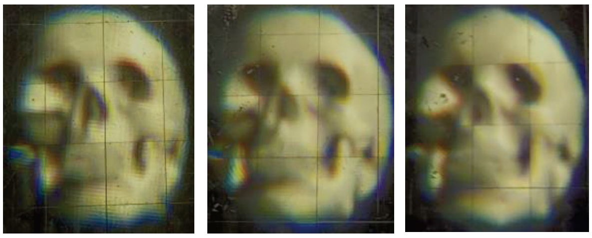

Fig. 9 Images observed from different viewpoints.

4 Conclusions

A new prototype of coarse integral imaging display is realized based on the lens array composed of interleaved elemental lenses. The width of elemental prism composing an elemental lens is changed gradually, which contributes to realization of smooth motion parallax. Further improvement of image quality is expected by using an integrated lens array sheet in place of aligning separate elemental lenses, which enables to erase lines at the joint of elemental lenses.

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