Integral imaging system with enhanced depth of field using birefringence lens array

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Abstract

In this paper, it is proposed that the integral imaging technique is applied to reconstruct 3D (three dimensional) objects with enhanced depth of field, computationally and optically. Lens array using birefringence material is adopted to obtain the reconstruction. The elemental images sets are picked up through common micro lens array and utilized to present 3D reconstruction images using adopted lens array.

1. Introduction

Investigations of three-dimensional (3D) display system have been advanced variously for high resolution and wide-viewing angle. Integral photography (IP), which was first proposed by Lippmann in 1908 [1], is known as one of the most attractive methods for 3D display techniques because it does not require any special glasses and provides continuously varying viewpoints within a viewing angle. However, bottlenecks of integral imaging appear to be limitations in depth and viewing angle of the integrated image. The principle of integral imaging(II) system is that the elemental images of object are picked up through lens array and then the elemental images are integrated in front of or behind of lens array through that, in reverse order. The picked up elemental images have been obtained using two dimensional (2D) light sensitive device such as a charge coupled device (CCD) instead of the photographic film, recently. For displaying integrated image with picked up elemental images, liquid crystal (LC) display have been used. The object or the integrated image should be located around the image plane of the lens array used in the pick up or display systems. 3D integral image system with double device has been proposed for removing the blurring of images with two different depths [2]. An integral imaging system using variable focusing lens array (VFLA) was proposed to enhance the depth of focus for reconstruction of moving objects [3]. But two separate objects with different depth of focus can not be picked up and integrated around the image plane. As the result, picked up images or integrated images produce blurring. A lens array with large depth of focus could be a possible solution. However, this type of lens array may be too complicated, and it may not be adaptable for the 3D integral imaging system. By controlling polarization of light which comes from LCD using variable wave plate in front of birefringence lens array, the blurring of images can be decreased. In this work, as another kind of method to remove the image blurring of two objects with different depths, the integral imaging system with enhanced depth of focus is proposed using birefringence lens array.

2. Principle of integral imaging system using birefringence lens array

The basic principle of II system using birefringence lens array is shown in Fig. 1.

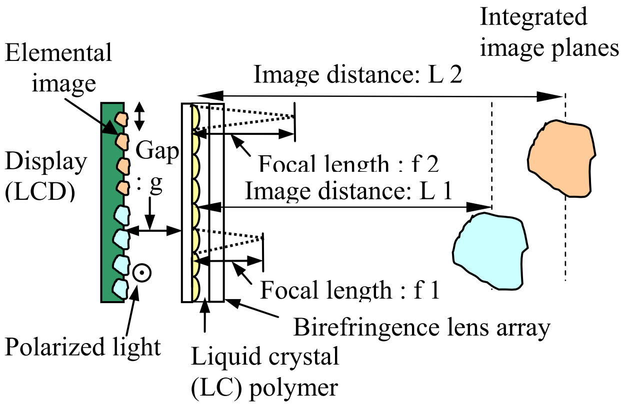

Fig. 2 The integral imaging system using Birefringence lens array for enhanced image depth

Generally, the focal length f and the distance L from the lens array to the central depth plane of integral image is expressed as the lens equation:

$$\frac{1}{g}+\frac{1}{L}=\frac{1}{f}, \qquad (1)$$

where g is gap between the display panel and the lens array. Integral images of II are classified by two mode due to real and imaginary element images. Elemental image for real or virtual mode is integrated in front of or behind the lens array. If g and f is fixed for these modes the resolution of integral image is reduced because of the increase of focusing error. By adjusting g[2] or f, the focusing error can be removed. We chose the change of focal lengths in the lens array. The focal length of the variable focusing lens array is represented as follows [3]:

$$f=\frac{1}{(n_l-n_p)C}, \qquad (2)$$

Where n_l and n_p are the effective index of liquid crystal polymer and the refractive index of polymer, respectively, and C is curvature of lens. For an integral imaging system using VFLA was proposed [3], because applied voltage alters effective index, the focal length is changed. The setup by use of VFLA can generate images at different depth locations. However, to make the images overlapped to the human eye, the variation of the focus should be fast enough to include afterimages. The time-sharing display requires faster response time than that of image separation. Considering liquid crystal response time, time-sharing method is difficult to realize real time display. But, in the proposed configuration of Fig. 1, two images at different depth locations can be simultaneously provided without any fast focus variation. The different focus lengths can be given by applying the different polarized light on each elemental lens for each elemental image. By adjusting these focus lengths, the two image with different depth can be integrated without decrease of resolution.

3. Experimental

We fabricated 9×13(4×6mm) plano-convex birefringence lens arrays. The lens array is made by fabrication process of the liquid crystal display. The a well-aligned homogeneous alignment was achieved by coating the lens array and ITO glass with JALS 130 polyimide and baking, and then rubbing them in one direction with a rubbing machine. Spacer 10um was spread on the ITO glass. The substrates were glued together with epoxy in anti-parallel direction. By capillarity the cell was filled with liquid crystal E7.

To measure the focal lengths, firstly the plane wave using spatial filter and lens was made and behind the lens, test cells were placed. He-Ne laser as light source was used. To find out focusing point, a photo detector is used. In case intensity has maximum, focal lengths are determined. When the polarization of source is parallel to rubbing direction, focal lengths of the lens array cell were 400 mm. When the polarization of source is vertical to rubbing direction, focal lengths of the lens array cell were 1500 mm.

4. Results and discussion

The results are presented computationally. The diagram of integral imaging system is shown in Fig. 2 as follows.

Fig. 2 shows the reconstructions of objects in the conventional integral imaging system and proposed integral imaging system, computationally.

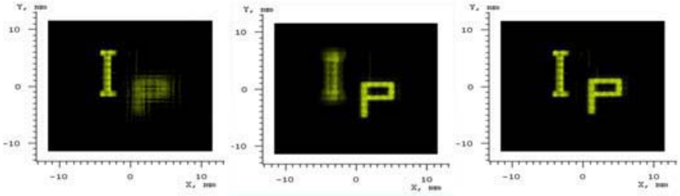

Fig. 2 The computational reconstruction of (a) 'I' plane and (b) 'p' plane in the conventional integral imaging system, and (c) the reconstruction image in proposed integral imaging system using birefringence lens array.

According to refractive indices of birefringence material, the distances from reconstruction plane of 'I' and 'P' to lens array are calculated as shown in Table 1.

Table1. According to refractive indices of birefringence material, the distances from reconstruction plane of 'I' and 'P' to lens array are calculated

Lens	Birefringence	'I' plane	'P' plane
n=1.5	n=1.4	38 ~ 54	63 ~ 76
n=1.7	n=1.43	0 ~ 4	10 ~16
	n=1.5	23 ~ 29	32 ~42
	n=1.6	39 ~ 58	65 ~ 81

4. Summary

In this work, integral imaging system using birefringence lens array is proposed to obtain enhanced depth of focus. Optically, lens array using birefringence material is adopted to obtain the reconstruction. By adjusting the focal length according to polarization state of light which is entered to birefringence lens array, two separate images with different depth can be integrated with enhanced depth. The possibility of the reconstruction is verified by fabrication of the birefringence lens array.

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