Simplification of integral imaging system by using a lenticular lens array*

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Integral imaging is a 3D display technology without any additional equipment. A new system is proposed in this paper, which uses a lenticular lens array to replace the lens array in the conventional integral imaging system. The lenticular integral imaging system reduces the complexity and the price of integral imaging system. The positive characteristics of conventional integral imaging system, such as full parallax and quasi-continuous view points, are still kept on the proposed system in horizontal direction. Optical results show that the time for calculating the elemental images is reduced by 25% compared with the conventional one. The resolution of integrated image in vertical direction is 4 times higher than that of conventional system. This proposed system opens a new way on application of integral imaging.
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Integral imaging, as a three-dimensional (3D) display technology, was proposed by Lippmann in 1908[1]. Compared with other 3D display technologies, for example parallax and holograph, integral imaging has many positive characteristics, such as full parallax, quasi-continuous view points and depth perception with relatively low eye fatigue[2]. A conventional integral imaging system uses a lens array and corresponding elemental images to reconstruct a 3D image, and the elemental images are displayed by flat panel display devices or projectors. Viewing angle, depth-of-field and resolution of the reconstructed image are important characteristics for an integral imaging system. Many methods have been reported to enhance these characteristics[3-15]. Depth-of-field can be enhanced by multi-layers[4] or dual-mode display technology[5]. And viewing angle can be enhanced by negative index planoconcave lens array[8] or high refractive index medium[9]. But limited by the parameters of the lens array and the principle of integral imaging, the quality of the reconstructed image is not very good.

In conventional integral imaging system, the resolution of the reconstructed image on focused plane is determined by the focal length of elemental lens, the gap between elemental image planes and the resolution of the elemental images[16], which is expressed as

$$\delta_{\mathrm{I}} = \frac{g}{a} \times \delta_{0} , \tag{1}$$

where g is the gap from the elemental images to the lens array, a is the gap from the lens array to the focused plane, which can be calculated by lens law and the focal length of elemental lens, δ_{I} is the resolution for the reconstructed images on focused plane, and δ_0 is the resolution for the elemental image. Though the conventional integral imaging has many positive characteristics, such as full parallax and quasi-continuous view points, the low resolution is a drawback which prevents its wide application on 3D display.

In this paper, a lenticular lens array, which is a consummate production, is used to replace the lens array in the conventional method. The new lenticular lens array is used to integrate images in one direction. The resolution of the reconstructed image is higher than that of the conventional method. And only one direction has the full parallax, which is more suitable for human's eyes to perceive the world. After this replacement, the simulated calculation results show that the resolution for reconstructed image is enhanced from 480 (H)×270 (V) to 480 (H)×1 080 (V). And some optical experimental results are presented to demonstrate the feasibility of the proposed method.

Fig.1 shows the schematic diagram of the lenticular integral imaging system. g is the distance between the lenticular lens array and the elemental images, and a is the distance between the lenticular lens array and the focused plane. The lenticular lens array is used to integrate the image in the horizontal direction. In the vertical direction, the lenticular lens array has no effect and is just like a series of parallel glass. The resolution isn't reduced in the vertical direction because of the lenticular lens array. And the elemental image in lenticular integral imaging system is not the same as that in the conventional method. The elemental images of the conventional method and the proposed method calculated by computer are shown in Fig.2.

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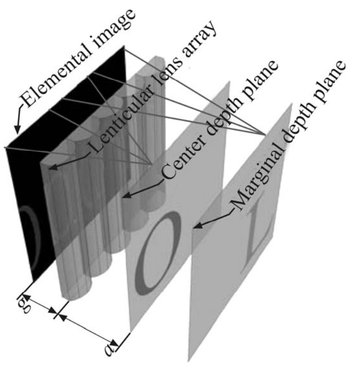
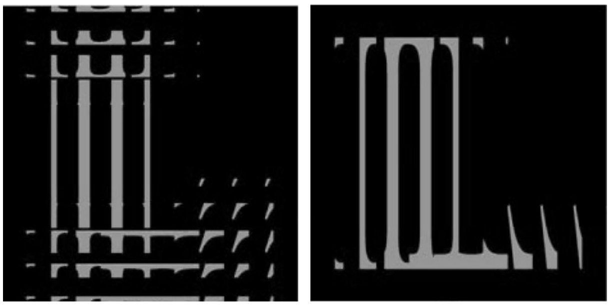


Fig.1 Schematic diagram of the lenticular integral imaging system



(a) (b)

Fig.2 Elemental images for (a) the conventional method and (b) the proposed method

As shown in Fig.2(a), there are $M \times N$ elemental images in the conventional integral imaging, but there are only M elemental images in the proposed integral imaging as shown in Fig.2(b). So when the elemental images are calculated by a computer, the time for calculating the elemental images is largely reduced. In this paper, the time for the proposed method is reduced by 25% at least compared with that for the conventional method.

Some optical experiment is done to compare the resolutions of the proposed lenticular integral imaging system and the conventional method. The parameters for the optical experiment are shown in Tab.1.

Tab.1 Parameters in the optical experiment

Specification	Characteristics
Lens shape	Rectangle
Aperture of element lens	2.5 mm×180 mm
Focal length	4 mm
Lens number	128 (H)×1 (V)
Pixels of element images	1 920 pixel (H)×1 080 pixel (V)
g	5 mm
a	20 mm

The setup of the simplified integral imaging system is shown in Fig.3. This lenticular integral imaging system uses a projector to display the elemental images on a screen. And a lenticular lens array is used to integrate the image. The area for elemental images is 320 mm×180 mm. The elemental images are calculated by computer based on the ray tracing. The devices in this system are easy to expand to large size.

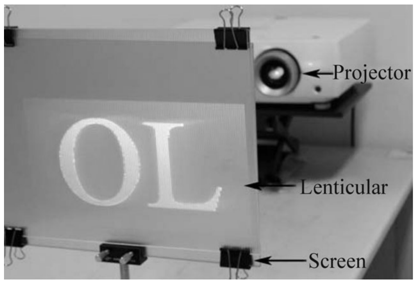
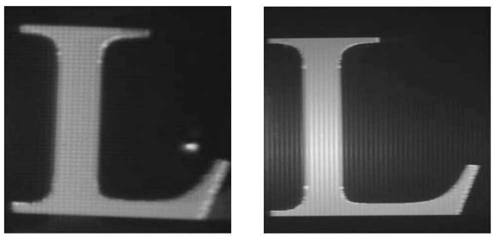


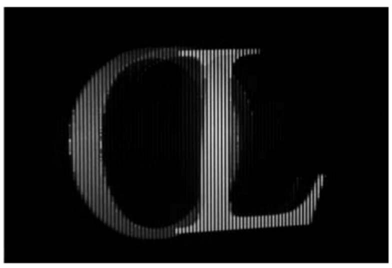
Fig.3 Setup of the simplified integral imaging system

In conventional method, the lens array has 128 (H)×72 (V) elemental lenses, and the other parameters are all the same as those of the proposed method shown in Tab.1. The experimental results in Fig.4 show that the resolution of the proposed method is much higher than that of the conventional method. Fig.4(a) shows that the reconstructed image integrated by the lens array is illegible and not sharp. Compared with the conventional method, the reconstructed image in the proposed method shown in Fig.4(b) is more sharp, because the lenticular lens array has no effect and is just like a series of parallel glass in the vertical direction. In the proposed method, the reduction of resolution only happens on the horizontal direction, but that in the conventional method happens on both vertical and horizontal directions. The resolution of the elemental images is 1 920×1 080. From Eq.(1) and Tab.1, the resolution for the reconstructed images is 480×1 080, and the resolution for the conventional method is 480×270. The positive characteristics of the conventional method, such as full parallax and quasi-continuous view points, are still kept on the lenticular integral imaging system in horizontal direction. The different viewing points for the reconstructed image obtained by the proposed lenticular integral imaging system on the optical experiment are shown in Fig.5.

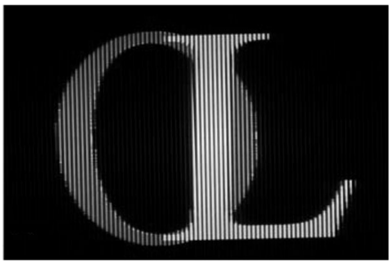


(a) (b)

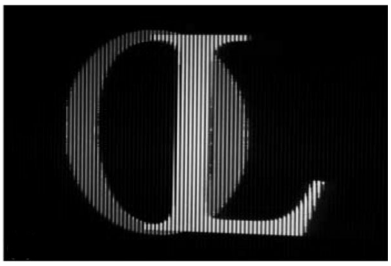
Fig.4 Reconstructed images by using (a) the conventional method and (b) the proposed method



(a) Left view point



(b) Middle view point



(c) Right view point

Fig.5 Different viewing points for the proposed method

In this paper, a simplified integral imaging system is proposed by using a lenticular lens array to replace the lens array in the conventional integral imaging system. The lenticular lens in the proposed simplified integral imaging system is easy to produce. After replacing, the resolution in the vertical direction can be enhanced effectively. If the rectangle pixels are used in this proposed method, the resolution can be enhanced much more. Optical results show that the reconstructed image has the same stereoscopic effect as the conventional method, but it is more sharp. And the simplification opens a new way to apply integral imaging to 3D display. Based on industrialization, the large-size lenticular lens can be produced perfectly. And our proposed method will contribute to the widespread application of large-size or outdoors 3D display devices.

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