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Иконика

High resolution integral imaging display by using microstructure array

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A novel integral imaging method which can be used to display three dimensional (3D) images with high resolution is proposed. The integral imaging system consists of a delicate microstructure array and microlens array. The microstructure array displays the information of the microimage array. Due to the application of the delicate microstructure array, a large number of efficiency pixels in the microimage array are regularly imaged through the microlens array, which will result in the 3D images with high resolution. In this paper, the relationships among the resolution of the 3D images, the focal length of the microlens, microstructure array/microlens array distance, and the feature size of the microstructure array are analyzed theoretically based on optical design theories. The related experiments are performed. The microstructure array with 1 μm feature size is fabricated by lithographic method and applied on the integral imaging system, which forms the 3D images with the resolution 10 lines/mm. Compared with traditional integral imaging system, the resolution of the 3D images generated by the method is effectively enhanced. It is inferred that the method has great potential on static 3D display such as 3D photograph, 3D advertisement, and so on.

Keywords: *three-dimensional image processing, high resolution.*

OCIS codes: *100.6890, 350.5730.*

Интегральный дисплей с высоким разрешением, использующий матрицу микроструктур

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Предложен новый метод интегрального построения изображений, пригодный для создания объёмных (3D) дисплеев с высоким разрешением. Интегральная изображающая система содержит матрицы микроструктур и микролинз. Информация отображается на матрицу микролинз через матрицу микроструктур, элементы которых однозначно связаны, что повышает разрешение 3D изображения. Теоретически проанализированы и выведены соотношения между разрешением 3D изображений, фокусным расстоянием микролинз, расстоянием между микролинзами и микроструктурами и геометрическими параметрами микроструктур. Для экспериментальной проверки литографическим методом были изготовлены матрицы микроструктур с шагом 1 мкм, которые были использованы в интегральной изображающей 3D системе, обеспечивающей разрешение 10 лин/мм, что превосходит характеристики обычных интегральных изображающих систем. Сделан вывод о значительных перспективах использования метода для создания статических 3D дисплеев, так, например, как 3D фотографии, 3D реклама и т.п.

Ключевые слова: *обработка трехмерных изображений, высокое разрешение*.

1. INTRODUCTION

Integral imaging, proposed by Lipmann in 1908, uses a microlens array to pick up and display three dimensional (3D) scenes [1]. Compared with other existing 3D display technologies, integral imaging has obvious advantages, such as continuous parallax, full color, perfect matching with modern display, and so on [2–9]. Because of this, integral imaging attracts extensive attention of researchers, which is considered to be one of the most promising 3D display technologies. However, because the resolution of the microimage array is limited by that of traditional displays (computer display resolution about 3.8 lines/mm), the generated 3D images have low resolution, which will lead to the limitation on the application of integral imaging [10–14].

In order to obtain the micro image array with high resolution, several methods are adopted, such as improving the pixel number by fast shocking the lens array [12], the microimage array displayed by high resolution projectors or displays [13, 14], and so on. The pixel number of the micro image array taken through the lens array can be enhanced through rapid shocking the lens array. The resolution of the 3D images generated by the rapid shocking method is effectively enhanced and four times of that generated by traditional integral imaging [12]. However, it inevitably brings mechanical noise and high manufacturing cost for the application of electromechanical components. The integral imaging by using high resolution projectors (11.8898 lines/mm) can generate the 3D images with high resolution (1 lines/mm) without mechanical noise [13], and this method has been used in the field of medicine. However, a large number of projectors are applied in the system, which causes that the mechanical control is extremely difficult and has large size [13]. In 2006, Jun Arai proposes a method to enhance the resolution of the 3D images by employing a high resolution display [14]. They independently develop the high resolution display (8.0315 lines/mm). The display is used on integral imaging system. The 3D images with high resolution are successfully achieved. However, it takes more time and effort on the high resolution display.

In this paper, we propose a novel integral imaging method with high resolution by using a microstructure array. The microstructure array is used to display the information of the microimage array. Through theoretical calculation, the effects of the microstructure array resolution, the focal length of the microlens array, and microstructure array / microlens array distance on the 3D image resolution are analyzed. It is demonstrated that the resolution of the 3D images increases with the feature size of the microstructure array decrease. After that, the microstructure array with high contrast is fabricated and applied on the integral imaging system. The 3D images with high resolution are perfectly achieved.

2. THEORETICAL ANALYSIS OF INTEGRAL IMAGING WITH HIGH RESOLUTION

2.1. The principle of integral imaging

The integral imaging system consists of two parts: image acquisition and reconstruction, as shown

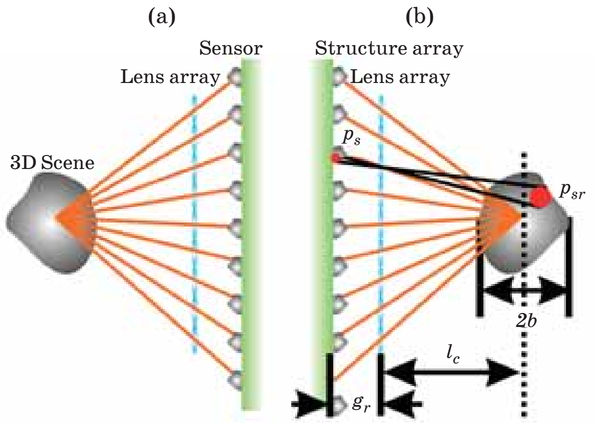

Fig. 1. Integral imaging system. Image acquisition system (a), reconstruction system (b).

in Fig. 1. The image acquisition is to record the information of a 3D scene at various perspective and form a microimage array, as shown in Fig. 1(a). Generally speaking, microimages can be captured by a microlens array. The microimages are processed based on the two step pickup method [2, 3]. A microimage array is generated. The information of the 3D scene at various perspective is dispersed in the microimage array. Reconstruction is that the pixel information of the microimage array is taken by the identical microlens array. The 3D image can be formed based on the reversibility principle for light rays, as shown in Fig. 1(b).

2.2. Parameter analysis

As shown in Fig. 1 and according to the optical design theory, the pixels in a microimage array are taken through the corresponding lens array, which satisfies the following formula,

$$\frac{1}{g_r}+\frac{1}{l_c}=\frac{1}{f}. \tag{1}$$

Here, g_r is the distance between the microimage array and the corresponding lens array, l_c is the distance between the central plane of the 3D image and the microlens array, and f is the focal length of the microlens.

Assuming the pixel size of the microimage array is p_s, the pixel size of the 3D image is p_{sr}, and the distance between the central plane and the edge plane of the 3D image is b, at the edge plane it is satisfied that,

$$\frac{P_{sr}}{l_c+b}=\frac{p_s}{g_r}. \tag{2}$$

According to Equations (1) and (2), we can obtain that

$$P_{sr}=\frac{g_r f+g_r b-fb}{g_r(g_r-f)}p_s. \tag{3}$$

The resolution of the micro image array and that of the 3D image are defined as following,

$$R_s = \frac{1}{p_s}. \quad (4)$$

$$R_{sr} = \frac{1}{p_{sr}}. \quad (5)$$

Among them, R_{sr} is the resolution of the 3D image, which represents the pixel number in the unit length. R_s is the resolution of the microimage array. Therefore, the relationship between the 3D image resolution and the resolution of the microimage array is

$$R_{sr} = \frac{g_r(g_r - f)}{g_r f + g_r b - fb} R_s. \quad (6)$$

In the Equation (6), it is inferred that three main ways can be used to improve the resolution of the 3D image: (1) reducing the focal length of the microlens f, (2) enlarging the distance between the microlens array and the 3D scene g_r, (3) improving the resolution of the microimage array R_s. Reducing f and increasing g_r can improve the 3D image resolution, but it would lead to the decrease of the field angle and the 3D image aberration [15]. From the Equation (6), it can be seen that the resolution of the 3D image is proportional to that of the microimage array. Therefore, improving R_s is the best way to enhance the resolution of the 3D image.

For improving the resolution of the microimage array R_s, the microimage array is displayed by the microstructure array fabricated by lithographic method. Lithography is an effective method to fabricate micro- and nanometer structures through optical exposure and development. By the method, the microstructure array with small feature size can be achieved. The resolution of the microimage array R_s is improved with the feature size of the microstructure decrease. Therefore, the microimage array with high resolution can be formed. It means that the 3D image with high resolution can be achieved by using the delicate microstructure array.

2.3. Acquisition and transformation of the microimage array

In order to perform the relevant experiment, microimages at various perspective are captured by the software 3Ds Max. The image acquisition system is shown in Fig. 2(a). 3D scenes are three butterfly models and a vase model at different positions. The distance between two adjacent models is 30 mm. 40000 microimages are taken and recorded the information of the 3D scenes at various perspective. The microimages are analyzed and regularly combined, which form the microimage array with 100 μm period, as shown in Fig. 2(b). Then, the boundary of the microimage array is extracted through the software written by ourselves. The image array with JPG format is converted into that CIF format which can be processed by direct writing instruments.

(a) (b)

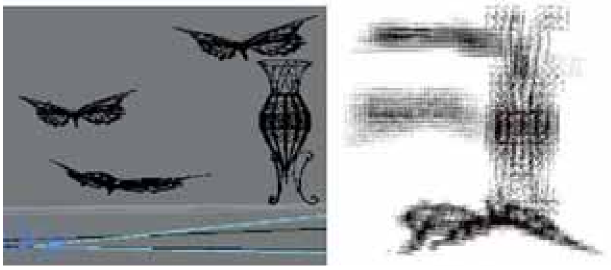

Fig. 2. The micro image acquisition. Capture process of the micro images (a), micro image array (b).

3. FABRICATION OF KEY COMPONENTS

In order to achieve the delicate microstructure array and microlens array for the integral imaging system, the lithographic method is used in the experiments.

3.1. Fabrication of the microstructure array

The mask of the microstructure array is fabricated and obtained by using a laser direct writing technique, as shown in Fig. 3. The critical dimension and period of the mask are 1 μm and 100 μm, respectively.

For achieving the microstructure array with high contrast, we propose that the microstructure array is prepared by metallic materials. The preparation process is as follows: (1) the K9 glass substrate is immersed and cleaned by dilute nitric acid solution (nitric acid : water = 10:1) for 6 hours. After that, the glass substrate is dried at the temperature 160 °C. (2) The Chrome with 120 nm thickness is evaporated on the substrate. (3) The resist with model AZ3100 is coated on the surface of Chrome layer with the parameters: spinning speed 3000 rpm (revolutions per minute), spinning time 30 s (second). After coat-

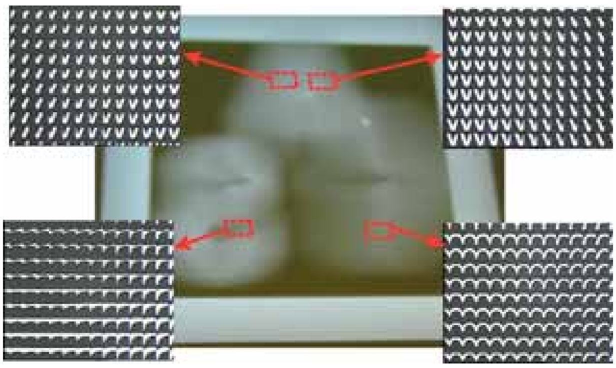

Fig. 3. The mask of the microstructure array.

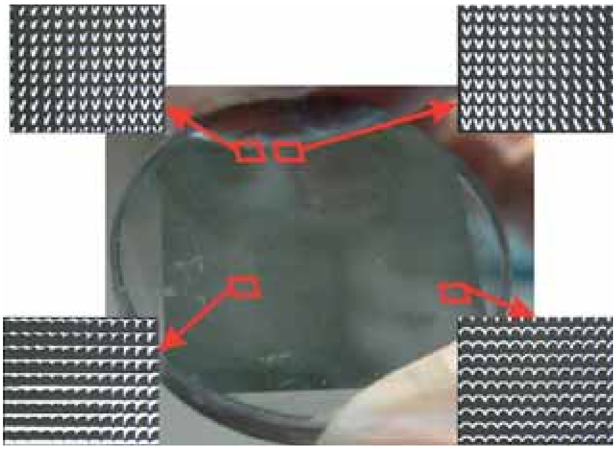

Fig. 4. The fabrication result of the microstructure array.

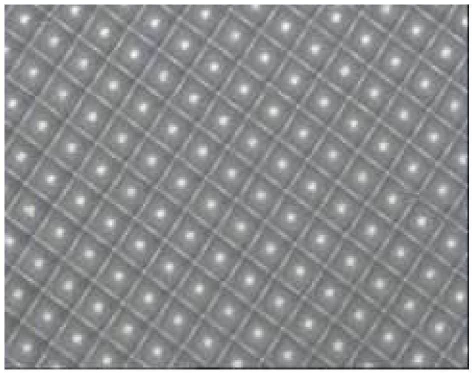

Fig. 5. Fabrication results of the micro lens array.

The parameters of microlens array

Microlens array	Pith, mm	0.1
	Radius, mm	0.1626
	Focal length, mm	0.29
Plastic substrate	Thickness, mm	0.35
	Material	Polyethylene terephthalate (PET)

ing the resist, the resist thickness is 1.3 μm. (4) The resist on the substrate is exposed through the mask of the microstructure array by using the ultraviolet (UV) light with 365 nm wavelength and 10 mW/cm^2 power. The exposure time is 8 s and the development time is 12.5 s. (5) After removing Chrome and cleaning the resist, the microstructure array with Chrome material is formed on the substrate, as shown in Fig. 4. The four microscopic images are the images of the microstructure array at different positions. The microstructure array is period, but each microstructure is different, which is consistent with the mask of the microstructure array.

Because of the microimage array displayed by the microstructure array, the microimage array has the same period and critical dimension with the microstructure array. The period and critical dimension of the microimage array are 100 μm and 1 μm, respectively. The resolution of the microimage array is 1000 lines/mm. The resolution of the microimage array is about 265 times that of the traditional display.

3.2. Fabrication of microlens array

After the fabrication of the microstructure array, the microlens array is prepared by the moving mask lithography [16, 17]. The preparation method of the microlens array comprises the following steps: (1) The K9 glass substrate is immersed and cleaned by using dilute nitric acid solution (nitric acid : water = 10:1). After that, the glass substrate is dried at the temperature 160 °C. (2) The resist with the type AZ 50XT is coated on the substrate with the spinning speed 2500 rpm and the spinning time 20 s. (3) The resist on the substrate is exposed by using the moving mask lithographic method with the UV light [16, 17]. The wavelength of the UV light is 365 nm. The power of the UV light is 5 mW/cm^2. The exposure and development time are 93 s and 72 s, respectively. Then, the microlens array is formed on the resist.

(4) The soft mould of the micro lens array is fabricated by the casting technology [18]. The material of the soft mould is polydimethylsiloxane. (5) The microlens array is imprinted on the PET film with the UV curing materials. The microlens array has high transmittance. The microscopic image is shown in Fig. 5. The parameters of micro lens array are shown in table.

After that, the microstructure array with high contrast and the microlens array are carefully aligned and tightly bonded on the substrate. Here, the miniaturized structure of integral imaging is successfully achieved.

4. EXPERIMENT RESULTS AND ANALYSIS

Then, the 3D images of three butterflies and a vase are distributed around the microlens array in experiment, as shown in Fig. 6. The 3D images are delicate and the critical dimension of the 3D images is about 100 μm. It illustrates that the resolution of the 3D images is around 10 lines/mm. According to the Equation (6), the resolution of the 3D images is calculated to be 11.0439 lines/mm. The experimental results are basically consistent with the theoretical calculation of the integral imaging. The resolution of the 3D images is far higher than that by using a traditional display or projector array and 265 times of that by using a traditional display. It is demonstrated that the 3D images with high resolution can be perfectly obtained by the method.

Fig. 6. The 3D images generated by the integral imaging system.

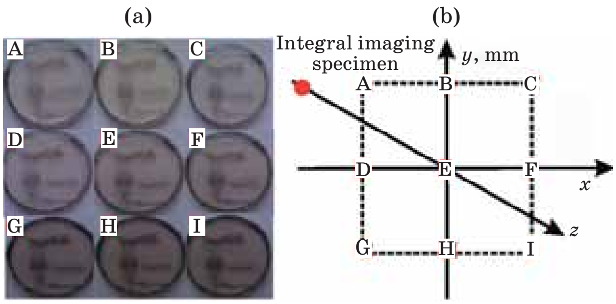

Fig. 7. The 3D images at various perspective and locations. The shooting results (a), the shooting locations (b).

In order to prove that the images shown around the microlens array are 3D images, the images at various perspective are taken. The shooting results and locations are shown in Fig. 7 (a) and (b) respectively. As the change of the shooting location, the relative distance between the butterfly and vase images changes. It is caused that the floating and immersed images around the microlens array relatively move with the location change. Therefore, the images have the various perspective and depth information of the 3D scene. It illustrates that the obtained images are 3D images, which is different from the microimage array displayed by the microstructure array. Due to the 3D images with ultra high resolution, the method has great potential on static 3D display, such as static 3D displays with high resolution, security labels, and so on.

5. SUMMARY

A high resolution integral imaging method by using a microstructure array is proposed and demonstrated in this paper. The microstructure array fabricated by lithographic method has high resolution, which is used to display the microimage array. The pixels of the microimage array are taken through the corresponding microlens array, which forms the 3D images with high resolution. Theoretical analysis and experimental results show that the 3D images with the resolution around 10 lines/mm can be formed by the method. The resolution of the 3D images is much higher than that by using the microimage array displayed through a traditional display or projector array. It is inferred that the method has great potential on static 3D displays with high resolution, security labels, and so on.

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