Computational Technique of Volumetric Object Reconstruction in Integral Imaging by Use of Real and Virtual Image Fields

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We propose a computational reconstruction technique in large-depth integral imaging where the elemental images have information of three-dimensional objects through real and virtual image fields. In the proposed technique, we reconstruct full volume information from the elemental images through both real and virtual image fields. Here, we use uniform mappings of elemental images with the size of the lenslet regardless of the distance between the lenslet array and reconstruction image plane. To show the feasibility of the proposed reconstruction technique, we perform preliminary experiments and present experimental results.

Keywords: 3-D display, integral imaging, computational reconstruction, lenslet array.

Manuscript received Dec. 20, 2004; revised June 16, 2005.

This research work was supported by ITRC project of Korea Ministry of Information and Communication.

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I. Introduction

Integral imaging, which is a three-dimensional (3-D) image display technique with full parallax and continuous viewing points, has been the subject of much research [1]-[12]. In the pickup part of integral imaging, the rays coming from 3-D objects are recorded as 2-D elemental images with a lenslet array (or pinhole array) and a 2-D image sensor. In the display part of II, the recorded 2-D elemental images are displayed in a display device, and rays coming from the elemental images are then gathered in space to form 3-D real images.

Recently, studies have been reported for two kinds of integral imaging according to the gap distance between a lenslet array and a display panel; depth-priority integral imaging (DPII) and resolution-priority integral imaging (RPII) [13], [14]. DPII is obtained by setting the gap equal to the focal length of the lenslets. It provides 3-D images with low resolution and large depth through both real and virtual image fields. On the other hand, RPII is obtained when the gap distance is not equal to the focal length of the lenslets. It gives us 3-D images with high resolution and small depth.

In II, computational reconstruction techniques can be used to overcome image quality degradation caused by optical devices and to have the freedom to generate the viewing angle of the reconstructed objects without optical devices [15]-[19]. In particular, Hong and others have reported on a computational reconstruction technique to obtain full 3-D volume information, which can be used for image processing applications such as 3-D surface extraction, based on linear mapping according to ray optics [18]. Their technique is considered only in a real image field because its elemental images have information of the real image field and are simply inverse mappings of elemental images with different perspectives at the different distances in RPII. Here, the size of mapping for each pixel in the elemental images is linearly proportional to the distance between lenslet array and the reconstruction image plane. However, the DPII system is different. In the DPII system [13], the elemental images are synthesized with information of 3D objects for both real and virtual fields. Therefore, the reconstruction should also be considered through both real and virtual image fields to extract full volume information.

In this paper, we propose a computational reconstruction technique for use in DPII where the elemental images have information of 3-D objects through real and virtual image fields. In our technique, we reconstruct full volume information from the elemental images through both real and virtual image fields. Here, we use uniform mappings of elemental images with the size of the lenslet regardless of the distance between the lenslet array and reconstruction image plane. To show the feasibility of the proposed technique, we reconstructed 3-D reconstructed images plane by plane in both real and virtual image fields by using synthesized elemental images. Our method can give us full 3D volume information through both real and virtual image fields.

II. Computational Reconstruction Technique in Integral Imaging by Use of both Real and Virtual Image Fields

Figure 1 illustrates the DPII system. Here, we suppose that the system is diffraction-free for simplification. The distance between lenslet array and image sensor is g, and the focal length of the lenslet is f. We obtain DPII by use of real and virtual image fields when $g=f$. The rays from the pixels of a display panel become parallel through the lenslet array. The spot size of the integral point image in space is similar to lenslet size d regardless of distance L. The elemental images of 3-D objects to be displayed in a display panel are synthesized with the method in [13]. The pinhole array is used for synthesizing elemental images. Figure 2 shows the pickup of elemental

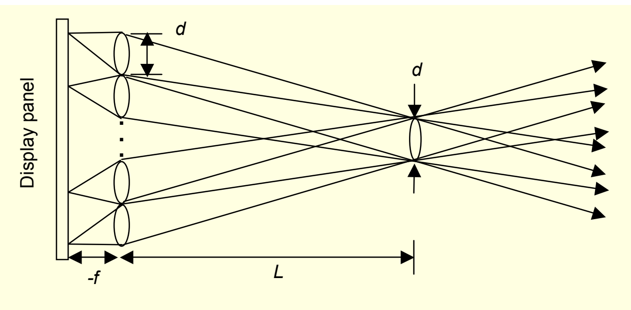

Fig. 1. DPII system by use of both real and virtual image fields.

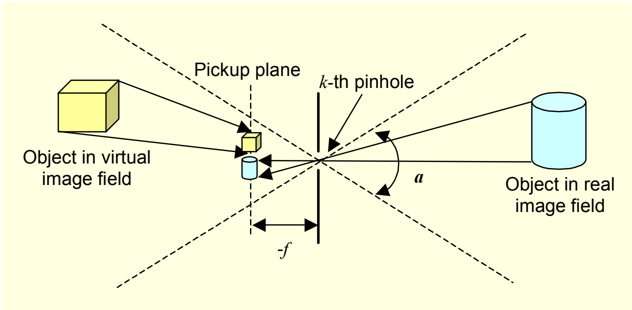

Fig. 2. An example to obtain the synthesized elemental images in DPII.

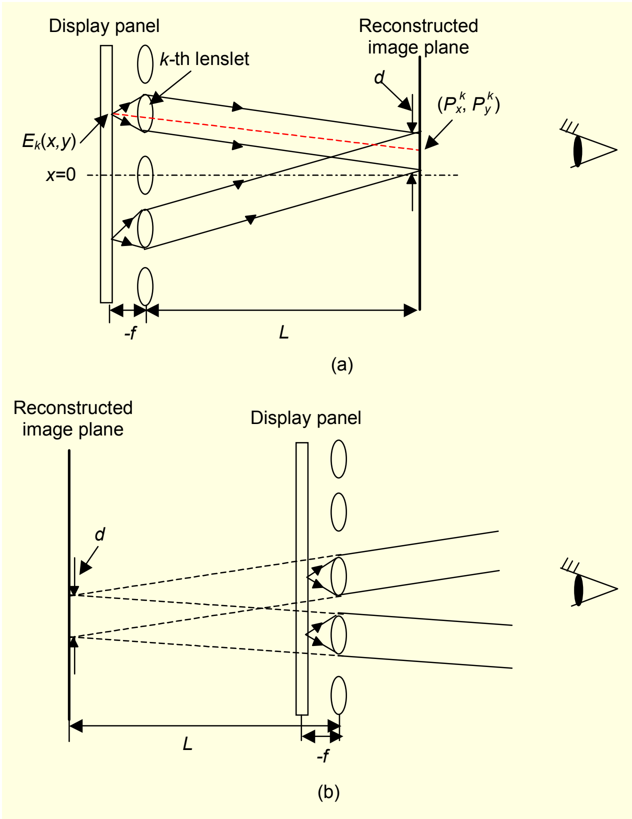

Fig. 3. Computational reconstruction technique: (a) real image field and (b) virtual image field.

image through the k-th pinhole in DPII. Rays of the object located at the real image field are mapped inversely through the pinhole into the pickup plane. And those at the virtual image field are mapped directly into the pickup plane as shown in Fig. 2. To avoid interference between the neighboring elemental images, the pickup angle $\alpha=2\tan^{-1}(d/2f)$ should be satisfied.

Figure 3 illustrates the proposed reconstruction technique in DPII by use of both real and virtual image fields. A display panel and a reconstruction image plane are located at $-f$ and L from the display lenslet array, respectively. When $L\geq0$, we can obtain the reconstructed image of 3-D objects in the real image field, as shown in Fig. 3(a). The rays from each pixel in the display panel are parallel because a display panel is located at focal length f of the lenslet. Let us assume that $E_k(x,y)$ is a pixel of k-th elemental images as shown in Fig. 3(a). And we consider a mapping procedure of $E_k(x,y)$ to the reconstructed image plane. Then, the mapping position can be calculated by

$$(P_x^k, P_y^k) = \left(kd - \frac{L}{f} x, kd - \frac{L}{f} y \right), \tag{1}$$

where x and y are from $-d/2$ to $d/2$. At the mapping position, the mapping size of reconstructed image point from each pixel becomes

$$S(P_x^k, P_y^k, L) = d \tag{2}$$

in the reconstructed image plane. From (1) and (2), all rays from elemental images are uniformly mapped at their mapping positions with beam size d into the reconstructed image plane regardless of distance L. On the other hand, a reconstruction image in the virtual image field is obtained when $L<0$, as shown in Fig. 3(b). Here, mappings of all rays from elemental images are performed behind the display lenslet array. By repeating the mappings of elemental images for the entire range of L, we can obtain full reconstruction information of 3-D images throughout both real and virtual image fields.

III. Experiments and Results

To demonstrate the proposed reconstruction technique in DPII, we performed preliminary experiments. The experimental structure is shown in Fig. 4. We used a 3-D object composed of four 2-D character patterns, 'I', 'T', 'R' and 'C' whose size is 1020 × 750 pixels. The patterns are longitudinally located at +90 mm, +30 mm, -3 mm, and -45 mm from the origin of the lenslet array, respectively. The lenslet array has 34 × 25 lenslets whose sizes are 1 mm. Each lenslet is 30 × 30 pixels. Focal length f of the lenslets is 3 mm. The elemental images were synthesized as shown in Fig. 2. Figure 5 shows the synthesized elemental images used in the experiment.

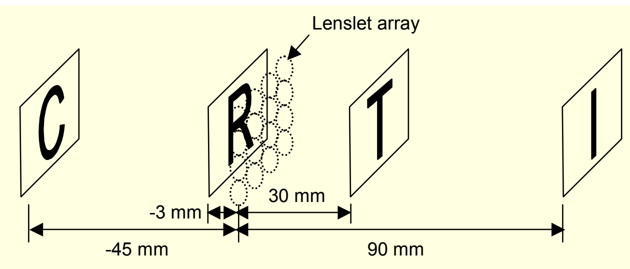

Fig. 4. Experimental structure.

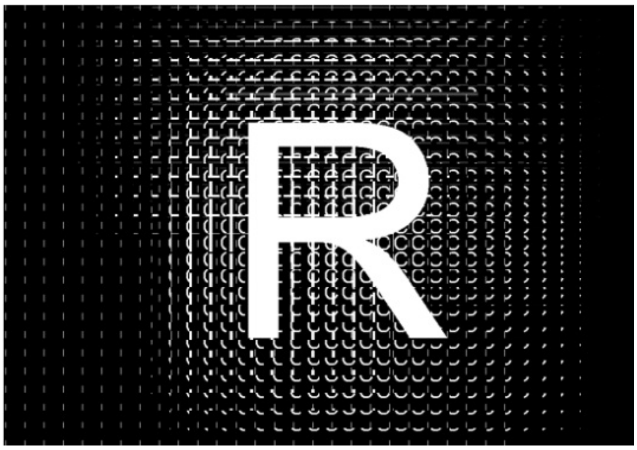

Fig. 5. The elemental images used in the experiment.

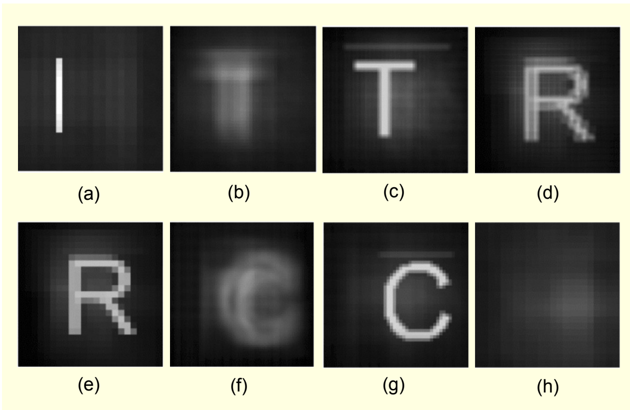

Fig. 6. Eight reconstructed images, where L = (a) +90 mm, (b) +45 mm, (c) +30 mm, (d) 0 mm, (e) –3 mm, (f) –30 mm, (g) –45 mm, and (h) –90 mm.

The reconstruction was performed by use of synthesized elemental images. Each pixel from the elemental images was uniformly mapped with a beam size of 3 mm into the reconstructed image plane. The entire reconstruction image was obtained by repeating all the pixels of the elemental images. Figure 6 shows the computationally reconstructed images at various display planes using the proposed reconstruction technique. The size of each reconstructed image is 1000 × 1000 pixels. Eight reconstructed images at distances of L = +90, +45, +30, 0, -3, -30, -45, and -90 mm are shown in Figs. 6(a) through 6(h), respectively. We can see clear images at L = +90, +45, -3, and -45 mm, which are the image display planes of the patterns. However, we can see blurred images at other distances. Even though the computational conditions are not perfect, we believe that our experiment was successfully demonstrated.

IV. Discussion and Conclusion

Although DPII provides a wide depth presentation of 3-D images, there is a problem of reconstructing a low resolution 3-D image. In DPII, the resolution of 3-D images largely depends on the number of lenslets in the display lenslet array. Therefore, a high resolution 3-D image requires the number of lenslets to be as large as possible. In real implementation, however, this is not easy due to the limitations of devices such as the display panel and lenslet array. We should consider this tradeoff in a system design.

Until now, elemental images in DPII have been synthesized using only a computer. This is the reason why it is not easy work to pickup strong intensity distribution of 3-D objects in a Fourier-transform plane of lenslets in an optically direct pickup. Even though there is no method of direct pickup at present, DPII with a wide depth range can be used in other 3-D display applications such as a 3-D animation display without the use of optical devices. We believe that the direct pickup in DPII will be the focus of our future work.

In conclusion, we have proposed a computational reconstruction technique in DPII by use of both real and virtual image fields. We performed experiments with 3-D objects to show the feasibility of the proposed reconstruction technique. Our full 3-D reconstruction information throughout real and virtual image fields can be used for image processing applications.

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