

Three-dimensional Dynamic Display System Based on Integral Imaging

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Abstract

Three-dimensional dynamic display system based on computer-generated integral imaging is discussed and its feasibility is verified via some basic experiments. Integrated images observed from different viewing points are seen to have full parallax and the animated 3D image was implemented successfully. Moreover, using large size Fresnel lens array was found to helps widen viewing angle and to make the system more practical.

Keywords : three-dimensional display, integral photography, integral imaging, fresnel lens array

1. Introduction

Three-dimensional(3D) display technologies based on integral photography(IP) has been modified and has developed since Lippmann first proposed it in 1908[1~4]. Integral photography is an attractive method in that it provides continuous viewpoints and does not require any special glasses. Moreover, the integrated images have full parallax (vertical parallax as well as horizontal parallax) unlike the lenticular-based system. Fig. 1 shows the basic principle of forming 3D images. A number of slightly different views of the object, observed from the various directions, are made to pass through the lens sheet which consists of many elemental lenses and are recorded on the film. For the reproduction process, the film is irradiated with a diffused light. The rays retrace the original routes and reproduce the image at the position where the object was located. However, this method is not suited for animated object because of the film pickup process. On the other hand, the computer-generated integral imaging (CGII) scheme can implement 3D animation[5]. In this scheme, an elemental image array of an imaginary 3D object is generated with the aid of a computer. Hence, only producing animated elemental images is enough to display moving objects. Fig. 2 shows a basic schematic diagram of the CGII system. With a lens array and display panel, the 3D image can be formed in free space. Such easiness in making a 3D image without difficulties in the image pickup process makes the CGII attractive to be applied in compact system. To generate elemental image arrays, we assume an imaginary object which contains 3D information. If we define the lateral plane which is parallel to the display panel as the x-y plane, the z direction represents the information relative to image depth. An imaginary object includes information relative to x, y, z and each elemental image on the display panel has x, y data. Therefore, if we generate calculated elemental images which correspond to a point of the imaginary object, the 3D information is mapped on to an array of 2D information. We refer to this process as

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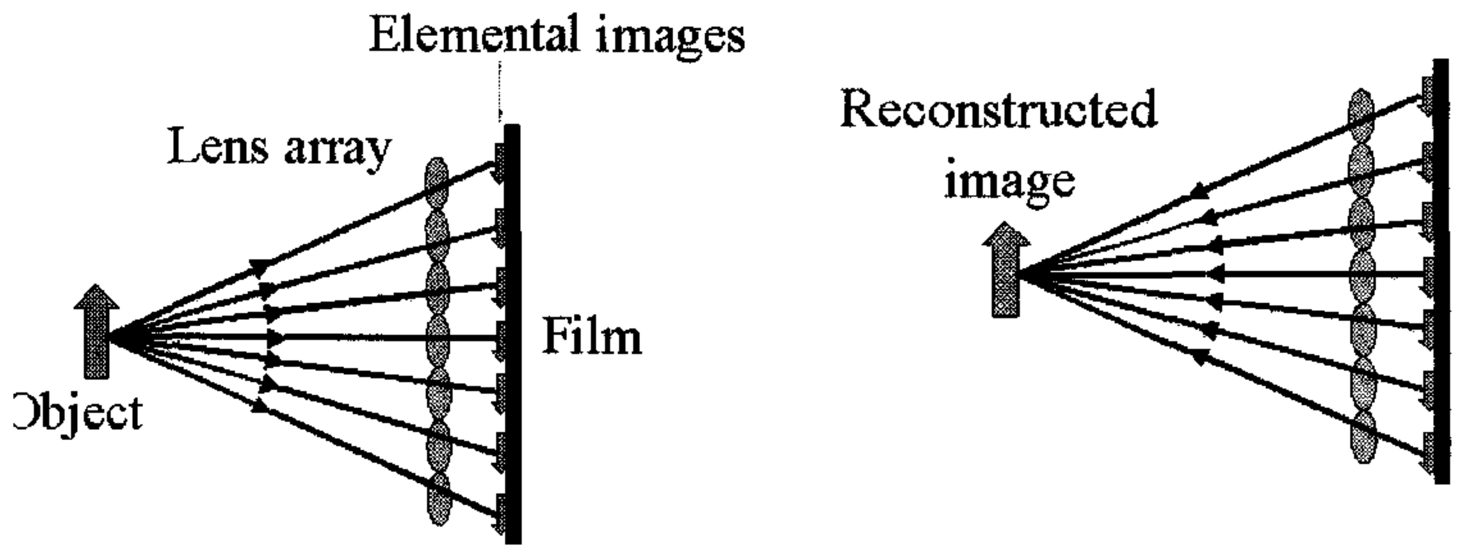


Fig. 1. Conventional integral photography.

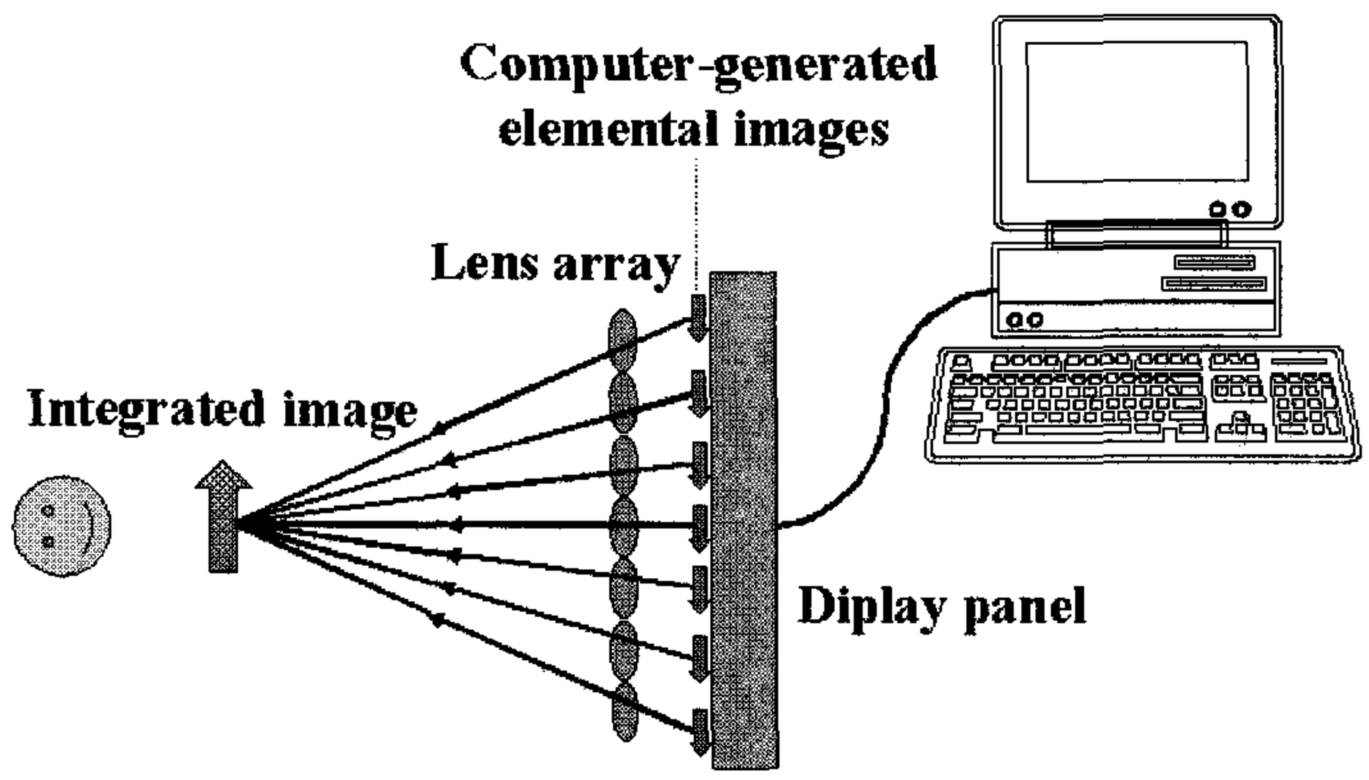


Fig. 2. Schematics of the CGII system.

image mapping. Image mapping is performed point by point taking into consideration depth (z-direction) information. In addition, the calculated elemental images are made orthoscopically. In this way, the problem of pseudoscopic images can be solved naturally.

2. Advantage of Using a Fresnel Lens Array

In general, the viewing angle of the IP increases with the decrease in the f-number of the elemental lens. However, the distortion of the lens becomes severe as the f-number decreases. A well-designed Fresnel lens array which has non-continuous surfaces is advantageous in that the only little image distortion occurs even with a small f-number. Moreover the Fresnel lens array is easily available and cost-effective. Fig. 3 shows the compared results of integrated images using a conventional lens array (f-number: 2.67, width of elemental lens: 5 mm, focal length of elemental lens: 30 mm) and a Fresnel lens array (f-number: 1.15, width of elemental lens: 19 mm, focal length of elemental lens: 22 mm). As seen in Fig. 3(b), although there are some blur noise, cracks at the intersection points of elemental lenses can not be seen in spite of using a lens array with smaller f-number. This proves that adopting a Fresnel lens array with a small f-number is an effective method of widening the viewing angle of IP system. The measured viewing angle for the Fresnel lens array is approximately 35 degrees. Around the edge of the viewing angle, the integrated image overlapping appeared and the repeated flipping image was seen in the area over the maximum viewing angle.

3. Practical IP System

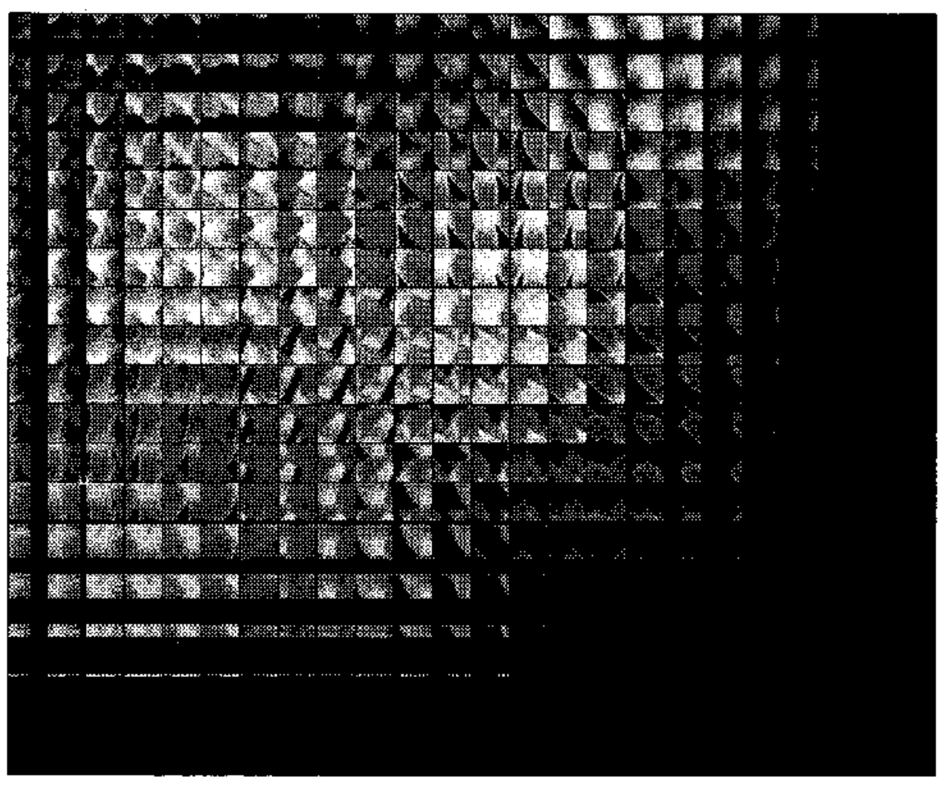
3.1. Use of a large size lens array

As the number of elemental lenses increase, more information about the various elemental images can be presented and the capability of displaying a large size object also increases. In addition, a very large screen is effective in enhancing the feeling of depth

(a) with conventional lens array

(b) with Fresnel lens array

Fig. 3. Integrated images with different lens arrays.

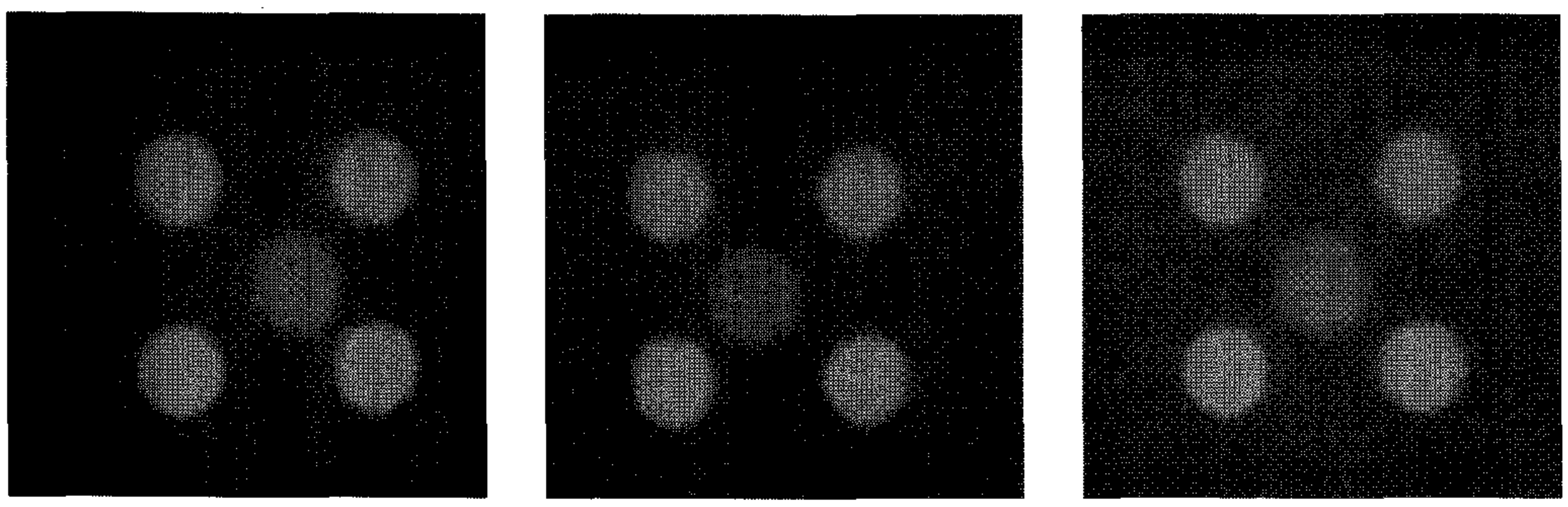


(a) elemental image array

(b) integrated image

Fig. 4. Images using large size IP system.

psychologically. Hence, we implemented a large size CGII system with a lens array that is composed of many elemental lenses. The lens array used in the experiment has 26 × 24 elemental lenses and each elemental lens has a width of 10 mm and focal length of 22 mm. We adopted a Fresnel lens array instead of the conventional lens array in order to guarantee wide viewing angle without lens aberrations. The total size of the lens array corresponds to 14" panel. The pixel pitch of the LCD panel on which elemental image sets are displayed is 0.24 mm. Figs. 4(a) and (b) show examples of elemental image array and the integrated image. As can be seen from Fig. 4(a), computer-generated elemental images are more clear than those generated with pickup process. The sequence of image mapping is simple. First, the center of each elemental lens (in a lens array) is calculated. Then the imaginary object is assumed as the combination of planes with different depths, which are arranged along the depth direction. In the case of an object, a set of elemental image points can be obtained. The procedure is as follows. Information of the x-y coordinates of a point in an imaginary object determines the center of corresponding elemental image points. Based on information of the z coordinate of an imaginary object, the positions and the number of elemental images can be calculated and, as a result, the set of elemental image points can be plotted. This calculation process is performed repeatedly until the set of elemental images for all points of an imaginary object is determined. Through this image mapping procedure, elemental images of an arbitrary object can be made. (using a CCD camera) Fig. 5 shows the pictured integrated images taken using seen from various viewpoints and these images are located at multiple image planes. The image



(a) from the left viewpoint (b) from the center (c) from the right viewpoint

Fig. 5. Integrated images at different observing angles.

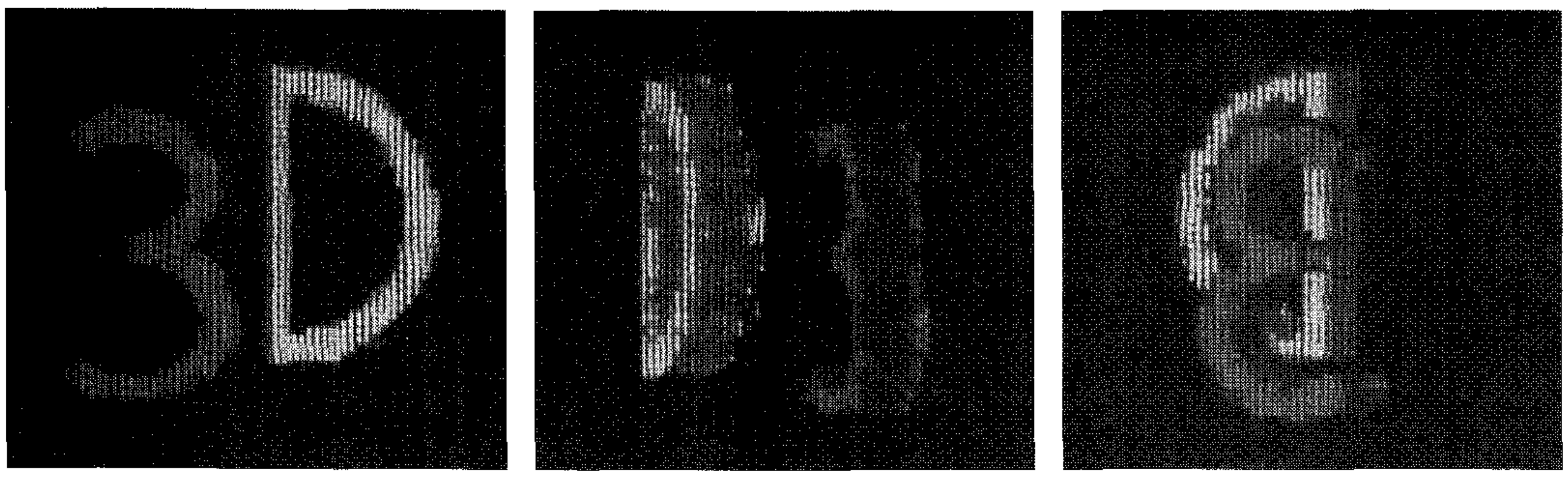


Fig. 6. Example of 3D animation: Two letters are rotated in free space.

plane of the center circle is 80 mm in front of the image plane of the 4 circles at the corners. The integrated images observed from different viewing points are have differences. This fact clearly indicates that the integrated images are autostereoscopic. The measured viewing angle was approximately 20 degrees.

3.2 Display of animated image

Another advantage of the CGII scheme is the possibility of displaying 3-D animated images in real time. As the animated object is composed of several snapshots, many elemental images are generated and stored in the computer. Therefore, displaying stored elemental images continuously can implement 3D animated imaging. Fig. 6 shows an example of 3D animation which is generated by our system (pictured images with a CCD camera). The letters '3' and 'D' rotate around the central axis which is 10 cm far from the lens array. Both the two letters are 2 cm far from the central axis. Figures are some snapshot images of the rotating image. Although high-speed computer system is required for complex long-time animation, common systems are enough for simple animation. The lens array used in the experiment consisted of 13 × 13 elemental lenses and each elemental lens had a width of 5 mm and the focal length of 30 mm. The measured viewing angle was approximately 10 degrees.

4. Conclusions

In conclusion, the 3D display technique based on CGII is an attractive method because it has several advantages. Adopting a large size Fresnel lens array is useful in widening the viewing angle and maks the system more practical. This method will be especially helpful in displaying 3D animation.

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