Computational integral imaging with enhanced depth sensitivity

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Abstract

Novel computational integral imaging technique with enhanced depth sensitivity is proposed. For each lateral position at a given depth plane, the dissimilarity between corresponding pixels of the elemental images is measured and used as a suppressing factor for that position. Experimental and simulation results show that reconstructed depth image on the incorrect depth plane is effectively suppressed.

1. Introduction

A basic limitation of a conventional visual display is that the surface of the display screen is two dimensional whereas the natural world is three dimensional (3D). A 3D display has some applications such as architectural and design models, computer games, or 3D medical images. There are several methods to display the 3D image, for example, stereoscopy [1], autostereoscopy, holography, and integral imaging (II) [2-3]. The most important parameter of the 3D image system is a depth, because depth helps for human to feel the third dimension. Therefore, adepth detection is an interesting research area of 3D image processing. Recently computational integral imaging reconstruction (CIIR) [4] has been actively studied for this purpose.

Integral imaging, which was first proposed by G. Lippman in 1908, has been regarded as one of the most attractive three-dimensional (3D) imaging and display techniques, because it can provide full-color, full-parallax and continuous-viewing images. Integral imaging technique consists of two processes, pickup and reconstruction [4-5] as shown in Fig. 1. Proposed method enhances the depth sensitivity of the CIIR by using pixel weight. In the followings, we explain the principle of the proposed method and present the results of simulation and experiment.

2. Principle of the proposed method

The proposed method consists of three steps. The first step is the depth plane reconstruction using a new pixel weight method. The second step produces a mask of the objects from the reconstructed plane images. The last step reconstructs each detected object at the corresponding correct depth plane.

In Figure 1, three object points P_1, P_2, and P_3, which have three different colors, are projected by a lens array into an elemental image plane. P_{C2} and P_{I2} are reconstructed pixels of object point P_2 in a correct plane and an incorrect plane, respectively. P_{C2} is reconstructed by three pixels, E_{2-1}, E_{2-2}, and E_{2-3}, on three elemental images. P_{I2} in the incorrect plane is reconstructed by five pixels that have different colors.

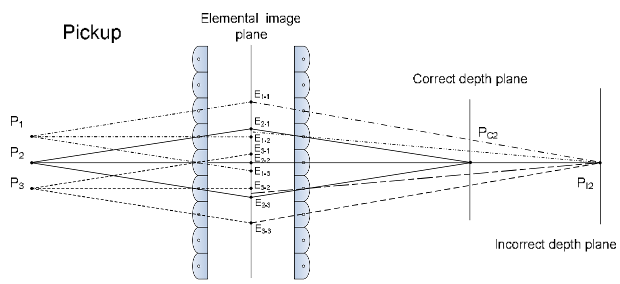

Fig. 1. Basic structure of integral imaging.

For a given reconstruction point, the corresponding elemental image points are collected and averaged. Also one pixel among the corresponding elemental image pixels is selected and identified as center elemental image pixel such that its lateral position is nearest to that of the given reconstruction point. If an average value of the color of the collected corresponding pixels is greater than the color of the center elemental image pixel, a weight for the given reconstruction pixel is calculated by

$$WP(x,y) = \left(\frac{C(x,y)}{Avr(x,y)} \right)^{WF}, \quad (1)$$

where $Avr(x,y)$ is the average value of the color of the corresponding elemental image pixels, WF is a coefficient determining linearity of the weighting function, and $C(x,y)$ is a color of the center elemental image pixel. If the average value of the corresponding elemental image pixels is smaller than or equal to the color of the center elemental image pixel, the weight for the reconstruction pixel is calculated by

$$WP(x,y) = \left(\frac{Avr(x,y)}{C(x,y)} \right)^{WF}. \quad (2)$$

A reconstructed pixel is defined by

$$I(x,y) = C(x,y) \cdot WP(x,y). \quad (3)$$

When a plane image is reconstructed far from the correct depth plane, the *WP* is low, and consequently the reconstructed pixel is suppressed. The *WP* equals one when the image is reconstructed at the correct depth plane. The amount of suppression at the incorrect depth plane depends on the weighting factor *WF*. The relationship between the pixel weight and the average value of the pixel, when $C(x,y)$ is 250, is shown in Fig. 2.

Figure 3 shows the simulation results. An image of two objects is used and their depth is 29 mm for "3" image and 33 mm for "D" image. Figures 3(a)-3(e) are the result of the conventional CIIR at 5 different depth planes, Figs. 3(f)-3(j) are the result of the proposed CIIR with the *WF*=3, and Figs. 3(k)-3(o) are the result of the proposed CIIR with the *WF*=6.

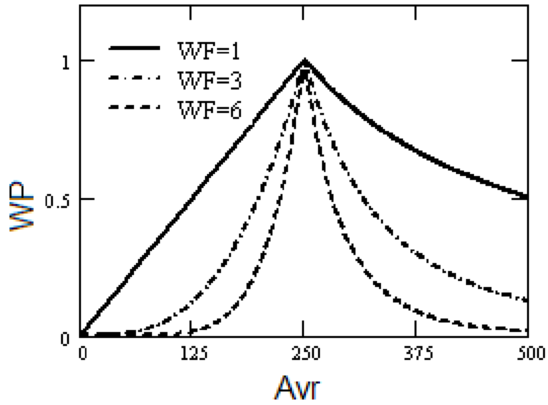

Fig. 2. Relationship between the pixel weight and the average value.

From the Fig. 3, if the weighting factor is high, the unfocused plane image is more suppressed, but a quality of the image at the unfocused plane is not good. When there is only one plane object, by measuring total intensity value in the reconstructed depth images we can determine correct depth plane, and can obtain clear reconstructed depth plane image by performing conventional CIIR at the detected correct depth plane. When there are multiple plane objects, however, the depth detection cannot be done by simple measurement of the total intensity value. Moreover, in multi-object case, when one plane object image is reconstructed at the correct depth plane, the blurred and unfocused images of other objects are also reconstructed, which gives additional noise to the focused image. It reduces the depth detection accuracy and the quality of the correct depth plane image.

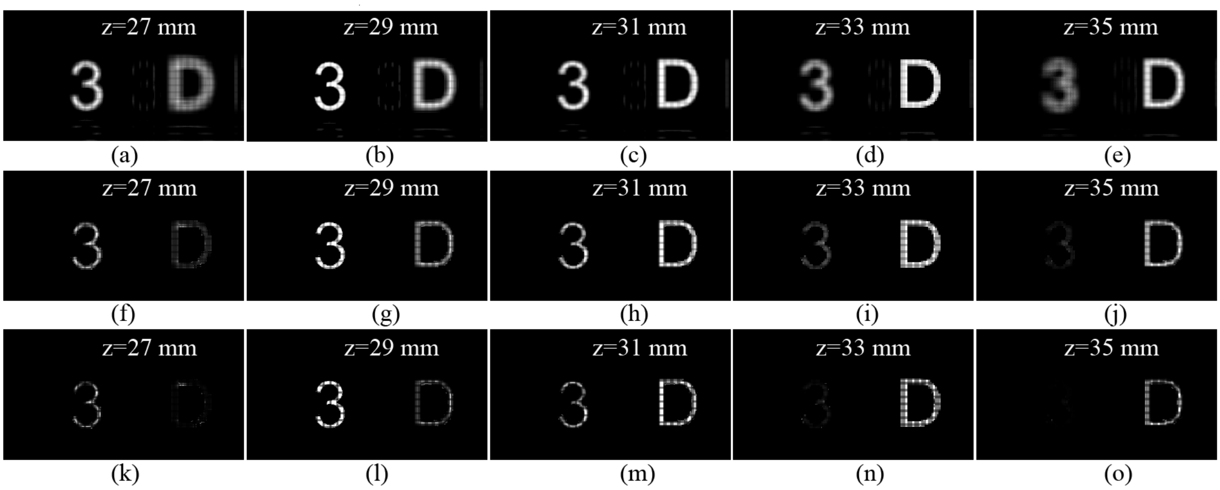

Fig. 3. Simulation result. Depth plane images reconstructed by the conventional CIIR (a)-(e), by the pixel weight method with WF=3 (f)-(j), and by the pixel weight method with WF=6 (k)-(o).

In order to alleviate this problem, we apply the pixel weight method to mask each object and detect correct depths of all objects. For object masking, the reconstructed image by the pixel weight method is converted into a binary image. If that binary image is located at the unfocused plane, many individual pixels and separated regions will appear by the pixel weight method in the binary image. For example, black lines and some pixels appear in Fig. 3(k). Those black lines and pixels make it hard to get a complete object mask. Therefore, we use a morphological image closing algorithm [5], which can remove the gaps and smooth the edges of a binary region, to combine the individual pixels and eliminate the black lines.

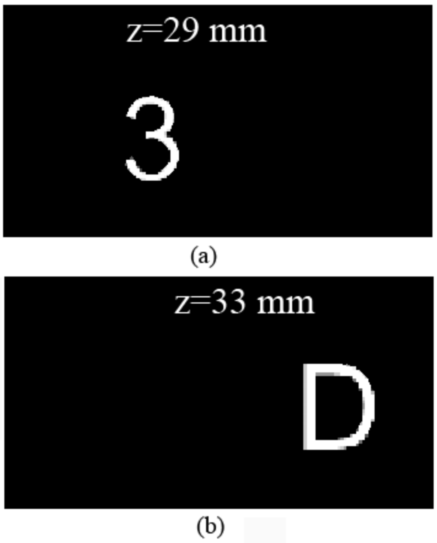

Fig.4. Simulation result of proposed method.

The object mask is determined for each depth plane by finding boundary of the morphologically closed image obtained in the previous step. The mask of one depth plane image cannot identify all objects because some reconstructed image of the plane object disappears at some depth plane, such that the corresponding object of that image cannot be identified. For example, a "3" object disappears in Fig. 3(o), and the "3" object cannot be identified. By repeating this process to all reconstructed image all different depth planes, the correct mask of the multiple objects can be determined.

The last step is the object depth detection and reconstruction. We use the mask of objects and reconstructed images at all depth planes by the pixel weight method to define correct depth planes of each object. Finally we reconstruct each object at the corresponding correct depth plane while masking other objects masking other objects. The simulation results are shown in Fig. 4.

3. Experimental results and discussion

We capture a "D" object and a rectangular object, which are located at 29 mm and 33 mm from the lens array, respectively. A lens array consists of 68×38 elemental lenses, each of which is 1×1 mm rectangular lens of 3.3 mm focal length. The resolution of each elemental image is 36×36 pixels. Figures 5(a)-5(e) are the result of the conventional CIIR at 5 different depth planes, Figs. 5(f)-5(j) are the result of the proposed CIIR with the *WF*=3, and Figs. 5(k)-5(o) are the result of the proposed CIIR with the *WF*=6. The suppression at the incorrect depth plane is not visually obvious, because captured objects are not exactly plane and some environment noise. Still, however, the proposed method can detect correct depth planes of each object. Figure 6 shows a total intensity value of each masked object at different depth planes from 26 mm to 36 mm, when the weighting factor *WF* is 6.

From Fig. 6, we can determine correct depths of the "D" object and the rectangular object as 29 mm and 32 mm, respectively. Finally, the reconstruction is performed on those two depth planes using the object mask, resulting in clear object image shown in Fig.7.

4. Summary

The pixel weight method suppresses pixels of one plane object image at unfocused plane successfully, such that the total pixel intensity is low. It is used to detect the on focused plane. In the multi plane object case, the pixel weight method is combined with our object detection method. Our proposed method successfully detects and reconstructs clear object image without noise of the unfocused plane image.

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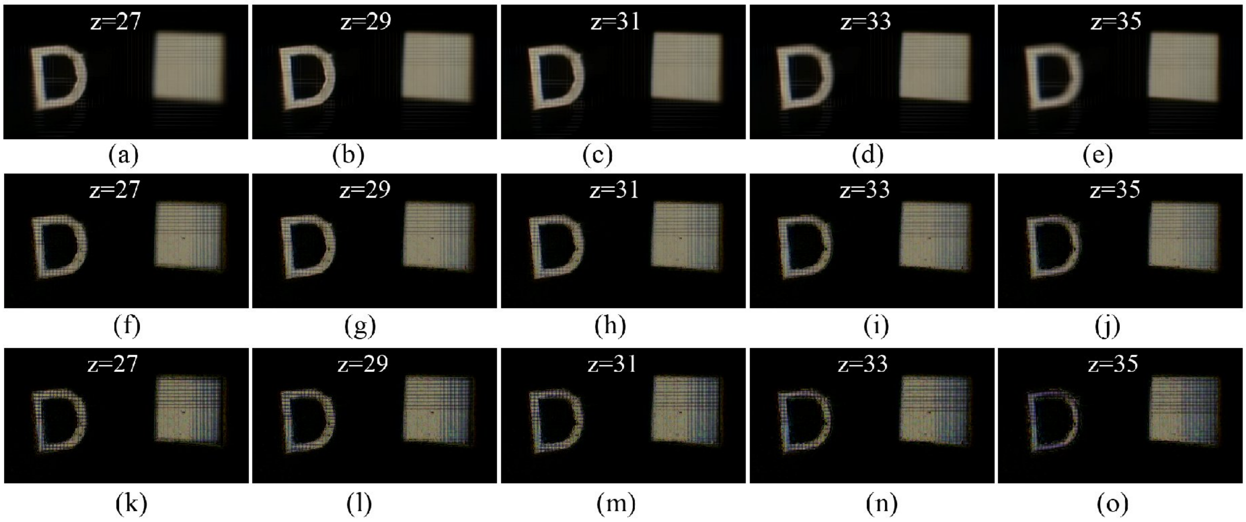

Fig. 5. Experimental result. Depth plane images reconstructed by the conventional CIIR (a)-(e), by the pixel weight method with WF=3 (f)-(j), and by the pixel weight method with WF=6 (k)-(o).

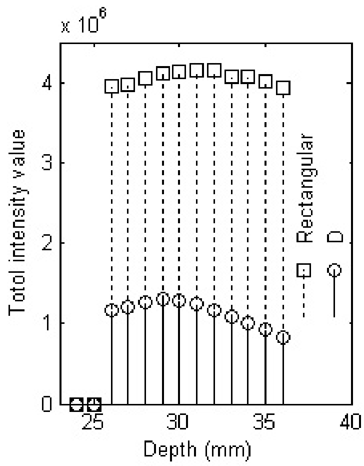

Fig. 6. Total intensity of each object in reconstructed depth plane image.

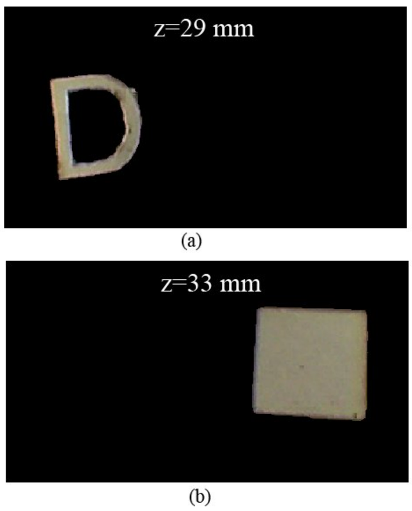

Fig.7. Experimental result of proposed method.

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