Computational integral imaging reconstruction of 3D object using a depth conversion technique

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Abstract

In this paper, a novel CII method using a depth conversion technique is proposed. The proposed method can move a far 3D object near lenslet array and reduce the computation cost dramatically. To show the usefulness of the proposed method, we carry out the preliminary experiment and its results are presented.

1. Introduction

Integral imaging is a promising technique for 3D imaging and visualization. It can record and reconstruct 3D objects with full parallax, continuous viewing points and the use of white light [1-6]. However, there are several problems to be solved such as low resolution, narrow viewing angle, and pseudoscopic image. In order to overcome the pseudoscopic problem which is reversed in depth, some techniques on depth conversion have been reported such as two-step integral photography [7], gradient-index lens array [8] and computer-generated integral imaging [9-11].

Recently, for 3D visualization and recognition using integral imaging, a concept of computational integral imaging (CII) has been proposed [12-14]. This CII is composed of the optical pickup process and the volumetric computational reconstruction (VCR). In optical pickup process, 3D object is recorded as the elemental image array (EIA) through a lenslet array. In the VCR process, the EIA is digitally reconstructed by using a computer in order to obtain volumetric 3D images. In CII, there are several problems to be solved such as a poor resolution of reconstructed image, high computation cost, reconstruction limitation of far 3D object and so on [13-15].

In this paper, to reduce high computation cost, we propose a CII method without optical device. In the proposed CII method, we apply a depth conversion technique to the conventional system. This function of depth conversion provides us with moving a far object near a lenslet array and then reducing the computation cost of reconstructed 3D image for far objects. To show the usefulness of the proposed method, we carry out the preliminary experiment.

2. Problem of VCR process in CII

The general CII system shown in Fig. 1 is composed of two processes. First process is the pickup process of 3D objects and second one is the VCR using elemental images. In the pickup process of CII, elemental images are recorded by use of a lenslet array and an image sensor. On the other hand, the VCR process provides full volume pixels information by reconstructing 3D images at any arbitrary distance from the lenslet array.

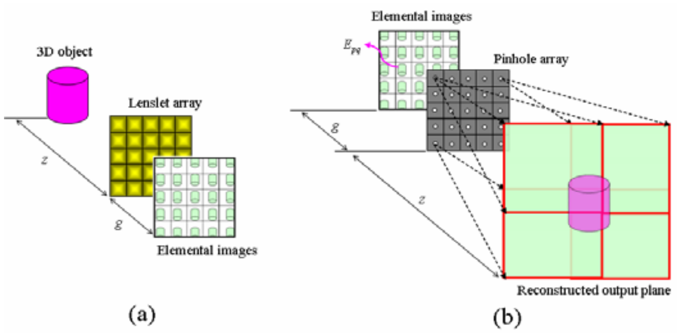

Fig. 1. The CII system. (a) Pickup process (b) VCR process.

The principle of VCR is well described in Ref. [12]. However, the conventional VCR suffers from the problem of higher computation cost as the distance between lenslet array and reconstructed output plane (ROP) increases. In other words, the computational time of VCR is mainly related to the magnification factor. An example of the computational times according to the distance is shown in Fig. 2. We see that the time increases proportional to the distance dramatically. Therefore, we can see that reducing the ROP distance of 3D object is a good solution of computation cost problem.

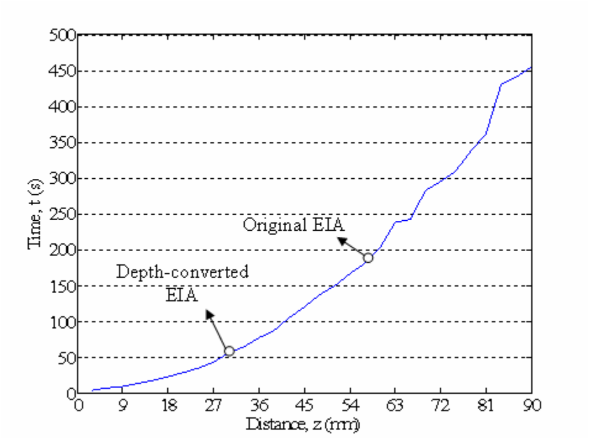

Fig. 2. Computational time of VCR process according to the distance *z*

3. Proposed CII method

To overcome the problem of the heavy computation cost in VCR, we propose a CII method using a depth conversion technique. Figure 3 shows the diagram of the proposed CII method. Compared with the conventional CII as shown in Fig. 1, our method uses a depth conversion technique additionally to obtain the depth-converted EIA. First, EIA of 3D objects are picked up through the pickup process. In order to generate a depth-converted EIA, a depth conversion technique is applied to the pickuped EIA. With the depth-converted EIA, a reconstruction output image (ROI) is calculated computationally by using the VCR process. Also the depth conversion technique can be performed computationally.

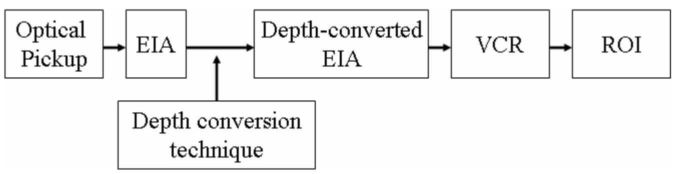

Fig. 3. Block diagram of the proposed CII method

For the depth conversion technique used in this paper, we can consider the previous computational methods [9-11]. In this paper, we use the SPM algorithm [9] in order to show the usefulness of the depth conversion effect. SPM is a computational pseudoscopic-to-orthoscopic (PO) conversion technique which able to produce undistorted real, orthoscopic integral images. The original EIA obtained in the optical pickup process is applied with SPM algorithm to form the depth-converted EIA.

Figure 4 shows the mapping process of SPM algorithm based on the computational model. We consider M elemental images which are composed of N pixels per each elemental image. Under the condition of M=2L/g and N=aM where a is a positive integer number, the SPM algorithm for one-dimensional case is formulated as

$$T_{i,j} = O_{k,l} \tag{1}$$

where

$$l = (M+1) - j$$

and

$$k = \begin{cases} i + M/2 - j & \text{if } M \text{ is even} \\ i + (M+1)/2 - j & \text{if } M \text{ is odd} \end{cases}.$$

Here, T and O are the depth-converted EIA and original EIA, respectively. The subscripts are corresponding to the cell number and the particular pixel number in the given elemental image cell. From Eq. (1), we can simply calculate the depth-converted EIA using only digital process. This process is not consumed in the respect of the computation cost because of the simple pixel exchanges.

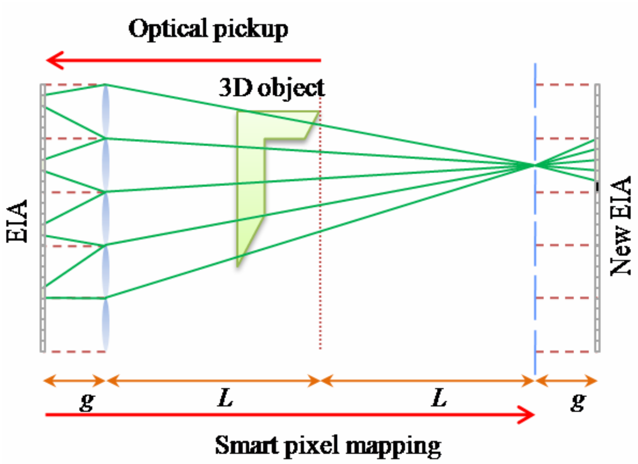

Fig. 4. Principle of SPM

Next, the depth-converted EIA is used to reconstruct 3D image using the VCR process as shown in Fig. 1(b). The reconstruction process of VCR can extract voxel information at coordinates (*x*, *y*, *z*) for 3-D object from the EIA.

4. Experiments and results

To show the usefulness of the proposed method, we carried out the preliminary experiments. Figure 5(a) shows an experimental setup for optical pickup. The '3D' character pattern is used as a 3D object and captured by using a capture device. The used optical lenslet array has 30 × 30 square lensets and each lenslet size is measured to be 1.08 mm. The focal length of the lenslet is measured to be g=3 mm. In the experiment the distance between the character pattern and the lenslet array was z=60 mm. The captured EIA was shown in Fig. 5(b). The size of each elemental image is 30 × 30 pixels. With this condition, we modeled the system structure for SPM where M=N and L=45 mm as shown in Fig. 4. Using this SPM structure, the captured EIA was mapped into the depth converted EIA. The resultant EIA having 900×900 pixels is shown in Fig. 5(c). It can be seen from Fig. 5 that our designed SPM model provides a function of depth conversion well.

Next, we reconstructed the computationally 3D object images at the distance of 30 and 60 mm by using the VCR process as given in Eqs. (2) and (3). The reconstructed images are shown in Fig. 6. Figure 6(a) and 6(b) are the images reconstructed using the original EIA and our depth-converted EIA, respectively. In case of using the original EIA, the clear images of 3D object was reconstructed at the distance of 60 mm where the 3D object was located originally. On the other hand, in case of using the depth-converted EIA in the proposed method the clear image was found at 30 mm. This shows that our method can move the ROP distance near lenslet array effectively. According to the result of Fig. 2, the computational time was approximately 187 sec when the original EIA was used, while our method spends approximately 54 sec to reconstruct the clear image. Therefore the proposed method can significantly reduce the computational time by approximately 3.5 times. Therefore, it is seen that the proposed method can be an effective solution to reduce the computation cost problem.

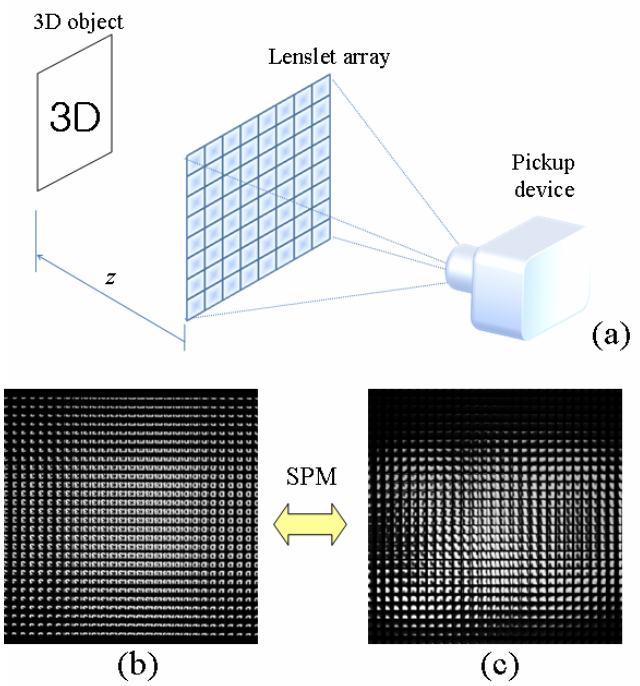

Fig. 5. (a) Optical pickup setup (b) Captured EIA (b) Depth-converted EIA using SPM

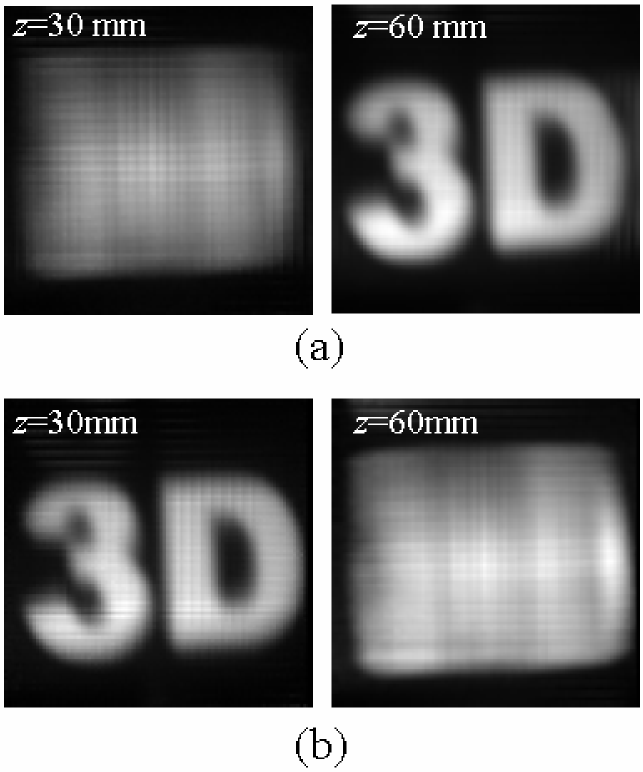

Fig. 6. Reconstructed images at the distances of 30 mm and 60 mm (a) Original EIA (b) Depth-converted EIA.

5. Conclusion

In conclusion, we proposed a novel CII to reduce the computation cost dramatically. We applied a computational depth conversion technique to the conventional CII method. This function of depth conversion provided us with moving a far object near a lenslet array and then reducing the computation cost of reconstructed 3D image for far objects. From the preliminary experiment we demonstrated our CII method effectively. Therefore the proposed method can be usefully applied to the 3D visualization and pattern recognition.

6. References

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