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A defocus-information-free autostereoscopic three-dimensional (3D) digital reconstruction method using direct extraction of disparity information (DEDI)

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Abstract: Autostereoscopy based three-dimensional (3D) digital reconstruction has been widely applied in the field of medical science, entertainment, design, industrial manufacture, precision measurement and many other areas. The 3D digital model of the target can be reconstructed based on the series of two-dimensional (2D) information acquired by the autostereoscopic system, which consists multiple lens and can provide information of the target from multiple angles. This paper presents a generalized and precise autostereoscopic three-dimensional (3D) digital reconstruction method based on Direct Extraction of Disparity Information (DEDI) which can be used to any transform autostereoscopic systems and provides accurate 3D reconstruction results through error elimination process based on statistical analysis. The feasibility of DEDI method has been successfully verified through a series of optical 3D digital reconstruction experiments on different autostereoscopic systems which is highly efficient to perform the direct full 3D digital model construction based on tomography-like operation upon every depth plane with the exclusion of the defocused information. With the absolute focused information processed by DEDI method, the 3D digital model of the target can be directly and precisely formed along the axial direction with the depth information.

OCIS codes: Autostereoscopy; 3D reconstruction; Disparity information; Statistical analysis;

1. Introduction

As an important subcategory of three-dimensional (3D) technology, autostereoscopy based 3D technology has been a hot research spot because of its unique strengths [1-6]. One of them is the function of digital reconstruction methods, which can provide digitized 3D information in the many application fields [3-6]. Many literatures focused on the methods of digital reconstruction or depth extraction have been reported [7-11]. Hong et al. [7] proposed a computational reconstruction method based on the magnification of elemental images and the superposition of them in the reconstructed image plane. However, the computation is very heavy and highly influenced by the periodic stripes. Shina and Yoo [8] proposed a novel method that focused on the visual quality improvement through a pixel-to-pixel mapping and an interpolation technique, but the method may cause lost of details or generate error due to the interpolation process. Similarly, Cho and Javidi [9] proposed a method based on Pixels of the Elemental Image Rearrangement Technique (PERT) which can evade from the heavy computation. Nonetheless, the fixed number of the total pixels brings the limitation to the resolution of reconstructed images. Chung et al. [10] also proposed a new method with sub-pixel resolution by using a genetic algorithm to achieve high axial resolution, but it suffers from the high costs of massive computation caused by genetic algorithm. Lee, et al. [11] described a computational depth extraction method using block matching for slice images in synthetic aperture integral imaging (SAII). However, this method is not compatible to all autostereoscopic systems.

Since the defocused information of every depth plane can jeopardize the process of 3D digital model reconstruction of the object scene by meddling into every slice images along the axial direction, there is a lack of methods that can provide a precise and complete digital 3D model of the entire object scene based on autostereoscopic system. In this paper, a direct extraction of disparity information (DEDI) method for 3D digital reconstruction is presented. The DEDI method is a generalized method built based on the autostereoscopy theory. It can be used to any transformed integral imaging system. The 3D information of the captured scene is digitally reconstructed without defocused information at different axial positions in the experimental studies which provide concrete basis for the tomography-like 3D model construction.

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2. DEDI method

An autostereoscopic system can be divided as recording and reconstruction process which are symmetrical. Micro lens array (MLA) based and camera array (CA) based systems are the two classic systems. Although the setups of the systems are different, the disparity information as the key parameter which supports the autostereoscopy theory remained the same. In the recording process, an object point is recorded as corresponding image points [12] through each elemental imaging system [13] as shown in Fig. 1(a). A universal expression of disparity information concerning certain depth location and through certain elemental lens can be expressed in Eq. 1:

$$\frac{\Delta D_R^{(n,0)}}{\Delta D_R^{(n,0)} + n \times D_{EI}} = \frac{g}{g+SD} \tag{1}$$

which $\Delta D_R^{(n,0)}$ denotes the disparity information between nth elemental lens and the central one (marked as 0th).

The depth information is the unique characteristic that can determine the pattern of corresponding points. Fig.1 (b) and Fig. 1(c) showed the standard mode and shift mode of corresponding image points pattern (CIPP) generated by the recording system. The standard mode depicts recording process of the object point that is located at certain position along the central axis of the MLA or CA. The CIPP can be quantitatively ensured according to Eq. 1 and the coordinate information of the elemental images. In the shift mode, since the disparity information of the same depth is identical according to Eq. 1, for the object points located in the same depth, their related corresponding image points in the elemental images are the same patterns with standard mode just has a certain overall movements as shown in the right image of Fig. 1(c). The CIPP is working like a filter. All the elemental image points are screened by different patterns based on their axial location. The image points after screening can form the image of the scene at the corresponding depth without any defocused information, which makes the CIPP to be the theoretical fundamentals of the DEDI method. The passed pixels can be viewed as potential corresponding points for further process.

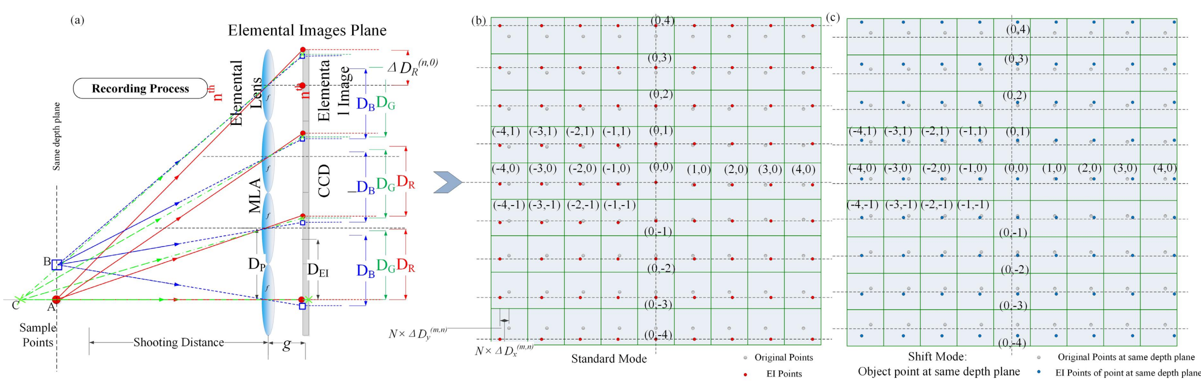


Fig. 1: Quantitative analysis of recording process and Corresponding image points pattern (CIPP).

However, CIPP is not the only property of the corresponding point. Although the definition of the corresponding points shows that the originality of every corresponding point is identical, the pixel value of these corresponding points can be various. The difference among corresponding points can lead to the defects or error of any component of the system. The illumination status and the specialty of the object scene can also be the reason to cause these differences. Accordingly, considering the uncertain difference of pixel value of these elemental image points which fulfill the CIPP, the proposed DEDI method makes use of statistical method to undertake the comprehensive evaluation of screening of the elemental image points in terms of pixel value. With the use of standard deviation, it can provide a precise judgment of the corresponding points. It can comprehensively analyze the distribution, even a singular value can only cause limited influence towards the corresponding point's judgment. Moreover, another proper statistical characteristic quantity also exists in the small neighborhood of pixels around these filtered image points. The gradient information of this selected continuous range represents the variation trend among certain pixels along with certain direction in the neighborhood, which remained the same although these filtered pixels have various values.v

By applying these criteria to ensure the corresponding points among filtered elemental image points, these finalized corresponding points of certain depth information can converge into a fine point on their related depth in the reconstruction space. In this sense, after the process of the proposed DEDI method, a series of 2D reconstructed images without the defocused information of its related depth can be established along the axial direction. These 2D images can be directly used to construct the digital model of the whole 3D scene. The flowchart of the DEDI method is shown in Fig. 2.

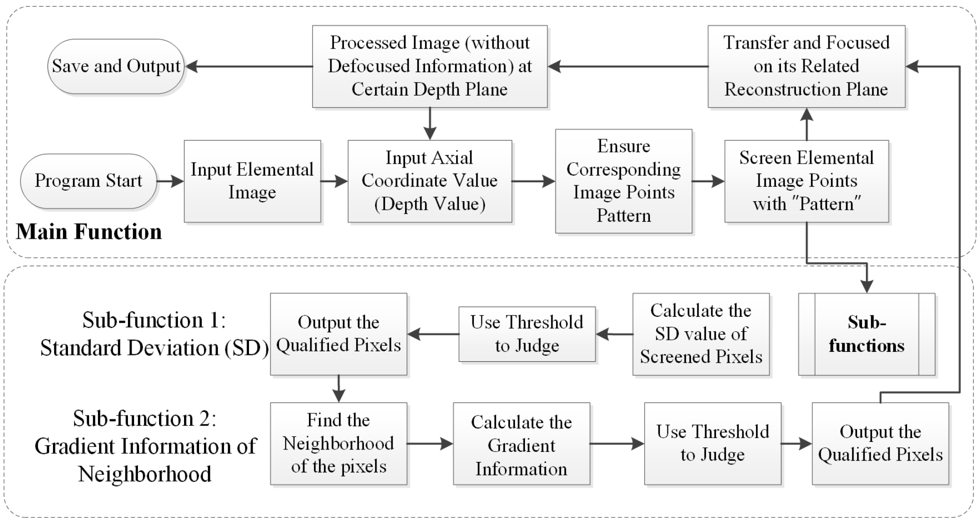
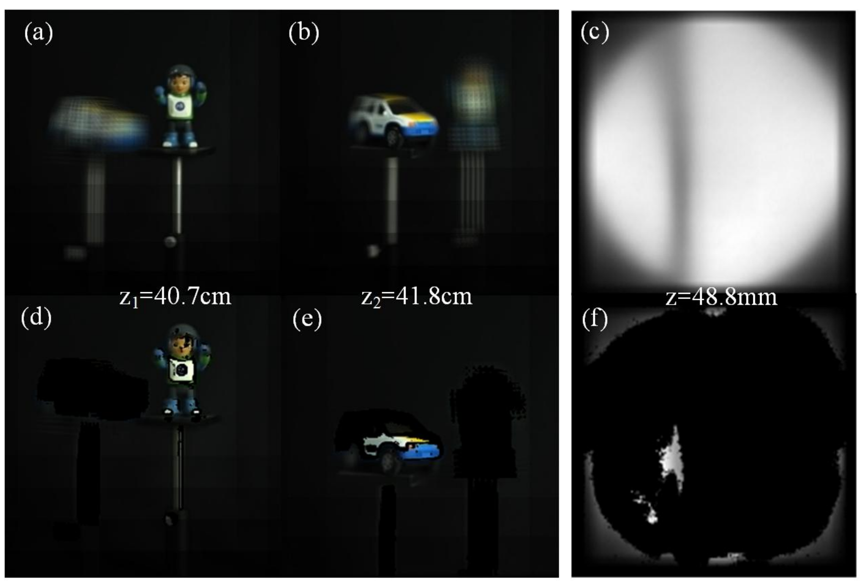


Fig. 2: Flowchart of DEDI method



CA-based system experiment results MLA-based system experiment results

Fig.3: Experimental results from different autostereoscopic systems. ((a), (b) and (c) are traditional depth extraction results which the defocused information is NOT excluded; while (d), (e) and (f) are results of DEDI method which the defocused information is excluded.

3. Experimental study

In order to verify the technical feasibility of the proposed DEDI method, multiple optical experiments were conducted in the present study. The results of DEDI method are compared with the results generated by traditional depth extraction methods in the same axial position as shown in Fig. 3. The results are acquired from different system setups which include MLA based and CA based system as shown in Fig. 4 while the specifications are shown in Table. 1. The defocused information has been precisely excluded.

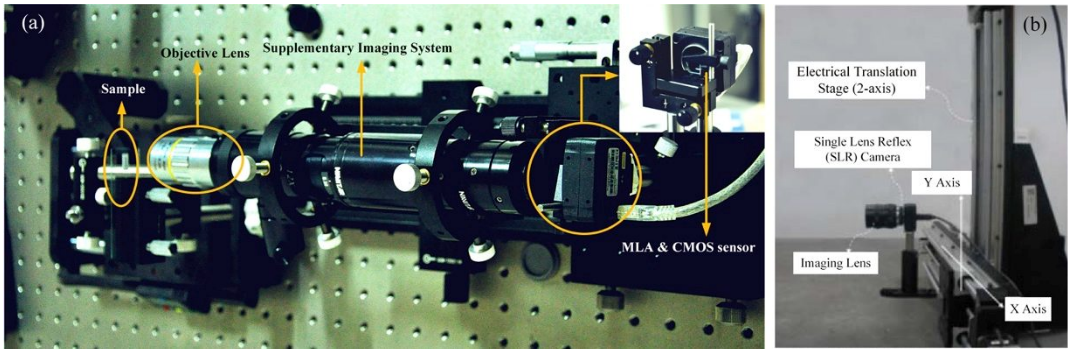


Fig.4. (a): Micro Lens Array based (MLA-based) and (b): Camera Array based (CA-based) Experimental system setups

Table. 1 Specification of the experimental system setups

Camera Array (CA) autostereoscopy system		Micro Lens Aray (MLA) autostereoscopy system	
Camera Scale	5×5	Lens Scale	20×20
Camera Pitch	100 mm	Lens Pitch	500 um
Shooting Distance	40 cm	Shooting Distance	4.2 mm
Sensor type	Nikon D3100 SLR camera	Sensor type	CMOS
		Sensor size	1/2 inch
		Pixel size	6.75 um

4. Conclusion and future work

On the whole, the proposed DEDI method is a promising 3D digital reconstruction method for autostereoscopic system which can be adaptable to different system setup. The experimental studies showed that the DEDI method can precisely reconstruct 3D digital information of the object scene without defocused information, which can be used for the 3D digital modeling process. The future research of the DEDI method will be focused on the adaptable criterion for corresponding points selection in different kinds of recording situation and object scene.

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