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Extended depth of field integral imaging using multi-focus fusion

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ABSTRACT

In this paper, we propose a new method for depth of field extension in integral imaging by realizing the image fusion method on the multi-focus elemental images. In the proposed method, a camera is translated on a 2D grid to take multi-focus elemental images by sweeping the focus plane across the scene. Simply applying an image fusion method on the elemental images holding rich parallax information does not work effectively because registration accuracy of images is the prerequisite for image fusion. To solve this problem an elemental image generalization method is proposed. The aim of this generalization process is to geometrically align the objects in all elemental images so that the correct regions of multi-focus elemental images can be exacted. The all-in focus elemental images are then generated by fusing the generalized elemental images using the block based fusion method. The experimental results demonstrate that the depth of field of synthetic aperture integral imaging system has been extended by realizing the generation method combined with the image fusion on multi-focus elemental images in synthetic aperture integral imaging system.

1. Introduction

Integral imaging (II) has been known as one of the most promising three-dimensional (3D) display techniques, in which it can provides full parallax, continuous viewing points, and color images [1–7]. Generally, the conventional II system consists of two processes: pickup and reconstruction. In the pickup process, rays emanating from 3D object are captured through a lens array and recorded as a set of 2D elemental images (EIs) by an image sensor. In the reconstruction process, the recorded 2D EIs are reconstructed by using the display panel and lens array [3–6]. However, the conventional II has the limitations of low resolution, narrow viewing angle and shallow depth range due to the small pitch of micro lenses.

One of the major drawbacks of the conventional II system is the limited depth of field (DoF) which draws a lot of attentions. Recently, several 3D imaging techniques based on multiple perspectives are proposed to solve this problem [8–17]. Among them, synthetic aperture integral imaging (SAII) was proposed to capture high resolution elemental images from a 3D scene by translating a camera on a 2D grid [8–13]. Although the DoF of the SAII system is extended, the DoF is still limited by the lens of the camera. Because a lens is capable of precisely focusing objects of a single distance, some objects will be precisely focused while others in a scene will be out of focus and even blurred. This might result in loss of sharpness and fine details due to the limited DoF of the camera. W.T. Welford proposed an annular aperture method to increase the focal depth of II [14]. Also, Martínez-Corral et al. proposed an amplitude-modulating method to extend the DoF of II by placing an opaque circular mask behind the microlens array (MLA) [15]. In [16], a time-multiplexed II method was presented, in which an array of lenses with different focal lengths and aperture sizes are used to extend the DoF. Although those methods effectively extend the DoF of the II system, those devices are expensive to fabricate in terms of cost. Hector Navarro et al. proposed a computational method to extend the depth of field of SAII [17]. The method is based in the combination of deconvolution tools and stereo vision algorithms. However, the deconvolution process may produce significant image distortion and ringing effect.

In this paper, we present a new method to extend the DoF of the SAII system where multi-focus EIs are captured from different perspectives. Image fusion achieves DoF extension of 2D images, where information of two or more images of a scene are combined to synthesize an image with better focus across the scene, also called an all-in focus image [18]. Image fusion methods fit the situation where all images are captured from the same perspective. Simply applying the image fusion method to the EIs in the SAII system might not allow to generate images with better focus across the 3D scene because all the EIs in the SAII

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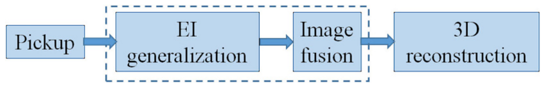

Fig. 1. Block diagram of the proposed method.

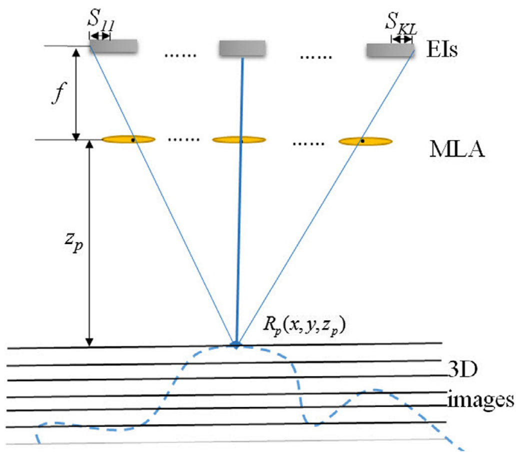

Fig. 2. Schematic diagram of depth estimation.

system hold rich information such as different color, intensity, positions and directions of a 3D scene such that those EIs lack of registration accuracies. Generally image fusion assumes that the objects in all images are perfectly geometrically aligned. All-in focus EIs where objects of interest lying inside of the DoF of the camera are crucial to produce the reconstructed images with the extended DoF in the SAII system. With such a process to obtain the desired EIs, an EI generalization method is proposed combined with the image fusion method to extend the DoF of the SAII system. This EI generalization method uses the depth information extracted from the multi-focus EIs to register the target object in the EI. The aim of this generalization process is to geometrically align the objects in all EIs so that the correct regions of multi-focus EIs can be exacted, meanwhile, misjudgments of both edges and smooth regions can be avoided. The all-in focus EIs are then produced by fusing the generalized EIs using the block based fusion method. This enables us to obtain the reconstructed images with the extended DoF in the SAII system. The experimental results demonstrate that the DoF of the SAII system has been extended by realizing the generation method combined with the image fusion on multi-focus EIs.

This paper is organized as follows: Section 2 describes the proposed method which includes EI generalization and image fusion; Section 3 analyzes the DoF of the proposed method; Section 4 and Section 5 show the experimental results and conclusions, respectively.

2. Proposed method

Fig. 1 depicts the block diagram of the proposed method, which is basically composed of four process: (1) pickup of the multi-focus EIs, where the EIs are taken from different perspectives at different focal lengths, (2) generalization of the multi-focus EIs, where the depth information extracted from the multi-focus EIs is used to register the target object in EIs, (3) fusion of the generalized EIs, where the all-in focus EIs are generated, and (4) reconstruction of the all-in focus EIs, where the reconstructed images with the extended DoF can be produced in the proposed system.

2.1. EI generalization

In the first step, suppose I_{kl} denotes the EI located on the kth row and the lth column of $K \times L$ EIs. Assume that a reconstructed object

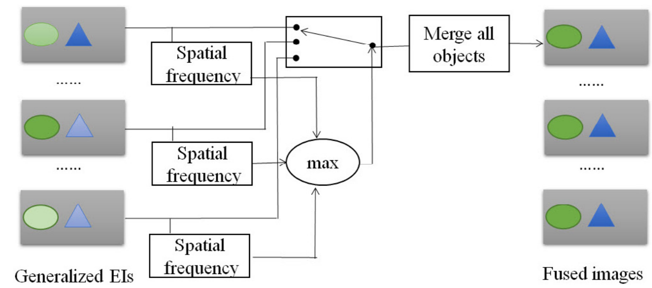

Fig. 3. Schematic diagram of the image fusion method.

point R_p located at distance z_p is calculated by Eq. (1)

$$R_p(x, y, z_p) = \frac{1}{K \times L} \sum_{k=1}^{K} \sum_{l=1}^{L} I_{kl}(x - S_k(z_p), y - S_l(z_p)) \tag{1}$$

where x and y denote the indices of the pixels in the horizontal and vertical directions, shifting parameters S_k and S_l are given by

$$S_k(z_p) = \frac{g \times c \times (k - K/2)}{\delta \times z_p}, \quad S_l(z_p) = \frac{g \times c \times (l - L/2)}{\delta \times z_p} \tag{2}$$

where δ is the pixel size, g is the gap between the imaging lens and EIs, and c is the pitch of the imaging lens. For a given reconstruction distance z_p as shown in Fig. 2, The corresponding object points p_{kl} on the EIs are projected at a reconstructed point R_p. Therefore, the depth map z_{map} can be obtained by calculating the depth for all reconstructed points as given below

$$z_{map} = find\left(\underset{z_p}{\text{argmin}} \sqrt{\sum_{l=1}^{L} \sum_{k=1}^{K} (p_{kl} - \bar{p})^2}\right) \tag{3}$$

where $\bar{p}$ is the average of the object point p_{kl}. Then, the objects in each EIs are geometrically aligned. Then, the process of elemental image fusion can be implemented.

2.2. Elemental image fusion

In the final step, the generalized EIs can be fused using the block based fusion method to obtain all-in focus EIs. The image fusion is the process of combining two or more images into a single image with better focus across the 3D scene. Here, the spatial frequency (SF), which measures the clarity of an image, is used to our image fusion method. The process of image fusion is as shown in Fig. 3.

Assume that the generalized EI is divided into n regions, each of which consists of $X \times Y$ pixels. Thus, spatial frequency SF_{kl}^n for the nth region of the generalized image IR_{kl} is defined as:

$$SF_{kl}^n = \sqrt{(RF_{kl}^n)^2 + (CF_{kl}^n)^2 + (DF_{kl}^n)^2} \tag{4}$$

where row frequency RF_{kl}^n, column frequency CF_{kl}^n and diagonal frequency DF_{kl}^n are calculated as:

$$RF_{kl}^n = \sqrt{\frac{1}{X \times Y} \sum_{x=0}^{X-1} \sum_{y=1}^{Y-1} [IR_{kl}^n(x, y) - IR_{kl}^n(x, y-1)]^2}$$
$$CF_{kl}^n = \sqrt{\frac{1}{X \times Y} \sum_{y=0}^{Y-1} \sum_{x=1}^{X-1} [IR_{kl}^n(x, y) - IR_{kl}^n(x-1, y)]^2} \tag{5}$$
$$DF_{kl}^n = \sqrt{\frac{1}{X \times Y} \sum_{y=0}^{Y-1} \sum_{x=1}^{X-1} [IR_{kl}^n(x, y) - IR_{kl}^n(x-1, y-1)]^2}.$$

The focused region can be computed by maximizing SF_{kl}^n

$$IF^n = IR_{uv}^n, \quad where\ [u, v] = find[\max(SF_{11}^n, SF_{12}^n, \ldots, SF_{KL}^n)]. \tag{6}$$