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Elemental image array generation based on object front reference point of optical axis of camera array for integral imaging

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ABSTRACT

We propose a general and simple elemental image array (EIA) generation method for orthoscopic integral imaging (INI) in which perspective images (PIs) are captured with the optical axis of cameras crossed on a reference point ahead of the object. This method is generally applicable to display systems with different parameters. The number of the PIs equals to that of elemental lens, so it is very effective for such a system in which elemental lenses are less than the pixels of each elemental image (EI). And each EIA can be generated with corresponding PI rotated 180°, instead of intercepting and mapping those pixels. We did experiments to prove the feasibility of the method.

1. Introduction

Integral imaging (or integral photography) is a technique proposed by Lippmann in 1908 for three-dimensional (3D) imaging and visualization [1–9], in which people can observe dynamic 3D image by recording and reproducing system without wearing assistant devices. Typical integral imaging (INI) includes two processes: recording and reproducing [2,9]. The perspective images (PIs) of typical INI are captured by lens array or camera array with parallel optical axis at equal intervals in a plane, the 3D parallax information of the object is recorded in the form of two-dimensional (2D) images [4,9–13]. Based on the reversibility of optical path, the elemental image array (EIA) generated with PIs with parallax information is displayed on the screen, the light beams emitted by pixels of the elemental images (EIs) pass through the micro lens array (MLA) restoring the optical path of the object [11–13], so that observers can see reproduced images with different parallax information from different perspectives and the 3D object is reproduced.

In the typical INI system, of which the optical axis of camera array are parallel, the pseudoscopic problem of depth information reversal occurs [5–8,14]. The two-step recording method of INI can reproduce orthoscopic image [6–8], but some partial edge parallax information is lost in the second recording process. The pixel mapping methods can solve the pseudoscopic problem [14,15] and those based on the interweaving process [5,11–13] improve the viewing angle of the system, such as the multi-view display method (MVD) [5]. However, in the synthesizing EIA process, each EI is mapped with several PIs that have to be intercepted, reducing the utilization of parallax information. Several methods of backward ray-tracing [4,16,17] were reported, in which the problem of depth inversion is solved by tracking and calculating the light path of the object for each pixel in the EIA, this digital method is equivalent to capturing PIs from the direction of observes, but these methods are limited to record virtual objects. A real-time display method [17] with optical axis of camera-projector array crossed on the object was proposed. However the reproduced object may be distorted when the light paths are reconstructed to reproduce the object near the display system with high utilization rate of the EIA.The light field camera methods are very effective for INI system [11,16–18], but the parameters of its camera array are mostly fixed, and that is not applicable with all the systems.When we did experiments of typical INI system trying to overcome the

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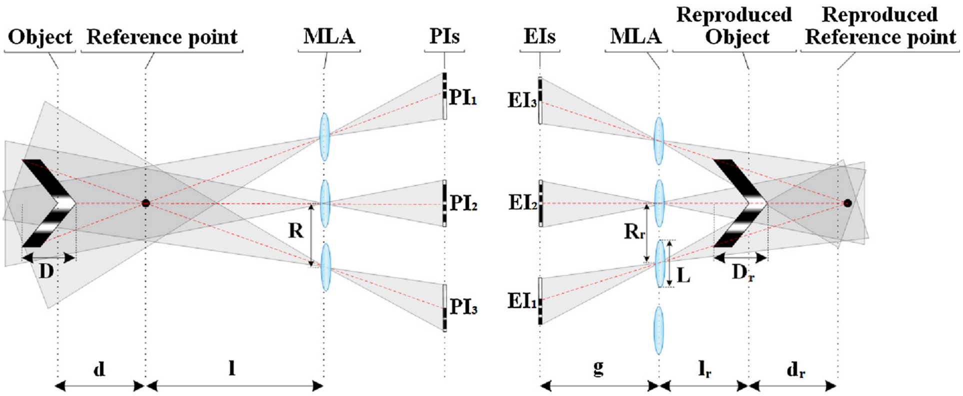

Fig. 1. The principle and geometric relationship of light path in the proposed method for INI.

pseudoscopic problem with a quite simple way, we found that the way we reproduce an orthoscopic image is to capture the object with depth reversal, it is like adding the negative a minus to become a positive. On one hand, we tried to find an "adding a minus" way to reproduce the image of orthoscopic object, on the other hand, we were thinking about whether we can directly generate the EIA with each whole PI for orthoscopic INI display.

In this paper, we propose an EIA generation method for orthoscopic INI display, in which the parallax information is captured with the optical axis of cameras crossed on a reference point ahead of the object. Based on the reversibility of optical path, we trace the light and map each whole PI onto the EIA. This is an improvement on the typical method, in which the number of PIs is equal to number of lenses of MLA. Each PI is mapped to the position of the corresponding EI and the EIA can be generated. By setting the reference point, the method is easy to apply to systems with different parameters. The EIA generation not only improves the operation efficiency, but also improve the utilization rate of the PIs, and it is very effective when elemental lens are less than the pixels of each EI. First, in Section 2, we explain the principle of our proposed method that contains two processes of capturing the PIs and generating the EIA. In Section 3, we do experiment to record the PIs of object with a virtual camera array, and apply the proposed method to generate the EIA which is displayed on the INI system. Finally in Section 4, we summarize the main achievements of our method research.

2. Principle

In the proposed method, the intensity and direction information of the light beam emitted by the object are recorded and we reconstruct the object image with the same intensity and direction of light beams. The PIs are used to reconstruct the light beam, in which the geometric relationship of the optical paths in the recording process and the reproducing process are the same, as shown in Fig. 1. Reproducing is the inverse process of recording, that is, the optical path of the reproducing process need to be the same as that of the capturing process. We need to preset the size and position of the reproduced object according to the actual INI display system, and preset the camera reference point according to the parameters of the system and reproduced object, so that the optical path of the light beam emitted by the recorded object can be determined and the parameters of the camera array can be calculated. Then tracking the path of light beams from each perspective point to the object, we can map the PIs onto the EIA.

The ratio of the reproduced object depends on the geometric parameters in recording and reproducing process. The optical axis of the camera array cross on a reference point, the position of which is related to the parameters of the INI display system and the maximum capturing angle we can observe. In the INI display process, the relative position between each EI and lens depends on the geometric relationship of the light emitted by the object during recording process. Usually, we pre-set the center of the object on the central depth plane of the system. Because the light beam emitted by the pixels on the screen through the MLA cross onto the points, the plane containing those points is called the center depth plane [19] of the INI display system, on which highest resolution images can be displayed. Our proposed EIA generation method for INI system has two processes: capturing the PIs and generating the EIA.

2.1. Capturing the PIs

For an INI display system, if observers see the reproduced object which is very close to the MLA with an excessive perspective angle, the light beam emitted by EIs may pass through the non-corresponding lenses (or adjacent lenses) distorting the reproduced image. So if the PIs that are captured to the object directly generate the EIA and as many EIs as possible provide the parallax information, the reproduced image will be disturbed by interference object images based on the geometry of the light beam emitted. As shown in Fig. 2, the camera array and the viewing area are on the same side of the object, the INI display system on the other side, and we display the light paths of the process of recording and displaying in this figure. The object which is close to the display system, is reproduced by methods of capturing PIs directly to the object shown as (a) and the reference point shown as (b). The light emitted by EIs reconstructs the typical emitting state of the object, in which the intensity and direction of the light beams are the same as those of the light beams recorded. We can easily observe the difference between two groups of light paths. By setting the reference