3D augmented reality with integral imaging display

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ABSTRACT

In this paper, a three-dimensional (3D) integral imaging display for augmented reality is presented. By implementing the pseudoscopic-to-orthoscopic conversion method, elemental image arrays with different capturing parameters can be transferred into the identical format for 3D display. With the proposed merging algorithm, a new set of elemental images for augmented reality display is generated. The newly generated elemental images contain both the virtual objects and real world scene with desired depth information and transparency parameters. The experimental results indicate the feasibility of the proposed 3D augmented reality with integral imaging.

Keywords: 3D display, augmented reality, pseudoscopic-to-orthoscopic conversion

1. INTRODUCTION

As an autostereoscopic three-dimensional (3D) imaging technique, the concept of integral imaging (InIm) [1]-[3] is to use a two-dimensional (2D) sensor behind a lenslet array to capture light rays eliminated or reflected from the 3D space. Light rays from the surface of the 3D scene passing through each lenslet, and can be recorded by a 2D image sensor. The captured 2D image array is named as an elemental image array, which contains both the intensity and directional information of the 3D scene. For InIm optical display, light from the display device passes through the identical lenslet array used in the capture process, and converges in the image space to form the 3D images. InIm has been widely researched by various groups for its advantages such as continuous viewpoints, virtual and real 3D display, both horizontal and vertical parallaxes and etc [4]-[6].

Augmented reality [7] [8] is a novel interactive technique for superimposing the virtual information into a real world scene. Information from the virtual objects and the real world can be combined to enhance observer's perception of the reality. This technology has applications in various fields such as medical, entertainment and manufacturing, etc [9]-[11]. Recently some studies have been done for the combination of augmented reality and 3D InIm [12]-[14].

In this paper, we present a 3D augmented reality display with InIm. Methods to generate elemental images are discussed for format matching [15] 3D display. By using the smart pseudoscopic-to-orthoscopic (SPOC) conversion [16] method, elemental images with various capture conditions are converted to a unified format which matches with the display system. A merging method between the elemental images of the real and virtual objects is presented. For the case that the overlap exists between the real world scene and the virtual objects, the corresponding elemental images can be superimposed with partial transparency. The pixel information in the overlapped areas will be kept for both of the front and rear objects.

2. GENERATION OF ELEMENTAL IMAGE ARRAY FOR AUGMENTED REALITY 3D DISPLAY

The capture and reconstruction processes of a conventional InIm system require the lenslet array with identical parameters. The smart pseudoscopic-to-orthoscopic conversion (SPOC) method has been proposed to convert a depth reversed 3D image to orthoscopic 3D image. This method can be used for format matching 3D display between different

capture and display devices. For the algorithm of SPOC, by setting an imaging reference plane and a virtual pinhole array, SPOC will computationally generate a new elemental image array on the synthetic capture plane from the captured elemental images. Figure 1. shows the concept of the SPOC method. The parameters designed for the virtual pinhole array and the reference plane (the pitch of the pinhole, the distance between the pinhole and the reference plane), are determined by the specifications of the display device, such as the pixel size, focal length and the resolution, etc. Recently, SPOC has been further developed and applied for tunable field of view display, improvement the display resolution, and head tracking 3D display [17]-[19] etc.

Figure 1. Diagram of the smart pseudoscopic-to-orthoscopic conversion method (SPOC).

To implement augmented reality in a 3D display, the computationally generated virtual objects need to be combined with the real world scene. The depth information of the 3D scene is extracted [6] through the captured elemental images. We can design the relative position between the virtual objects with the real world. By setting a threshold for the decided depth, the virtual objects can be abstracted from the original elemental images and superimposed with the real world scene.

To further explain the proposed algorithm, suppose we have two sets of elemental images. One set is captured from the real world, the other is the set of computationally generated elemental images which record the virtual information. To combine the real world scene and the computed virtual objects, image processing is further conducted by pixel mapping the corresponding pixel information into a new elemental image array. If overlap exists between the virtual objects and the real world scene, the pixels in the overlapped area will be mapped by the front virtual object, so that the information of the real world scene will be lost. To keep both of the real and virtual objects in the overlapped area, one possible solution is by setting the corresponding pixels of the front virtual objects with half transparency. In this case, both information of the front and rear objects can be recorded in the new elemental image array for augmented reality 3D display.

3. EXPERIMENTAL RESULTS

We conducted optical 3D display experiments. As shown in Fig. 2, a real world scene (soccer) and computationally generated objects (letters '3' and 'D') were captured separately with different pickup specifications by the synthetic aperture integral imaging (SAII) method [20] and 3dsMas, respectively. The specifications of the capture process for the real world scene and the virtual objects are shown in Table 1.

A Canon 5D camera was used to capture the real world scene. A total of 49 (7×7) elemental images were obtained to form the elemental image array. In the display process, a HTC-One smart phone and a microlens array were used as a display system. The resolution of the display screen is $1920 (H) \times 1080 (V)$ pixels, and each pixel owns a pixel size of $\sim 53\mu\text{m}$. The focal length of the lenslet array is 3.3 mm and the pitch of the lenslet is 1mm. Each lenslet will cover about 20×20 pixels. As the parameters of the real captured elemental image array do not match with the display system, we first processed the captured elemental images to generate a new elemental image array matching with the display system.

This process is performed by using the SPOC method. For virtual objects, it is easy to control the computer software (3dsMax) to generate elemental images to match with the display format.

In the pickup process, the soccer was placed at 300 mm in front of the camera, with the SPOC method, the distance (d_2) between the reference plane and the virtual pinhole array plane was set as 20 mm. The new generated elemental image array records the soccer with a distance of 20 mm from the display plane. For augmented reality, the real world scene and the virtual objects need to be merged as a synthetic scene. We set the soccer, the letters ‘3’, and letter ‘D’ at 20 mm, 40 mm and 60 mm from the display plane, respectively. The virtual objects are set in front of the real world scene for 3D display.

Figure 2. (a) Real world scene with a soccer and (b) computationally generated virtual objects, letters ‘3’ and ‘D’.

Table 1. Specifications of integral imaging capture process for the real world scene and virtual objects

Description	Real world scene	Virtual objects
Total number of elemental images (EIs)	7 (H) × 7 (V)	104 (H) × 58 (V)
Resolution of each EI	5616 (H) × 3744 (V) pixels	20 (H) × 20 (V) pixels
Sensor pitch	10 mm (H) × 10 mm (V)	1 mm (H) × 1 mm (V)
Size of objects	Soccer ball: 12.5 mm (radius)	‘3’: 25 mm × 30 mm ‘D’: 36 mm × 30 mm
Distance between pickup plane and objects	300 mm	‘3’: 40 mm ‘D’: 60 mm

Figure 3. 3D integral imaging augmented reality display results. (a) Left view and right view with occlusion. (b) Left view and right view partial transparency.

Figure. 3(a) shows the left and right perspectives of the augmented reality 3D display results by using elemental image array with direct pixel mapping. The soccer is partially occluded by the virtual objects. With the partial transparency elemental image array, the rear occluded information is kept in the overlapped areas, as shown in Fig. 3(b). The proposed method has the potential to be applied to the see-through augmented reality 3D display.

4. CONCLUSIONS

A three-dimensional (3D) augmented reality integral imaging display is presented by combining conventional 3D display and an augmented reality technique. With the smart pseudoscopic-to-orthoscopic conversion (SPOC) method, elemental image array of the captured real world scene is firstly converted into a new format for 3D display. Then by combining the elemental image arrays of the real world scene and the computationally generated virtual objects, a new elemental image array is generated for augmented reality 3D display. For the case that the overlap exists, elemental images can be merged with partial transparency to keep the information of both front and rear objects. 3D display experiments were conducted to validate the feasibility of the proposed method.

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