PROCEEDINGS OF SPIE

Three-Dimensional Imaging, Visualization, and Display 2010 and Display Technologies and Applications for Defense, Security, and Avionics IV

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6–8 April 2010
Orlando, Florida, United States

SPIE Defense, Security+Sensing

Volume 7690

SPIE

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Optical slicing of large scenes by synthetic aperture integral imaging

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ABSTRACT

Integral imaging (InI) technology was created with the aim of providing the binocular observers of monitors, or matrix display devices, with auto-stereoscopic images of 3D scenes. However, along the last few years the inventiveness of researches has allowed to find many other interesting applications of integral imaging. Examples of this are the application of InI in object recognition, the mapping of 3D polarization distributions, or the elimination of occluding signals. One of the most interesting applications of integral imaging is the production of views focused at different depths of the 3D scene. This application is the natural result of the ability of InI to create focal stacks from a single input image. In this contribution we present new algorithm for this optical slicing application, and show that it is possible the 3D reconstruction with improved lateral resolution.

Key words: Integral imaging, 3D imaging display, optical processing

1. INTRODUCTION

Integral imaging (InI) is a 3D display and visualization technique well suited to provide with 3D images to audiences of more than one person. An InI procedure consists of two stages: capture and display. The capture of the 3D scene is usually done by inserting a microlenses array (MLA) in front of the objective of a digital camera. The system is arranged so that the MLA produces a collection of 2D aerial micro-images (usually named as elemental images) of the 3D scene. Any elemental image stores information of a different perspective of the 3D scene, so that the 3D info is codified in the collection of 2D elemental images. Finally the camera objective images the elemental images onto the matrix sensor (typically a CCD or a CMOS) and therefore the collection of elemental images (also named as the integral image) are recorded. Naturally, the resolution and depth of field with which the integral image is recorded depends on many factors like the number of microlenses, the number of pixels, or the *f*-number of the objective [1]. Take into account, however, that a big amount of pixels is not recommendable because this increments severely the data extent.

Naturally, the use of a MLA is not the only form of collecting the elemental images. There are a number of other possibilities to pick up perspective images and/or to use a computer to create the integral images corresponding to the 3D scene (see for example [2]-[4]). In case of large 3D scenes, it may be preferable to use an array of digital cameras [2]. When the acquisition speed is not an issue, it is possible to use only one camera that is mechanically translated following a path [3].

In the optical reconstruction stage, the recorded images are displayed by a matrix display device, such as a LCD or OLED monitor, placed in front of another MLA. Another possibility is the use of a digital projector to project the elemental images onto a diffuser placed in front of the MLA [5]. The ray-cones emitted by the pixels of the matrix display follow the say path as in the pickup; therefore, they intersect with high density in the same positions as the original pixels of the 3D scene. This 3D imaging system is said to be auto stereoscopic, because the observer can perceive the 3D

Three-Dimensional Imaging, Visualization, and Display 2010 and Display Technologies and Applications for Defense, Security, and Avionics IV, edited by Bahram Javidi, Jung-Young Son, John Tudor Thomas, Daniel D. Desjardins, Proc. of SPIE Vol. 7690, 76900M · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.852157

scene without the help of any additional viewing device, such as special glasses. Advantages of InI over other auto stereoscopic techniques are the fact that InI offers not only horizontal, but also vertical parallax, and that the parallax is almost continuous over the viewing angle.

InI principles were first proposed by Lippmann [6] under the name of integral photography, and some relevant work was done in the meantime [7]-[11]. However, the interest in InI was lethargic due to the limited applications achievable with the technology available by that time. The interest in InI was resurrected about one decade ago for its application to 3D TV and display [12].

Since its rebirth, InI has overcome many of its challenges. It is remarkable, for example, that some smart techniques for the pseudoscopic to orthoscopic conversion were developed [13]-[15]. Some methods were proposed to overcome the limits in lateral resolution imposed by the pixelated structure of the CCD [16]-[18], or by the microlens array [19], [20]. Another challenge faced is the enhancement of the depth of field (DOF) [21], [22] of elemental images obtained in the pickup stage. Other approaches to multi view display have been reviewed in [23]-[26].

In this contribution we exploit the natural ability of InI to create focal stacks from a single input image, to present a new algorithm for this optical slicing application, and show that it is possible the 3D reconstruction with improved lateral resolution.

2. TOPOGRAPHIC RECONSTRUCTION

In Lipmann scheme, a picture of a self-luminous 3D scene is obtained setting the film in the neighborhood of the back focal plane of a microlens array. This pickup setup provides with a set of elemental images, each having information of a different perspective of the object. In the display stage, the properly processed film is placed in front of another microlenses array, and back illuminated so that each elemental image acts as a spatially incoherent object. Such setup allows the reconstruction of a real, but depth-reversed image of the 3D scene. The major drawback of the scheme proposed by Lipmann is the poor light efficiency, the second problem is that the film processing inherent to a photographic process is very slow and does not match the current requirements of 3D imaging. A solution of these problems is to substitute the pinhole array by a microlens array and the photographic film by an electronic matrix sensor. As shown in Fig. 1, the elemental images are formed in the image plane of the microlenses. However, now an important problem appears: the limitation in DOF. Due to the imaging properties of the lenses, now only one plane of the object space is in focus. Then light proceeding from other planes does not focus onto the CCD. The same problem happens in the display stage. Only points within the object plane are reconstructed sharply. Other parts of the 3D scene are increasingly blurred. Besides, this blurring effect is more significant when the pixilation of the CCD (or the LCD in the display stage) is taken into account. Consequently, this realization of the integral imaging process gives rise to much more luminous reconstructed images, but with low resolution even in case of the in-focus plane.

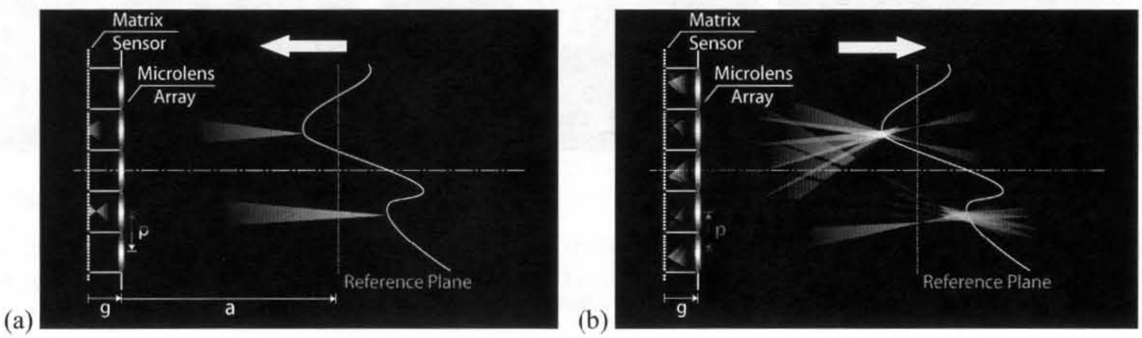

Figure 1.- Scheme of an integral imaging system: (a) the pickup; (b) The display

Apart from 3D display purposes, InI technology has demonstrated to be well adapted for the topographical reconstruction, slice by slice, of 3D colored, macroscopic, far scenes. The application of the back-projection technique described in [27], is used to reconstruct the scene at different depths. Specifically, each elemental image is back-projected computationally on the desired reconstruction plane through its unique associated pinhole. The collection of all the back projected elemental images are then superimposed computationally to achieve the intensity distribution on the reconstruction plane.

In practice the algorithm is implemented as illustrated in Fig. 2. First one has to select the size and number of pixels of reconstructed sections. Although this selection strongly depends on the application, one good selection could be to fix the size of the section equal to the lens array size, and the number of pixels equal to that of the integral image. Then, for each reconstruction plane, the intensity value at any pixel is obtained by summing up the values of the pixels from the elemental images that are impacted by the straight line defined by the pixel from the reconstruction plane, and the center of the corresponding microlens. Naturally, this process has to take into account the optical barriers between elemental images.

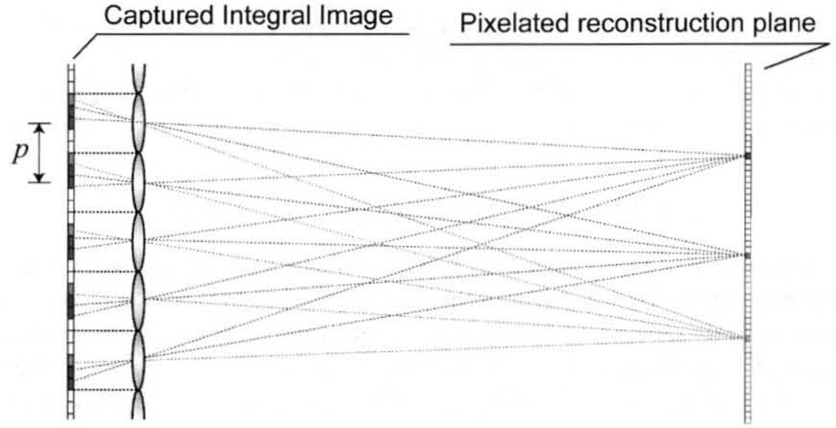

Figure 2.- Scheme for illustration of the reconstruction algorithm.

What is new in our method is the fact that the resolution of reconstructed images can be much higher than the resolution of any elemental image. As illustrated in Fig. 3, the adequate interlacing of many low resolution elemental images can produce high-resolution reconstructions.

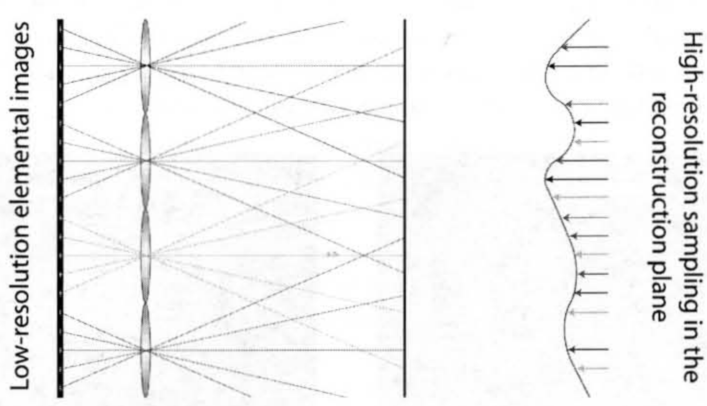

Figure 3.- Illustration of the improved resolution of reconstructed sections.

3. EXPERIMENTAL RESULTS

To show the utility of the method we have performed the following InI experiment. On the optical table we prepared, over a black background, a 3D scene composed by an optometrist doll, and a resolution chart. The transverse dimension of the scene was of about 20 cm, while the axial depth was of about 20 cm (see Fig. 4).

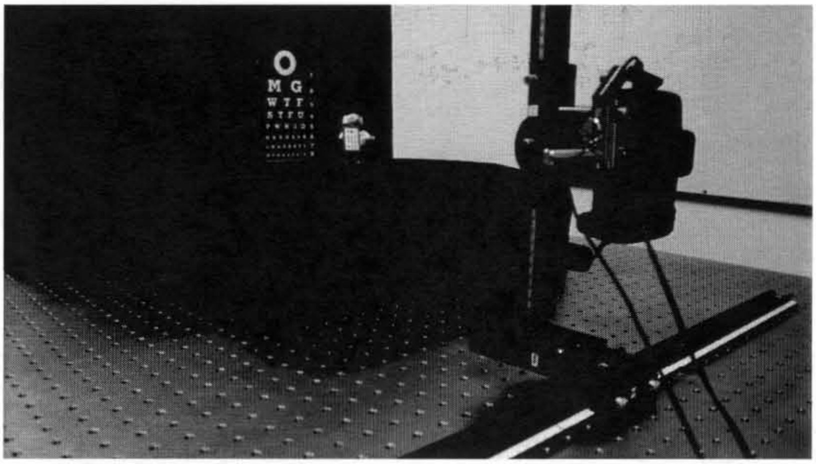

Figure 4.- Scheme of the experimental set up for the acquisition of the set of elemental images of a 3D scene.

For the acquisition of the elemental images, instead of using an array of digital cameras, we used the so-called synthetic aperture method, in which all the elemental images are picked up with only one digital camera that is mechanically translated. The digital camera was focused on the doll. The camera parameters were fixed to focal length $f = 50\ mm$ and $f_{/\#} = 3.5$. The depth of field was big enough to allow to obtain pictures were the images of all the objects of the 3D scene were sharp. We obtained a set of 13Hx13V images with pitch $P = 10\ mm$. Since the size of the CMOS sensor was $22.2 \times 14.8\ mm$, we cropped any elemental image in order to remove the outer parts. By this way we could compose the integral image which consisted on 13Hx13V elemental images of $10 \times 10\ mm$ and 1972x1972 px each.

The reconstruction stage was performed in the computer following the next protocol. First, to consider a realistic display situation, the calculations were performed considering a MLA of pitch $p = 1.0\ mm$. The elemental images were resized to 71x71. In Fig. 5 we show three elemental images from the same row.

Figure 5.- Three elemental images of the 3D scene

Next, in Fig. 6 we show the result of the reconstruction in the plane of the optometrist doll and also in the plane of the dark resolution chart. Note that, together with the well known ability of reconstruction procedure for removing occluding objects, the reconstructed images exhibit a resolution clearly superior to the resolution of the elemental images.

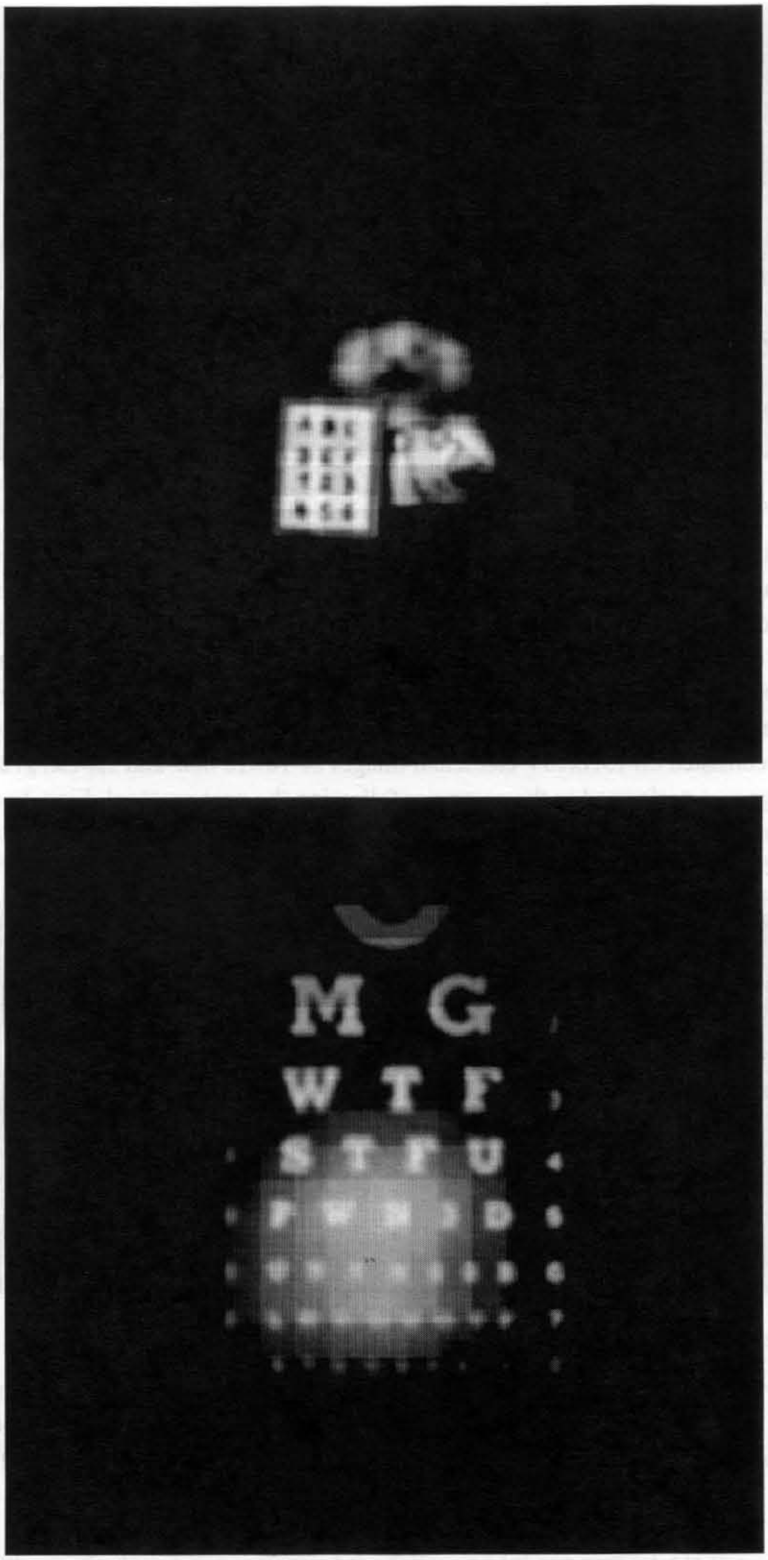

Figure 6.- Reconstructed images in two planes of the 3D scene.

4. CONCLUSIONS

We have shown that an adequate application of reconstruction algorithm allows not only the precise slicing of 3D scenes, but also the improvement of resolution of reconstructed slices.

ACKNOWLEDGEMENTS

This work has been funded in part by the Plan Nacional I+D+I (grant FIS2009-9135), Ministerio de Ciencia e Innovacion (Spain). We also acknowledge the support from the Generalitat Valenciana (grant PROMETEO2009-077).

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