From the plenoptic camera to the flat integral-imaging display

Manuel Martínez-Corral, Adrián Dorado, Héctor Navarro, Anabel Llavador and Genaro Saavedra

Department of Optics, University of Valencia, E-46100 Burjassot, Spain.
Manuel.Martinez@uv.es, Adrian.Dorado@uv.es, Hector.Navarro@uv.es, Anabel.Llavador@uv.es, Genaro.Saavedra@uv.es,

Bahram Javidi

Electrical and Computer Engineering Dept., University of Connecticut, Storrs, CT 06269-2157
bahram@engr.uconn.edu

ABSTRACT

Plenoptic cameras capture a sampled version of the map of rays emitted by a 3D scene, commonly known as the Lightfield. These devices have been proposed for multiple applications as calculating different sets of views of the 3D scene, removing occlusions and changing the focused plane of the scene. They can also capture images that can be projected onto an integral-imaging monitor for display 3D images with full parallax. In this contribution, we have reported a new algorithm for transforming the plenoptic image in order to choose which part of the 3D scene is reconstructed in front of and behind the microlenses in the 3D display process.

Key words: 3D display, Integral Imaging, plenoptic camera.

The development of the Integral Imaging field began in 1908 with the proposal of Lippman's integral photography [1]. The aim of Integral Photography is to capture and display 3D information without the need of any special glasses, opposite to previous 3D imaging and display systems, like Wheatstone stereoscope [2] or Rollmann anaglyphs [3]. In his proposal, Lippman was able to record and reconstruct a real 3D image by using light rays intersections, performing the first autostereoscopic system.

Over the years, the interest in 3D technology grew. In 1992, Adelson and Wang proposed another autostereoscopic device, known as the Plenoptic Camera [4], which is based in the Lightfield concept proposed by Adelson and Bergen [5] and was developed recently by Levoy and Ng [6]. More recently, Georgiev et al. [7] proposed a modification in the original plenoptic architecture to improve the lateral resolution of rendered images. Plenoptic camera have many applications, some of the most remarkable are: virtually generating views ([6], [8]), obtaining images of the scene focused at different depths ([6], [9,10]) and projecting the images into a display to 3D reconstruction, similar to the integral imaging method [11].

In general, the plenoptic camera is a portable and easy-to-use device whose main drawback is the low spatial resolution of the reconstructed images. Also, the plenoptic camera is a closed system, in the sense that once the system is built, the recorded information is limited by the camera features. In contrast, integral imaging systems tend to be a little more complicated (capture using an array of cameras [12], the synthetic aperture method [13]) providing images with, usually, better resolution.

Three-Dimensional Imaging, Visualization, and Display 2014, edited by Bahram Javidi, Jung-Young Son,
Osamu Matoba, Manuel Martínez-Corral, Adrian Stern, Proc. of SPIE Vol. 9117, 91170H
 · CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2051119

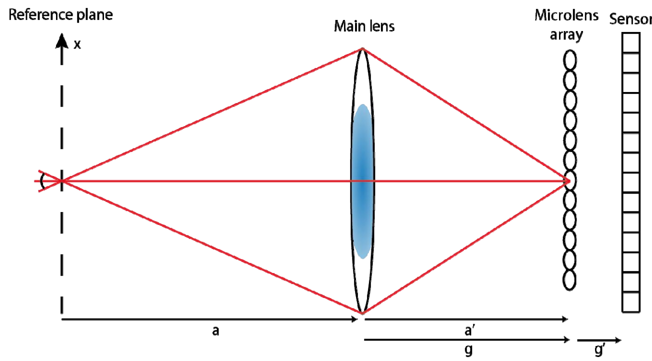


Figure 1 Diagram of a plenoptic camera.

To perform a plenoptic camera, a microlens array should be inserted at the sensor plane of a conventional camera and thus the sensor plane is displaced at the focal-back plane of the microlens array. A basic scheme is depicted in Figure 1. To work properly, the plenoptic camera has to accomplish a pair of conjugation relations: (i) the reference plane has to be conjugated with the microlens array plane and (ii) the main lens (see Figure 1) has to be conjugated with the sensor. Note that adjusting the aperture of the main lens is mandatory to avoid losing sensor resolution or the overlapping of the microlenses images [6].

From a plenoptic image it is possible to obtain different views of a 3D scene due to fact that the pixels behind each microlens store information of different perspectives of the same part of the scene. These views, commonly named as subimages [14], are equivalent to the elemental images that could be obtained with an integral imaging system in which the cameras or microlenses where placed in the main lens plane [15], as shown Figure 2. However there is a discrepancy, the barriers in integral imaging are parallel and the plenoptic ones are conical.

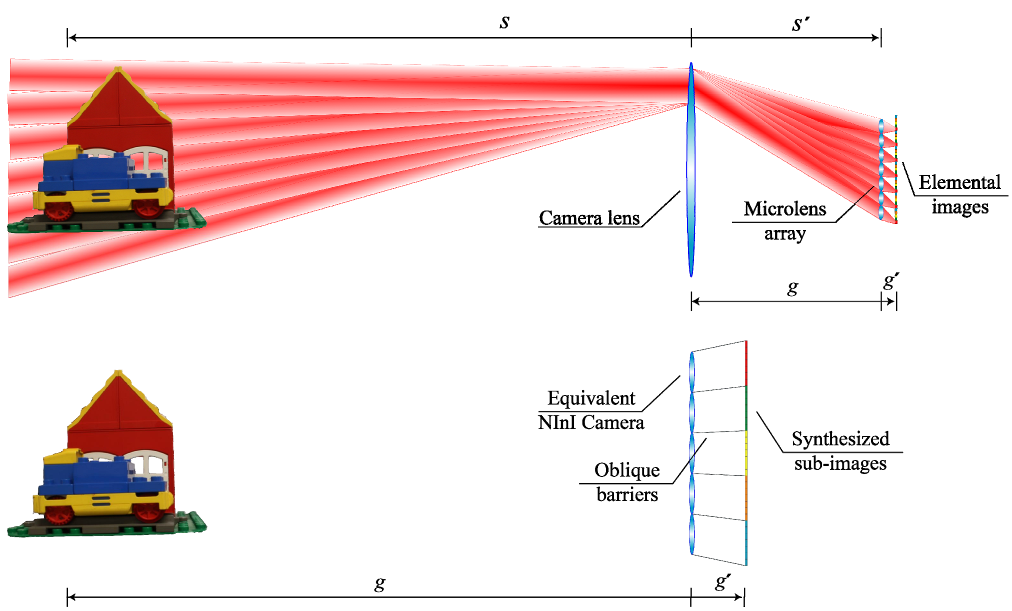


Figure 2 Subimages of a plenoptic camera. Note that they are equivalent to the elemental images of an integral imaging system when the lenses are placed in the main lens plane.

Typically, in the capture process, the image of a reference plane is formed at the microlens plane. For that reason, during the 3D display, the image recorded at that plane is reconstructed at the microlens array plane of the display system. The goal of this work is to move digitally the position of the reference plane of the plenoptic image once the image has been acquired. This can be achieved with a simple algorithm, which allow us to change at will which parts of the 3D scene are reconstructed in front of or behind the microlens plane.

As shown in Figure 3, by shifting the subimages in one direction the convergence of the light rays is modified and, consequently, the position of the reference plane is changed. This shifting depends on both the vertical and horizontal position of the subimage inside the array of views and takes the zero value for the central subimage (see Figure 3). In order to shift the convergence plane, this process should be made for the vertical and horizontal axis. Finally, after modifying the subimages following this way and transforming them back into a plenoptic image, the reference plane of the plenoptic image is permuted to another one.

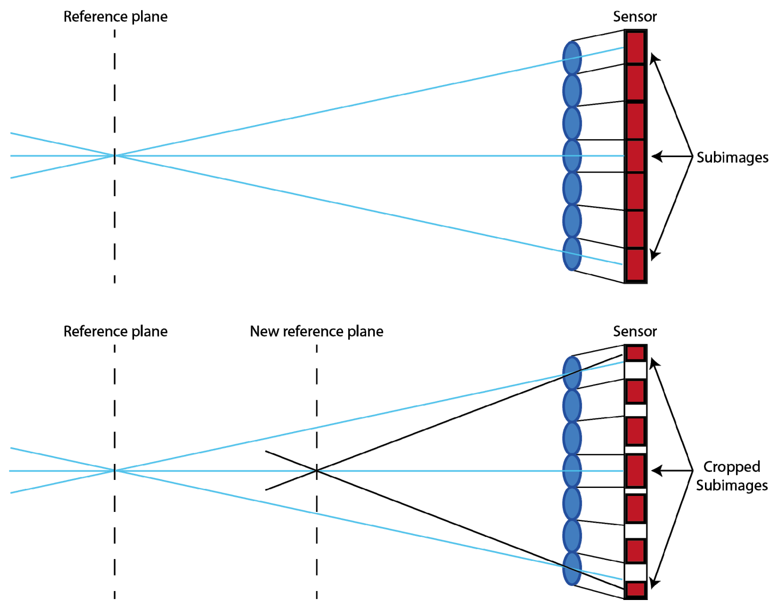
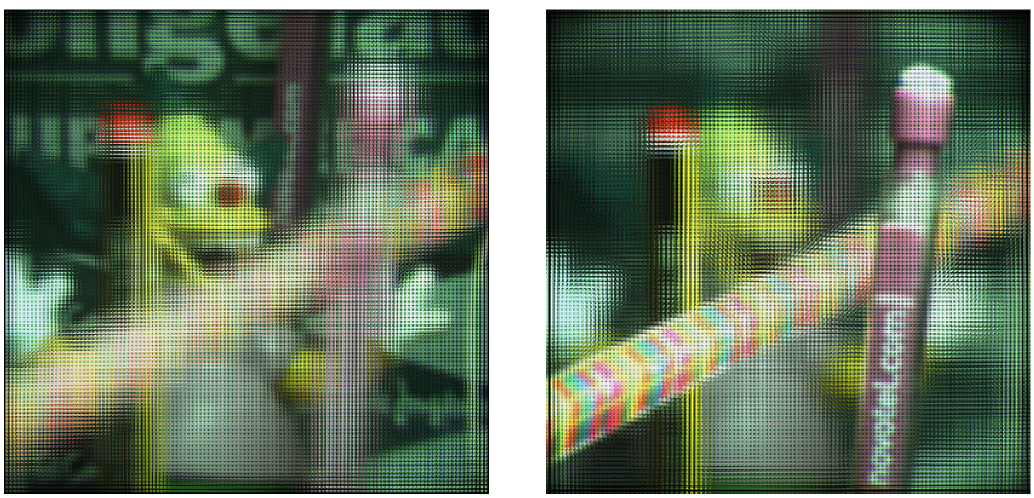


Figure 3 Illustration of how the position of the reference plane is moved in plenoptic systems.

To prove this concept, we have calculated and shifted the subimages of the plenoptic image shown in Figure 4. In this image, the reference plane is placed at the pencil plane. We are interested in changing the reference plane to two new positions: the background and the mechanical pencil located at the front plane of the image. In order to achieve these new images, it is worth to mention that the direction of the displacement of the subimages enables us to focus the background or the front plane. From the results shown in Figure 5 one can see that the reference plane is now located at the background (see Figure 5(a)) and at the mechanical pencil (see Figure 5(b)).

Figure 4 Plenoptic image used for the verification in which the reference plane is placed at the pencil plane.



(a) (b)

Figure 5 Plenoptic images obtained by using our proposal from the plenoptic image of Figure 4. The reference plane now at: (a) the background and (b) the front plane.

Furthermore, we have made a computer reconstruction of the 3D visualization process of the three images in which the reference plane is changed. We show three different views that an observer can see by observing the 3D display. These results are depicted in Figure 6. In each set of images, we have plotted three lines to highlight the three reference planes under study. In the original plenoptic image (first column) it is shown that the central pencil does not move. However, for the other two columns, the plane that does not change is at the front mechanical pencil and the background, respectively. An observation of Figure 6 tell us that only the objects located at the reference plane remain still whereas the rest of them are shifted. In addition, note that the reference plane will be reconstructed at the microlens plane during the 3D display.

Summarizing, we have demonstrated our capacity to virtually change the reference plane of a plenoptic image without performing a new recording of the scene. Following this proposal we are able to modify the way in which the 3D scene is reconstructed in a 3D display.

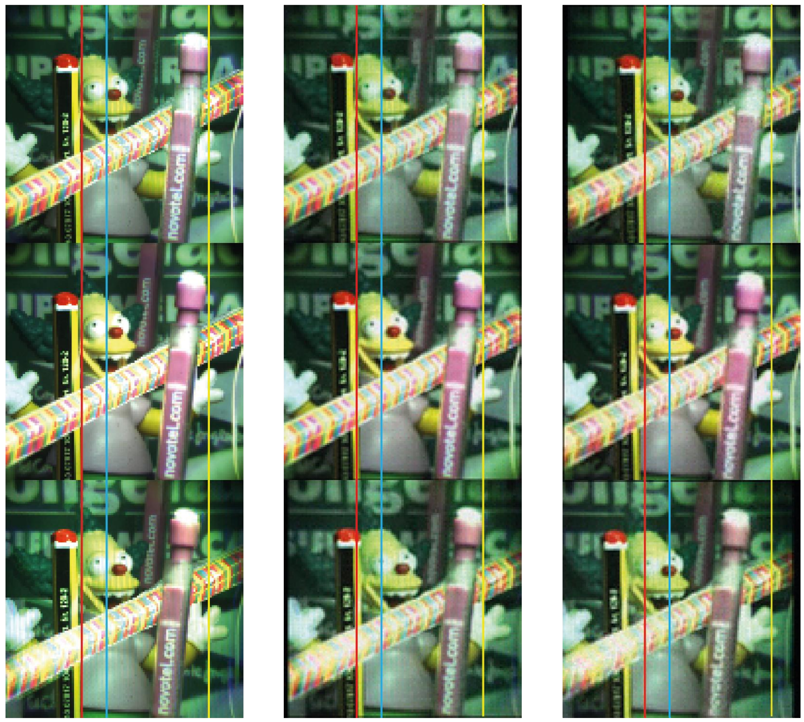


Figure 6 Computer reconstruction of the visualization process. Each column of images corresponds with one set of views obtained from the plenoptic image shown in Figure 4 and Figure 5. In each set of images, three lines have been plotted to highlight the invariance of the reference plane.

ACKNOWLEDGEMENTS

This research was supported in by the Ministerio de Economia y Competitividad (MINECO, Spain), under Grant DPI2012-32994, and also from Generalitat Valenciana under Grant PROMETEO2009- 077. A. Llavador acknowledges predoctoral fellowship from the University of Valencia. A. Dorado acknowledges a predoctoral fellowship from the MINECO. We gratefully acknowledge the CAFADIS group from the University of La Laguna (Spain) for providing us the plenoptic image.

REFERENCES

[1] G. Lippmann, “Epreuves reversibles donnant la sensation du relief,” J. Phys. **7**, 821–825 (1908).

[2] C. Wheatstone, “Contributions to the Physiology of Vision,” Philosophical Transactions of the Royal Society of London **4**, 76-77 (1837)

[3] W. Rollmann, “Notiz zur Stereoskopie,” Ann. Phys. **165**, 350-351 (1853)

[4] E. H. Adelson, and J.Y.A Wang. “Single lens stereo with a plenoptic camera,” IEEE Trans. Pattern Anal. Mach. Intell. **14**, 99–106 (1992)

[5] E. H. Adelson and J. R. Bergen, “The plenoptic function and the elements of early vision,” Computational Models of Visual Processing, **1**, 3-20 (1991).

[6] R. Ng, M, Levoy, M. Brédif, G. Duval, M. Horowitz, P. Hanrahan. “Light Field Photography with a Hand-held Plenoptic Camera,” Stanford Tech Report CTSR 02, 2005.

[7] A. Lumsdaine, T. Georgiev, “The focused plenoptic camera,” Proc. ICCP 1-8, 2009.

[8] M. Levoy and P. Hanrahan, “Light field rendering,” in Proc. ACM SIGGRAPH, 31–42(1996).

[9] A. Isaksen, L. McMillan and S. J. Gortler, “Dynamically Reparameterized Light Fields”, Proc. ACM SIGGRAPH 297-306 (2000).

[10] V. Vaish, G. Garg, E. Talvala, E. Antunez, B. Wilburn, M. Horowitz and M. Levoy, “Synthetic Aperture Focusing using a Shear-Warp Factiruzation of the Viewing Transform”, Proc. CVPR, 129-129, 2005.

[11] T. Iwane, “Light field camera and IP display,” Proceedings of 3DSA, 32 (2013).

[12] J. S. Jang and B. Javidi, “Three-dimensional synthetic aperture integral imaging” Opt. Lett. **27**, 1144-1146 (2002).

[13] Stern and B. Javidi, "3-D computational synthetic aperture integral imaging (COMPSAII)," Opt. Express **11**, 2446-2451 (2003).

[14] J.-H. Park, K. Hong, and B. Lee, “Recent progress in three-dimensional information processing based on integral imaging,” Appl. Opt. **48**, H77–H94 (2009).

[15] H. Navarro, J.C. Barreiro, G. Saavedra, M. Martínez-Corral, and B. Javidi. “High-resolution far-field integral-imaging camera by double snapshot,” Opt. Express **20**, 890-895 (2012)