Display of travelling 3D scenes from single integral-imaging capture

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ABSTRACT

Integral imaging (InI) is a 3D auto-stereoscopic technique that captures and displays 3D images. We present a method for easily projecting the information recorded with this technique by transforming the integral image into a plenoptic image, as well as choosing, at will, the field of view (FOV) and the focused plane of the displayed plenoptic image. Furthermore, with this method we can generate a sequence of images that simulates a camera travelling through the scene from a single integral image. The application of this method permits to improve the quality of 3D display images and videos.

Key words: 3D display, Integral Imaging, Plenoptic image.

Integral imaging is a very promising 3D technique and one of the most suited for 3D display. This technique was proposed by Lippmann in 1908 [1], but it wasn't until many decades later that the technology progressed enough to be able to implement Lippmann ideas. Another approach to 3D technology similar to Lippmann InI is the plenoptic camera. The idea of the plenoptic camera was proposed by Adelson and Wang [2], based on Adelson and Bergen concept of Lightfield [3]. The plenoptic camera was developed by Levoy and Ng [4], modified by Georgiev [5] and finally, implemented in a commercial version, [7]. There were other attempts to produce robust integral imaging systems as a multi-focus plenoptic camera [8] or an InI television [9].

Although InI and plenoptic imaging present some differences in the way they manage 3D information, both are very similar at their core [10]. As previously researched in [11], it is possible to transform an integral image into a plenoptic image, or vice versa, via a transposition of the spatial and angular information. In addition, using the SPOC 2.0 algorithm, developed in [11], it is easy to adapt an image captured with InI into any InI monitor, regardless its characteristics.

We propose a method to improve the quality of the 3D content displayed in an InI monitor, images or videos, by smartly application of SPOC 2.0 algorithm to generate plenoptic images whose FOV and reference plane have been chosen at will. Moreover, we can also enhance the quality of a 3D movie by generating, from just one integral image, a sequence of images that simulates a camera travelling through the scene.

Plenoptic images are made of an array of elemental images (EIs), which store the spatial and angular information of the captured 3D scene. Note that these EIs are slightly different from the ones in InI. While in InI each EIs stores all the spatial information of one specific view of the scene, the EIs in plenoptic images store all the angular information of a specific spatial point of the scene. For that reason we distinguish between both of them by renaming the plenoptic image's EIs as microimages. Microimages are easier to be projected onto an InI monitor but InI has a more flexible capture system. Therefore, it is a correct choice to use the SPOC 2.0 method [11], which transforms an integral image into its corresponding plenoptic image, see Figure 1. The transformation between InI and plenoptic imaging is computed as a simple pixel mapping which makes a transposition between the spatial and angular information.

Still, the true strength of the SPOC 2.0 method lies in its flexibility when generating the equivalent plenoptic image, as it permits to adapt the calculated image to be displayed onto any InI monitor [11]. The workflow of the SPOC 2.0

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algorithm is a two-step process. First it crops the EIs of the integral image and second it applies the transposition that will convert the cropped EIs into microimages. The cropping is done by applying to each EI a cropping window that will extract the pixels falling within it. The position and size of the cropping window will establish the FOV of the generated microimages. In addition, changing the relative position of the cropping window with respect the center of the EIs will change the position of the reference plane (the focused plane) in the generated plenoptic image, see Figure 2, similar as shifting the position of the subimages in [12].

(a) (b)

Figure 1. (a) Set of 5x5 elemental images from an 11x11 integral image. (b) Plenoptic image generated from the integral image shown in (a).

(a) (b) (c)

Figure 2. Different microimages generated from the same integral image using SPOC 2.0. The FOV of the images (a) and (b) are the same but the position of the reference plane changes from the driver's plane to the car's plane. The (c) image has the reference plane at the same position as image (a) but FOV is different.

Note that the shift in the relative position of the cropping window applied to an EI depends on the relative position of the EI in the array. The EIs situated on the left or the right of the central EI will have its cropping window shifted a specific number of pixels into that direction, the same occurs for the ones above or below the central EI. The number of pixels the cropping window is shifted is $i \cdot d$. The value of i corresponds to the position of the EI inside the array, being 0 for the central EI, positive for the EIs situated to the right or above of the central one and negative for the EIs situated to the left or below. The variable, d, acts as a parameter that changes the global position of the cropping window. Modifying its value changes the position of the reference plane of the calculated image.

Therefore, the SPOC 2.0 algorithm is able to change the FOV and the reference plane of the generated plenoptic image just by modifying the parameters of the algorithm. Being able to choose the FOV and the reference plane is a useful asset in 3D display. It permits to display an image or sequence of images with the characteristics desired without the limitations of traditional InI. But, SPOC 2.0 is also able to enhance the results obtained with a 3D display even further. From just a single integral image, by changing the parameters of the SPOC 2.0 algorithm, it is possible to generate a sequence of images with different FOV and reference plane. If done properly, the sequence of images can simulate a camera travelling through the scene, see Figure 3. This can be applied to generate a static InI video, as in Figure 3, or to improve the quality of a 3D movie by adding frames computationally after recording the integral images.

Figure 3. Sequence of images generated from a single integral imaging. The sequence simulates a camera approximating to the scene. The FOV and the reference plane change as the camera gets closer.

To prove this concept we captured an InI video composed by twenty-one integral images. The video records a 3D dynamic scene: a car parks in front of a house and the driver goes inside it, see Figure 4. This sequence of images will be projected onto an InI monitor to display a 3D video but, thanks to our proposed method, we can enhance the quality of the movie displayed.

Figure 4. Central EI of some of the integral images composing the InI video.

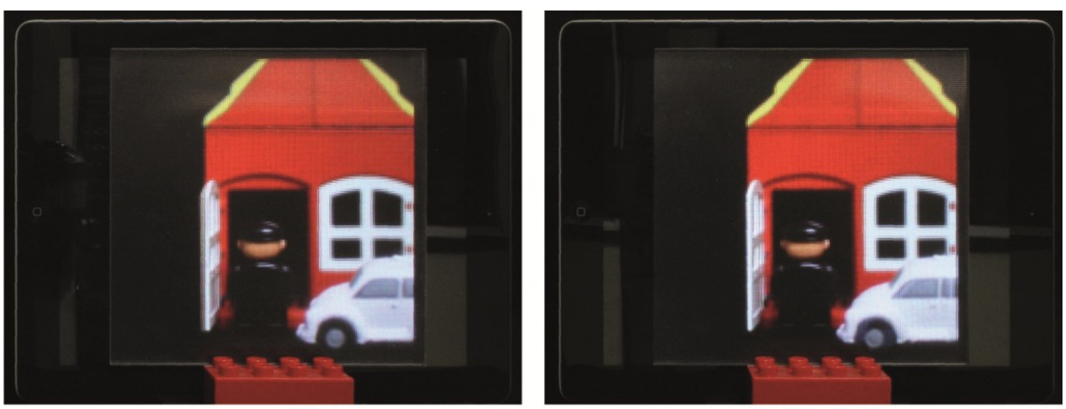
We want the attention of the observer focused on the driver. Therefore, we make the necessary adjustments to the parameters of SPOC 2.0 so, when applied to the integral images, the algorithm generates the plenoptic images with the FOV and the reference plane centered and focused on the driver. In addition, we add several frames to the movie by generating a set of plenoptic images from the integral image where the car is parked in front of the house. This set of new images simulate a zoom in and increases the number of frames of the video from twenty one to forty. The generated video frames are shown in Figure 5.

The movie frames can be projected onto an InI monitor to display the movie in 3D with full parallax, see Figure 6 and Figure 7. The InI monitor employed for the experiment is an iPad with retina display and a microlens array of 1 mm pitch. The observer is simulated by a canon 450D camera, which shifts its position to emulate the movement of the head.

Summarizing, it is easier to project an integral image onto an InI monitor by transforming it into a plenoptic image. This is done by applying the SPOC 2.0 method which, in addition, permits to choose the FOV and reference plane of the transformed image. Furthermore, with this method we can also generate a sequence of images that simulates a camera travelling through the scene from a single integral image. We have shown that using these techniques can enhance the quality of 3D images or movies.

Figure 5. The forty frames of the generated sequence. The FOV and reference plane changes to follow the movement of the driver. Also, we added a zoom in effect by generating a set of plenoptic images, from only one of the integral images, with different FOV.

Figure 6. Photos of the InI monitor displaying the 3D movie.



(a) (b)

Figure 7. Two photos of the InI monitor displaying the same frame of the 3D movie. Each photo was taken from two different position to simulate the movement of an observer viewing the InI monitor and moving the head from left to right. (a) Shows the view from the left and (b) the view from the right.

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REFERENCES

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

[2] 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)

[3] 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).

[4] 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.

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

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

[7] [Online]. Available: https://www.lytro.com.

[8] C. Perwab and L. Wietzke "Single Lens 3D-Camera with extended Depth-of-Field," Proc. SPIE. **8291** (2012).

[9] J. Arai, F. Okano, M. Kawakita, M. Okui, Y. Haino, M. Yoshimura, M. Furuya, and M. Sato, "Integral Three-Dimensional Television Using a 33-Megapixel Imaging System" J. Display Technol, **6**, 10 (2010).

[10] 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)

[11] M. Martinez-Corral, A. Dorado, H. Navarro, G. Saavedra, and B. Javidi, " Three-dimensional display by smart pseudoscopic-to-orthoscopic conversion with tunable focus", Appl. Opt. **53**, 22 (2014).

[12] M. Martínez-Corral, A. Dorado, H. Navarro, A. Llavador, G. Saavedra and B. Javidi, “From the plenoptic camera to the flat integral-imaging display” Proc. SPIE **9117**, 0H (2014).