



Integral Imaging Monitors with an Enlarged Viewing Angle

Adrián Dorado, Genaro Saavedra, Jorge Sola-Pikabea, and Manuel Martínez-Corral*, *Member, KIICE*

3D Imaging and Display Lab., Department of Optics, University of Valencia, Burjassot, 46010 Valencia, Spain

Abstract

Enlarging the horizontal viewing angle is an important feature of integral imaging monitors. Thus far, the horizontal viewing angle has been enlarged in different ways, such as by changing the size of the elemental images or by tilting the lens array in the capture and reconstruction stages. However, these methods are limited by the microlenses used in the capture stage and by the fact that the images obtained cannot be easily projected into different displays. In this study, we upgrade our previously reported method, called SPOC 2.0. In particular, our new approach, which can be called SPOC 2.1, enlarges the viewing angle by increasing the density of the elemental images in the horizontal direction and by an appropriate application of our transformation and reshape algorithm. To illustrate our approach, we have calculated some high-viewing angle elemental images and displayed them on an integral imaging monitor.

Index Terms: Computational photography, Integral imaging, Three-dimensional display, Viewing angle

I. INTRODUCTION

In order to reach the rank of commercial devices for three-dimensional (3D) vision, integral imaging (InI) displays need to overcome some drawbacks, such as a small viewing angle, pseudoscopic problem, and limited depth of field. Previous studies have addressed these issues, and some solutions have been reported to overcome the pseudoscopic problem [1-5], the viewing angle limitation [6-11], and the problem of limited depth of field [12-14] of InI monitors; these solutions show that the research in this field is on track to achieve a commercial-quality device.

This study is based on the proposal for increasing the viewing angle of elemental images (EIs) by Miura et al. [10]. Their method does not require any special device or complex algorithms, but their results are very promising. However, their proposal shows some lack of flexibility, and the images obtained cannot be easily projected on an InI

monitor, since the spatial and angular resolution of these images cannot be adapted to the monitor characteristics. Our research group has developed a new method, which benefits from the concept of Miura et al. [10] but overcomes the abovementioned drawbacks.

The rest of this paper is organized as follows: first, the relationships between the parameters related to the viewing angle of a 3D plenoptic image are obtained. Second, the method developed by Miura et al. [10] and SPOC 2.0, and the proposed method are explained. Next, the experimental process and the results are described. Finally, we present the conclusions of this research.

II. VIEWING ANGLE OF InI MONITORS

The viewing angle is an important feature of any 3D visualization system because it establishes the range of

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*Corresponding Author Manuel Martínez Corral (E-mail: manuel.martinez@uv.es, Tel: +34-96354-4718)

3D Imaging and Display Lab., Department of Optics, University of Valencia, Burjassot, 46010 Valencia, Spain.

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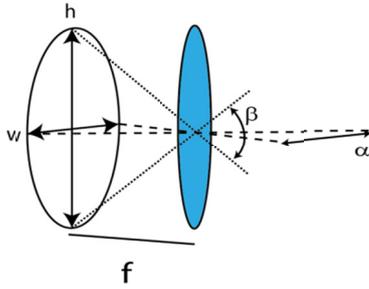


Fig. 1. Parameters involved in the magnitude of the viewing angle.

positions from the display in which a viewer can observe the 3D reconstruction. In an InI monitor, the collection of microimages is projected onto the high-resolution display and the microlens array is placed in front of it, so that every microimage is under one microlens. The best visualization is obtained when the microimages are set at the focal plane of the microlenses (see 0). Then, from this figure, we can easily obtain the horizontal (α) and vertical (β) viewing angles of the 3D reconstruction. Their expressions are as follows:

$$\alpha = 2 \tan^{-1} \frac{w}{2f} \quad (1)$$

and

$$\beta = 2 \tan^{-1} \frac{h}{2f}, \quad (2)$$

where w denotes the width of the microimage, h represents the height, and f indicates the focal length of the microlenses. From Eq. (1), one can realize that the larger the microimages are, the bigger is the viewing angle. However, for a proper visualization, one should be careful to avoid the overlapping of the microimages.

III. METHOD

In this section, we will explain the method proposed for the enlargement of the viewing angle of InI monitors. First, we will briefly explain the two ideas already reported (Miura et al.'s method [10] and SPOC 2.0 [5]). Second, we will show that a proper fusion of the concepts of these two methods leads to the development of a new and effective method for increasing the viewing angle.

A. Enlarged View

The basic idea of Miura et al. [10] involves changing the size of the EIs by increasing their width while decreasing the height, keeping invariant the total number of pixels. To do so, the researchers tilted the microlens array in the capture and

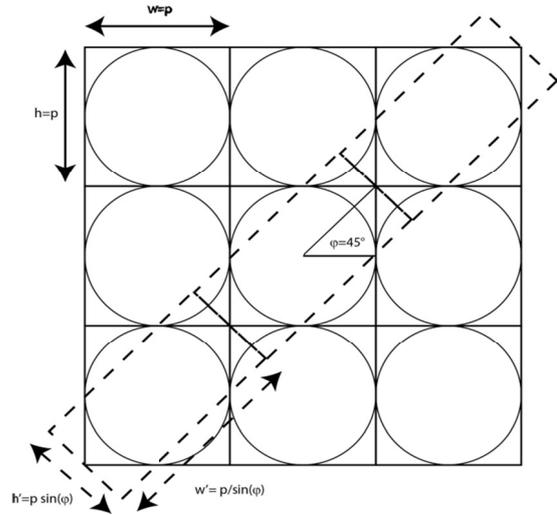


Fig. 2. Microimages size and distribution. Continuous line is standard elemental images captured using a rectangular microlens array. Dotted line is enlarged elemental images captured using the same microlens array but tilted $\varphi = 45^\circ$. The width increases while the height decreases, keeping invariant the total number of pixels.

reconstruction processes. The overlapping issue in the capture stage was solved by inserting an aperture stop in the capture system. Following this architecture, the size of the EIs and the viewing angles were properly modified. In 0, the effect of tilting a microlens array, with a square arrangement, is shown. In this configuration, the size of the EIs are calculated using Eq. (3),

$$w' = \frac{p}{\sin \varphi}, \text{ and } h' = p \sin \varphi, \quad (3)$$

whereas the viewing angle of the enlarged EIs is expressed as follows:

$$\alpha' = 2 \tan^{-1} \frac{p}{2f \sin \varphi} \text{ and } \beta' = 2 \tan^{-1} \frac{p \sin \varphi}{2f}. \quad (4)$$

In the above equations, p denotes the pitch of the microlenses, f represents their focal length, and φ indicates the tilted angle. Although this idea is an easy and good solution for improving the viewing angle, it has the disadvantage of a lack of flexibility: the microlenses used in the capture must be the same as the ones used in the reconstruction stage, and, consequently, both processes are limited.

B. SPOC 2.0

We reported a method called SPOC 2.0 that can be used to solve this type of problems [5]. Basically, SPOC 2.0 takes advantage of three facts: 1) the flexibility that InI offers in

the capture process, 2) the possibility of obtaining an equivalent plenoptic image from an integral image [5, 15], and 3) the fact that a plenoptic image can be easily projected into a display. The last fact enables the projection of an InI image by transforming it into a plenoptic image already adapted to the chosen microlens array and display. Therefore, SPOC 2.0 provides the freedom to perform the capture process and, additionally, adapts InI to any given display and any given microlenses. Besides, the images obtained are already orthoscopic and we can choose, with some degree of freedom, the reference plane and the field of view of the scene.

The characteristics of the integral image determine the characteristics of the equivalent plenoptic image. For example, the number of elemental images in an integral image fixes the pixels per microimage of the equivalent plenoptic image. In addition, the number of pixels of any elemental image determines the microimage count of the equivalent plenoptic image. However, there is another question to account for: does the spatial configuration of the pixels within any elemental image determine the distribution of the microimages centers? Note that in order to build a microimage, the same pixel from any EI is mapped taking into account its relative position in the integral image. Therefore, the first pixel of every EI corresponds to the first microimage. Then, we can assume that every pixel in the EI relates with one microimage, and therefore, the relative position of the pixels in an EI determines the distribution of microlenses. For example, in a normal camera, the pixels are distributed in a rectangular grid, and therefore, the microimage distribution will be equivalent. However, if the pixels in the EIs were distributed in a hexagonal grid, the equivalent microimages would be rearranged following a hexagonal pattern. Therefore, we can obtain a hexagonal microimage distribution from EIs with a hexagonal pixel distribution. This can be easily obtained with a normal camera just by resizing or averaging pixels because of the fact that the EIs captured with the synthetic aperture method have more pixels than required, permitting considerable flexibility in the adapting process.

C. SPOC 2.1

The proposed method is based on combining the concepts behind the two previously described methods. Our goal is the generation of a plenoptic image with an enlarged viewing angle that can be projected into any InI monitor by using any microlenses for 3D visualization.

As stated before, from an integral image, we can obtain an equivalent plenoptic image. To reproduce Miura et al.'s enlarged EIs, we need to obtain a plenoptic image with asymmetric microimages arranged in a hexagonal distribution. Therefore, the integral image captured has to

have an asymmetric number of photographs in which the EIs have a hexagonal pixel distribution. The equivalent microimage size and distribution of the plenoptic image depend on the tilted microlens array that will be used in the visualization stage. Taking this into account, we proceed to describe the steps needed to produce plenoptic images with an enlarged viewing angle.

First, the display and the microlenses that are going to be used in the 3D reconstruction must be chosen. Second, the number of pixels of the selected display that will form a microimage, which has the same size of a microlens of the chosen array, is calculated. This will be the size in pixels of a microimage of the standard projected plenoptic image. Third, we decide the tilting angle of the microlenses, we can determine the increase in the viewing angle. Note that, because of the overlapping of the microimages, not all rotating angles are valid [11]. Fourth, we calculate the new size in pixels, using Eq. (2) in the case of a rectangular microlens array, of the microimages after tilting the microlens array. This will be the size in pixels of one microimage of the enlarged view plenoptic image. Fifth, the integral image of the 3D scene, with the number of EIs equal to the number of pixels per microimage of the standard plenoptic image, is captured. Sixth, another integral image with the number of EIs equal to the number of pixels per microimage of the enlarged view plenoptic image is captured. Seventh, we transform the two integral images into plenoptics images by applying SPOC 2.0, but resizing the EIs of the enlarged view case so that they have a hexagonal distribution and taking into account that the final plenoptic image has to have a hexagonal microimage distribution. Eighth, resize both images so that each has the correct number of pixels per microimage. Ninth, project the images onto the display.

IV. EXPERIMENTS

In order to test our proposal, we capture two integral images, transform them into plenoptic images, and finally project them onto a display. While one of the plenoptic images is a standard image, with square microimages (the same number of pixels in the x and y directions), the other has an enlarged horizontal viewing angle, with rectangular microimages (with the width of the EI greater than the height). Both captures are performed following the classic synthetic aperture method: shifting the position of the camera per shot [16].

For the display process, we used a rectangular microlens array with focal length $f = 3.3$ mm and pitch $p = 1$ mm. The display is an iPad with a pixel density of 10.39 pixels/mm. The microimages in the normal plenoptic image have the same size as the microlenses, $w = 1$ mm and $h = 1$ mm.

In our method, the tilt angle for the enlarge case is $\varphi = \pi/4$; therefore, the size of the microimages is $w = \sqrt{2}$ mm and $h = 1/\sqrt{2}$ mm.

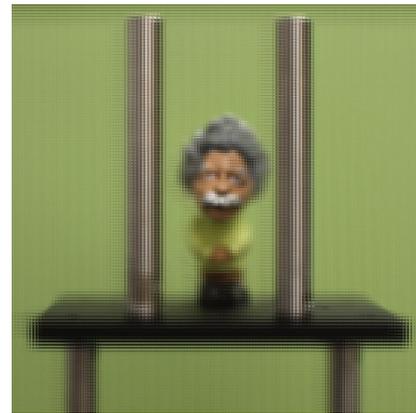
The integral image is recorded using a Canon 450 D with an objective focal length of 18 mm, focused at the infinitum. The photographs have a resolution of 4272×2848 pixels. The whole 3D scene is captured by moving the camera with a pair of motors. The camera moves in the (x, y) directions with a step of 5 mm between photographs. The scene is composed by a background 52.5 cm away from the camera, a toy placed at a distance of 40 cm from the camera, and two steel cylinders at 35 cm from the camera.

To obtain the correct microimages for both images, the number of photos captured should be equal to the number of pixels per microimage. However, as these values must be integers, for the standard image, 11×11 photographs are recorded, and for the enlarged view case, we capture 15×8 photographs. To these experimental photographs, SPOC 2.0 is applied. Both images are processed to obtain 139×139 microimages for each. After the transformation, both plenoptic images are resized in order to match the correct dimensions of the microimages. The final images are shown in Fig. 3.

To show the increase in the viewing angle, we recorded a series of photographs simulating the head movement of an observer visualizing the projected images. The distance between neighboring photographs corresponded to an angular difference of 0.5° . We found a viewing angle of 15° for the standard image and 22° for the enlarged image, see Figs. 4 and 5.

Although it is clear that the viewing angle is increased, we are interested in comparing the experimental value with the theoretical one. Using Eq. (3), we obtain the theoretical values of 17.23° and 24.19° for the normal and enlarged view cases, respectively. Obviously, there is some discrepancy between the theoretical and experimental values. This discrepancy can be attributed to the fact that Eq. (3) is obtained assuming that the microimages are placed at the focal plane of the microlenses. Experimentally, this condition is not fulfilled because of the existence of a plate protecting the pixels in the iPad, making it impossible to place the image at the focal plane of the microlens array.

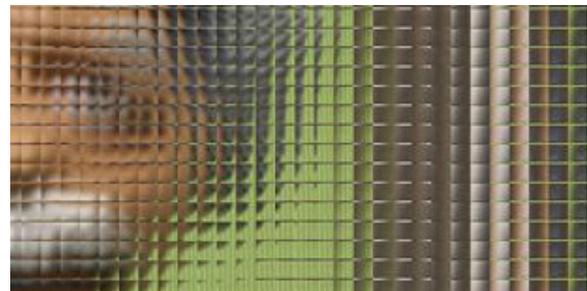
To check whether this measured discrepancy is really produced because of the crystal layer, another measurement of the viewing angle is conducted. In this experiment, the standard plenoptic image was printed on photographic paper and placed at the focal distance of the microlenses. For this case, the measured viewing angle is $17.5^\circ \pm 0.5^\circ$, very close to the theoretical value within the experimental error. From this result, we can conclude that the measured discrepancy in the viewing angle for the standard and the enlarged view plenoptic images is principally due to the crystal layer of the iPad.



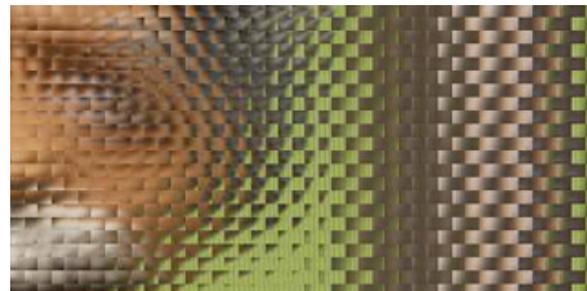
(a)



(b)



(c)



(d)

Fig. 3. (a) Standard plenoptic image with 139×139 microimages and 10.39×10.39 pixels per microimage, (b) enlarged viewing angle plenoptic image with 139×139 microimages with 14.6937×7.3468 pixels per microimage, (c) microimages of the standard plenoptic image, and (d) microimages of the enlarged viewing angle plenoptic image.

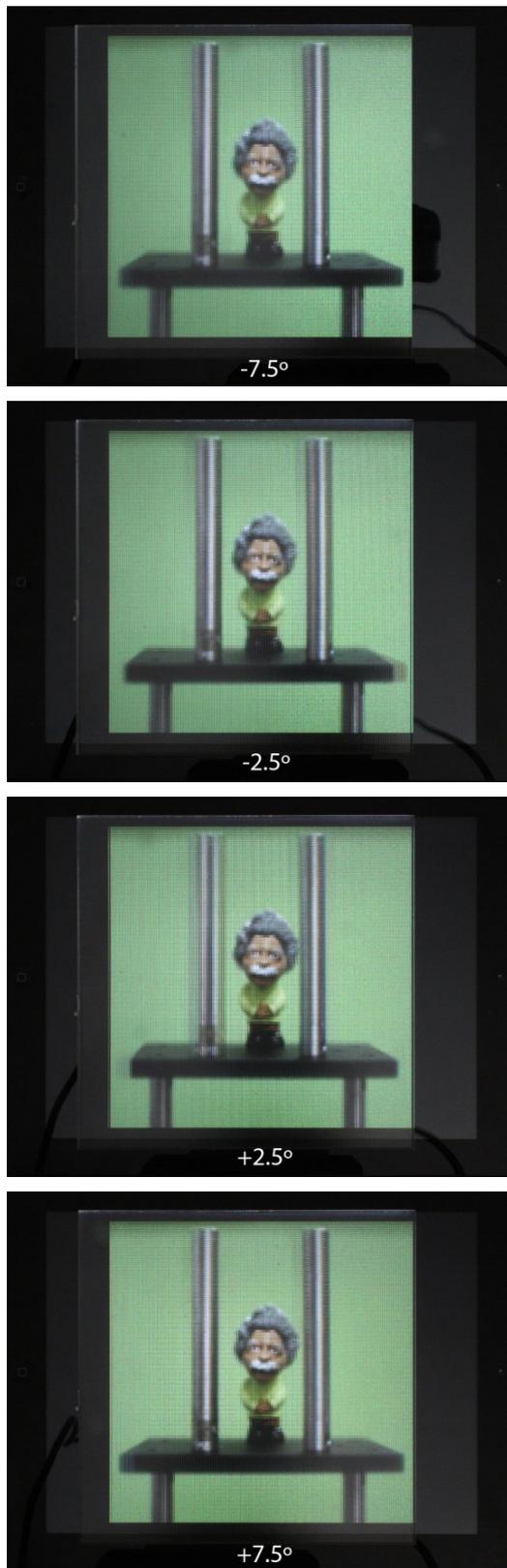


Fig. 4. Selection of photographs composing one loop of the viewing angle for the standard image case.

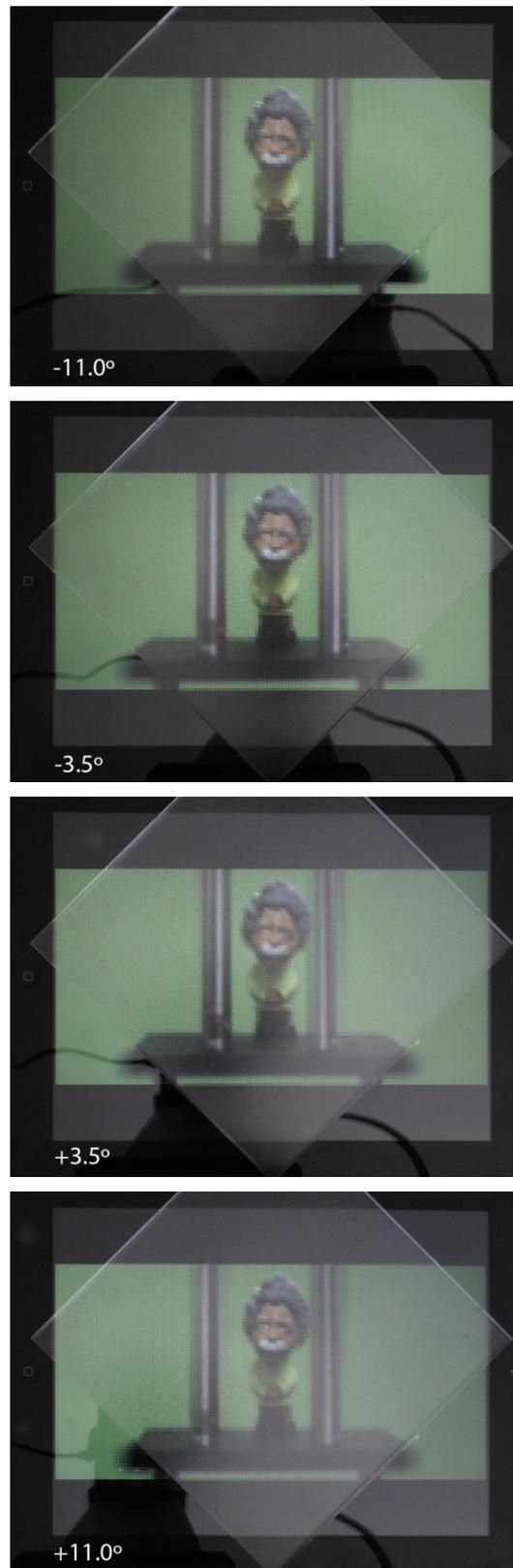


Fig. 5. Selection of photographs composing one loop of the viewing angle for the enlarged view case.

V. CONCLUSIONS

We have reported a new algorithm for the calculation of microimages, with an enlarged viewing angle, which can be projected on an InI monitor. We have presented experimental results proving this algorithm. Our algorithm is an improved version of SPOC 2.0, which adds the idea of reshaping the EIs to increase the viewing angle.

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Manuel Martínez-Corral

was born in Spain in 1962. He received his M.Sc. and Ph.D. in physics from the University of Valencia, Spain, in 1988 and 1993, respectively. He is currently Full Professor of Optics at the University of Valencia, where he is with the "3D Imaging and Display Laboratory." Since 2010, he has been Fellow of SPIE. His research interests include scalar and vector properties of tightly focused light fields, resolution procedures in 3D scanning microscopy, and 3D imaging and display technologies. He has published more than 70 technical articles in major journals, which have received more than 1,500 citations, and delivered more than 25 invited and keynote presentations in international meetings. He has been member of the Scientific Committee in more than 15 international meetings. He is Topical Editor of the IEEE/OSA Journal of Display Technology and of the Springer journal 3D Research. He is Associate Editor of JICCE.



Bora Kim

received her B.S. degree in 2013 from Department of Electric Engineering, Mokpo National Maritime University in Mokpo, Korea. She is currently pursuing her M.S. degree at Department of Electronic Materials Engineering, Kwangwoon University, Seoul, Korea. Her research interests include 3D image signal processing, digital holography, and watermarking.



Adrián Dorado

was born in Spain in 1988. He received his B.Sc. and M.Sc. in physics from the University of Valencia, Spain, in 2011 and 2012, respectively. Since 2010, he has been with the 3D Imaging and Display Laboratory, Optics Department, University of Valencia. His research interests include 3D imaging acquisition and display.



Jorge Sola-Pikabea

received his BSc in Physics from the University of Valencia, Spain, in 2014 and is currently pursuing his MSc degree. Since 2013, he has been with the "3D Imaging and Display Laboratory" at the Optics Department of the University of Valencia. His research interests include 3D microscopy.