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Enhanced Still 3D Integral Images Rendering Based on Multiprocessor Ray Tracing System

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***Abstract*—The main purpose of this paper is to introduce 3D integral imaging interpolation method, to overcome the 3D missing information problem occurred between *cylindrical lenses* (micro-images) due to occluded areas in the previous cylindrical lens, new cylindrical lens shows an area, to generate one single photo-realistic 3D integral imaging frame. The method is based on a Multiprocessor ray-tracer containing 3D integral imaging parser, 3D integral camera model, a 3D integral imaging renderer, *spatial coherence* and 3D scene transformations. Consequently, an increase in speed in the generation of *still* 3D integral image is achieved compared to fully ray tracing time of missing pixels. Experiments show that a significant reduction in execution time is achieved by using the 3D integral interpolation process. Savings up to (57%-66%) in the ray tracing time when compared to fully ray tracing the missing pixels depends on the complexity of the scene.**

***Index Terms*—computer graphics, 3D Integral Images Generation, 3D Interpolation, spatial coherence, Enhancement geometric, 3DTV**

I. INTRODUCTION

The method is introduced in order to overcome missing information (visual artefacts) problem, encountered with the generation of photo-realistic still 3D integral image. Consequently, reducing the execution time required for the generation of still 3D integral images. An interpolation algorithm is adopted in order to compute the 3D missing information using information from the neighboring cylindrical lenses micro images each side of the current micro-image.

This will avoid the need to ray-trace all of the missed pixels in new micro-image and that has noticeably resulted in the reduction of the number of computations and hence in acceleration of execution time. On the other hand, the 3D integral imaging quality is slightly affected. Both objective and subjective micro-image qualities are assessed where a comparison between a fully ray traced still 3D integral image and one generated using the proposed method is carried out. The method uses *spatial coherence* within the micro-images in an integral image. Information from one micro-image is used to produce the adjacent micro-image on the right without the need to fully ray trace the new micro-image.

II. COMPUTER GENERATED 3D INTEGRAL IMAGES

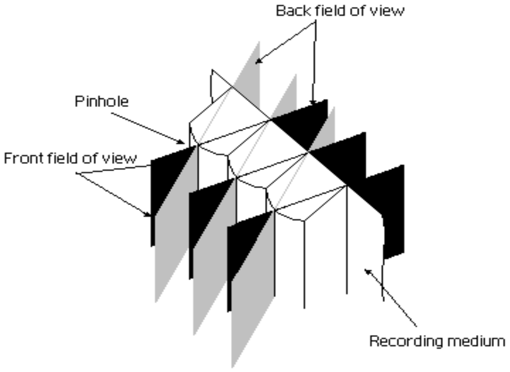

Figure 1. Lenticular sheet model in integral ray tracer.

Integral imaging is attracting a lot of attention in recent year and has been regarded as strong candidate for next generation 3D TV [1]-[7]. Computer generation of integral imaging has been reported in several literatures [8]-[11]. A computer generated synthetic 3D Integral image is presented as a two dimensional distribution of intensities termed a lenslet-encoded spatial distribution (LeSD), which is ordered directly by the parameters of a decoding array of micro lenses used to replay the three-dimensional synthetic image. When viewed, the image exhibits continuous parallax within a viewing zone dictated by the field angle of the array of micro-lenses. The replayed image is a volumetric optical model, which

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exists in space at a location independent of the viewing position. This occurs because, unlike stereoscopic techniques, which present planar perspective views to the viewer's eyes, each point within the volume of a 3D Integral image is generated by the intersection of ray pencils projected by the individual micro-lenses.

Due to the nature of the recording process of 3D Integral imaging, many changes to the camera model used in standard computer generation software are carried out. To generate a unidirectional 3D Integral image using a lenticular sheet, each lens acts like a cylindrical camera. A strip of pixels is associated with each lens forming a micro-image. Each cylindrical lens records a micro-image of the scene from a different angle as shown in the Fig. 1. For micro-lens arrays each lens acts like a square or a hexagonal camera depending on the structure of the lenses, as shown in Fig. 2. In the lateral cross section of the lenticular or the micro-lenses, a pinhole model is used. In the case of lenticular sheets, the pinhole forms a straight line parallel to the axis of the cylindrical lens in the vertical direction. For each pixel, a primary ray is spawned. The recording path of the primary ray draws a straight line going forward towards the image plane and backward away from the image plane. Similar primary rays of neighbouring lenses are spawned to similar directions parallel to each other.

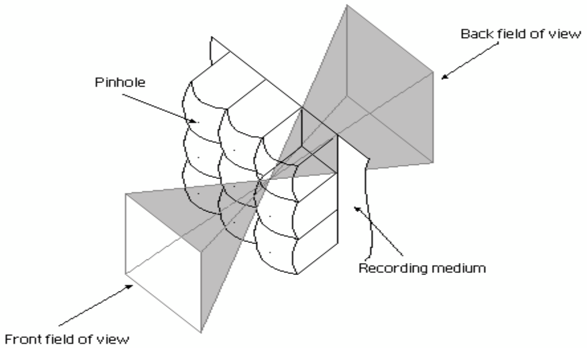


Figure 2. Micro-lens array in integral ray tracing.

Therefore highly correlated micro-images are produced which, is a property of 3D integral imaging.

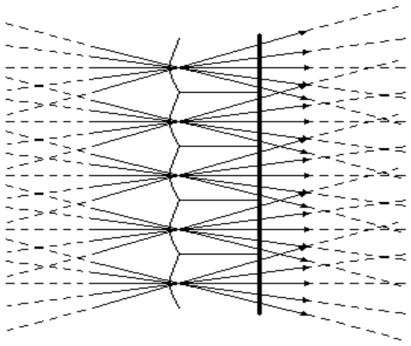


Figure 3. Camera model in 3D integral images for computer graphics.

The structure of the lenses and the camera model in the in 3D Integral computer graphics affects the way primary rays are spawned as well as the spatial coherence among them. The camera model used for each micro-lens is the pinhole approximation, where each micro-lens acts like a separate camera. The result is a set multiple cameras. Each of them records a micro-image of the virtual scene from a different angle see Fig. 3 and Table I. Primary rays pass through the centre of the micro-lens and the image plane. The scene image straddles the micro-lens array. Therefore there are two recording directions, in front and behind the micro-lens array.

The specific characteristics of 3D integral imaging, allows us to deal with each cylindrical lens separate from the others, and to measure the number of pixels behind each lens, focal length and the image width. All these parameters including the number of lenslets in the virtual cylindrical array are selected on the basis of the characteristics of the display device.

TABLE I. 3D UNIDIRECTIONAL CAMERA PARAMETERS.

Parameters	Lenticular sheet	
Resolution	512 512	[pixel]
Lens Pitch	2.116667	[mm]
Lens Pixels	8	[pixel]
Aperture Distance	10.0	[mm]
Number of lenses	64	[lens]
Focal length	6.8	[mm]
Ray Depth	2	[integer]

The pixels intensity values of the micro-image for each lenslet are read, saved, and then mapped to pixels locations on the screen so that all the vertical slots are displayed at the same time forming the 3D integral image. The location of the vertical elemental image on the computer screen is identical to the location of the corresponding lenslet in the virtual lenses array.

III. 3D MISSING PIXLES (BLANK REGIONS)

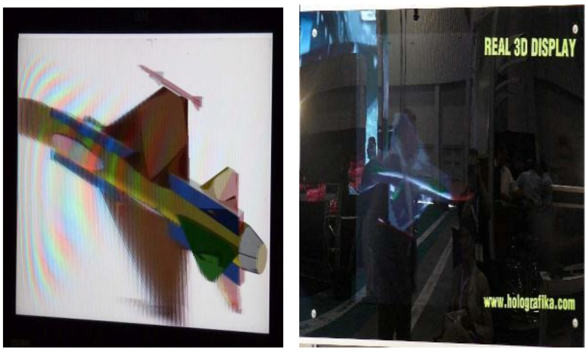


Figure 4. 3D Integral images Display Using LCD panel with a Lenticular sheet [1], [2].

Pixels with no points mapped onto them are called 3D missed pixels. They appear as holes or blank regions in the cylindrical lens and its status is (-1) which means no point is projected onto this pixel. 3D missed pixels are the result of: (1) Occluded areas in the previous cylindrical lens that should appear in the new cylindrical lens which are missing. This is illustrated in Figs. 4, and 5. (2) The new cylindrical lens shows an area that has not been covered by the previous cylindrical lens [3], [6]. In example of this occurrence is shown in Fig. 4, which shows the upper left corner of Fig. 5. To overcome this problem the missed pixels are interpolated instead of ray tracing them in order to generate their intersection points and to produce their colour.

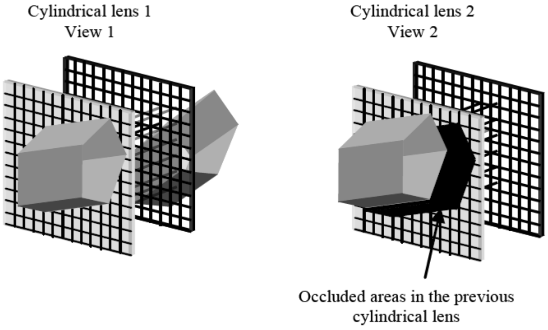


Figure 5. Occluded areas in the previous micro-image [4].

After interpolated missed pixels, the new generated points are stored in the point image. The associated colours are recorded onto the pixel image and their status flag is set to ‘0’.

IV. 3D INTEGRAL IMAGE INTERPOLATION RENDRING

The main purpose of 3D integral imaging interpolation algorithm is to avoid ray tracing the missed pixels and to use interpolation algorithm in order to produce 3D missing information and their colour by generating two point arrays. In this process the micro-images are split into odd and even micro-images. The odd micro-images define the micro-images occupying the odd position in frame i.e. first, third, fifth etc… micro-images. While the even micro-images define the micro-images occupying the even positions in the frame i.e. second, fourth, sixth etc… micro-images. The odd micro-images are generated using the integral imaging lens view algorithm, including fully ray-tracing the missing pixels. The even micro-images are also generated using the integral imaging lens view algorithm, except the missing pixels are obtained through interpolation of the information from neighbouring odd micro-images. To generate one even micro-image, two point arrays are used to store the point image from the neighbouring odd micro-images. The colour components (R, G, B) of the missing pixels in even micro-images are obtained by taking the average of point image colour components (R, G, B) of the point image arrays corresponding the neighbouring odd micro-images. The associated generated new point image colours are recorded onto the point image array. This is illustrated in Fig. 6 and Fig. 7.

The points generated through interpolation are stored in the point image. The associated colours are recorded onto the pixel image and their status is set to ‘0’. This is illustrated in Fig. 7 and Fig. 8. The recursive operation is then continued where the image points of the previous cylindrical lens and the following cylindrical lens are both used to generate the current cylindrical lens. The even micro-images are generated by ray tracing the image points onto the pixel image [3], [6], [7].

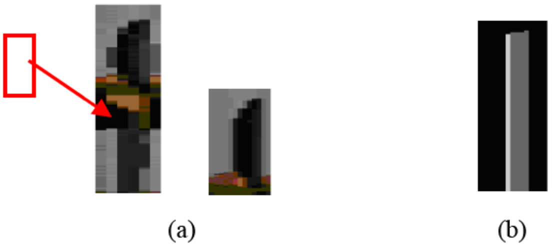


Figure 6. Missed information: (a) occluded areas coloured black. (b): area is not covered in the previous micro-image, is coloured black.

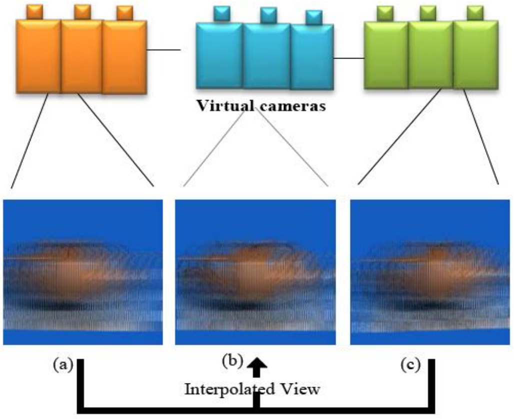


Figure 7. Interpolation process (a): fully ray traced cylindrical lens. (b): 3D interpolated the missed pixels cylindrical lens. (c): fully ray tracing the missing pixels.

The missed pixels are obtained by using the 3D integral interpolation algorithm. Whereas the odd micro-images lenses are generated by ray tracing the image points onto the pixel image and the missed pixels are produced by ray tracing.

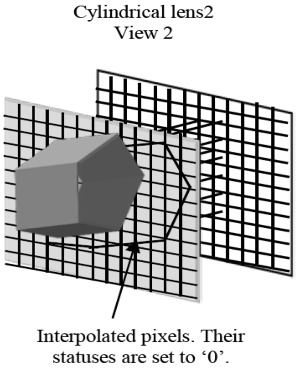


Figure 8. Interpolated missed pixels.

V. EXPERMITAL AND RESULT

A reliable quality measure is a much-needed tool for determining the type and amount of image distortion. The method most commonly used for comparing the similarity of two images is to compute the *PSNR* [12], [13]. The first 3D integral image $f(i,j)$ is generated by using fully integral ray tracing algorithm, and the second 3D integral image $g(i,j)$ is obtained by using 3D integral interpolation algorithm. Where *RMSE* is the root mean square error and it is defined as:

$$RMSE = \frac{1}{M \times N} \sum_{i=0}^{M} \sum_{j=0}^{N} (f(i,j) - g(i,j))^2 \quad (1)$$

From Table II, it can be seen that a significant reduction in execution time is achieved by using the 3D integral interpolation algorithm. Savings up to (57% - 66%) in the ray tracing time for different scenes is achieved by using the interpolation process when compared to fully ray tracing the missing pixels. More significant saving in terms of execution time is achieved when compared to the integral imaging lens view algorithm. This made the generation of a single still 3D integral image three times fast than its original execution speed before applying the 3D integral imaging interpolation algorithm.

TABLE II. COMPARISONS OF TIMINGS OF 3D INTEGRAL IMAGING FRAME FOR DIFFERENT RENDERING ALGORITHMS.

SCENE	Total time for rendering the frame using fully integral ray tracing algorithm (in seconds)	Total saved time after using 3D integral imaging interpolation algorithm (in seconds) & (%)
Teapot	3.000	1.750 sec 58 %
Room	2.000	1.232 sec 61 %
Small-balls	2.000	1.236 sec 61 %
Primitives	2.000	1.201 sec 60 %
Tree	14.000	9.791 sec 66 %
Gears	5.000	2.875 sec 57 %

The approach adapted saved up to (9.791) seconds on the computation of Tree scene. Where $f(i,j)$ and $g(i,j)$ are the original image that has been fully ray traced, the interpolated image that has been fully interpolated respectively, and the approximated version respectively. *M x N* is the dimension of the image.

The average root mean square error (*RMSE*) for Red, Green and Blue colours is defined as:

$$AverageRMSE = \left(\frac{RMSERED + RMSEGREEN + RMSEBLUE}{3} \right) \quad (2)$$

$$PSNR = 10\log_{10}\left(\frac{255^2}{AverageRMSE} \right) \quad (3)$$

$$PSNR_{AVR} = \frac{1}{N} \sum_{i=0}^{N-1} PSNRperlens_i \quad (4)$$

The performance of the proposed system was measured in terms of the interpolation achieved (expressed in bits per pixel) and the quality of the fully ray traced image (relative to the original). The PSNR was used as a measure of image quality, its value decreasing with increasing distortion [12]-[14].

TABLE III. 3D INTEGRAL IMAGES QUALITY MEASUREMENT OF TEAPOT

Scene Teapot	RMSE Red	RMSE Green	RMSE Blue	RMSE Average	PSNR (dBs)
Cylindrical lens 30	14.3402	11.0637	15.3345	13.5795	36.8020
Cylindrical lens 37	10.7068	7.6300	11.3042	9.8803	38.1831

$PSNR_{AVR}$ is the peak signal to noise average ratio of several micro-images that have been measured. Table III shows the results that have been obtained using 3D integral image quality measurements for teapot scene. Similar results were obtained for other 3D integral images. The average *PSNR* is given as:

$$PSNR_{AVR} = \frac{301.3942}{8} = 37.674275 \quad dBs \quad (5)$$

Generally a *PSNR* above 30 *dBs* is considered acceptable in assessment of digital image quality. Furthermore from the subjective assessment no degradation in image quality was observed.

The scenes used are shown in Fig. 10 to Fig. 12: The resolution of the frame is set to 512 × 512 pixels Fig. 11, and the resolution per cylindrical lens is set to 512 × 8 pixels Fig. 9. From the Table II, it can be seen no significant savings in the execution time is achieved using interpolation process for Teapot, Room, Small-balls, and Primitives scenes, due to the simplest of the scenes. But there is a respectful reduction in execution time is complex scenes such as Tree, and Gears scenes.

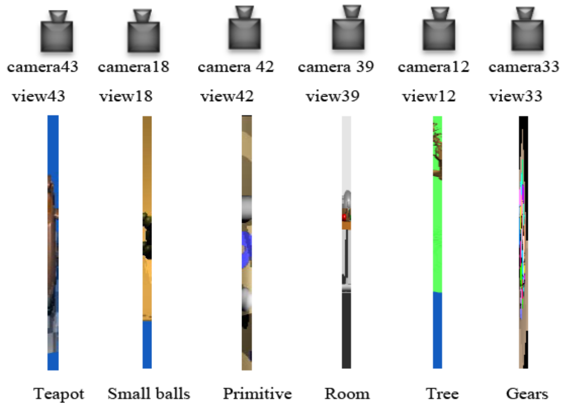


Figure 9. Fully Ray-tracing cylindrical lenses of different tested scenes.

VI. COMPOSITION OF CYLINDERICAL LENSES

Basically, a photo-realistic 3D integral images frame consists of several cylindrical lenses. The final phase of the algorithm is to combine those micro-images in still 3D integral image frame Fig. 10 and Fig. 11. The 3D integral Multiprocessor ray tracer software is adapted in order to generate a two-dimensional array as an image buffer in order to save the micro images. The image resolution of the cylindrical lens is set up to 8 × 512 pixels per cylindrical lens. The resolution of still 3D integral image frame is set up to 512 × 512 pixels per frame and 64 lens per frame.

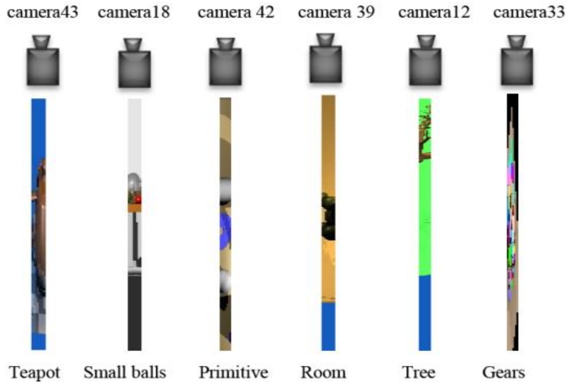


Figure 10. Micro-images of different tested scenes generated after interpolation process.

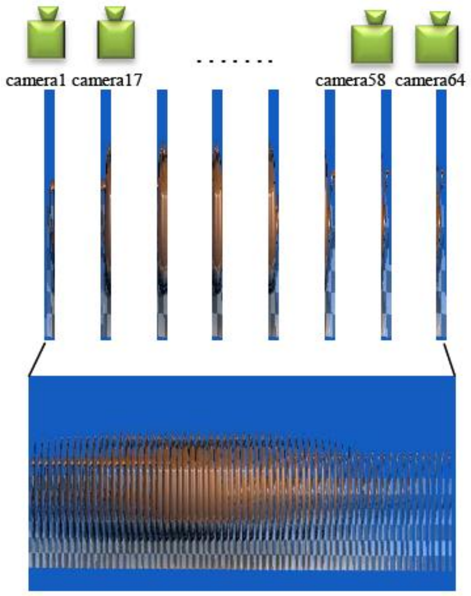
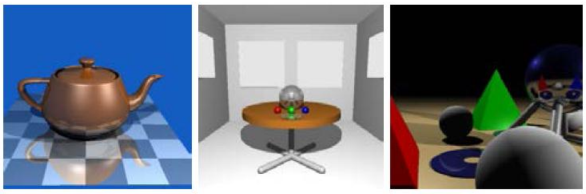


Figure 11. Composed interpolated frame of 3D integral image teapot scene.

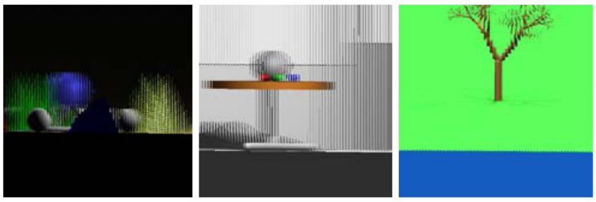


a) Frame of Primitives scene.

b) Frame of Room scene.

c) Frame of Tree scene.

Figure 12. Tested scenes before converted to 3D integral images.



a) 3D integral image Frame of Primitives scene.

b) 3D integral image Frame of Room scene.

c) 3D integral image Frame of Tree scene.

Figure 13. Interpolated still 3D integral image frames of different scenes tested after converted and composed to 3D integral images.

VII. CONCLUSION

This paper provides the processes of strategies are developed to overcome 3D missing information problem based on spatial coherence among cylindrical lenses, with vast improvement in the execution time. A trade off between execution time and image quality has to be considered and it noticed that the improvements in the execution time are achieved without any visible degradation in the 3D integral images quality, composition of cylindrical lenses to generate still 3D integral images frame is achieved.

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