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Computer Generated Integral Imaging (II) System Using Depth-Camera

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Abstract: **This paper presents a computer generated integral imaging (CGII) system that makes better the visual quality of three-dimensional (3D) reconstructed images based on real depth of 3D object. Two dimensional (2D) images are used as an object image in conventional CGII system, therefore all pixels of an integrated image just located in the same depth plane. This problem has been reduced by extracting each pixel's own depth data from a real 3D object's surface using depth camera to generate integral images. It is evaluated the proposed CGII method through comparing with the integral image generated in CGII conventional method. Experimental results indicate that the integrated images have full parallax since all pixels locate in its own depth plane. So, it displayed more natural 3D image.**

Keywords: **Integral Imaging, Computer generated integral imaging.**

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1. INTRODUCTION

The present era is three-dimensional (3D) era but all displays are presenting two-dimensional (2D) images. 3D displays are needed for so many important applications, namely: a remote control, a virtual surgery, a 3D design and so on because of this imaging provides extra information that is helpful to human. Some 3D technologies have been developed, for example, stereoscopy, auto stereoscopy, holography, and integral imaging (II). Among the aforementioned techniques, II [1], [2] has been one of the attractive autostereoscopic 3D display techniques. The II technique does not require any extra viewing aid and has continuous viewpoints within the viewing angle [3], [4] that are considered the striking features of this technique. It also provides full parallax, continuous viewing angle, full color and real-time displaying [5]. In general, an integral imaging system comprises of two parts; pickup and reconstruction. In the pickup part, the rays coming from 3D object through a lens-array is recorded as elemental images representing different perspectives of a 3D object. In the reconstruction part, the recorded elemental images are displayed on a display panel and the 3D image can be reconstructed and observed through a lens-array [6], [7]. In this configuration, the specifications of lens arrays used in the pickup and display parts should be same. Recently computer generated elemental image has been discussed by Singsong Jung *et al.* [8]. Instead of pickup process in conventional II that recording elemental image by optical device, the elemental images of imaginary objects are computer-generated. In recent works of CGII, one of the major problems was the plane depth of reconstructed image due to object images for generating elemental image usually contains only color value, and all pixels depth data were given same depth data by user. Here, the x and y values of elemental images can be calculated from given values which satisfies for all pixels of an object image. However, every pixel of a reconstructed image locates in same depth plane [9-13]. Therefore it is not enough for feeling parallax because there is no depth disparity between pixels which locate in same object image. While using more than two object images with different depth values respectively, it can be feel the parallax only between plane images as shown in Fig. 1. In fact, the real 3D image depth not only in a depth plane.

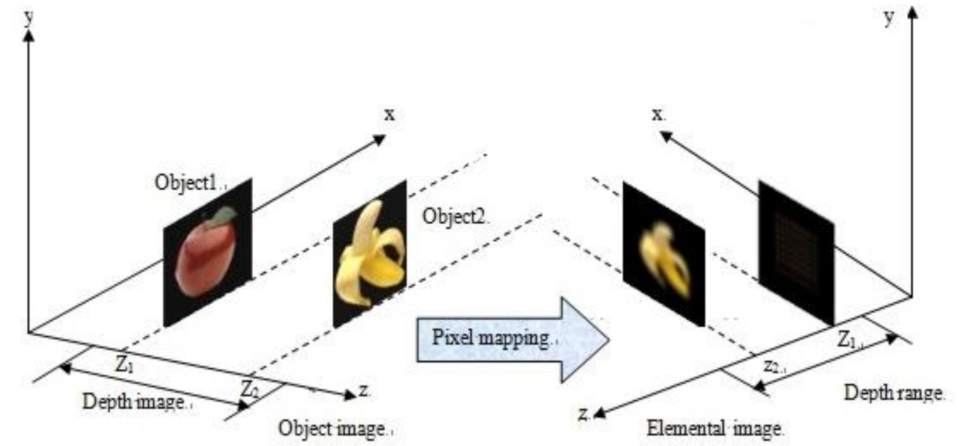
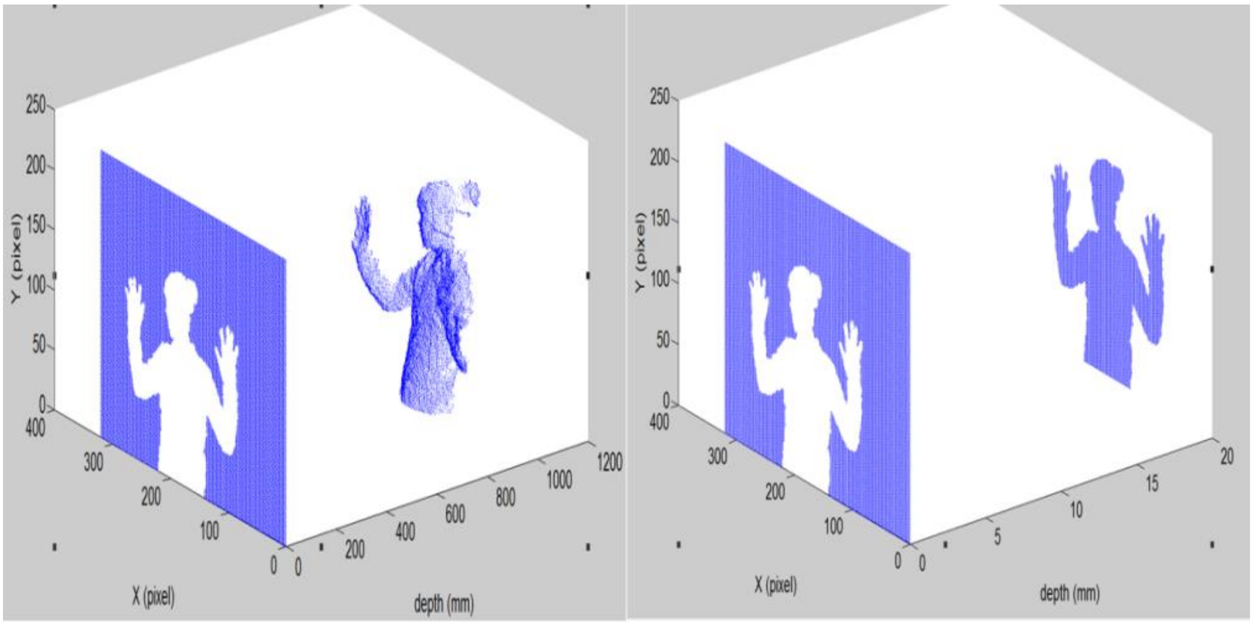


Fig.1. Conventional generating elemental image from object image

To overcome the drawbacks we proposed a new method to generate elemental images based on all pixels depth data of real-3D object. We extracted 3D information of object by depth-camera and calculated its depth map that include pixels own depth data. Fig. 2 shows comparison of object image pixel position in conventional and proposed method as shown Fig. 2(b) depth data z = 20mm is not calculated from actual depth data that is given arbitrarily by user. If we generate elemental image use the pixels set, all of the integrated image pixels will just locate at one depth plane. The Fig. 2(a) shows pixels position in proposed method that each pixel's depth is calculated from real depth by depth camera.



(a) **(b)**

Fig.2. (a) Proposed method of obtain object pixel (b) Conventional method of obtain object pixel

Elemental images would be generated by proposed method and then we integrated them into 3D images using a lens array. Finally, we can observe a more natural 3D image that every pixel reconstructed on its own depth plane.

2. CGII BASED ON EACH PIXEL'S REAL DEPTH DATA

The main purposed of CGII is to compute elemental image' pixel coordinates. Elemental image pixels were formed by pixels of object focusing through lens-array. In conventional CGII, the object image pixels are all on the same depth plane. It leads to all pixels integrated image locate on the same depth plane. To overcome this problem, a new CGII method has been proposed in our system. Table1. Shows the architecture of proposed generating elemental image from real-3D object.

Table: 1. Elemental image generation of the proposed architecture

	Parameter Input	**Object Image Input**
Input	Information of Lens- array -size of elemental lens -Number of elemental lens -Focal length of elemental lens Information of Display -Pixel pitch of LCD -Gap between lens and display	Object Image -Obtained colour and depth image of the 3D object -Extract region of interest -Convert pixels real depth data -Arranging pixel coordinates of object image
Calculation	Calculation of pixel coordinates	
	Mapping object pixel to elemental image pixel -Coordinates of object pixel -Pass through lens array centre -Locate at elemental image pixel plane -Arranging elemental image pixel	
Display	Display elemental image pixel on elemental image plane	

The proposed method consists of three parts. In the input stage the parameters of lens-array and display were inputted, furthermore information of 3D object should be also inputted such as pixel's color, depth and index. In calculation stage we mapped object pixels to elemental image plane. Finally, in display stage the calculated elemental image pixels set will display on LCD.

2.1 Information of input for proposed CGII computation:

In the input stage, the parameters of lens-array and display are inputted. It includes the size, number and focal length of virtual elemental lens, pixel pitch of display and the gap between display and lens-array. Furthermore it is necessary to arrange pixels of 3D object. Fig. 3 shows the color image of object and its depth map image. Fig. 3(a) is the object image and Fig. 3(b) is its depth map.

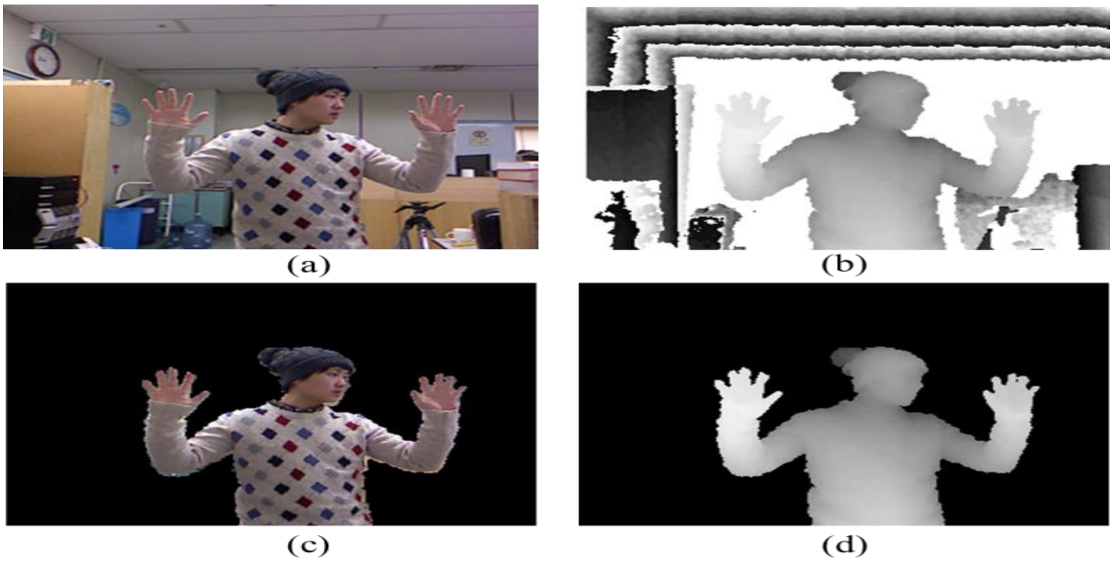


Fig.3. Color images of object and their depth map images

(a) Color image (b) Its depth map (c) Region of interest (d) Its depth map

In order to extract the region of interest in depth map we have separated the background and people. It is shown in Fig. 3(c) and Fig. 3(d). The depth data of every pixel on the 3D object surface has been calculated. In order to arrange pixel's coordinates of object image in x, y, z axis we need map the depth data to each corresponding pixel. It is noticeable from Fig. 4 object pixels located in the depth from 842.6mm to 1123.9mm since every pixel's depth data is the real distance between the point of object surface and the depth camera. However, in our integral imaging system the depth range is from 39.09mm to 43.9mm. In order to locate pixels of object image in the limited depth range we have to convert the real depth data.

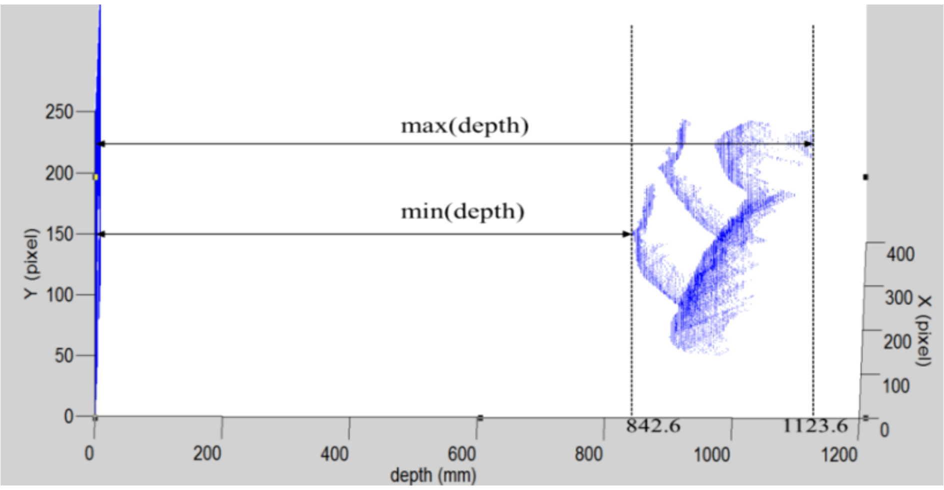


Fig.4. Real depth data of from 3D object

From lens law central depth *cd* is given by Eq.1

$$cd = \frac{f.g}{f+g} \text{...(1)}$$

$$L_{ij} = \frac{cd(\max(rd)+\min(rd))}{rd(j,i)\times 2} \text{............................(2)}$$

The $L_{i,j}$ is the converted distance from (i, j)-th pixel’s to lens array.

2.2 Calculation and generating elemental image by proposed object image:

In the calculation stage we make three buffers generally every pixel’s depth and color data stored in first buffer second for center of elemental lenses and third for the calculated elemental image pixels set. The coordinates of elemental lens are computed based on pitch size and index of the elemental lenses. In the following, the coordinates of pixels in elemental image plane are calculated by coordinates of object pixels and center of lenses array. Fig.5 shows the geometry of mapping pixels of object to elemental image plane. The pixel at (x_i, y_i, z_i) positioned after passed through center of lenses and then locate on elemental image plane and the coordinates of pixel in elemental image plane (u_i, v_i) is given by Eq. 3-5.

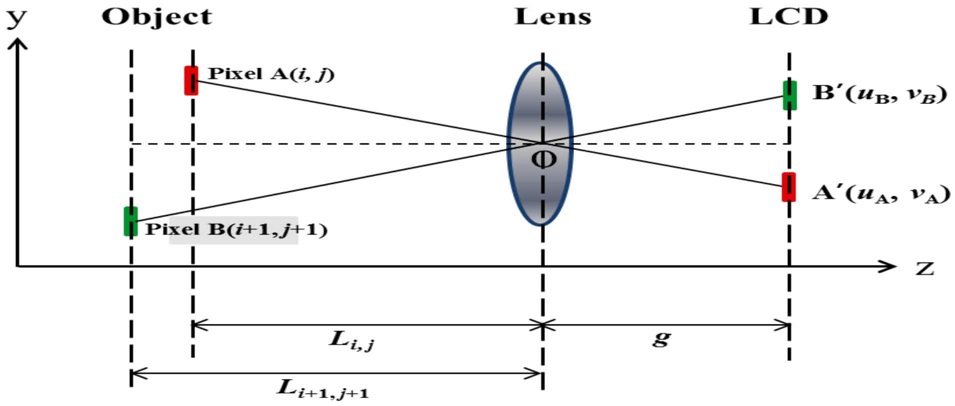


Fig.5. Geometry for mapping elemental image

$$P_I = \frac{f.g}{(g-f)}.\frac{P_D}{g} \text{...(3)}$$

$$u = P_L.i_L - (i - P_I - P_L.i_L).\frac{g}{L_{i,j}} \text{........................}(4)$$

$$v = P_L.j_L - (j.P_I - P_L.j_L).\frac{g}{L_{i,j}} \text{........................}(5)$$

Where *i*, *j* are pixels index of object image in x, y axis, i_L , j_L the index of lens center in x, y axis, P_L the size of lens and P_D the pixel size of display, *f* the focal length of the lens, *g* the gap between the lens-array and elemental image plane. As a result, the set of elemental image points can be plotted. From the above mentioned equations we can see every pixel's position in elemental image plane are calculated by their own depth data $L_{i,j}$ and the calculation process is performed repeatedly until the set of elemental images for all pixels of an imaginary object are determined. Fig .6 shows the elemental image set that generated by proposed method.

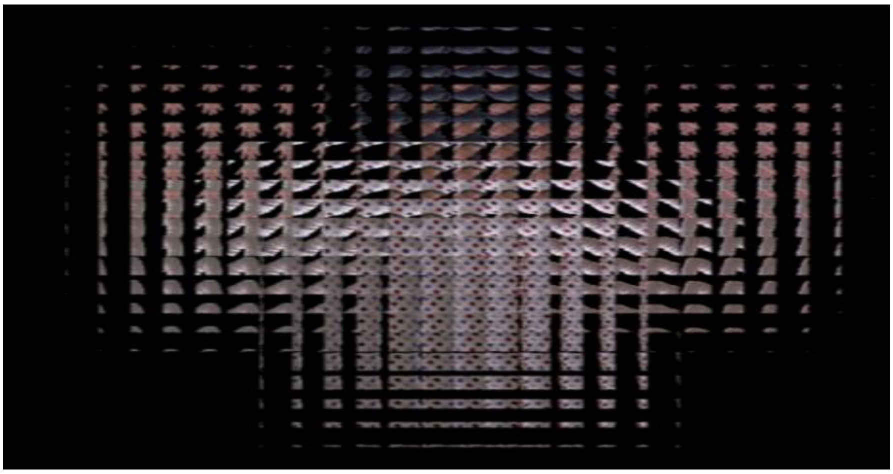


Fig.6. Elemental image generated by proposed method

3. EXPERIMENT

We showed the experimental results by using our proposed method. For justifying the advantages of the proposed method we compared pixels parallax of proposed CGII with conventional CGII. Fig.7 shows the configuration of proposed system. It consists of a depth camera, RGB camera, high-resolution display and a lens-array. In our experiment we use Kinect sensor as the depth-camera and RGB camera. It is shown the specification of experimental setup by Table.2.

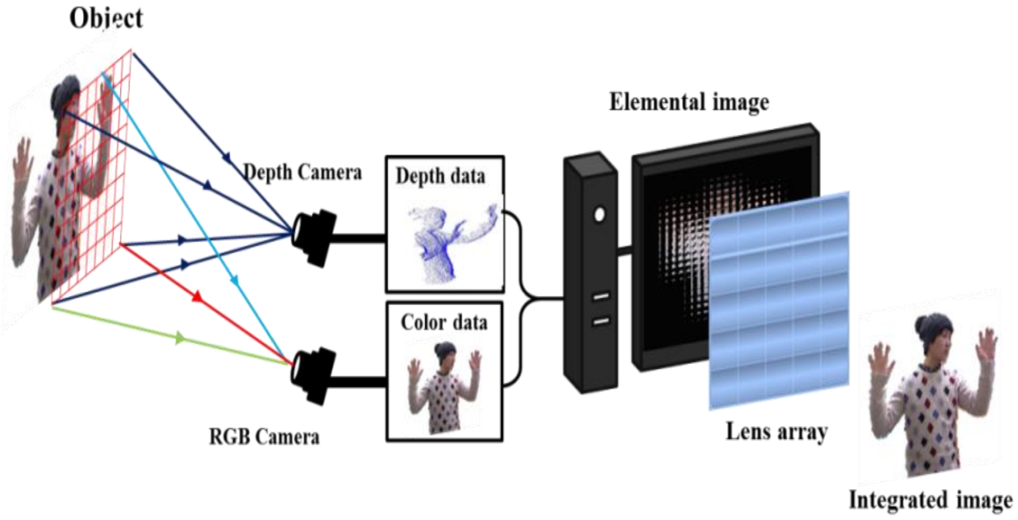


Fig.7. Configuration of proposed system

Table: 2. Specification of the experimental setup

Set up	Specifications	Characteristics
Lens array	Focal length Number of elemental lens Pitch of elemental lens	8mm 30(H) × 30(V) 5mm
Depth Camera	Model	XBOX 360 KINECT sensor
Object	Transverse dimension	320pixels × 240pixles × 10mm
Display	Pitch of pixel Number of elemental lens	0.1245mm × 0.1245mm 3840 × 2400
Gap	Between lens array and display	10mm

The 3D object is demonstrated by proposed CGII and the conventional CGII respectively and then observed from five unlike viewing positions. As shown in Fig. 8 the horizontal distance x and vertical distance y between marked pixels are different since all pixels generated based on its real depth so pixels of integrated image located variety depth plane in different viewing positions we can observe parallax image. It can be verified that proposed method triumphantly creates pixels disparity. However, in Fig. 9 we just observed that the image pixels shifted all together but the value of x, y didn't change. It indicates that the integral image generated by conventional method doesn't have pixels disparity because all pixels depth data were same. Through the comparison of Fig 8 and Fig 9 we can confirm that the integral image generated by proposed method displays more natural 3D image. In experimental result there are some distortions. It is because of the rudimentary lenses are simple spherical lenses which have significant aberration. If improve the quality of lens array it can be avoided. Furthermore we evaluate the lateral resolution of integrated image in proposed and conventional CGII. There are two types of resolution of the integrated image, namely: Lateral resolution and longitudinal resolution. The lateral resolution which signify the resolution of the integrated image at a given image plane and the

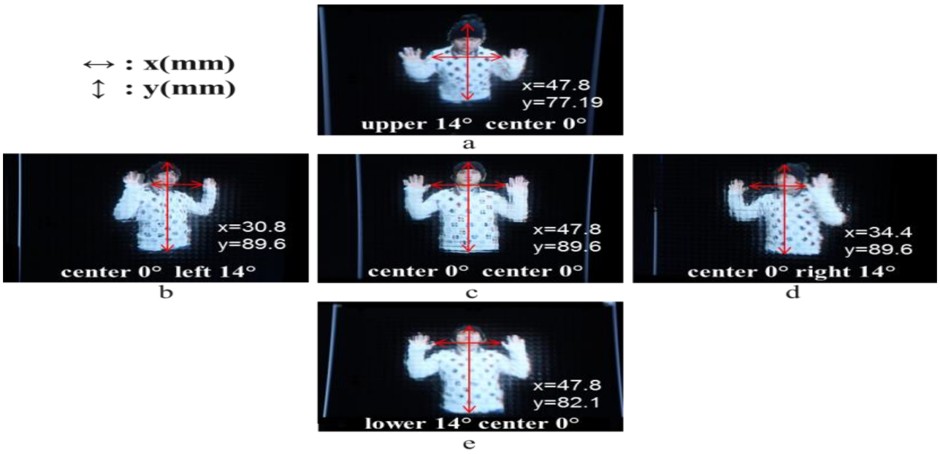


Fig.8. Experimental result of proposed method at five positions

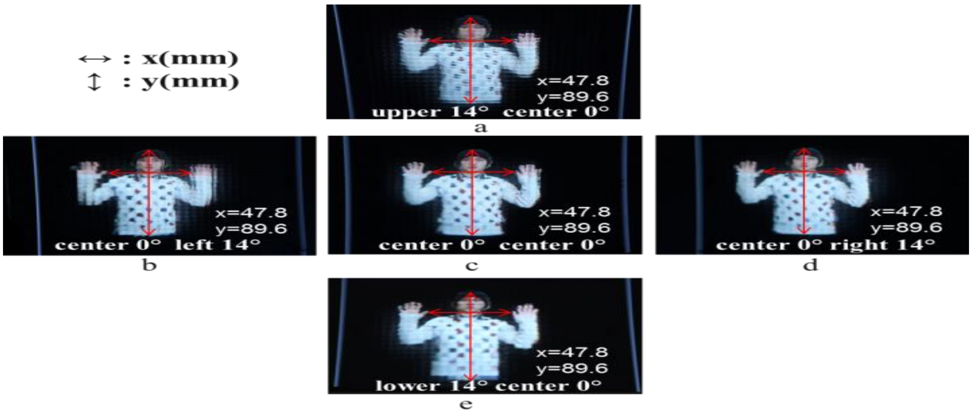


Fig.9. Experimental result of conventional method at five positions

longitudinal (depth) resolution which is related to the number of image planes into the depth direction. If we label the lateral resolution R_i as the spatial resolution of the i-th pixel at depth plane $z = z_i$, f_i can be obtained by calculating the cutoff frequency of the modulation transfer function (MTF) of the lens. For incoherent illumination the MTF is expressed as follows:

$$MTF = \left\{1 - \frac{\lambda f_i L_i}{P_L}\right\} \operatorname{sinc}\left[P_L \left\{1 - \frac{\lambda f_i L_i}{P_L}\right\} R_i L_i err(L_i)\right] \text{..........(6)}$$

Where

$$err(L_i) = \left|\frac{1}{Z_i} + \frac{1}{g} - \frac{1}{f}\right| \text{...(7)}$$

The formula of lateral resolution R_i of integral image was derived in. Singsong Jung *et al.* [8].

$$R_i = \frac{1}{\left|\dfrac{gP_L}{P_D + \dfrac{gP_L}{L_i}} - L_i\right|} \text{..(8)}$$

Here, L_i is the distance between i-th pixel of integrated image and lens array. The Eq.3 shows the relation between the pixel's lateral resolution and its depth data L_i. We have calculated all pixels lateral resolution and drew its distribution in Fig. 10.

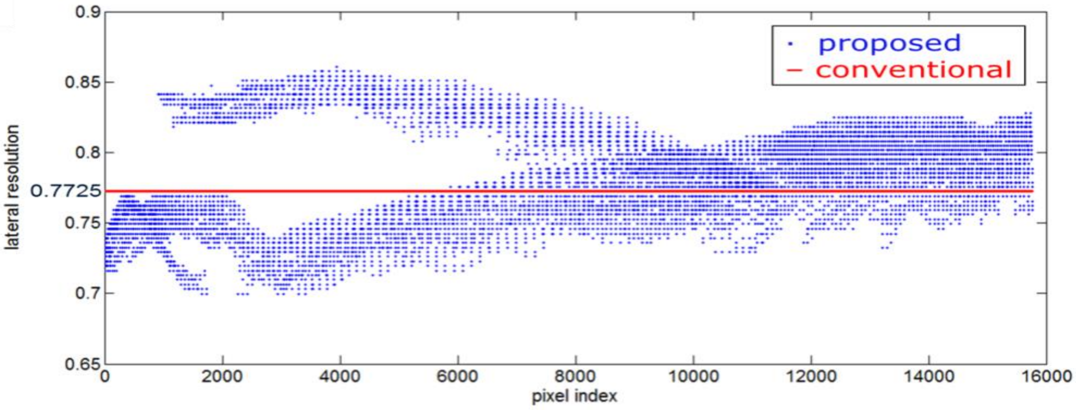


Fig.10. Lateral resolution distribution of integrated image pixels

It is shown in Fig.10 the pixel integrated by proposed method has various values. However, conventional lateral resolution of all pixels is same since pixels in different depth has different lateral resolution. we can confirm again that the integral image generated by proposed method displayed more natural 3D image.

4. CONCLUSION

In this paper, we proposed a different CGII technique to improve the viewing quality of 3D reconstructed images. We extracted the actual depth data from all pixels of real 3D object surface to generate more natural 3D image. We confirmed the advantage through some experiments that comparing with conventional method. Since the pixels disparity, we can observe parallax image in different view position. Experimental results showed that proposed method is efficiently improving the 3D image viewing quality. If we improve the speed of calculation then real-time integral imaging display can be implemented and might be applicable to real-time 3D display system.

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