PROTOTYPE OF HIGH RESOLUTION 3D DISPLAY USING TWO LENS ARRAYS AND DEPTH SAMPLING

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ABSTRACT

This paper presents a prototype of high resolution 3D display with a new principle. We have proposed a new 3D display which has the features of both Integral Imaging (II) and volumetric display. The proposed display consists of two lens arrays and a thin volumetric display. When the viewer watches a thin volumetric display through two lens array, he can perceive a thick 3D image. In other words the two lens arrays can play a role of a convex lens which has a large diameter as a amplification of a depth. The advantage of the proposed display is that it has higher resolution than II and it is smaller than volumetric display with a large convex lens. In this paper, we show a detail of a prototype 3D display. We took various errors into consideration when we simulated 3D display and we found suitable lenses parameter from the simulation result. Then we confirm that the prototype will be able to reconstruct 3D images.

Keywords: 3D display, Integral Imaging (II), volumetric display, lens array

1. INTRODUCTION

There are many researches about autostereoscopic displays, which provide a 3D perception without any special glasses. One example is Integral Imaging (II), which is based on the principle of Integral Photography (IP).[1] It consists of a micro-lens array and 2D image display. The problem of II is that it needs high resolution 2D image because each lens requires a different small elemental image. Another example of 3D display is volumetric display.[2] Volumetric display reconstructs 3D space by displaying depth division images at the proper position within the time of the afterimage. The problem of volumetric display is that the size of this display must be large.

We therefore have proposed a novel 3D display with a new principle.[3] The proposed display has the features of both II and volumetric display and there is no need to wear special grasses. This display's resolution is higher than that of II and its size is smaller than that of volumetric display. The proposed display consists of two lens arrays and a thin volumetric display. Two lens arrays can amplify the depth of volumetric display. A large convex lens can also amplify the depth of images but two lens arrays can reduce the size of the display. The feature of the proposed display is that the element images, which are similar to II's one, are formed by optical system so the resolution of the proposed display can be higher.

In this paper, we show a detail of a prototype 3D display. When we product a prototype, as a practical matter we must take a manufacture error into consideration because we plan to use small lenses. Furthermore a lens aberration affects a 3D image so we must find a suited position and a form of lenses. Thus we took these parameters into consideration when we simulated 3D display and we designed a prototype display based on this simulation result. In the near future, We plan to make a prototype and it will consist of plastic lens arrays and several films. The films play a role of thin volumetric display. Finally, we confirm that the prototype will be able to reconstruct 3D images with the simulation.

The reminder of this paper is organized as follows. Section 2 explains the principle and feature of the proposed display. The display design is explained in Section 3. Section 4 presents the simulation with a proposed display. Section 5 concludes this paper.

2. PROPOSED DISPLAY

In this section, we describe a overview, a principle and application of a proposed display.

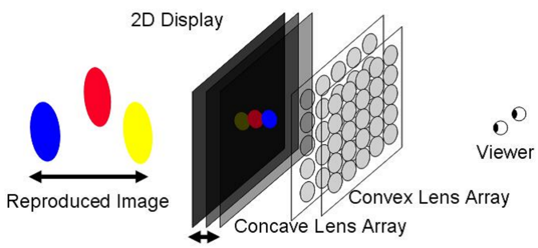

Fig. 1: Structure of proposed display

2.1 Overview

The proposed display consists of a thin volumetric display and two lens arrays. We plan to use a vibrating 2D display or a multiple liquid crystal scattering shutters as a thin volumetric display. Two lens arrays are a convex lens array and

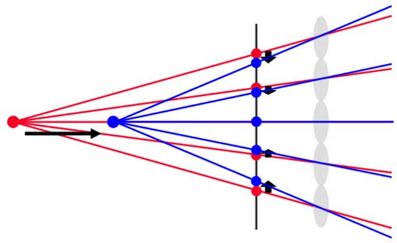

Fig. 2: Depth change by pitches

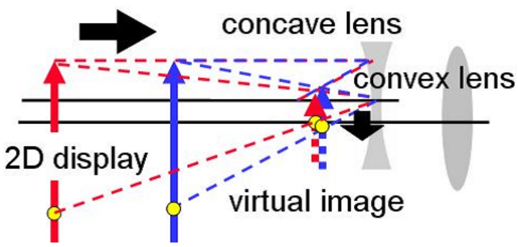

Fig. 3: Close up of element image shift

a concave lens array. The overview of the proposed display is shown in Fig. 1. The two lens arrays are placed between the thin volumetric display and the viewer, and the convex lens array is closer to the viewer. And the lens pitch of the convex lens array is smaller than that of the concave lens array. The viewer can perceive 3D image when he watches the thin volumetric display through two lens arrays.

2.2 Principle

In the proposed display, element images and convex lens array are used for a reconstruction of 3D images in the same way as II. (Figure 4) The element images must be aligned at various pitches because the element image pitch affects a reproduced position of element images, in particular, the pitch change lead to the position change of the reproduced image as shown Fig. 2. In II method, if you want to improve a performance of a display, you must use a high resolution 2D display because small element images are displayed by it.

We therefore use a concave lens array in order to form element images. Each of the concave lens forms the virtual image of the image displayed on the 2D display. These virtual images work as the elemental images, which have almost the same role of II's one. The element image corresponds one-to-one with the convex lens of convex lens array. In doing so, the element images have the resolution of the 2D display, and the resolution of the proposed display will be higher than that of II. Thus a 2D display and two lens arrays can reproduce the high resolution image at one depth position as shown in Fig. 5. However the reproduced image is not 3D image but 2D image because the pitch of element images is fixed.

So we should change the position of the 2D display to change the pitch of element images. If the distance between 2D display and concave lens array is changed, the virtual images, or element images, formed by concave lens should be enlarged or reduced. This scaling leads to the change of element image position because of a declination of axes of lens from a difference of pitch of concave lens and convex lens. So the relative position of element images to the convex lenses is changed and element images are shifted at right angle to the axes when we move 2D display toward to lens arrays as shown in Fig. 3 The element images also shift at parallel to the axes of lenses but we can exclude the parallel shift because it is smaller. When we take the element image shift as a whole, we can regard the shift as the change of the pitch of element images. As we described this means that the depth position of the reproduced image is changed as shown Fig. 6. This is how a moving 2D display or a thin volumetric display and two lens arrays can reproduce images at various depth positions. So the proposed display can reconstruct 3D space by displaying the image corresponding to the reproduced depth on the moving 2D display, as volumetric display does. In other words two lens arrays can amplify the depth. This also means that the reproduced 3D images are see-thorough as with volumetric display.

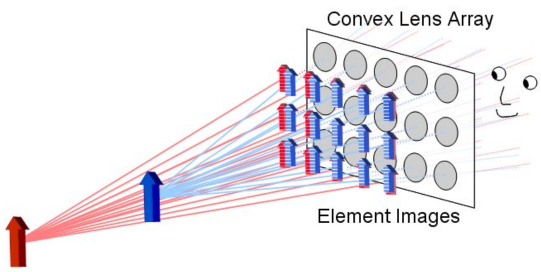

Fig. 4: Element images and convex lens array

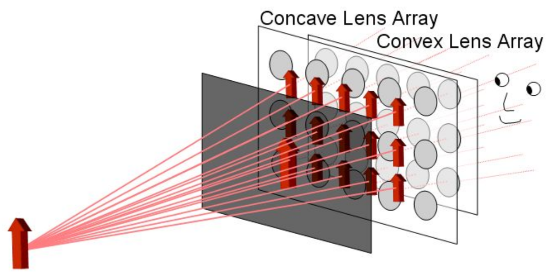

Fig. 5: High resolution image is reproduced

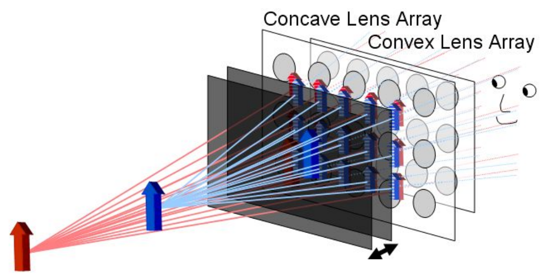

Fig. 6: Images are reproduced at two depth

2.3 Features and Application

The features of the proposed display are as follows. First the resolution is higher than II' s one and the size is smaller than volumetric display's one. Second, the reproduced 3D images are see-thorough as well as volumetric display and the viewing area is narrow because the viewer watches the display through two lens arrays. Finally, 2D display must be vibrated in our method, but in the case of reproducing the 3D image at a long distance, we don't have to vibrate widely.

Considering these features, the proposed display may suit for 3D head up display.(Figure 7) 3D head up display will show the traffic information, for example oncoming cars, traffic lights, road traffic signs and course information. If it is possible to show as if these kinds of information existed at the actual position when we cannot see these kinds of information because of the obstacles, 3D head up display become beneficial device. But we assume these kinds of information must be far away. To reproduce the distant objects, the display must be a high resolution one, because it needs to show the small objects and to express small change of the parallax. Furthermore, when we assume that we mount 3D head up display in a car, it should be as small as possible. And only the driver watches the 3D head up display so it is not trouble that the viewing area is narrow.

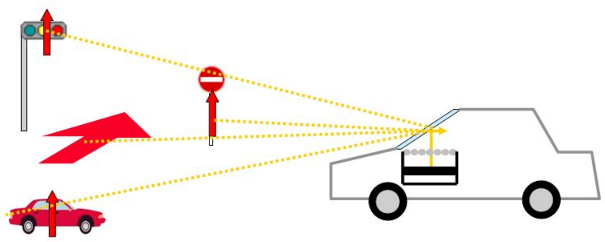

Fig. 7: 3D head up display

3. DISPLAY DESIGN

3.1 Reproduced Depth Position

In section 2, we show that a 2D display and two lens array can reproduce a high resolution image at a certain depth position. The depth position is determined by the lens parameter and 2D display position. The depth position of the reproduced image d is expressed by:

$$d = \frac{1-m}{\frac{f_{cc}}{x+f_{cc}} - m} f_{cv} \quad (1)$$

where f_{cc} and f_{cv} are a concave lens focal length and a convex lens focal length. x is the position of 2D display from the viewer. m is a degree of a declination of lens axes. m means how different the axes of concave lens and convex lens are. Fig. 8 is the graph of equation 1. Fig. 8 shows

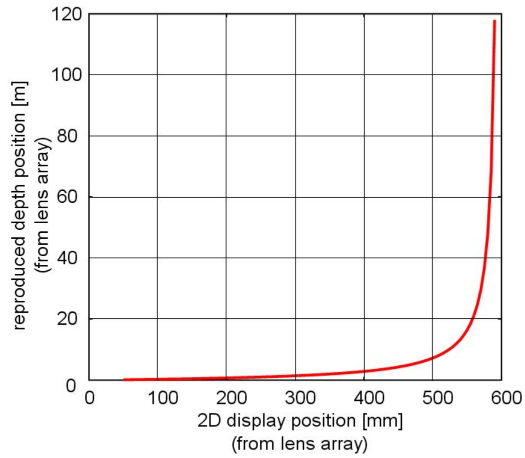

Fig. 8: Rreproduced depth and 2D display position (overall)

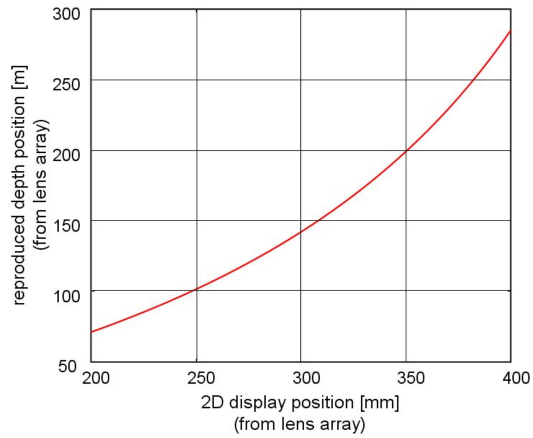

Fig. 9: Rreproduced depth and 2D display position (close-up)

the relationship between the position of 2D display and the position of the reproduced image. The real line is the relationship between the 2D display-to-lens array distance and the reproduced image-to-lens array distance. Fig. 9 is the close-up of Fig. 8.

3.2 Image Size

We must change the size of the image displayed on 2D display to corresponding to the reproduced depth. The image size to display is expressed by:

$$i_{size} = \frac{1 - \frac{x+f_{cc}}{f_{cc}} m}{1-m} r_{size} \quad (2)$$

where i_{size} is the image size on 2D display, or input image size and r_{size} is the real object size.

3.3 Display Performance

In this section, we describe relationships between a viewing area and a 3D image quality and between a display size and a 3D image quality.

- Viweing Area and Image Quality
  To enlarge a viewing area, we must use a lenses which have a short focal length. However if radii of curvature of these lenses are small, a reproduced image quality will drop because of a lens aberration. In particular, a focal length of a concave lens more affects a 3D image quality because the focal length of concave lenses is shorter than that of convex lenses. In addition, a light ray which doesn't go through around center tends to be affected by a lens aberration. We therefore have light rays pass through around a center of concave lenses by extending a focal length of convex lens.(Figure 10) If we extend a focal length of convex lenses, light rays will tend to concentrate at a center of concave lenses. As a result, an affection of a lens aberration will lessen.

- Display Size and Image Quality
  To reduce a display size, we must enlarge a declination of convex lens and concave lens axes. However a large declination will lose a quality of 3D image.

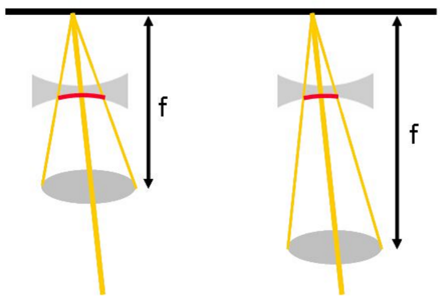

Fig. 10: Light ray tends to pass throw around a lens center by extending a focal length of a convex lens.

4. SIMULATION

In this section, we show the simulation result about a prototype display. We simulated this display considering a lens aberration and manufacturing errors. And we determined lens pitch and form and a lens array position.

4.1 Lens Form

We simulated a proposed display while comparing lens forms. For example, in the simulation we used a plano-concave lens and biconcave lens which have same focal length and we compared images with each lens. As a result, the quality of 3D image with biconcave lens is superior to the other as shown in Fig. 11. The reason of this is plano-concave lens has a small radius of curvature. However, we will be not able to use a biconcave lens array because of manufacturing method. Producing a biconvex lens is more difficult than doing a plano-concave lens. Thus in this paper, we use a plano-concave lens which doesn't have too small radius of curvature, 3mm.

4.2 Lens Pitch and Lens Array-to-Lens Array Distance

A difference between concave lens pitch and convex lens pitch significantly affects a quality of 3D image and display depth size. If a difference is reduced, a quality is improved but a display size is enlarged. In this paper, we determined a different value with putting a high priority on a 3D image quality.(Figure 12)

Lens array-to-lens array distance is determined by a focal length of a convex lens. As we described in section 3.3, if a focal length of convex lens is extended, a quality is improved but a viewing area is reduced. In this paper, we put a high priority on a 3D image quality so we determined that a focal length is 7mm. We therefore plan to use a plano-convex lens array, because it needs not reduce a radius of curvature and lens aberration will be small. We show the simulation results in case of focal lengths of convex lens is 6mm and 7mm.(Figure 13)

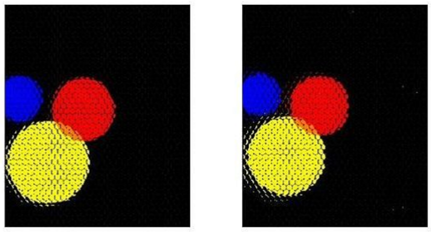

Fig. 11: 3D image. Left image is produced with biconcave lens and right is with plano-concave. The concave focal length is 3mm and the convex lens focal length is 6mm

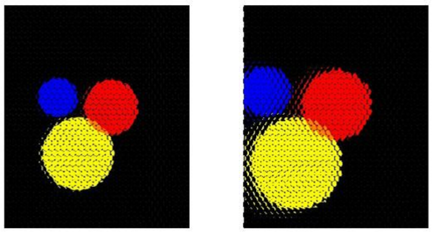

Fig. 12: 3D image. Left image is produced with concave lens whose pith is 2.01mm and right is 2.02mm. The convex lens pitch is 2.00mm

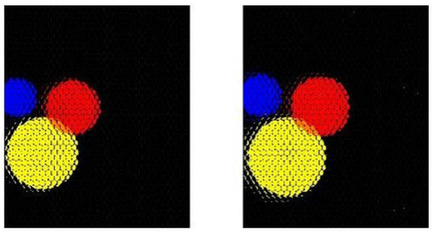

Fig. 13: 3D image. Left images is produced with convex lens whose focal lenght is 7mm and right is 6mm)

4.3 Manufacturing Error

We plan to make a prototype of a proposed display and it will consist of plastic lens arrays which have parameters shown in tabl 2. However these values, in particular, lens pitches are small. We therefore simulated this display considering manufacturing errors, a variation of an individual lens position and of a radius of curvature in lens arrays and a declination of a lens arrays position. The variation of individual lens position means a position variation of each lens on a lens array plane surface. These error values are shown in table 1.

Table 1: Manufacturing error

object	standard deviation
each lens position	0.002
radii curvature	0.002

4.4 Error of Placement of Lens Arrays

We also considered an error when we place two lens arrays, or a declination of positions of lens arrays. The concave lens pitch is 2.01mm so the 0.005mm variation of each lens array position may be the most effective value. This error is shown in table 3.

4.5 Simulation Result

Finally we simulated this 3D display using ray tracing method with the parameters as shown in tables 2 and 3. We considered a variation of individual lens position and of a radius of curvature in lens arrays and a declination of positions of lens arrays. In this simulation we assume that three circles are put at three depth positions as shown in table 4, and a camera captured images from 50cm from a display. The camera moved from side to side by 10cm each side and it faced a display center. The simulation result is fig. 14. The result shows a moving parallax and 3D image is high quality.

Table 2: Lens array parameters

lens array size	100mm×100mm
material	acrylic (PMMA)
refractive index	1.492
concave lens form	plano-concave lens
convex lens form	plano-convex lens
concave lens array pitch	2.01mm
convex lens array pitch	2.00mm
concave lens focal length	-3.0mm
convex lens focal length	7.0mm
lens alignment	hexagonal alignment

Table 3: Display parameters

2D display size	200mm×200mm
viewing distance	500mm
lens array distance	4.8mm
declination of lens array	0.035mm

Table 4: Reproduced Depth

2D display position (from lens array)	reproduced depth (from viewer)
250mm	1.52m
300mm	1.92m
350mm	2.49m

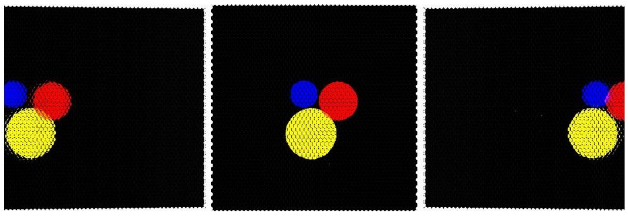

Fig. 14: Simulation result. The camera moved from side to side by 6cm each side and it faced a display center. We can confirm a moving parallax and 3D images are high quality. The viewing distance is 50cm.

5. CONCLUSION

We presented the detail of the prototype of the new 3D display using the new principle. The proposed display has the features of both II and volumetric display and it fundamentally has the higher resolution than II and it is smaller than the volumetric display. In this paper we designed the display for the prototype and we simulated the display considering the manufacturings error and the lens aberration. Finally we confirmed that the proposed display will be able to convey the 3D image to the viewer. In the future we plan to product the prototype display.

6. REFERENCES

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