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Volumetric 3D Display using a Rotating Spiral Screen - Evaluation of the Visible Region -

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ABSTRACT

We have proposed a volumetric 3D display in which cross-sectional images are projected on a rotating spiral screen. One of challenges of this method is an existence of a blind region generated depending on observation angle. We evaluated dependence of the size of the blind region to the screen shape.

1 Introduction

The binocular stereo displays are currently the most popular 3D system. They have however, apparent weak points. They only offer a single or, at most, limited number of viewpoints and they cannot provide side nor backside view of objects. They often request wearing special glasses. On the other hand, the volumetric 3D displays, which provide light pixels in 3D spaces, can offer observation from universal directions without using special eyeglasses. Typical volumetric displays were already developed by using rotating LED arrays; they have weak points of not only mechanical difficulty due to rotating heavy LED arrays but also low resolution.

We have been focusing on another kind of volumetric display method in which multi layers of cross-sectional images are formed, on rotating spiral screen, by a projector synchronized with the rotation speed [1]. This 3D system, however, has a potential problem that the blind region is partially assumed in the cylindrical display volume formed by the rotating spiral screen [2], [3]. This is because the body of the spiral screen often blocks the light path from viewpoints to the spiral screen surface.

In this study, we used ray tracing method to identify this blind region. We evaluated dependence to the spiral screen shape of the size of the blind region.

2 Construction of our 3D Display System

An arrangement of our 3D display system is shown in Figure 1. A projector is synchronized with a spiral screen that is rotating at high speed. The projector forms multi layers of cross-sectional images onto the rotating spiral screen. Three directional images are formed by the accumulated afterimages on the spiral screen.

We have once used a staircase type screen (Figure 2 (a)). The number of cross-sectional images was thus determined by the limited steps of the staircase. We are now using a slide type screen (Figure 2 (b)). This type can accept an infinite number of cross-sectional images on the screen. This allows us to display smooth 3D images. We are forming 64 layers of cross-sectional images in our prototype system.

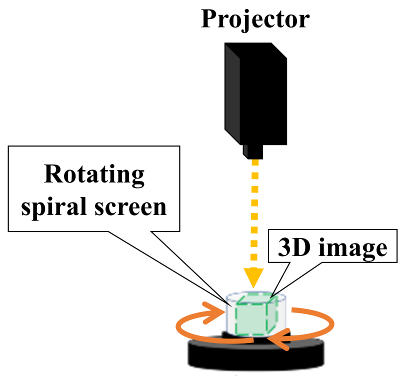
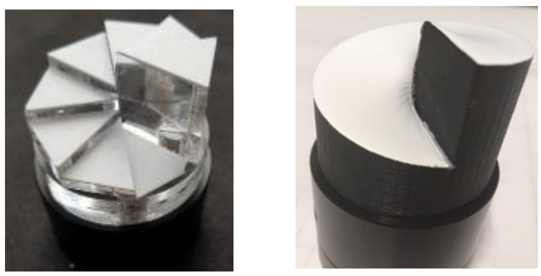


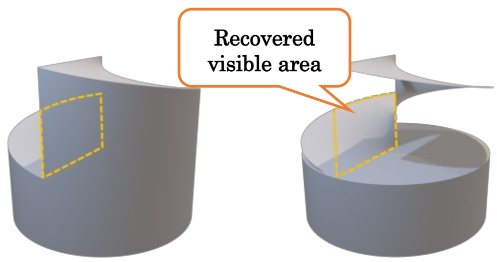
Figure 1. Arrangement of the proposed 3D display system



(a) Staircase type (b) Slide type
Figure 2. The type of the spiral screen used

3 Evaluation Method

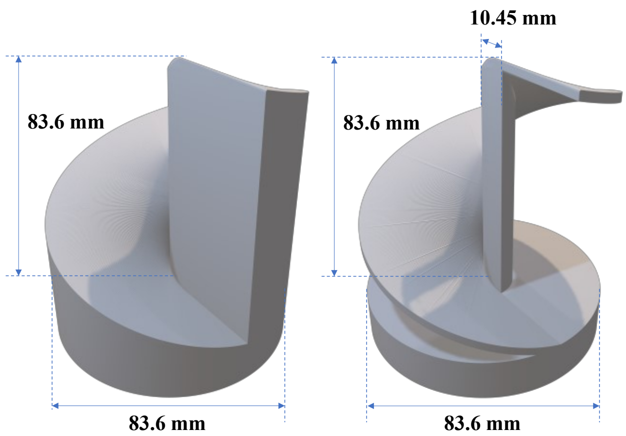
Slimming of screen body can be expected as a good solution to reduce the blind region. Figure 3 shows how the slim type screen (Figure 3 (b)) can recover the invisible region in the conventional fat type screen (Figure 3 (a)). The area surrounded by the yellow dotted line in Figure 3, can be recovered as a visible area by using the slim type screen.



(a) Fat type (conventional) (b) Slim type
Figure 3. Effects of screen shapes

Figure 4 shows a 3D model of the spiral screen; (a) is a fat type with full cylindrical body, (b) is a slim type, which has the minimum body for providing the spiral slope. The extent of the blind region was evaluated by using ray tracing method on the 3D CAD data of the spiral screen.

A screen area is visible from a viewpoint when the light from the viewpoint can reach the screen area. We extracted the accumulation of screen areas where the light from each viewpoint cannot reach as the blind region. Observation angle θ was defined as the angle of the viewpoint relative to the horizontal top surface of the spiral screen (Figure 5). The blind region of the screen surface was calculated for each rotated position of the spiral screen. The screen rotation angle was set in increments of 5.625 degrees, which is 64 divisions of 360 degrees. The observation angle θ was set in 10-degree increments from 10 to 80 degrees. The visible area ratio of the screen surface was calculated for each 64 screens angle respectively. The visible volume ratio in the total cylindrical volume scanned by the spiral screen was calculated as the average of the visible area ratio for each 64 screens angle.



(a) Fat type **(b) Slim type**

Figure 4. Two types of the spiral screen

4 Evaluation Results

Figure 6 shows the visible volume ratio for each quarter volume when the cylindrical displaying volume of the fat type (Figure 4 (a)) is divided into each quadrant in Cartesian coordinates. Figure 7 shows the visible volume ratio of the slim type (Figure 4 (b)) in the same way. Figure 6 and Figure 7 show common characteristics of the two types of the screens. The visible volume ratio of the areas ③ and ④ nearer the viewpoint is higher than that of the areas ① and ②.

For the purpose of comparison between the fat type and slim type, the ratio of the visible volumes in the two types was calculated by equation (1); *a* is the visible volume ratio of the fat type, and *b* is the visible volume ratio of the slim type.

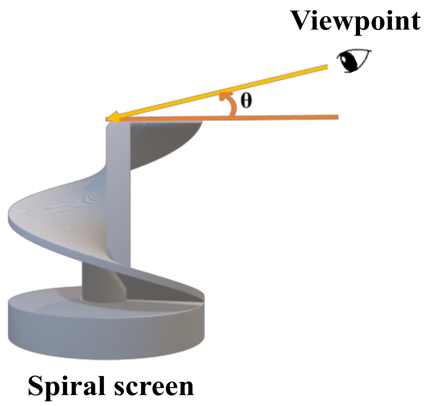


Figure 5. Definition of observation angle θ

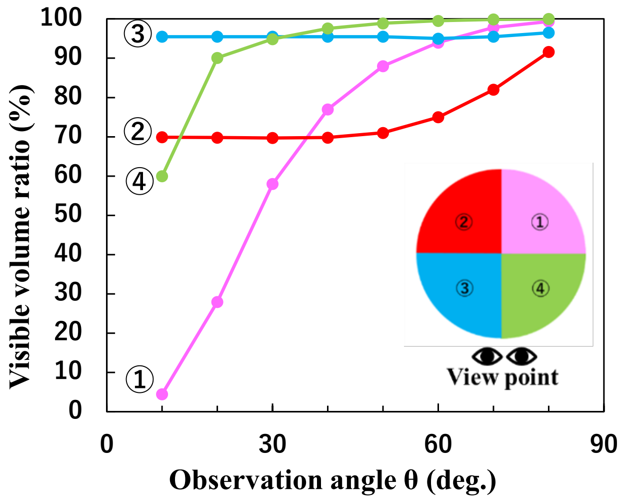


Figure 6. Visible volume ratio in each quadrant (at fat type)

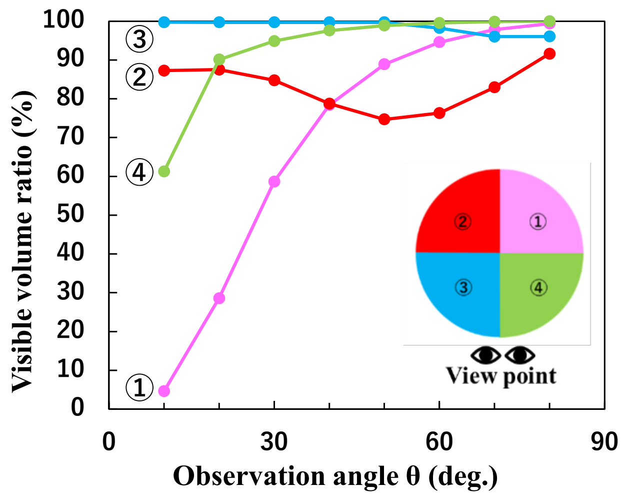


Figure 7. Visible volume ratio in each quadrant (at slim type)

The ratio of the visible volumes in the two screen types
= *(b - a) / a*   (1)

Calculated results by equation (1) are shown in Figure 8.

Figure 9 shows the visible volume ratio of each area when the cylindrical displaying volume of the fat type (Figure 4 (a)) is divided into four donuts shape regions divided by equally spaced radius. Figure 10 shows the visible volume ratio of the slim type (Figure 4 (b)) in the same way. Figure 9 and Figure 10 show common characteristics of the two screen types. The visible volume ratio is decreasing from the outer to the inner circumference. The visible volume ratio in area D is always the lowest.

The ratio of the visible volumes in the two screen types was calculated from equation (1) also for each of the four donuts shape regions. The results are shown in Figure 11. General superiority of the slim type screen is clearly shown by Figure 8 and Figure 11; visible volume of the slim type is always higher than that of the fat type. The superiority of the slim type is especially greater for smaller observation angles θ. Figure 8 also shows that the superiority of the slim type is especially high in the area ② when the screen surface is divided into each quadrant. Thus, we should assess the performance of our 3D system based on the visible volume ratio of the slim type of spiral screen

Figure 7 shows that more than 90 % of display volumes are visible at the areas ③ and ④ quadrants when the observation angle θ is larger than 30 degrees. Figure 10 shows that more than 85 % of the display volumes are visible at the A and B donut areas when the observation angle θ is larger than 30 degrees. The results of this study can be summarized about the blind region of the spiral screen as follows. The blind region can be reduced by slimming the redundant cylindrical volume unnecessary for sustaining the spiral slope. The blind region is concentrated in the distant side from the viewpoint in the cylindrical display region and the neighboring region to the central axis.

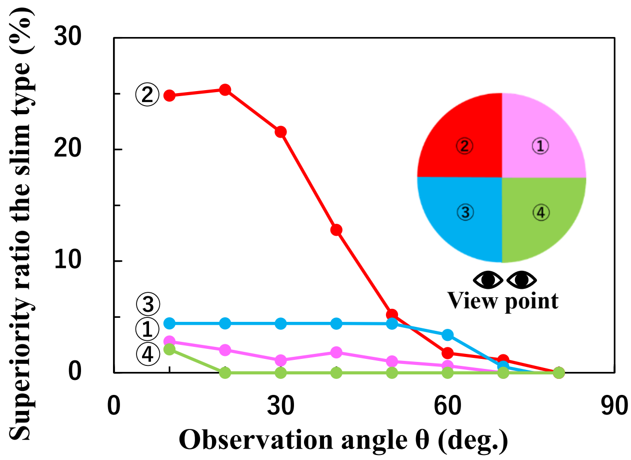


Figure 8. Superiority of visible display volume at the slim type screen compared with the fat type in each quadrant

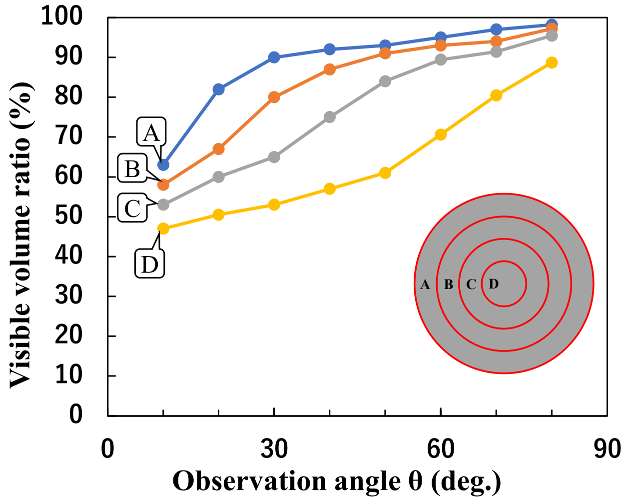


Figure 9. Visible volume ratio in the 4 donut areas (at fat type)

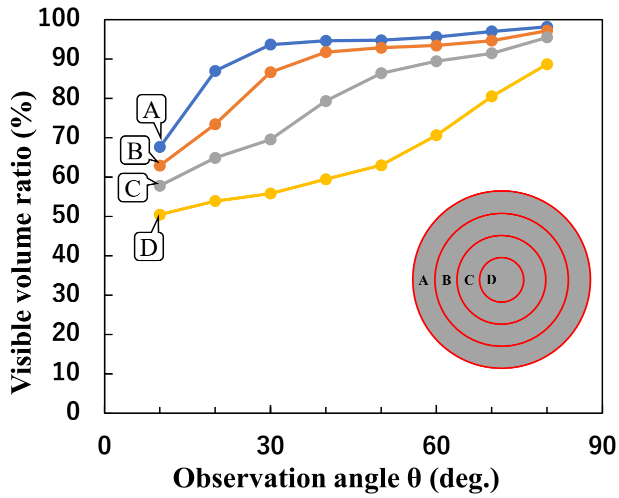


Figure 10. Visible volume ratio in the 4 donut areas (at slim type)

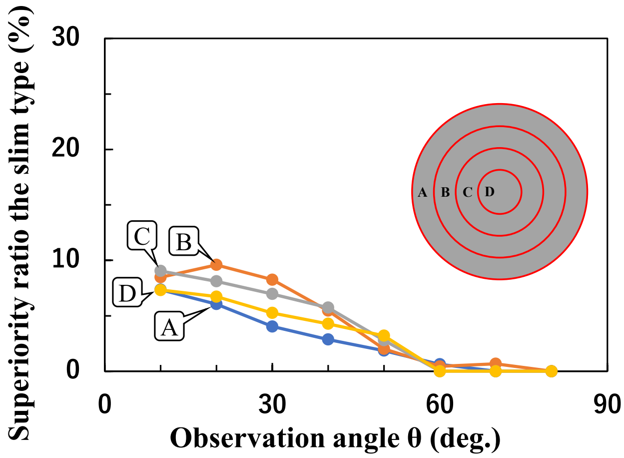
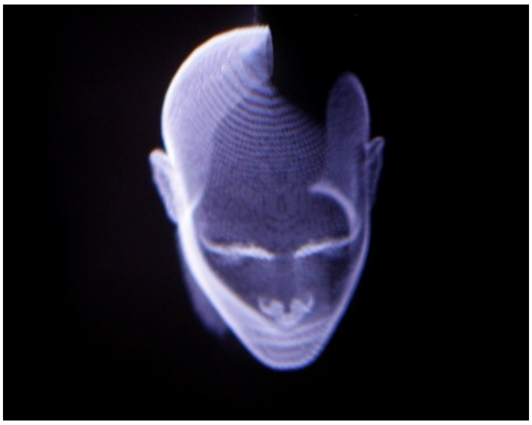
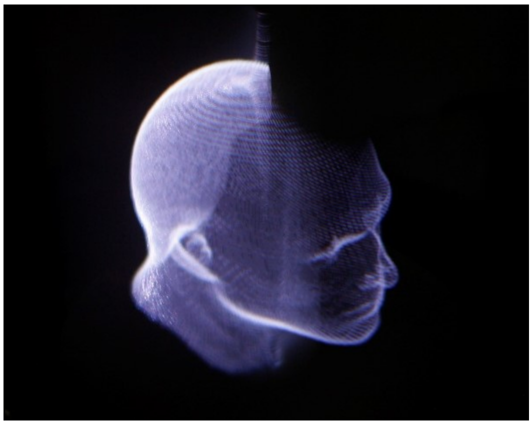


Figure 11. Superiority of visible display volume at the slim type screen compared with the fat type in the 4 donut areas



(a) Front view



(b) Left view

Figure 12. Typical 3D image displayed by the slim type screen (observation angle θ is 40 degrees)

By the way, when looking at non-transparent objects, it is not possible to see the back of the object nor its inside. This suggests that visibilities of the back side and the inside of the object can be considered to be less necessary in 3D display systems. Fortunately, Figure 7 and Figure 10 show that the cylindrical display volume provided by this method has less blind region at the viewpoint side and the periphery, which are generally important for 3D displays.

A typical projected image of a human head is shown in Figure 12 using the slim type screen. Favorable 3D images were displayed but missing region was still remained partially. This position of missing region can be explained by our simulation results.

5 Conclusions

In this study, we have evaluated magnitude and position of the blind region, which is one of challenges in 3D display systems using a spiral screen. Main results are as follows.

1) We confirmed that the blind region can be reduced by slimming the redundant cylindrical volume unnecessary for sustaining the spiral slope.
2) The blind region is generally smaller when the 3D image is observed with higher angle to the horizontal position to the displayed image.
3) The blind region mainly exists in the distant side from the viewpoint in the cylindrical display region and in the neighboring region to the central axis.
4) The clarified position of the blind region is in the area of low importance for observers because the visibility of the back side nor the inside of the object is generally unnecessary when viewing opaque objects in 3D display systems.
5) Favorable 3D images were displayed by the slim type screen but missing region was still remained partially.

Our future works are to more precisely identify the position of blind region and, by improving the spiral screen design, to realize practical disappearance of the image defect.

References

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