Analysis on the viewing characteristics of integral floating display

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Abstract

Integral floating is three-dimensional display technique which is a combination of integral imaging and floating display. In this paper, we explain and analyze the relation between the special viewing characteristics and the system factors of integral floating system. The experimental results which prove the analysis will be presented.

1. Introduction

Integral floating is three-dimensional (3D) display technique which is a combination of integral imaging and floating display.[1] Integral imaging is one of the most promising methods among the autostereoscopic displays.[2-3] This type of stereoscopic display can provide a full color image and both vertical and horizontal parallaxes without the need for any special aids for the observer. The integral imaging display system consists of a lens array and an ordinary two-dimensional display device, and the 3D reconstructed images are integrated by the lens array from elemental images that are displayed on the display device. Figure 1 shows the conventional concept of integral imaging system.

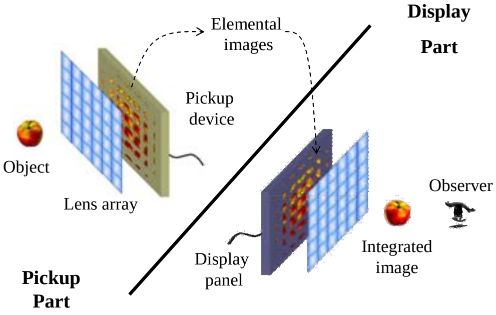

Fig. 1. Concept of integral imaging.

Floating display is an antiquated 3D display method, and the floating display system uses a large convex lens or a concave mirror to display the image of a real object to the observer. Since the 3D image of the object can be located in close proximity to the observer, the floating display system can provide an impressive feel of depth, in that the image appears to be located in a free space near the observer. Electro-floating display system is a floating display system in which the volumetric display system is substituted for the real object.

The integral floating display system is an electro-floating system of which volumetric display part consists of the integral imaging system. In other words, in the integral floating system, the 3D image displayed by the integral imaging system is augmented using floating display technique. Figure 2 shows the structure of integral floating system.

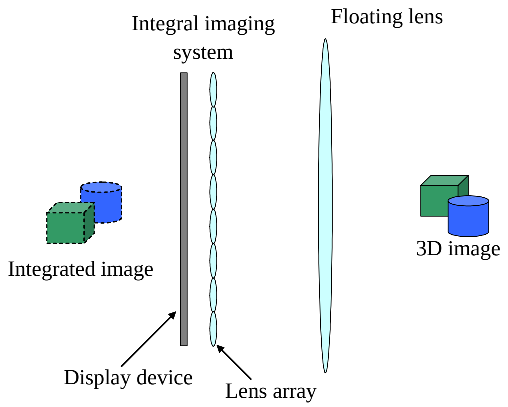

Fig. 2. Structure of integral floating.

The integrated image has full parallaxes with continuous viewpoints, but has viewing limitations due to the system characteristics. There are three viewing parameters of the integrated image,[4-5] which are image resolution, viewing angle, image depth. The image resolution means the lateral resolution of integrated image which is determined by the magnification of elemental lens. The viewing angle is the angular limitation where the integrated image can be observed without the flipping image being observed. The image depth means the expressible depth range of the system which is formed around the central depth plane of the system which can be calculated by lens law of elemental lens.

These limitations of integrated image have influence on the viewing characteristics of integral floating system. In this paper, we analyze the viewing characteristics of integral floating to focus on the viewing zone, the observing distance, and the expressible depth range of the integral floating display.

2. Analysis of integral floating system

The integral floating system has the limited viewing zone, the restricted expressible depth range and finite angular resolution. The viewing angle of integral imaging causes the viewing window of the integral floating display, which makes the 3D image only observable when the image is observed through the window. The expressible depth range of the integral imaging is limited by the existence of the central depth plane only around where 3D image can be constructed without degradation on the quality. Such central depth plane also exists in the integral floating display, which limits the depth range of 3D expression.

2.1. Viewing zone

The viewing angle of the integral floating can be calculated by considering the position and the size of the viewing window and the 3D image. We will first find the position and the size of the viewing window before the calculation of the viewing angle.

The viewing window is a two-dimensional space only through which the 3D image constructed by integral floating can be observed. Its size and position can be found by considering the viewing angle of the integral imaging. In integral imaging, the 3D image is only observable when the observer is in the viewing angle. In other words, only rays which has smaller angle than the viewing angle contain the information of the 3D image.

To calculate the position and the size of the viewing window, we assume a bundle of rays which consists of rays with certain angle. The rays in the bundle will converge to a point after passing a convex lens, which is a floating lens in the case of the integral floating display, and the point will be on the focal plane. The converging point is the intersection between the focal plane and the chief ray which meets the floating lens at the center. Thus, the border of the viewing window is the set of converging points of the ray bundle with the viewing angle of the integral imaging system as in Fig. 3.

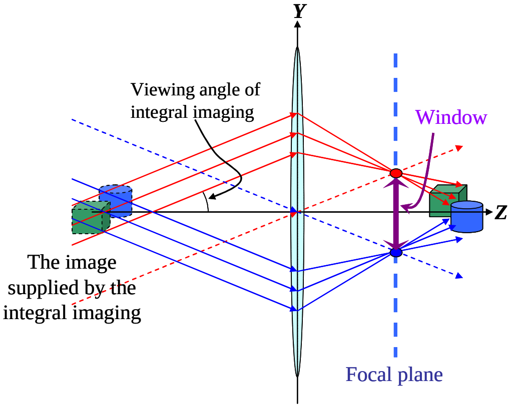

Fig. 3. The illustration of the formation of the viewing window of the integral floating display.

The position of the viewing window is the focal plane of the floating lens and its size can be calculated by finding the converging point of the ray bundle with the viewing angle of the integral imaging. Every ray with valid information about the 3D image will pass the viewing window because it has smaller angle than the viewing angle of the integral imaging. Thus, the size of the viewing window can be calculated by considering Fig. 4.

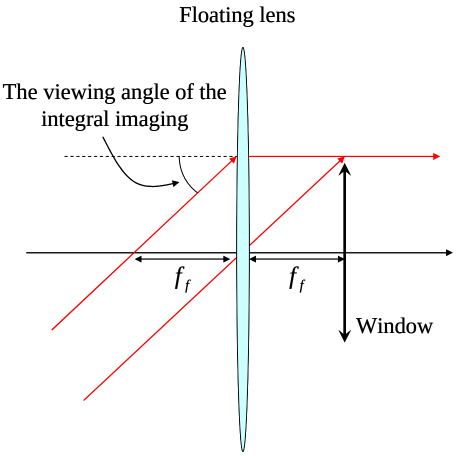

Fig. 4. The calculation of the viewing window.

The calculated size of the viewing window h is

$$h = 2 f_f \tan\theta, \qquad (1)$$

where θ is the viewing angle of the integral imaging system and f_f is the focal length of the floating lens.. The viewing window is firmly determined by the system parameters according to the calculation of Eq. (1).

The viewing zone of the 3D image will be the region where the observer can see the whole 3D image through the viewing window. Therefore, the viewing angle should consider the size and the position of the 3D image, which varies according to the contents produced by the 3D display system. We provide the equation which calculates the size of the viewing zone when the position and the size of the 3D image and the position of the observer are known. Figure 5 illustrates such situation.

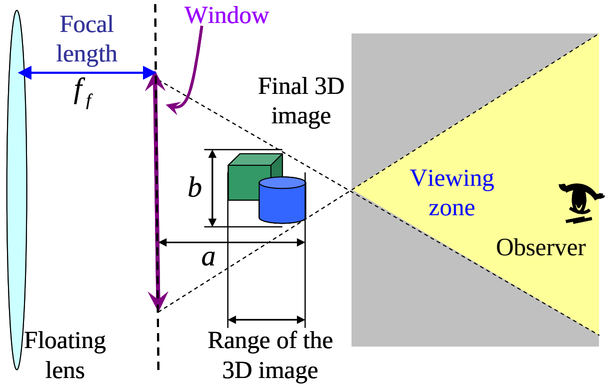

Fig. 5. The illustration of the calculation of the viewing angle.

Here, the position and the size of the viewing window is already known and the size of the 3D image is assumed to be b and the closest point to the observer is a distant from the viewing window. In this case, the size of the viewing zone of the integral floating display u is calculated to be

$$u = d_o \frac{h-b}{a} - h, \qquad (2)$$

where d_o is the distance between the observer and the viewing window.

2.2. Maximum observing distance for binocular disparity

Before the analysis, a precise discussion about the 3D perception of integral imaging is needed. The central depth plane is where each elemental lens images the elemental image drawn on the flat panel display. It means that each elemental lens forms 2D image on the central depth plane. But an integral imaging system can do form a 3D image because it uses an array of lens, as shown in Fig. 6.

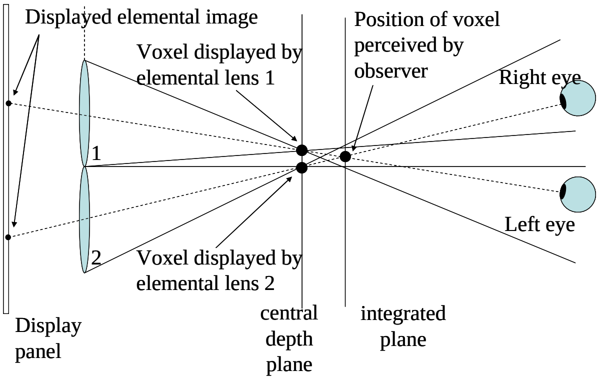

Fig. 6. 3D perception of a voxel in integral imaging through the binocular disparity.

It is known that the binocular disparity (3D depth perception through the difference between two scenes observed by left and right eyes) is the most important depth cue for depth perception of a human. In Fig 6, a voxel out of the central depth plane is perceived by each eye sees the voxel through the different elemental lens.^{6} As the observer moves farther from the integral imaging system, there is higher chance for the observer to see the voxel through the same elemental lens. Similarly, the observer will see the voxel through different elemental lens within a certain distance. This distance is defined to be a maximum observing distance for binocular disparity and the situation is drawn in Fig. 7.

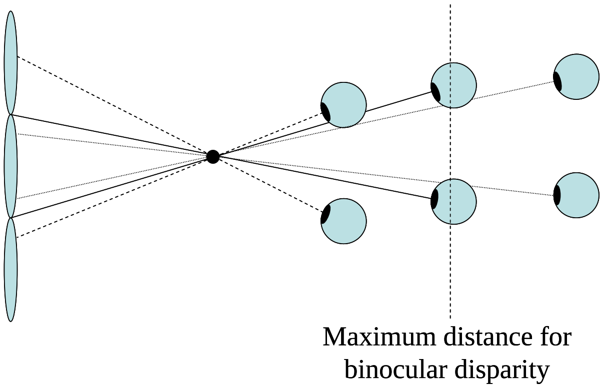

Fig. 7. Concept of the maximum observing distance for binocular disparity

The maximum observing distance for the binocular disparity in integral imaging can be found easily through geometrical calculation considering that the distance between two eyes are approximately 55mm.

The same principle can be applied to the integral floating display. In integral floating display, the 3D image and the lens array are imaged by the floating lens. Therefore, the maximum observing distance for binocular disparity can be calculated as in the case of the integral imaging system with the newly imaged lens array and the final 3D image of the integral floating display. The specific calculation process is simple in principle and the result is

$$D_{ob} = \frac{d_{eye} l f_f + \varphi\left(d+l\right) f_f}{\varphi\left(d+l-f_f\right)}. \tag{3}$$

Here, the meaning of each parameter is illustrated in Fig. 8.

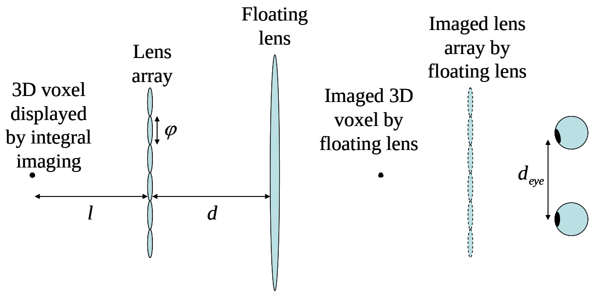

Fig. 8. Illustration of the parameters in Eq. (3).

By assuming that l is 150mm, f_f is 175mm, φ is 10mm and d_{eye} is 55mm, we calculated the maximum observing distance for binocular disparity when d (the distance between the lens array and floating lens) varies. The maximum observing distance is assumed to be measured from the floating lens.

2.3. Expressible depth range

In integral imaging system, there exists a central depth plane and only objects apart from the central depth plane by less than certain distance are displayable. The certain distance is called expressible depth range. If Δ_o is the expressible depth range of integral imaging and z_c is the central depth plane, we can find the two end points of expressible depth range separated from the floating lens by z_{o1} and z_{o2},

$$z_{o1} = z_c - \frac{\Delta_o}{2}, z_{o2} = z_c + \frac{\Delta_o}{2}. \tag{4}$$

By using the lens' law and calculating the imaged points of z_{l1} and z_{l2}, we get the expressible depth range of the integral floating display by

$$\Delta_i = z_{i2} - z_{i1} = \frac{2 f_f^{\,2} \Delta_o}{\left(2d - \Delta_o - 2f_f\right)\left(2d + \Delta_o + 2f_f\right)}. \tag{5}$$

As in Eq. (5), the expressible depth range is larger as the integral imaging system is located closer to the focal plane of the floating lens.

3. Summary

In this paper, we analyze the viewing characteristics of integral floating to focus on the viewing zone, the observing distance, and the expressible depth range of the integral floating display. These viewing characteristics of integral floating system are analyzed on the basis of the research results of integral imaging. This analysis about the viewing parameters of the integral floating system can help this future-oriented system to be advanced.

4. References

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