Analysis on the optimized depth of 3D displays without an accommodation error

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Abstract

Accommodation error is one of the main factors that degrade the comfort while watching stereoscopic 3D images. We analyze the limit of the expressible 3D depth without an accommodation error using the human factor information and wave optical calculation under Fresnel approximation.

1. Introduction

The three-dimensional (3D) display is a method to provide various aspects of an original object as if it really existed. For the 3D display system, it is reported that there are four major cues such as binocular disparity, motion parallax, convergence, and accommodation. However, most 3D displays only provide binocular disparity and even some advanced systems can realize only binocular disparity and motion parallax. As a result, a 3D nausea is reported for some observers because of the conflict between the 3D perceptions of different cues[1,2]. Therefore, it is needed to research a method to minimize this problem. The 3D nausea basically comes from the '3D feelings'. If the observer feels a 3D image using current 3D display systems, he/she sees two different kinds of planar images for each eye. From this difference which is called binocular disparity, the observer's brain calculates the 'imaginary depth' of the 3D image. However, the observer's eyes are actually focused on the location of the display system, not on the imaginary 3D location. As a result, two kinds of different 3D information are provided to the observer's brain and the mismatch between them occurs as shown in Fig. 1. This is called 'accommodation error' and is regarded as the major cause of 3D nausea.

The ideal method to resolve this problem is to provide not only the binocular disparity but also the correct 3D accommodation information to the observer. However, with the limitations on the current display technology, it requires too much system resources and very high price to realize the accommodation cue and makes the 3D display harder to be commercialized. Therefore it is required to analyze and to optimize the 3D depth for minimizing 3D nausea. For that purpose, in this paper, we simulate the focusing property of human eye and analyze the accommodation resolution by using the eye modeling and Fresnel approximation[3]. From these researches, the optimized depth of 3D display system without accommodation error is acquired and proved by experiments.

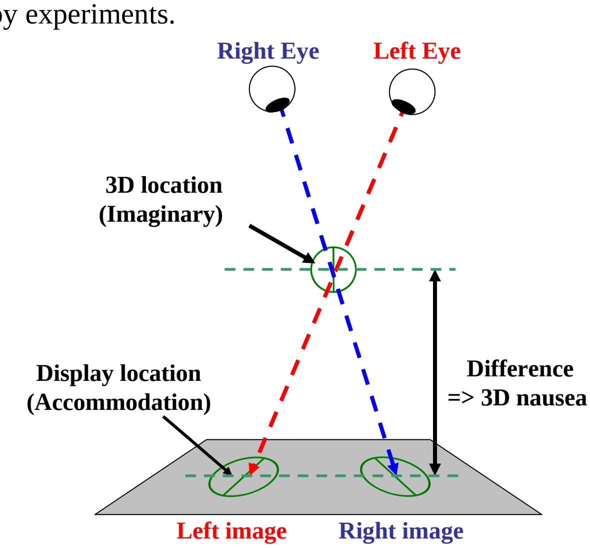

Fig. 1. Accommodation error in 3D displays

2. Simulation principle and result

Our simulation tries to find the 3D depth range of such situation, using the Fresnel approximation and eye modeling. The simulation is based on the principle of the human vision system. For the accommodation, the human eye can be thought as a camera system and has two main organics – the lens and visual cells. The lens is an optical device which can control its focal length and focus the image of original object at the retina clearly. In the retina, there are a large number of visual cells which have a typical size of 2.3um and convert the light into electric signal and transmit it to the brain through the optic nerves. From the above specification of human eye, it is known that the threshold of perception, which means the smallest perceptible area in the retina, has a diameter of about 4.8 um. In other words, the resolution of the human vision is not infinite, but has a limit. Based on this assumption, it can be derived that the accommodation of human eye also has a limitation because the accommodation is based on the information which the visual cells provide. The accommodation process is controlled by the feedback of the midbrain and can be modeled as shown in Fig. 2.

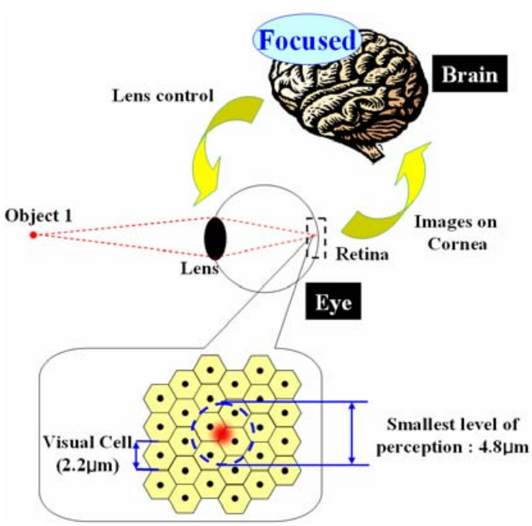

Fig. 2. Modeling of accommodation in human vision system

When the human observes an object at certain distance, the midbrain can control the lens in order to eliminate the blurring (defocusing) of the object image at the retina. However, since the human vision system cannot detect the blurring smaller than 4.8um, it is possible that two objects at slightly different locations can be detected as 'focused' in the midbrain. In other words, there is a threshold of gap between two objects or 3D images where the accommodation error in 3D display does not occur. Figure 3 shows the concept of accommodation accuracy and an example. If two objects (object 1 and object 2) are located close to each other, even though the lens is focused on object 1, the blurring of the image of object 2 at the retina does not exceed the smallest level of perception in human vision as shown in Fig. 3(a). Then, the midbrain will recognize that both objects are 'focused'. However, if the two objects are located with a larger distance as shown in Fig. 3(b), the blurring of image of object 2 will exceed the level of perception and the midbrain will recognized that the object 2 is 'defocused'. Therefore, the gap between the object 1 and object 2 in Fig. 3(a) can be the region without accommodation error because it is beyond the depth perception accuracy by accommodation of human vision system.

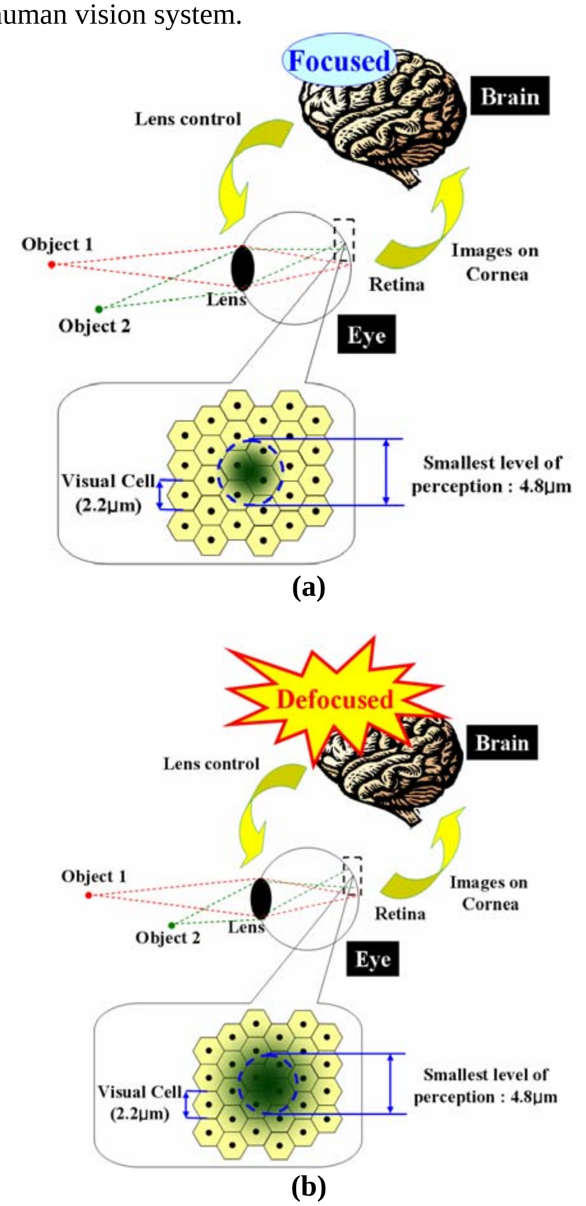

Fig. 3. Limit of depth perception accuracy by accommodation

Using this property, we can calculate the maximum 3D depth where there is no conflict between the accommodation and other depth cues. In other words, the observer will not be able to notice the conflict between depth perception cues, if the differences between the depths which are perceived through the accommodation and other cues are within the limit of depth perception accuracy by accommodation.

Figure 4 shows a graph which is the result of the simulation by Fresnel approximation. We started our simulation where the depth information from other cues of the displayed point, on which the eye is focusing, coincides with the zero 3D depth. By moving the plane on which the eye is focusing to the observer, we measured the width of the image on the retina simulated using wave optics under Fresnel approximation. In Fig. 4, the horizontal axis represents the distance between the image point and the plane where the eye is focusing on, and it is normalized by the observing distance. The simulation result implies that there is a range of depth for practical 3D display systems where human vision system cannot perceive any accommodation error. For example, it will be about 40cm from the image point when the observing distance is 3m which is good for 30-40 inch size displays.

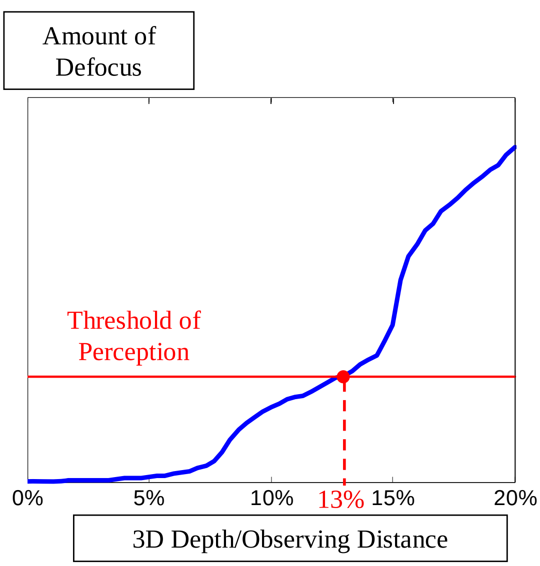

Fig. 4. Simulation results

3. Experimental results and discussion

We have performed preliminary experiments to prove the simulation principle and results. Two objects at different distances from the observer are prepared for the experiments and the observers have been requested to detect the distance difference between two objects by using only accommodation. The procedure of the experiment is as follows. At first, the two objects are at the same distance from the observer. Then, the object 2 is moved to the observer when the observer has a focus to the object 1. With the increase of the distance between two objects, the level of blurring of object 2 in the retina continues to enlarge. However, if the blurring is smaller than the perception level (4.8um), the observer cannot detect that the object 1 and object 2 are at different locations only by accommodation as shown in Fig. 3(a). The defocus of the object 2 can be finally detected by the observer's vision system when it exceeds the perception level as shown in Fig. 3(b). With this procedure, the experimental results are the records of the distance difference between the two objects when the observer recognized that the two objects are at different locations for the first time only by accommodation. In other words, within the recognized points, those two objects have the same accommodation in observer's vision system even though they are at different distances. The participants of the experiments are eight people in age of 24~32 and the experimental results are shown in Fig. 5 as a graph. In the experimental results, all participants reported that they have detected the defocus of object 2 around the expected distance of simulation results as shown in Fig. 5.

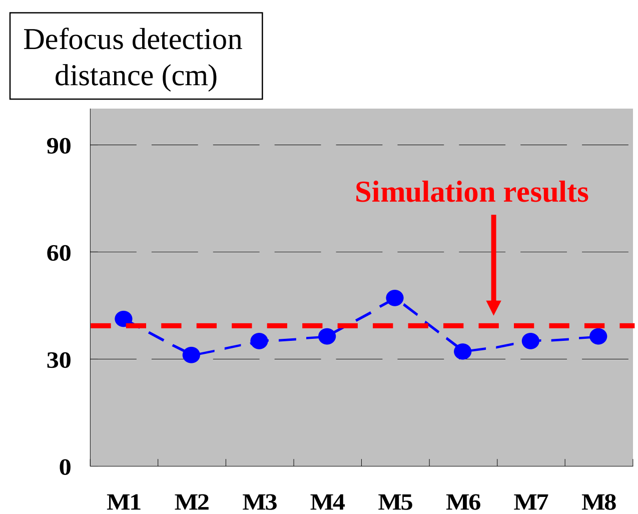

Fig. 5. Experimental results

4. Summary

As mentioned formerly, it is almost impossible in practice to achieve correct accommodation cue in 3D display methods that are not volumetric type due to the limitation in current display technology. Although there are many researches to achieve accommodation cue, the required speculation for the implementation is still too high to be commercialized in near future. Our simulation and the analysis can have a very practically high impact since it suggests there is a range of depth in which the accommodation error is not perceivable by human vision and in which the 3D nausea is expected to be significantly decreased. Moreover, it is also discovered that the range is not quite small (40cm when observing distance is 3m); so the simulation and experimental results are meaningful for realizing practical autostreoscopic 3D displays.

References

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