ドーム型ディスプレイにおける映像のバーチャルな奥行き感

– 心理物理学による映像効果の評価 –

Virtual Depth Effects for Non-Stereoscopic Dome Images

- The estimation of the depth effects of the Dome Image by Psychophysics

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Abstract: The abstract should summarize the contents of the paper and should contain at least 70 and at most 200 words. It should be set in 9-point font size, justified and should have a hanging indent of 2-centimenter. There should be a space before of 12-point and after of 30-point.

Keywords: Virtual depth effect, Dome image, Psychophysics, Curved screen, Planetarium

1. Introduction

New technologies for projecting large images have become available for educational and entertainment presentations. Among the new technologies, projection on a dome screen is particularly interesting, since this allows us to project images that cover the whole visual field of spectators. This projection technique, however, has a peculiar feature which has been known among contents developers and probably among keen spectators. Images projected on a dome screen appear to exist on a virtual front parallel surface that is located nearer or farther than the physical screen surface without using any stereoscopic attachments (cf. EARTH ROOM, EXPO 2005 AICHI). This peculiar aspect of dome projection may be useful for creating some illusory mysterious effects, but is often rather problematic for contents production. The effect is especially serious for contents production for planetariums since planetariums these days use projectors and it is now possible to project various images other than stars. The creators of planetarium contents have been trying to get away with this problem based on their past experiences without any scientific bases. In this study, we tried to measure this phenomenon quantitatively by using psychophysical method, first with a small curved screen in our laboratory (Exp. 1), then with an actual planetarium, to obtain the exact nature of the phenomenon. The ultimate goal of this study is to obtain data for scientific interpretations of the phenomenon, and to provide the knowledge useful for better contents creations.

Images on a dome screen are perceived on the physical screen when the room light is bright enough to perceive the screen's 3D curvature, or when the projected images are not corrected for the curved screen and perceived as being distorted. When the room is dark and appropriate distortion correction is applied to the images, their depth becomes nearer than the screen surface and appears as if they are projected on the frontal parallel virtual screen. We called this phenomenon the virtual depth effect in this study.

2. Experiment1

In Experiment 1, we measure the magnitude of the virtual depth effect with images projected on a smaller curved screen (Fig. 1). Observers were asked to judge the relative depth between non-stereo test images and stereoscopic probe (a small image with binocular disparity). The binocular disparity of the probe was systematically varied and the matched depth was obtained from the data. A curved screen (CCRoom, 3 m x 3 m, Fig. 1.1) and a flat screen of the similar size (CS Gallery, 2.6 m x 2.1 m, Fig. 1.2) were used for this experiment.

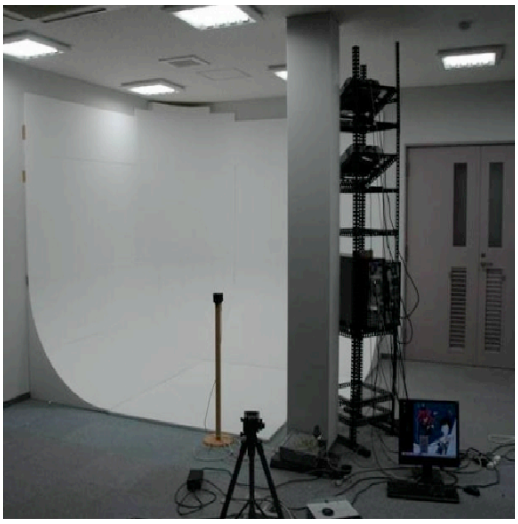


Figure 1.1. The curved screen used in experiment 1 (CCRoom).

Figure 1.2. The flat screen used in experiment 1 (CS gallery).

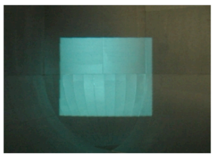
The measurements were conducted by using a staircase method (REF) involving two alternative forced choices. Observers were asked to judge which, the test or probe, stimulus is nearer to them. If they answer the probe is nearer, then the disparity of the probe was decreased by one step. If the probe is farther, then the disparity was increased by one step. One step of disparity change corresponded to 10 cm physical depth change. We recorded the disparity value where observers' answers, i.e. the change direction of disparity changed from one way to the other. The procedure was repeated until 7 turnings occur. Then, we calculated the mean of disparity values at the 7 turning points. This mean value can be considered as the disparity that gives the depth of the probe that is subjectively equal to that of test image. Figure 3 shows the test and probe stimuli. There were two types of test stimuli, one square shape and the other depicting a dog. There were 3 size conditions (small: 0.3 m x 0.3 m, medium; 1 m x 1 m, large; 1.5 m x 1.5 m). These images' distortion of the images caused by the curvature of the screen was corrected and the corrected objects moved along the horizontal axis (2 m by 1.3 m per sec). The retinal size of the test stimuli was constant because of the distortion correction when they moved across the screen. The Probe was a white bar (0.2 m) with binocular disparity and red random dots (05 m x 0.5 m) without binocular disparity were also presented. The random dots were presented for easier perception of the depth of probe. There were three viewing distances (2.5 m, 3 m, 3.5 m). Observers were 5 students and they had some experience of viewing stereoscopic images.

3. Results and Discussion

All subjects reported that the moving objects were located on a virtual front parallel surface. This seems to be a property of human perception to the images projected on a curved screen. This virtual surface is always positioned nearer than the physical screen (figure 3), even though the retinal size of the test stimulus did not change during the motion. This is a new phenomenon which does not correspond to the previous knowledge in psychophysics. Some special mechanisms or properties of human perception may function with objects projected on a curved screen. In contrast, images projected on the flat screen were always positioned on the physical screen surface in all the conditions. Calculated depth is shown in figure 3.

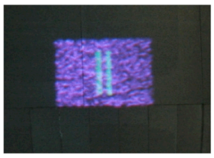
The way the observers perceive objects on a flat screen in this experiment os quite similar to our experiences in a movie theater. No matter how large actors' retinal sizes are, they are never positioned in front of the screen. Off course, they are located on some depth by using some depth cues (i.e. perspective), but they never pop out of the screen. If there is no information except for the object itself, we will locate it on the physical screen.

When projected on the curved screen, the objects in all the conditions were positioned at least 0.5 m nearer than the physical screen at the center. When the stimuli size was large, they are positioned about 1.5 m nearer than the physical screen. This happens even when the viewing distance was 2.5 m. Therefore, in this case, the large objects were perceived as if they were very close (i.e. two thirds of actual distance) from observers. The effect of size may be related to the size-distance invariance hypothesis. If the observers assume the objects have a constant size as a real object, a large retinal size suggests that the distance to the object is small, and a small retinal size suggests a longer distance. In the curved screen this estimation can be applied, but not in the flat screen. The difference in perceived distance across different image sizes could be, thus, related to size-distance invariance, but the difference between curved and flat screens cannot be attributed to this. The difference between the two different screens may be related to the fact that the screen used in this experiment has only one dimensional curvature along the horizontal axis. We will discuss this point together with the results of Exp. 2. Whether the image was meaningful or meaningless did not affect the results. The several tendencies in the two conditions were very similar. Thus we can conclude that this virtual depth effect can be induced by any kind of image.



(A)

(B)



(C)

Figure 2. The test stimuli and the probe. (A) is a square and (B) is a dog image. (C) is the probe.

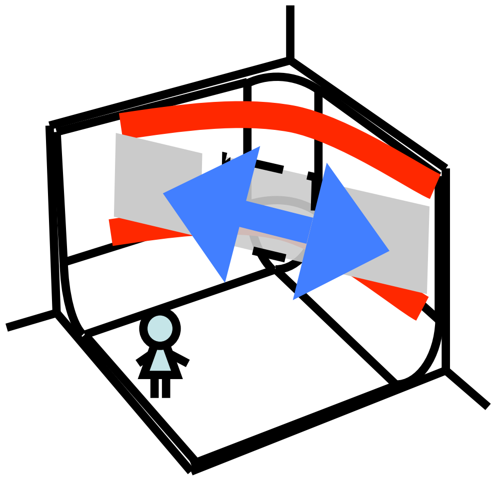


Figure 3. The Virtual Depth Effect.

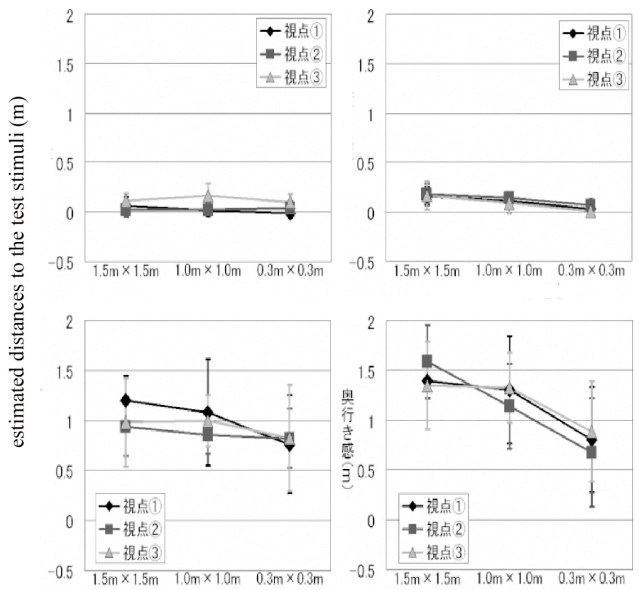


Figure 4. The results of estimated distances of test stimuli. The upper graphs are the results of the flat screen, the lowers are those of curved screen. The left graphs are results of squares and rights are dogs. Abscissa is the sizes of test stimuli.

Viewing distance did not affect the results. The average disparities between the 3 distance conditions were almost the same. It probably indicates that the effect of curved screen in addition to the distortion correction is independent of the viewing distance. However we could not set the distance beyond 3.5 m in this experiment. Thus it is not clear whether the virtual depth effect found in this experiment occurs in the same fashion at large distances such as in planetariums.

4. Experiment 2

We examined whether the virtual depth effect found in Exp. 1 can be observed at large distances. To examine this, we conducted an experiment in a planetarium. The screen used in Exp. 1 had a one-dimensional curvature along the horizontal axis, but the screen at the planetarium had a dome shape. Because of this difference, the screen used in Exp. 2 had curvature along the vertical axis as well as the horizontal axis.

We used a planetarium at HOKUTOPIA in Tokyo. The diameter of the planetarium dome was 18 m. The dome was inclined by 20 degrees and all seats were set under the dome in a theatre-like fashion (figure 5). Projector was a NP200J (NEC) with fisheye lens (RAYNOX: DCR-CF185PRO). The power of NP2000J was 4000 lumen.

In the planetarium we could not present images with binocular disparity, so we had to use another method to measure the depth of projecting images. We chose the method of magnitude estimation. In this method, first, observers were asked to assume the distance between themselves and a standard stimulus (a pole, 2.7 m) having a subjective value of 100. The standard stimulus was standing at the bottom of the screen. The physical distance between the standard stimulus and observers was 7 to 11 m. Second, we present a test stimulus (images of walking man or moving square). The observers were asked to estimate the distance to the test stimuli and report the subjective value relative to the standard distance (100). The value will be smaller than 100, if the images are perceived at a position nearer than the standard, If the distance is located as being at farther, it will be larger than 100. The standard stimulus could be confirmed after each test stimulus presentation, and it never occluded the test.

The test stimuli had 2 object-type conditions (a square/animation of a running man), 3 size conditions (the height of the stimuli were 2.2m, 4.4 m, or 6.6 m), and 3 background conditions (no background, with the ground, or with the ceiling). In addition to these, we had moving object and moving camera conditions. In the moving object condition, objects actually moved on the screen along the horizontal axis (15m by 1.1 m per sec). The moving camera condition mimicked the situation where a moving object is panned by a movie camera. That is, only the random-dots in the background moved while the object itself stayed stationary at the center of the screen. Observers received motion impression object from this display although there was no motion information from the object. The background covered horizontally the whole visual field (15 m) and vertically from the bottom up to the center (ceiling condition) or from the top down to the center of the screen (ground condition) (5 m). Observers were 11 students. Each condition was repeated for 6 times. Eye position was also recorded (TalkEyeⅡ: Takei Scientific Instruments) for one observer.

Figure 5. The planetarium that is used in experiment 2.

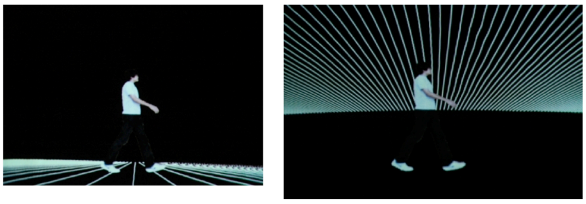


Figure 6. The examples of test stimuli. Walking man with ground or ceiling.

5. Results and Discussion

First of all, all subjects reported that the images were not on the physical screen, rather, they perceived images on a front-parallel virtual surface. Figure 7 shows the average subjective distance. The effect of image size was significant. The estimated value was about 60 for the large stimuli and 110 for the small stimuli. These results indicate that images were perceived as being nearer or farther than the physical screen. Object type in general did not cause any significant difference (figure 8). There was no significant difference between the moving object and moving camera conditions (figure 9).

In contrast, there was a difference between the different background types (see Fig. 10). The existence of ceiling made the distance shorter and the ground made the distance longer. It may be related to the observers' attention and eye position.

The height of the average eye position and estimated values were correlated. The higher the eye position was, the smaller the estimated values were (figure 12). It seems that observers created a virtual surface from the position where their eyes or attention were fixated. This could be the reason that the existence of ceiling causes nearer image localization. That is, the fixed point serves as a kernel for depth decision (figure 13). If this is the case, all effects of background, size, object/camera moving, can be explained in a unified way. In experiment 1, the left and right edges of the screen served as the depth kernel, and in experiment 2 the top and bottom of the screen served as a depth kernel. Thus, the depth of the virtual surface is determined by and dependent on the experimental environment. The estimated depth was farther than the screen when the object size was small in experiment 2 but not in experiment 1. This difference reflects the difference of the curvature. There was only a curvature in a horizontal axis in experiment 1, however, there was also a curvature in a vertical axis in the planetarium. This vertical curvature contributed to locating the objects farther than the screen.

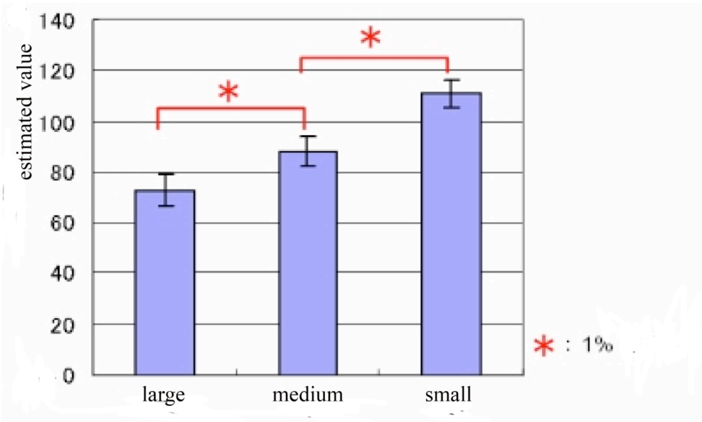


Figure 7. The results of estimated values. The abscissa indicates three conditions of size.

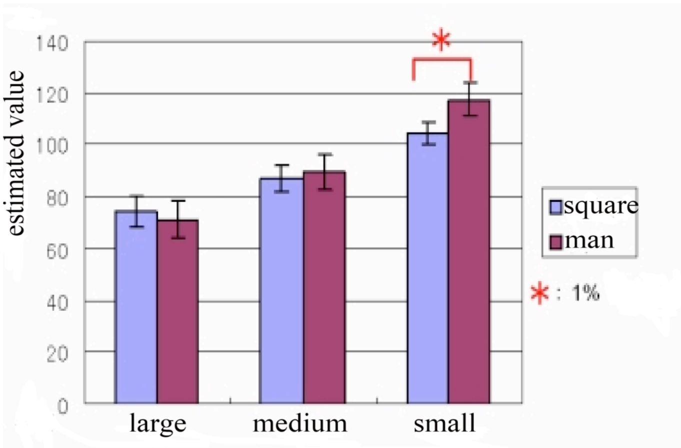


Figure 8. The comparison of two stimulus types. The abscissa indicates three conditions of size.

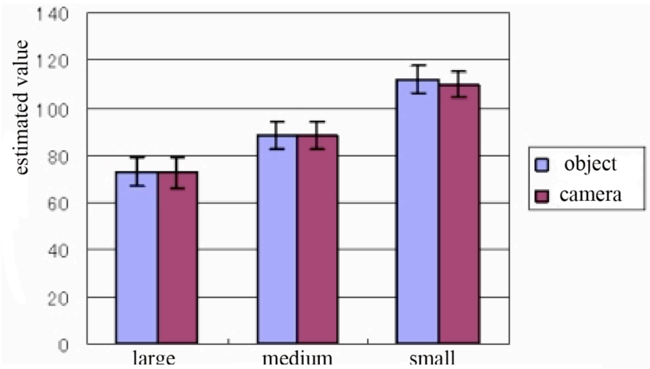


Figure 9. The comparison of two stimulus types (moving object or camera conditions).

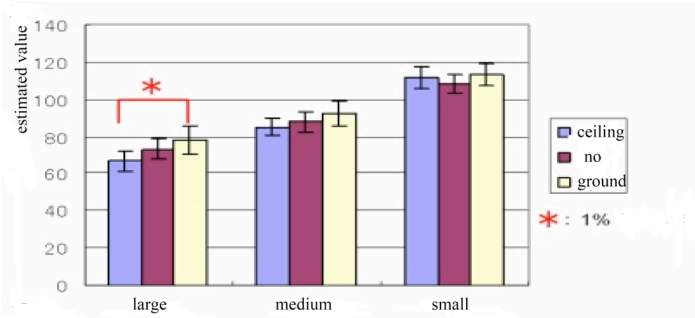


Figure 10. The comparison of three background types.

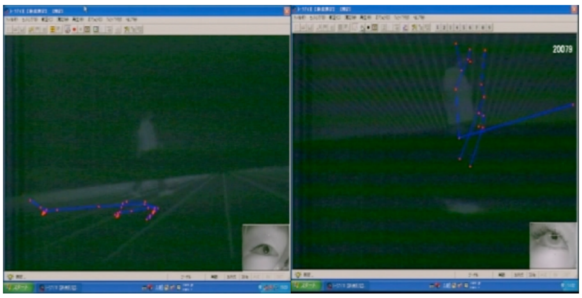


Figure 11. The recordings of eye position. Two examples of with ground condition and with ceiling condition.

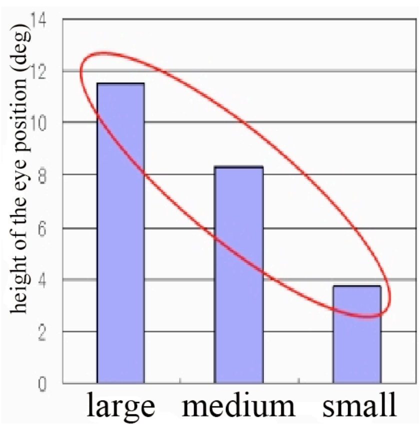


Figure 12. The results of eye position.

4. General Discussion

In Exp. 1 it was shown that observers created a virtual surface in a frontal parallel plane when they perceive a moving objects projected on one-dimensionally curved screens. In Exp. 2, by using a planetarium dome, it was found that similar phenomenon occurs even at longer distance as long as 10 meters. However, there was an intriguing difference between results from Exp. 1 and 2. The moving objects in Exp. 1 were always located on the frontal parallel surface in front of the screen. However, in Exp. 2, objects were located either in front or in back of the screen, and the localization depended on the size of objects. We conjecture the difference comes from the fact that the dome screen used in Exp. 2 was curved vertically as well as horizontally, whereas the screen in Exp. 1 was curved only in horizontal axis. The localization of the virtual surface in depth probably is related to the position, or height of eye or attention that change dependent on the stimulus size. The fixated position or focus of attention serves as a kernel point for depth localization, and the virtual surface was perceptually created from the point. This hypothesis requires observers' prior knowledge about the 3D shape of the screen. Further analysis on this point is needed.

In this study, we clarified the basic nature of perception of objects projected on curved screens including dome screens. The images on curved screens are located on a virtual surface in a frontal parallel plane, but the location in depth of such surfaces is determined probably by using information from the environment (3D shape of the screen). These perceptual features are important factors when we create visual contents to be projected on a curved screen. Figure 14 shows an example of our contents on a flat screen and dome screen.

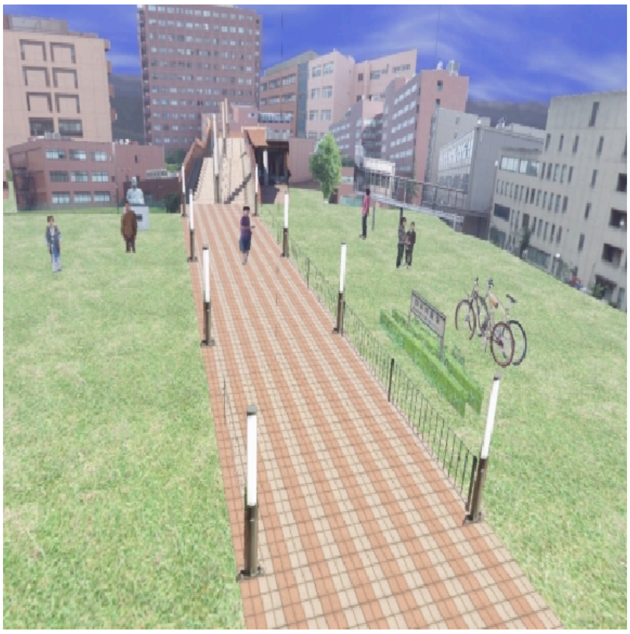


Figure14. Examples of our contents.

Acknowledgements

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