ICAT 2002
December 4-6, Tokyo, JAPAN

An Evaluation Method of Depth Perception on Stereoscopic Display

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Abstract

We proposed an improved evaluation method of depth accuracy in the virtual world, and discuss a result of this evaluation. In this evaluation, we focused the disorder of the convergence and the accommodation, and used a subjective assessment method applying moving stimulus images and quantitatively observed effects involving the disorder of the convergence and the accommodation. This method was based on the evaluation method of the depth accuracy of real space. In this method, we used three objects in the virtual world, and compared these position relationships. The main index of the evaluation was the distance between static objects and the dynamic object. A result of the evaluation suggests that the size of appearance was most important factor. However, it seemed also that this disorder lead to an inaccurate perception of depth.

Key words: Stereoscopic Display, Depth Accuracy, Convergence, Accommodation, Subjective Assessment

1. Introduction

Stereoscopic display systems, such as HMDs or lenticular screens, are most commonly used to represent a virtual world. These systems are effective devices for enhancing the sense and feel of immersion in the virtual world. However, there is a disadvantage with their generated depth cues [1][2][3]. It is widely known that this disadvantage is mainly caused by the disorder of the convergence and the accommodation in the stereoscopic displays. Figure 1 shows this disorder. The physiological burden by such disorder not only causes the visual fatigue [4], but become the cause of the depth inaccuracy in virtual world. Especially, there is a possibility of having fatal influence about the latter problem in applications, such as medical treatment in a virtual world which needs high accuracy to the depth direction. We focused this problem and had so far proposed the evaluation method of depth perception.

In this paper, we propose an improved evaluation method of the depth accuracy in a virtual world, and discuss a result of this evaluation. In this evaluation, we focused the concept that is the inspection method of the visual acuity for the depth in real world.

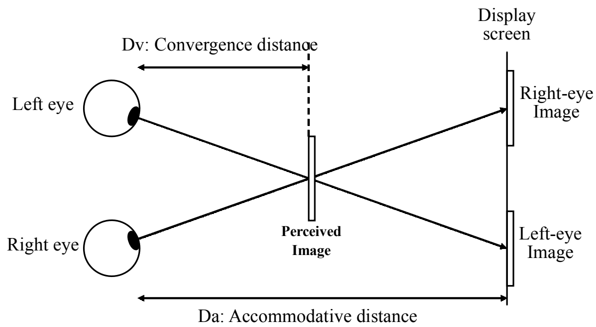

Fig.1 The contradiction between convergence and accommodation in the stereoscopic displays

2. Methodology

2.1 Old Method and There Problem

In this subsection, we describe the evaluation method that proposed in the past works [5] [6], and its problem. As mentioned in the previous section, the disorder of the convergence and the accommodation in the stereoscopic display strongly influenced the applications that need high accuracy of the depth. We need to consider two cases that the object of observation is static or dynamic, when we evaluate the depth accuracy in these applications. This is based on the idea that the visual acuity for the static object differs from one for the dynamic object as SVA (Static Visual Acuity), KVA (Kinetic Visual Acuity) and DVA (Dynamic Visual Acuity), these are evaluation methods of the sport vision in real world. In the past works, many experiments about the depth accuracy to the static object set in virtual space was reported. However, there are not so many examples of report about it to a dynamic object. Especially, there were barely works that focused the disorder of the convergence and the accommodation.

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In the past works, we had suggested an evaluation method of depth accuracy, which used ball-catching task, in the virtual sports environment as an application of the virtual world, and had conducted assessments using this method. It is because players have to precisely determine the hitting or catching position of the ball in the real world and this is also important factor for sports in a virtual world. Therefore, the depth accuracy strongly influenced the catching task score. In the concrete, we gave ball-catching tasks to the subject when the relative positions of the subject and the stimulus object in the assessment were shown as figure 2. We used a dynamic 3-D CG object for the stimulus image, which simulated the moving ball during simple ball-game as sports in a virtual world. The stimulus object was a tennis ball that generated by 3-D CG. It appeared at the center of the screen, and moved rectilinear from far to near at a constant velocity. The subject judged the collision timing of the ball object image to their face. This emulated the action of catching. Then, the subject clicked the mouse button at the moment of collision, and the timing data was recorded into the measurement system.

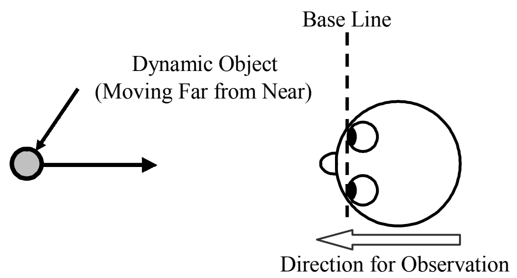

Fig. 2 Relative position between subject and stimulus object in a virtual space (old method)

In this assessment, the time difference between the correct ball-catching moment and the mouse clicking moment was the main evaluation index. This index value can be influenced by the depth accuracy of each stimulus condition. Therefore, we could evaluate the characteristics of the depth accuracy from the statistics of the index value, under each of the different conditions for the stimulus representation. This is a basic idea of this evaluation.

As mentioned in the previous sections, the disorder of the convergence and the accommodation is a major weakness of current stereoscopic displays. We therefore focus on the relationship between the convergence and the accommodation in the stimulus representation, and we used an experimental stereoscopic display system 3DDAC (Figure 3) [7], the 3DDAC system can regulate the depth position of the binocular disparity images, and this feature can control the relationship between the convergence and the accommodation by the optical mechanism in our assessment. The 3DDAC system was originally developed by ATR Media Integration and Communication Research Laboratories in 1997.

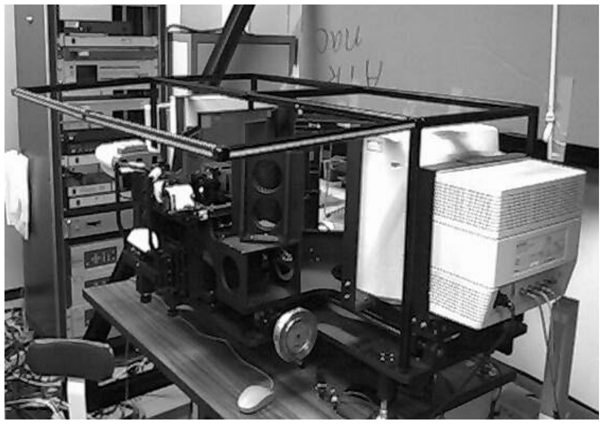

Fig. 3 Stereoscopic display with the accommodative compensation (3DDAC)

A result of the subjective assessments that used this evaluation method suggested that this contradiction lead to an inaccurate perception of depth. However, the reference position differs between each subject in this evaluation method, it is because the positions that they felt that they had to catch the ball differ a little among each subject. Therefore, it was difficult to do comprehensive evaluation even though we could evaluate the result of each subject. And so, we thought that evaluation in higher accuracy can be performed by unifying a reference position of the measurement in new improved evaluation method that is reported in this paper. We describe the detail of this improved evaluation in next subsection.

2.2 Improved Evaluation Method

As evaluation methods of the depth accuracy for dynamic objects in the real world, the inspection method that is shown as Figure 4 is known besides KVA and DVA that were mentioned above. In this method, each subject observes three bars that are located in the inspection machine (Figure 4) via a window for observation.

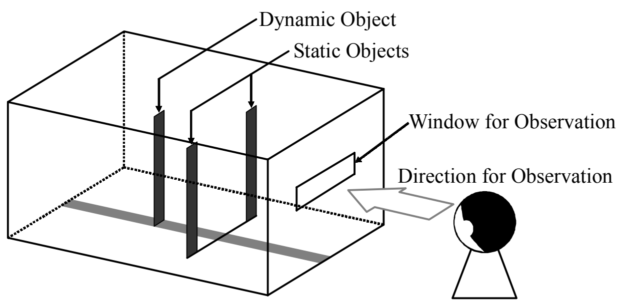

Fig. 4 Inspection method of the visual acuity for the depth

Then, the subject judged the timing of the three bars, that are a dynamic bar and two static bars, were located on the straight line. In this assessment, the main evaluation index is the distance between the straight line that connects two static bars and the position of the dynamic bar. In this method, the subject can always check on the position of static bars, and this position turns into a reference position seen from the subject. In the improved method that we describe in this paper, we reproduced an environment of the inspection method of the depth accuracy in a virtual world, which is generally used as a method in the real world. And we have set static objects used as a reference position in a virtual space, in the same manner as it. This performs detailed evaluation by unifying the reference position between each subject. The relative positions of the subject and the stimulus object in a virtual world were shown as figure 5. In the same manner as the evaluation method in the real world, we present and is observed three objects generated by 3-D CG via stereoscopic display to the subject. Two of three objects of outside are static, and one of the centers is moved back and force to the depth direction. Then, in case a dynamic object moves to force from back, and back from force, we so moved the dynamic object that it surely passes through the straight line, which connects two static objects at once.

Here, we gave the judging task to the subject. The subject judged the timing of the three objects, that are a dynamic object and two static objects, were located on the straight line. Then, the subject clicked the mouse button at the moment. Here, the main evaluation index is the distance between the straight line that connects two static objects and the position of the dynamic object.

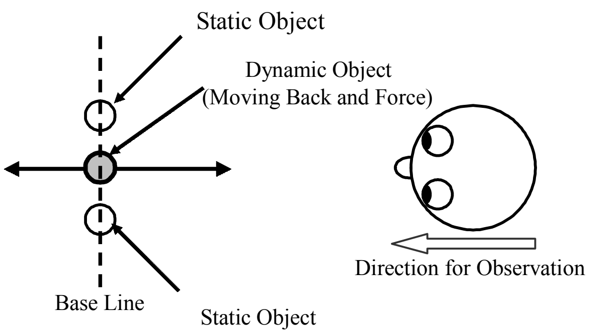

Fig. 5 Relative position between subject and stimulus object in a virtual space (improved method)

3. Assessment

In accordance with the new evaluation method that mentioned in the previous section, we developed stimulus images for assessment and conducted a subjective assessment. The detail of this assessment was as follows.

3.1 Stimulus Development

Stimulus: In the inspection method of the visual acuity for the depth in the real world, three bars were used as objects of attention. Then, we used cylinders as stimulus objects in virtual space. These stimulus images are 3-D CG objects, generated by each disparity images. In this disparity image generation, we set the pupil distance to 65 mm. Figure 6 shows an example of the stimulus image that was observed by the subject in assessment. And we also evaluated the case of using point lights as stimulus object.

Fig. 6 Stimulus

Location: In the inspection method of the visual acuity for the depth in the real world, the distance between a subject and static bars is set as about 2m in many cases. Therefore, we set static objects in the position 2.5m ahead of a subject.

Display Device: We gave stimulus images to each subject, via stereoscopic display. These are generated by an SGI workstation, and output to the 3DDAC system. As mentioned in the previous section, the screen of this display has a function for accommodative compensation. It can regulate the depth position of the perceived image at a designated depth position. By using this function, stimulus images are presented to the subject, while the accommodative distance is changed in a discretional manner.

Appearance Size: It is known that the size of its appearance will become an important factor as a pictorial cue other than the convergence and the accommodation. However, we had set the size of stimulus object's appearance may become the same as real world and experimented, it was because we keep the specific application in mind.

In an assessment that we describe in this paper, we expected the pictorial cue by keeping the size of its appearance constant, and we purposed to examine the depth inaccuracy that was caused only from the disorder of the convergence and accommodation. Moreover, we considered also about the case where the size of its appearance is changed according to the depth of an object as the target of evaluation, and compared whether a difference would be seen among both. The size of the cylinder in a reference position was made into the diameter of 20cm.

Speed: In past works, we set the speed of each stimulus object to every 2km/h between 30-50km/h and these were comparatively high speed. This is based on the example of application that assumed in past works was sports in a virtual world. However, we assumed that the disorder much affect the depth accuracy in such slower speed condition. It is because an experimental result is considered a possibility of being influenced of the accommodative reaction time and experiences becomes high, if the moving speed of a stimulus object is fast. In this assessment, we considered these influences as important and set the speed of each stimulus object to 1km/h.

Moving Method: Considering the practical effect of measurement, we measured in the range that the convergence and the accommodation strongly influence. Two cases of different patterns as the moving method of a dynamic object were set up within this range. First, we set up the case which moves a dynamic object only the equidistance (1.5m) back from force / force from back on the depth direction across the reference position as moving method of a dynamic object, pattern A. At this time, the initial position of a dynamic object was just the same as the distance of static objects (2.5m from a subject). Relationship between the elapsed time and the moving method of dynamic object in pattern A was shown as Figure 7. Next, we set up the case which moves a dynamic object the setting distances back from force / force from back on the depth direction across the reference position as pattern B. In this assessment, we set up three steps of distance (100cm, 150 cm, and 200cm) as depth distances to the front than a reference position. Moreover, we were set three steps of distance (350cm, 400 cm, and 500cm) as depth distances to back than the reference position. When a dynamic object moved in the depth direction, we beforehand determined patterns which surely pass through a reference position at once in random order. And we used it as patterns common to all subjects. Relationship between the elapsed time and the moving method of dynamic object in pattern B was shown as Figure 8. At both pattern, the initial position of a dynamic object was just the same as the distance of static objects (2.5m from a subject). In the case with a dynamic object moves only the equidistance on the depth direction across the reference position, like pattern A, it is for preventing passage timing being memorized by the subject. We assumed the moving method shown as Figure 7 as a cycle. And the subject observed two cycles as a set in the actual experiment. In both pattern, the number of times, which a dynamic object passes through the reference position, was 12 times in a set and 6 times in a cycle.

Accommodative Distance: To evaluate influences of the disorder of the convergence and the accommodation, we set the depth positions of the virtual images with some cases using the accommodative function of 3DDAC. In this assessment, we set the depth positions of the virtual images at accommodation distances of 1m, 2.5m, and 5m in the stereoscopic display system. The distance of 2.5m is the reference position. And we set the distance of 5m as the far point and the distance of 1m as the near point. We also evaluated the case of adapting the accommodation distance to the position of the dynamic object, like in the real world. To change the convergence distance, we regulated the position of the stimulus objects in each condition.

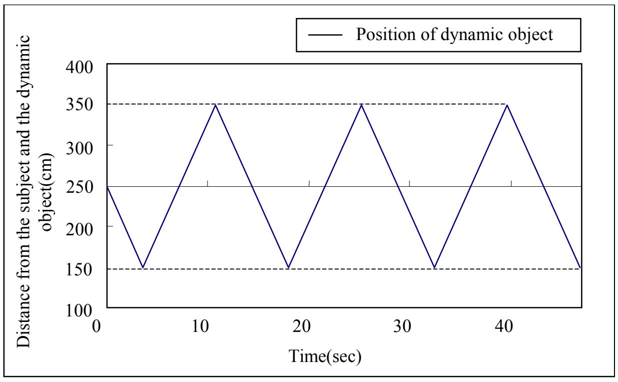

Fig. 7 Moving Method of Stimulus Object(Pattern A)

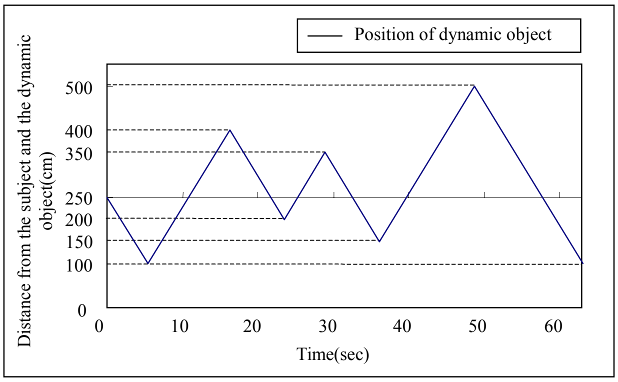

Fig. 8 Moving Method of Stimulus Object(Pattern B)

If the convergence distance is D_v, the accommodative distance is D_a, and the pupil distance of the subject is d, the convergence angle θ_v and the accommodative angle θ_a can be expressed with the following formulas, respectively.

$$\theta_v = \tan^{-1}\left(\frac{d}{2D_v}\right), \quad \theta_a = \tan^{-1}\left(\frac{d}{2D_a}\right) \qquad (1)$$

From the moving method of a dynamic object mentioned above, the disorder of the convergence angle and the accommodative angle becomes the maximum when D_v =5m and D_a= 1m, or D_v =1m and D_a= 5m. In this case, the disorder of these was 1.37deg.

The presentation conditions for the stimulus image were summarized as Table 1.

Table 1 Stimulus

No.	Object	Scaling	Moving method of stimulus	Accommodation distance
1	Cylinder	No	A	variable, 1m 2.5m, 5m
			B	
2		Yes	A	
			B	
3	Point Light	No	A	
			B	
4		Yes	A	
			B	

3.2 Subjective Assessment

We conducted a subjective assessment by using the developed stimulus. In this assessment, we used 13 subjects (9 male and 4 female subjects, aged 19-24) with normal visual acuity. Table 2 shows the list of subjects.

Table 2 Subjects

Subject No.	Age	Gender
a001	22	M
a002	20	M
a003	21	F
a004	20	F
a005	19	M
a006	19	F
a007	19	M
a008	20	M
a009	22	F
a010	24	M
a011	19	M
a012	19	M
a013	20	M

We explained the procedure of the assessment to each subject before the assessment. And we taught about the key operation at the time of measurement and who to observe the display screen of a stimulus. At this time, we instructed the subject to closely watch the dynamic object and follow its movement with their eyes. Explanation about moving patterns of the dynamic object is not given to each subject so that a prejudice may not be given. We use a dark room for this subjective assessment. We present a stimulus image to the subject after they adapt to the dark. Then, we showed stimulus images to the subject without drawing method of scaling and were answered a direction of dynamic object (back to force / force to back). Herewith, the assessment was started after checking that the subject can correctly recognize disparity images only from the convergence and the accommodation.

4. Result

Figure 9 is the example of the data that measured in the assessment.

We conducted statistical analyses on the results of the assessment. First, we compared averages and a standard deviations of the distance between static objects and dynamic object (f-test, $p<0.05$), and the results was follows.

1) Independently of kinds of the stimulus object and the moving method of it, standard deviation decreased as compared with the case where the drawing method with scaling was not used and with the case where it was used.

2) We do not found conspicuous influences about depth accuracy by setting of the accommodative distance. However, we found a tendency that the subjective task is carried out after passing through a reference position with the case where the accommodative distance was set to a near point.

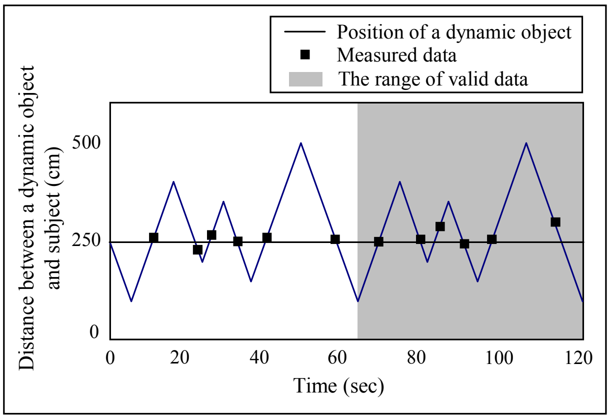

Fig. 9 Sample of measured data.

Next, we classified all the effective data into two groups. One was a group of data that were measured when the object moves to far from near, and the other was a group of data that were measured when the object moves to near from far. And we analyzed the average of time difference that was measured at each group. Consequently, there was a tendency for a task to be carried out after the dynamic object got through the reference position with both groups. It is guessed that the actual depth distance and the subject felt one are according to a hysteresis curve.

5. Conclusion

In this paper, we proposed a new evaluation method of the depth accuracy of dynamic objects in a virtual world, which solved the problem of the evaluation method proposed in past works. We also conducted a subjective assessment by using this method, and analyzed its results.

By the result of the subjective assessment using this method, we found that an apparent size is most important factor to the influence on the depth accuracy. Moreover, although the evaluation result using the old method was not remarkable, it has reconfirmed that the influence of the convergence and the accommodation also existed. If it considers with the result of the experiment using the old method, it is thought that the influence which disorder of the convergence and the accommodation has on the depth accuracy is what changes a lot, by the relationship between a task execution position and the accommodative distance. In other words, it was suggested that influence of this disorder was larger than the case where a task execution position has a far direction when a task execution position is very close to a viewpoint.

References

1. S. Nagata: "Visual sensitivities to cues for depth perception", J. of ITE, Vol. 31, No. 8, pp. 649-655 (1977) (in Japanese).
2. Amigo, G.: "Variation of Stereoscopic Acuity with Observation Distance", J. of Opt. Soc. America, Vol.53, No.5, pp.630-635 (1963).
3. Wann, J. P., et al.: "Natural Problems for Stereoscopic Depth Perception in Virtual Environments", Vision Research, Vol.35, No.19, pp.2731-2736 (1995)
4. F. Okuyama: "3D Images and Virtual Fatigues", Proceeding of The Fourth IDW, pp. 839-842 (1997).
5. S. Kawahara, et al.: "An Evaluation of Depth Perception in a Virtual Space", The Seventh International Display Workshops (IDW'00), pp.1123-1126 (2000).
6. S. Kawahara, et al.: "A Proposal of New Method for the Depth Accuracy in a Virtual World", Electronic Imaging 2002, pp.9-17 (2002).
7. S. Shiwa, et al.: "Proposal for a 3-D display with accommodative compensation: 3DDAC", Journal of SID, 4/4, pp. 255-261 (1996).