View-Dependent Focal Blur for Immersive Virtual Environments

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ABSTRACT

Recently, researches using immersive virtual environments are widely carried out. While computers and projection devices become highly efficient, image distortion and perception errors, etc. become a problem in virtual environments. Therefore, the technique for more accurately transmitting the contents of virtual environments to the user has been required. Based on a such background, purposes of this research are to provide a view-dependent focal blur in immersive virtual environments and to consider that effects on depth perception. Focal blur enables us to perceive depth informations accurately in 3-D computer graphics. Therefore, it can provide better reality and presence of virtual environments.

In this research, we realized the view-dependent focal blur by the method for not depending on a screen position and our view direction in real time. Then, the effectiveness of this technique on depth perception was shown through some experiments.

Key words : Virtual Reality, Immersive Virtual Environment, Focal Blur, Depth Perception

1 Introduction

In recent years, immersive projection displays have been attracting the attention of researchers interested in VR (Virtual Reality). A CAVE system [1], which had been developed at the University of Illinois at Chicago in 1993 is typical system of an immersive projection display. By the present, many clone systems of CAVE [2] are made. These systems can generate highly immersive virtual environments. The application to various fields, therefore, is expected.

Immersive projection displays, however, has some problems in the practical use [3]. As one of the large problems, the special sensory property in the virtual environment generated with immersive projection displays is mentioned. Because of this property, we are confused when we use virtual environments. The main cause of this property is 1) measurement errors of a 3-D position tracker, and 2) effects of oblique screens used for immersive projection displays.

In some virtual environments, user's viewpoint and its direction are measured with 3-D position trackers. The 3-D scene is generated with these user's viewpoint information got by the 3-D sensors. The sensors are, however, very sensitive for its installation environment, and it is very difficult to reduce measurement errors. The generated 3-D scene gives the discomfort to the users when the measurement errors are included for user's viewpoint information. There is a object in front of a user in a virtual environment, for example. The object's position is not changed when the user moves toward the object. That position is, however, changed when the viewpoint information of the user has some measurement errors. The user is, therefore, greatly confused by this phenomenon. Therefore, the measurement error of the viewpoint exerts an enormous influence on the 3-D scene when we use an immersive projection display. The precision of the 3-D position tracker is, therefore, very important.

On the other hand, the effect of oblique screens is also a serious problem. It is possible that users freely move in the region surrounded with screens, when immersive projection displays are used. The positional relation of screens and user's viewpoint, therefore, dynamically change as shown in Figure 1(a). In the situation shown in figure 1(a)-iii, the user has to extremely view the screen from a oblique direction. In this case, depth perception errors which is peculiar to immersive projection displays occur. It is generally considered that the cause of this error is the effect by the focus adjustment increasing further than the parallax information for realizing the stereoscopic image [4]. This tendency strengthens, when the screen is more viewed from a oblique direction.

This situation is explained in detail using Figure 1(b). In this figure, there are two object placed

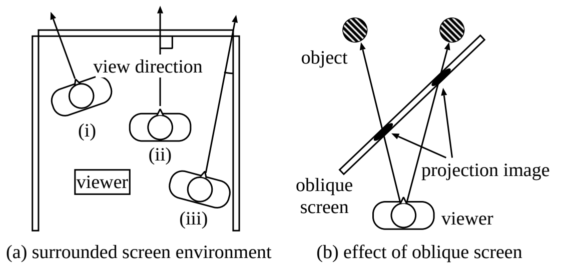

Figure 1: Positional relation between viewpoint and screen

at the equal distance from a viewpoint, and these objects are completely identical. The distances to the projection images on the screen from the viewpoint are, however, greatly different because of the oblique screen. In such situation, it is not possible to focus on those two projection images simultaneously. In immersive projection displays, 3-D images with parallax in order to realize stereoscopic images are generated, and users can accurately perceive the depth. With information got from the focus adjustment, the user, however, perceives that the object which projection image is more close to the viewpoint than the other is placed more close to them when the effect of the oblique screen becomes more strong as shown in Figure 1(b).

Especially in this study, the effect of the oblique screen is noticed and focal blur effects are introduced as new information for reducing the depth perception error. In the daily life, our view is blurred depending on the focus point, and the focal blur is very important to perceive depth information. With recent immersive projection displays, we can realize binocular stereoscopic vision and changes of our viewpoint with high resolution images. A few VR systems, however, consider the focal blur [5]. In order to construct more natural and more realistic VR systems, it is necessary to consider focal blur depending on our viewpoint.

In this paper, we realized view-dependent focal blur in immersive virtual environments generated with immersive projection displays like a CAVE system. Then we carried out two experiments in order to examine the relationship between view-dependent focal blur and depth perception in virtual environments.

The remainder of this paper is structured as follows. Section 2 reviews previous related work. Section 3 describes the view-dependent focal blur. Section 4 illustrates a variety of results of some experiments. Section 5 discusses advantage and defect of our approach. Finally, section 6 provides conclusions.

2 Related Work

On a focal blur effect, many examinations have been carried out. In this section, some of them are introduced briefly.

Matter [6] observed that depth perception was produced only with focal blur. He placed the region with focal blur in a natural image, and the depth feel got from that region was evaluated. The evaluation of the case that blur reaches the edge of the region is also carried out. As the result, it was proven that the depth feel could be intentionally controlled by selectively adding the blurred region.

Shipley et al. [7] investigated the independent effects of three aspects of aerial perspective: blur, contrast and color change. They prepared many natural images applied these effects. Each image contained a pair of similar objects with a natural background. A subject's task was to indicate which object appeared closer. This experiment showed that focal blur assisted the depth perception.

The research on atmospheric effects which consider the view direction of the user though it has no direct relationship on focal blur is also carried out. "Fog" is famous as a effect for showing the image more naturally. Fog makes objects fade into the distance. It can be used to simulate haze, mist, smoke, or pollution. Fog, however, generally functions in the front-back direction of a display because the distance used for generating fog is the eye-coordinate distance between the viewpoint and the object. In order to solve this problem, Heidrich [8] proposed "Euclidean distance fog". In this method, the true Euclidean distance from the viewer to the object is used to compute more accurate fog. Euclidean distance fog ,therefore, effects with the dependence to the view direction. This is most useful in visual simulation application where realism is a top requirement.

The researches introduced in previous paragraphs had made a non-stereoscopic image to be an object. The study which used focal blur effect for stereoscopic image is shown next. Okajima et al. [9] developed a rendering system that can simulate focal blur of the human lens in real time. The system provides focal blur information in 3-D computer graphics images while the observer's eyes are moving around naturally. In their research, focal blur was used in stereoscopic images. Three environment, 1) focal blur effect, 2) stereo effect, 3) focal blur and stereo effect, was presented to the user in a experiment. In each environment, two objects are presented and the one perceived more closer was selected by the user. From this experiment, it was found that a depth is most correctly perceived when focal blur effect and stereo effect were simultaneously used. It was also proven that focal blur was more effective for depth perception than stereo effect. Matter et al. [10] reported same results about a relationship between focal blur effect and stereo effect.

In a special example, focal blur is used not to assist depth perception, but to obstruct user's view. Hirose et al. [11] used focal blur to simulate visual field of visually handicapped person in virtual environment. This experiment is useful for barrier-free town planning.

By summarizing all of this section, it was proven that focal blur is effective for depth perception by many previous works. In this paper, we try to create more realistic and immersive virtual environment by using focal blur on immersive projection displays in which depth perception error frequently arises.

3 View-dependent focal blur

In the real world, our vision is in perfect focus only for objects left in a certain distance from the viewpoint. The farther the object is from this focused point, the more out of focus it is. It is called focal blur effect. In general 3-D computer graphics, the focal blur effect is not used, and everything we draw is in focus. Not only the lose of reality, but also it results in the lose of accurate perception of the 3-D scene.

In order to solve this problem and offer new information for the accurate depth perception described in a previous section, we introduce view-dependent focal blur which modified DOF (Depth-of-Field) effect [12] in immersive virtual environments.

3.1 Algorithm

In many VR systems, 3-D scenes are rendered with OpenGL. A method to realize DOF effect generally uses the accumulation buffer which is a part of OpenGL. This method is briefly shown in Figure 2(a).

In this method, we have to choose some pseudo viewpoints so that positions of them vary slightly around a true position and each viewing volume shares a common rectangle that lies in a perfectly focused plane. The images generated from these pseudo viewpoints are synthesized with the accumulation buffer. After this process, images which include focal blur effect are generated.

However, the relationship between our view direction and a position of a screen changes dynamically in immersive projection displays surrounded by large screens like a CAVE system. In the conventional technique, the focus plane and the screen must be parallel. Focal blur, therefore, functioned only for the front-back direction of the screen as shown in Figure 2(b). It is clear that the conventional technique is insufficient in immersive projection displays. To resolve this problem, we modified the traditional method as shown in Figure 2(c). In this new method,

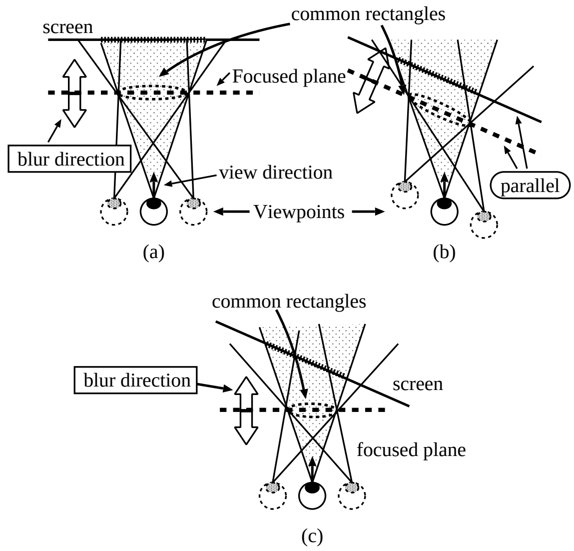

Figure 2: Viewing volume for view-dependent focal blur

the direction of the focus plane follows our view direction obtained with a 3-D position sensor. Focal blur, therefore, effects without dependence on the positional relationship between our view direction and a position of a screen.

With this method, the view-dependent focal blur is realized in immersive virtual environments. By using high-end graphics workstations, this method can be processed in real-time.

3.2 Application to actual 3-D scene

In this section. we introduce a sample 3-D scene rendered with the view-dependent focal blur effect. Positions of virtual objects drawn in that scene are illustrated in Figure 4. In this figure, a user views a screen from a oblique direction, and virtual objects arranging at 3 rows are placed in front of the user.

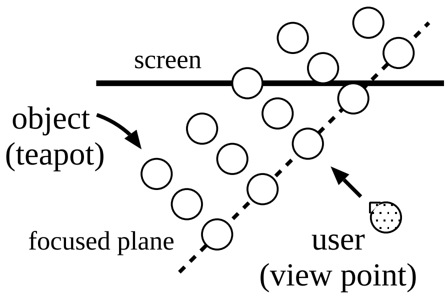

Figure 3: Structure of example scene

The rendered image of this scene is shown in Figure 4. Teapot images are used as virtual objects. In this image, objects are more and more blurred as their distance from a perfectly focused plane increases. It is very important that the focal blur effect is depend on the distance from not the screen but the user's focused plane.

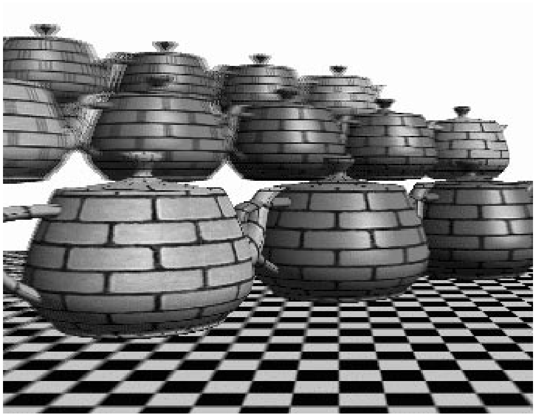

Figure 4: 3-D scene with view-dependent focal blur

3.3 Effect on visual acuity

Our proposed method gives focal blur effect on the region which is out of focus on the screen. In other words, the region is hard to be observed according to this blur effect. In this section, we measured the degree of focal blur effect with visual acuity as a criterion for evaluation.

The environment for the evaluation is shown in Figure 5. Subjects focused their eyes on a object which is d1 distant from their viewpoint. Next, we presented an eye examination chart at the distance of d2 from the subject's viewpoint, and measured their visual acuity. The eye examination chart contains "Randolt ring" generated by computer. The Randolt ring was displayed for 150 msec. This period is shorter than the time until the eye adjusted the focus on the examination chart.

We carried out this evaluation in three situations listed in Table 1. In the situation A, a user focuses on a object and measures visual acuity by using a eye examination chart (i). In this measurement, the user's eyes are not focused on the chart. This situation simulates unfocused conditions in the real world. On the other hand, in the situation B, chart (ii) is used instead of chart (i). The chart (ii) is projected image of the chart (i) on the screen shown in Figure 5. This situation is normal virtual environments without focal blur. The user's eyes, therefore, equally focus on both the object and the chart (ii). In the situation C, focal blur is added to the situation B. It realizes

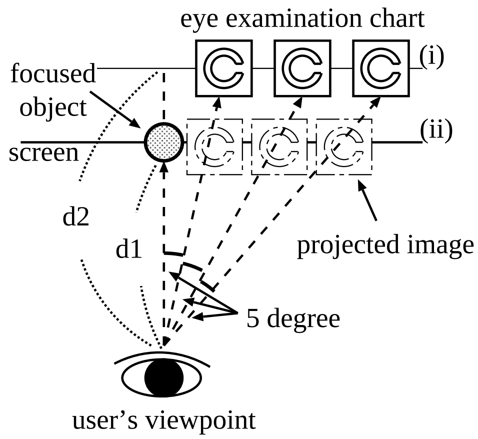

Figure 5: Evaluation with visual acuity

the virtual environment using focal blur effect. In all situation, distant parameters are d1 = 1500 mm and d2 = 2500 mm. These values are decided on the assumption of a CAVE system.

Table 1: Experimental condition

situation	eye examination chart	focal blur
A	(i)	OFF
B	(ii)	OFF
C	(ii)	ON

The result of this evaluation is shown in Figure 6. In this figure, a horizontal axis indicates a angle from a view direction focused on a object, and a vertical axis indicates visual acuity. The result of situation B is different from that of situation A. Situation B, which indicates a general virtual environment, realizes high visual acuity when the angle is within 20 degree. On the other hand, the result of situation C is similar to that of situation A. From these results, it is found that focal blur effect can realize a visual characteristic which is similar to the one in the real world.

4 Experiments and Results

In order to illustrate the relationship between the view-dependent focal blur and its effect on the depth perception in virtual environments, we performed two experiments.

The first one examined how the view-dependent focal blur contributed for accuracy of the depth perception in immersive virtual environments. In the situation in which the effect of the oblique screen

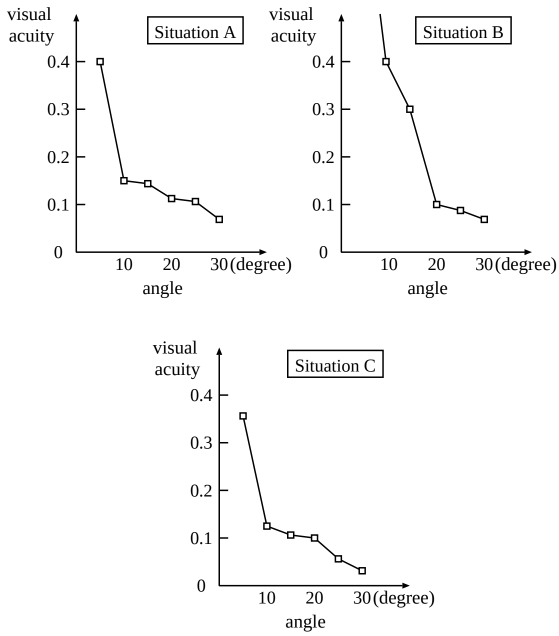

Figure 6: Visual acuity of unfocused region

was strong, the depth perception accuracy of the examinee was measured. In this time, the change of the accuracy by adding the view-dependent focal blur effect was observed.

The other one confirm reality reinforced with the view-dependent focal blur. In addition to conventional parallax information, the focal blur effect was added to the 3-D scene in this experiment. The change of the reality by adding the focal blur effect was measured.

In the following sections, we first explain our experiment equipment. Next, we describe each experiment in detail.

4.1 Experiment environment

We constructed a system shown in Figure 7 for following experiments. This is a simple immersive projection display. A large screen was prepared in order to cover a subject's field of view. The size of the screen is 120 inches. 3-D images generated with SGI Onyx is projected on the screen with a CRT projector.

We can also use a CAVE system. In the following experiments, however, precision of position measurement and flatness of the screen are extremely important. The 3-D position tracker which is used in our CAVE system contains some measurement error. The screens of our CAVE system is not completely flat, because these are soft screen stretched on a frame with some wires.

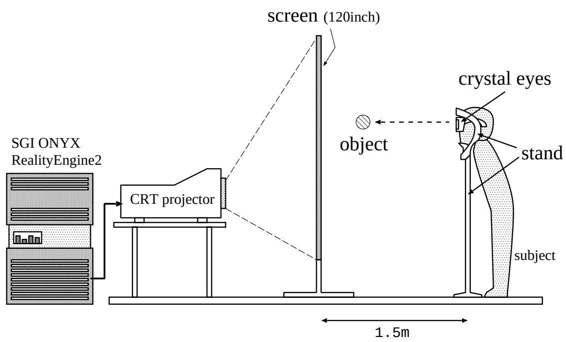

Figure 7: Experimental system

In order to resolve these problems, some contrivances are done in our experimental system illustrated in Figure 7. To begin with, a hard screen is used in the system. It is possible to remove distortion of projected images because the hard screen is perfectly flat. In addition, the head of the user is fixed by the stand. The position of the stand is precisely measured. It is possible to remove distortion of the images by the measurement error of the user's viewpoint because the head tracking is carried out without depending only on the 3-D position sensor.

In this system, parallax information is fundamentally contained. Subjects can experience a stereoscopic images by wearing a liquid crystal shuttering glasses.

4.2 Experiment 1: Evaluation of Accuracy

A purpose of this experiment is to study accuracy of the depth perception in immersive virtual environments with the view-dependent focal blur. For this experiment, the situation illustrated in Figure 8 was prepared. In this situation, we first placed two teapot objects at the same distance from a subject's viewpoint. The subject observe a oblique screen leaned toward thirty degrees from their view direction, on the assumption of immersive projection displays like a CAVE system. It is known that depth perception errors are occurred frequently and the users tend to perceive the object of the right side nearer because of the effect of the oblique screen as mentioned in the previous section.

In this experiment, the object of the right side is moved before and behind for the viewpoint in each trial, and the subjects are made to judge which one seems to be more close within two teapot objects. From this result, how the depth perception accuracy changed by adding the focal blur effect, was examined.

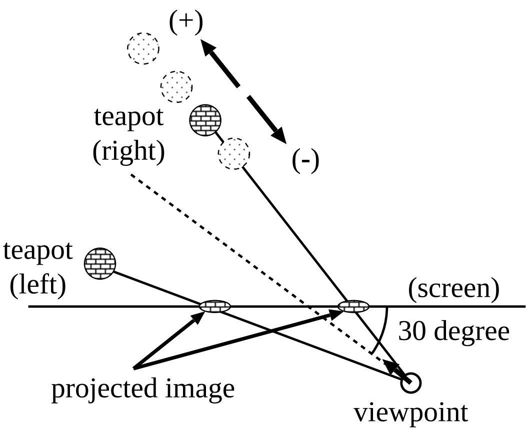

Figure 8: The accuracy of depth perception

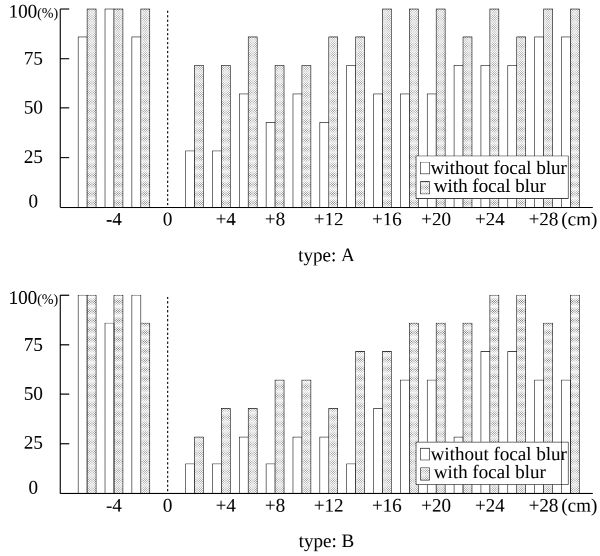

Figure 9: The accuracy of depth perception

4.3 Experiment 1: Results

A example of this result is shown in Figure 9. In this figure, the horizontal axis shows the distance at which we moved the right object before and behind, and the vertical axis shows the proportion of correct depth perception. This experiment was carried out for four subjects. These results are classified into two types as shown in Figure 9.

In case of users of type-A in Figure 9, The accuracy rate without the focal blur effect is around 50%, when the moved distance of the object is within 20 cm. With the focal blur effect, the accuracy rate is improved around 75%. The accuracy rate reaches 100% by the case. On the other hand, the accuracy rate of the type B is worse than type A as shown in Figure 9. There are many cases in which the accuracy rate is around 25% without the focal blur effect. The accuracy rate is 50% or less by the case even if the focal blur effect is added.

The cause of these differences is regarded as mainly user's individual difference. However, It was proven that the more accurate depth perception can be carried out in all subjects by using the view-dependent focal blur. This result shows that the focal blur effect reduces the depth perception error by the oblique screen.

4.4 Experiment 2: Evaluation of Reality

In this experiment, we examined the reality of an immersive virtual environment with view-dependent focal blur effect. We prepared three kinds of immersive virtual environments shown in Table 2 . The first one is a virtual environment with the view-dependent focal blur. The second one is with binocular stereoscopic effect and the last one is with both of view-dependent focal blur effect and binocular stereoscopic effect. Five subjects experienced above three kinds of environments, and compared two inside of them from a viewpoint of the reality and presence. The more realistic environment is scored, and the score is accumulated as shown in Figure 10. The examination was carried out at each eight times every each.

Table 2: Virtual environment for experiment 2

Env. Name	*Visual Effect*
A	Focal Blur
B	Stereo
C	Focal Blur + Stereo

4.5 Experiment 2: Results

In Figure 10, the result is classified in two groups. Three persons in five inside are in Type-I, and the remainder is in Type-II. In the Type-I, focal blur functions more efficiently than stereo effect. Conversely, stereo effect functions more better in the Type-II. In both case, a combination of focal blur and stereo is most effective. Because the individual difference is mainly included for this result, it is difficult to decide merits and demerits of focal blur and stereo effect. However, we can realize that the focal blur enhances the reality of the immersive virtual environment.

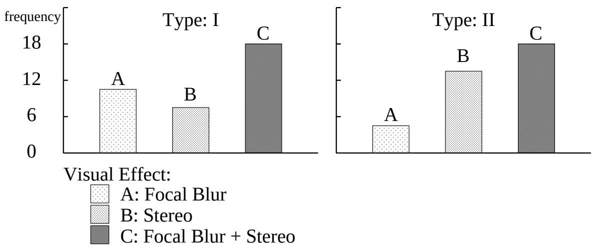

Figure 10: The reality of the virtual environment

5 Discussion

We illustrated the advantage of the view-dependent focal blur in previous sections. It can easily reduce the depth perception error and enhance the reality and presence of the virtual environments. This method, however, still contains some problems. In this section, we discuss about two subjects within the problems which is important when the method is used practically.

5.1 Optimization to individual

The results of the experiments in section 4 indicate the effectiveness of the view-dependent focal blur. This method, however, is unable to completely improve abovementioned problems like a depth perception error. It is considered that the main cause of this result is a individual variation. In the view-dependent focal blur, a degree of blur effect is controlled with some parameters. In the experiments of section 4, the parameters are dedicated by using heuristics. In order to function the method more effectively without individual variation, an optimization to individual users is needed.

There are many approach of the optimization. In this section, we introduce an approach using visual acuity. A visual acuity is also used in section 3.3. The experimental environment shown in Figure 5 is prerequisite. In this experiment, the characteristic of visual acuity in the real world and virtual environments with focal blur is measured as shown in Figure 6. By using this information, parameters which control a degree of blur are adjusted in order to simulate the characteristic of focal blur in the real world.

In a practical use of the view-dependent focal blur, the optimization is very important as a next step of this research. Therefore, we plan to wrestle this problem in the future.

5.2 Speed up

The view-dependent focal blur is very easy to implement if the accumulation buffer of OpenGL is available on conventional systems. It is suitable to enhance the reality and presence of traditional applications at a little cost.

The operations using the accumulation buffer is, however, very slow when inexpensive graphics hardwares are used. In this case, we must consider the speed up technique of the view-dependent focal blur. For example, the restriction of the blurred region is one of the approach. It is not necessary to use focal blur for the whole of the screen because our field of view is limited. If the blurred region becomes small, the view-dependent focal blur can be used without expensive graphics workstations. In recent years, VR systems based on PC (Personal Computer) have been a sudden increase. If the view-dependent focal blur is implemented on these systems, many virtual environments and its applications can take advantage of this method.

6 Conclusions

In this paper, we realized the view-dependent focal blur, and illustrated that focal blur is effective for natural and accurate depth perception in immersive virtual environments. In immersive projection displays like a CAVE system surrounded with screens, a depth perception error caused by the oblique screen is a big problem. The view-dependent focal blur is also used to reduce the effect of the oblique screen and to realize more correct depth perception.

In the future, we plan to optimize a degree of focal blur effect in order to effectively function for all users, and simulate more natural and realistic user's view in immersive virtual environments.

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