Representing Virtual Transparent Objects on OST-HMDs Considering Accommodation and Vergence

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ABSTRACT

We represent virtual transparent objects on OST-HMDs, considering the defocus by accommodation and the binocular disparity by vergence. In augmented reality with conventional stereoscopic displays, it is difficult to reproduce the defocus and the disparity between the images, surface, reflection, and refraction, of a transparent object with different depths. The reason why is that the accommodation focal is always fixed on the display screen, and furthermore, the reflection and refraction images considering the disparity do not exist in real-time, as they require a ray-tracing method for each eye. In this study, we represented transparent objects by reproducing the defocus with blur processing, and the disparity with pseudo parallax refraction. In our experiment, it was confirmed that the transparent object reproduced with the proposed method makes the images more realistic compared to the unprocessed one.

Index Terms: Human-centered computing—Human-computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Human-computer interaction (HCI)—Interaction devices—Displays and imagers

1 INTRODUCTION

Real transparent objects have some different depth images (*e.g.* object surface, reflection, and refraction). The human eye can freely adjust the vergence and the crystalline lens accommodation for each image. Therefore, to represent transparent objects realistically in computer graphics, it is necessary to reproduce the defocus caused by accommodation, and the binocular disparity caused by vergence. In non-stereoscopic displays, transparent objects are represented by only considering the defocus [3]. In contrast, in stereoscopic displays, the effective representation of the disparity is accounted for. In head-mounted displays (HMDs) and the representation of transparent objects, both the defocus and the disparity should be considered. In conventional HMDs, the crystalline lens accommodation focus is fixed at the display focus. Therefore, the defocus does not occur spontaneously in virtual objects with different depths. In addition, to represent parallax images of reflection and refraction, it is necessary to perform calculations for each eye by using the ray-tracing method. However, this is not done in most cases as it requires high calculation costs. Some HMDs such as light field displays [1] and varifocal displays [4] can provide the defocus and represent transparent objects in conformance with actual visual phenomenon. However, even these are subject to problems such as high computational costs, narrow field of view, and the requirement of large equipment. We use optical see-through HMDs (OST-HMDs), which can observe the real world directly, to make conditions except for virtual objects follow the actual phenomenon.

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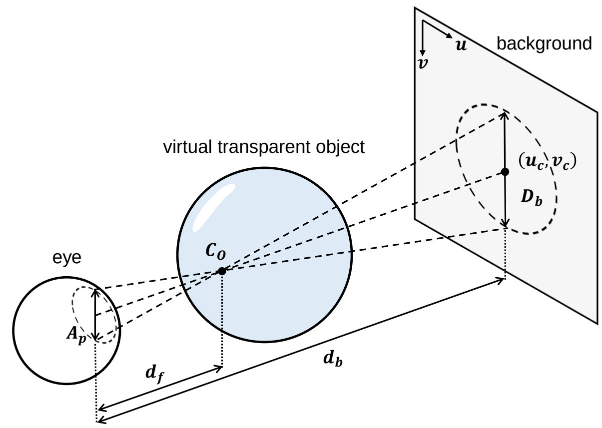

Figure 1. The model for calculating transparent object's color.

In this study, we represented virtual transparent objects realistically on OST-HMDs by reducing the visual mismatch of the accommodation and the vergence between the real and the virtual. Specifically, virtual transparent objects were represented realistically by reproducing the defocus and the disparity using blurring and pseudo parallax refraction, respectively. The defocus was reproduced by appropriately blurring with Gaussian functions, considering the crystalline lens accommodation. The disparity was reproduced by calculating the pseudo parallax refraction image from the refraction vector.

The hypothesis of our experiment is that users tend to perceive the transparent object reproduced by using the proposed method to be more realistic than the unprocessed one. From the experiment, we show that the transparent object reproduced with the proposed method is more realistic than the unprocessed one. We also show the contribution of each effect in enhancing the reproduced image, by including the only parallax and the blur in comparison.

2 PROPOSED METHOD

We propose a method in which virtual transparent objects are rendered by calculating a refraction image suitable for each eye and then blurring them, considered the defocus. Figure 1 shows the relationship between the eye, the virtual transparent object, and the real background. The pseudo parallax refraction image is computed by sampling the intersection (u_c, v_c) between the refraction vector and the background texture. The refraction vector is calculated by Snell's law for each polygon using the polygon's normal vector, the view vector, and the relative refractive index. Then, the defocus is computed by blurring with Gaussian function. The amount of blur is calculated, considering the crystalline lens accommodation according to the gaze point. When the color (R, G, B) of the transparent object surface is $\boldsymbol{C_s}$ and the color of the blurred refraction image is $\boldsymbol{C_b}$, the output color to the OST-HMDs $\boldsymbol{C_o}$ is given by:

$$\boldsymbol{C_o} = \alpha \boldsymbol{C_s} + (1-\alpha)\boldsymbol{C_b}. \quad (1)$$

Here, α is the ratio of an alpha blend, and $\boldsymbol{C_b}$ is calculated from: