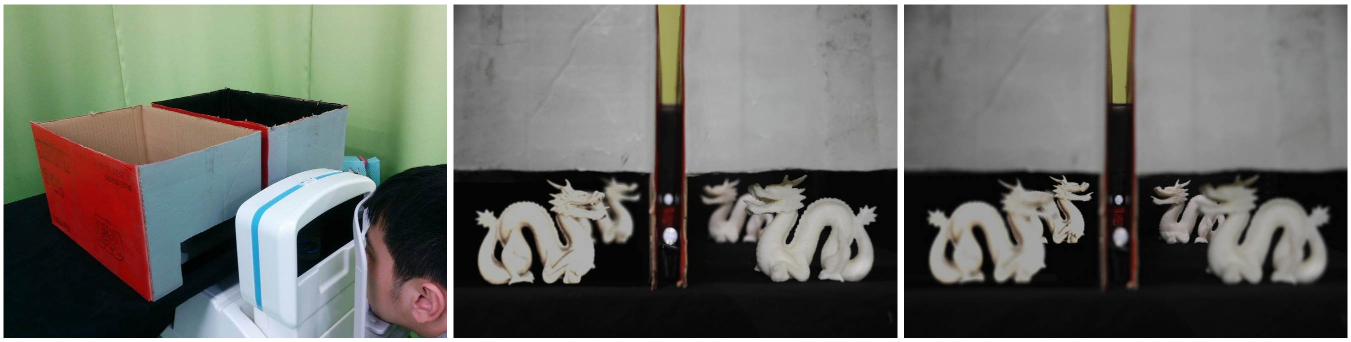
EyeAR: Physically-Based Depth of Field through Eye Measurements

Damien Constantine Rompapas * Kohei Oshima * Sei Ikeda†
Takafumi Taketomi * Goshiro Yamamoto * Christian Sandor * Hirokazu Kato *
*Interactive Media Design Laboratory, Nara Institute of Science and Technology
†Mobile Computing Laboratory, Ritsumeikan University



(a) (b) (c)

Figure 1: The goal of our demo is to embed computer graphics (CG) objects into the real world, which are indistinguishable from real objects. Up to now, this has been impossible in Optical See-Through Augmented Reality, because of the mismatch between the properties of the user's eyes and the virtual camera used to generate CG. Using an Auto Refractometer (a), we measure the user's pupil size and accommodative state and feed these values into a realtime raytracer. (b, c) The resulting Depth of Field of the CG dragons (left) matches 3D-printed dragons (right) - as the user focusses on dragon in front (b) and back (c).

Abstract

Augmented Reality (AR) is a technology which superimposes computer graphics (CG) images onto a user's view of the real world. A commonly used AR display device is an Optical See-Through Head-Mounted Display (OST-HMD), which is a transparent HMD, enabling users to observe the real-world directly, with CG added to it. A common problem in such systems is the mismatch between the properties of the user's eyes and the virtual camera used to generate CG. The goal of our system, is to accurately reflect the state of the user's eyes in our renderings.

Using an Auto Refractometer, we measure the user's pupil size and accommodative state and feed these values into a realtime raytracer. The resulting renderings accurately reflect the Depth-of-Field (DoF) blur effect the user perceives in their view of the real world. In our demo, users can verify the accuracy of our system by simultaneously observing 3D-printed objects next to their CG counterparts.

We believe that our technique is the most promising way for achieving augmentations that are indistinguishable from real objects. Integrating it into consumer OST-HMDs will be a crucial step for bringing photo realistic AR to the masses.

Keywords: Raytracing, Physically Based AR, Augmented Reality, Depth of Field, Optical Defocus

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; I.3.7 [Three-Dimensional Graphics and Realism]: Computer Graphics—Raytracing; I.3.3 [Computing Methodologies]: Picture/Image Generation—Display Methods;

1 Background

Augmented Reality (AR) is a technology which superimposes a CG image on a user's view of the real world. Ideally we aim to do so in a way which directly reflects the user's view of the surrounding environment. There are two main archetypes of Augmented Reality: Video See-through where CG is composed onto a video background of the environment observed by a camera, and Optical See-through, where CG is rendered on a transparent background allowing the user to observe the real world directly with CG added to it. Due to this key difference between the two archetypes above, it has been , up until now, impossible to create coherent CG. This is because of the significant difficulty to model the eye compared to a camera lens, which was previously done in [2].

What makes this demo unique and special? AR is becoming an increasingly popular technology, especially with the mass production of commodity OST-HMD devices. Since the Microsoft Hololens and Google Glass are attracting attention, we believe this will be an engaging demo.

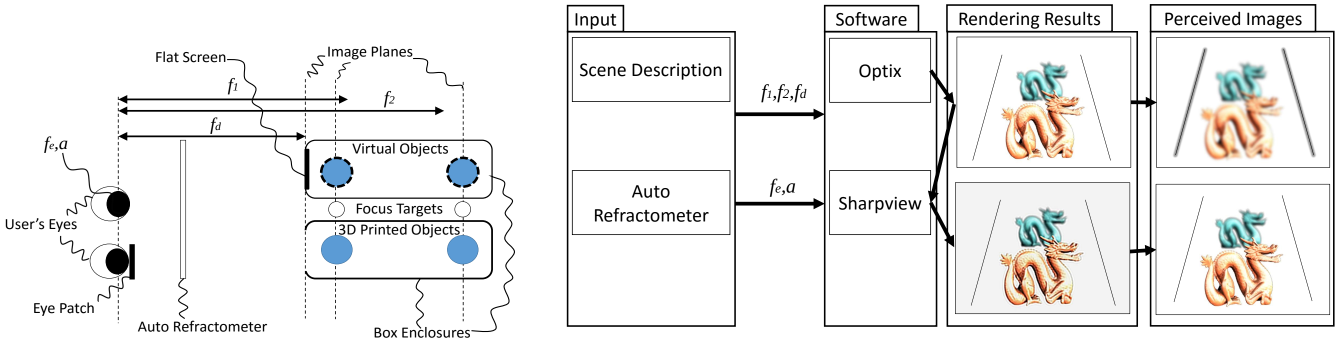
Additionally, users will become aware of the need to measure the eye since it is a major requirement in coherent CG for AR. Through this demo, users can experience a perfect DoF AR rendering during this demonstration, further enforcing the need for EyeAR.

2 Related Work

Previously[2] shows physically correct DoF in AR using Distributed Raytracing methods based on [1], however a major restriction is that the camera properties are pre-calculated for Video see-through AR (Such as the aperture size and focus length) for rendering Depth of Field effects.

Contribution: We extend this research to relieve this limitation, allowing use with Optical See-Through AR. We do this by measur-

*e-mail: {damien.rompapas.dk1, oshima.kohei.of0, takafumi-t, goshiro, sandor, kato} @is.naist.jp
†e-mail:ikeda.sei.jp@ieee.org



(a) (b)

Figure 2: (a) Top-down layout schematic of the demonstration setup: two physical targets are placed at distances f_1 and f_2, and virtual objects are also rendered at image planes with distances f_1 and f_2 in the left enclosure with 3D counter parts at distances f_1 and f_2 in the other. We also measure the distance f_d to the screen. The Auto Refractometer measures the eye's aperture a and focus distance f_e. (b) Pipeline of the demo: we pass in values from input into software then do a two-pass rendering; the first producing a DoF image. This image, when shown unmodified, will be perceived blurry due to optical defocus. The second pass adds the Sharpview adjustments, which will correct the optical defocus. This is then presented on the flat screen display.

ing the user's eye properties with an Auto Refractometer, passing the measured eye size and focus target into the Distributed Raytracing platform, and applying the Sharpview[4] technique which corrects the optical defocus that occurs due to the difference between screen and user focus depths.

3 System Design

Measuring the Eye: Measuring the eye is crucial for both the DoF CG and the Sharpview as we require the state of the users eye. The Auto Refractometer measures at 5Hz the eye's pupil size a and Diopter D, from which we calculate the focal length at $\frac{1}{D}$.

Distributed Raytracing: We use a Realtime Raytracer for creating a physically correct scene as the world is perceived by light rays entering our eye. Raytracers shoot primary rays from the center of the 'eye' towards a defined frustum, these primary rays intersect an object then shoot secondary rays toward a light source. This process generates a photo-realistic image. Our viewing frustum is defined in a similar way to the lens frustum shown in [2] except for the use of pupil size a as the aperture size and f_x as the focal length. Sampling along this lens using the same method shown in [1] provides a physically correct DoF rendering.

Use of Sharpview: Sharpview [4], based on [3], solves the optical defocus problem caused by a focal difference between the OST-HMD and the user's gaze target by applying a Wiener sharpening filter based on the eye's Point Spread Function (PSF). This PSF is approximated using a Gaussian function based on the eye's pupil size a and focal distance f_e, then sharpens according to the focal difference $f_d - f_e$.

4 Demo description

We sit a user in front of an Auto Refractometer and cover one of their eyes with an eye patch. They then gaze at the scene in front of them and focus on one of the two focus targets between the two box enclosures.

As the user focuses on the physical target, the Auto Refractometer passes measurements of the user's pupil size and diopter to the Raytracer, which displays a physically correct DoF rendering to the flat screen.

The user is then able to observe through peripheral vision two 3D Stanford Dragons with the physically correct DoF applied on a screen in the left box enclosure and a pair of 3D printed Stanford dragons in the right box enclosure. The user is free to change their focus between the two placed physical targets.

5 Demo Requirements

- *The amount of floor or desktop space needed*:
  - Floor space: 5m x 5m
  - Desktop space: one table(1m x 2m) and two chairs
- *The list of equipment you will bring(as detailed as possible)*:
  - Grand Seiko WAM-5500 Auto Refractometer
  - Desktop computer, Cables, Monitor
  - Netgear R7500 Wireless router
  - Flat-screen display
  - 2x Box-Enclosures
  - 2x 3D Printed Models
- *Any power, socket and outlet needs*:
  - 3x power outlet
  - Total power consumption 1- 1.5 kw
- *Environment requirements*:
  - Please provide one table (1m x 2m) and one chair.
  - We require constant illumination because pupil size depends on light environment.

References

[1] R. L. Cook, T. Porter, and L. Carpenter. Distributed ray tracing. In *Proceedings of the 11th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH, pages 137–145. ACM, 1984.

[2] P. Kán and H. Kaufmann. Physically-based depth of field in augmented reality. In *Proceedings of EUROGRAPHICS*, pages 89–92. Eurographics Association, 2012.

[3] B. Okumura, M. Kanbara, and N. Yokoya. Augmented reality based on estimation of defocusing and motion blurring from captured images. In *Proceedings of International Symposium on Mixed and Augmented Reality*, ISMAR, pages 219–225. ACM, 2006.

[4] K. Oshima, D. C. Rompapas, K. Moser, E. Swan, S. Ikeda, G. Yamamoto, T. Taketomi, C. Sandor, and H. Kato. Sharpview: Improved legibility of defocussed content on optical see-through head-mounted displays. *Demo under submission for: ACM International Symposium on Mixed and Augmented Reality*, 2015.