Does naive ChromaBlur drive accommodation?

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1 Introduction

Virtual reality engineers strive to improve immersion and realism. Conventional depth-of-field (DoF) rendering takes typical camera parameters, such as aperture size and focal distance, into account, but neglects the optical aberrations of the human eye. By including the chromatic aberration of the human eye into the calculations for blur, the realism of the scene can be heightened.

This technique was first demonstrated by Banks, et.al, in [1], however their methods, involving a computationally intensive deconvolution step, were not suitable for low-latency VR rendering. In the conclusions of [1], it was suggested that a similar accommodation response might be achieved with low-latency inside the graphics pipeline with a color-dependent, depth-dependent blur function. The purpose of this experiment was to determine whether a naïve wavelength-dependent DoF blur might drive accommodation.

2 Naive ChromaBlur algorithm

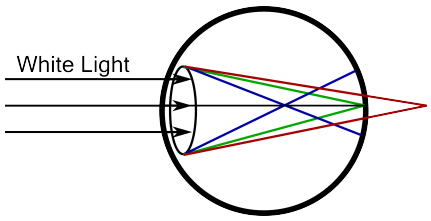

Figure 1: Chromatic aberration of the human eye focused at infinity.

The human eye has chromatic aberrations that cause only one wavelength to be perfectly in focus on the retina, as seen in 1 [3, 4, 2]. In a black and white image, it is assumed that green ($\lambda = 580$nm) is in focus. The wavelength dependent relative defocus (in diopters) can be written as,

$$D(\lambda) = 1.731 - \frac{633.46}{\lambda - 214.10} \tag{1}$$

where λ is in nanometers.The relative defocus can be used to determine an effective depth (in mm) for each color channel of each pixel. This effective depth can be expressed as,

$$d_e(\lambda) = \frac{1000}{\frac{1}{d_0} + D(\lambda)} \tag{2}$$

where d_0 is the real distance to the fragment. Using this effective depth, the radius of the blur for each color channel can be computed as,

$$blur(\lambda) = \frac{p|d_e - d_f|}{d_e} \tag{3}$$

where d_f is the focus distance and p is the pupil diameter. This blur can be implemented inside of a fragment shader similarly to conventional DoF rendering with a cylindrical blur [6, 5].

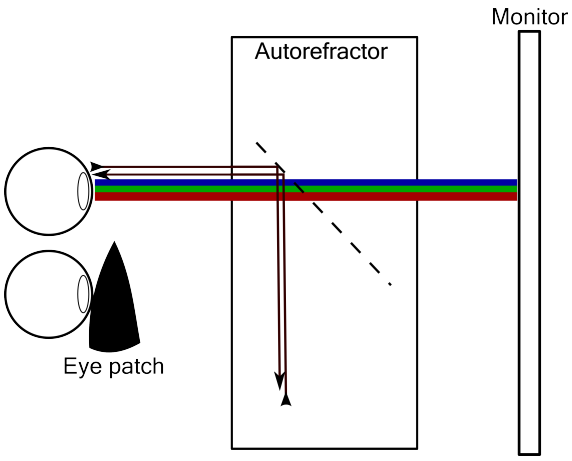

Figure 2: Experimental setup to measure the accommodative state of the subject.

3 Experimental Setup

The experiment consisted of measuring the monocular accommodative state of the subject with a Grand Seiko WAM-5500 autorefractor as seen in 2. The opposite eye was covered with an eye patch for the duration of the experiment.

One of the three images seen in 3 was displayed on a monitor 2 D away from the subject.The three images tested consisted of (a) a plane in focus at the depth of the monitor, (b) the plane rendered with conventional DoF rendering to be at -1 D, and (c) the plane rendered at -1 D using the naïve ChromaBlur algorithm detailed in Section 2. A blank (black) screen was shown for at least 1 second before each new stimulus.The accommodative state of the subject was measured multiple times within 3 seconds after the stimulus was changed, and the resulting accommodation was averaged. The experiment was run on a female subject with normal acuity, normal color vision, and no corrective lenses.

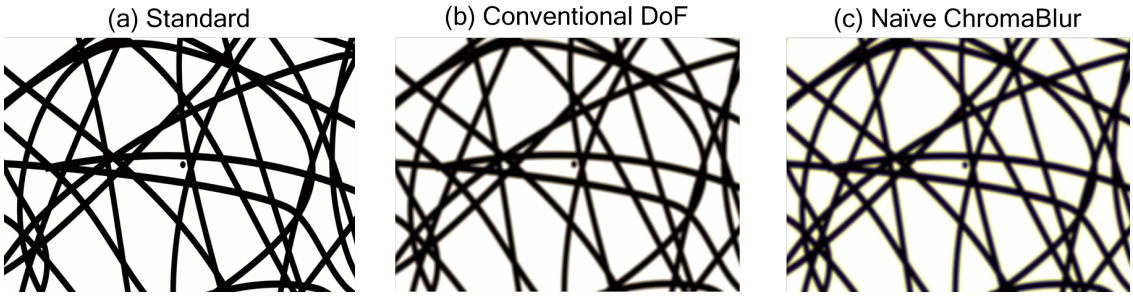

Figure 3: The three images used in testing.

4 Results

The tests were run 9 for conventional DoF blur and 12 times for naive Chromablur. Each of the data points in 4 and 5 represents the average accommodation of the subject for that sample. The average relative accommodation across all of the conventional DoF blur tests was -0.05 D. The average relative accommodation across all of the naïve ChromaBlur tests was -0.10 D. In a real scenario, we would expect close to -1 D of accommodation. For this subject, naïve ChromaBlur clearly does not appear to drive accommodation to the level seen in [1], although it was still slightly better than the conventional blur.

There are many potential reasons for this lack of accommodation. Primarily, the lack of smoothing in the rendering algorithm might be limiting the accommodative response. The deconvolution step in [1] seems to mostly serve to smooth the blur in each color channel. This smoothing might be achieved with a variable width Gaussian blur or similar, inside of the fragment shader, without the computationally-intensive deconvolution. The difference in the color channels with and without a Gaussian smoothing function can be seen in figure 6. The smoothed function appears much closer to the color gradients seen in [1].

This experiment could also be improved with continuous data from the autorefractor as well as a larger sample size of test subjects. Future studies to explore this area might include implementing a smoothing function in the rendering

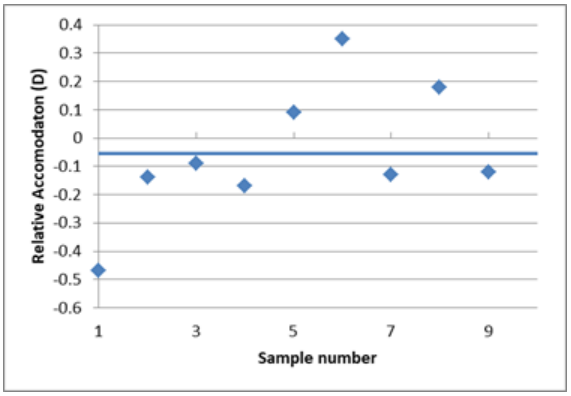

Figure 4: Relative accommodation for the conventional DoF image in 9 different trials.

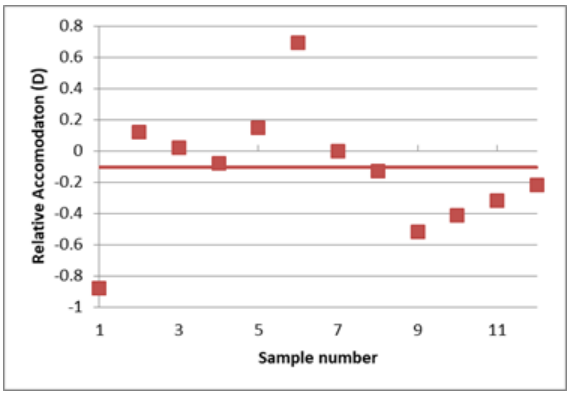

Figure 5: Relative accommodation for the ChromaBlur image in 12 different trials.

pipeline, binocular studies, and perceptual experiments. However, it is clear that driving monocular accommodation with naïve ChromaBlur does not work.

References

[1] Steven A. Cholewiak, Gordon D. Love, Pratul P. Srinivasan, Ren Ng, and Martin S. Banks. ChromaBlur: Rendering Chromatic Eye Aberration Improves Accommodation and Realism. *ACM Transactions on Graphics*, 36(6):1–12, 2017.

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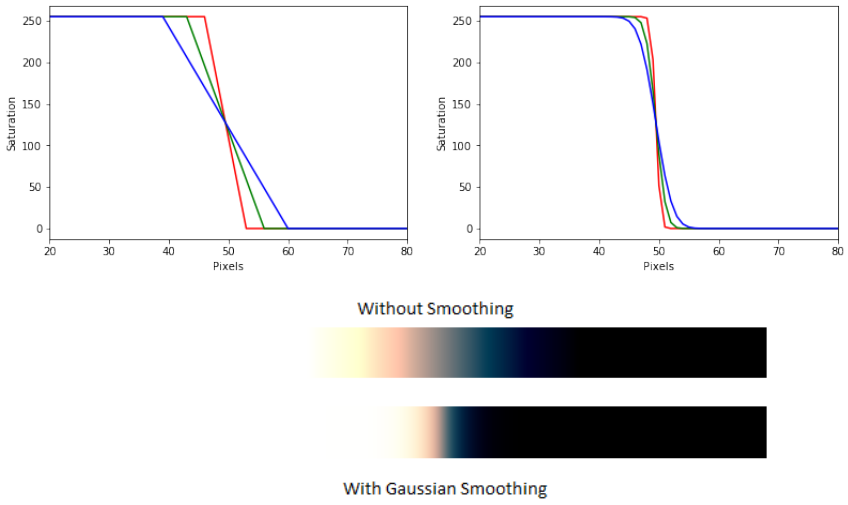

Figure 6: ChromaBlur color channels and resulting image (for a white to black step) rendered with and without a variable-width Gaussian smoothing function.