EE 267 Project Final Report
VR/AR Foveated Lens

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Introduction

VR/AR displays which are promised future mobile displays can revolutionize different aspect of human's life such as communication, shopping, and advertisement. They can also propose a variety of application in areas such as medical, education, and entertainment. However, these displays with great potential suffers from lack of acuity, field of view, etc. For high quality performance, they also need a powerful computational hardware. To address the problem of high cost graphical computation, people take the advantage of low fidelity of the Human Visual System (HVS) in the periphery. Human eyes has the highest acuity in the fovea, small region in retina, with 5 degree field of view and acuity rapidly falls by increasing angular distance(eccentricity) from the fovea. Therefore, we do not need a very high resolution rendered screen at the periphery. Funkhouser and Sequin[1] used this method with fixed gaze point at the center of the screen. Duchowski[2] and O'Sullivan et al[3] proposed application for using eye trackers for multi-resolution gaze-contingent displays. Guenter et al[4] optimized graphics computation by a factor of 5-6 on desktop HD display (1920*1080). Rachel et al[5] studied the latency requirements for the VR displays which are the main targets for the foveated rendering.

Project Summery

All the above works exploit foveated rendering to reduce computational costs and save bandwidth. However, most of VR displays support acuity of 5cpd, while human can perceive up to 30 cpd. The goal of this project is to use foveal vision to increase resolution of screens to beat the maximum perceivable of human acuity. In order to do that I leverage freeform optics to build a lens that can squeeze pixels of a screen into foveated region to increase acuity for foveated region while it does not change the field of view.

For designing the lens, I used the equation(1) that relates the input light to the desired output light by adjusting the phase profile of the lens. For the screen size, lens sizes and the distances, I used google cardboard parameters.

$$\theta_f = \theta_i + \frac{\lambda}{2\pi}\frac{d\phi}{dx} \quad (1)$$

In this approach, we calculate the angle of the light that comes form screen to lens, and we adjusted the gradient phase as well as phase profile of the lens in a way that light go through a pinhole eye. The result of the optical setup, phase profile, and gradient phase profile is depicted in figure(1). This shows that the phase profile is in consistent with what we expected for the quadratic phase profile of the simple lens.

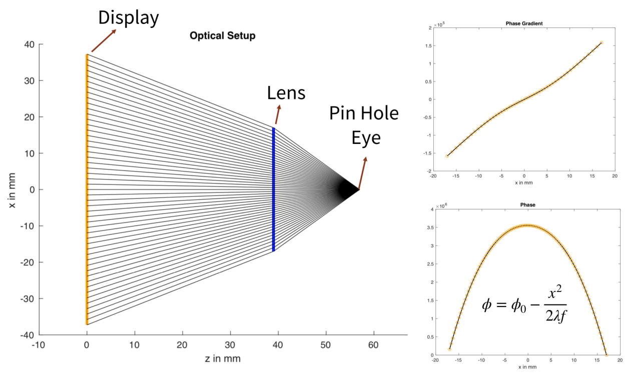

Figure 1

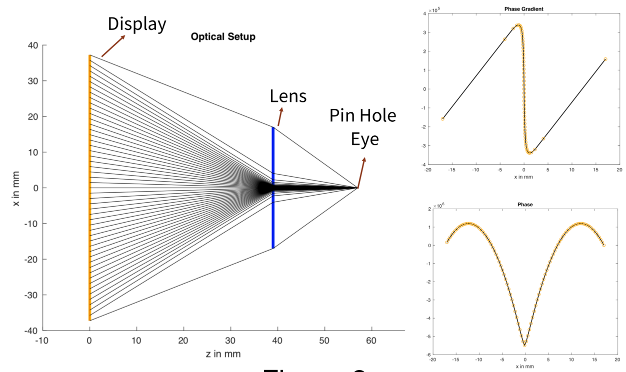

Figure 2

However, for designing foveated lens, we used the reciprocity of the light propagation. We assume that lights comes out from the eye and hit the screen. Therefore, we linearly sample the acuity of the human perception as a function of the eccentricity, and we designed the lens phase profile in a way that light linearly hit the screen. The result of the optical setup, phase profile, and gradient phase profile of the foveated lens is depicted in figure(2).

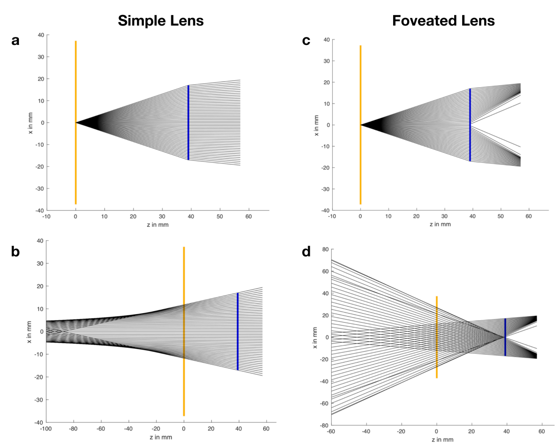

Figure 3

Now to see the imaging of the lenses, We studied the ray optic analysis of the point spread function of the lenses. Figure 3.a and 3.c show the responses of the simple and foveated lens to the point source. To see the virtual image, I extended the light ray after the lens and I plotted them in the figure 3.b and 3.d. Simple lens forms a virtual image behind the screen and foveated lens form two virtual images one close to the lens and the other far away from the screen.

As we saw in figure (3), both lenses suffer from the huge aberration, because equation (1)is based on small angle approximation, and we also assume that we have pinhole eye. This means that the screen should be much more smaller than the lens, which is not true for this case. And as we can see in figure (4) for the off-axis imaging the field of view of the image close the to the lens is very small.

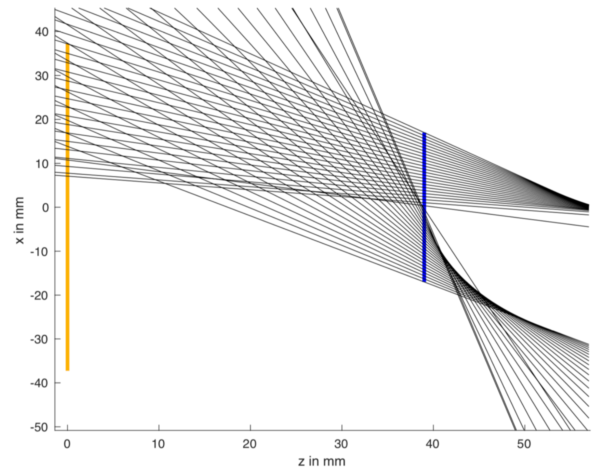

Figure 4

References

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[4] Guenter, Brian, et al. "Foveated 3D graphics." *ACM Transactions on Graphics (TOG)* 31.6 (2012): 164.

[5] Albert, Rachel, et al. "Latency requirements for foveated rendering in virtual reality." *ACM Transactions on Applied Perception (TAP)* 14.4 (2017): 25.