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DIPARTIMENTO INFORMATICA, BIOINGEGNERIA, ROBOTICA E INGEGNERIA DEI SISTEMI

Computer Science Workshop
PhD program in Computer Science and Systems Engineering

Improving visual experience in virtual reality systems through foveated depth-of-field

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Introduction

Virtual reality (VR) has expanded possibilities for how people learn and communicate. However, prolonged exposure to VR devices can cause users to feel discomfort and nausea, spoiling the immersive experience. Modern head mounted displays provide limited and often mismatching visual cues as compared to the real world. Over the years, many attempts have been made to address this discomfort. Dynamically altering the field-of-view has previously been shown as an effective measure [1], however, it leads to a reduced sense of immersion. Incorporating defocus blur has been shown as a successful tool in minimizing simulator sickness [2]. The aim of this research is to develop a system that takes its inspiration from the human physiological system and the optical characteristics of lenses. The developed system couples the output of foveated rendering and depth of field (DoF) blur to provide an artifact-free scene in the central region. A user study was conducted to evaluate whether foveated DoF can significantly reduce the level of induced cybersickness in virtual environments [3].

Methodology

- All processing is done at the shader level to ensure real-time performance.
- Image space methods are used in the linear color space.
- Bokeh/disc filter is used as the main smoothing function since it better mimics the aperture present in the human eyes and can lead to a more realistic output.
- The filters are applied at half resolution of the source image and the resultant frames are later up-sampled to boost processing times.
- Four pass shader was utilized to achieve the effect.
- **Pass 1**: This is the pre-processing step. The pixel-wise parameters (circle of confusion diameter and pixel radii) required by the subsequent shader passes are computed.
- **Pass 2**: DoF effects based on the circle of confusion are applied to the source image.

$$\sigma_d = KAs\left|\frac{1}{Z_f} - \frac{1}{Z_p}\right| \tag{1}$$

- **Pass 3**: Foveation effects are applied to the source image. For the multi-region foveation, the overall view is divided into three circular sections, representing the foveal, near and mid peripheral regions.
- **Pass 4**: Artifact removal is performed along with merging the outputs of DOF effect and foveation through the introduction of a blending function.

$$B_j(x,y) = \begin{cases} 0 & d(x,y) \le r_j \\ \frac{d(x,y)-r_j}{r_{j-1}-r_j} & r_j < d(x,y) < r_{j-1} \\ 1 & d(x,y) \ge r_{j-1} \end{cases} \tag{2}$$

$$O(x,y) = B_j(x,y)I_j(x,y) + (1 - B_j(x,y))I_{j-1}(x,y) \tag{3}$$

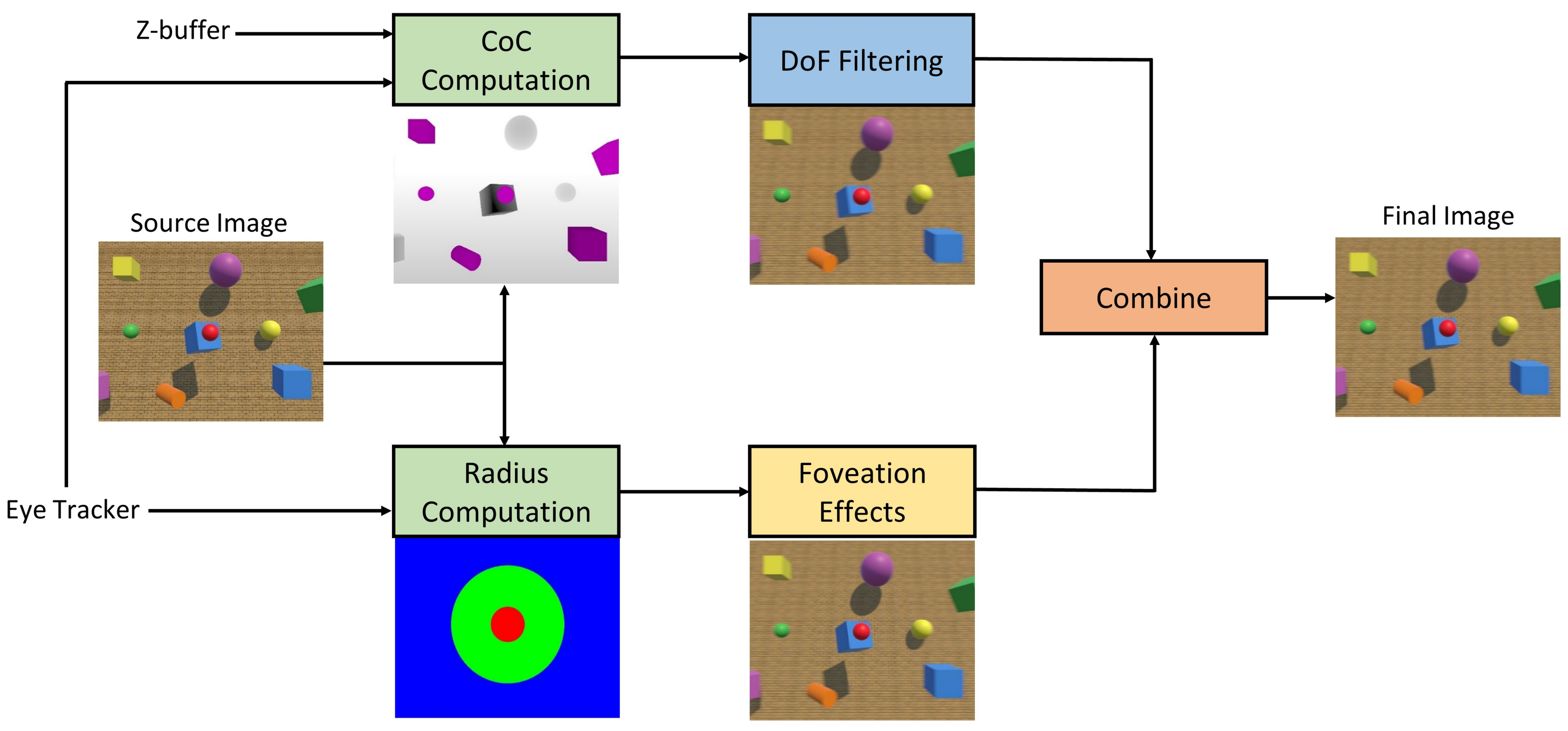

Figure 1: Process flow of the developed foveated DoF technique showing the intermediate outputs.

Experimental setup

- Objective was to understand whether foveated DoF effect helps with cybersickness.
- 18 participants aged from 18 to 46 years.
- An HTC Vive Pro Eye device that has an integrated Tobii eye tracking system was used for interacting with the user.
- A VR rollercoaster environment was designed to induce motion sickness.
- We consider three conditions: NB—No Blur; GC—Unity DoF Blur; FD—Foveated DoF.
- Simulator Sickness Questionnaire (SSQ) and Igroup Presence Questionnaire (IPQ) used for subjective evaluation.
- Eye gaze data and heart rate measurements used for quantitative analysis.

Results

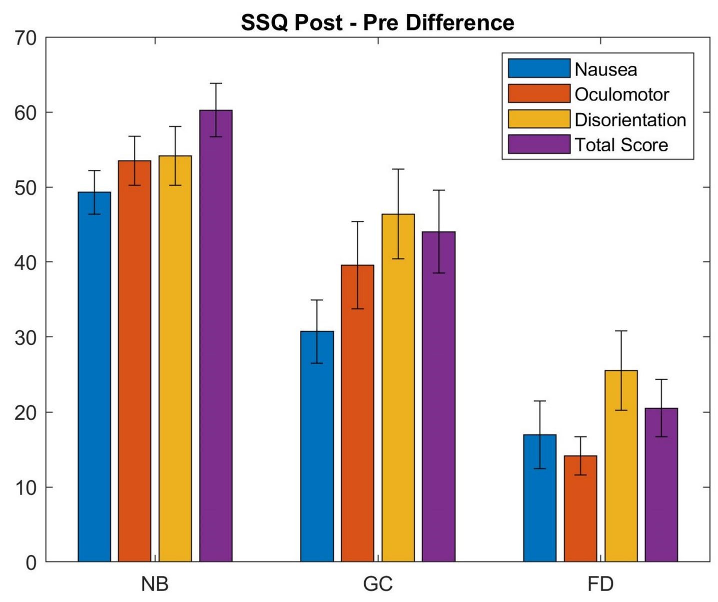

Figure 2: Comparison of the Post-Pre difference of the SSQ scores for each condition.

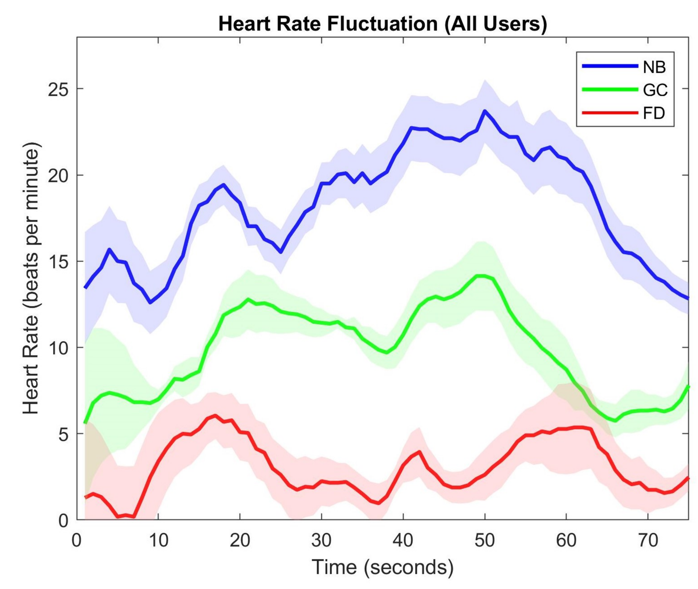

Figure 3: Average heart rate fluctuations from a resting heart rate during a rollercoaster cycle.

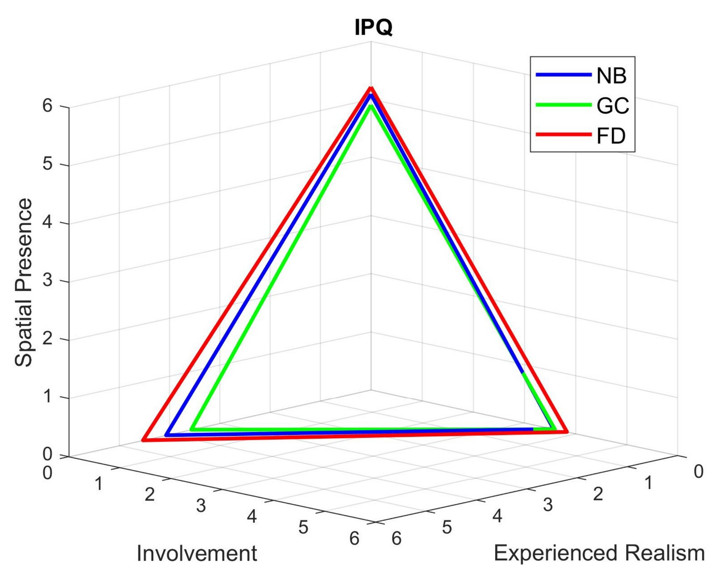

Figure 4: IPQ scores for the cybersickness experiment.

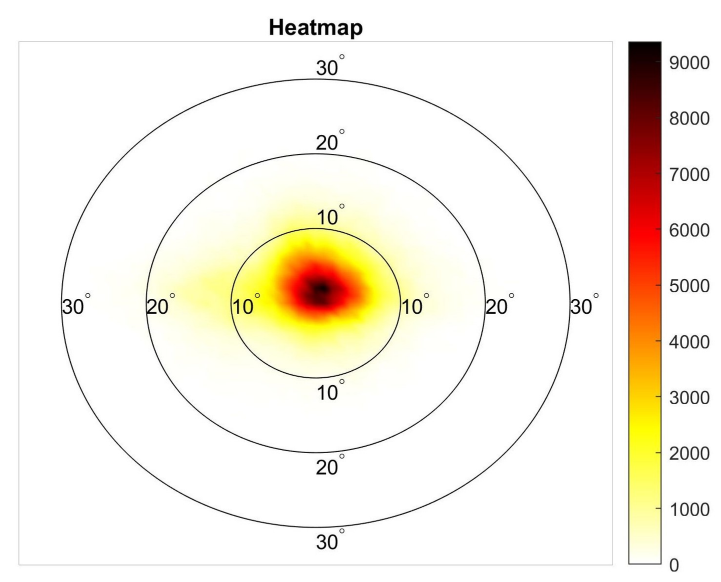

Figure 5: Heatmap of the visual field for user gaze combined for all sessions performed.

Conclusions

- A reduction of 27% and 66% in the SSQ total score for the Unity blur and our technique respectively as compared to the full fidelity condition.
- Circular motion has a more adverse effect as compared to linear motion.
- No statistically significant difference between the age and gender groups.

References

[1] Ajoy S Fernandes and Steven K. Feiner. Combating vr sickness through subtle dynamic field-of-view modification. In *2016 IEEE Symposium on 3D User Interfaces (3DUI)*, pages 201–210, 2016.

[2] Samuel Ang and John Quarles. Gingervr: An open source repository of cybersickness reduction techniques for unity. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pages 460–463, 2020.

[3] Razeen Hussain, Manuela Chessa, and Fabio Solari. Mitigating cybersickness in virtual reality systems through foveated depth-of-field blur. *Sensors*, 21(12), 2021.

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