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Carnegie Mellon University

Ph.D. Defense

Occlusion-aware Multifocal Displays

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Abstract:

The goal of three-dimensional (3D) displays is to recreate reality by satisfying all perceptual cues used by the human visual system. While many perceptual cues can be replicated by showing 2D images to our eyes, the accommodation cue, or the change of the focal length of the ocular lens, is very difficult to satisfy with today's 3D displays. This inability to support the focusing of the eyes causes a problem called the vergence-accommodation conflict, which causes visual discomfort after long periods of use.

Multifocal displays satisfy the accommodation cue by displaying content on multiple virtual planes, each at a different depth. However, current designs of multifocal displays suffer from a limited number of focal planes and their inability to block light. The small number of focal planes significantly reduces the supported depth range of multifocal displays. The light leaking from far focal planes also dramatically reduces the contrast of the image formed on the retina and weakens the occlusion cue --- another important perceptual cue used by the human visual system to estimate depth.

This dissertation focuses on solving the two limitations of multifocal displays --- the paucity of focal planes and the weak occlusion cue. Specifically, we design and build a multifocal display that can generate a dense focal stack --- with an order of magnitude increase in the number of focal planes over existing works. To create proper occlusion cues, we endow multifocal displays with a unique capability to tilt the light emitted by each pixel. We show that the capability enables multifocal displays to generate occlusion cues without losing spatial resolution. The dissertation also contributes to the theoretical understanding of multifocal displays. We analyze the domain of light fields that can be generated by multifocal displays and characterize multifocal displays in terms of their depth-of-field, spatial resolution, and the required number of focal planes.

The proposed methods enable natural accommodation and occlusion cues that are critical for an immersive virtual world. Virtual and augmented reality (VR/AR) devices stand to benefit significantly from the advancements made in the dissertation. Moreover, all of the proposed methods require only simple modifications to existing AR/VR displays and are computationally and bandwidth-efficient. In this sense, the technologies are timely and could pave the way to a more immersive AR/VR experience.