Varifocal Virtuality: A Novel Optical Layout for Near-Eye Display

Kaan Akşit
NVIDIA Corporation

Ward Lopes
NVIDIA Corporation

Jonghyun Kim
NVIDIA Corporation

Josef Spjut
NVIDIA Corporation

Anjul Patney
NVIDIA Corporation

Peter Shirley
NVIDIA Corporation

David Luebke
NVIDIA Corporation

Steven A. Cholewiak
University of California at Berkeley

Pratul Srinivasan
University of California at Berkeley

Ren Ng
University of California at Berkeley

Martin S. Banks
University of California at Berkeley

Gordon D. Love
Durham University

CCS CONCEPTS

• **Human-centered computing → Displays and imagers**; • **Applied computing → Physics**; • **Hardware → Emerging optical and photonic technologies**;

KEYWORDS

Near eye displays, See-through Displays, Varifocal Displays, Computational Displays, Augmented Reality Displays, Holography, Holographic Optical elements

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OVERVIEW

Augmented reality (AR) has recently gained momentum in the form of a variety of available optical see-through near-eye displays (NEDs) such as the Meta 2and the Microsoft Hololens. These devices are a big step forward towards Sutherland's vision of an *ultimate display* [Sutherland 1968]. The device we demonstrate attempts to deal with the main limitations of current devices. First, the graphics images are at a constant virtual distance for the eyes' accommodation mechanism, while the vergence of the two eyes working in concert places the virtual object(s) at a distance other than the accommodation distance. This *vergence-accommodation conflict* is one of the main problems in many AR and VR systems [Kress and Starner 2013]. The second limitation is achieving a wide FOV with compact optics. Cakmakci et al. [2006] contend that achieving a wide field-of-view (FOV) is the major optical design challenge in AR NEDs.

We demonstrate a novel wide FOV optical design (see Figure 1) that can adjust the accommodation depth dynamically so that the graphical object the user is looking at will be at the correct accommodation distance to match the vergence. The eye moves dynamically and can have objects at differing distances visible with in the fovea. For objects not at the eye's current accommodation distance, we computationally blur the graphics using the most up-to-date blurring technology: ChromaBlur. By accounting for high-order and chromatic aberrations of human eyes, ChromaBlur generates a blur signal that is more effective in terms of depth perception and driving accommodation.

CHROMABLUR

We include ChromaBlur in our prototype, now under review at ACM TOG [Cholewiak et al. 2017]. Blur occurs naturally when the eye is focused at one distance and an object is present at another distance. Computer-graphics engineers and vision scientists often wish to create display images that reproduce such depth-dependent blur. Typical methods correctly account for the scene geometry, pupil size, and focal distances, but does not take into account the optical aberrations of the person who will view the resulting images. This approach makes sense when the viewer's position relative to the display is not known. But in head-mounted displays (HMDs), viewer position is known. We developed a method that, by incorporating the viewer's optics, yields displayed images that produce retinal images close to the ones that occur in natural viewing. In particular, we create displayed images that properly take into account the chromatic aberration of the viewer's eye. This produces different chromatic effects in the retinal image for objects farther or nearer than current focus. We call the method ChromaBlur. Accommodation is driven accurately and quickly when ChromaBlur is used and is essentially not driven at all when conventional methods are used. Perceived realism is greater with imagery created by our ChromaBlur method than in imagery created conventionally.

ACHIEVING VARIFOCAL WIDE FOV AND PHYSICAL COMPACTNESS

A common approach to AR NEDs is to use a *beam splitter* where a partial mirror is used to reflect an image of a computer display. Looking through the beam splitter allows the user to see the image of the display while also observing the user's environment directly

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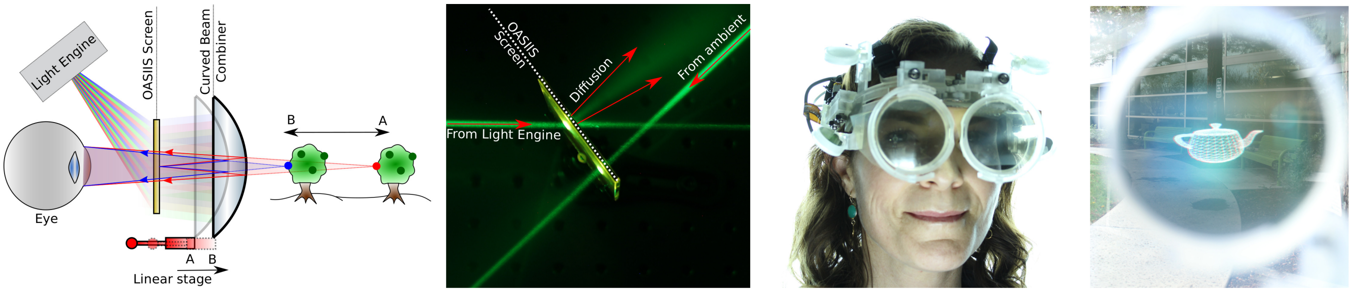

Figure 1: We will demonstrate a see-through, varifocal, near-eye display. Left: A light engine projects an image onto a thin, light-weight, see-through screen directly in front of the eye. The resulting image is relayed to a desired optical depth determined by the distance from the screen to the curved beam combiner. Middle left: Importantly, the screen is a hologram designed so that laser beams coming from each side act differently – light from the light engine diffuses towards the beam combiner while external light from the environment (and reflected light from the beam combiner) pass through the screen. Middle right: A wearable prototype uses two light engines through two optical folds to project onto the screens. Right: A daylight photo taken from the eye position demonstrates the brightness achieved by our design.

through the beam splitter. This necessitated placing the display to the side of the user's field of view and angling the mirror to reflect the light from the display to the viewer's eyes. The main innovation in what we present is to place a viewing screen directly in front of the user's eye so that a curved beam splitter can be placed on axis with the viewer's eyes. This can only work if the screen is transparent to the viewer (or it would block the user's view). This is achieved by using a one-way diffusing holographic screen of our own design that is directly invisible to the viewer, but the virtual image of the screen can be seen in high quality and in focus by looking through the curved beam-splitters. This design maintains the wide field of view associated with beam splitter designs which allowing for a more compact optical layout relative to other designs. The geometry of the beam-splitter and position of the screen determines the focal plane of the virtual objects. By dynamically positioning the screen along the optical axis we can dynamically move the focal plane. Both the holographic screen or the mirrors are light and small parts so moving either linearly with a small actuator is straightforward and achieves this varifocal property.

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