Steerable Application-Adaptive Near Eye Displays

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Figure 1: *(A)* A three dimensional rendering of our proposed near eye display's optical layout that is based on projection light engines with moving lenses colored in sky blue, three dimensionally printed application-adaptive optical diffusers colored in yellow, beam-splitters colored in dark blue, partially reflective beam combiners colored in white, and electronics colored in green. *(B)* A three-dimensional rendering showing our wearable near eye display design. *(C-D)* Actual photographs showing our printed wearable prototype from different perspectives, *(E-F)* Actual photographs showing how a single eye of an user observe high resolution augmented content displayed with our prototype at a sunset scenery. Top photograph is taken when an application-adaptive optical diffuser is used. Bottom photograph is taken without application-adaptive optical components leading to a steerable exit pupil. Both cases has the ability to steer the image by moving lenses of a projection light engine, promising a design candidate to future foveated near eye displays.

ABSTRACT

The design challenges of see-through near-eye displays can be mitigated by specializing an augmented reality device for a particular application. We present a novel optical design for augmented reality near-eye displays exploiting 3D stereolithography printing techniques to achieve similar characteristics to progressive prescription binoculars. We propose to manufacture inter-changeable optical components using 3D printing, leading to arbitrary shaped static projection screen surfaces that are adaptive to the targeted applications. We identify a computational optical design methodology to generate various optical components accordingly, leading to small compute and power demands. To this end, we introduce our augmented reality prototype with a moderate form-factor, large field of view. We have also presented that our prototype is promising high resolutions for a foveation technique using a moving lens in front

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of a projection system. We believe our display technique provides a gate-way to application-adaptive, easily replicable, customizable, and cost-effective near-eye display designs.

CCS CONCEPTS

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

KEYWORDS

Near eye displays, See-through Displays, Application Adaptive Displays, Computational Displays, Augmented Reality Displays, 3D printed optical components, projection displays

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OVERVIEW

Augmented reality (AR) near-eye displays (NEDs) promise to be the next mobile platform that provides a gateway to countless AR applications improving our day-to-day lives. To fulfill this promise, as described by Kress and Sterner [2013], AR NEDs for consumers need to provide immersive and natural looking scenes by tackling optical design challenges including accommodation, resolution, eyebox, and field of view (FoV).

A major challenge in achieving natural looking virtual scenes, and a key cause of discomfort is the vergence-accommodation conflict (VAC) [Hoffman et al. 2008], which is caused by the mismatch between binocular disparity of a stereoscopic image and optical focus cues provided by a display. Many approaches have been proposed for addressing the VAC problem, but each approach has limitations preventing the realization of a practical solution, e.g. varifocal displays (synthetic defocus cues, bulky components to actuate), light field displays using lenticular arrays or pinlights/pinholes (high computation, spatial-angular resolution trade-off), compressive light field displays using stacked LCDs (low contrast, high computation, diffraction), holographic displays (limited entendue leading to either small field of view or small eyebox, expensive).

Inspired by Sprague et al.'s [2015] findings that different daily tasks lead to different range of eye fixations in optical depth, the work of Matsuda et al. [2017], and the recent development in 3D printing optical components for desktop sized display applications [Brockmeyer et al. 2013; Pereira et al. 2014; Willis et al. 2012], we propose a NED that uses interchangeable application specific optical components generated by 3D printing and polishing processes. In our approach, a 3D printed diffusive surface with content specific geometry forms the projection screen for a pico-projector. The diffuse surface forms an optical conjugate of the desired virtual image surface. Our approach allows us to have a wide field of view, high resolution, large eyebox and an arbitrary virtual image surface geometry particular to a specific application. Given the shape of the adaptive diffuser, our proposed manufacturing pipeline for the adaptive diffusers takes less than a day. With an assortment of such adaptive diffusers, the user can switch among them quickly when moving from task to task.

We also address the trade-off between field of view and resolution by optically integrating a gaze contingent foveal inset which is moved in the field of view by moving a lens at the exit pupil of the foveal image's pico-projector. Previous works on foveated displays include the work of [Rolland et al. 1998] where multiple copies of the foveal image is created using a lenslet array but only one copy is transmitted using an amplitude mask, and the recent work of Konttori [2017] where foveation is achieved by actuating optical components similar to our approach.

We demonstrate our approach by building a headset and interchangeable 3D printed custom optical components for certain applications such as personal workspace, social interaction, driving & navigation, etc. As shown in Figure 1, We base our design to an optical layout using reflective beam combiners similar to the ones found in literature [Akşit et al. 2017; Dunn et al. 2017].

We also demonstrate a gaze-contingent steerable exit pupil in the same prototype by simply removing custom optical diffusers highlighted with yellow color in Figure 1. Therefore, both the demonstrated scenarios, steerable exit pupil and application adaptive imagery, promise a foveated display methodology embedded in optical hardware of a near eye display.

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