# Adaptive Dynamic Refocusing: Toward Solving Discomfort in Virtual Reality

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## ABSTRACT

We present an approach for eliminating the vergence-accommodation conflict, a fundamental cause of discomfort in today's Virtual Reality. We replace traditional lenses in a head-mounted display with a focus-adjustable optical system which provides accommodation cues consistent with the true depth of an observed object. In addition, we take into account the eyeglasses prescription of the user to enable the use of Virtual Reality without eyeglasses. We integrate our system into a commercial headset and demonstrate that solving the vergence-accommodation is possible in a compact form factor without affecting the resolution.

## CCS CONCEPTS

•**Computing methodologies** →**Virtual reality;**
•**Hardware** →*Emerging optical and photonic technologies;*

## KEYWORDS

vision correction, vergence-accommodation conflict, depth perception, virtual reality discomfort

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**Figure 1: Our prototype head-mounted display is based on a commercial Samsung GearVR headset (2016 edition). It integrates focus adjustable optical systems in a compact form factor, enabling dynamic refocusing and vision correction in addition to the original headset's capabilities.**

## 1 INTRODUCTION

Virtual Reality Head-Mounted Displays rely on a stereoscopic display which presents a distinct image to the left and right eye of the user. The disparity between these images produces vergence eye movements which provide a sense of depth to the user, who may then perceive the virtual environment in three dimensions. Current generation Virtual Reality (VR) head-mounted displays (HMDs) are focused at a fixed distance during normal use, and do not require the user's eyes to accommodate. This is not consistent with real-world vision and results in conflict between accommodation and vergence: the vergence cues provide the user with depth cues which vary depending on the observed region, whereas the accommodation cues suggest that the environment is flat, with a constant depth. Many studies suggest that this vergence-accommodation conflict contributes to distorted depth perception, visual fatigue and general discomfort, especially when using such displays over extended periods (Hoffman et al. 2008; Vienne et al. 2014).

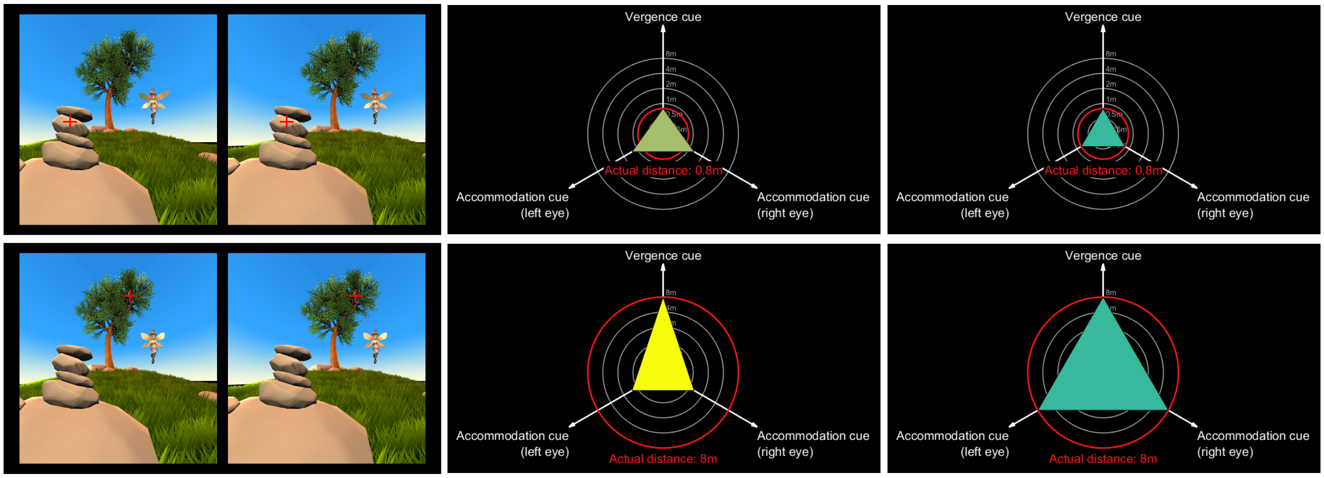
We present a focus-adjustable head-mounted display to overcome the vergence-accommodation conflict in Virtual Reality, and correct for the user's refractive errors such as myopia and hyperopia. In particular, we make the following contributions:

- a focus-adjustable optical system as a drop-in replacement of traditional HMD lenses;
- a software-based approach for determining the optimal focus dynamically, based on integrated eye tracking, refractive properties of the user's eye, and the virtual environment;
- a functional head-mounted display in a compact form factor, based on a commercial headset (Samsung GearVR), augmented with dynamic refocusing and vision-correcting capabilities.

## 2 RELATED WORK.

*Vision correction.* Most commercial VR headsets available today are designed for users with perfect eyesight, and are uncomfortable or impossible to wear for users with eyeglasses. While manual adjustment of focus or inter-pupillary distance is possible on some models, it is generally performed by the user through trial and error. In (Laffont et al. 2016), we presented a smartphone-based approach for measuring the user's eyeglasses prescription, and a virtual reality headset with moveable lenses to adjust the focus.

*Vergence-accommodation conflict.* Prior art is extensively reviewed in (Hua 2017; Kramida 2016). Existing vari-focal approaches adjust the focal distance of single plane displays based on the eye fixation point (Konrad et al. 2016; Liu et al. 2008; Shibata et al. 2005; Shiwa et al. 1996), but suffer from a low field of view when using electronically tunable lenses. Light-field displays sample projections of the virtual scene at different depths or light rays across multiple directions (Akeley et al. 2004; Lanman and Luebke 2013; Liu and Hua 2009; Love et al. 2009; Suyama et al. 2000), but face significant




(a) Stereoscopic pair (b) Conflicting cues in standard headset (c) Consistent cues with dynamic refocusing

**Figure 2: Current virtual reality headsets provide conflicting vergence and accommodation cues. Left: stereo pairs where red reticle indicates the region observed by a user in a virtual environment. Middle: Current VR headsets provide conflicting depth cues. Because of the fixed focus (1.3m in this example), accommodation cues for both eyes are fixed irrespective of the distance of the object observed. These accommodation cues conflict with vergence cues and the true depth of each object. Right: By dynamically adjusting the optical focus of the headset, our method provides consistent cues for each object being observed. The accommodation cues from both eyes agree with the vergence cues and the true depth of the object.**

resolution, refresh rate, and/or computational challenges. Furthermore, many of the previous approaches assume the viewer's eyes are aligned with the display system (e.g., on the optical axis of a lens) and do not handle deviations from those positions. Closest to ours is the work developed concurrently by Padmanaban et al. (2017), who describe a VR HMD with dynamic focus adjustment through an external stepper-motor. In comparison, we enable the independent adjustment of focus for each eye necessary to correct anisometropia, and describe a compact form factor where an automated optomechanical system replaces traditional lenses.

## 3 OUR SYSTEM

We augment a commercial Virtual Reality headset (Fig. 1) with the ability to correct for eye refraction errors while solving the vergence-accommodation conflict. We dynamically adjust the focus based on the user's gaze direction and the scene content, while accounting for the user's eyeglasses prescription to enable a sharp and comfortable viewing experience without eyeglasses. Our system builds upon three core components:

- eye tracking to determine the user's gaze direction;
- real-time analysis of the virtual environment to determine the depth of the object being observed;
- a compact optomechanical system replacing traditional HMD lenses to dynamically adjust the optical focus.

The effect of the proposed adaptive dynamic refocusing is illustrated on Fig. 2 for a user observing objects at two different distances (80cm and 8m) in a virtual environment. While a traditional headset creates conflicting vergence and accommodation cues, which induce eye strain when observing close or far objects in the virtual environment, ours provides consistent depth cues for all viewing distances.

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