SharpView: Improved Clarity of Defocussed Content on Optical See-Through Head-Mounted Displays

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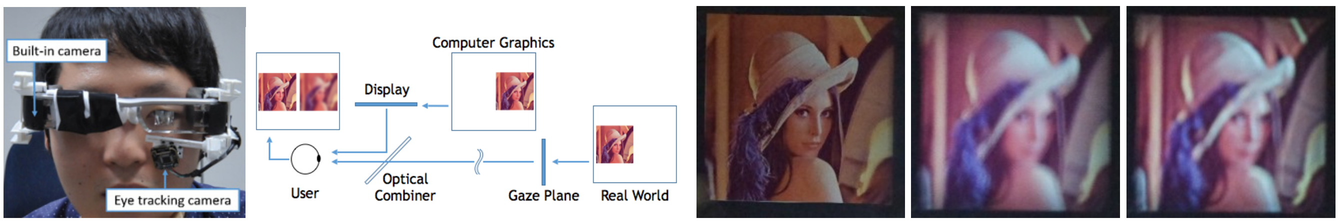

(a) (b) (c) (d) (e)

Figure 1: The cause and effect of focus blur in Optical See-Through (OST) Head-Mounted Display (HMD) systems. (a) A user wearing the OST HMD and related hardware used in our study. (b) Simplified schematic of an OST AR system. Blurring occurs when the virtual display screen and real world imagery are viewed at unequal focal distances. (c), (d), (e): Views through an OST Augmented Reality system, where the real world image (c) is in focus, causing the virtual image (d) to appear blurred; (e) an improved virtual image after application of SharpView.

Abstract

A common factor among current generation optical see-through augmented reality systems is fixed focal distance to virtual content. In this work, we investigate the issue of focus blur, in particular, the blurring caused by simultaneously viewing virtual content and physical objects in the environment at differing focal distances. We examine the application of dynamic sharpening filters as a straight forward, system independent, means for mitigating this effect improving the clarity of defocused AR content. We assess the utility of this method, termed SharpView, by employing an adjustment experiment in which users actively apply varying amounts of sharpening to reduce the perception of blur in AR content. Our experimental results validate the ability of our SharpView model to improve the visual clarity of focus blurred content, with optimal performance at focal differences well suited for near field AR applications.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; I.4.4 [Image Processing and Computer Vision]: Restoration—Wiener filtering

1 Introduction

Optical See-Through (OST) Head-Mounted Displays (HMDs) have seen an increase in both popularity and accessibility with the release of several consumer level options, including Google Glass and Epson Moverio BT-200, and announced future offerings, such as Microsoft's HoloLens, on the horizon. The transparent display technology used in these HMDs affords a unique experience, allowing the user to view on-screen computer generated (CG) content while maintaining a direct view of their environment, a property extremely well suited for AR systems. Unfortunately, the current generation of consumer-level OST HMDs are only capable of presenting CG content at a single fixed focal distance. This inherent limitation becomes problematic as the user attempts to simultaneously view the world and CG objects together, inducing focal rivalry as the eye's optical system must continuously adjust to accommodate both the real and virtual items.

Existing techniques for correcting blur and distortion, produced by the lenses of OST HMD devices, use static correction schemes, and therefore cannot adequately address the blur produced by focal rivalry, which does not remain constant, but continuously changes as the user fixates on objects throughout the environment. Solutions for OST focus blur require a dynamic approach, able to continually adjust to match the changing focal demand of the user. The Point Spread Function (PSF) [2], used to measure the focal ability of a system, also has application for identifying the refractive power limit of the eye's internal lens [4]. In this work, we present an active focus blur correction method capable of producing dynamic image improvement by continuously updating a PSF model for the user during system runtime. Our technique, designated SharpView, is the first methodology proposed for on-line processing of virtual imagery to counteract focus blur in OST AR.

2 SharpView Algorithm

Consider the simple optical system, shown in Figure 2, used to model the eye and OST HMD screen. As the user's gaze fixates at point M in the real environment, the light traveling from this point creates an image at point m on the eye's imaging plane, after passing through the lens. Similarly, light emitted from point M' on the HMD screen is imaged at point m' on the retina. The diffraction pattern of the light is modeled by a PSF. This same procedure can be analogously expressed, within the image processing domain, as a deconvolution operation between the image focused on the retina and the PSF. Therefore, if a PSF is known in advance, it is possible to restore a degraded image through deconvolution.

We generate our PSF approximation by modeling the intensity of the light rays, emitted from the display screen, intersecting varying

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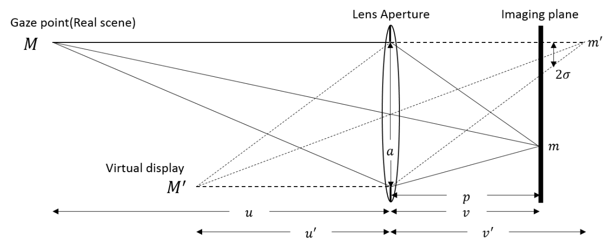
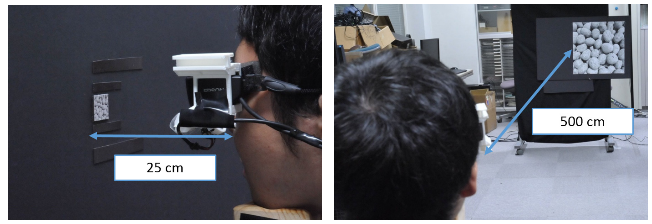


Figure 2: Optical system formed by the user's eye and an OST HMD. The imaging plane corresponds to the user's retina and the lens aperture to the user's pupil.



(a) (b)

Figure 3: Views of evaluation task with real world reference images placed in front of at 25 cm (a) and 500 cm (b) from the subjects' eyes.

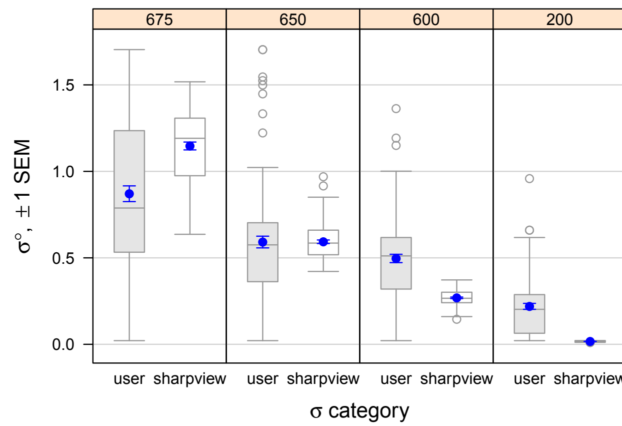


Figure 4: User-σ and SharpView-σ, expressed as visual angle, grouped by focal disparity. The mean and standard error of the mean (SEM) are shown in blue.

points on the retina. The intensity distribution, p, can be represented by the following function.

$$P(x,y) = \frac{1}{2\pi\sigma^2} exp(-\frac{x^2+y^2}{2\sigma^2}) \quad (1)$$

In equation (1), σ represents the radius of the focal blur, while x and y represent the pixel position of the emanating screen point. Our simplified PSF model, therefore, requires only one parameter, σ, to be determined at run time. σ itself can be derived from the basic triangle ratio and lens equations as follows:

$$\sigma = \frac{av}{2}(\frac{1}{u'} - \frac{1}{u}) \quad (2)$$

Once obtained, it is then necessary to scale from the eye's image plane back to the virtual display. If the radius of display blur is expressed as σ_d, the ratio between the eye's image plane and screen is expressed as follows.

$$\sigma : \sigma_d = v : u' \quad (3)$$

Here, σ_d is directly obtainable from equations (2) and (3),

$$\sigma_d = \frac{a}{2}(1 - \frac{u'}{u}) \quad (4)$$

where a is pupil diameter, u distance between the eye and real world gaze point, and u' the distance from eye to HMD image plane.

3 SharpView in Action

Common deconvolution operations include inverse filtering, Wiener filtering, and the iterative Richardson-Lucy algorithm [1]. Difficulty in performing deconvolution with a PSF arises, however, due to inaccuracies in the diffraction pattern model. Okumura et al. [3] have utilized information from captured images of 2D markers to estimate the PSF of a camera based system. Unfortunately, the same principles are not applicable to the human eye, since only the user themselves have access to the perceived image. Our SharpView algorithm overcomes these limitations by employing a simplified PSF model based on three user and system specific parameters: pupil diameter, distance to real world gaze point, and focal distance of the HMD display screen.

We developed SharpView based on the premise that perceived focus blur varies according to the focal disparity between the display and world. Based on this presumption, we implemented a user study investigation utilizing a simple adjustment task to obtain measures for the amount of perceived focus blur and preferred level of sharpening correction for subjects viewing real and virtual content through an OST AR system. Focus blur is induced by making subjects fixate their gaze upon real reference images, placed in front of the display, at distances differing from the actual focal distance of the HMD, Figure 3. A virtual image, identical to the real reference image, is then rendered to the display screen, and subjects are allowed to directly adjust the σ value of the corrective sharpening filter until optimal clarity of the on-screen image is achieved.

Figure 4 provides the user selected σ as well as the predicted σ values from our SharpView methodology, recorded for adjustment trials performed at four reference image focal distances. Our results show that the SharpView model is able to most accurately produce sharpening correction for focus blur at a focus disparity level of 650cm. For our system, which uses an Epson Moverio BT-200 with a focal distance of 700cm, SharpView performs optimally when subjects view AR content in relation to real objects that are located at approximately 50cm, or arms length, away. This means that applications requiring the use of AR for near field, or near vision, tasks, such as maintenance, 3D modeling, or medical procedures, will experience the largest benefit from SharpView compensation.

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