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

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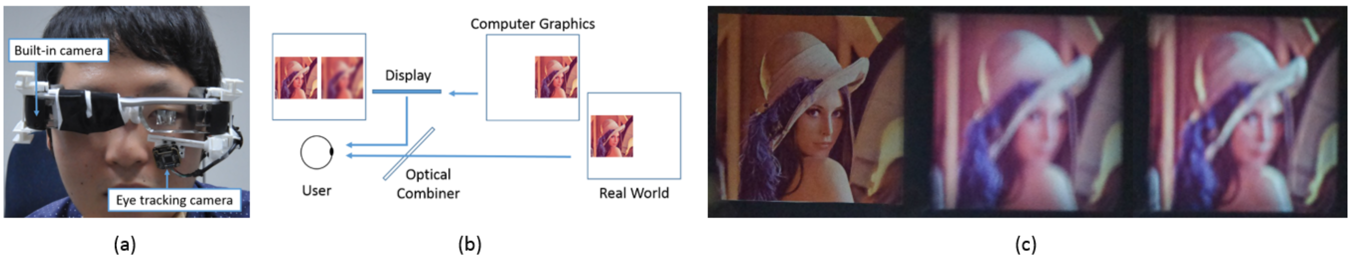

Figure 1: Illustrations of the cause and effect of focal disparity in Optical See-Through Head-Mounted Display (OST HMD) systems. (a) Image of a user wearing the Epson Moverio OST HMD hardware configuration used by our demonstration system. (b) Schematic of a general OST AR setup showing the distance discrepancy between the observed virtual screen and real world imagery. (c) Views through an OST HMD, with real world image at left and CG imagery at middle and right. The camera is focused on the real world image causing the virtual screen to appear blurred. Middle side of (c) Uncorrected view of the CG content. Right side of (c) View of the CG content after application of SharpView.

Abstract

Augmented Reality (AR) makes it possible to insert computer generated information and objects onto a user's view of the real-world. Optical See-Through (OST) Head-Mounted Displays (HMDs) are becoming an increasingly common medium for presenting AR content, with the added benefit of enabling users to observe the real-world directly, through transparent display material, alongside computer graphics (CG) content. A problem in OST HMD systems, though, is the existence of focal rivalry resulting from the distance disparity between real world objects and the virtual screen of the HMD. Due to the focal limitations of the human eye, this focal discrepancy results in the CG image appearing blurred when real objects are fixated upon. The goal of our SharpView system is to ameliorate this problem through sharpening.

SharpView utilizes a variable sharpening filter, based on the eye's Point Spread Function (PSF), to process the CG imagery before it is displayed. We derive the PSF from three parameters in real-time: pupil size, fixation distance, and the focal distance of the virtual display screen. Our demonstration allows users to experience the focal disparity problem in OST HMD hardware and view the improved legibility of CG content provided by the SharpView technique.

Keywords: Augmented Reality, Optical-See-Through Head-Mounted Displays, Focus Blur, Depth Perception, Sharpening Filter, Point Spread Function

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

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1 Background

OST HMDs are increasing in popularity and accessibility, with several consumer level devices, such as Google Glass and Epson Moverio, already available and newer options, such as Microsoft's HoloLens, on the horizon. The transparent display technology used in these HMDs affords the user an unobstructed view of their environment during use, but are only able to display virtual content at a fixed focal distance. Since the user is able to fixate their gaze on real objects directly, focal rivalry results when the distance to the real object differs from the focal requirement of the virtual screen. Figure 1 (b) provides a rough illustration of an OST AR system, in which the user observes a real and CG image at unequal focal distances. The perceived CG content, shown on the middle of Figure 1 (c), appears blurred due to the inability of the eye to focus over the distance range between the real world point and virtual image. Our demonstration proposes one solution for solving the focus blur problem. Our SharpView technique, applied on the right side of Figure 1 (c), utilizes sharpening filters to process the CG image and counteract the defocus effect, improving the quality and experience of the AR system.

What makes this demo unique and special? Through this demonstration, participants will receive an increased awareness of usability issues associated with the current generation of OST HMD hardware, particularly the focus blur effect, and experience our SharpView correction technique within a real use case scenario. Given the increased awareness of OST AR technology within the general populous, due largely to coverage of Microsoft Hololens and Googles Glass, we believe this work will provide a very relevant and engaging demonstration.

2 Related Work

Light Field Displays (LFDs) are hardware technology capable of producing images by controlling the color and direction of each light ray emitted by the device into the user's eye [2]. Since the properties of each visible ray are independently controlled, the focal distance of images produced by LFDs is not fixed. This property makes it possible to create an OST AR system without focal rivalry using LFD devices. The difficulty in building such a system, however, is the availability of head mounted LFDs and the efficiency, or calculation time, required to properly produce each ray of a single image. Even though a number of LFDs have been developed, the accessibility of these devices is largely limited to non-consumer level groups due to their high price points and lack of physical robustness. The processing requirements for LFDs is also far higher. Huang et al. [1], for example, present a LFD which requires 20 sec to resolve the Light Field projection equation of an image. In addition, Andrew et al. [3] mentioned that an ultra high density display is needed for near-eye LFD. Due to these current limitations, the majority of studies aiming to improve the visual quality of AR have used more common HMD hardware.

Vitor et al. [6] developed a Video See-Through system for providing optical correction to visually impaired users. Further work extending the application of improving visual limitations in OST AR devices was performed by Montalto et al. [4]. There is, however, no current efforts aimed at correcting the focus blur effect every user of OST HMDs experiences. The SharpView technique we are presenting in this demonstration is a novel method for addressing the inherent focal disparity produced by OST AR.

Explanation of the novelty We are able to apply the correction technique in real-time using image processing methods for calculation reduction and application to conventional OST HMD hardware. The SharpView technique is also able to create custom correction tailored to each user by utilizing the PSF estimation for the human eye. There are some methods to measure the camera's PSF[5] but the technique of measuring the eye's PSF in real time doesn't exist. The PSF model incorporates values from three user and system specific parameters: pupil diameter, distance to the real world gaze point, and focal distance of the virtual display. By correcting the image in real-time according to the estimated PSF, we are able to present an optimally sharpened image to the user.

3 System Design

The focus blur effect can be equated to the application of a blurring filter within the image processing domain. The resulting defocussed image perceived by the user can, therefore, be improved using the estimated PSF to produce an inverse filter. A Wiener Deconvolution is optimal for this application given the large degree of noise in the perceived blur image. This filter is commonly applied to sharpen images in order to counteract the defocus. We apply this same technique to create a sharpened image that has perceivably better visibility than the original. In the case of our system, we apply a Wiener filter to the original image according to the PSF of the user and display the sharpened result on the OST HMD.

We approximate the eye's PSF as a Gaussian function. During fixation, when the user is actively gazing at a point in the real world, light rays emitted from the display intersect points on the retina at different intensities. The intensity distribution of the PSF p can be represented as a Gaussian function through the following equation.

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

In equation (1), σ is the focal blur size, x, y represent the pixel position. Therefore, σ must be determined in order to estimate a value for the PSF.

Consider the optical system created by the eye and OST HMD. Figure 2 shows the simplified model created by the eye's internal lens and the virtual image plane reflected onto the retina. As the user gazes at point M in the real environment, the light emitted from point M intersects point m on the imaging plane through the lens. In this case, the light emitted from point M' on the virtual HMD display intersects point m' on the back of the imaging plane resulting in a blurred image. The radius of this blur is equal to the σ value of the Gaussian function.

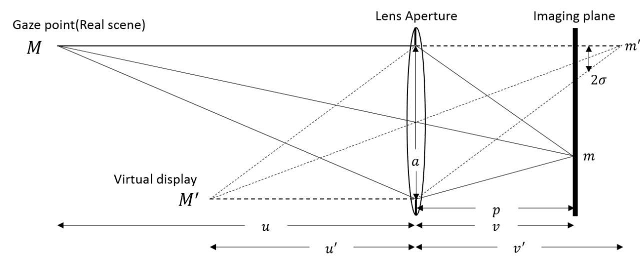

Figure 2: Schematic of the optical system created by the eye's internal lens and virtual image plane of the HMD.

4 Demo Description

Our demonstration is arranged to both illustrate the focus blur problem inherent to OST HMDs and showcase our SharpView correction technique within the context of a real world scenario. The user will read a "newspaper" while wearing the OST HMD in order to observe AR content registered in relation to the real text. Figure 1 (a) provides an image of a user wearing our hardware setup. We employ an Epson Moverio BT-200 OST HMD. A small camera is mounted below the left eye piece and is used for pupil-diameter measurements. The right eye piece of the display is covered to reduce the effects of binocular rivalry. The Moverio's built-in camera is used for position and orientation tracking of the user's head through the detection of fiducial markers placed onto the "newspaper". This allows for properly registered AR content to be placed at various locations around the text. As the user's gaze moves around the "newspaper" their focus will naturally adjust between the text and the AR imagery. During fixation on the text, the AR content will be perceived as blurred due to focal disparity. The user will be able to switch the display of the AR images between the normal unfiltered view and our SharpView correction filter. This will allow the user to compare in real-time the benefit of SharpView over the normal uncorrected state.

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