2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) | 979-8-3503-4839-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/VRW58643.2023.00209

Color calibration in virtual reality for Unity and Unreal

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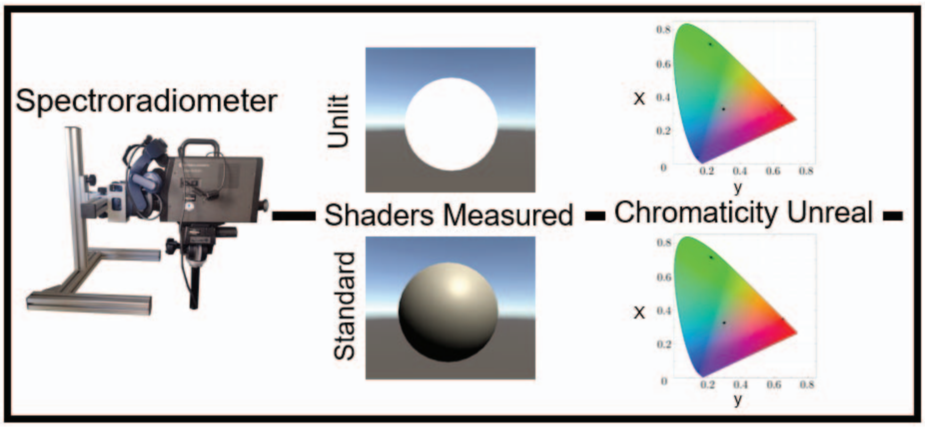

Figure 1: Color calibration in virtual reality head mounted displays. The left panel shows the spectroradiometer used to measure the chromaticity of the different shaders/materials tested, examples shown in the central panel. The right panel shows the chromaticity (x,y) values of the RGB intensities for the R,G, and B color channels in Unreal.

Abstract

This work measures the relationship between RGB intensities and the reflected color for each color channel of the HTC Vive Pro Eye virtual reality (VR) headset. The study additionally measured the display spectra of the device and characterized how Unity and Unreal 3D rendering software influences chromatic behavior. The results were compared to measurements taken without rendering software to quantify the pure characteristics of display primaries. A methodology was proposed to carry out a color calibration customized to the type of material or graphics engine used for more accurate and realistic color representation in VR.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality; Human-centered computing—Visualization—Visualization techniques—Visualization design and evaluation methods

1 Introduction

The improvement in image quality and advances in Head Mounted Display (HMD) technology have made it possible to develop rich and immersive virtual experiences. However, realistic representations of color are one of the most relevant features for a physically correct representation of virtual scenes. Currently, there has been work to understand chromatic characterization issues in VR, and improvements in color reproduction have been introduced in recent years [2], [3]. However, there have been no comprehensive studies or methodologies proposed to disentangle the many possible factors driving HMD behavior. In this work, we compare the quality of color representation across two popular open-source graphics engines, Unity and Unreal, to provide a better understanding of how different game engines or materials affect color representation, which will be beneficial for both recreational and professional tasks. In addition, we measure and quantify the spectral properties of the HTC Vive Pro Eye, which is challenging due to the small recessed displays and non-uniform optical aberrations between the center and periphery of the display.

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2 Shaders. Unlit vs Standard

Unlit shaders enable control over the final color shown by providing options for surface type, emissive color, and GPU instancing but are uninfluenced by lighting effects. Standard shaders, on the other hand, provide options for lighting, reflectance, and other features. This enables versatility for creating realistic, physically-based materials.

3 Methodology

Hardware. The Konica-Minolta CS-2000 spectroradiometer (shown in Fig. 1) was used to characterize the HMD spectrally [4]. It has a spectral resolution of 1 nm between 380 and 780 nm, a radiance measurement error <2 and a CIE 1931 color error x = 0.0015; y = 0.0010 for an A illuminant. To perform the measurements, we have followed the recommendations of other works on color measurements in Near-Eye Displays (NEDs) [5]. The I29 imaging colorimeter [6] allows for measurements of chromaticity CIE(x,y) and luminance values Y(cd/m^2). The device has a resolution of 6576x4384 pixels with an accuracy of ±-0.003 for x and y coordinates. This imaging colorimeter comprises a specific AR/VR lens which is specialized to measure HMD devices. This provides a FOV of 120x80° and enables the colorimeter to be positioned at the entrance pupil (as close as possible to the human eye position) in the HMD.

Different set-ups. We used Psychtoolbox3 [1] to perform an alignment of the measuring tool and the headset. We displayed a set of concentric circles, and by aligning the device with the central circle, measurements are taken at the same location in the display.

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DOI 10.1109/VRW58643.2023.00209

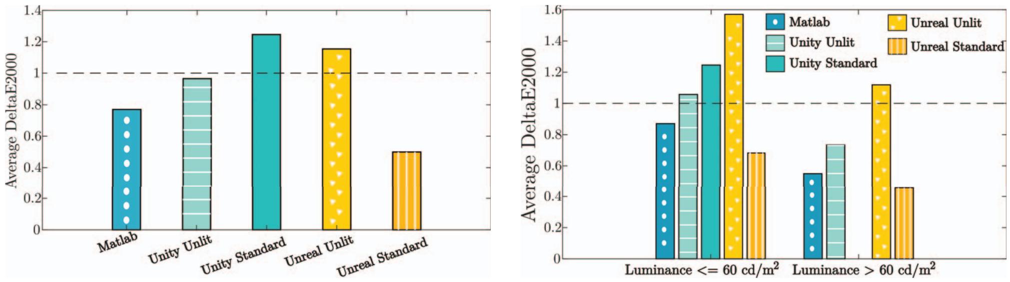

Figure 2: On the left, the average DeltaE2000 metric for the validation RGB values under the five different setups: Matlab, Unity Unlit, Unity Standard, Unreal Unlit and Unreal Standard. On the right, the luminance versus the average DeltaE2000 for the validation RGB value under each setup. We differentiate between low ($< 60\ cd/m^2$) and high luminance values ($> 60\ cd/m^2$). The Unity Standard material does not produce any luminance values above 60 cd/m^2.

Measurements were taken in Psychtoolbox3 which measures the pure characteristics of display primaries without rendering software. We compare this to measurements taken using 3D rendering platforms Unity and Unreal. We characterized the display primaries for both unlit and standard shaders. Unity and Unreal were configured to set the color rendering behavior to linear mode, deferred behavior for lighting was applied, HDR, tone mapping, and post-processing were disabled as well.

Calibration proccess. We performed 234 measurements for each graphics engine and environment, divided into characterization and validation groups. We developed software connecting Matlab and the spectroradiometer to the graphics engine, allowing for quick, automatic measurements.

HMD Uniformity. We analyzed the uniformity of the display using the I29 colorimeter. This tool acquires an image of the entire lens in xyY coordinates, alongside coordinates to describe distance in degrees from the center of the image. Uniformity measurements were taken by displaying a white image using Psychtoolbox3 (HMD was used as an extended display).

4 Color management on different graphic engines

UNITY. In this case, the most appropriate color space will be the tristimulus space associated with the CIE 1931 standard observer and the color characterization approach is a classical matrix model connecting RGB and XYZ spaces [7] (Eq. 2), including a prior linearizing gamma correction (Eq. 1).

$$R' = R^{\gamma_1}, \qquad G' = G^{\gamma_2}, \qquad B' = B^{\gamma_3} \tag{1}$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_{R'max} & X_{G'max} & X_{B'max} \\ Y_{R'max} & Y_{G'max} & Y_{B'max} \\ Z_{R'max} & Z_{G'max} & Z_{B'max} \end{pmatrix} * \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}. \tag{2}$$

UNREAL. For a given XYZ value, we can estimate its corresponding RGB value as follows,

$$\begin{aligned} X &= X_R + X_G + X_B \\ &= m_{X_R} \cdot R + k_{X_R} + m_{X_G} \cdot R + k_{X_G} + m_{X_B} \cdot R + k_{X_B}, \end{aligned} \tag{3}$$

where m_{X_i} corresponds to the slope of X in its corresponding i =R,G,B channel, and k_{X_i} the shift value. We can define the same equation for Y, Z respectively, and obtain a system of equations that results in the following linear transformation,

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} m_{X_R} & m_{X_G} & m_{X_B} \\ m_{Y_R} & m_{Y_G} & m_{Y_B} \\ m_{Z_R} & m_{Z_G} & m_{Z_B} \end{pmatrix} * \begin{pmatrix} R \\ G \\ B \end{pmatrix} + \begin{pmatrix} k_{X_R} + k_{X_G} + k_{X_B} \\ k_{Y_R} + k_{Y_G} + k_{Y_B} \\ k_{Z_R} + k_{Z_G} + k_{Z_B} \end{pmatrix}. \tag{4}$$

5 Results

Calibration error as DeltaE2000 is shown in (Fig. 2). A DeltaE2000 value close to or below 1 is a calibration error imperceptible to the human visual system. Although all configurations tested were in this range, the Unreal Standard shader showed the lowest error. In addition, we measured the uniformity of the display using the I29 colorimeter. We found that the center of the display has an average luminance of $80.22 cd/m^2$, and luminance decreases in the periphery. The chromaticity channels also show an increase in error towards the border of the display. Error is computed as the Euclidean distance of the chromaticity values in the CIELab* color space. Within the central 10 degrees region, the chromatic error is 1.37 on average. Towards the periphery, this error increases to 8.62, six times more than in the center (Table 1).

	10°	20°	30°	40°	50°
Luminance (cd/m^2)	80.22	77.90	73.22	66.51	59.89
Chromaticity (error)	1.37	2.25	3.73	6.14	8.62

Table 1: Uniformity of the lens measured with I29 colorimeter. Absolute luminance and chromaticity error computed over eccentricity.

Acknowledgments

The study was funded by the European Research Council Advanced Grant 'An object-oriented approach to color: Color3.0.' – project number 884116 –.

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