Color Calibration in Virtual Reality Using Different Head Mounted Displays

Francisco Díaz Barrancas, Raquel Gil Rodríguez, Avi Aizenman, Florian S. Bayer and Karl R. Gegenfurtner.
Justus-Liebig Universität, Gießen, Germany.

Advanced Grant
Color 3.0

HMDs analysed

HTC Vive Pro Eye | Pimax 8KX DMAS | Varjo Aero

Specs/HMDs	HTC Vive Pro Eye	Pimax 8KX DMAS	Varjo Aero
Released Date	2018	2018	2021
Resolution	1140 x 1660	3840 x 2160	2880 x 2720
Display	AMOLED	CLPL	Mini LED
Refresh Rate	90 Hz	90 Hz	90 Hz
Lenses	Fresnel	Fresnel	Aspheric
Field of View	110º	220º	121º
Interpupillary distance	61-72 mm	60-72 mm	57-73 mm

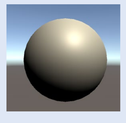
Graphics engines and materials

We used Unity 2019 in a **linear response** and **we disabled the use of HDR and any post-processing** that the graphics engine may perform to the environment.

We used Unreal Engine 4.27.1 by **disabling post-processing and tone mapping,** resulting in a **linear response** for chromaticity and luminance values.

Unlit

The fact that **light does not influence** the final color calculation gives us more control over the application of chromaticity to the different objects.

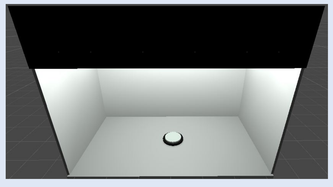


Standard

This shader facilitates a realistic appearance for rendering materials like stone, wood, and plastic. **Standard shader takes the light calculation into consideration during rendering** of a specific material. This increases the complexity of rendering a particular color faithfully.

Measurement process

Konica Minolta CS2000-A



JUST Normlicht LED simulated in VR

We divided the measurements into two parts:

- **Characterization values:** known RGB values to create the chromatic characterization model.
- **Validation values:** we performed 100 random RGB values to check the validity of the calibrated systems.

In total, we have **taken 308 measurements for each graphics engine and HMD**. To perform the measurements, we have developed an automation software using Matlab This script allows us to obtain a wide range of measurements in a short time.

Calibration models

Unity

$$R' = R^{\gamma_1} \quad G' = G^{\gamma_2} \quad B' = B^{\gamma_3}$$

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

UNREAL

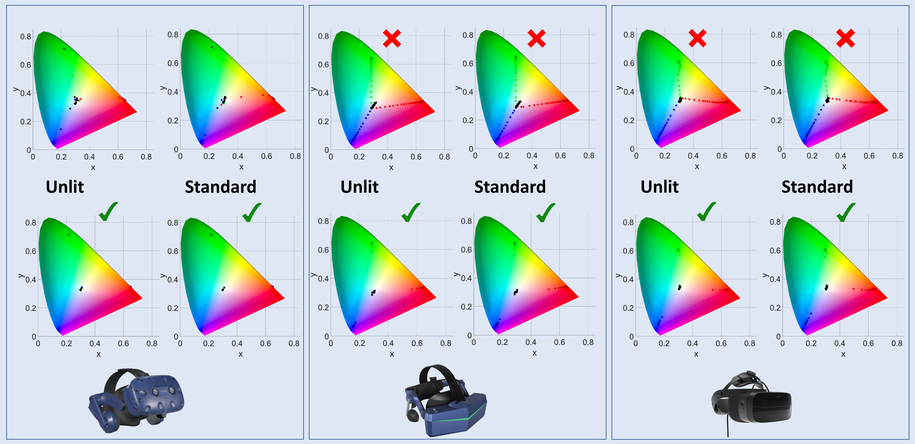
$$X = X_R + X_G + X_B \qquad X = m_{X_R} * \mathrm{R} + k_{X_R} + m_{X_G} * \mathrm{G} + k_{X_G} + m_{X_B} * \mathrm{B} + k_{X_B},$$

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.

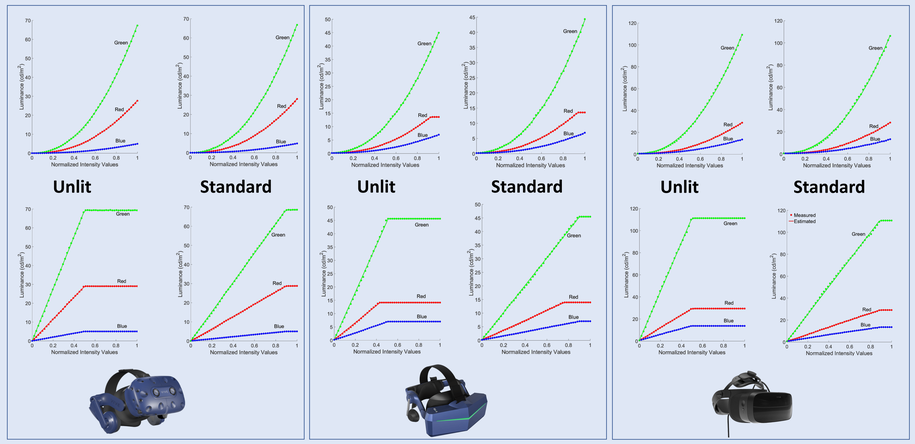
$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} m_{X_R} & m_{X_G} & m_{X_B} \\ m_{Y_R} & m_{Y_G} & m_{Y_B} \\ m_{Z_R} & m_{Z_G} & m_{Z_B} \end{pmatrix} * \begin{pmatrix} R \\ G \\ B \end{pmatrix} + \begin{pmatrix} k_{X_R} & k_{X_G} & k_{X_B} \\ k_{Y_R} & k_{Y_G} & k_{Y_B} \\ k_{Z_R} & k_{Z_G}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

Results

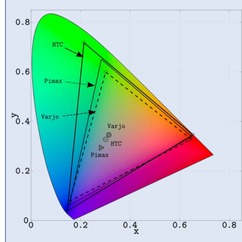
Primary chromaticities at different intensities



Intensity values vs Luminance

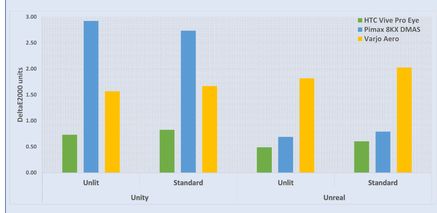


Gamut and calibration error



Gamut coverage with respect sRGB (%)

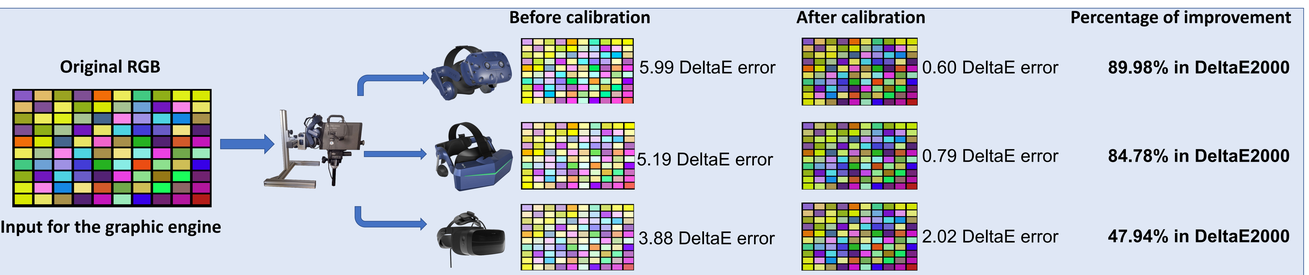
HTC Vive Pro Eye – **145.20%**
Pimax 8KX DMAS – **114.89%**
Varjo Aero – **97.09%**



Unity
1. 0.82
2. 1.67
3. 2.73

UNREAL
1. 0.60
2. 0.79
3. 2.02

Testing colors in Unreal Standard (best scenario)



Conclusions

- **Unreal produces less error than Unity** in color reproduction for all VR devices.
- **HTC Vive Pro Eye** is the device of all those we tested that **produces the lowest color reproduction error in all situations.**
- **Standard materials generate more realistic scenarios than Unlit** although it generates a larger error that is not significant.

References

1. F. Díaz Barrancas, R. Gil Rodríquez, A. Aizenman, F. Bayer and K.R. Gegenfurtner, "**Color calibration in virtual reality for Unity and Unreal"**, 2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Shanghai, China, 2023, pp. 733-734.
2. R. Gil Rodríguez, F. Bayer, M. Toscani, D. Guarnera, G. C. Guarnera, K.R. Gegenfurtner, "**Colour Calibration of a Head Mounted Display for Colour Vision Research Using Virtual Reality**". SN COMPUT. SCI. 3, 22 (2022).

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