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Colour Management in Virtual Reality applied to Lighting Simulations

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ABSTRACT

In this work, we studied the chromatic characterization of Head Mounted Displays (HMD) applied to Virtual Reality (VR) with the purpose of obtaining a better colour fidelity reproduction. We used two of the latest commercial version of HMD through Unity, a game development platform. It has been verified that no type of colour management is performed by default. We have defined in a 3D scene a uniform cube whose colour can be freely changed using RGB coordinates. We have made the chromatic characterization of both HMDs by measuring the spectral radiance of the HMD through its lens.

We have defined and programmed a colour management system applied just to light sources. Results show that it is possible to apply a chromatic characterization method to this type of display and it is also possible to define a colour management system to this type of virtual scene in real-time computing.

Keywords: *Colour Management, Lighting, Virtual Reality, Head-Mounted Displays, Colour Rendering*

INTRODUCTION

The measurement of the quality of light in both indoor and outdoor environments is a relevant topic that has gained attention due to its multiple applications. Recently, two colour rendering measurement recommendations have been approved; a) one sponsored by the Illuminating Engineering Society (IES, 2015) and b) another one subsidized by the International Commission on Illumination (CIE, 2017). These two standards allow us to measure the quality of light sources in terms of their colour reproduction properties. In addition to the concept of colour rendering, there are other important concepts related to the quality of a light source, such as the colour discrimination capability, colour rendering capacity, visual clarity, contrast perception, colour preference, or harmony. However, the effects of using an specific light source is difficult to simulate in terms of colour reproduction. There are few computer applications that allow spectral treatment of light sources and even less in real time. Recently, Virtual Reality (VR) has experienced a great development. Several commercial devices oriented to virtual reality have been developed by different companies such as Google, Oculus, and HTC. These Head Mounted Displays (HMD) allow visual immersive experiences in virtual environments.

In a previous work, the authors stated that the colour is the most significant factor influencing the quality of the virtual reality experience in terms of generation of the virtual image in relation to the original one (Pardo et al., 2018). In consequence, the improvement of the fidelity in the chromatic reproduction can be considered as a suitable further step towards the evolution of the quality of virtual reality systems.

The chromatic characterization of electronic devices is essential in order to accomplish the improvement of the chromatic reproduction of digital images; in this way, the univocal relation between digital and colorimetric values has to be known. This mathematical relation can vary depending on the type of device and has to be studied for each different type of technology (CRT (Berns, 1999), TFT (Pardo et al, 2004), OLED (Suero et al., 2010)). Once the mathematical relation between digital colour and colour independent from the device is known, a system for colour management has to be implemented and the colorimetric ICC profiles associated to each device have to be used.

The colour management system sets up a series of colorimetric transformations that allows to transform the coordinates of the colours spaces independent of the device (CIE XYZ, CIE Lab) to those of the colours spaces device-dependent (RGB, CMYK) and vice versa. All these mathematical transformations require a computation time that is often too long, since the device resolution and refresh frequency values are such that the colour management becomes inviable from the technical point of view, because the linking of several colorimetric transformations is needed.

Therefore, it is time to wonder whether it is possible to make a correct colour management in VR devices as it was done in other digital environments through the colour characterization of colour reproduction devices (Displays, printers, etc.) and the use of ICC colorimetric profiles. In this work, we face this issue in a first approach, propose a solution and show the results obtained.

EXPERIMENTAL

The difference between calibration and colorimetric characterization of a colour display device is always confusing. The calibration consists in setting its state to a known value.

This can be done, for example, by fixing the white point, the gain, and the offset for a cathode ray tube. This guarantees the production of consistent results, and the calibration process can be completed without any information on the relationship between the device's input coordinates and the colorimetric coordinates of the output. The colorimetric characterization of the device, however, requires this relationship to be known: characterization consists in obtaining the relationship between the device's input coordinates and other device-independent coordinates. Due to the large number of chromatic stimulus that can be shown by any digital device, the direct measurement of this relation is impossible, and therefore a mathematical model is usually applied, allowing to reduce the number of runs.

We chose a display characterization model that does not require the actual operation of the display to be followed, but only seeks to relate as simply and accurately as possible the values of the DAC with the chromatic values of the stimulus in any reference colour space. In this work, we used the classical linear model implementing a previous non-linear gamma correction.

Prior to the chromatic characterization of both HMD, we tested the default colour management done by the 3D software platform used in this study, *Unity Game Engine*. Unity supports different rendering paths, and programmers can choose which one to use depending on the game content and the target platform: software and hardware. Different rendering paths have different performance characteristics that mostly affect visual appearance of the rendered scene. In particular, we defined a 3D scene in which we displayed an image with an embedded ICC profile which allowed us to easily check if the colour management had been is performed by the system.

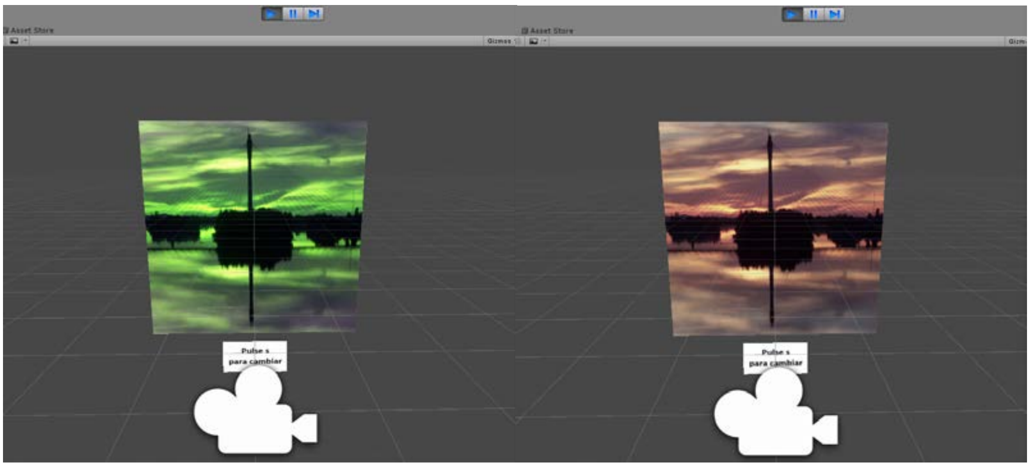

Figure 1: Screen capture of developed 3D scene without (left) / with (right) colour management.

This image altered the chromaticity coordinates of red and green channel in such a way that if the image is shown in red/orange tone, the system manages the colour in the correct way. On the other hand, if the appearance is greenish the colour management is wrong. In this case, it was verified that no type of colour management is performed by default (Figure 1, left). We implemented a colour management system that we can apply to the 3D scene to obtain a right colour reproduction of the image (Figure 1, right).

In the same 3D scene, we defined a uniform colour cube whose colour can be changed freely using RGB coordinates. We made the chromatic characterization of the HMD by changing the cube's colour and measuring the spectral radiance of the HMD through its lens. After the chromatic characterization of both HMD, we have defined their ICC colour profile files.

Figure 2: Experimental setup used for chromatic characterization of both HMD.

The measurement instrument employed was a Konica-Minolta CS-2000 tele-spectroradiometer with a spectral resolution of 1 nm between 380 and 780 nm, a <2% radiance measurement error and CIE 1931 x = ± 0.0015; y = ± 0.0010 colour error for an illuminant A simulator.

By means of a 3D model of a colour checker calibration chart (figure 3), scanned using a 3D scanner, we studied the effect of employing different real light sources (TL84, D50 simulator, A simulator) over the rendered scenes in Unity. We introduced the spectral power distributions (SPD) of all these light sources inside the chain of chromatic transformations done by our colour management system for Virtual Reality devices. Starting from the SPD, we have calculated the CIE 1931 XYZ tristimulus values of the light sources and the theoretical XYZ tristimulus values of each of 24 colour patches composing the colour checker. After this, we obtained the RGB, 24 bits per sample, digital values applying the ICC Colour Profile of each VR device.

On the other hand, we captured the experimental RGB digital values of the colour checker using several virtual light sources inside Unity. Then, we calculated the XYZ tristimulus values applying the ICC Colour Profile in reverse way.

The main goal of these colour transformations is to compare the fidelity of colour reproduction at the virtual 3D scene illuminated with different light sources using a colour management system.

Figure 3: Virtual Light booth with colour checker calibration chart.

RESULTS AND DISCUSSION

Table 1 collects the colour differences between real and expected RGB and XYZ colour values, as obtained after the chromatic characterization of two virtual reality glasses and after capturing the digital images generated by Unity for each light source.

Light Source	$\overline{\Delta RGB}$			$\overline{\Delta XYZ}$			$\overline{\Delta E00}$
	R	**G**	**B**	**X**	**Y**	**Z**	
TL84	2.7	2.4	1.8	0.6	0.5	0.3	2.4
D50 Simulator	1.1	1.0	0.6	0.3	0.1	0.4	0.9
A Simulator	1.6	1.5	4.0	0.4	0.1	0.4	3.5
D50 Illuminant	0.6	0.4	0.3	0.3	0.2	0.2	0.5

Table 1: Average difference between theoretical and measured 24 bits RGB & CIE1931 XYZ values of 24 colour checker colours calculated for four light sources.

The results showed different average color differences depending on the simulated light source. The greater the difference between the simulated light source and the light source used to generate the virtual image of the colour checker, the higher the colour average difference. It has to be taken into account that in this type of 3D scene design software there is a complex system of shadow calculation, secondary light reflexion, etc, that reduce the effectiveness of the digital colour managing systems.

CONCLUSION

Virtual Reality devices need a very high image refresh frequency and a very high screen resolution for a good immersive experience. These requirements make it difficult to apply a correct colour management to digital images. In this study, we made the chromatic characterization of this device and defined a colour transform library and an ICC colour profile. In this way, we have shown that it is possible to apply colour management transformations to colour images in VR devices and to obtain a better colour fidelity reproduction. A further step will be to apply spectral technics in lighting simulations.

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