Is it possible to apply colour management technics in Virtual Reality devices?

[1]Francisco Díaz-Barrancas, [1]Pedro J. Pardo, [2]María Isabel Suero, [2]Angel Luis Pérez
[1]Dept. Computer Systems and Telematics Engineering, University of Extremadura, frdiaz@unex.es, pjpardo@unex.es
[2]Dept. of Physics, University of Extremadura, suero@unex.es, aluis@unex.es

1. Introduction

Virtual Reality (VR) has witnessed a great development during last years. The improvement of Head Mounted Displays (HMD) allows visual immersive experiences in virtual environments and will have many applications, in both recreational and professional fields [1] [2]. The quality of these immersive experiences is a key factor and depends on the capability to generate the feeling of presence over a distance [3].
The feeling of telepresence starts with the perception of depth, which is visually achieved by generating two different views of the same scene. Each of them must be generated with a different point of view that differs by a distance equivalent to that existing between the pupils of humans and a proper eye alignment. This generates the effect of stereoscopic vision or three-dimensional perception, which provides the observer the depth perception of a scene. In addition, the visual system of the observers must have complete functionality (simultaneous perception, fusion and stereopsis). However, differences in depth and camera distances have significant impacts on depth perception [4].
Showing a stereoscopic image is not enough to obtain a good telepresence feeling. This stereoscopic image must have several visual properties. For example, it is necessary to have a wide field of view, larger than the field of view shown on a film or television screen [5] [6]. While the human being has a visual field of about 200°, the stereoscopic vision can only provide about 110° [7]. From a technical point of view, the large field of vision in a HMD is achieved by placing the screen very close to the observer eyes; this forces to introduce lenses that allow to accommodate the eye on the screen at a short distance in all VR HMD devices. These lenses, in turn, can deform the visual field, due to the optical aberrations introduced by themselves, and can also cause the perception of light dots on the screen (image pixelation) [8].
In addition, in order to produce a good feeling of telepresence, the VR device must be able to detect the movements of the head and generate different views of the same scene with sufficient speed and very little delay. This concept is known as low latency [9] [10].
The VR imaging system must be able to generate images at a rate enough to detect no flicker and, moreover, to change the image generated according to the movements performed by the observer's head as quickly as possible (at least between 90 and 120 Hz). To achieve this, it is necessary to have some hardware and software elements that can track the movements and render the images with sufficient speed. These hardware elements are gyroscopes, accelerometers and positioning cameras that, by simple calculations, allow to know the exact position of the head of the person who uses the VR device. All this results in an improved telepresence perception and a better quality of the virtual reality experience.

In a previous work, the authors have 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 [11]. 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 the systems of virtual reality.

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, TFT, OLED, …) [12] [13] [14]. 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 resolution and refresh frequency values of the device 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 obtained results.

2. Methodology

In recent years, different commercial devices oriented to virtual reality have been developed by different companies such as Google, Oculus, and HTC. In all cases, the VR imaging system is able to generate images at a high enough rate (at least between 90 and 120 Hz). In this work, we have employed the latest commercial version of the Oculus Rift virtual reality glasses (CV1). This HMD is equipped with two custom displays, one per lens, manufactured by Samsung Display Co. These displays are AMOLED type with a native resolution of 1200 x 1080 pixels, 3.51" of diagonal size and a resulting pixel density of 456 ppi.

The difference between calibration and colorimetric characterization of a colour display device is always confusing. Calibration of one of these devices consists in setting its state to a known value. This could be done by fixing the white point, the gain, and the offset for a cathode ray tube, for example. It ensures that the device produces 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 is 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 applied, enabling to reduce the number of runs.
We have chosen 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. We have chosen the classical linear model using a previous non-linear gamma correction.
The chromatic characterization of the Oculus Rift was performed by making some previous studies, which allowed to generate the chromatic stimulus needed. These works are mainly related to the software that allows to use this device.
Oculus Rift is provided with a Software Developer Kit (SDK) that includes a simple predefined project for Visual Studio with several graphics libraries as DirectX11, DirectX12 and OpenGL. Specifically, we have defined a 3D scene in that project using OpenGL. In this scene, we have displayed an image with an embedded ICC profile which allows us to easily check if the colour management is performed by the system.

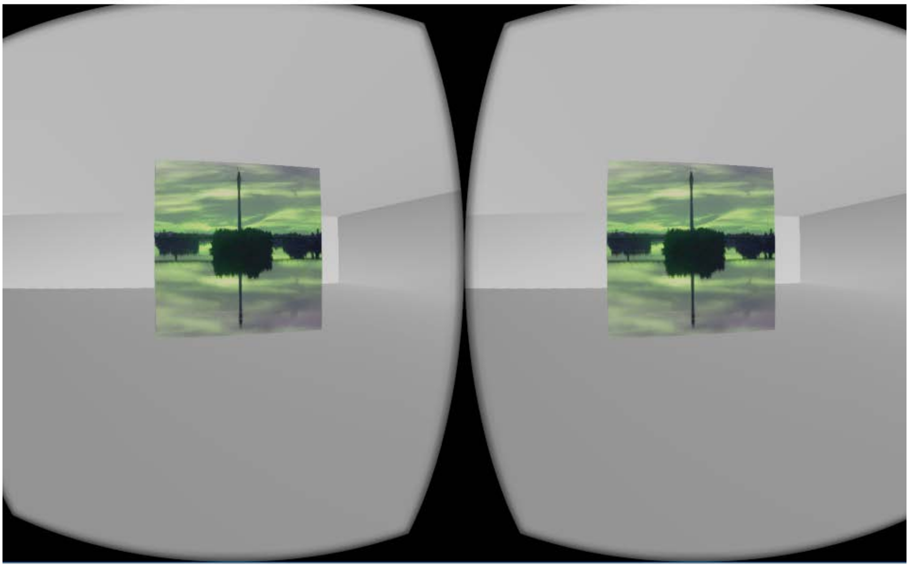

Fig. 1 – JPEG image with embed ICC profile shown in a virtual room for checking colour management.

This image has 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 has been verified that no type of colour management is performed by default.
In the same 3D scene, we have defined a uniform colour cube whose colour can be changed freely using RGB coordinates. We have made the chromatic characterization of the HMD by changing the cube's colour and measuring the spectral radiance of the HMD through its lens.

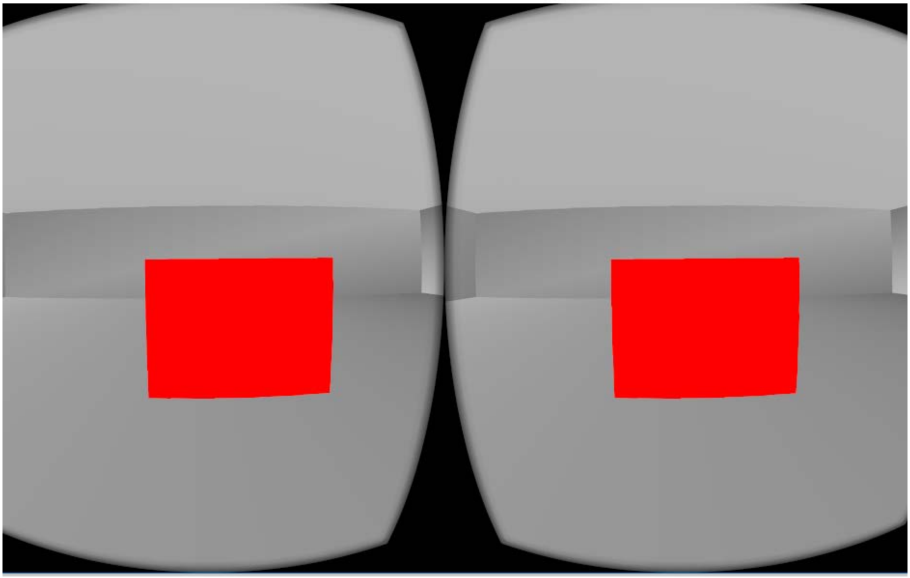

Fig. 2 – Colour cube shown in a virtual room for radiometric measurements while colour is changed.

We have modified the original project called *Oculus Room Tiny* in OpenGL version for Visual Studio 2015 provided by the Oculus SDK. Using the initial room as starting point, we have removed all the objects and have created a new cube-shaped geometrical figure where the colour changes have been applied. This cube has been implemented by using the method *AddSolidColourBox* modifying the constructor parameters in order to locate it in the target site.

Once the cube has been built, we have implemented a method that allows changing the cube colour as a function of the RGB values introduced, and, later on, we have made the spectroradiometric measurements needed for a correct chromatic characterization. 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.

Fig. 3 – Experimental setup used for chromatic characterization of Oculus Rift Device.

3. Results

The chromatic characterization of the Oculus Rift virtual reality glasses has been made using the experimental set up shown in figure 3 and has allowed obtaining the following conclusions.

3.1. Spectral Power Distribution

The spectral power distribution of the white point was measured using the setup shown in fig. 4. The spectral radiance of each channel reveals the OLED nature of this display with a narrow bandwidth for each primary RGB.

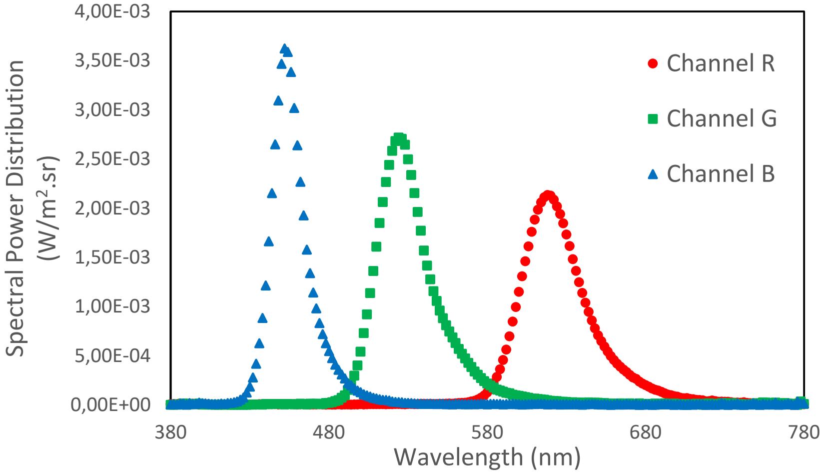

Fig. 4 – Spectral power distribution of RGB channels at maximum DAC value.

Table 1 shows the chromaticity and luminance of each independent channel and the media white point.

	x	Y	Y (Cd/m2)
White	0,306	0,322	75,1
R	0,664	0,332	22,4
G	0,227	0,712	58,2
B	0,146	0,041	4,5

Tab. 1 – Chromaticity coordinates and luminance of channel RGB at maximum DAC value and media white.

3.2. Colour gamut

The colour gamut is a subset of colours which can be accurately represented in a given colour space or by a certain output device like a display. We have measured the colour gamut of our oculus rift device showing a wider gamut than other display types.

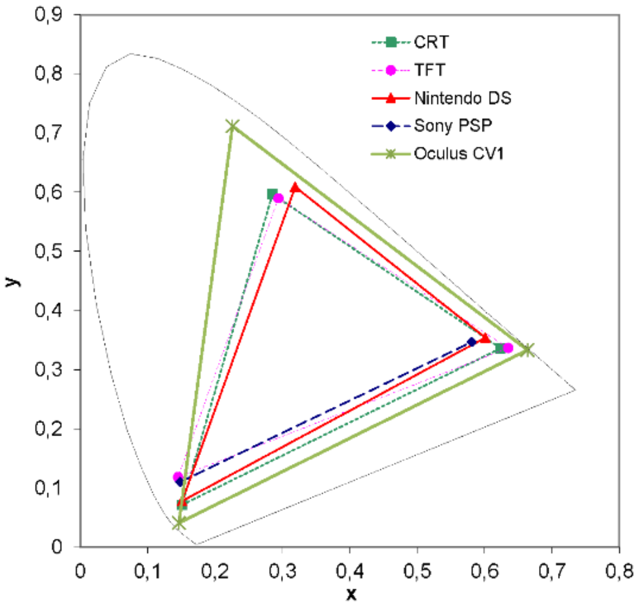

Fig. 5 – Colour gamut of Oculus Rift display compared with colour gamut of different types of displays.

3.3. Relation between Device Dependent and Device Independent colour coordinates

We have measured the relation between device dependent RGB colour coordinate and device independent XYZ tristimulus coordinate for each colour channel independently. This relation is shown in figure 6. By analysing the subjacent mathematical model using a non-linear fit we have obtain three gamma values, one for each RGB channel. The R-squared coefficient of each mathematical fit is close to 1.

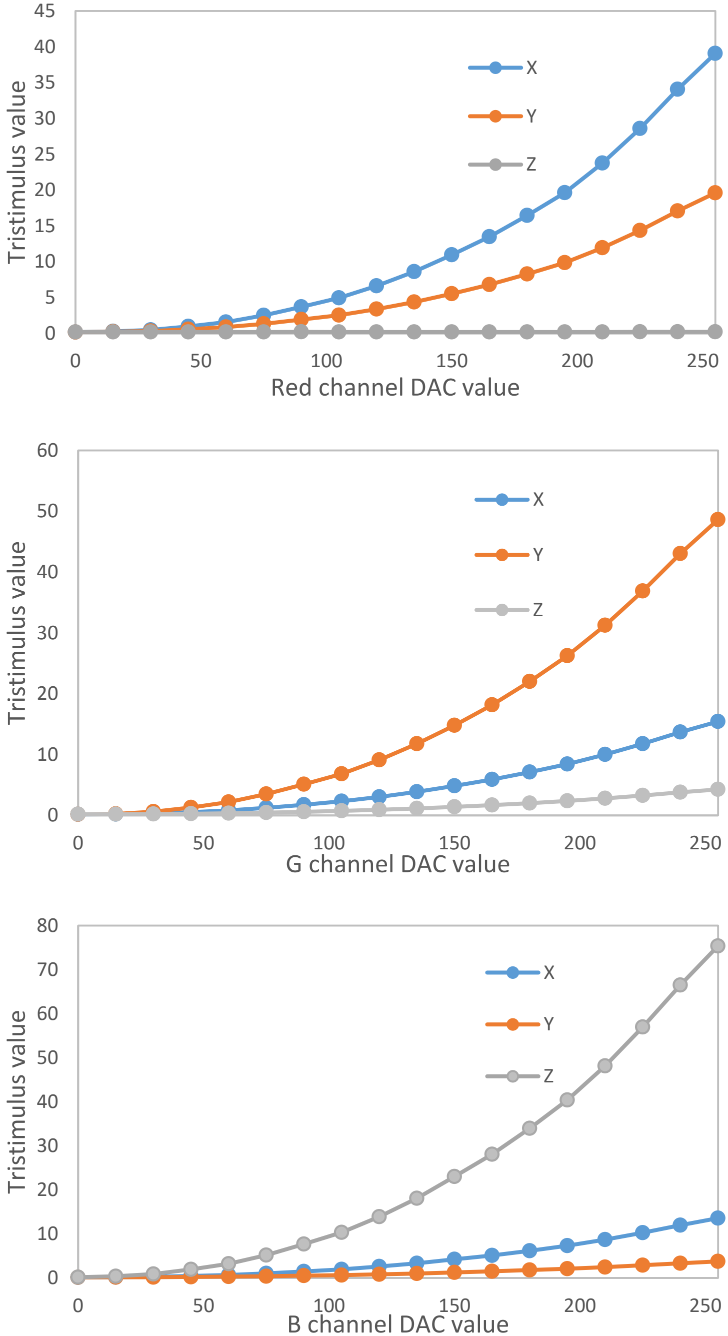

Fig. 6 – Relation between DAC and tristimulus values for each RGB independent channel.

In order to confirm the goodness of the chromatic characterization made, 30 RGB colour measurements, generated at random, were made. These values were compared to those forecasted by the mathematical model, obtaining an average colour difference of ΔE_{00}=1.72.

3.4. Colour management system

Using the previous colorimetric characterization data, we have defined a custom ICC colour profile for our Oculus Rift device. We have developed a simple library that allows us to define a colour in CIE XYZ and CIE Lab coordinates and transform it to the default RGB coordinates of the system. In this way, it is possible to apply colour management transformations to colour images in VR devices and obtain a better colour fidelity reproduction. We have checked this library with our test image obtaining a fine colour reproduction of it.

4. Conclusions

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

References

[1] Y. Wang, W. Liu, X. Meng, H. Fu, D. Zhang, Y. Kang, R. Feng, Z. Wei, X. Zhu and G. Jiang, “Development of an immersive virtual reality head-mounted display with high performance,” App. Optics 55, 2016.

[2] M. Xu, H. Hua, "High dynamic range head mounted display based on dual-layer spatial modulation," Opt. Express 25, 2017.

[3] V. Milesen, D. Madsen and R.B. Lind, Quality Assessment of VR Film: A Study on Spatial Features in VR Concert Experiences (Aalborg University, 2017).

[4] S. Baek, C.Lee, "Depth perception estimation of various stereoscopic displays," Opt. Express 24, 2016.

[5] J.D. Prothero, H.G. Hoffman, “Widening the field-of-view increases the sense of presence in immersive virtual environments,” Human Interface Technology Laboratory Technical Report TR-95, 2 (1995).

[6] E.D. Ragan, D.A. Bowman, R. Kopper, C. Stinson, S. Scerbo and R.P. McMahan, ”Effects of field of view and visual complexity on virtual reality training effectiveness for a visual scanning task,” IEEE Trans. Vis. Comput. Graphics 21, 2015.

[7] I.P. Howard and B. J. Rogers, Binocular vision and stereopsis (Oxford University Press, 1995).

[8] J. Faubert, “The Influence of Optical Distortions and Transverse Chromatic Aberration on Motion Parallax and Stereopsis in Natural and Artificial Environments,”in Three-dimensional television, vídeo, and display technologies. B. Javidi and F. Okano, eds. (Springer Science & Business Media, 2002), pp. 359-396.

[9] P. Lincoln, A. Blate, M. Singh M, T. Whitted, A. State, A. Lastra and H. Fuchs, “From Motion to Photons in 80 Microseconds: Towards Minimal Latency for Virtual and Augmented Reality,” IEEE Trans. Vis. Comput. Graphics 22, 2016.

[10] M. Di Luca, “New method to measure end-to-end delay of virtual reality,” Presence 19, 2010.

[11] P.J. Pardo, M.I. Suero, A.L.Pérez, "Correlation between perception of color, shadows, and surface textures and the realism of a scene in virtual reality," J. Opt. Soc. Am. A 35, 2018.

[12] R. Berns, ”Methods for characterizing CRT displays”. Displays 16, 1996.

[13] PJ Pardo, AL Pérez, MI Suero, ”Validity of TFT-LCD displays for colour vision deficiency research and diagnosis,” Displays 25, 2004

[14] MI Suero, PJ Pardo, AL Pérez,”Colour characterization of handheld game console displays,” Displays 31, 2010