https://doi.org/10.2352/ISSN.2470-1173.2020.15.COLOR-259

Visual fidelity improvement in virtual reality through spectral textures applied to lighting simulations

Francisco Diaz-Barrancas[1], Halina C. Cwierz[1], Pedro J. Pardo[1], Angel Luis Perez[2], Maria Isabel Suero[2]

[1]Department of Computer and Network Systems Engineering, University of Extremadura, Centro Universitario de Mérida, C/Santa Teresa de Jornet 38, Mérida E06800, Spain

[2]Department of Physics, University of Extremadura, Facultad de Ciencias, Avda. de Elvas s/n, Badajoz E06071, Spain

Abstract

Virtual reality has experienced a strong advance in recent years, its use in industries such as video games, automotive and medicine is now a reality.

Previous work has determined that color is one of the most important characteristics when it comes to creating a sense of realism in the user. Therefore, through the use of spectral techniques we have found that it is possible to improve the fidelity in the reproduction of a real scene inside a virtual reality scene. In order to do this, we have developed a workflow that allows the user to compare real scenes with virtual scenes. The results of this test show that there exists an improvement of the visual fidelity in the reproduction of real scenes inside a virtual reality system compared with previous works.

Introduction

Previous work has demonstrated the great improvement of visualization systems based on Head Mounted Display (HMD) and virtual reality. In particular, a study was carried out on the subjective assessment of virtual reality scenes in which it was possible to display replicas of works of art. This study analyzed various aspects related to the visual quality of the image such as geometry, lighting, shading and color. An overall assessment was also made of the sense of realism perceived by observers when comparing the virtual scene with a real scene. The results indicated that the level of realism currently achieved is considerable and that one of the factors that most influenced this sensation of realism is color [1].

With this background, we proposed to improve this sensation of realism by improving the reproduction of color in the virtual reality environment. To do this, we have introduced a color management system into the virtual reality software. The initial starting point has been the chromatic characterization of two commercial HMD display devices (Oculus Rift CV1 and HTC Vive) and the definition of the colorimetric profiles associated to these devices [2]. Subsequently, a 3rd part color management library (LittleCMS) has been introduced in the color management software [3]. With these two elements it is already possible to perform a correct color management in digital images as long as we do not change the color of the light source used to illuminate the virtual reality scene. As a further improvement step, functions have been implemented in the virtual reality software that allow the calculation of tristimulus values for any light source characterized by its SPD and its subsequent transformation to the native RGB values of the VR software by means of ICC profiles and the Color Management System. As results of previous works, they have developed different virtual applications that allow simulating lighting changes inside a booth.

Finally, the same authors have used hyperspectral techniques on 3D objects to improve the appearance of color in virtual scenes.

With all this, it is possible to define a new workflow in virtual reality systems that allow the developers to use all these concepts unified. We have performed a test with real users to test their experience with the visual appearance and the visual fidelity of color.

Methods

We are going to divide the methodology into 3 steps to explain the whole procedure followed until we get the results shown in this work. We will begin by explaining previous works in which different steps were carried out to obtain a chromatic characterization and a color management in virtual environments. We will continue analyzing the development of the software, which contains spectral material and finally we will explain which has been the procedure used to evaluate the results obtained.

Chromatic characterization of HMD

Previous work has shown that it is possible to obtain a chromatic characterization of virtual reality devices. So it is the first step if we want to make a faithful representation of the color vision by computer, something that is highly recommended to develop test of visual impairments in color.

Therefore, we are going to show the data obtained from the chromatic characterization and we are going to use for the next step elements such as the ICC profile obtained from this characteristic.

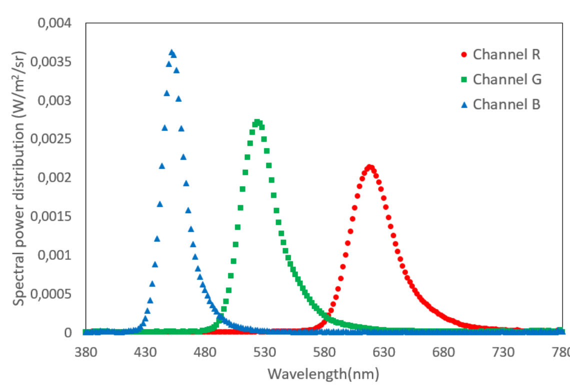

Figure 1. Spectral Power Distribution of HMD

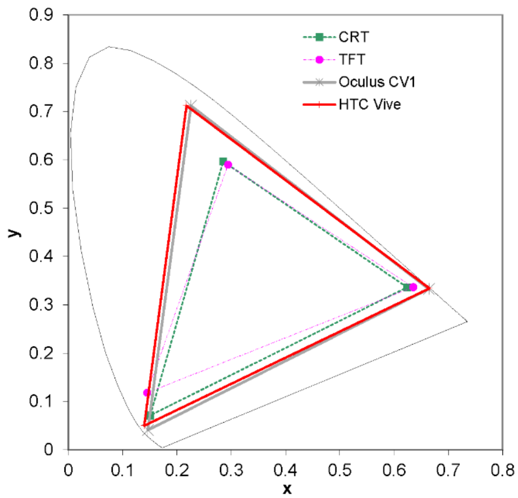

Figure 2. Gamut comparative

To verify that the chromatic characterization performed fits well with the model used, 30 random measurements of RGB values have been made, obtaining an average color error of 1.78 units in terms of CIEDE2000 with a standard deviation of 1.2.

Color Management Module for VR

To achieve our goal, we have introduced a Color Management System (CMS) into Unity's software, whose native color space is RGB. The starting point was the color characterization of the HMD HTC Vive display device and the definition of its associated colorimetric profile. The LittleCMS color management library has been introduced and, by means of colorimetric transformations, the tristimulus values of different light sources defined by their spectral distribution of power. Subsequently, a color transformation has been applied from the CIE XYZ color space 1931 to Unity's native RGB color space, via ICC profiles and the color management system.

Software developed: Virtual Scenes

We have developed a software that allows to simulate through a scene in Unity, the development environment of our proposal. In the scene we will place a simulation of the LED cabin Color Viewing Light (Just Normlicht) with different light sources to which we will assign the result of the calculation we obtain from the spectral curve of each light source [4].

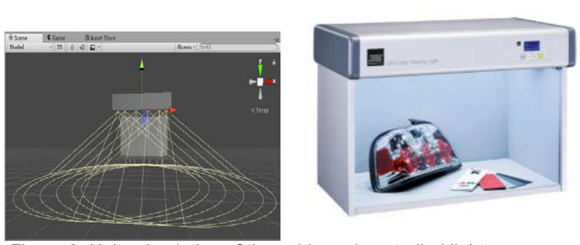

Figure 3. Unity simulation of the cabin and controlled light sources

Along with this scene, a script has been developed that allows us to simulate the change in lighting applied directly to the texture, since we have the reflectance values of the object. It should be noted that the calculation of new color values obtained from reflectances and light sources is quite expensive, so it requires quite a lot of time [5][6].

Figure 4. Final software

Results

Table shows the average color difference between theoretical and recorded color coordinates in terms of the expected XYZ and RGB color coordinates of 24 Color Checker patches for the different light sources and the measured colors for the same color patches, as well as the mean color difference calculated using the CIEDE00 color difference formula in the CIE color space.

Table 1. Color Checker Measurement with ICC Profile and with Spectral Calculations.

Color Management	Light Source	$\overline{\Delta RGB}$			$\overline{\Delta XYZ}$			$\overline{\Delta E00}$
		R	G	B	X	Y	Z	
ICC Profile Color	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
Spectral Calculations	TL84	1.3	0.7	1.5	0.3	0.2	0.2	1.4
	D50 Simulator	0.7	0.4	0.6	0.2	0.1	0.2	0.6
	A Simulator	0.7	1.3	3.5	0.2	0.1	0.3	2.3
	D50 Illuminant	0.5	0.4	0.2	0.2	0.2	0.2	0.5

The results show average color differences between different light sources. These differences are much smaller than the color differences obtained using only a color management system.

In view of the results obtained we can conclude that it is possible to obtain an improvement in color reproduction at virtual reality scenes through the application of spectral textures obtained from hyperspectral data base.

We have managed to set up a virtual stage with colour management and simulation of different light sources (D50, D65, A). We have also managed to scan 3D objects and apply hyperspectral textures to improve the visual appearance in virtual reality.

Figure 5. Different illuminants with hyperspectral textures objects.

Conclusions and Discussions

In view of the results we can say that it is possible to obtain an improvement in the color reproduction in virtual reality scenes by reconstructing the objects using hyperspectral images. We can emphasize that the values obtained in the measurements of color differences are better than using a color management system with RGB textures. This gives us a great advance within the virtual reality paradigm. At the same time, it opens up a wide range of possibilities for future work.

It should be noted that the improved color representation of 3D objects imported into VR devices does not slow down the execution of the virtual scene. It is in the previous process, of creation of the 3D object and rendering with light sources where a great deal of processing time is required, which we hope to improve by means of new studies that accelerate the colorimetric transformation, applying parallelization techniques known in the world of computing.

Funding Information

Consejería de Educación y Empleo, Junta de Extremadura and European Regional Development Fund (ERDF) (GR18131, IB16004).

References

[1] P. Pardo, M. Suero and A. Pérez., “Correlation between perception of color, shadows, and surface textures and the realism of a scene in virtual reality.,” JOSA A, vol. 35, pp. B130-B135, 2018.

[2] F. Díaz-Barrancas, P. J. Pardo, M. I. Suero and A. L. Perez, “Is it possible to apply color management technics in Virtual Reality devices?,” in XIV Conferenza del Colore, Firenze, 2018.

[3] H. Cwierz, F. Díaz-Barrancas, P. J. Pardo, A. L. Perez and M. I. Suero “Cómo realizar una correcta gestión del color en sistemas de realidad virtual” in XII Congreso Nacional del Color, 2019.

[4] H. Cwierz, F. Díaz-Barrancas, P. J. Pardo, A. L. Perez and M. I. Suero “Colour Management in Virtual Reality applied to Lighting Simulations” in AIC Lisboa 2018.

[5] F. Díaz-Barrancas, H. Cwierz, P. J. Pardo, M. I. Suero and A. L. Perez, “Hyperspectral textures for a better colour reproduction in virtual reality” in XV CONFERENZA DEL COLORE, Macerata, 2019.

[6] F. Díaz-Barrancas, H. Cwierz, P. J. Pardo, M. I. Suero and A. L. Perez, “Improvement of realism sensation in virtual reality scenes applying spectral and colour management techniques” in ICVS, Riga, 2019.

Author Biography

Francisco Díaz-Barrancas *- received the B.S degree in computer engineer in 2017 and the M.S degree in computer technologies research in 2018, both from the University of Extremadura (UEx), Mérida, Spain.*

He is currently working toward the Ph.D. degree in the visual appearance in virtual reality devices. He is a Research Assistant at the University of Extremadura (UEx) in Spain. He has been involved in several projects related to application of hyperspectral and virtual reality techniques to measure the color performance of LED light sources.

Halina Cwierz *received the B.S degree in computer engineer in 1987, and the M.S degree in computer technologies research in 2016, both from the University of Extremadura (UEx), Mérida, Spain. She is currently working toward the Ph.D. degree in application of virtual reality devices to the screening of colour vision deficiencies.*

She is Associate Professor at the University of Extremadura (UEx), Mérida, Spain. She has been involved in several projects related to the application of augmented reality to education. Her research interests include colour vision, augmented and virtual reality devices.

Pedro José Pardo *- received the B.S. degree in physical sciences in 1998, and the M.Sc. and Ph.D. degrees in physics at the same University in 2000 and 2004, respectively, all from the University of Extremadura (UEx), Mérida, Spain.*

He is an Associate Professor at the University of Extremadura (UEx), Mérida, Spain. He has been involved in several projects related to the detection and influence of visual anomalies in students. His research interests include color vision, optical instrumentation, neural networks, computer networks, and physics education.

Ángel Luis Pérez *- received the B.S. degree in chemical sciences, and in the Ph.D. degree in electronic devices for teaching, both from the University of Extremadura (UEx), Mérida, Spain, in 1976 and 1981, respectively. Associate Professor at the University of Extremadura (UEx), Mérida, Spain.*

He has been involved in several projects related to physics education, detection of misconceptions, concept mapping and collaborative learning. His research interests include collaborative reconstruction of knowledge, physics education, color vision in challenged and normal observers, and adaptative behavior for colorblind observers.

María Isabel Suero *- received the B.S. degree in chemical sciences and the Ph.D. degree in spectroscopy from the University of Extremadura (UEx), Merida, Spain, in 1975 and 1982, respectively.*

She is a Full Professor at the University of Extremadura (UEx), Mérida, Spain. She has been involved in several projects related to physics education, detection of misconceptions and collaborative learning. She also has an interest in color vision in challenged and normal observers, adaptative behavior for colorblind observers, and spectroscopy, as well as in physics education.