Hyperspectral textures for a better colour reproduction in virtual reality

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1. Introduction

Virtual reality devices are having a great development nowadays. These Head-Mounted-Displays (HMD) based systems allow visual immersive experiences in virtual environments.
Recently, the group of authors have made the chromatic characterization of two of the most worldwide used virtual reality devices [1]. Likewise, they have developed a colour management system compatible with the real-time image rendering performed on these virtual reality devices. It should be noted that this type of devices have a high refresh rate (between 90 and 120 Hz) to shorten the latency and thus produce a better immersive sensation.
Developed colour management system is based on a pre-computation phase in which the necessary colorimetric transformations are carried out in order to obtain a reliable reproduction of the colour before changing light sources at virtual scenes. However, applying colorimetric transformations by a colour management system based on three-dimensional algebra is not enough to correctly reproduce the surface colour of rendered objects within a 3D virtual scene. In this case, it is necessary to apply spectral calculations that allow us to move from the universe of infinite degree of variance, like the spectral power distribution and spectral reflectance universe, to the trivariant world of colour representation spaces. However, these calculations must be compatible with the native system usually applied in virtual reality software to perform the luminosity and shading calculations as well as within the new colour management system introduced by the authors in this type of devices.
Therefore, it is time to wonder whether it is possible or not to apply hyperspectral textures to VR devices improving the colour fidelity reproduction of virtual scenes. In this work, we face this issue in a first approach, propose a solution and show the results obtained.

2. Methodology

We have followed several steps to make the reconstruction of 3D objects using the SfM technique and to obtain the hyperspectral texture of the objects.
The first step has been the development of a system for capturing 3D real objects based on images taken by a Cubert UHD 285 hyperspectral one-shot camera. This camera provides on each shot a hyperspectral cube of 1000 x 1000 pixels and 125 spectral channels defined between 450 and 950 nm with a spectral resolution of 4 nm. The setup used to capture images with the hyperspectral camera is the one shown in figure 1.

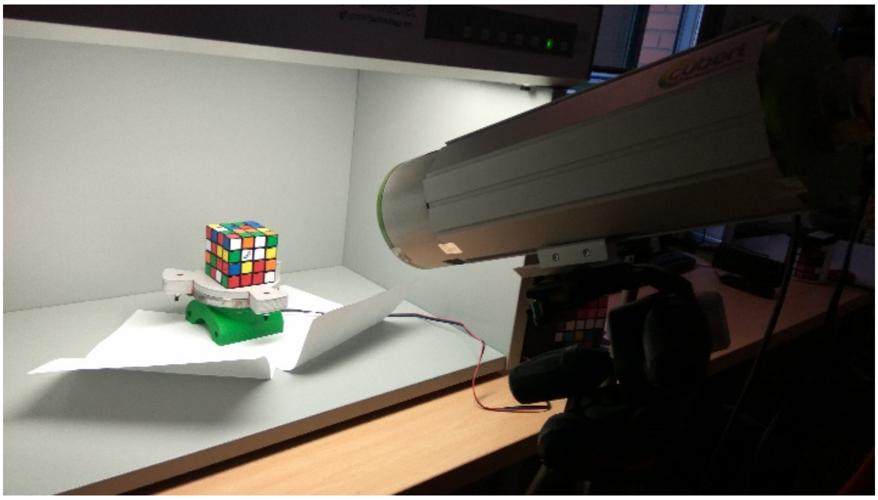

Fig. 1 – Experimental setup used to take pictures with our hyperspectral camera.

Secondly, we need to modify the PMVS object reconstruction software [2] to store the spectral reflectances obtained from the hyperspectral camera with each spatial coordinate obtained from the reconstruction software. The SfM technique obtains the 3D point cloud starting from pictures obtained at different viewing angles (Fig. 2).

Fig. 2 – Graphic scheme of SfM technique for 3D objects reconstruction

Finally, we have developed a program that allow us to simulate lighting changes in a virtual scene defined in *Unity Game Engine*, the VR development platform used in this work. In the virtual scene we have placed a virtual version of a LED lightbooth (Just Normlicht). Figure 3 shows the design of the virtual lightbooth with several spotlights placed at the same position of real ones.

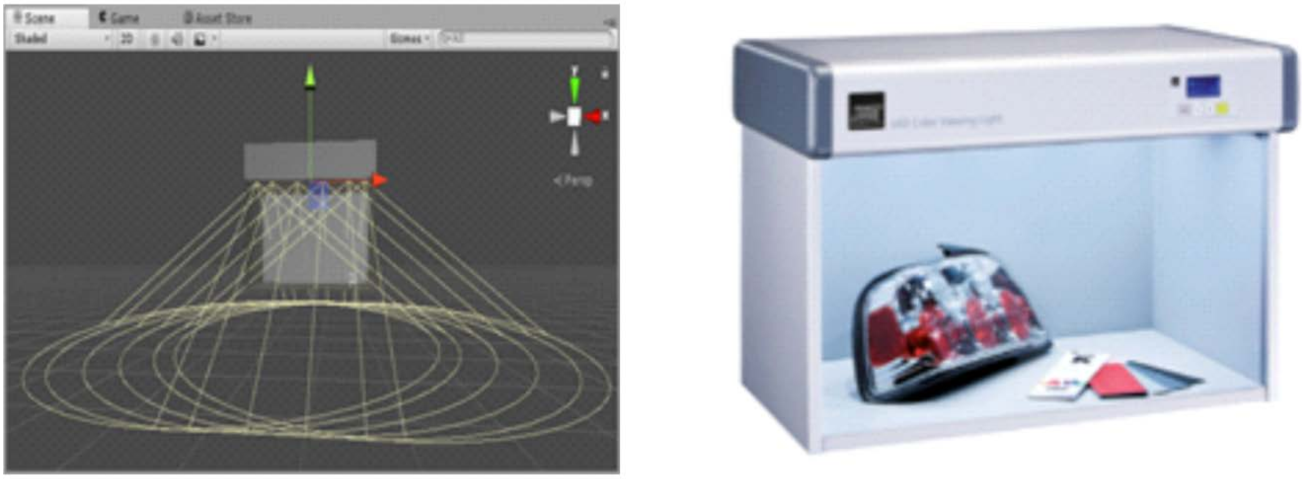

Fig. 3 - Simulation in Unity Game Engine of the real lightbooth and controlled light bulbs

Along with this virtual scene, a C# script has been implemented to compute the changes of lighting sources. We have defined 4 light sources using their spectral power distribution and we have calculated the final colour that the colour texture should acquire starting from the spectral reflectance of each point of the 3D object. It should be noted that the calculation of the new colour values obtained from the spectral reflectance and the spectral power distribution of the light sources requires a long processing time since it is necessary to calculate it for each point of the point cloud defining the virtual 3D object.

3. Results

We have calculated the average coefficient of variation (relative standard deviation) for each of the 125 channels of the reflectances obtained through the 3D reconstruction using several hyperspectral cubes from different view angles. Figure 5 shows that the coefficient of variation remains stable around 10 percent for all spectral channels.

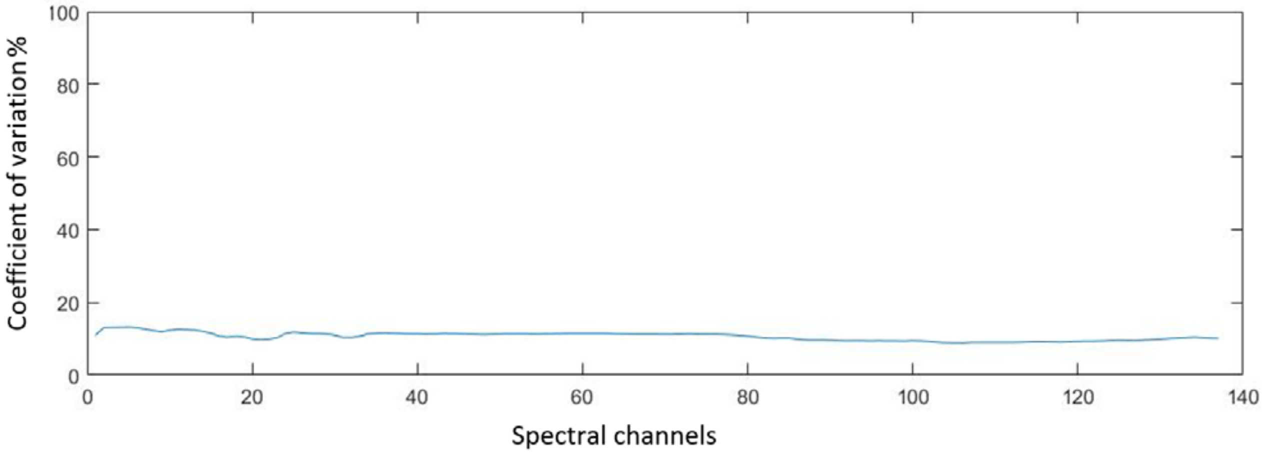

Fig. 5 - Graph of typical deviations in each reflectance channel

The main objective of this work consisted in the improvement of the chromatic representation of virtual objects visualized in a virtual reality platform. To check if this improvement has been implemented or not, we have introduced a virtual Color Checker in the virtual reality platform. This virtual Color Checker is defined with a hyperspectral texture captured from the real Color Checker.
We have also defined 4 light sources in the virtual reality software. These light sources are defined by their spectral power distribution. Using spectral calculations in the tristimulus CIE 1931 colour space domain, we have calculated the XYZ value of each light source. From this XYZ value, we have transformed it into the native RGB colour space using a colour management system and then applying this RGB value to the virtual light source. In Fig. 4, we can see the appearance of the final virtual scene.

Fig. 4 - Lighting simulation with Color Checker

Table 1 shows the average colour difference between theoretical and recorded colour coordinates in terms of the expected XYZ and RGB colour coordinates of 24 Color Checker patches for the different light sources and the measured colours for the same colour patches, as well as the mean colour difference calculated using the CIEDE00 colour difference formula in the CIE colour space.
The results show minimal colour differences. These differences are much smaller than the colour differences obtained using only one colour management system.

Table 1. Average colour differences between colour management using ICC profile or using spectral calculations

Colour Management	Light Source	$\overline{\Delta RGB}$			$\overline{\Delta XYZ}$			$\overline{\Delta E00}$
		R	G	B	X	Y	Z	
ICC Profile Colour	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

4. Conclusions

In view of the results obtained we can conclude that it is possible to obtain an improvement in colour reproduction at virtual reality scenes through the application of hyperspectral textures obtained from hyperspectral multi-view images. We can emphasize that the registered colour differences are better using this procedure than those recorded using a colour management system with RGB textures. This gives us a breakthrough within the virtual reality paradigm. At the same time, it opens up a wide range of possibilities for future work.
It has to be highlighted that the improvement in the colour representation of 3D objects imported into virtual reality 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 needed, which we hope to improve by means of new studies enhancing the acceleration the colorimetric transformation, by applying parallelization techniques well-known in the world of computing.

Acknowledgements

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References

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[2] Y. Furukawa, J. Ponce , “Accurate, dense, and robust multiview,” IEEE transactions on pattern analysis and machine, vol. 32, pp. 1362-1376, 2010.