Validating Perception of Hyperspectral Textures in Virtual Reality Systems

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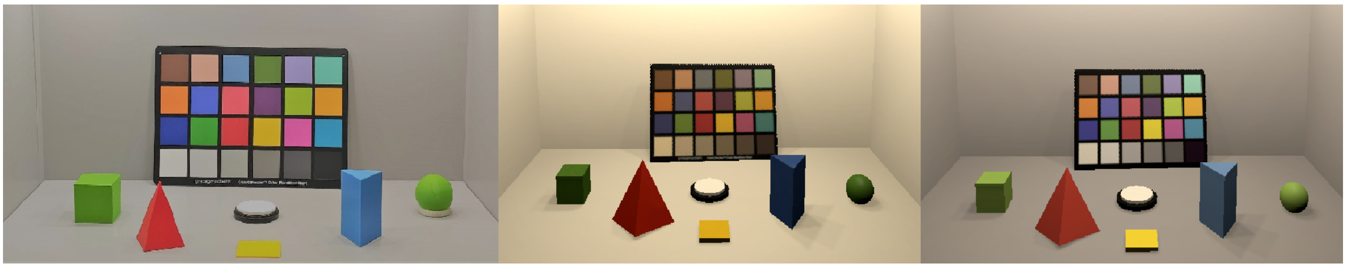

Figure 1: *The quantitative experimental environment. Left: Scenario on a real light booth and real several objects created with a 3D printer; Center: Virtual environment with 3D scanned objects and RGB textures under D50 illuminant; Right: Virtual environment with 3D scanned objects and hyperspectral textures under D50 illuminant.*

Abstract
Virtual reality (VR) environments are increasingly offering higher quality content. They use different computing techniques to improve the final user experience. In this work, we create different light sources and introduce hyperspectral textures for the object reflectance to boost the VR environment's quality. In addition, we perform a quantitative study to demonstrate that hyperspectral textures improve the final quality of the content in virtual reality systems.

CCS Concepts
• ***Computing methodologies*** → *Computer graphics;* • ***Software and its engineering*** → *Software development techniques;* • ***Human-centered computing*** → *Visualization;*

1. Introduction

When we talk about hyperspectral textures, we have to know that by having information measured directly from the object such as reflectance we can obtain a much more accurate calculation of the color, since we are separating the dependence that the light source can give to the color representation. We assume that the reflected color of an object is the summation/integration over the visible light of the object reflectance by the light source spectra. If we can measure the reflectance spectrum, from now on hyperspectral textures, of a given object, then we can accurately estimate the reflected color of this object under different illuminations. This allows us to make a much more accurate and closer to reality calculation.

From the point of view of immersive image quality in a Virtual Reality (VR) scenario, great efforts have been made in the application of computer graphics techniques to improve the final rendering [WLM*16]. Some examples are ray tracing [WDB*06], zone-based rendering [SKHR01] or advanced techniques such as the use of spectral information in the color texture assigned to an object to create a full sense of realism [DBCP21]. All these enhancements make VR systems more realistic, but only the latter focuses on the color fidelity by taking into account the different light sources. It is the base point to verify that hyperspectral textures certainly improve the users' perception in a virtual reality scenario.

2. Methodology

During this work, we use as software Unity Engine in its last version for the creation of virtual reality content. For the visualiza-

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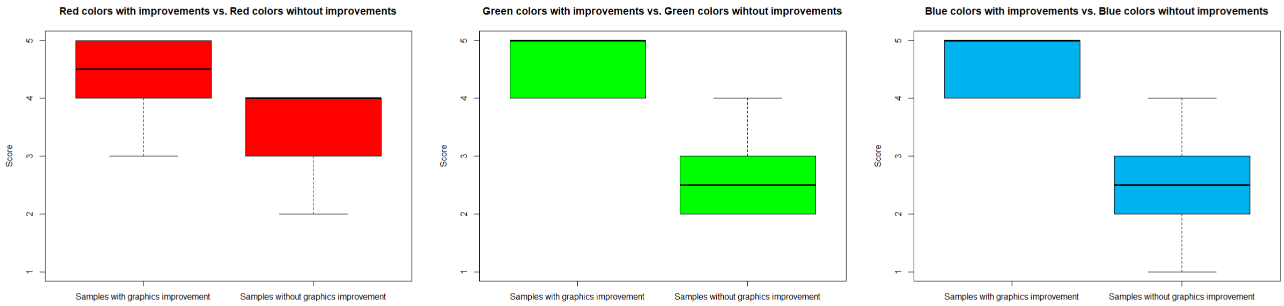

Figure 2: *Scores obtained for each RGB channel from 0 (not similar) to 5 (equal similarities) for the virtual scenario with and without graphic enhancements.*

tion of this content, we use the HTC Vive Pro [HTC18] Head Mounted Display. We divide this methodology section into three main groups: calibration, simulation of light sources and introduction of hyperspectral textures to a virtual reality system.

Calibration of Head Mounted Display. The first step is the calibration of the display [DBCP*20], in our case an HTC Vive Pro. The calibration allows us to estimate the transformation between XYZ and RGB color spaces. This transformation is the composition of a 3×3 matrix and a power law function, known as gamma correction.

Simulation of Light Sources. The second step of our system was to simulate different light sources in a VR system using their spectral power distribution (SPD) curves. We calculate the tristimulus values for each light source using the CIE 1931 colorimetric pattern observer [HP85]. Using the calibration realized before, we can obtain the RGB value needed to simulate each light source in a VR system. For this work, 4 light sources (D50, D65, illuminant A and 2-peak illuminant with no red primary -3 standard illuminants and one to verify/check the system-) have been selected to compare the visual appearance of different objects to which hyperspectral textures have been applied. These scenes represent an LED light booth (Just Normlicht) with 12 LED spotlights.

Introducing Hyperspectral Textures. Finally, we included our hyperspectral textures to all the objects in the virtual scenario. For this purpose, we measured the reflectances of these objects, and the radiance of the light sources using the spectroradiometer Konica Minolta CS-2000 [Min15]. After that, we represented the hyperspectral textures in the virtual environment using a color management system.

3. Observers validation

Five participants evaluated the similarities between the colors presented in the VR viewer (w/wo graphical enhancement) and the real scene. Observers scored the color similarities (red, green and blue tones) between 0 and 5. The experiment was performed five times under each illuminant (total of 20) and each participant run the test 3 times on different days. The objective is to find statistically significant perceptual differences when using or not hyperspectral color and texture management techniques.

To check the distribution of the samples, we applied the Kolmogorov-Smirnov test [Lil67], which revealed non-normal samples. In order to carry out the statistical study, we have applied the Wilcoxon test [Geh65] with a confidence level of 95%. This means that we have established a significance level of α=0.05.

4. Results

The results show that once we have managed to develop a color management system in VR and apply hyperspectral techniques to the objects, the observers are able to perceive the improvement obtained in the graphic quality of the final scenario under different light sources. To verify the improvement obtained in terms of visual perception of the observers in the new developed scenario, a validation model was proposed through the observation and scoring of users comparing the classic scenario with the scenario with improvements. Figure 2 shows the scores obtained for each of the RGB channels. We can observe that in each of the channels, the similarity between the real scenario and the virtual reality scenario without graphical improvements is on average lower than the scenario with graphical improvements in each channel.

5. Conclusions

In view of the results obtained, we can draw several conclusions related to the introduction of hyperspectral information in a VR system. First, it has been demonstrated that a color management system can be introduced in a virtual scenario. Secondly, it has been possible to perform the corresponding calibration of the VR viewer to ensure high color fidelity in color reproduction. Finally, we can affirm that these improvements are reflected in the final perception of the observer, since we obtained data indicating that they perceive a significant difference in each of the questions that were established to test the operation of the system (red tones, blue tones, green tones).

Acknowledgments

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