A study of physical and perceived linearity in a virtual reality environment

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Abstract

Virtual reality has become a great multimedia tool in which it is possible to represent 3D content. It can be used for many applications such as video games, telemedicine, teleworking or airplane simulators. However, visual appearance is an aspect that needs to be further improved if virtual reality wants to take on a much more professional use. Should color be reproduced in the same way in the real world as in the virtual world? We observed that although the chromaticity coordinates were matched, the visual appearance meant that the user did not perceive the colors in the same way. Then, it is necessary to establish a correction in the virtual reality scenario that corrects the user's perception. In this work, we have measured target linearity in a 3D environment. By measuring the different achromatic spectra, we found that the Head Mounted Display linearly behaved if we applied spectral and chromatic characterization techniques.

Keywords: *virtual reality, color appearance, Head Mounted Display*

INTRODUCTION

The rapid emergence of virtual reality has led to numerous areas using these devices to help professionals perform their tasks. These tasks can be simulations of real environments in which they have to be pre-tested outside the real world given their high danger. Some examples can be medicine, flight simulation or tests that require high professionalism. However, in the improvement of these devices, the fidelity of color rendering and the required adaptation of the user to the environment is often forgotten. In this work we will use HTC's Head Mounted Display on their HTC Vive model with AMOLED display. It is necessary to emphasize that the behavior that these screens offer is not the same as that of a computer monitor or a mobile screen. These devices are composed of display and lenses which makes their representation specific. Therefore, it is necessary a study of their colorimetric calibration before any study and behavior of the same. This Head Mounted Display (HMD) renders the objects with the graphic card of the computer since it must be connected to it. Unlike other HMDs, we do not use a mobile screen to represent the 3D images. In previous work, we measured colorimetric x, y values reproduced by reflectances within the virtual reality system. We compared these samples with the same samples measured in a physical lighting booth and obtained close values in CIEDE2000 color difference. However, we obtained diffuse responses from users regarding the appearance of these samples (Garcia et al. 2007). Although the x, y coordinates matched that of the physical samples, the appearance perceived by the users was different. Other works demonstrated the influence of colors within the scene and advised to treat the scene as a complex scenario with different color samples (McCann et al. 2014). We decided to focus on achromatic values to take a first step towards what could be a future color constancy work in virtual reality. To do this, we removed all color noise from the scene and treated only achromatic values in a first step. Therefore, the objective of this work is to test the relationship between values measured through the HMD and values perceived by users. In this way, we will be able to conclude if it is necessary to establish any corrections on the virtual reality system to solve this.

METHODOLOGY

In this section we will explain the different steps followed for the development of the research work. We have organized this section into 3 subsections: Colorimetric calibration of Head Mounted Display, Physical measurements on the HMD, Virtual environment developed

Colorimetric calibration of Head Mounted Display

The first step performed in this work was the colorimetric calibration of the HMD device. For this purpose, we measured RGB values from 0 to 255 for all channels. In addition, we include some RGB random values. Full procedure can be seen in detail in previous work (Díaz-Barrancas et al., 2020). We have also applied these techniques in other works in which a virtual scene was developed to detect visual deficiencies (Cwierz et al. 2020).

The measurement instrument employed in this work 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 color error for an illuminant A. In order to make the measurements, we have followed the recommendations of other works about color measurements in Near-eye displays (NEDs) (Hong 2021; Penczek et al. 2020; Varshneya et al. 2020). Figure 1 shows the measurement procedure in the HMD. We have obtained a CIEDE2000 color difference error of 1.8 in HMD calibration. To check that the calibration was performed correctly, we measured other random samples introduced by their reflectance. The error obtained on these samples were between 2-3 according to the CIEDE2000 color difference.

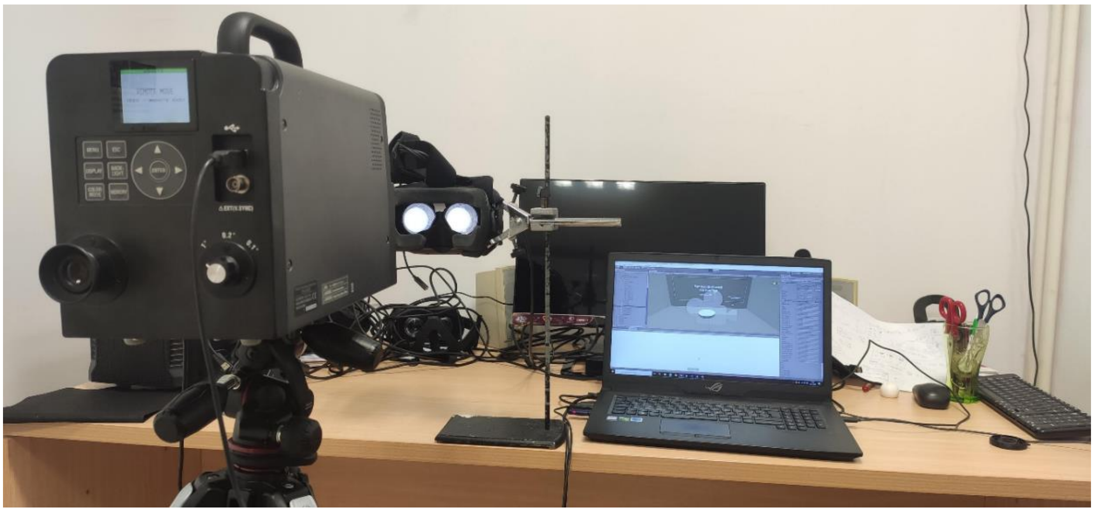

Figure 1: Scenario set up for the chromatic characterization of the HMD.

Graphics settings Unity rendering

To get the best visual appearance and the most realistic graphical representation possible, we have chosen the high quality options. In addition, options such as reflections have been activated to give a more natural look to the virtual scenery. Also, we have to know that the High Definition Render Pipeline (HDRP) allows us to render Lit Materials using Forward or Deferred rendering. Unity allows us to configure your Unity project to use only one of these modes, or allow you to use both and switch at runtime on a per-camera basis. When we use a Forward HDRP, Unity calculates the lighting in a single pass when rendering each individual Material. However, if we use Deferred HDRP, Unity processes the lighting for each GameObject in the Scene. With this definition, based on giving the best possible image of the virtual scenery, we have considered using a Deferred rendering pipeline.

Physical measurements on the HMD

In order to know the real values obtained from the achromatic samples in values from 0% white to 100% with differences of 20%, we have measured with the Konica-Minolta CS-2000 spectroradiometer on the HMD. The procedure followed to perform these measurements is similar to that used in the colorimetric calibration set up in the previous section. Table 1 shows the luminance (Y) values obtained for each percentage of white measured.

White measurement (%)	Y (Luminance)
100 %	144.86
80 %	114.89
60 %	87.64
40 %	62.28
20 %	31.71
0%	0.4

Table 1: Luminance values (Y) corresponding to different percentages of white.

Virtual environment developed

We have developed a virtual reality environment consisting of a lighting booth under the D65 illuminant. Furthermore, inside this light booth, we have placed two fixed capsules: One of them with an absolute white (reflectance values of 1 over 1 in its entire spectrum) and another one with an absolute black (reflectance values of 0 over 1 in its entire spectrum). In the middle of the two capsules, we represent another capsule with changing values. Figure 2 shows the scene represented in virtual reality for this work.

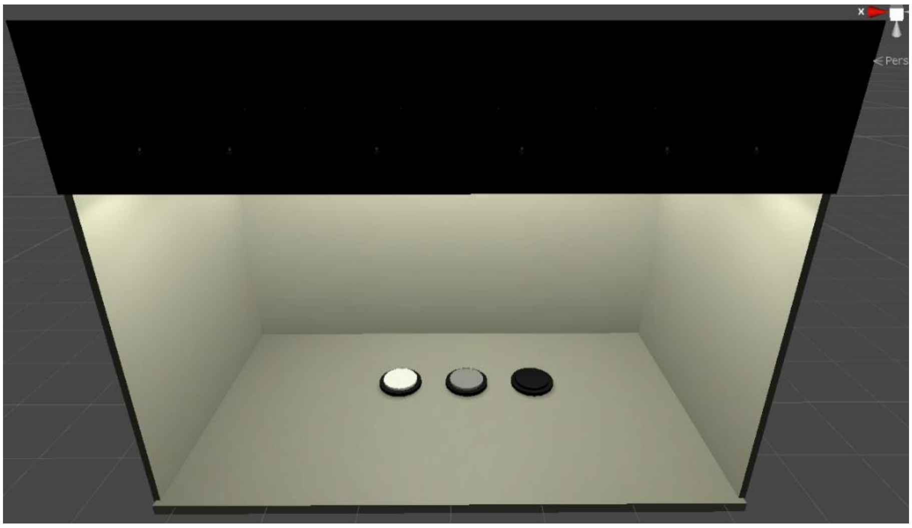

Figure 2: Virtual environment developed to measure both the physical linearity of the Head Mounted Display and its appearance.

OBSERVERS AND PROCEDURE

In this section, we will explain the procedure followed with the users to measure the appearance in terms of white linearity within the virtual reality system.
We have chosen 5 users between 24 and 45 years of age. Once the users have been chosen, each one will pass 5 complete tests of 20 samples each. In other words, each user will generate 100 responses at the end of the full test. Therefore, with 5 users we will be generating 500 answers to achromatic appearance values.

The procedure followed is as follows: First of all, the user stays with the HMD for 60 seconds to adapt to the scenario and its illuminant. Once these 60 seconds have expired, we start with the test. The two fixed capsules (black and white) always appear in the virtual reality scenario. However, the user has a maximum of 20 seconds to decide the level of white he/she observes in the capsule that appears in the middle. These values range from 0% to 100% with differences of 10%. Between samples, the sample is hidden, leaving only the two fixed capsules on the scenario for 5 seconds. Once this time has elapsed, another capsule will appear with a different value of white in which the user will have to decide again the appearance of the capsule. Figure 3 shows the procedure for a capsule that would result in 80% of the white.

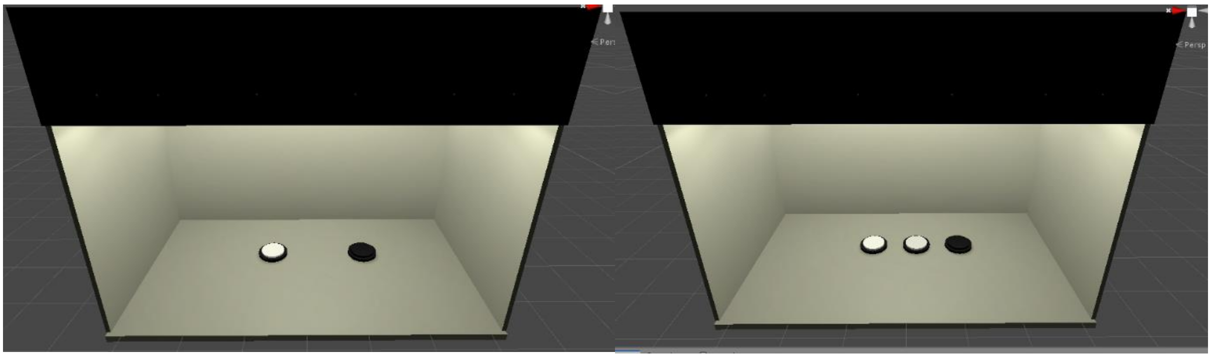

Figure 3: Sample of one of the tests performed on a user. The middle capsule shows 80% of the value of the left capsule and 20% of the right capsule.

RESULTS

After performing physical measurements on the HMD and appearance tests on users, we have seen that the white linearity produced is not the same as that perceived by the users. This means that if we want to represent certain colorimetric values in a virtual reality scenario, it will not correspond to the appearance perceived by the user. Therefore, it is necessary to make a correction so that users can perceive within the HMD the color values that we want to represent. Figure 4 shows this difference between physical measurement and perceived user appearance.

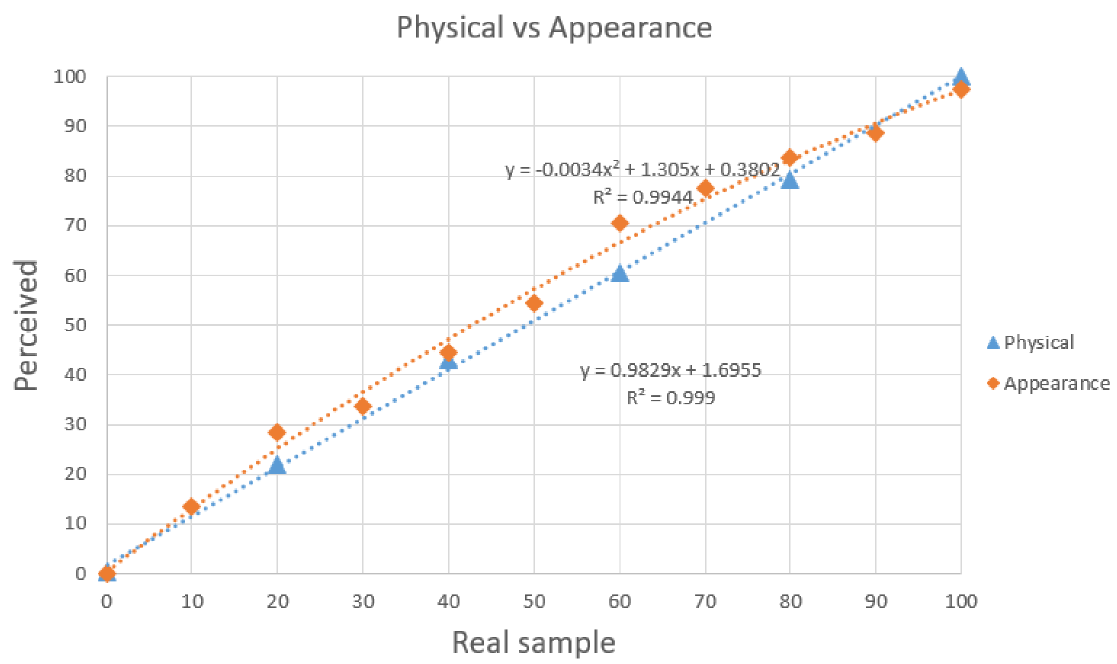

Figure 4: Virtual environment developed to measure both the physical linearity of the Head Mounted Display and its appearance.

CONCLUSIONS

In the results we have been able to verify that after measuring directly with the spectroradiometer on achromatic samples and then asking observers about their appearance, both have a significant difference. Therefore, we can introduce new techniques to simulate a better image reproduction. In future work, we want to study the influence of color constancy within a virtual reality system. Is it possible to treat virtual reality as the real world in terms of adaptation to the environment? In this first work, we have managed to take a first step towards this goal.

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