Evaluation of Colorimetric Characteristics of Head-Mounted Displays

Imad Benkhaled[1(✉)], Isabelle Marc[1], Dominique Lafon-Pham[2], and Luc Jeanjean[3]

[1] LGI2P, Ecole des mines d'Alès, Nîmes, France
{imad.benkhaled,isabelle.marc}@mines-ales.fr
[2] C2MA, Ecole des mines d'Alès, Pau, France
dominique.lafon@mines-ales.fr
[3] CHU, Service d'ophtalmologie, Nîmes, France
luc.jeanjean@chu-nimes.fr

Abstract. In order to determine if four HMD offer characteristics that are sufficient for applications that require precise control of colors displayed, we use a method inspired by two tests extensively used for screening of deficiencies in color vision: the Farnsworth Munsell D-15 and the Lanthony test, which are both based on the arrangement of fifteen color caps so as to reduce the color difference between two neighboring caps. After performing colorimetric characterization of the HMD, patches that match for the Farnsworth and Lanthony cap colors are created, and the color differences between two patches are measured in the CIE Lab space. We find out that, for some of the devices, differences in color may become very slight, and reach the perception threshold. It is deduced that these devices would fail to display the color characteristics of an image with a sufficient level of accuracy.

Keywords: HMD · Colorimetric characterization

1 Introduction

Relevant efforts are currently in progress for the development of technologies of virtual reality, with the emergence of new head mounted displays (HMD) that combine wide field of view and high resolution. In order to improve immersive sensation when using these devices, a particular attention must be paid to their colorimetric characteristics: they should give access to images with a large range of lightness, hue and saturation, along with the capability to not distort colors, and give a natural appearance to any object in the scene.

This work is devoted to a comparison of colorimetric properties of four HMD. The comparison of different displays cannot be reduced to the comparison of technical data such as contrast, resolution, brightness; it must include colorimetric data, as well as human perception based evaluation. The choice was made to base our study on psychophysical tests commonly used to detect color blindness. In the so called Farnsworth Munsell D-15 (FM D-15) and Lanthony tests, the task is to arrange 15 colored caps in a

C. Stephanidis (Ed.): HCII 2016 Posters, Part I, CCIS 617, pp. 175–180, 2016.
DOI: 10.1007/978-3-319-40548-3_29

specified order of hues. The question to be answered is then: do these HMD have sufficient resolution in color rendering to allow for discrimination of the cap color?

Precise knowledge of the way they can manage with color is therefore a mandatory milestone. This knowledge is inferred from a thorough colorimetric characterization process, aiming to define the relationship between each point in the device color space, based on its RGB primaries, and the physical properties of the emitted light. Method used for this colorimetric characterization is briefly presented in the first part of this paper. The methods and materials used for colorblindness assessment are explained. Finally, experimental procedure and calculations leading to evaluation of color difference are described.

2 Material

Mainly, two technologies share the market of HMD: the first one, very similar to smartphone displays or computer monitors, is based on liquids crystals (LCD), while the other is based on OLED (Organic Light emitting Diode). The colorimetric parameters of four head mounted devices (Sensics ZSight, Occulus Rift, Vuzix W1200VR and Razer OSVR), whose technical specifications are listed in Table 1 have been evaluated. Technical specifications of these displays are listed in Table 1:

Table 1. Technical specification of HMD

Display	Technology	Resolution	Luminance max cd/m^2
Oculus Rift	LCD	1280 × 800	176
Vuzix WRAP 1200 VR	LCD	852 × 480	4.24
Sensics Zsight	OLED	1280 × 1080	10,41
Razer OSVR	OLED	1920 × 1080	84

3 Colorimetric Characterization

As electronic display characteristics vary considerably in terms of color gamut, white point, and brightness, etc. it is important to be able to control the light emitted in terms of luminance and chrominance. It is then necessary to perform a colorimetric characterization, that is a modeling step aiming to map digital RGB values to device-independent tristimulus CIE XYZ values [1].

Over the years, the characterization of color displays has been widely studied in the literature and several models have been proposed [2]. The first ones have been initially developed for CRT technologies, and rely on two assumptions that are usually verified for this kind of displays: the channel independence (i.e. light emitted by one the three channels is a function of the digital value driving this particular channel, et do not depend on values driving the two others) and chromaticity constancy of primaries (i.e.: for each channel, chromatic coordinates x and y remain constant when driving with various digital counts). Classical linear method which leads to estimate chromatic components as a linear combination of primaries and approximate the tone response curve by a power law has been used for our LCD and OLED displays.

Spectral radiance measurements have been collected using a Konica CS-100 spectrophotometer in a dark room with the apparatus at a fixed distance from the display to be tested, and with a 0° incident angle, in order to ensure evaluation consistency between each display. Any flare resulting from stray residual ambient light or the display itself was corrected for in the calculations.

All colorimetric coordinates are determined using the CIE 1931 Standard Colorimetric Observer (2°).

4 Psychophysical Tests

Numerous methods have been developed for color vision assessment. Arrangement tests, during which people are asked to place small disks or caps according to their hue, have been designed to quantitatively assess the degree of color vision impairment. The Farnsworth-Munsell 100-Hue test appears as a standard, widely used for in the assessment of acquired color deficiencies [3]. It has also been used in studies of color rendering of different light sources, for instance [4]. But it appears to be time-consuming. A shortened version, the Farnsworth-Munsell D-15 test has then been developed for a more rapid assessment: the number of caps is reduced to fifteen plus a reference one, from which the arrangement is started. Subjects with color vision deficiency will arrange the color discs in a different order than a person with normal color vision. Errors in the placement are linked to the type of vision defect, and to its severity. In order to increase the sensitivity for subjects experiencing only slight loss of color discrimination, the Lanthony test, for which the caps exhibit strongly desaturated colors, is often performed along with the FM D-15.

For the both tests, the caps exhibit color of equal saturation, and more or less equal luminance, while the hues are distributed almost uniformly on an oval curve in the CIE xy diagram. These tests are prone to error if lighting conditions are not carefully controlled, and the better accuracy is obtained with standardized C or D65 sources. In this case, the color difference between two adjacent caps is intended to be nearly constant.

5 Experimental Procedure

Our purpose is to investigate if the colorimetric characteristics of our devices make it possible to display the same colors as the Farnsworth and Lanthony test caps. The first step in our experimental procedure is to determine the chromaticity coordinates for each cap. Spectral measurements have been made under daylight conditions, for light reflected by each cap, and for light reflected by a perfect reflecting diffuser: it is then possible to infer the spectral reflectance of each cap, as light is the product of the reflectance spectrum of an object by its illumination spectrum. It is now possible to simulate the light reflected by the caps under any illumination. For each display, a D65 source is simulated by weighting D65 illuminant spectrum by the maximum luminance that can be emitted by the display.

The next step is to evaluate difference between colors of two simulated adjacent caps. This difference has to be calculated in the standardized Lab color space. We use the following equations for CIE Lab color, lightness and chroma difference [5].

$$\Delta E^{*}_{Lab} = \sqrt{\Delta L^{2} + \Delta a^{2} + \Delta b^{2}} \;\; \Delta E^{*}_{ab} = \sqrt{\Delta a^{2} + \Delta b^{2}} \;\; \Delta E^{*}_{L} = \sqrt{\Delta L^{2}}$$

6 Results

6.1 Colorimetric Characterization

The difference between the tristimulus values obtained from measured data and those predicted by the model was evaluated using the CIELab color difference. The values of the mean color difference for the three channels are summarized on Table 2.

Table 2. Performance results of characterization model: mean color difference for the three channels.

	Razer	Vuzix	Occulus	Sensics
Average $\Delta E(Lab)_{mean}$	5.23	9.23	2.65	9.92

The observed difference can be explained by the fact that for at least two devices, the assumptions of channel independence and chromaticity constancy do not hold. In this case, some more sophisticated methods could be used. For instance, Tamura et al. [6] propose a masking model intended to account for channel interaction.

6.2 Effect of Luminance

All the HMD under test exhibit a low luminance level, that may lead to poor color perception: according to the Hunt effect, it is known that as absolute luminance levels

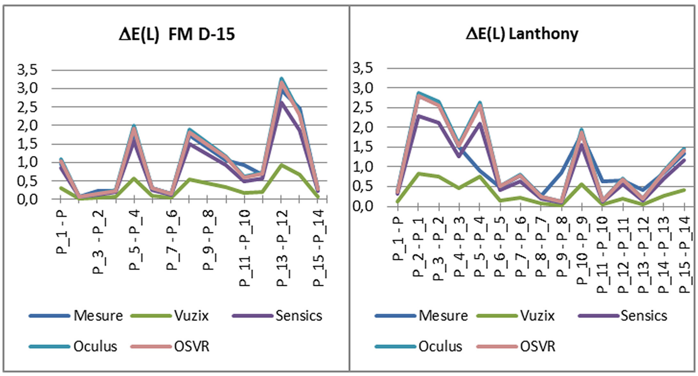

Fig. 1. Lightness difference between two adjacent caps (Color figure online)

decrease, the colorfulness of a stimulus also decreases, with the perceived chromaticity shifting toward white point [7].

Lightness difference between adjacent caps have been calculated for all the HMD, and compared to measured data (Fig. 1). It can be seen that for the Sensics Wrap 1200VR, difference are always behind the detection threshold. For others devices, this happens only between some of the caps, i.e. in some parts of the total gamut, differences are not noticeable.

6.3 Effect of Chroma

Chromaticity coordinates obtained after spectral measurement for each cap and after simulation on a specific display are shown on Fig. 2.

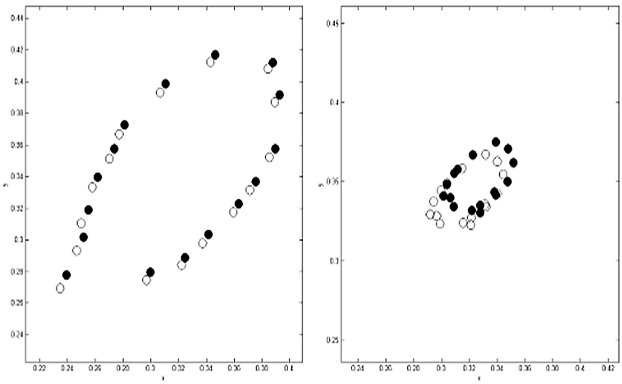

Fig. 2. Cap chromaticity coordinates. Left: FM D-15, right: Lanthony. Black dots: x y obtained from measurements, blank dots: x y obtained by simulation.

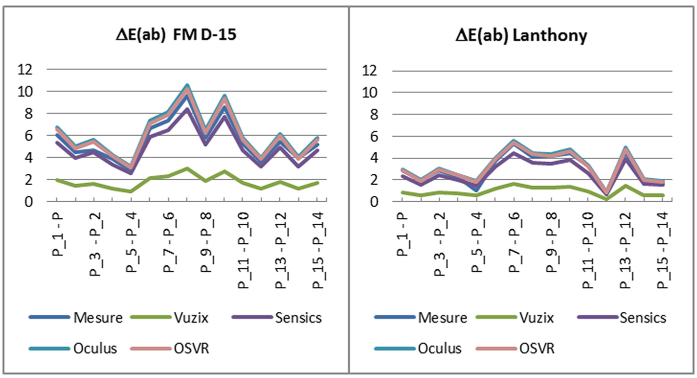

Fig. 3. Chroma difference between two adjacent caps. Left: FM D-15, right: Lanthony

We then evaluate the color difference between two successive caps for a correct arrangement. Results of our calculations are compared to measured values as shown on Fig. 3. Results are coherent with values gained from literature [8]. But once again, the Vuzix HMD exhibits the worst performances for the both tests. All the devices under test do not let the user to discriminate between two colors when they are strongly desaturated.

7 Conclusion

It appears that the HMD under test exhibit somehow different colorimetric behavior: one of them (Vuzix) seems to be definitely inefficient for precise color rendering. The technology (OLED or LCD) is not sufficient for explained such a difference.

Acknowledgements. This work was supported by SopraSteria, Areva, Capgemini, Credit Agricole and SOS Retinite.

References

1. Brainard, D.H., Pelli, D.G., Robson, T.: Display characterization. In: Encyclopedia of Imaging Science and Technology (2002)
2. Thomas, J.-B., Hardeberg, J.Y., Trémeau, A.: Cross-media color reproduction and display characterization. In: Maloigne, C.F. (ed.) Advanced Color Image Processing and Analysis, pp. 81–118. Springer, Heidelberg (2013)
3. Farnsworth, D.: The Farnsworth-Munsell 100-Hue Test for the Examination of Color Discrimination (1957)
4. Rea, M.S., Freyssinier-Nova, J.P.: Color rendering: a tale of two metrics. Color Res. Appl. **33** (3), 192–202 (2008)
5. Tremeau, A., Fernandez-Maloigne, C., Bonton, P.: Image numérique couleur: de l'acquisition au traitement. DUNOD, ISBN **2**(10), 006843 (2004)
6. Tamura, N., Tsumura, N., Miyake, Y.: Masking model for accurate colorimetric characterization of LCD. J. Soc. Inform. Display **11**(2), 333–339 (2003)
7. Reinhard, E., et al.: Color Imaging: Fundamentals and Applications. CRC Press, Boca Raton (2008)
8. Bowman, K.: A method for quantitative scoring of the Farnsworth Panel D-15. Acta Ophthalmol. **60**(6), 907–916 (1982)