Controlling color in display: A discussion on quality

Jean-Baptiste Thomas
Centre de Recherche et de Restauration des Musées de France

ABSTRACT: Display technology evolves and changes incredibly fast. Tools designed to control color within them are mostly the same since Cathod Ray Tube era. Should we be afraid of this fact? Which colorimetric accuracy do we need to aim? The following considers the purpose of the colorimetric characterization and its accuracy. We propose a qualitative analysis of different characterization models through the relationship between the nature and the number of measurements one need to perform, the display technology and the purpose.

1 INTRODUCTION: Colorimetric characterization of a color display device is a major issue for the accurate color rendering of a scene. We recall that display color characterization aims to define the transformation between the device digital color space, typically *RGB*, and a reference color space, describing the perceived color, based on the *CIE* standard observer, typically *CIEXYZ* or *CIELAB* [1]. The forward transformation aims to predict the displayed color for any set of digital values input to the device. The inverse transformation provides the set of digital values to input to the display in order to display a desired color. A calibration process precedes the characterization. This step maintains the settings (gamma, contrast, brightness, correlated color temperature, etc) of the display in a given state. The characterization model is set up with some knowledge about the display that can come from the technology, the manufacturer and/or from a set of measurements.

In this communication, we want to discuss the choice of a model in relation with the technology and the purpose. In the following, we explicit what is the need, then we discuss the evaluation of a model depending on the purpose. Before to conclude, we propose a qualitative comparison of some display characterization methods.

2 PURPOSE: Like any image processing technique, a display color characterization model has to be chosen considering needs and constraints. For our purpose, the need is mainly the expected level of accuracy. The constraints depend mainly on two things: the time and the measurement. The time is a major issue, because one may need to minimize the time of establishment of a model, or its application to an image (computational cost). The measurement process is critical because one may need to have access to a special device to establish the model. The constraint of money is distributed on the time, the software and hardware cost, and particularly the measurement device.

In the display case, the combination needs vs constraints seems to be in agreement. Let us expose two situations:

- The person who needs an accurate color characterization (such as a designer, a color scientist) has often a color measurement device available, is working in a more or less controlled environment, and does not mind to spend 15-20 minutes every day to calibrate his/her monitor/projector. This person may typically want to use an accurate method, an accurate measurement device, to take care of the temporal stability of the device, etc.
- The person who wants to display some pictures in a wedding party or in a seminar, using a projector in an uncontrolled environment does not need a very accurate colorimetric rendering. That is fortunate, because he/she does not have any measurement device, does not have much time to perform a calibration or to properly warm up the projector. However, this person needs the colors not to betray the meaning she/he intends. in this case, a fast end-user characterization should be precise enough. This person might use a visual calibration, or even better, a

visual/camera based calibration. The method should be coupled to a user-friendly software for making it easy and fast.

We can see a duality between two types of display characterization methods and goals: the consumer, end-user purpose, which intends only to keep the meaning and aesthetic unchanged through the color workflow, and the accurate professional one, which aims to have a very high colorimetric fidelity through the color workflow. We see also through these examples that the constraints and the needs are not necessarily going in the opposite direction.

In the next section, we relate the quality of a model with colorimetric objective indicators.

3 QUALITY: Once a model is set-up, there is a need to evaluate its quality to confirm we are within the accuracy we wanted. In this section, we discuss how to use objective indicator for assessing quality.

3.1 Evaluation: The first goal of a method is to model the display and predict the displayed color. A point-wise quality evaluation process is straightforward. We process a digital value with the model to obtain a result and compare it in a perceptually homogeneous color space with the measurement of the same input. Figure 1 illustrates the process.

3.2 Toward a(nother) rule of thumb: Once we have an estimation of the model failure, we would like be able to say how it is good or not for a given purpose. The ideal colorimetric case is to have an error below the Just Noticeable Difference [1](JND). Kang [2] said on the page 167 of his book that the JND is of 1 ΔE^*_{ab} unit. Mahy et al. [3] study assessed that the JND is of 2.3 ΔE^*_{ab} units. Considering that the *CIELAB* color space is not perfectly uniform, it is impossible to give a perfect threshold with an euclidean metric[2]. Moreover, these thresholds have been defined for simultaneous pair comparison of uniform color patches. This situation almost never fit with a display use, it may then not be the best choice when comparing color display devices.

In the case of color imaging devices, many thresholds have been used [4, 5, 6, 7], considering ΔE^*_{ab}, for color imaging devices. Stokes et al. [8] found a perceptibility acceptance for pictorial images of an average of 2.15 units. Catrysse

[1] A JND is the smallest detectable difference between a starting and secondary level of a particular sensory stimulus, in our case two color samples.

[2] The JND while using ΔE^*_{00} should be closer to one than with other metrics but has still been defined for simultaneous pair comparison of uniform color patches.

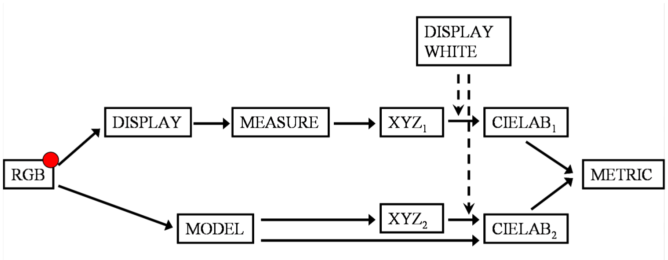

Fig. 1 Evaluation of a forward model scheme. A digital value is sent to the model and to the display. A value is computed and a value is measured. The difference between these values represents the error of the model in a pseudo-perceptually uniform color space.

et al. [9] used a threshold of 3 units. Gibson [10] found acceptable a characterized display that has a prediction error average of 1.98 and maximum of 5.57, while the non-acceptable has at the best an average of 3.73 and a maximum of 7.63 using ΔE^*_{94}.

We propose another set of thresholds that would be an attempt to quantify the success of the color control depending on the purpose. This is only a basis or a tool for an evaluation, and does not aspire to be exact. In Table 1, we distinguish between accurate professional color characterization, which purpose is to ensure a really high quality color reproduction, and a consumer color reproduction, which aims only at the preservation of the intended meaning, and relate the purpose with objective indicators.

Considering the professional reproduction, let us consider the following rule of thumb.

If we want to reach a good accuracy and in our opinion we need to consider the two indicators, the average and the maximum eror. Let us consider the average: from 0 to 1 it is good, from 1 to 3 it is acceptable, and over 3 it is not acceptable. If now we consider the maximum, from 0 to 3 it is good, from 3 to 6 it is acceptable, over it is not acceptable. If we compare this scale with the rule of thumb used by Hardeberg [5], it makes sense since below three it is hardly perceptible, the same if we look at the work of Abrardo et al.[4]. If we look at the JND proposed by Kang [2] or Mahy et al. [3] it seems to make sense since in both cases, the *good* is under the JND. In this case we would prefer results to be good, and it may be possible to discard a couple model/display if it does not satisfy this condition. In the case of this professional reproduction, it could be better to use the maximum error to discard a couple model/display. Considering the consumer prediction, we propose to consider that from 0 to 3 it is good, from 3 to 6 it is acceptable, and over 6 it is not acceptable. In this case we would rather accept methods that shows average results up to 6, since it should not spoil the meaning of the reproduction. This is basically the same than the rule of thumb proposed by Hardeberg [5], *perceptible but acceptable* being the basic idea of preserving the intended meaning.

Table 1 This table shows the set of thresholds one can use to assess the quality of a color characterization model, depending on the purpose.

<table>
<tr><td>ΔE^*_{ab}</td><td colspan="2">Professional</td><td>Consumer</td></tr>
<tr><td></td><td>Mean ΔE^*_{ab}</td><td>Max ΔE^*_{ab}</td><td>Mean ΔE^*_{ab}</td></tr>
<tr><td>$- < 1$</td><td>good</td><td rowspan="2">good</td><td rowspan="2">good</td></tr>
<tr><td>$1 \leq - < 3$</td><td>acceptable</td></tr>
<tr><td>$3 \leq - < 6$</td><td rowspan="2">not acceptable</td><td>acceptable</td><td>acceptable</td></tr>
<tr><td>$6 \leq -$</td><td>not acceptable</td><td>not acceptable</td></tr>
</table>

4 COLOR CORRECTION

Different approaches can be considered to characterize the color of a display. These methods are characterized by different parameters, such as the accuracy on a given technology, the computational cost, the number of measurements required, etc.

The accuracy of the color rendering depends on the choice of both the method and the display technology and features.

Display characteristics, such as temporal stability or spatial uniformity have to be taken into account. We will not develop this aspect in detail here because of the limited number of pages, some of these parameters are studied in previous works

[11, 12]. However, Table 2 presents a qualitative summary of different display colorimetric characterization models based on Table 1 and on the experimentation on several displays of different models in relation with the nature and number of measurements needed. The complete quantitative analysis of these models are presented in some previous works [13, 14, 15].

Table 2 Qualitative interpretation of different models based on Table 1. The efficiency of a model is dependent on several factors: the purpose, the number of measurements, the nature of the data to measure, the computational cost, its accuracy, etc. All these parameters depend strongly on each display.

Model	PLVC	Bala	PLCC*	Polyharmonic splines	GOGO
Type of measurement	54 (XYZ) measures	1 to 3 visual tasks times 1 to 3 pictures	54 (Y) measures 3 (XYZ)	216 (XYZ) measures	3 to 54 (Y) measures 3 (XYZ)
Technology	dependent	dependent	dependent	independent	CRT
Purpose	Professional or Consumer	Consumer	Professional or Consumer	Professional	Consumer

We only focus on five models that are a representative sampling of existing ones: The Piecewise Linear assuming Variation in Chromaticity (PLVC) model [16, 17, 14], Bala's model [18, 19, 15], an optimized polyharmonic splines based model [13], the offset corrected Piecewise Linear assuming Chromaticity Constancy model (PLCC*) and the Gain-Offset-Gamma-Offset (GOGO) [20, 16, 21, 22, 17, 23, 24].

CONCLUSION: In summary, the choice of a couple display/color characterization model depends on the purpose. However, all the considerations we discussed are taking into account colorimetric objective indicators. In the case of complex images, indicators based on pointwise colorimetry show their limit. As far as we know, there are no comprehensive work addressing color fidelity and quality for complex color images on displays based on more human indicators.

With this communication, we mainly wanted to show how we can evaluate the quality of a couple display/color characterization model with the tools we have in hands and to give an idea of how to select a model for a given purpose.

Furthermore, to reach an efficient perceived quality of displayed images, we need to relate the work on image quality metric and and the display color rendering quality. That means to define an objective indicator for color image quality viewed on displays related to the accuracy of the color rendering.

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