Additivity Based LC Display Color Characterization

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Abstract *We introduce an additivity based method to perform color characterization of LC display devices. We focus here on the forward transform from the device RGB color space to XYZ tristimulus values. Chromaticity constancy is an assumption in all chromaticity matrix based characterization models, but in practice this assumption does not hold perfectly. The main contribution of this work is to define a model where the chromaticity non-constancy is not a source of error. Our method outperforms traditional approaches such as the PLCC and GOG models without needed more measurements than those. The proposed approach could be particularly useful for multi-display systems characterization as it is not time consuming and gives precise enough results.*
Keywords: LCD, Color characterization, Projection displays.

Introduction

Characterization of color display devices is an important part of a color management system. The characterization of such a device defines the relationship between the device-dependent color space, typically RGB, and a device-independent color space describing the perceived color, typically XYZ which describes the color perception of the CIE standard observer. The forward transform make us able to predict the color which will be displayed (XYZ) for a given set of digital values input to the device (RGB) and the inverse (backward) transform will give us the digital values to input in order to display the desired color. Our work focuses on finding a forward model which is not subject to chromaticity non-constancy.

There exist a lot of methods to characterize color in a display device. Most part of them can be found in the following articles [1,2,3]. We could make the distinction between two main groups. The one which are performing 3D interpolation needs a lot of measurement and are computationally complex. However, they don't suppose any special device properties, i.e. the device can be consider as a black box, and no physical rules are assumed. It could be useful for example when you don't have any/enough information about the technology used. The models in the other group are trying to establish a mathematical model of the response of the device. For example, linearizing the intensity response curve of the display, by a global function or by interpolation, before applying a 3x3 chromaticity matrix to get the XYZ coordinates. This group of models do not need a lot of measurements but are making the assumption that the channels are independent and that the chromaticity of the primaries are constant. For instance, the response curve could either be a gamma shaped curve (defined by an offset and a gain) or a S shaped curve which could be defined by 4 parameters as in the S-Curve model [2].

In the case of a multi-display system or in the case of a projection device, we need an accurate characterization model which doesn't need a lot of measurement, as we could have to perform it on several displays or at several positions of the same display to

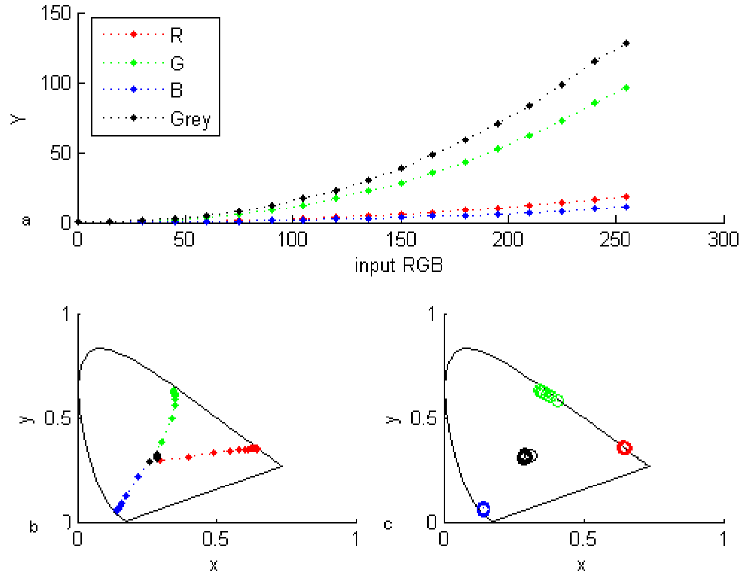

Figure 1: Projector 1. a : response curve for each channel and gray. b : chromaticity shift in xy diagram without black correction. c : Black corrected chromaticities.

correct for spatial non-uniformity [4]. Therefore the 3D LUT methods would be too heavy to be used in such a case, in spite of a good precision [1]. As desktop projectors are seldom belonging to CRT technology, the GOG model would not give good enough results. We would expect the classic PLCC [3] to give a good compromise between number of measurements, celerity and precision. A source of error in such a model is the non-chromaticity constancy of primaries (see fig.1.b and 2.b). One cause of this is the influence of the 'chromaticity' of the black offset which is mixed with the color, and have more and more influence as the intensity decrease, i.e. the smaller the input value is, the more the chromaticity is attracted by the black. One way to overcome this problem is to remove this black offset before to perform the linearization and apply the matrix. It's working well in the case illustrated in fig.2.b and 2.c where the chromaticity shift keep almost on a line in the direction of the black, i.e. the black level is almost the only cause of chromaticity shift. The PLCC model then give correct results (see table 1). In other cases we can observe that this chromaticity shift is taking the shape of a coma, i.e. the main part of the chromaticity non-constancy is not only due to the black level, the technology itself play an important role (see fig.3.b and 3.c). An explanation is given by Marcu in [5], the LC component properties change with the intensity, so the spectra is modified with the intensity. Typically, in Marcu's experiment, for the (0, 0, 0) RGB input, the black is bluish because of the poor filtering power in the low wavelength. In such a situation, the black correction is not at all efficient and the model give poor results (table 1).

The main idea of our work is to make this shift not a problem, supposing a perfect additivity and channel independancy. Doing that, the error of the model will come only from the channel's non-independancy, and from the time and spatial non-uniformities.

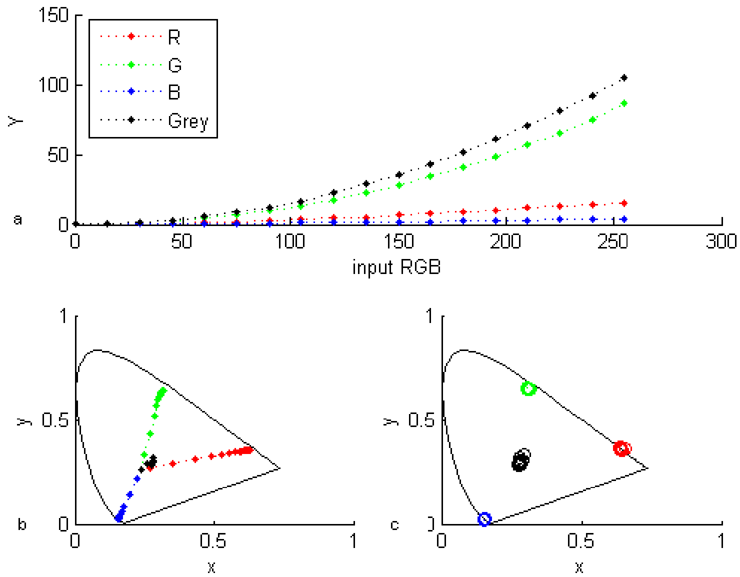

Figure 2: Projector 2. a : response curve for each channel and gray. b : chromaticity shift in xy diagram without black correction. c : Black corrected chromaticities.

Obviously the interpolation method used will have some influence as long as we want to limit the number of measurements. In the following sections we present our approach and some results. Our conclusion gives a way to perform the inverse model.

Model

The method itself is quiet simple as long as the additive mixture of color is the base of so-called additive displays (as LC panels and projection devices). From the measurement of the XYZ coordinates of a sampling of the digital ramp of each channel (i.e. N values regularly spaced on the 256 possibilities for an 8 bits device), we will suppose the perfect additivity of the device. Moreover, we keep on considering channels as independants. Note also that we perform the black correction in the manner of PLCC.

Then a color XYZ_o output from a RGB_i input to the device would be expressed as

$$X_o = Xr_i + Xg_i + Xb_i$$

$$Y_o = Yr_i + Yg_i + Yb_i$$

$$Z_o = Zr_i + Zg_i + Zb_i$$

Where Nn_i is the value of the color from the channel n along the dimension of N for an input $_i$.

To generalize from the measurements to all the color space, we perform a 1D interpolation along each channel R, G, B for each color component X, Y, Z (i.e. 3×3 1D

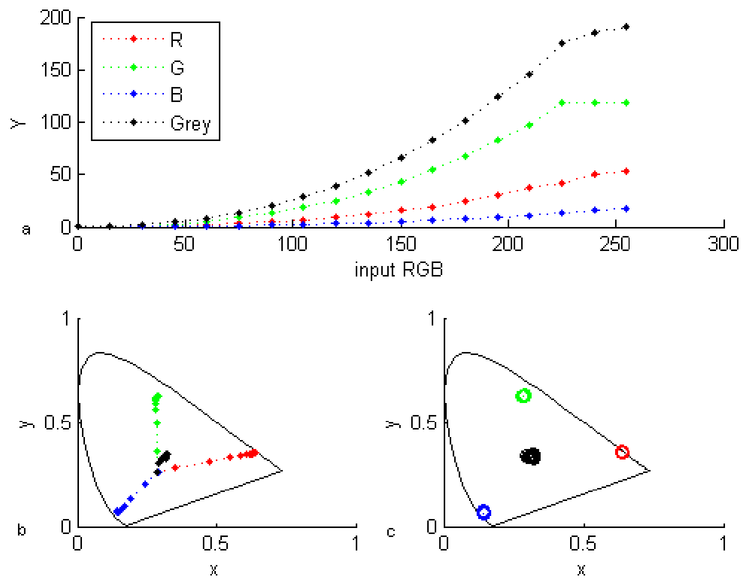

Figure 3: Monitor. a : response curve for each channel and gray. b : chromaticity shift in xy diagram without black correction. c : Black corrected chromaticities.

interpolations). Linear interpolation gives good results (see next section), and is already well implemented on a classical color management system. Therefore it would be easy to use this model with existing system and shift from a chromaticities matrix based model as PLCC to our approach without loosing any time as the matrix computation is replaced by linear interpolation.

Results

We have tested this forward model on 2 LCD projectors, the Panasonic PT-AX100E refered as projector 1, the 3M-X50, refered as projector 2. And on one LCD desktop panel, refered as monitor. We have compared the results with classic PLCC, and GOG characterization models. The interpolation method used were linear, cubic or spline performed with matLab. These results are based on a 18 patches by ramp measurements, for each device (see fig.1-3.a). We have calculated the ΔE^*_{ab} for the forward model from a set of 100 random RGB patches, the mean and the max of these errors for each method are given in table 1.

We can obviously see that the PLCC without correction for black level gives so bad results. Correcting for black level, results are better. As we have said in the introduction, if the black correction is the main part of channel non-constancy, results are good. It is the case for projector 2 with a mean error of 1.78. In the other case, result are not efficient at all with 3.93. It's quiet strange to note that the PLCC with or without black correction give almost the same accuracy for the monitor.

As expected, the GOG model doesn't give so good results for these devices with a mean error of 3.96 and 2.86 respectively for projector 1 and 2, and with a mean error of 6.89

Mean, Max and standard deviation of ΔEa*b* for 100 random patches	PLCC	PLCC (black corrected)	GOG	Additive model (Linear interpolation)	Additive model (Cubic interpolation)	Additive model (Spline interpolation)
Projection 1	Mean : 6.42 Max : 19.06 Stddev : 4.28	3.93 8.28 2.15	3.96 14.61 2.62	1.41 3.56 0.63	1.35 3.21 0.53	1.32 2.94 0.5
Projection 2	Mean : 15.19 Max : 55.62 Stddev : 14.94	1.78 2.96 0.51	2.86 11.41 2.3	0.54 1.64 0.28	0.53 1.54 0.27	0.53 1.61 0.27
Monitor	Mean : 4.66 Max : 12.08 Stddev : 2.3	4.88 9.36 2.16	6.89 45.54 6.09	2.04 4.55 0.91	2.21 5.20 0.95	2.16 5.36 0.95

Table 1: Results

Projection 1	X	Y	Z
White (full intensity)	115	128.6	155.4
R+G+B (full intensity)	111.93	125.12	154.11
Difference (%)	2.67	2.71	0.83

Projection 2	X	Y	Z
White (full intensity)	93.97	105	135
R+G+B (full intensity)	94.81	105.96	136.9
Difference (%)	0.89	0.91	1.41

Monitor	X	Y	Z
White (full intensity)	188.1	191.1	209.9
R+G+B (full intensity)	187.59	190.53	210.91
Difference (%)	0.27	0.30	0.48

Table 2: Additive properties of tested displays.

for the panel. Note that the settings of the monitor could be better adjusted to avoid the fact that the green channel saturate, doing that the GOG would give quiet better results. But seeing that our method give good result in such a case prove the robustness of the model.

With a linear interpolation, our additive model gives respectively 1.41, 0.54 and 2.04. We have reduced the mean error of the PLCC almost by 3 in the worst case. With other interpolation techniques results are quiet similar. The best results were obtained with Spline interpolation for projection device which gives mean error of 1.32 and 1.53, and with linear interpolation for monitor.

Maximum errors are quiet small too, around 1.6 for the projector 2, 3.2 for projector 1 and 5 for monitor.

Seeing at these results, we can see that our model overcome the classic PLCC and the GOG model for the forward transform. We can notice as well that the influence of the interpolation method is limited by the number of measurements on the ramp. With a smaller number of measurements, the interpolation would have more influence on the results.

We can notice as well that the additivity properties of tested displays is, as expected, still a source of errors. In Table 2 you can see the difference of additive quality of both projection displays. We have presented these results as in [2]. We can see, coupling information from table 1 and 2 that our results are poor as the device's quality for additivity decrease. However, the additivity quality of the monitor (table 2) is shown really good, but results are not as good as with projection devices. That mean that the channel interaction is big in this device.

Conclusion

We have defined a forward model for display characterization which is easy to implement as the PLCC, with noticeable better results. This model would be usefull to characterize multi-display systems and projectors, as it is easy to perform and doesn't need a lot of measurements.

The inverse model would be a bit more complex as there is no analytical solution. It could be performed by an optimization method to design a regular grid in XYZ, using the forward model. Then it's pretty easy to find an efficient algorithm to interpolate from this 3D LUT. Note that no more measurements would be needed to develop the inverse model, so it's possible to overcome one drawback of 3D LUT model.

Moreover, this model would be of great interest for multi-primaries displays or spectral approaches. This could be a part of our future works.

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Biography

Jean-Baptiste Thomas has received his bachelor's degree in Physics and applications in 2004 and his master's degree in Image, Vision and Signal in 2006 from the University Jean Monnet, France. He is currently pursuing the PhD degree at the University of Burgundy, France. His research focuses on colors in projection and tiled projection displays.