Color correction for tiled-displays: a comparison of automatic and manual approach

Jérérmie Gerhardt

Fraunhofer FIRST,
Kekuléstr. 7, 12489 Berlin
eMail: jeremie.gerhardt@first.fraunhofer.de
URL:http://www.first.fraunhofer.de

abstract In a tiled-displays installation it is more likely that all light sources (i.e. the beamers) will produce slightly different colors from each others, this for identical digital values sent as commands. Therefore there is a need for gamut mapping to correct the color differences between the displays. A regular approach for adjusting the colors between the sources is to modify the pixel values of each projector by a matrix operation. In this paper we compare two approaches to compute these matrices: a fully automatic based on the CIE XYZ measurement of the projectors primaries and the CIE 1931 standard observer to evaluate the color differences, a manual approach allowing to the user to tune directly the values of the matrices and to observe directly the results of the correction. After introducing our test setups and projector modeling we explain in more details the two approaches and then compare the correction obtained.

1 Introduction

Our test installation is a multi-projectors installation with the possibility to display 3D stereoscopic content on a curved surface with the Infitec technology [1]. Because of the installation setups the projectors have their filter always turned on and therefore present a reddish or greenish tint depending of the filter properties (see [2] for a more detailed description of this setup for stereoscopic display), therefor we call them the green projectors and the red projectors.

In this paper we focus on the green projectors. We would like to use this display for non-stereoscopic content; we need then to be colorimetrically corrected such that they appear less "green". The correction appears under the form of a matrix operation which modifies the RGB digital values to be displayed, this correction can be seen as gamut mapping

operation. So for a triplet of RGB digital command each projector will receive a slightly different triplet after the correction is applied.

In the next sections we describe our experimental setup, the gamut mapping operation and the two approaches to obtain the correction parameters: an automatic and a manual approach. Finally results will be discussed.

2   Experimental setup

An important part of the experiment is the measure of the color displayed by the projectors. The measurements were performed using a BLUE-Wave Spectrometer from Stellar-Net where the measuring device was receiving the light reflected by our screen simulating an observation position of a human observer.

In Fig. 1 we show the measurement of the white reference of our installation. This reference was obtained by projecting "white" by both a red and a green projectors. We can see in this figure the effect of the filters, each primary appearing with a pair of wavelength peaks instead of one.

Three green projectors were used for this experiment and the white measurement of each projector can be seen by looking at the full black line in Fig. 4, Fig. 5 and Fig. 6.

Later, to compute colorimetric values of the displayed color from the various RGB digital values input (in our experiment those corresponding to the projector primaries), we normalize the spectral signal using the following formula:

$$\mathbf{S} = \frac{\mathbf{s} - \mathbf{k}}{\mathbf{w} - \mathbf{k}} \tag{1}$$

that includes an offset correction $\mathbf{k}$ where $\mathbf{s}$ is the measure from our spectrometer and $\mathbf{w}$ is the white reference displayed in Fig. 1.

We worked only on the visible spectrum window of [400nm-700nm] and each spectral reflectance measured is resampled to obtain a resolution of 1nm such that each reflectance is represented by a vector of $400 : 1 : 700 = 301$ discrete values.

3   Automatic color correction by gamut mapping operation

Before obtaining a correction matrix per projector, we need to define the common color gamut of our installation. We use the technique described by Pagani [4] to compute the common gamut. This technique is achieved in two steps: first a displayability test is performed to find out which colors are reproducible in the CIE XYZ color space by all devices, secondly the colors obtained are sorted to define the limit of the common gamut. The common gamut is represented by a matrix $\mathbf{M_c}$ where each column is an XYZ vector of the primaries red, green and blue. This volume of colors can be seen as the gamut of a virtual projector. Now given $\mathbf{M_p}$ the equivalent matrix of a projector $\mathbf{p}$ from our installation, the transformation matrix for this projector will be:

$$\mathbf{A_{corr}^p} = \mathbf{M_p^{-1}} \mathbf{M_c} \tag{2}$$

and the correction applied as follows:
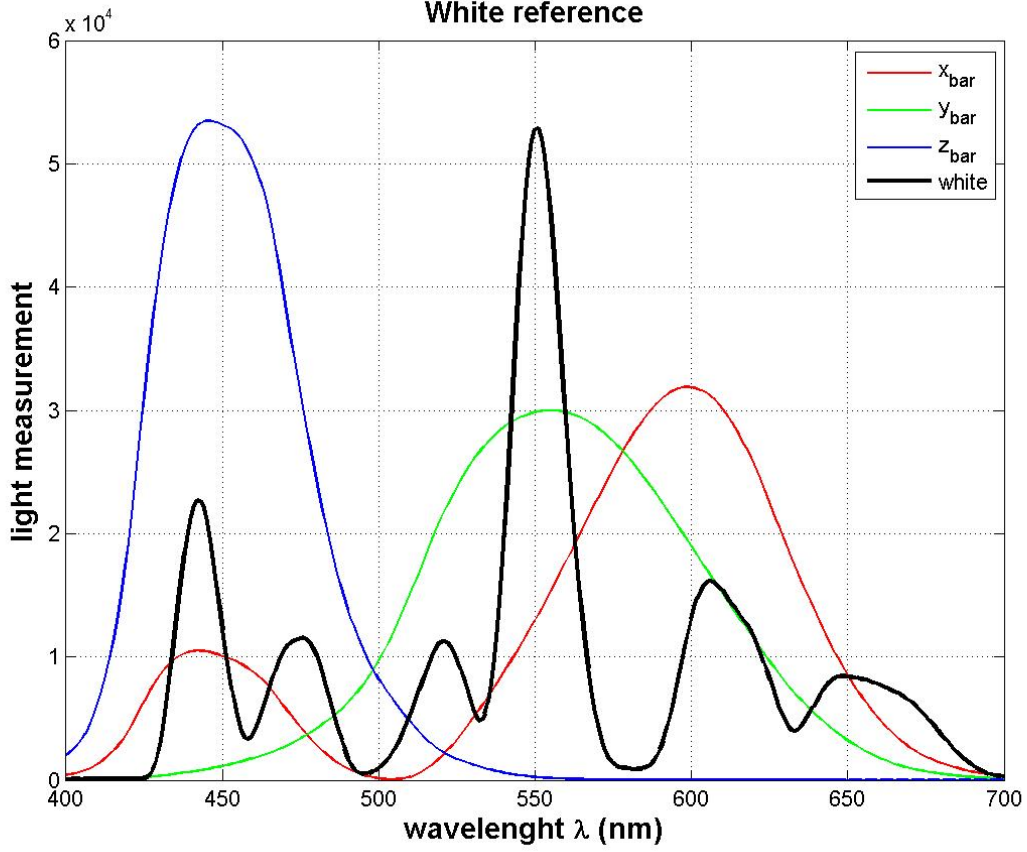
$$\mathbf{r}' = \mathbf{A_{corr}^p} \mathbf{r} \tag{3}$$

Abbildung 1: Measurement of the white reference of our installation. The red and green projectors were both receiving the digital command $\mathbf{r} = [R\ G\ B]^T = [1\ 1\ 1]^T$ to obtain this reference. A scale version of the CMFs CIE 1931 have been added to the figure to illustrate how to colors are perceived by human observer.

where $\mathbf{r}$ and $\mathbf{r}'$ are respectively the original RGB triplet and the modified RGB triplet. So for a given $\mathbf{r}$ the matrix operation simulates the XYZ values displayed by the virtual projector $\mathbf{M_c}$ and give the corresponding $\mathbf{r}'$ control values for the projector $\mathbf{p}$ by multiplying by $\mathbf{M_p}^{-1}$ (i.e inverse projector model).

This ensures that projectors display the same colors but the images projected can still have this greenish tint. To solve this problem we add the parameters of a non-modified projector when computing the common gamut, actually we use a pair of modified projectors: a red projector and green projector (see Fig.1). This operation should define a color gamut less "green" but not perfectly white neither, at least the intersection of both gamuts: an originally white image should then appear grayish.

Given the gamut limits of a group of projectors (one non-modified and three green projectors) we compute the common gamut using the algorithm explain by Pagani [4]. An illustration of the common gamut in a chromaticity diagram is presented in Fig. 2, the triangle with the borders colored in magenta corresponds to the common gamut.

And we obtain for the three projectors the following correction matrices:

$$\mathbf{A}^1_{\mathbf{corr}} = \begin{bmatrix} 0.84 & 0.02 & 0.16 \\ 0.05 & 0.98 & 0 \\ 0 & 0.11 & 0.85 \end{bmatrix}, \mathbf{A}^2_{\mathbf{corr}} = \begin{bmatrix} 1 & 0.01 & 0.19 \\ 0.05 & 1 & 0.01 \\ 0 & 0.13 & 1 \end{bmatrix}, \tag{4}$$

and

$$\mathbf{A}^3_{\mathbf{corr}} = \begin{bmatrix} 0.68 & 0.06 & 0.13 \\ 0.05 & 0.98 & 0 \\ 0 & 0.11 & 0.84 \end{bmatrix}. \tag{5}$$

The three projectors having similar properties their respective correction matrix have similar values. But we can observe that the second projector is the less modified since the diagonal entries are all equal to 1.

4   Manual correction

In this approach we set manually the values of the correction matrices and we do not need to compute a common gamut as in the first stage of the automatic approach, the correction matrices are directly obtained. This also means that this approach do not require to measure the primaries of each projector, the operation can be done directly by observing the color changes while tweaking the matrices values. And the modification of the RGB values follows the same workflow as for the automatic correction:

$$\mathbf{r}' = \mathbf{M}^{\mathbf{p}}_{\mathbf{corr}}\mathbf{r} \tag{6}$$

To set the correction matrices we proceed as follow:

1. Display white on all projectors (the projectors may overlap in some areas but not completely - one purpose of combining projectors is to increase the screen size) and find or choose the darkest one as reference.

2. Adjust all blue, then red and finally green channels between the projectors by tweaking the matrices $\mathbf{M}^{\mathbf{p}}_{\mathbf{corr}}$ according to the reference projector.

3. Adjust the parameters such that a white image projected loose progressively its greenish tint toward a grayish tint.

We obtain for the three projectors the following correction matrices:

$$\mathbf{M}^1_{\mathbf{corr}} = \begin{bmatrix} 0.89 & 0 & 0 \\ 0 & 0.88 & 0 \\ 0 & 0 & 0.91 \end{bmatrix}, \mathbf{M}^2_{\mathbf{corr}} = \begin{bmatrix} 0.97 & 0 & 0 \\ 0 & 0.91 & 0 \\ 0 & 0 & 0.91 \end{bmatrix}, \tag{7}$$

and

$$\mathbf{M}^3_{\mathbf{corr}} = \begin{bmatrix} 0.85 & 0 & 0 \\ 0 & 0.91 & 0 \\ 0 & 0 & 0.88 \end{bmatrix}. \tag{8}$$

In a similar fashion as for the automatic correction we illustrate in a chromaticity diagram the effect of the manual correction on the gamut of each projector, see Fig. 3. Once the manual correction is performed we re-measure the white of each projector. The measurements curves (black dotted lines) are shown in Fig. 4, Fig. 5 and Fig. 6. We have added to these figures a scaled version of the CMFs CIE 1931 curves in order to illustrate the tinted effect.
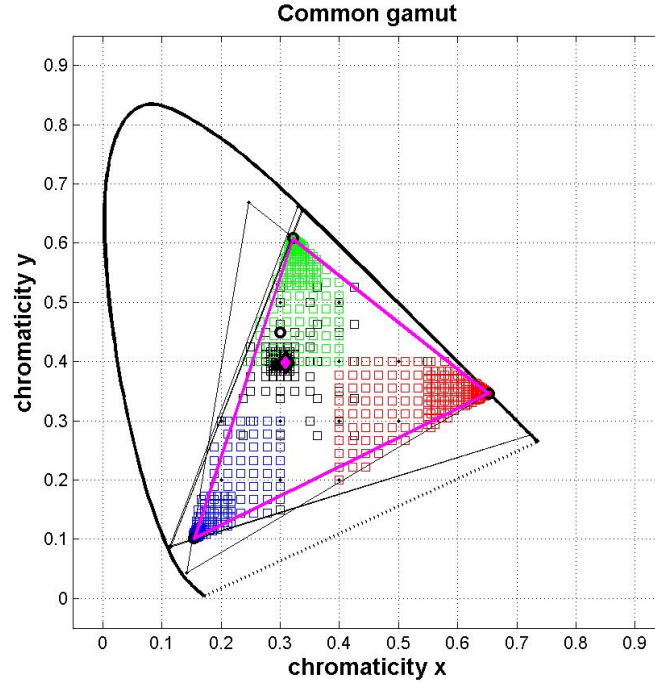
Abbildung 2: Illustration of the common gamut between the green projectors and a white reference. The common gamut boundaries are underlined in magenta in the diagram and the colored squares illustrate the algorithm search of the gamut limits.

5 Results and discussion

First observation the manual approach decreases more the intensity than the automatic approach (see the diagonals entries of the matrices). The reduction of intensity can be observed in the Fig. 4, Fig. 5 and Fig. 6 where except the projector 2 the result of the correction decreases the light intensity (this visible for the green channel). It has also to be noticed that the projectors in this setup haven't exactly the same response curve which can explain why a similar matrix value gives very different results (stronger attenuation of the green channel in projector 2 after re-measuring than projector 3).

Secondly we can observe that the automatic approach - because it has defined a common gamut - reduces the gamut volume by mapping all projectors gamuts to the biggest triangle in the common space (see Fig. 2). At the opposite the manual approach is more tolerant on shaping the common gamut, as we can see in Fig. 3 the primaries of each projector are almost unchanged. This can be explained by the experimental condition: when the user it tweaking the matrices values he is not comparing to white reference at any time, it is his own judgment to decide if the color displayed are white enough or if the greenish tint is not anymore visually disturbing.

6 Conclusion and future works

In this paper we have compared two approaches for color correction in a multi-projectors installation, an automatic and a manual approach. The tested installation presented the
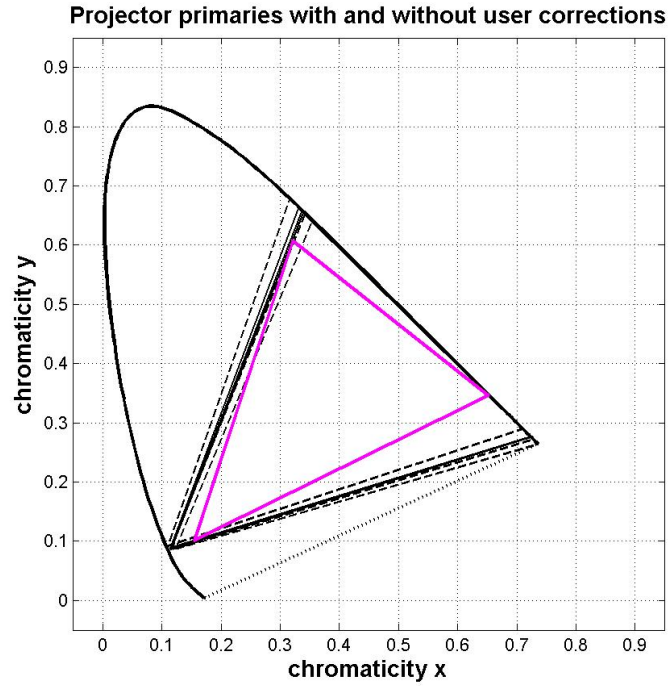
Abbildung 3: Illustration of the manual correction and how are modified the gamut of each projector once the correction applied. The previously computed common gamut is also displayed in magenta.
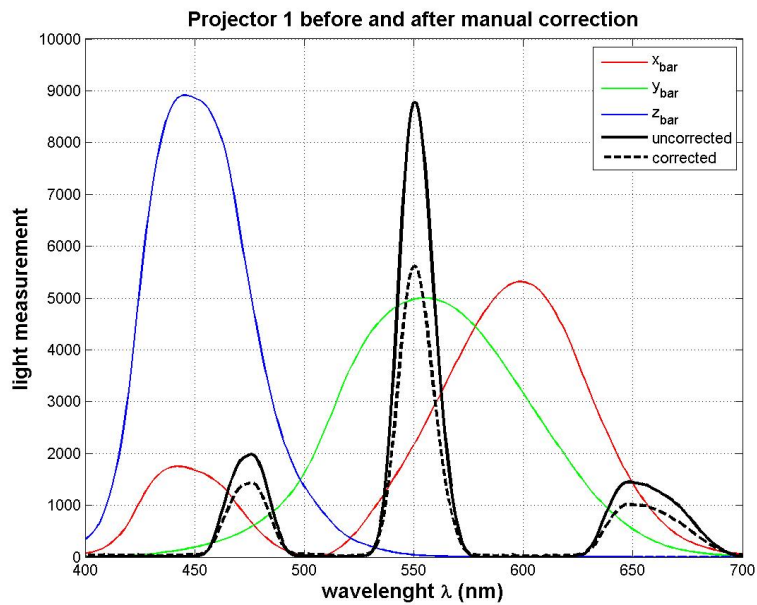

Abbildung 4: Measurement of the white projected by projector 1 before correction (in solid line) and after manual correction applied (in dotted line). A scale version of the CMFs CIE 1931 has been added to the figure to illustrate how to colors are perceived by human observer.
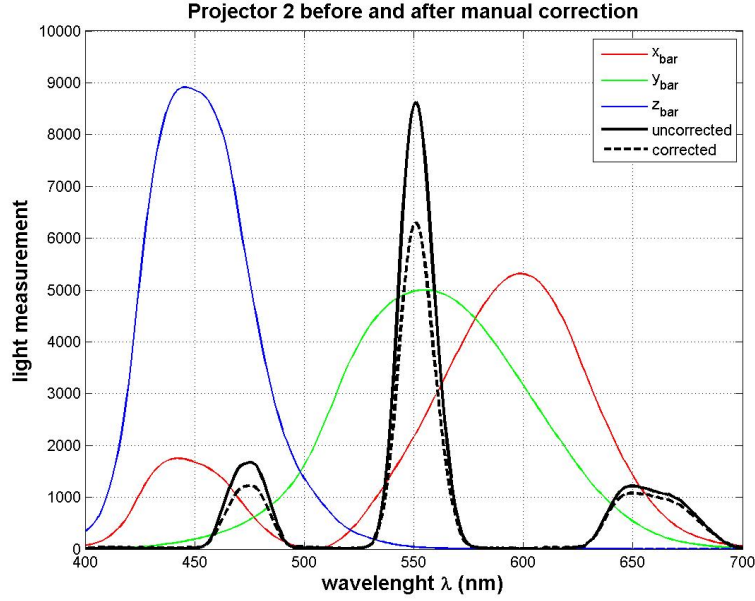
Abbildung 5: Measurement of the white projected by projector 2 before correction (in solid line) and after manual correction applied (in dotted line).
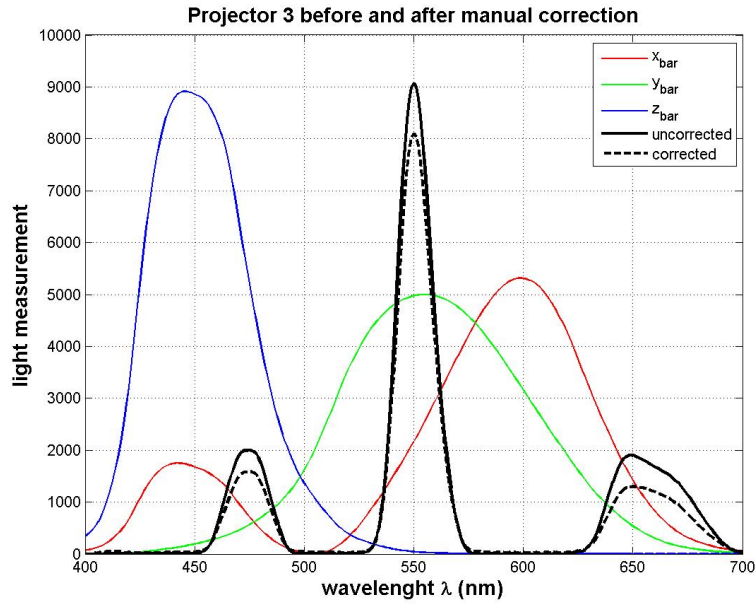

Abbildung 6: Measurement of the white projected by projector 3 before correction (in solid line) and after manual correction applied (in dotted line).

peculiarity to have filter on to cut the light signal, this in order to project stereoscopic content. As a result the projectors in their standard use have a greenish tint. The correction should correct as much as possible the tinted effect.

We observe that there is a compromise time and equipment to use to obtain the correction matrices in the automatic approach and direct matrices tweaking with the manual approach. If the automatic approach is colorimetrically correct it does not take into account

the adaptation of the user in the installation: a dark cinema room where no reference to white is available to the viewer, as result a grayish and even slightly greenish tint is perceived (or accepted) as white.

Further studies should be conducted to evaluate which approach becomes the most suitable when the number of projector increases. The difficulty being to incorporate in the automatic approach the human adaptation to the light condition, this to avoid to shrink completely the color gamut.

Literatur

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