Improvement of Monitor Calibration Using Other than CIE 1931 Color Matching Functions

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***Abstract*—The application of different Color Matching Functions (CMF) on the calibration of various monitors is demonstrated. Two experiments were proceeded to determine which is the best fitting data set. It was done a survey with 22 test persons and the results were summarized. It was shown that the preferred CMF depends on the monitor technology, so from the kind of the spectrum.**

***Index Terms*-- Broadcast displays, Color Matching Functions, Visual Appearance.**

Introduction

Modern broadcast and postproduction studios must rely on a precise calibration of their monitors. This is essential to ensure a high quality of the productions concerning the color management from the recording to the final product, either of a TV show or a movie. It must be secured that the visual appearance is as the director has intended it.

Nowadays monitors of different technologies like LCD with LED, CCFL or quantum dot backlight, OLED, Plasma and still CRT are used in studios. In case of video walls in production rooms mixed configurations of these technologies are usual.

Figure 1. Example of a small video wall in a studio

Therefore two problems arose in modern monitor measurement:

- The correct calibration of some displays usually ends with a slightly colored appearance of the white patterns. If an OLED will be calibrated to the D65 xy chromaticity values with a precise spectro radiometer based on the CIE 1931 2° standard observer CMFs, its white setting will mainly look somewhat greenish.
- Due to the very different spectra of monitors questions of metameric failures come into play. Therefore it is also difficult or even not possible to adjust models of different technologies to exactly the same visual appearance.

A simple solution, often applied to such problems, is to work with xy offsets for the white point setting. These offsets are obtained by visual comparison experiments or by calculation using e.g. the Judd Vos CMF data.

Sony recommends typically to subtract 0.006 from the original x readings and 0.011 from the original y readings to obtain a neutral white appearance of their OLED displays [1]. But this procedure will work for gray scale patterns only, not for the whole gamut.

Flanders Scientific proposes to match two monitors by setting a perceptually match of both in white pattern by adjusting one of them, measure the white point of the adjusted monitor and calibrate it in view of this white point [2]. This approach is better than simply to apply a xy shift for the white setting, but it is based on the perceptual and hence individual matching.

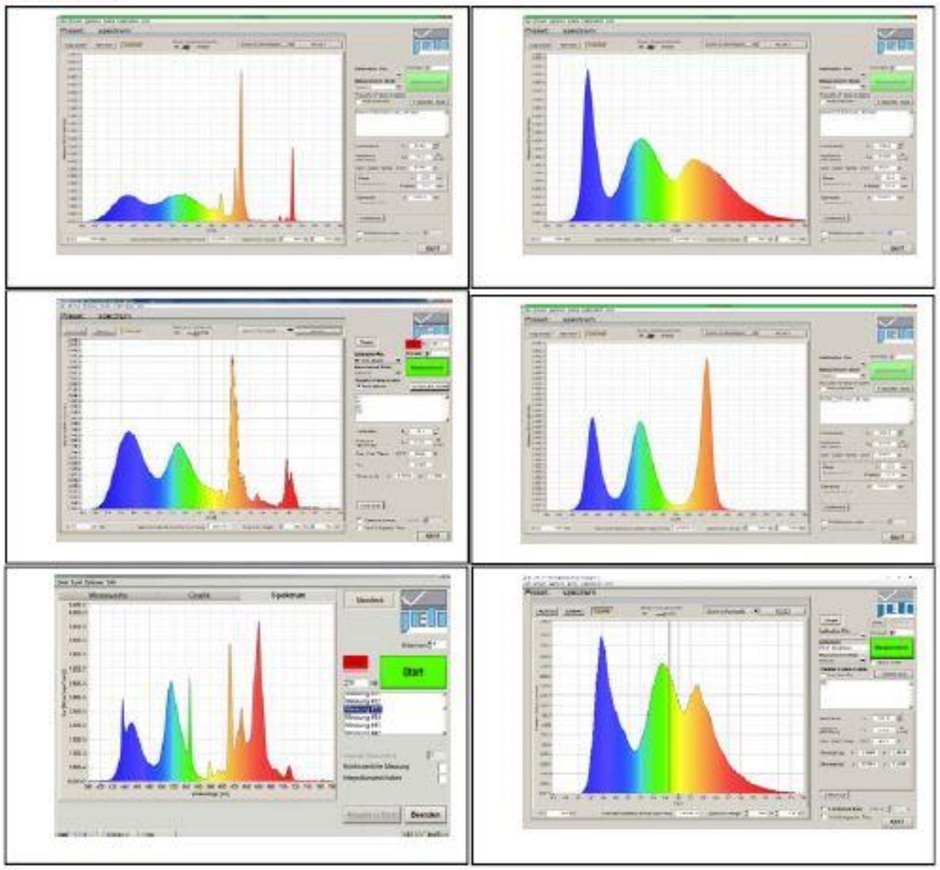

Figure 2. White spectra of different monitor technologies (CRT, LCD with LED wide gamut, Plasma, LCD with LED, LCD with CCFL and OLED)

ALTERNATIVE COLOR MATCHING FUNCTIONS

Doubts about the precision of the CIE 1931 Color Matching Functions (CMF) appeared shortly after their definition. Already in the 1950th alternatives were proposed. Especially with the increased application of power LEDs in general lighting the research in the field of alternate CMFs was reinforced.
Today commonly used alternative CMFs are:

- Stiles/ Burch 1955 [3]
- Jud modified by Voss 1978 [4]
- Data of CIE 170 publication (2006/ 2015) [5]
- Modification of CIE 170 by Schanda/ Csuti University Veszprem [6]
- Modification of CIE 170 by Polster TU Ilmenau [7]

The following diagrams show different CMFs in comparison with the CIE 1931 data:

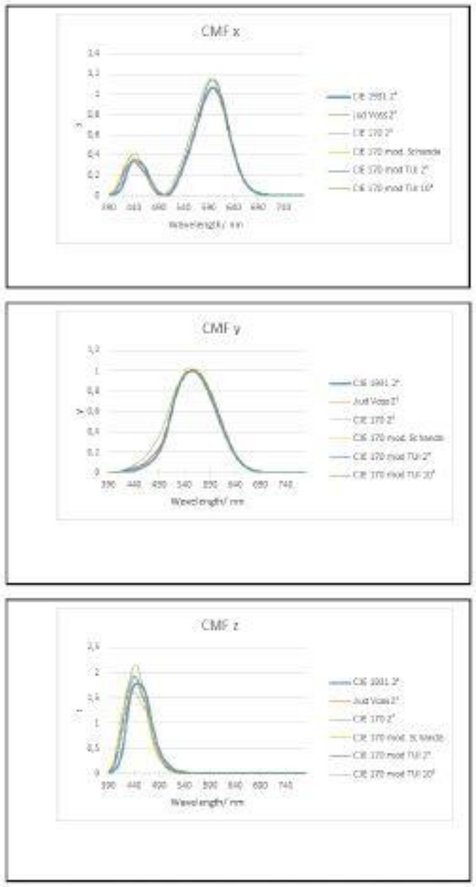

Figure 3. Different Color Matching Functions (CMFs) in comparison

It can be clearly seen, that the main differences arise in the blue wavelength range.
The different CMFs create different xy chromaticity diagrams and hence the whole gamut settings of a monitor will be changed if they are used.

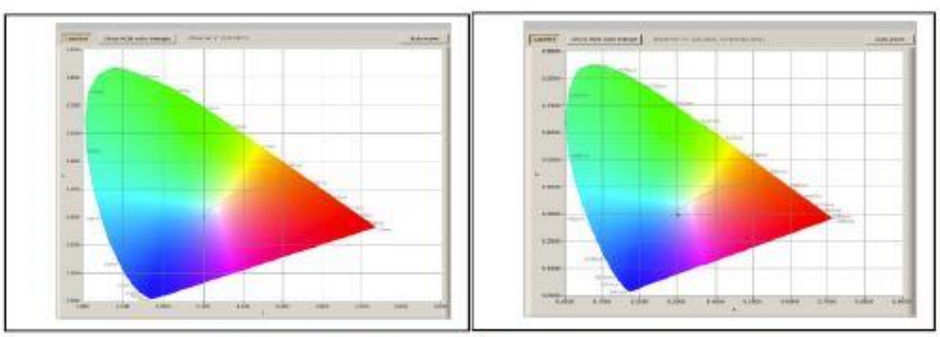

Figure 4. xy diagrams of CIE 1931 (left) and CIE 170, modified by TU Ilmenau (right)

The widely used target white point in monitor calibration is x 0.3128 y 0.3291, the chromaticity of the D65 spectrum in CIE 1931 definition. When other CMFs will be applied, this target point must be changed according to the following table:

TABLE I. XY COORDINATES OF D65 WHITE POINTS FOR DIFFERENT CMFs

CMF	CIE 1931 2°	CIE 1964 10°	Jud Voss 2°	CIE 170 2°	CIE 170 10°	Schanda Csuti 2°	TUI 2°	TUI 10°
X	0.3128	0.3138	0.3160	0.3135	0.3138	0.3161	0.3145	0.3149
Y	0.3291	0.3310	0.3351	0.3308	0.3313	0.3344	0.3325	0.3330
Δ x		0.0010	0.0032	0.0007	0.0010	0.0033	0.0017	0.0021
Δ y		0.0019	0.0060	0.0017	0.0022	0.0053	0.0034	0.0039

EXPERIMENTS

Practical tests were done using a spectraval 1501 spectroradiometer (JETI GmbH) [8]. It has an optical resolution of 4.5 nm (FWHM) and is therefore applicable for all kinds of monitors. The test objects were the following monitors:

TABLE II. MODELS OF MONITORS USED IN THE EXPERIMENTS

Technology	OLED	LCD/ CCFL backl.	LCD/ LED backl.	Plasma
Model	LG55EG9109	DT-V24G1	24PHK5210	LG42PT353
Manufacturer	LG	JVC	Philips	LG

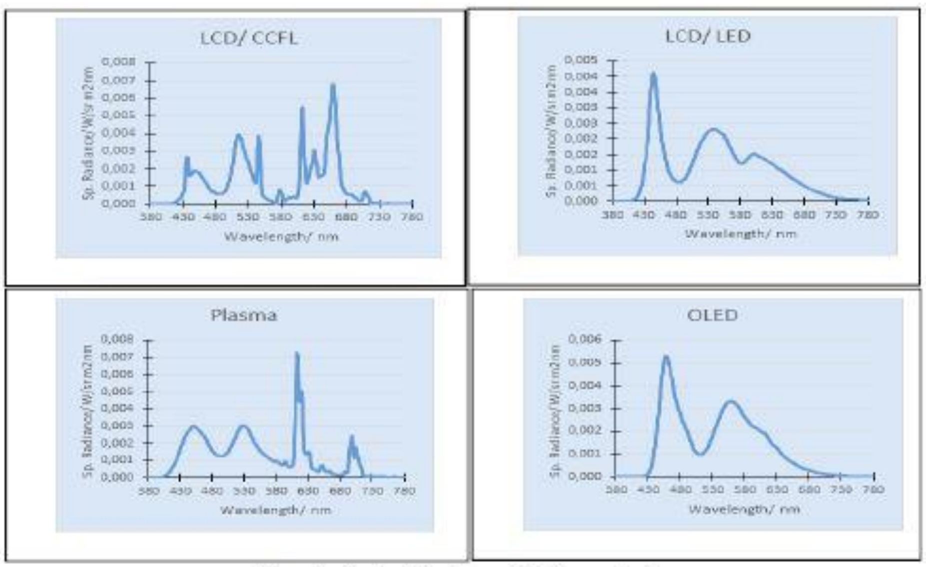

Figure 5. Spectra of monitors used in the experimants

All four monitors were adjusted to around 150 cd/m2 in their white pattern.
The radiometric software JETI LiVal [9] includes the listed CMFs. Additionally it calculates the RGB values depending from the selected gamut and white point. These features were used for the following two experiments (see fig. 6).
The pattern generator was a Murideo Fresco G-6 type. The complete set up is shown in fig. 7.

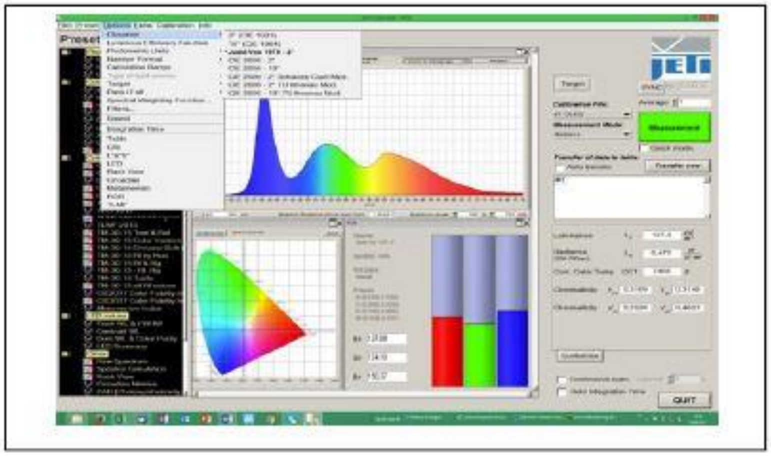

Figure 6. Screen shot of the radiometric software JETI LiVal used for the experiments

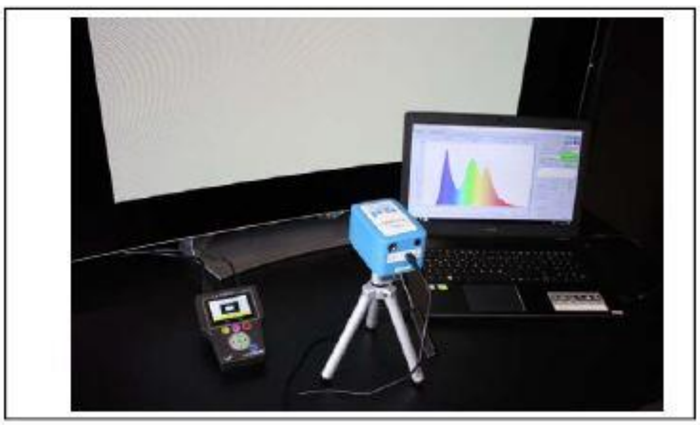

Figure 7. Measurement set up: spectraval 1501 in front of the OLED monitor

First Experiment

In the first experiment all four monitors were calibrated to the target white point of the different CMFs (tab. 1). This was done by adjusting the R, G and B signals of the pattern generator. The used pattern was 90 % white. Afterwards 22 test persons (experienced observers in the age of 25 to 63 years) were asked which white setting gave them the best neutral visual impression for every type of monitor (the monitors were operated separately). The switching between the different white points was done relatively fast to avoid a white adaptation by the observers. The following diagram shows the number of preferred selections of most neutral white for the four monitors. It was possible for the test persons to choose two favored CMFs instead of one in case of a very close visual agreement.

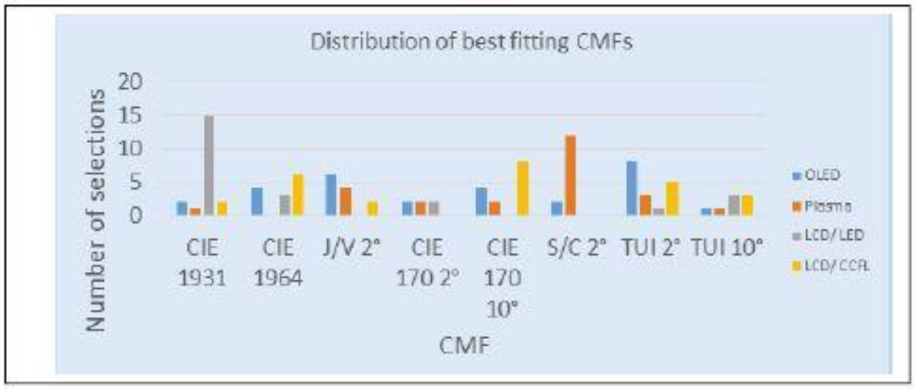

Figure 8. Distribution of the best fitting CMFs for the white setting of the four monitors

The CIE 1931 data were the significantly preferred CMF for the LCD with LED backlight, whereas the CIE 170 10° were the dominant data of the LCD with CCFL backlight. Schanda/ Csuti modified 2° dat were preferred for the plasma type and finally the TUI modified 2° for the OLED monitor. It means that the preferences in this experiment depend from the display technology and hence from the shape of spectrum. It is not possible to recommend one data set for all four monitors.

Second Experiment

A second experiment was done with a scene of two adjacent monitors in the viewing environment of the observer. The left monitor was the LCD/ CCFL type and the right one the LCD/ LED model.

Figure 9. Experiment 2 with tow different LCD monitors (left: CCFL backlight, right: LED backlight)

A white pattern was applied to the LCD/ CCFL display. The xy color coordinates were measured when applying the different CMFs. Afterwards the right display (LCD/ LED) was set to these coordinates and the same group of observers as in the first experiment had to estimate where the best visual agreement appeared. Again it was allowed to choose two CMFs in case of close visual agreement. Both displays were used with large white pattern because this is the normal practice during useage in studios. The surrounding black areas were covered by black cardboard to avoid any influence.

It was expected that either the CIE 1931 data or the CIE 170 10° ones give the best agreement because of the first experiment.

The results of the survey are shown in the following diagram:

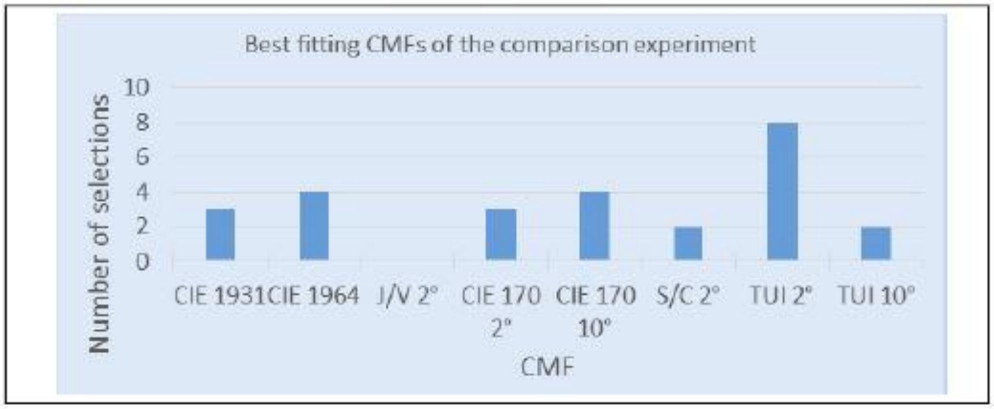

Figure 10. Best fitting CMFs for the comparison experiment

One can see that the favored CMF for the equalization of a CCFL and a LED based LCD screen is the 2° version of the TU Ilmenau modified data. They were identified by 36 % of the test persons as best fitting. All other CMFs were selected in lower quantities and Jud/ Voss 2° was never selected.

SUMMARY

The poster shows the application of different Color Matching Functions on the measurement of four different monitors. Two experiments were conducted and the result was, that four different CMFs were selected as preference, depending from the type of monitor.
Additionally the test persons mentioned different hues for the tiny color differences of the monitor settings. This shows that a common white setting is also not possible due to individual observer sensitivities.
In summary one can say that it is not possible to recommend one set of CMFs in general for the calibration of monitors of different technologies. It is always necessary to check the specific application.

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