Engineering

COLOUR MANAGEMENT FOR BACKLIT APPLICATIONS

Dorin Vasile PIȚIGOI[1]
Roman BYSHKO[2]
Emilia BĂLAN[3]
Miron ZAPCIU[4]

ABSTRACT:
UNTIL NOW COLOR MANAGEMENT FOR BACKLIT APPLICATIONS WAS PERFORMED MOSTLY BY APPLYING THE EDUCATED GUESS OF THOSE INVOLVED IN EDITING OR PRINTING. SUCH APPROACH IS SUBJECTIVE, TEDIOUS AND TAKES TIME WHILE THE RESULT MAY NOT BE THE EXPECTED ONE. THE METHOD PRESENTED IN THIS PAPER PROPOSES AN OBJECTIVE APPROACH TO PERFORM COLOUR MANAGEMENT FOR BACKLIT APPLICATIONS. AFTER OBTAINING THE MEDIA-RELATIVE TRANSMITTANCE MEASUREMENTS OF THE BACKLIT MEDIA AND THE MEASUREMENT OF SPECTRAL POWER DISTRIBUTION OF THE LIGHT EMITTED THROUGH THE MEDIA, AN ICC-PROFILE CAN BE CONSTRUCTED FOR EACH MEDIA AND LIGHTBOX COMBINATION. AN IMAGE IS MODIFIED FOR EACH OF THE LIGHT BOXES SO WHEN PRINTED IT IS EXPECTED TO LOOK PERCEPTUALLY THE SAME BEING LIMITED ONLY BY THE RESULTING COLOUR GAMUT. THE APPROACH IS INTENDED TO BE USED WITH THE GRAPHIC TECHNOLOGY COLOUR MANAGEMENT SYSTEMS, COMPONENTS AND DEVICES INCREASING THEIR EXISTING FUNCTIONALITY.

KEY WORDS: PRINTING THE EXPECTED, COLOUR MANAGEMENT, BACKLIT APPLICATIONS

INTRODUCTION

The SPD (spectral power distribution) of the light source and the observer visual adaptation are integral parts of the colour appearance models as defined by CIE (Commission Internationale de l'Éclairage). Graphic Technology assessment of colours between an original and a reproduction is based on the transmission or reflection properties of the samples to be evaluated. It results in two different types of standardized viewing conditions defined by ISO 3664[5]: T1 for viewing transmissive media and P1 for viewing reflective media using the warm white CIE D50 daylight illuminant as the standard illuminant since 1974. Typical transmissive objects are photographic transparencies while reflective objects are reproductions such as proofs or production prints. Closing the loop on "measure as we see"

[1] PhD students, University POLITEHNICA of Bucharest, Romania, dorinp@transilvae.ro.
[2] M.Sc., FOGRA, Graphic Technology Research Association, Germany, byshko@fogra.org.
[3] PhD, University POLITEHNICA of Bucharest, Romania, emilia.balan59@yahoo.com.
[4] PhD, University POLITEHNICA of Bucharest, Romania, miron.zapciu@upb.ro.
[5] ISO 3664:2009; *Graphic technology and photography -- Viewing conditions*, Geneva: ISO, 2009

principle, ISO 13655[6] defines the measurement conditions for front viewing conditions corresponding to reflectance response (0°:45° or 45°:0° geometry) and transmittance response (0°:d or d:0° geometry).

The current practice of colour appraisal is marked by a significant decline of transmissive media to be used as typical originals (e. g. slides). Nowadays the graphic content is being originated from digital data sources and the assessment protocols of the printed reproductions is based on hard proofing (e.g. proof/print comparison as per ISO 12647-7[7] scope) or soft proofing (e.g. display/print comparison as per ISO 14861[8] scope) situations. The past decade adoption of digital LFP (large format printing) technologies created a variety of printing applications, mostly for the signage sector, but also for interior decorations and other niche applications, where the reproduction of images is done on translucent or transparent substrates. To acquire correctly the light distribution and its interaction with the intended printing combination, both colour measurement and colour management processes requires a revamp.

When producing a colour reproduction using a printing technology, it is important that the parties responsible for data creation, colour separation, proofing and printing operations have previously agreed on a minimum set of parameters that define the visual characteristics and other technical properties of the planned print product[9]. Because of growing interest on this topic, Fogra (Fogra Graphic Technology Research Association) started the project “Colour management for backlit materials” aiming at developing methods for a high-fidelity color reproduction (“Printing the Expected”) on transparent media, focusing on three prioritized work packages[10]. One of the aims was to develop a concept for standardization (ISO 3664 and ISO 13655) by providing tools and guidelines for measuring, profiling and visual matching of transparent media. The project identified two main practical use cases:

- Campaign printing – same image will be reproduced using various printing combinations and displayed mounted on various light boxes;
- Proofing – side by side comparison under standardized viewing conditions P1/T1 between a reflective colour accurate contract proof of a characterized printing condition (e.g. FOGRA51) and backlit reproduction.

BACKLIT APPLICATIONS

Based on the effective light/media interaction, the actual products of backlit printing applications are designed to catch the eye and attention of the viewer (human observer). A printed backlit substrate mounted on a lightbox is easy to spot due to its vivid colours amplified by the lightbox high luminance. Most of these products are used indoor, but also outdoor in day/night backlit off/on setup. Backlit applications are one of the few where the viewing condition for the visual assessment of colour is in its ideal setup. This is because it is exactly the one in which the product is always viewed.

---

[6] ISO 13655:2017; *Graphic technology -- Spectral measurement and colorimetric computation for graphic arts images*, Geneva: ISO, 2017

[7] ISO 12647-7:2016; *Graphic technology -- Process control for the production of halftone colour separations, proof and production prints -- Part 7: Proofing processes working directly from digital data*, Geneva: ISO, 2016

[8] ISO 14861:2015; *Graphic technology -- Requirements for colour soft proofing systems*, Geneva: ISO, 2015

[9] Kraushaar, Andreas; *PSD ProcessStandard Digital, Fogra Graphic Technology Research Association*, Munich, 2012

[10] https://fogra.org/en/fogra-research/wc-digital-printing/digital-printing-current-projects/backlit-2-623/colormanagement-for-backlit-materials.html

The human observer mechanism modelled by CAT (chromatic adaptation transform)[11] is responsible for adjusting to the lightbox illumination overriding the ambient one dimming it less relevant. Even a change in the ambient light or simply turning it off will not significantly affect the adaptation as long as backlit light is still having the higher luminance level of the two. In contrast, the perception of any opaque printed substrate is always dependent on the ambient light.

To facilitate the proof of the concept, two typical printing combinations were selected for producing the printed part of the backlit applications based on the following components:

- HP Latex 560 printing system;
- Light scattering capable polyester film and textile printing substrates (translucent media exhibiting higher diffuse transmission).

Figure 4: LK1..LK9 designated lightboxes used for the project

To complete the framework, nine lightboxes (Figure 4) of different types and with different SPD were selected to provide the back light using various lighting technologies:

- Fluorescent tubes (LK1 and LK5);
- Edge lit (side) LED (LK3, LK7 w/ diffuser, LK8 w/ diffuser and LK9);
- Backlit LED (LK2, LK4 and LK6).

MEASUREMENT OF THE TRANSMITTANCE

For the purposes of colour management, a printing condition is fully characterized by giving the relationship between the CMYK digital input values (as defined in ISO 12642-2[12]) and the corresponding measured colorimetric values – characterization data set. To obtain this relation for the two combinations, the Universal LFP chart composed of 12 A4 pages and 1680 colour patches of 19x13 mm size was printed in device mode[13] (colour management turned off) and then measured.

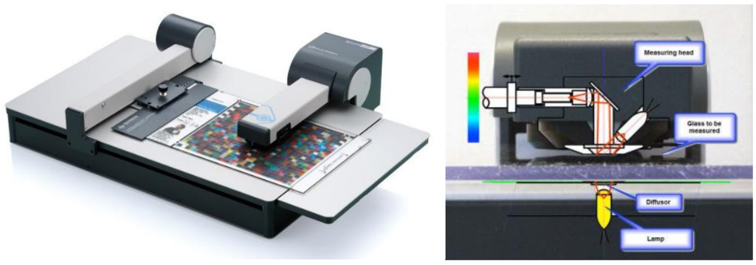

Figure 5: Barbieri Spectro LFP spectrophotometer and its d:0° geometry

[11] CIE TC 8-01; *A Color appearance model for color management systems. Publication 159*, Vienna: CIE Central Bureau, 2004

[12] ISO 12642-2:2006; *Graphic technology -- Input data for characterization of 4-colour process printing -- Part 2: Expanded data set*, Geneva: ISO, 2006

[13] https://www.fogra.org/en/fogra-research/prepress/expert-knowledge/expert-knowledge.html

A normal:diffuse (0°:d) or diffuse:normal (d:0°) geometry measurement device is typically used to replicate the "measure as we see" principle of capturing the diffuse transmittance. Due to the lack of choices, the selection was limited to the Barbieri Spectro LFP[14] spectrophotometer with automatic XY measurement table (Figure 5). Besides being limited to just one device type, its measurement condition is also limited by the CIE A illumination source similar to the ones specified by the M0 measurement condition as defined by ISO 13655 for 0°:d or d:0° measurement geometry. The definitions of M conditions for 0°:d or d:0° geometry were updated in 2017 by ISO 13655, specifying also a CIE D50 illumination source that results in M1 measurement condition, but no such device is commercially available yet. While both ISO 13655 and ISO 3664 defines the requirements that allows a proper visual/measurement reflectance correlation under CIE D50 illuminant by pairing the M1 measurement condition with P1 standard viewing condition, there is no sufficient research on the topic for transmittance and how OBA's (Optical Brightening Agents) are reacting when are simultaneously excited by both transmitted and reflected light thus limiting the visual/measurement correlation consistency caused by the high OBA content of the backlit printing substrates categorized as high fluorescence.

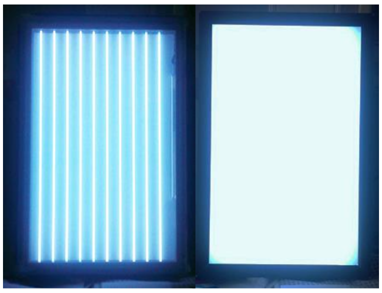

Figure 6: Light perception of a fluorescent tubes lightbox without (left) and with (right) substrate

Another consideration was to determine how the actual measurement process will be set to take place. In case of transmission, the observer colour perception results from directly seeing the light scattered (translucency dependent) through the printed substrate acting as a diffuser (Figure 6).

The complex scene composed from the sum of light and substrate is being interpreted by the HVS (Human Visual System), resulting the perceived (adapted) white point of what we see. Replicating this under "measure as we see" principle means that the transmission measurements should be done in media-relative mode as result of measurement device "zeroing" itself on the substrate. This is conceptually similar when viewing a display and every displayed colour is transformed from the white point of the display. The result of this approach is a characterization data set containing the spectral data just for the coloured part of the printing combination while the substrate measured spectral data has the transmittance set to a value of 1.0 (100%) for any wavelength.

The resulted measurement files were stored as standard CGATS.17 data files as per ISO 28178[15] and CxF/X files as per ISO 17972-3[16] for full compatibility with any colour enabled software environment.

[14] https://www.barbierielectronic.com/en/products/spectrophotometers/spectro-lfp/91-339.html

[15] ISO 28178:2009; *Graphic technology -- Exchange format for colour and process control data using XML or ASCII text*, Geneva: ISO, 2009

[16] ISO/FDIS 17972-3; *Graphic technology -- Colour data exchange format (CxF/X) -- Part 3: Output target data (CxF/X-3)*, Geneva: ISO, 2017

MEASUREMENT OF THE BACKLIGHT

The SPD is typically measured by a spectrometer/spectroradiometer in a wider spectral range (e.g. 340 nm – 850 nm using a GL SPECTIS) and with a spectral resolution of 1 – 3 nm as compared to typical Graphic Technology affordable handheld instruments of 380 – 780 nm and 10 nm resolution.

One of most commonly used devices for colour measurement is the X-Rite i1Pro2[17] spectrophotometer capable of measuring reflective spectrum, but also emissive spectrum and ambient light (diffused). Based on the considerations explained in previous part, the choice of emissive measurement capability of this device and its availability made it the perfect candidate for the task.

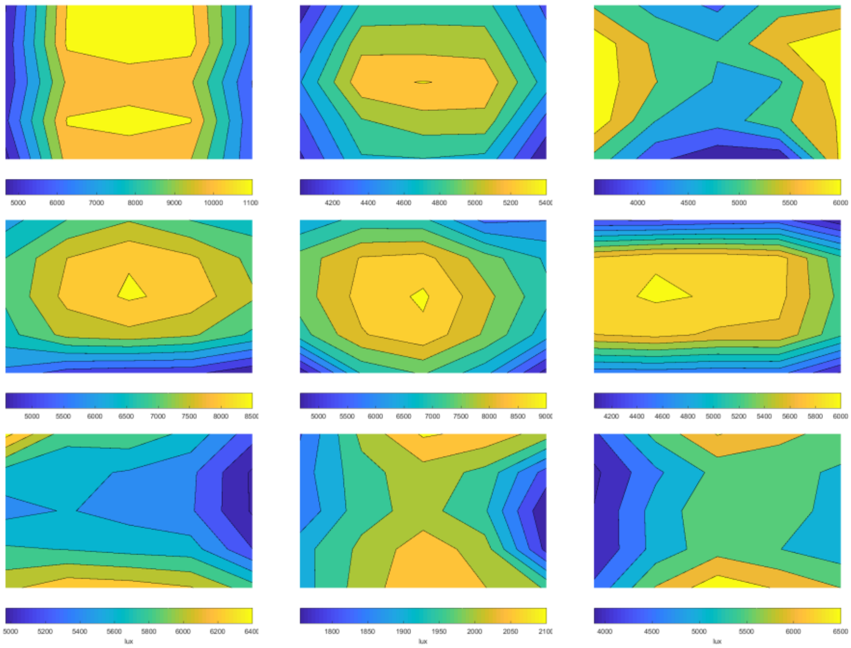

Figure 7: LK1..LK9 luminance variation relative to each lightbox min and max lux determination

The visual assessment of the nine lightboxes with the unprinted substrate mounted inside indicated a variation in luminance level between the center and the sides, varying from a lower to a higher degree of change in perception – luminance inhomogeneity. Even a small variation in substrate planarity in relation with the light source changed the brightness in that area. To prevent further influence over the measurements, the substrate had to be mounted as flat as possible to prevent deformations especially for the stretchable textile substrate and a special ruler sitting on the edges of the lightbox had to be used to align the X-Rite i1Pro2 at substrate level during the contact measurement of light and substrate emissive spectrum.

To confirm numerically the luminance variation, a 5 x 5 matrix with a center point evenly distributed over the illumination area was defined to measure the lightboxes. The result was consistent with the visual assessment. Most of the lightboxes have their most bright and/or stable illumination area in the center except the edge lit type of lightboxes (Figure 7). Since the observer attention will usually concentrate to the center of the viewing area it was decided to use only the center measurement of the SPD and not the average of the 25 measurements. Some of the lightboxes exhibited similar shaped SPD‘s of the light emitted through the substrate even if each came from different manufacturers.

[17] http://www.xrite.com/categories/calibration-profiling/i1publish-pro-2

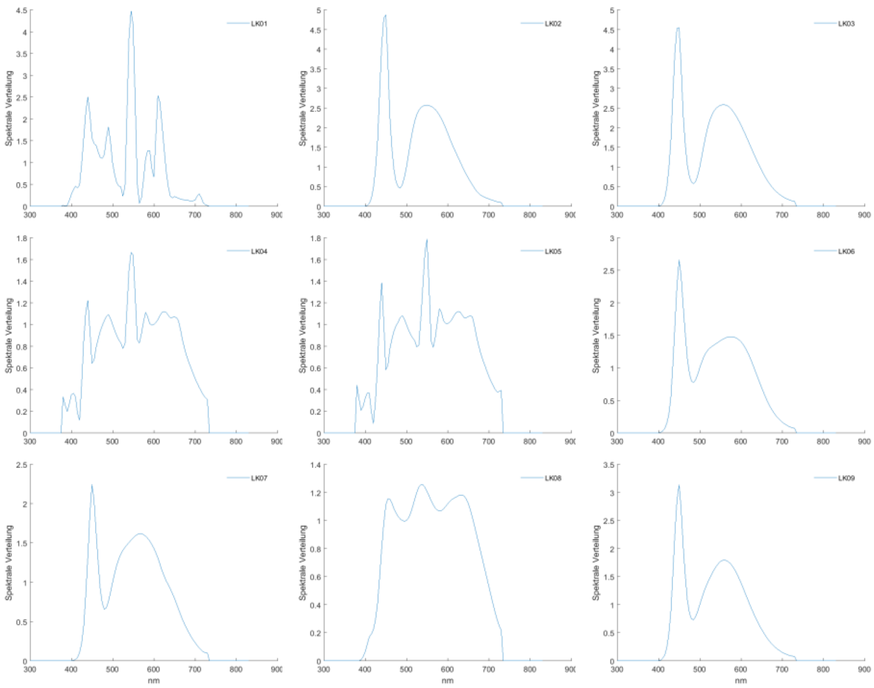

Figure 8: LK1..LK9 individual 380 nm to 740 nm SPD's of the normalized light emitted through the substrate

The resulted normalized measurements (Figure 8) were stored in the same manner as the transmittance measurements.

COLOUR MANAGEMENT

The two sets of spectral data one for each of the media-relative measurements of the used backlit media are now ready to be combined with each of the nine lightboxes SPD's characterization data set resulting in 18 lightbox/substrate dependent data sets. The combination of CMYK driving values with the spectral stimuli hitting the human eye is based on the additive model with the two sets being multiplied together wavelength by wavelength resulting the combined colour spectrum for each of the 1680 colour patches:

$$CS(\lambda) = T_{mr}(\lambda) \times S_{el}(\lambda) \quad (1)$$

where:

λ is the wavelength, in nanometers (nm) in the available 380 nm to 780 nm range (min. from 400 nm to 700 nm range);

$CS(\lambda)$ is the combined spectrum (final stimulus) at wavelength λ;

$T_{mr}(\lambda)$ is the media-relative transmittance at wavelength λ;

$S_{el}(\lambda)$ is the normalized SPD of the emitted light through the substrate at wavelength λ.

Two software solutions were used to generate the ICC colour profiles[18] from the resulted characterization data sets capturing the colour gamut capabilities of each combination and allowing their integration in the typical colour management LFP production workflow. The commercial available X-Rite i1Profiler[19] and open-source Argyll[20] profiling environments were successfully able to interpret the incoming data and generate the

[18] ISO 15076-1:2010; *Image technology colour management -- Architecture, profile format and data structure -- Part 1: Based on ICC.1:2010*, Geneva: ISO, 2010

[19] http://www.xrite.com/categories/calibration-profiling/i1publish-pro-2

[20] https://www.argyllcms.com/

corresponding ICC profiles. The key factor of the method is predicting colour by defining the mapping between the HVS perception and the ICC standard PCS (profile connection space).

The evaluation of the colour managed reproductions resulted from applying the method had two components based on the same "measure as we see" principle:

- A visual side-by-side evaluation of several printed images;
- A numerical comparison between measurements of the printed Color Checker with 24 colour patches resulted from applying the same method for light emitted through the substrate using X-Rite i1Pro2.

Such an assessment reflects the use cases of the practical applications but is only applicable for printing combinations when lightbox-media gamuts are similar in size and shape or when the smallest gamut is used as simulation colour space for all the others.

To maintain the independence of the reproduction from the printing combinations, the colour management approach should reflect a late binding, meaning that the same data will be used for printing and prepress colour management will be responsible for the correct transformations during processing stage from the objects colours (input) to simulation (output intent) and then to output (the actual printing combination). In both cases the digital data should be ideally delivered as PDF/X data file having its output intent a characterized printing condition insuring a complete exchange of data and satisfying colour management requirements. The recommended version as per Fogra PSD (Process Standard Digital)[21] industrially oriented and standardized procedure is PDF/X-4 as defined in ISO 15930-7[22] plus the additional requirements specified by PDFX-ready[23].

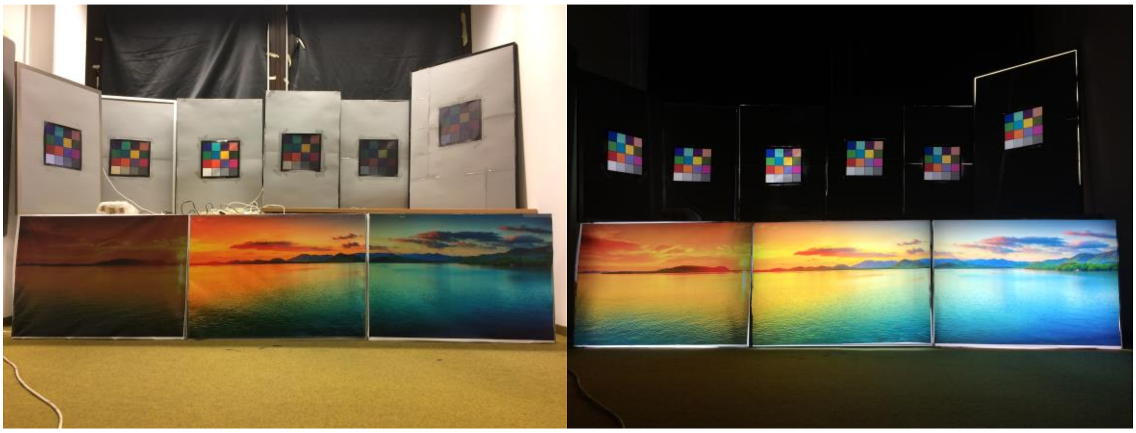

Figure 9: Typical evaluation setup with backlit off/light on (left) and backlit on/light off (right)

The unadjusted reproductions viewed with backlit off would had been look identical (same data printed, but not shown here) while with backlit on would had been look different due to the differences in SPD emitted through the substrate. By applying the method, the backlit off state reflects the differences between the infused SPD data (different data printed due to colour management conversions) while matching with backlit on (Figure 9).

The lightboxes LK3, LK6 and LK9 based combinations produced colour gamuts that are similar in size and shape and were selected for the validation. Six different patches of the X-Rite ColorChecker24 were selected for the validation. They were printed unadjusted,

[21] Kraushaar, Andreas; *PSD ProcessStandard Digital, Fogra Graphic Technology Research Association*, Munich, 2012

[22] ISO 15930-7:2010; *Graphic technology -- Prepress digital data exchange using PDF -- Part 7: Complete exchange of printing data (PDF/X-4) and partial exchange of printing data with external profile reference (PDF/X-4p) using PDF 1.6*, Geneva: ISO, 2010

[23] http://www.pdfx-ready.ch/index.php?show=3

meaning that the corresponding LK light was not considered, and adjusted for each of the lightboxes separately according to the method described above. The patches were then put in front of the respective lightboxes and measured with X-Rite i1Pro2. The u'v' measurements are presented in Figure 10. When compared the measurement produced by the unadjusted and adjusted hues formed clusters, the adjusted clusters are being much smaller in size. A simple MCDM (mean colour distance to mean) metric was applied to quantitively capture the reduction in the size of the clusters, see Table 1.

Table 1: CIEDE2000 (ΔE^*_{00}) MCDM for selected hues of the ColorChecker 24 reproductions

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Unadjusted	7.89	6.01	4.69	5.43	5.43	1.74
Adjusted	1.76	2.27	1.02	1.97	1.48	0.66

The numerical correlation improvement is consistent with the actual viewed perception and while the reduction in ΔE^*_{00} units is significant, its value may be misleading if compared for example with the colour accuracy tolerance of spot colours as specified by ISO 12647-7 (Maximum $\Delta E^*_{00} \leq 2,5$). The units are here comparable only relative to the reproduction and lightbox combination context.

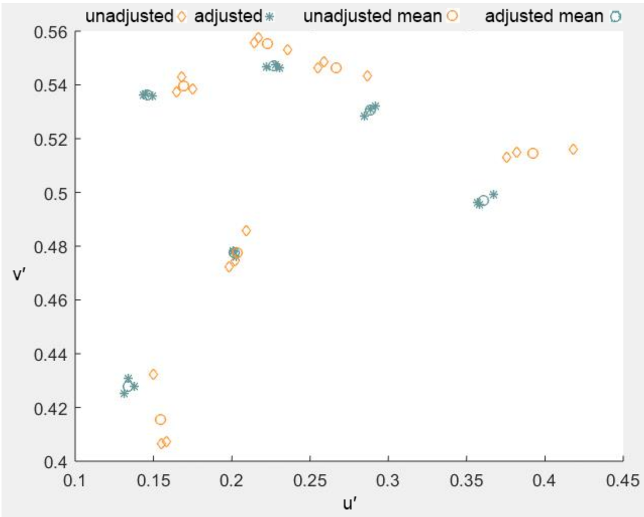

Figure 10: CIE (u′, v′) chromaticity diagram of the data clusters

CONCLUSION

The presented method improves the ability to apply colour management related activities to backlit applications. Even if is not an absolute colorimetrical match, the perceptual side-by-side match is moving the backlit applications to a new level of high-fidelity color reproduction (“Printing the Expected”) giving the printers the necessary tool to fulfill the expectations of their customers.

In current available colour management workflows the method will be easy to be integrated by adding just one additional step in the profile generation. An alternative way of the method and more in-line with its scope, would be the ability to program the light source of the measurement device with the SPD of emitted light through the substrate and use the traditional absolute-media measurement mode. The concept is similar with Konica Minolta

FD-7[24] spectrophotometer programmable device light source for any chosen illuminant, including self-measured illuminants.

Further study of the concept is required considering the impact of OBA's for both reflection and transmission and how to match opaque and translucent reproductions in mixed ambient and backlit light resulting into an absolute colorimetrical match.

ACKNOWLEDGMENTS:

Presented work has been supported by funding from Federal Economics and Technology Ministry (grant 18720N) distributed by the Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke" e.V. [AiF]/German Federation of Industrial Cooperative Research Associations. The authors thank Barbieri Electronic for providing the measurement devices and the required support.

[24] https://www.konicaminolta.eu/en/measuring-instruments/products/graphic-arts/fd-7/introduction.html

REFERENCES

1. **Kraushaar, Andreas;** *PSD ProcessStandard Digital, Fogra Graphic Technology Research Association*, Munich, 2012;
2. **Kraushaar, Andreas; Pitigoi, Dorin;** *Fogra Specification – System and Process Check for Large Format Printing application V2.0, Fogra Graphic Technology Association*, Munich, 2015.
3. **CIE TC 8-01;** *A Color appearance model for color management systems. Publication 159*, Vienna: CIE Central Bureau, 2004;
4. **ISO 12642-2:2006;** *Graphic technology -- Input data for characterization of 4-colour process printing -- Part 2: Expanded data set*, Geneva: ISO, 2006;
5. **ISO 12647-7:2016;** *Graphic technology -- Process control for the production of halftone colour separations, proof and production prints -- Part 7: Proofing processes working directly from digital data*, Geneva: ISO, 2016;
6. **ISO 13655:2017;** *Graphic technology -- Spectral measurement and colorimetric computation for graphic arts images*, Geneva: ISO, 2017;
7. **ISO 14861:2015;** *Graphic technology -- Requirements for colour soft proofing systems*, Geneva: ISO, 2015;
8. **ISO 15076-1:2010;** *Image technology colour management -- Architecture, profile format and data structure -- Part 1: Based on ICC.1:2010*, Geneva: ISO, 2010;
9. **ISO 15930-7:2010;** *Graphic technology -- Prepress digital data exchange using PDF -- Part 7: Complete exchange of printing data (PDF/X-4) and partial exchange of printing data with external profile reference (PDF/X-4p) using PDF 1.6*, Geneva: ISO, 2010;
10. **ISO 28178:2009;** *Graphic technology -- Exchange format for colour and process control data using XML or ASCII text*, Geneva: ISO, 2009;
11. **ISO 3664:2009;** *Graphic technology and photography -- Viewing conditions*, Geneva: ISO, 2009;
12. **ISO/FDIS 17972-3;** *Graphic technology -- Colour data exchange format (CxF/X) -- Part 3: Output target data (CxF/X-3)*, Geneva: ISO, 2017;
13. https://www.argyllcms.com/
14. https://www.barbierielectronic.com/en/products/spectrophotometers/spectro-lfp/91-339.html
15. https://fogra.org/en/fogra-research/wc-digital-printing/digital-printing-current-projects/backlit-2-623/colormanagement-for-backlit-materials.html
16. https://www.fogra.org/en/fogra-research/prepress/expert-knowledge/expert-knowledge.html
17. https://www.konicaminolta.eu/en/measuring-instruments/products/graphic-arts/fd-7/introduction.html
18. http://www.pdfx-ready.ch/index.php?show=3
19. http://www.xrite.com/categories/calibration-profiling/i1publish-pro-2