Improving Softproofing Performance with Observer-specific Colour Matching Functions

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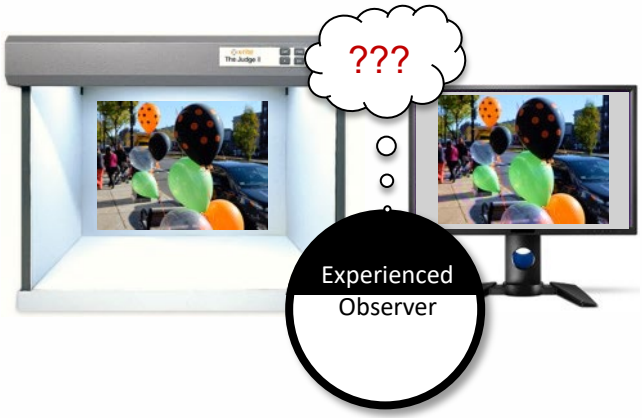
Research Background

- **When BenQ 1st LED backlight colour management monitor was announced in 2013.**
  - **Very exciting news!**
  - **Experienced users found out LED backlight monitor did not performed well in softproofing scenario.**



Symptoms

- **Variations in blue, green and pale yellow tones, for example.**
- **Difference in perceived saturation.**

Overall saturation is different

Viewing Booth
(Simulated)

LED Backlight Monitor
(Simulated)

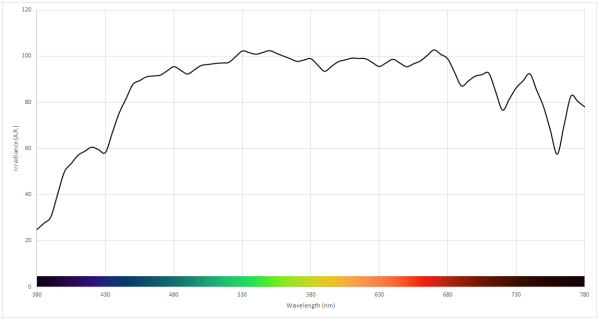
Slight hue shift in blue

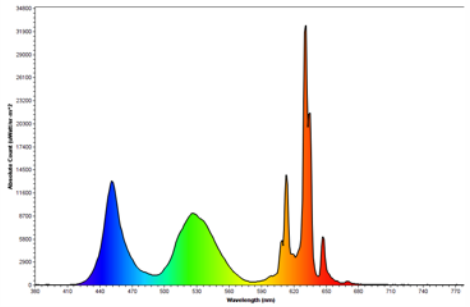
Slight hue shift in green

Slight hue shift in pale yellow

Why?


xrite
The Judge II


120
100
80
60
40
20
0
380
430
480
530
580
630
680
730
780
Wavelength (nm)



Experiment Overview

- **To conduct “visual matching” between a display and a hardcopy print.**
- **Adjusting the parameters on the display using designed software.**

Experiment Overview

- **Two experiments were conducted:**
  1. CMF (Colour Matching Function) Construction Experiment:
     - to use visual matching method to determine individual CMFs,
     - calculate average CMFs, and
     - utilize K-means method to obtain 3 groups of CMFs.
  2. Validation Experiment:
     - to validate the best matching set of CMFs.
- **45 observers participated the experiment:**
  - 24 male and 21 female
  - Age ranges from 25 to 45 years old.
- **Each observers were asked to conduct 3 trials.**
  - There were 45x7x3 = 945 judgements conducted in the experiment.

Experiment Procedure

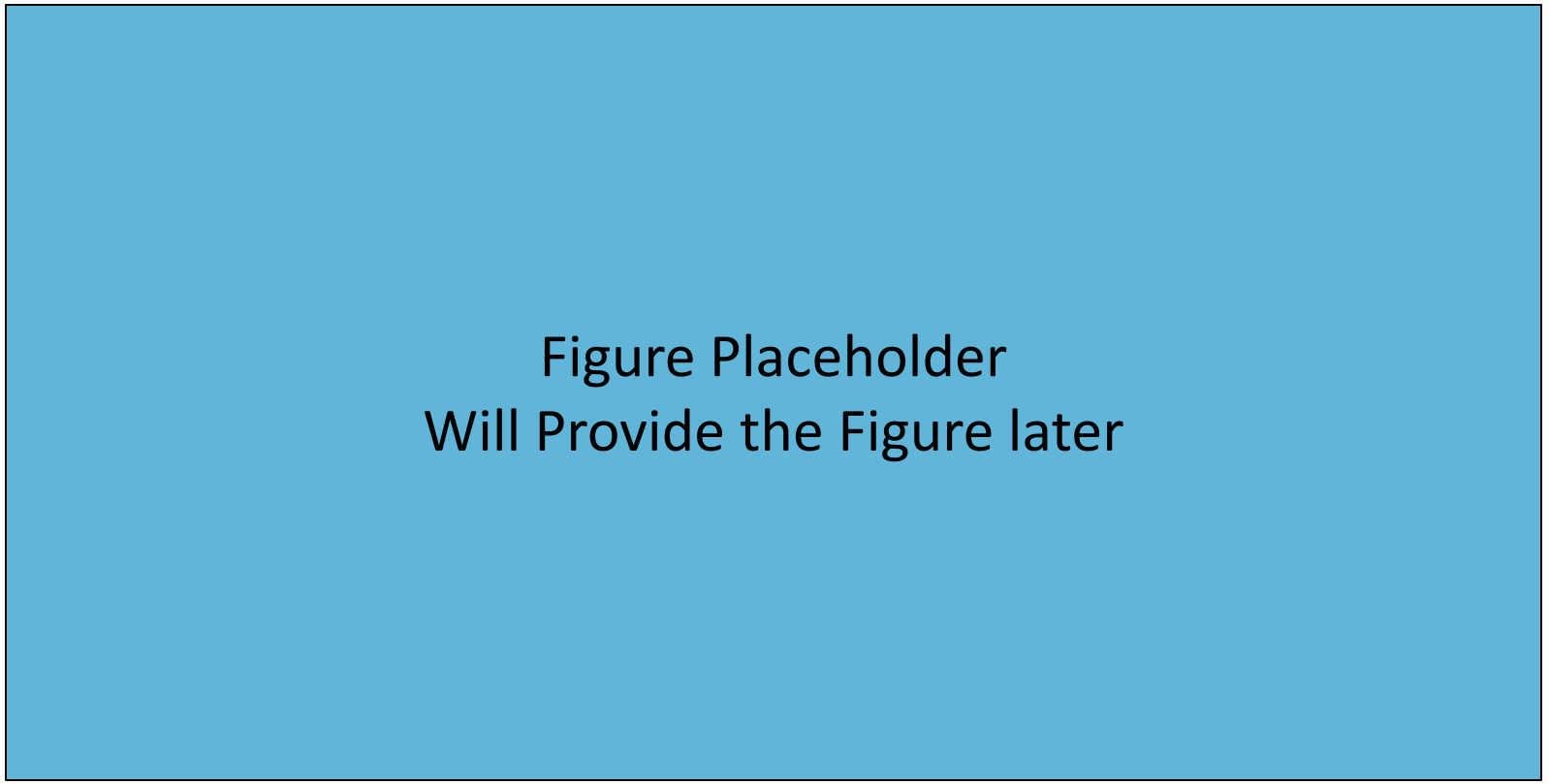
- **CMF Construction Experiment:**
  1. Calibrate the monitor to D50, and generate Display Profile.
  2. Use experiment software to adjust hue, saturation and lightness of the displayed image.
  3. Record the HSL values of each image.
  4. Repeat the adjustment for 3 times for each observer.
- **Validation Experiment:**
  1. Devise individual, average, and 3 K-means CMFs.
  2. Ask observer to evaluate 6 sets of CMFs (including 2°) for the best match.
  3. Calculate the ΔE values between the print and display.

CMF Construction Experiment

- **Experiment Procedure:**
  1. Calibrate the monitor to D50, and generate Display Profile.
  2. Use experiment software to adjust hue, saturation and lightness of the displayed image and colour patches.
  3. Record the HSL values of each image.
  4. Repeat the adjustment for 3 times for each observer.
  5. Measure the XYZ values of the colour patches for each observer.
  6. Construct individual CMFs using matrix transformation from 2° Standard Observer CMFs.
  7. Utilize 45 sets of individual CMFs to determine average CMF and 3 categories of CMFs using K-means method.

Experiment Results

- **45 observers' CMFs**



CMF Sets

Displaying with Different CMFs - Red

2 Degree

Individual

Average

K-means 1

K-means 2

K-means 3

Displaying with Different CMFs - Green

2 Degree

Individual

Average

K-means 1

K-means 2

K-means 3

Displaying with Different CMFs - Blue

2 Degree

Individual

Average

K-means 1

K-means 2

K-means 3

Displaying with Different CMFs - Cyan

2 Degree

Individual

Average

K-means 1

K-means 2

K-means 3

Displaying with Different CMFs - Magenta

2 Degree

Individual

Average

K-means 1

K-means 2

K-means 3

Displaying with Different CMFs – Yellow

2 Degree

Individual

Average

K-means 1

K-means 2

K-means 3

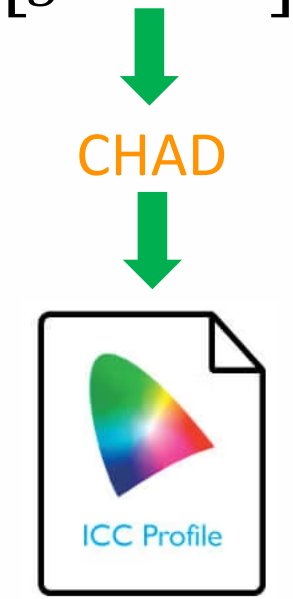
Validation Experiment

- **Need to determine which set of CMFs delivers better softproofing matching performance.**

Validation Experiment

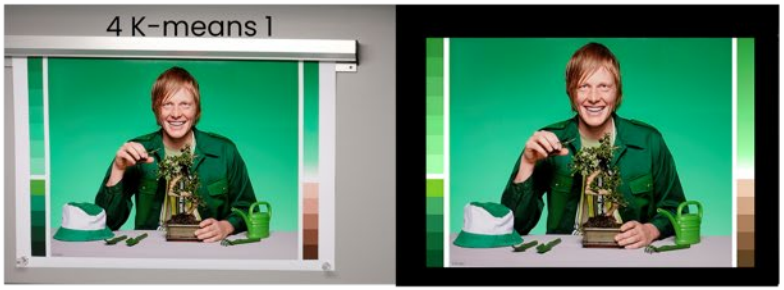
- **Experiment Procedure:**
  1. Calculate the corresponding matrices related to 2° Standard Observer CMFs from:
     - Individual CMFs
     - Average CMFs
     - 3 Categories of K-means CMFs
  2. Generate corresponding ICC profiles using CHAD tag.
  3. Ask observer to evaluate 6 sets of CMFs (including 2°) for the best match.
  4. Calculate the ΔE values between the print and display.

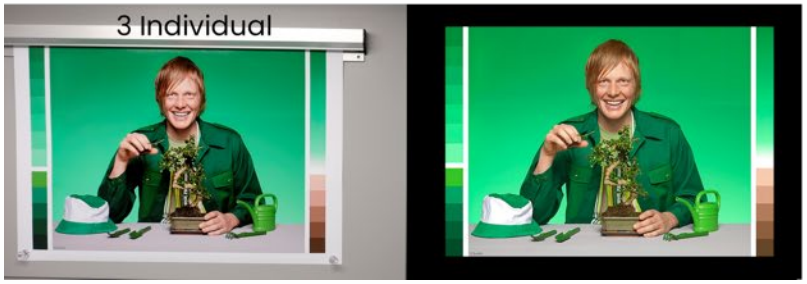
$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}$$



Softproofing with Different CMFs - Red

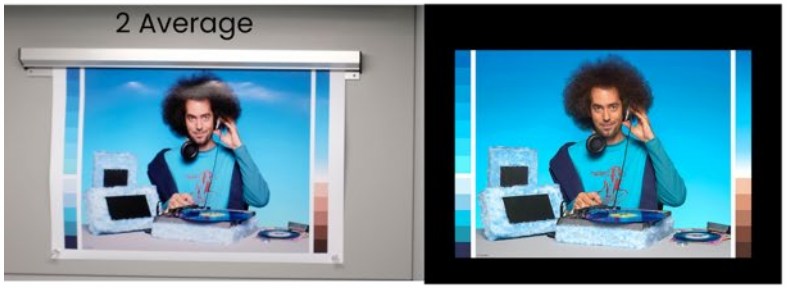
Softproofing with Different CMFs - Green

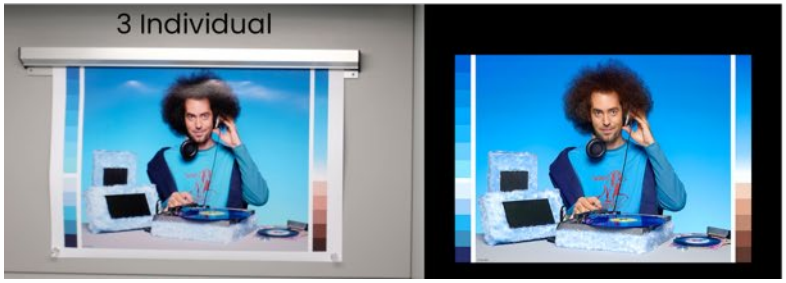




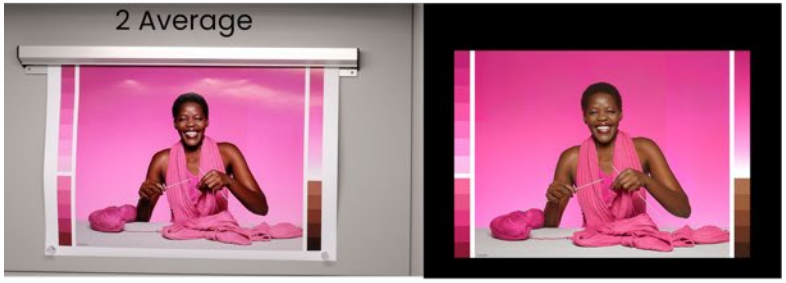
Softproofing with Different CMFs - Blue

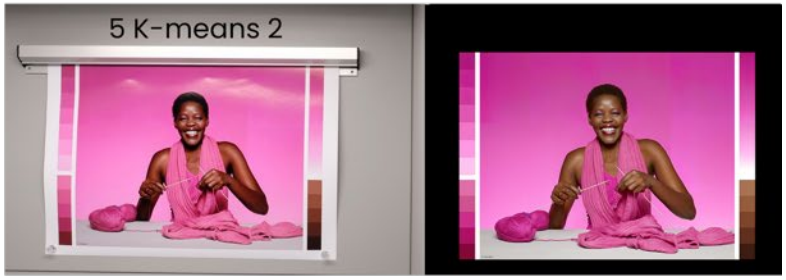
Softproofing with Different CMFs - Cyan

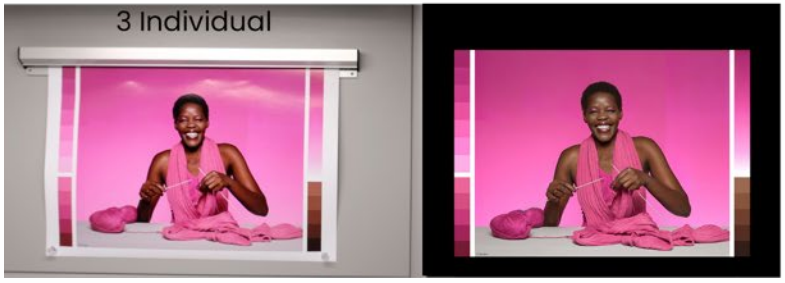


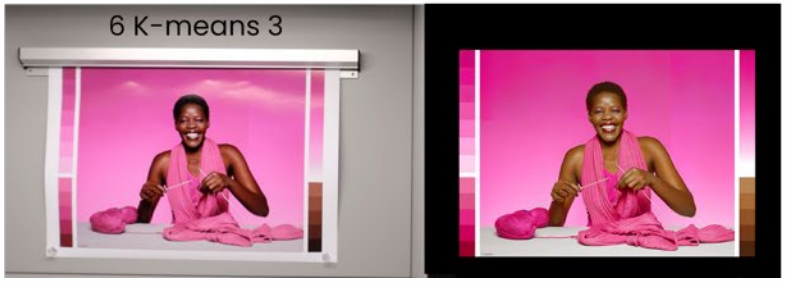


Softproofing with Different CMFs - Magenta

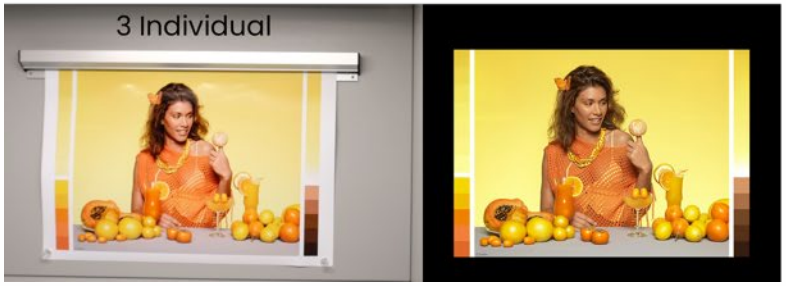




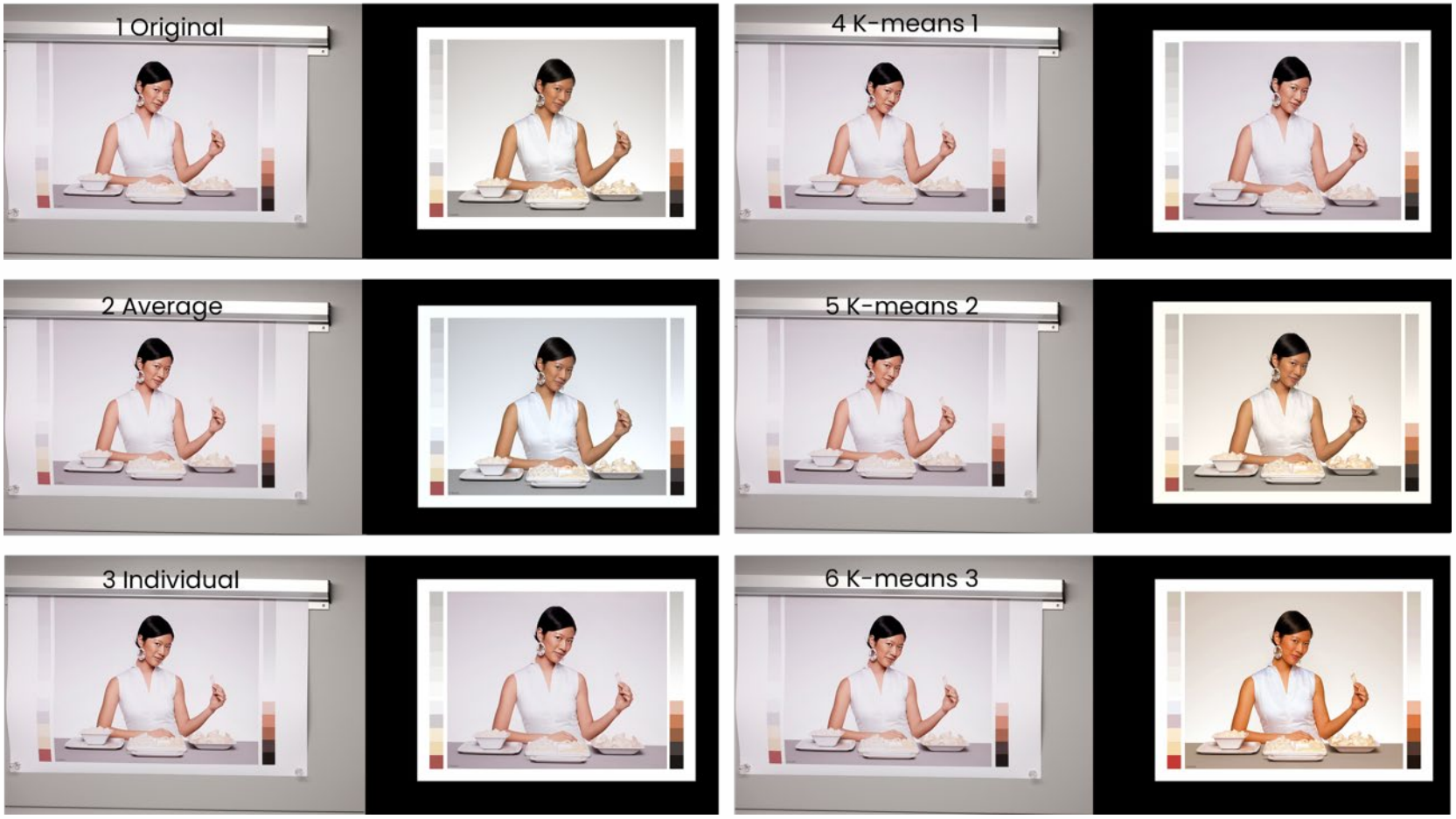




Softproofing with Different CMFs - Yellow



Softproofing with Different CMFs - White



Preliminary Validation Result

Observer	W	R	G	B	C	M	Y
A	3	3	3	3	3	4	1
B	4	3	4	3	3	1	1
C	4	3	4	3	3	4	1
D	3	3	4	3	4	1	1
E	3	3	4	5	4	4	1

1. Original Image	2. Average CMFs	3. Individual CMFs	4. K-means Cluster 1	5. K-means Cluster 2	6. K-means Cluster 3

Average	0.99735	0.01117	-0.0047
	-0.00895	1.02252	-0.00596
	0.00429	0.00324	0.98685

Individual	1.0064	0.0059	0.00937
	-0.03893	1.0297	0.01305
	-0.0068	0.00901	0.98823

K-means 1	0.92439	0.05876	-0.02164
	-0.03143	1.02909	-0.00851
	0.05247	-0.002	0.89287

K-means 2	0.97016	-0.01438	0.01763
	-0.00959	0.9896	0.00812
	-0.01495	0.0088	0.99652

K-means 3	0.94288	-0.00617	0.00851
	0.0068	0.96276	-0.0116
	-0.13801	0.11356	0.95021

Numeric Validation

- **Utilize ISO 14861 test patches to conduct numeric softproof validation.**

- **Use CCFL monitor as a reference baseline:**

Numeric Validation

- **ISO 14861 Softproofing Validation Results and Criteria:**

	CCFL	LED	LED with CMFs	Criteria
Mean ΔE_{00}	2.72	3.79	3.16	≤ 4.0
Maximum ΔE_{00}	5.81	6.81	6.46	≤ 6.5

- **Comparing Hardcopy Print to Displayed Colour Patches:**
  - CCFL display has the best match.
  - LED with individual CMFs can improve softproofing performance.

Conclusions

1. Modern wide colour gamut display can cause colour matching failure.
2. The degree of colour matching failure is observer specific.
3. Experiment results had shown using CMFs other than 2° Standard Observer CMFs can improve softproofing performance.
4. ∆E values also support the improvement.
5. Observer specific CMFs can be implemented in current ICC profile architecture.