Universitat Oberta de Catalunya

Optimization of grey reproduction in CMYK printing processes

ALESSANDRO BELTRAMI

January 2022

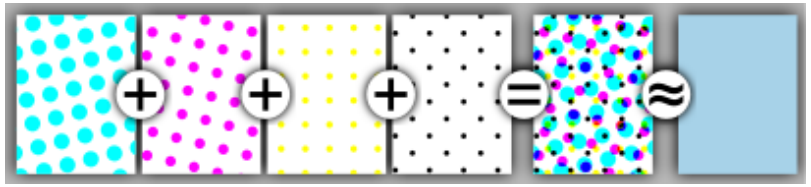
Index

What is CMYK printing?

Subtractive CMY(+K) model is a combination of Cyan, Magenta, Yellow, and Black, separated from a tristimulus value, halftoned and printed with inks over a white paper substrate in a specific sequence.

Digital file | Separation | Halftoning | Printing

From RGB to CMYK using CIELAB as colorimetric connection space



Indigo®

What is grey?

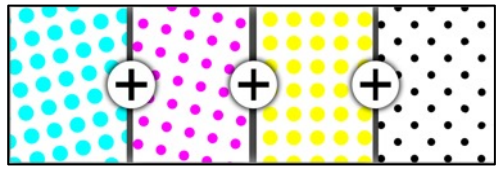
Is a colour intermediate between black and white, as ashes or lead.

Depends on white and black references

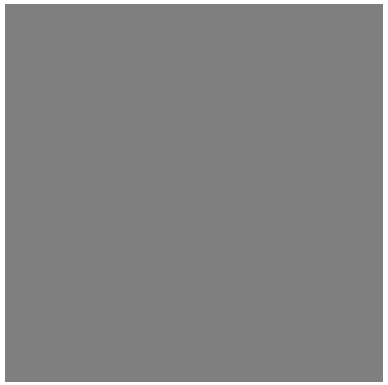
Depends on the illuminant

Affected by chromatic adaptation

Is printed with a combination of C,M,Y,K



Can have chromatic hue:

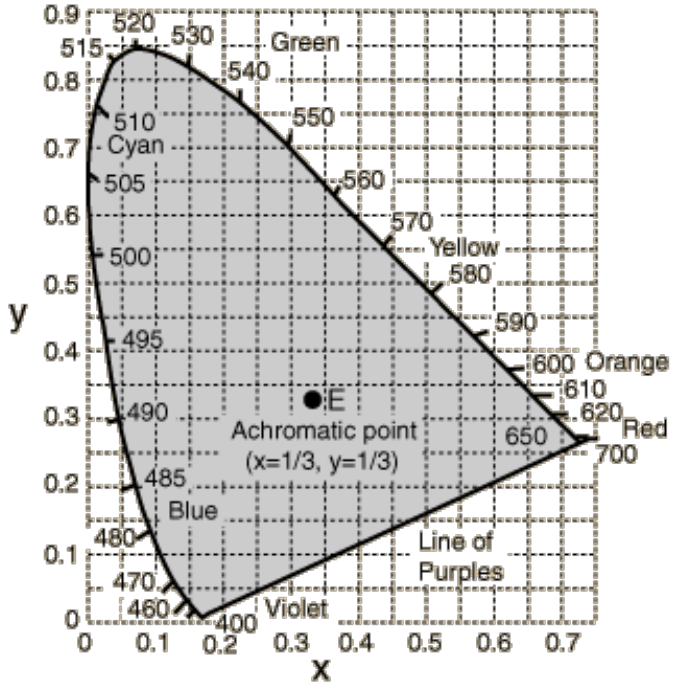
Neutral grey	Some red hue, but still a grey	More red hue, is it a grey?
		

Physics and colorimetry of grey colours

Defining grey in printing is complex, because his colorimetry depends on many factors and need to take in consideration the chromatic adaptation of human visual system.

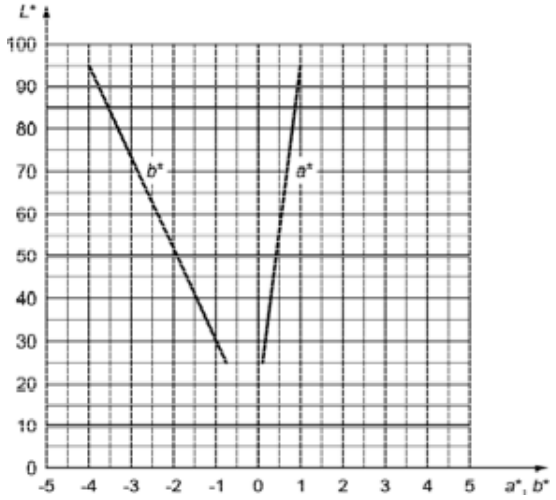
Stimulus grey (additive mix)

Illuminant → CIE xy → x=y=1/3



Printing (subtractive mix)

Illuminant + Substrate white point + Darkest achievable point → CIELAB → Chromatic Adaptation factor → a* and b* grey axis depending on L*



Origin and history of grey printing

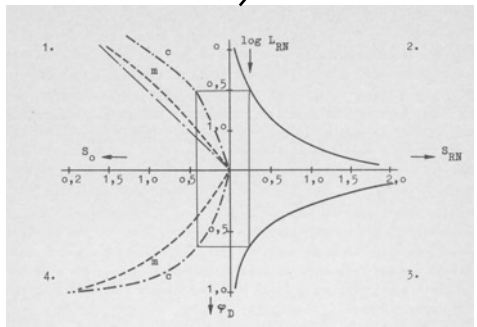
After 500 years, grey colours reproduction is still a challenge in many printing processes

III Century - China
Invention of printing

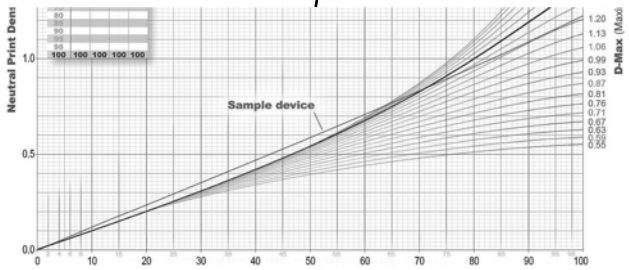
XVI Century – Germany/Italy
Invention of *chiaroscuro* woodprint:
first attempts
to reproduce grey shades
in series.

1939 – USA
Zone System
by A.Adams and F.Archer
the first method to control
grey definition and
reproduction in photography.

1955 – Germany
Grey color matching study from
Schirmer – Fogra.
One of the first examples
of densitometric and
mathematical approach
to grey calibration and
control.



2006 – USA
IdeAlliance G7 method.
Inspired by Zone System,
provide strong grey definition,
grey balance and grey
reproduction methods.



2013 – ISO 12647-2 standardized
grey definition
in offset printing,
as a tentative to start the reconcile
of
different methods.

Objectives

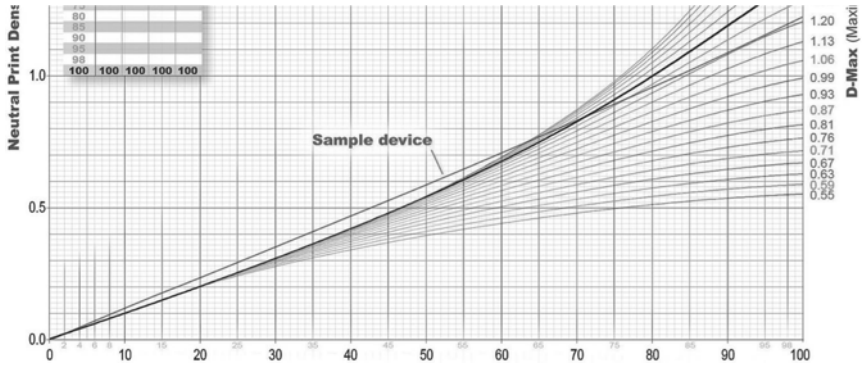
- **Describe** and **analyse** all the steps that allow a neutral grey calibration in a CMYK printing process.
- **Identify a process** that could be as automated as possible, to be performed by not-skilled users.
- Apply the new Grey Index formula to **communicate the results**

Calibration methods

Two different methods are used today, born in USA (G7®) and Germany (TVI)

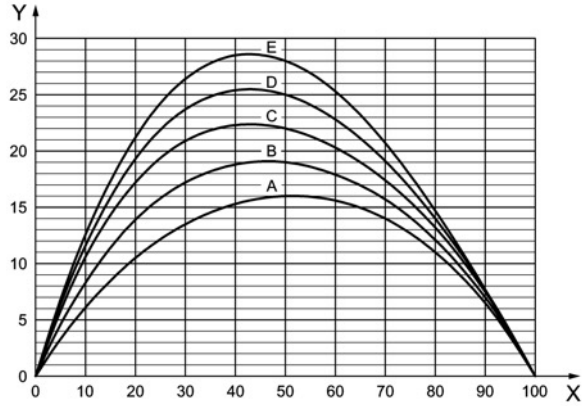
G7®

- Fixed grey balance for every paper
- Calibration made using colorimetry on a grey target
- Independent to printing process



TVI (Tone Value Increase)

- Variable grey balance, depends on ink-paper interaction
- Calibration made using densitometry on primary colours
- Screened CMYK printing processes



Methodology

3-step calibration method as a synthesis of TVI and G7® approaches

Definition
- Select paper and reference characterization
- Grey axis calculation
- Test charts definition

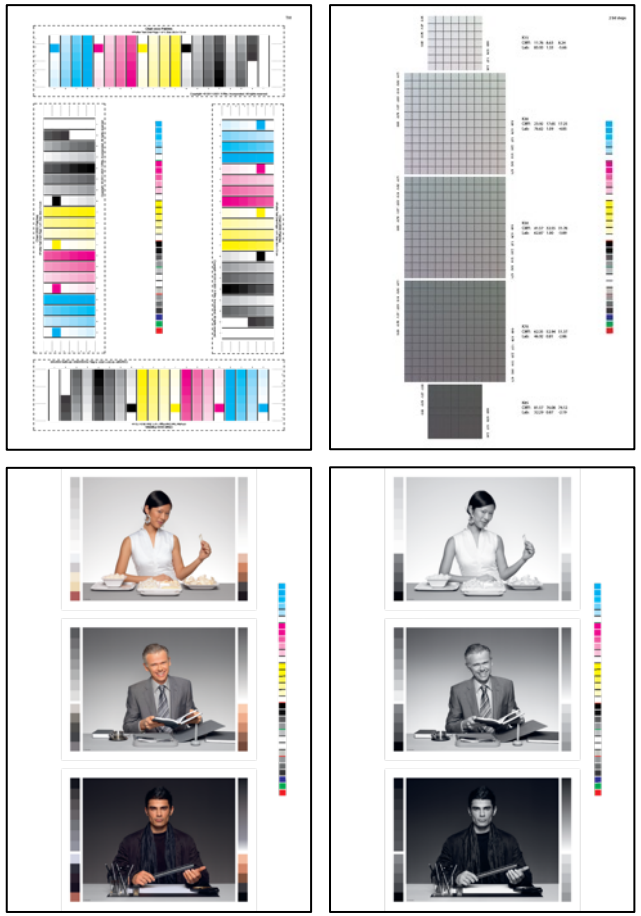
1 Linear
- Print using linear LUT
- Measure and calibrate TVI

2 TVI cal.
- Print using TVI calibrated LUT
- Measure and fine tune greys

3 Grey cal.
- Print using grey optmized LUT
- Measure and report data

GI
- Calculate the Grey Index before and after grey fine tuning
- Visual assessment of the results
- Comparison and conclusion

Test form to measure and evaluate the process



Tools

Calibrate an industrial screened CMYK system using the proposed method and analyze the results

Printer

HP Indigo® 12000 HD
CMYK digital screened printer
75x53 cm printing area
3’450 sheets/h
175-290 LPI resolution

TVI and color control

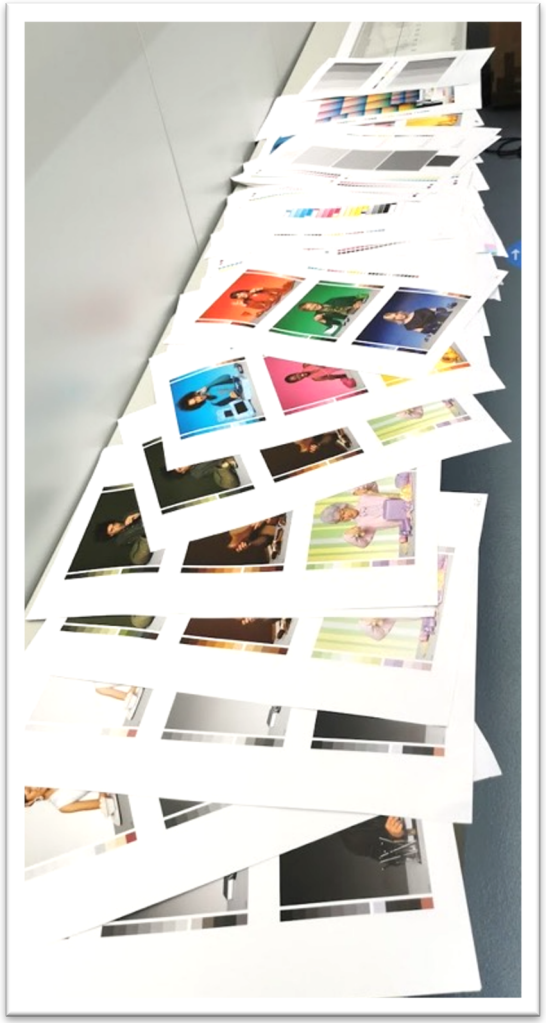
X-Rite eXact
handheld
spectrodensitometer
45:0° geometry
ISO 13655 M0, M1, M2, M3

Grey calibration

Konica Minolta FD-9
automated
spectrophotometer
45:0° geometry
ISO 13655 M0, M1, M2

Print matters production, measurement and evaluation

Printing made in Italy at corGae srl company, measurements and visual evaluations made in HP at Sant Cugat.

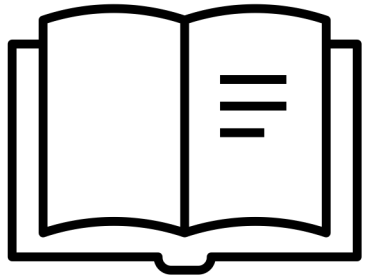


Deliverables

Proposed method implemented and intermediate steps

Analysis of the results

Visual evaluation of results



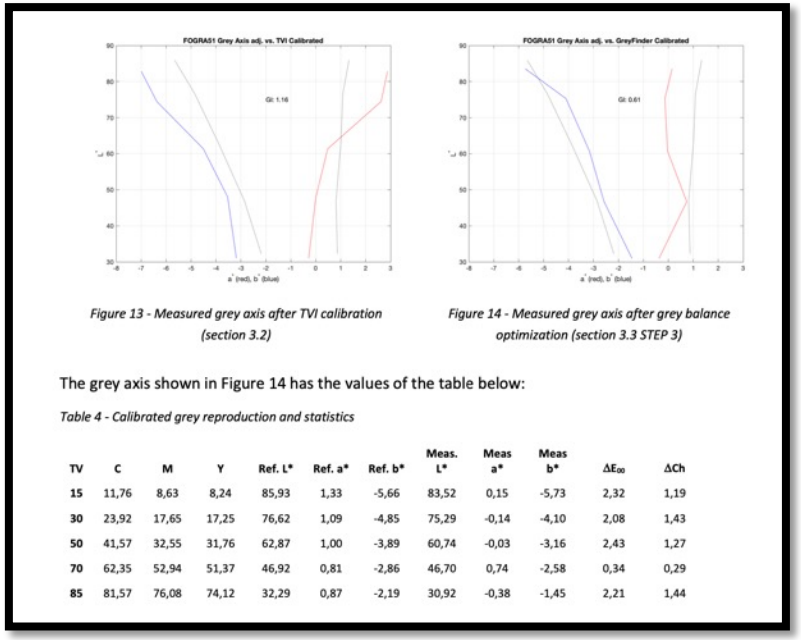


Figure 13 - Measured grey axis after TVI calibration (section 3.2)

Figure 14 - Measured grey axis after grey balance optimization (section 3.3 STEP 3)

The grey axis shown in Figure 14 has the values of the table below:

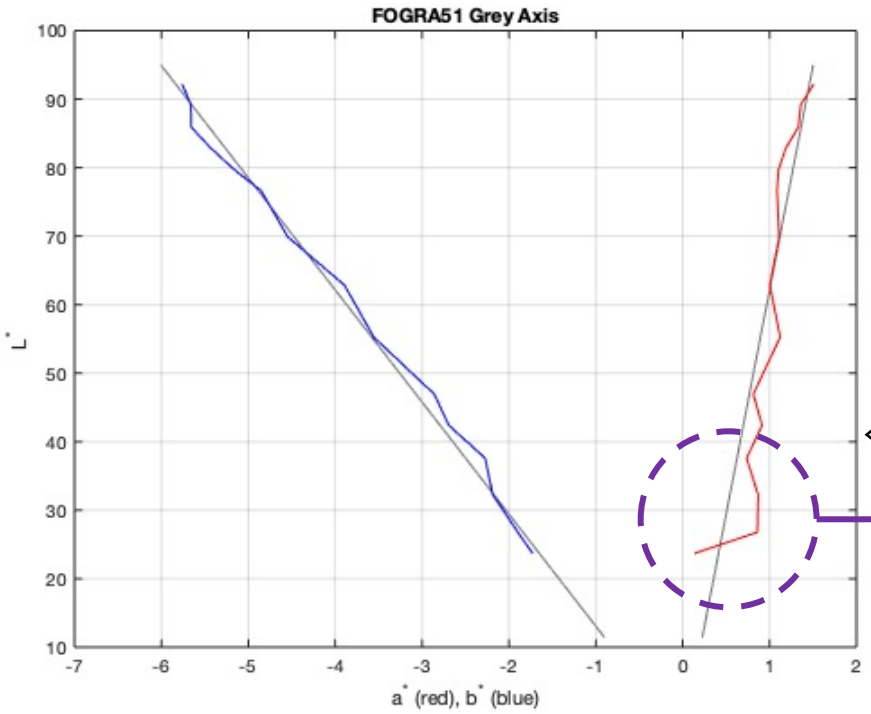
Table 4 - Calibrated grey reproduction and statistics

TV	C	M	Y	Ref. L*	Ref. a*	Ref. b*	Meas. L*	Meas a*	Meas b*	ΔE_{00}	ΔCh
15	11,76	8,63	8,24	85,93	1,33	-5,66	83,52	0,15	-5,73	2,32	1,19
30	23,92	17,65	17,25	76,62	1,09	-4,85	75,29	-0,14	-4,10	2,08	1,43
50	41,57	32,55	31,76	62,87	1,00	-3,89	60,74	-0,03	-3,16	2,43	1,27
70	62,35	52,94	51,37	46,92	0,81	-2,86	46,70	0,74	-2,58	0,34	0,29
85	81,57	76,08	74,12	32,29	0,87	-2,19	30,92	-0,38	-1,45	2,21	1,44

Grey Definition

Validation of FOGRA51 and calculation of target grey axis

Substrate	Lecta GardaGloss Coated Paper 150gr/m^2
White point (measured)	L*=94,80 a*=1,17 b*=-5,85
White point (from FOGRA51)	L*=95,00 a*=1,50 b*=-6,00
White point difference	0,48 ΔE_{00} ✓
Darkest achievable colour (from FOGRA51)	L*=11,43



RESEARCH TESTING CERTIFICATION Fogra EVENTS ABOUT US STORIES DOWNLOADS

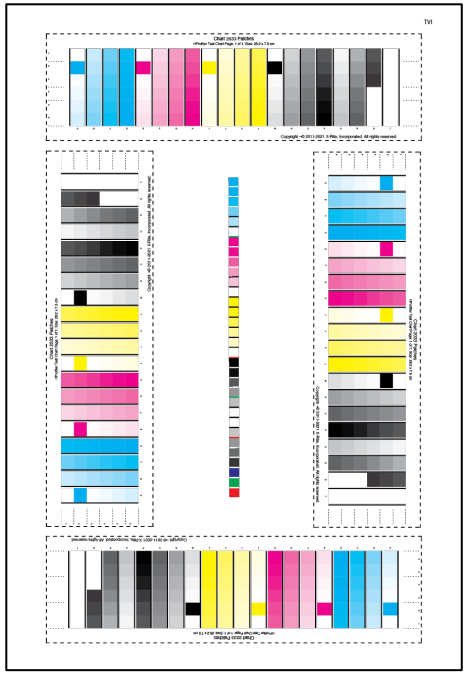
Title	Description/abstract	Version	Date	File type	File size	Download
FOGRA51-FOGRA52	Archive contains the characterisation data (Fogra Standards) FOGRA51, FOGRA51 spectral and FOGRA52.	V1.0	23.09.2020	zip	180 KB	DOWNLOAD

MATLAB

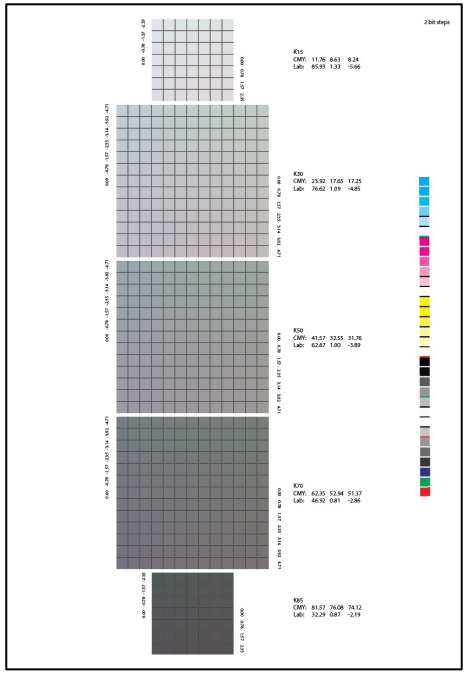
8-bit quantization deviations

Test form

Allows the print output to be measured by spectrophotometers

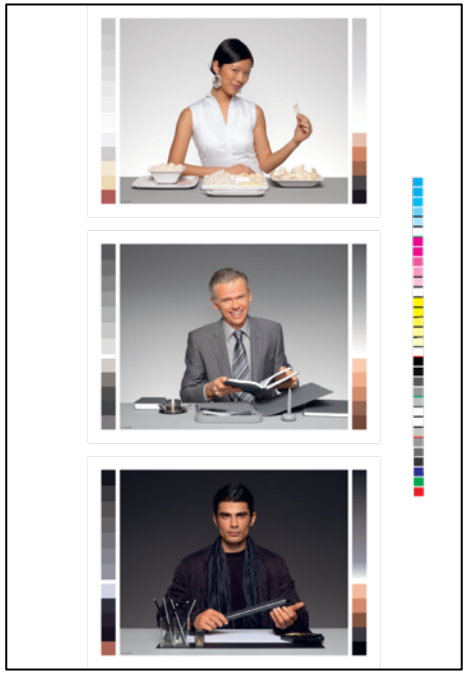


TVI calibration as per ISO 12647-2 *(out of scope)*

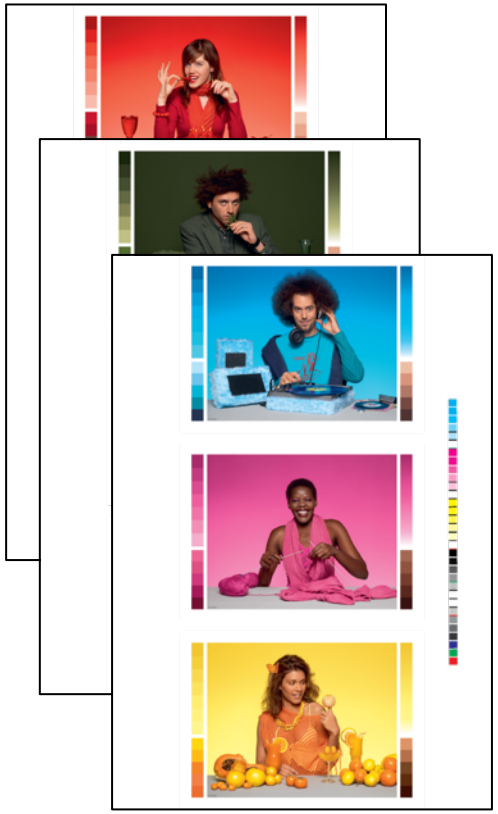


Grey fine tuning

MATLAB®

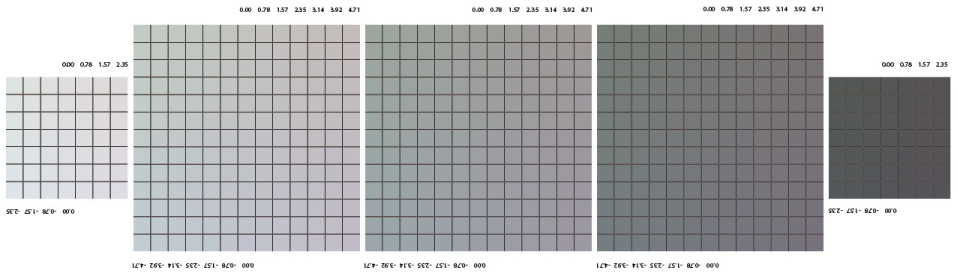


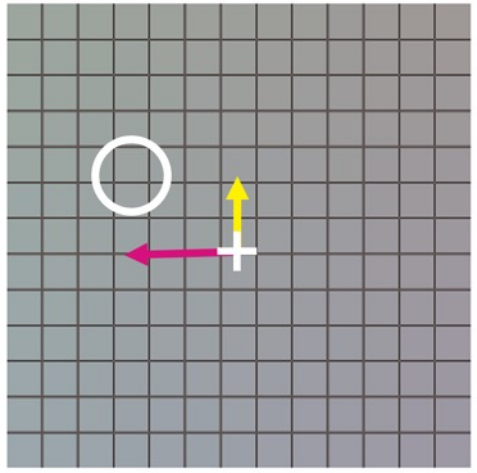
Visual evaluation (Roman16® images)

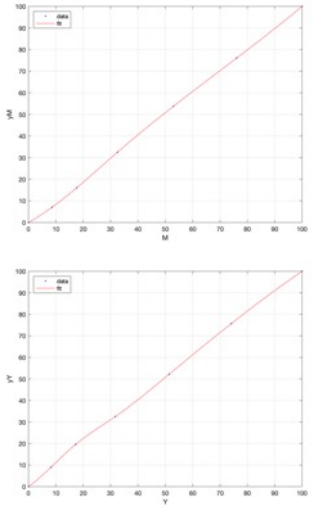


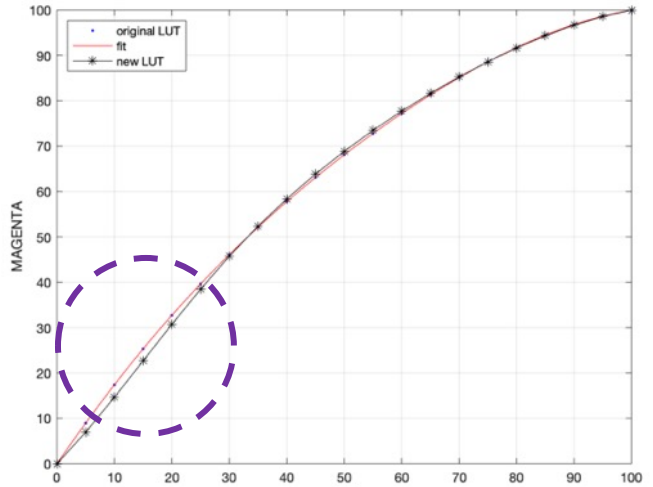
Grey fine tuning

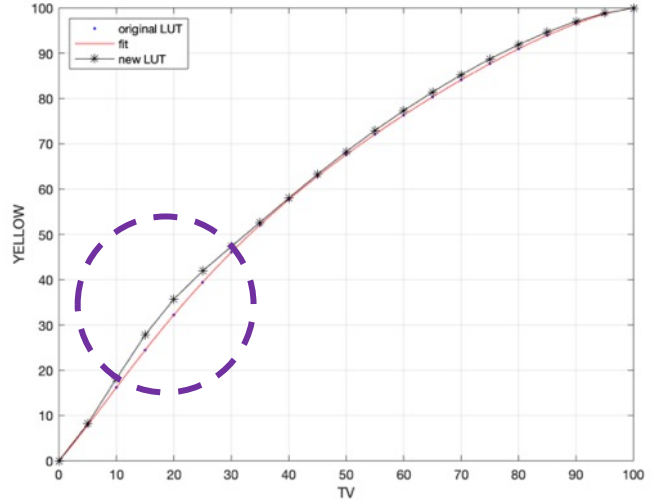
The corrections found in the grey chart are used to re-shape the printer Magenta and Yellow LUTs











Evaluation of grey reproduction: Grey Index

A single-number new metric to evaluate the grey reproduction of calibrated printing process

$$GI = \overline{abs(\Delta C^*_{ab})} \cdot \left[\frac{\sigma(\Delta h_{ab})}{2\pi} + 1\right]$$

Formula presented at 27th Color and Imaging Conference in 2019 and standardized, yet.

Standard approach:
CIE ΔH* formula → evaluation of chromatichness of a single point

New approach:
GI formula → evaluation of the neutrality of entire grey axis, considering the so called “rainbow” effect as a pejorative term

GI≃0
perfect result

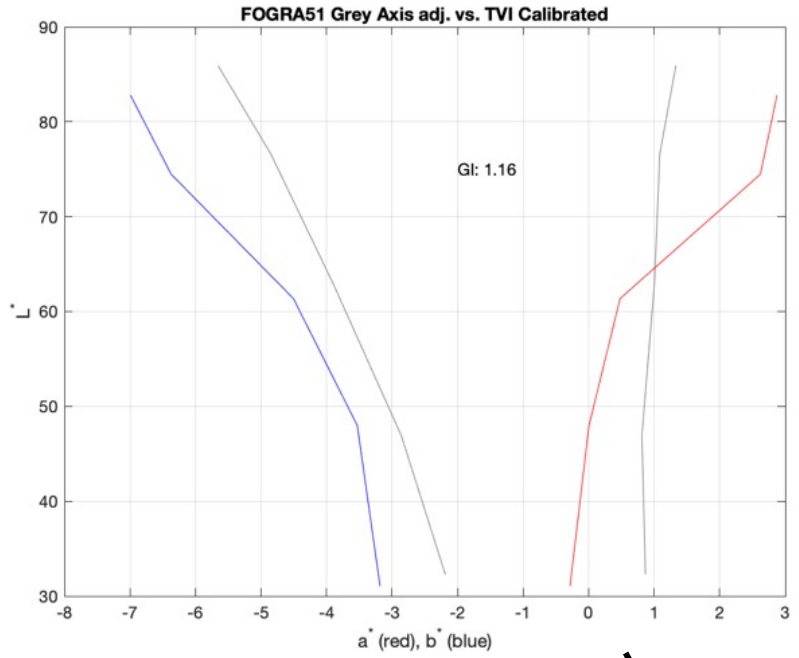
GI ≃1
some deviation

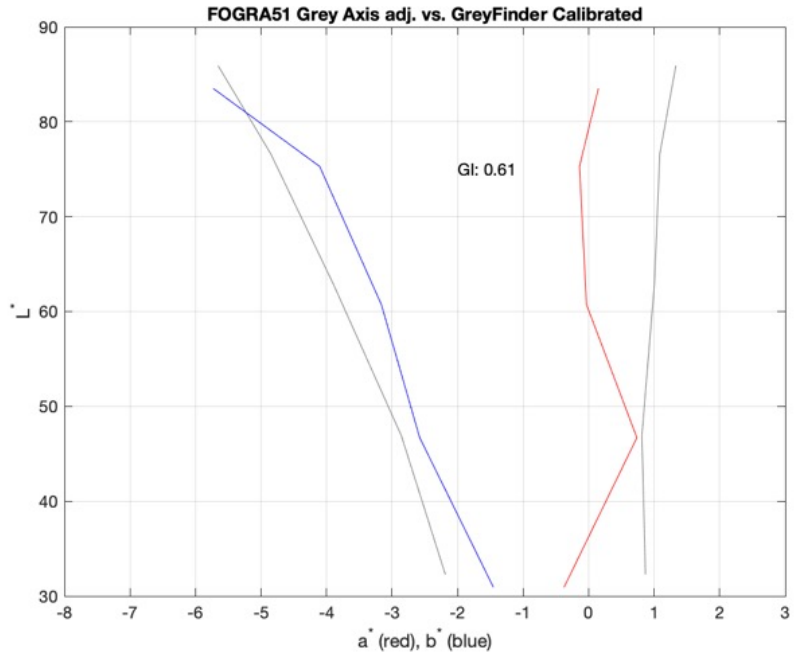
GI ≃2
“rainbow” effect

Simulation of possible GI results.
GI official thresholds not defined yet.

Results

Significative improvements comparing calibrated LUT vs. grey fine-tuned LUT printed matters





	Linear LUT	TVI calibrated LUT	Grey optimized LUT
GI	2,82	1,16	0,61

Visual evaluation

Significative improvements comparing calibrated LUT vs. grey fine-tuned LUT printed matters

	Linear LUT	TVI calibrated LUT	Grey optimized LUT
GI	2,82	1,16	0,61

Conclusions and further works

PROS:

- Automation
- Process control
- Grey Index as single-number metric
- Allow decent results without colour management

CONS:

- Spectrophotometer repeatability and accuracy
- Apply only to process that use LUTs
- The fine tuning does not consider L*

FURTHER WORKS:

- 1-step calibration
- Machine Learning to adapt to different papers
- Other calibration metrics
- Other colorimetric formulas (CAT02, RLAB, CIECAM02, ...)
- Correlate GI with visual assessment and find thresholds
- More test data

Universitat Oberta de Catalunya

Thank You

Alessandro Beltrami
abeltrami@uoc.edu

Photo credits

Title, ending, Slide 5: Wikipedia. Ansel Adams. [Online] 7 9 2021. [Cited: 18 9 2021.] https://en.wikipedia.org/wiki/Ansel_Adams.
Slide 2: HP Indigo 7900 catalog, HP Inc.
Slide 4: REINHARD, E., ET AL. *Color Imaging - Fundamentals and Applications.* s.l. : A K Peters / CRC Press, 2008. ISBN-13 : 978-1568813448.
Slide 4, 7: ISO 12647-2:2013 Graphic technology — Process control for the production of half-tone colour separations, proof and production prints — Part 2: Offset lithographic processes. [Online] 15 12 2013. [Cited: 18 9 2021.] https://www.iso.org/standard/57833.html.
Slide 5: Wikipedia. Ugo da Carpi. [Online] 4 3 2021. [Cited: 18 9 2021.] https://en.wikipedia.org/wiki/Ugo_da_Carpi.
Slide 5: SCHIRMER, K. H. *Untersuchung über Farbtonänderungen fon Druckfarben - Die auf Grau abgestimmte Farbwiedergabe im Dreifarbenbuchdruck.* München : Deutsche Gesellschaft Für Forschung Im Graphischen Gewerbe Ev, 1955.
Slide 5, 7: HUTCHESON, D. *G7 How To.* s.l. : IDEAlliance, 2009.
Slide 9: eXact™ spectrophotometer. X-Rite PANTONE. [Online] X-Rite. [Cited: 23 10 2021.] https://www.xrite.com/es/categories/portable-spectrophotometers/exact.
Slide 9: FD-9 catalog. Konica Minolta Sensing Europe. [Online] [Cited: 23 10 2021.] https://www.konicaminolta.com/instruments/download/catalog/color/pdf/fd9_catalog_eng.pdf.
Slide 2, 8, 11, 13, 15, 17: Roman16 BVDM Reference Images. BVDM. [Online] Bundesverband Druck und Medien e.V. [Cited: 10 12 2021.] https://www.bvdm-online.de/themen/technik-forschung/standardwerke/roman16-english/.
Others: author