Soft-proofing Applications for Six and Seven Colorants of High-Fidelity Printing Systems Using a Multispectral Approach

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Motivations

To bridge the gap between HDR imaging and Hi-Fi color reproduction.

→The intent of this research has two tasks:

1) to derive an HDR contone to Hi-Fi halftone-conversion model, via fitting spectral-reflectance approach.

(isomerism, color-gamut, tone-and-detail)

2) to derive both a contone and a halftone-palate types of image display models, for soft-proofing (simulation) of high-fidelity printing systems.

Methodologies

- High-Fidelity Color Printing
- Ideal CIE Multispectral Camera Model
- Proofing for Both Contine and Halftone palettes /Dithering

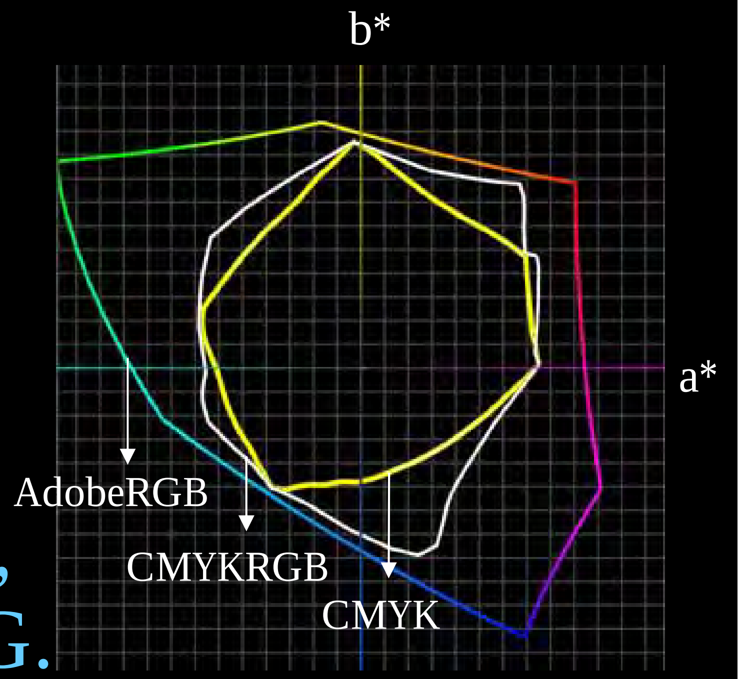
High-Fidelity Color Printing Characterization

CMYKRGB(Press)
~
CMYKROG(Proofer)
Color Printing

- Experiment of 6-colorant/7-ink Color Printing-

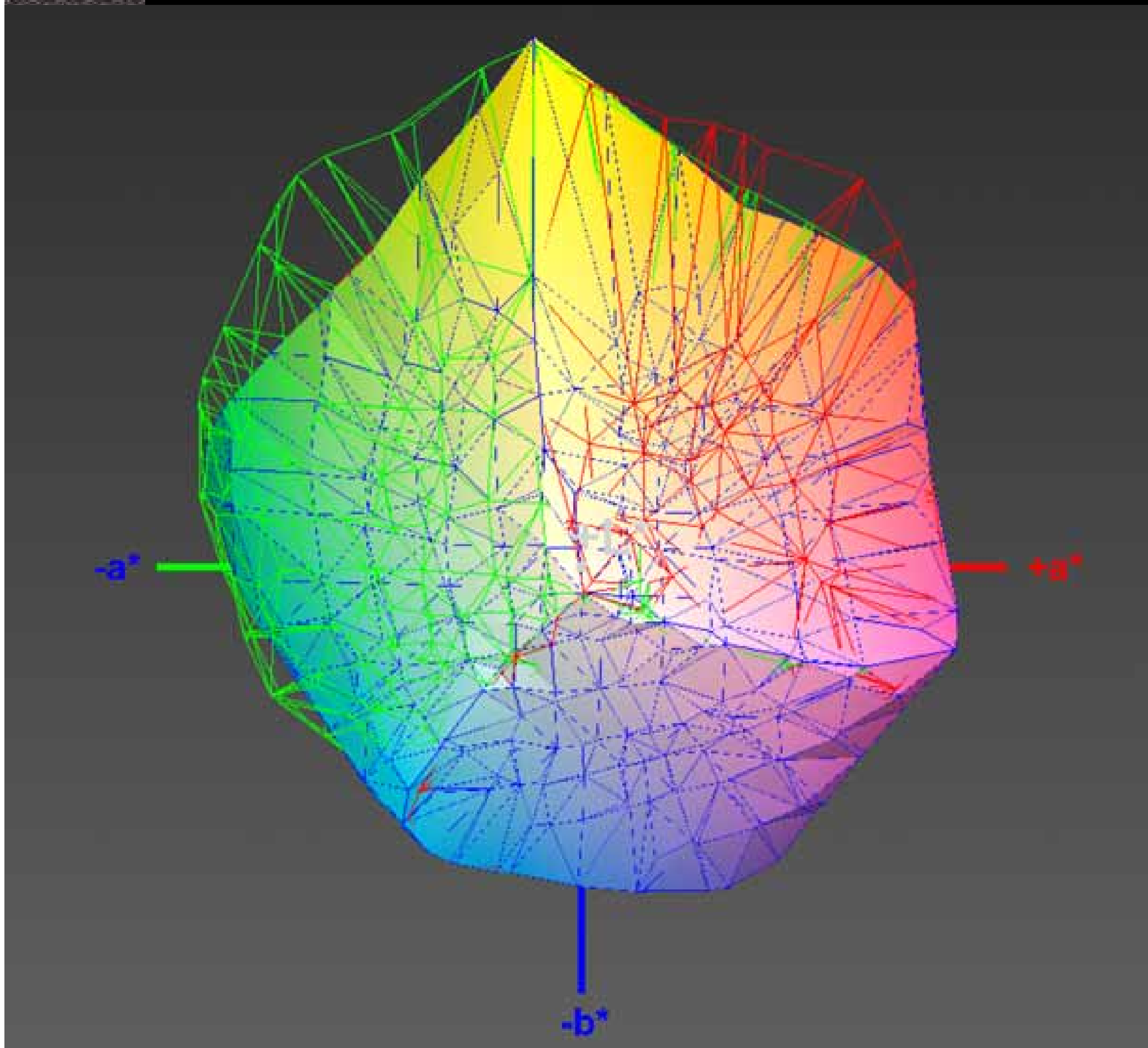
High-Fidelity Color Printing

- Multi-Color Separation (5-8 colors).
- Two directions suggested and induced:
  a. Imaging detail, e.g., CMYKLcLm.
  b. Gamut of printability, e.g., CMYKRGB, or CMYKOG.



Gamut Rendering

Illustration of the use of Hi-Fi colorants, Green and Orange to extend the gamut only achieved using standard CMYK colorants



(solid with natural coloring: 4-colorrant gamut; wireframes with colors: 6-colorant super-gamut (green: CMYKG subset), red: CMYKO subset, and blue: CMYK subset)).

7-Ink CMYKRGB Separation (Press)

- Subdivide the superset of 7-ink into 4 subsets
  - A 4-ink CMYK (1617 color; IT8.7/4)
  - Three 5-colorant subsets: CMYKR, CMYKG, and CMYKB (each 1716 colors)

Dominant Ink	Subgamut	Key Component
Black	CMYK	Black (K)
Red	CMYKR	Red
Green	CMYKG	Green
Blue	CMYKB	Blue

Table : 4 subsets of 7-ink color separation

7-Ink CMYKRGB Separation (PRESS)

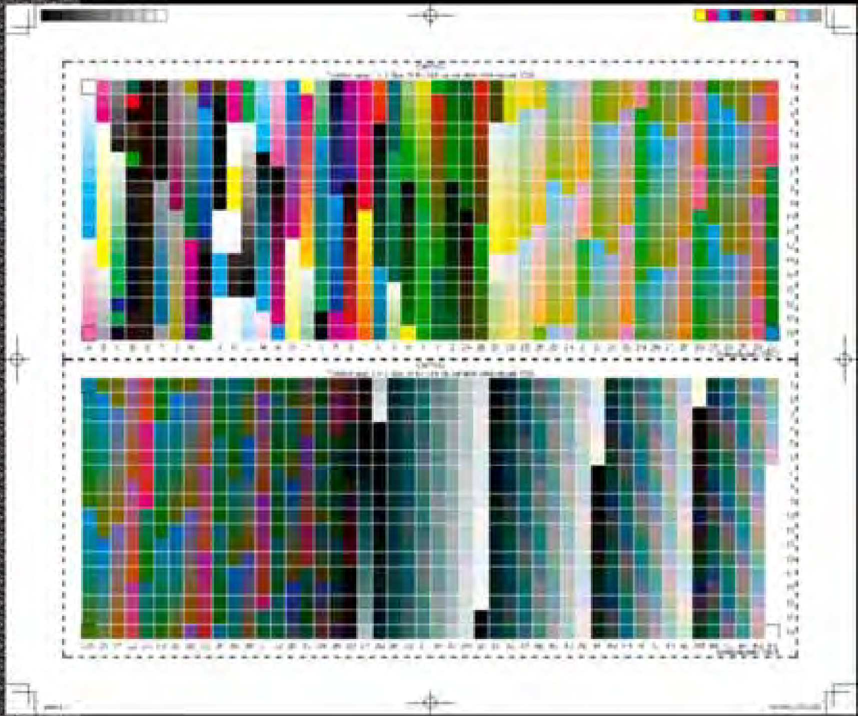
- 7-ink set used:
  - CMYK:SAKATA INX T Ecopure J;
  - Red ink: Pantone Red 032C;
  - Green ink: Pantone Green C;
  - Blue ink: Pantone Blue 072C

6-Colorant/Ink-subset (Proofer)

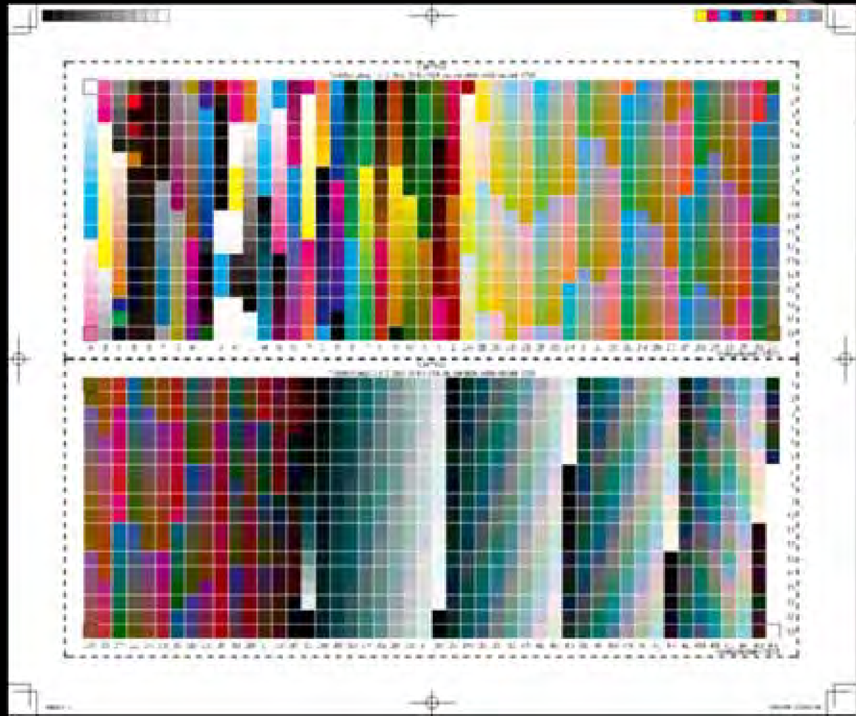
- Epson Stylus Pro 9900 (Printer)
- Subdivide the superset 6-ink into 3 subsets
  - A 4-ink CMYK (1617 colors; IT8.7/4)
  - Two 5-colorant subsets: CMYKO and CMYKG (each 1716 colors)

Dominant Colorant	Subgamut	Key Component
Black	CMYK	Black (K)
Orange	CMYKO	Orange
Green	CMYKG	Green

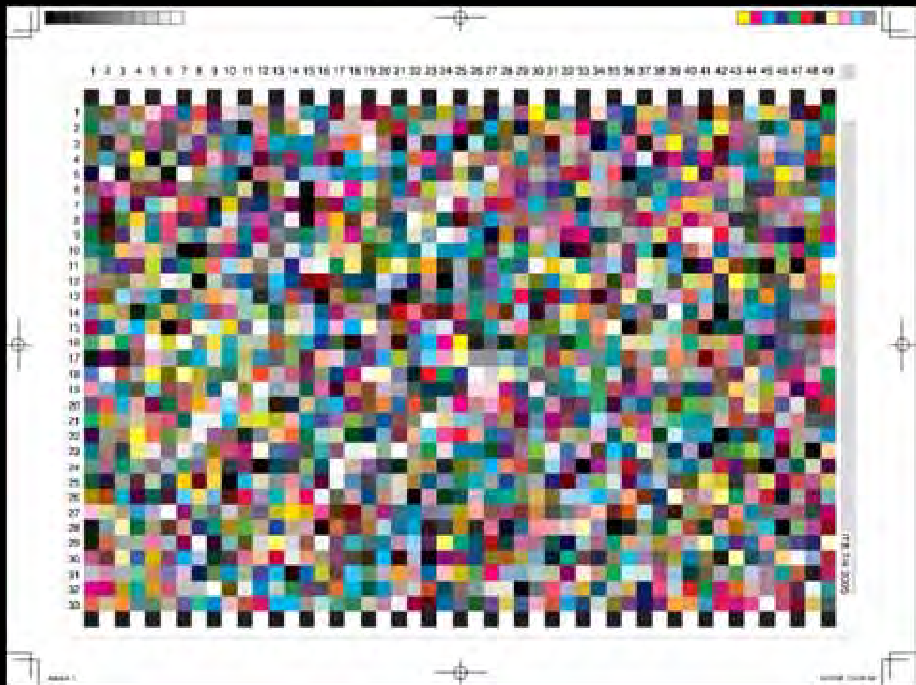
Table: 3 subsets of 6-colorant color separation



CMYKG



CMYKO



CMYK

Printer/Printing Characterization Models

- Neugebauer-Type Equation
- Masking-Type Equations

A modified type masking-type model using a multispectral approach was carried out here.

Colorimetric Density

- All of the colorimetric parameters were converted to colorimetric densities in the use of logarithm method as follows:

$$D_r = D_c = \log \frac{X_0}{X}$$

$$D_g = D_m = \log \frac{Y_0}{Y}$$

$$D_b = D_y = \log \frac{Z_0}{Z}$$

Polynomial Regressive Masking Equations (using SVD)

$$\sum_{j=1}^{C_n^{m+i}} a_j n^{Order}(m) + (n-1)^{Order} \sum_{j=C_i^{m+i}+1}^{C_n^{m+n}+C_{n-1}^{m+n-1}\ldots\ldots} a_j (m) + \ldots + 1$$

$f(x,y,z)=a_0+a_1x+a_2y+a_3z$

$f(x,y,z)=a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2$

$f(x,y,z)=a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz+a_{11}x^3+a_{12}y^3+a_{13}z^3+a_{14}xy^2+a_{15}x^2y+a_{16}yz^2+a_{17}y^2z+a_{18}zx^2+a_{19}xz^2$

Masking-Type Equations

Simple linear regression	$f(x,y,z) = D_r = a_0+a_1x+a_2y+a_3z$
2nd-order regression	$f(x,y,z) = D_r = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2 +a_8y^2+a_9z^2$
3rd-order regression	$f(x,y,z) = D_r = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+ a_9z^2+a_{10}xyz+a_{11}x^3+a_{12}y^3+a_{13}z^3+a_{14}xy^2+a_{15} x^2y+a_{16}yz^2+a_{17}y^2z+a_{18}zx^2+a_{19}xz^2$

※ $x=D_c=c$, $y=D_m=m$, $z=D_y=y$

(Principal Density or Equivalent Neutral Density)

Note : Forward model for 3-colors CMY superimposed

Broadband Type of Third-Order Model
(Colorant Models)

$$D_{r\text{-}3c} = a_{1,1}\,c + a_{1,2}\,m + a_{1,3}\,y + a_{1,4}\,c^2 +$$
$$a_{1,5}\,m^2 + a_{1,6}\,y^2 + a_{1,7}\,cm + a_{1,8}\,cy +$$
$$a_{1,9}\,my + a_{1,10}\,c^3 + a_{1,11}\,m^3 + a_{1,12}\,y^3 +$$
$$a_{1,13}\,c^2m + a_{1,14}\,c^2y + a_{1,15}\,m^2c + a_{1,16}\,m^2y +$$
$$a_{1,17}\,y^2c + a_{1,18}\,y^2m + a_{1,19}\,cmy$$

Similar terms are used for the calculation of $D_{g\text{-}3c}$ and $D_{b\text{-}3c}$.

Polynomial Models using SVD method In CMYKOG Model

order	Parameters	No. of Term	Polynomial Regression Model
n^{order}-SVD Equation	m	$(\sum_{i=0}^{n} H_i^m)+1$	$\sum_{j=1}^{C_n^{m+n-1}} a_j n^{Order}(m) + \sum_{j=C_n^{m+n-1}+.....+1}^{C_n^{m+n-1}+C_{n-1}^{m+n-2}......} a_j (n-1)^{Order}(m) + ... + 1$
3^{rd}-SVD Equation (MB)	$R_{\lambda C}$ $R_{\lambda M}$ $R_{\lambda Y}$ $R_{\lambda K}$ $R_{\lambda E}$	$(\sum_{i=0}^{3} H_i^5)+1$ $=56$	$\sum_{j=1}^{C_3^7} a_j 3^{rd}(R_{\lambda C}, R_{\lambda M}, R_{\lambda Y}, R_{\lambda K}, R_{\lambda E}) + \sum_{j=C_3^7+1}^{C_3^7+C_2^6} a_j 2^{nd}(R_{\lambda C}, R_{\lambda M}, R_{\lambda Y}, R_{\lambda K}, R_{\lambda E}) + \sum_{j=C_3^7+C_2^6+1}^{C_3^7+C_2^6+C_1^5} a_j 1^{st}(R_{\lambda C}, R_{\lambda M}, R_{\lambda Y}, R_{\lambda K}, R_{\lambda E}) + 1$

Note: 1) BB: *Broadband*, MB: *Multispectral;* 2) $R_{\lambda 5c}$ is the outcome for 3^{rd}-SVD equation in multispectral model (forward process); 3) SVD: Singular Value Decomposition method

Polynomial Models using SVD method In CMYKOG Model

$$\sum_{j=1}^{C_n^{m+n-1}} a_j n^{Order}(m) + \sum_{j=C_n^{m+n-1}+.....+1}^{C_n^{m+n-1}+C_{n-1}^{m+n-2}......} a_j (n-1)^{Order}(m) + \ldots + 1$$

$$\sum_{j=1}^{C_3^7} a_j 3^{rd}(R_{\lambda C}, R_{\lambda M}, R_{\lambda Y}, R_{\lambda K}, R_{\lambda E}) + \sum_{j=C_3^7+1}^{C_3^7+C_2^6} a_j 2^{nd}(R_{\lambda C}, R_{\lambda M}, R_{\lambda Y}, R_{\lambda K}, R_{\lambda E}) +$$

$$\sum_{j=C_3^7+C_2^6+1}^{C_3^7+C_2^6+C_1^5} a_j 1^{st}(R_{\lambda C}, R_{\lambda M}, R_{\lambda Y}, R_{\lambda K}, R_{\lambda E}) + 1$$

Gray Component Replacement (GCR)

- The gray component is the determination of black-ink channel (K channel) for reversal model.
- Conditional rules for GCR (e.g):
  - if ($D_{(4C,\ min)} < 0.6 \,||\, D_{4C} < FullColor_{3C}$) → $D_{GCR} = .0$ ($D_{3C} = D_{4C}$);
  - if ($D_{(4C,\ min)} >= K_{100}$) → $D_{GCR} = K_{100}$;
  - else → $D_{GCR} = D_{(4C,\ min)} * 0.7$;

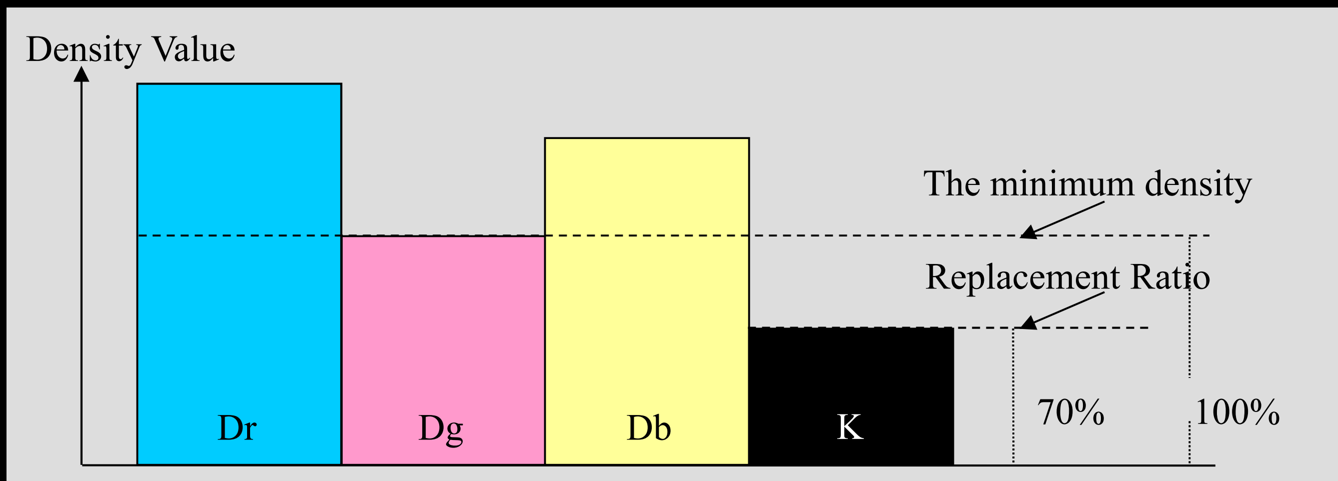
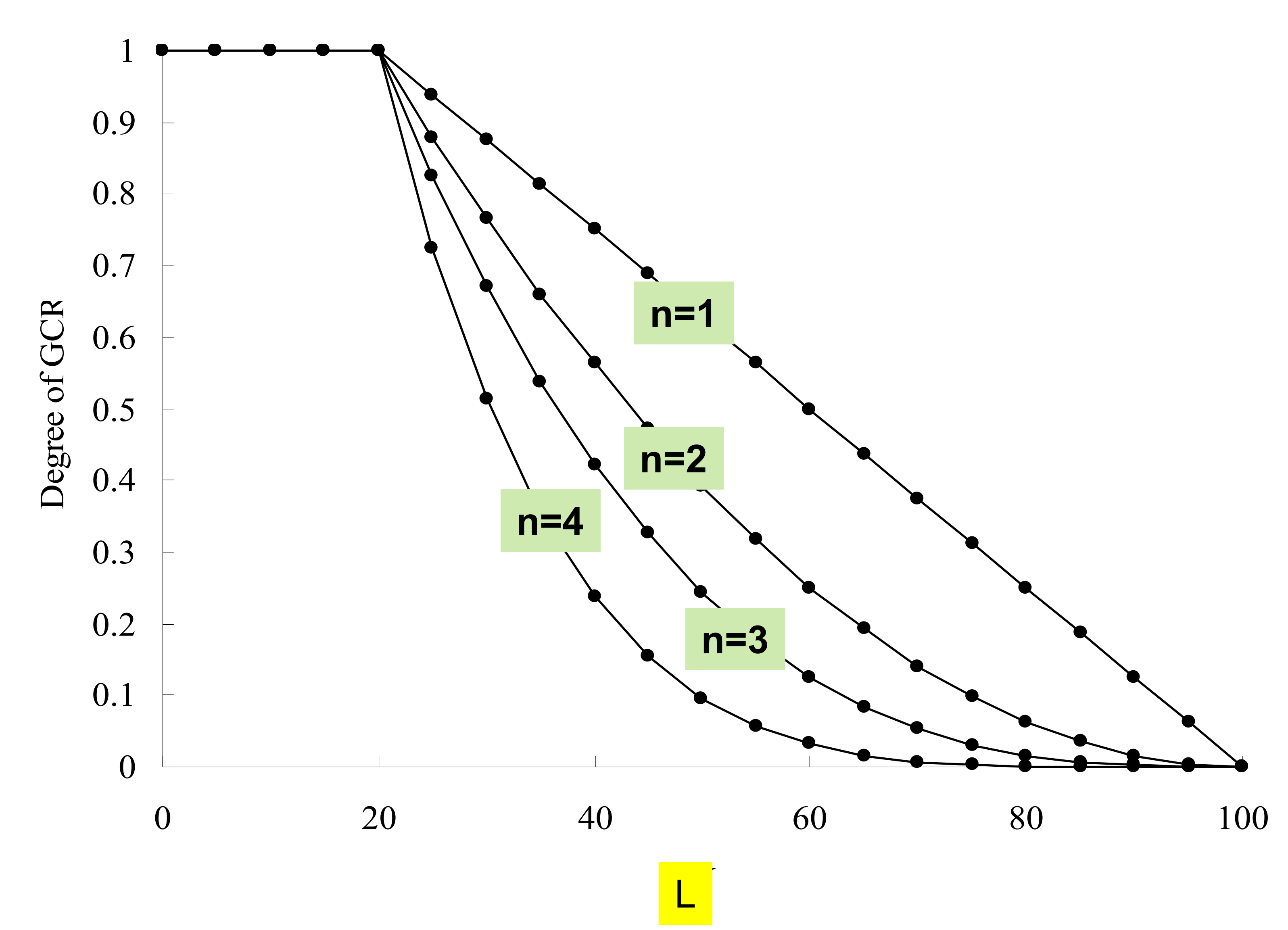


Figure : A schema figure of Gray Component Replacement



Adaptive Type of GCR: $\beta=[(100-L^*)/80]^n$

KCR: Key Component Replacement

Get FDA of Key-Color Component Using Look-Up-Table

↓

Compute ratio_distance

```
=computeDistanceAndRatio2KeyColor(Lch_pixel.h);
```

↓

```
extraComponent.E=
((Math.pow((1-ratio_distance),n_adjKCR_ConcaveC)))
*extraComponent.E;
```

Hue Angles of Key-Colors

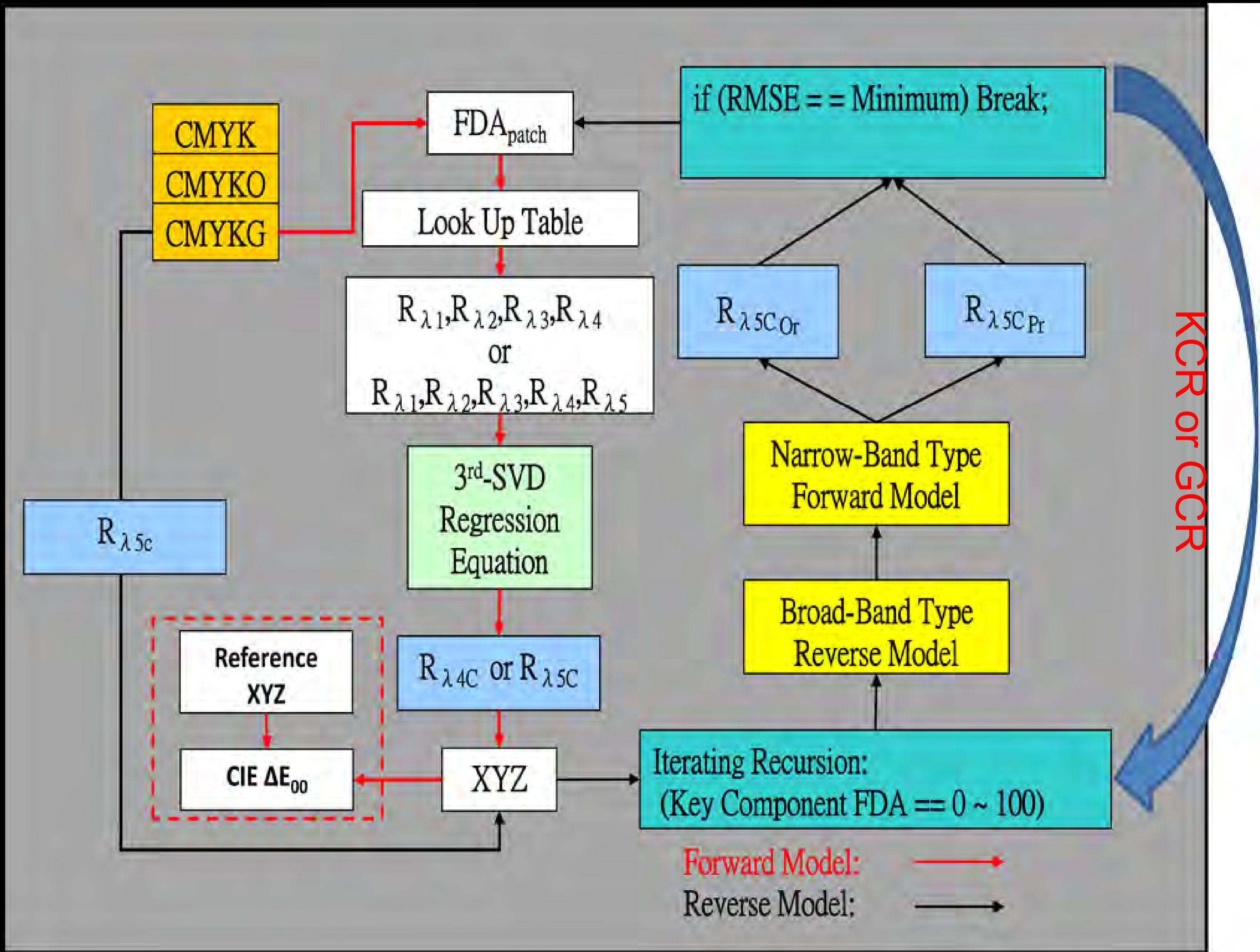
6C_CMYKOG

Hue	Red	E-Orange	Yellow	Green	E-Green	Cyan	Blue	Magenta	Red
L	52.0	66.5	94.6	41.6	83.5	51.3	13.4	52.7	52.0
C	97.5	110.4	106.9	85.0	61.9	70.2	78.1	84.6	97.5
h_i	39.7	55.6	94.8	161.5	163.1	243.6	306.0	356.3	399.7

Adobe_D50 (BenQ Display)

Hue	Red	E-Orange	Yellow	Green	E-Green	Cyan	Blue	Magenta	Red
L	64.0		98.0	86.0		90.0	40.0	72.0	64.0
C	127.7		96.5	158.2		98.0	122.7	122.1	127.7
h_i	41.6		97.2	150.8		194.2	291.9	330.5	401.6

Polynomial Models using SVD method In CMYKOG Model



Summary of Prediction performances of the multi-spectral 2nd-SVD model (CMYKOG)

Subset	CMYK		CMYKO		CMYKG	
Process	F	R	F	R	F	R
Max	4.44	4.97	3.53	4.98	4.25	4.43
Average	0.80	0.88	0.76	1.44	0.74	1.43
ΔE_{00} >6 Count	0	0	0	0	0	0
RMSE (Mean)	9.70 E-4	0.0017	7.92 E-4	0.0021	9.54 E-4	0.0040

- in terms of mean ΔE_{00}, of four derived Models for transform processes of both the forward (denoted as F) and the reverse (denoted as R) under the D_{50} condition.

Summary of Prediction performances of the multi-spectral 2nd-SVD model (CMYKRGB)

Subset	CMYK		CMYKR		CMYKG	
Process	F	R	F	R	F	R
Max	5.27	4.85	5.33	5.34	4.89	4.97
Average	1.15	0.92	1.26	1.85	0.99	1.67
ΔE_{00} >6 Count	0	0	0	0	0	0
RMSE (Mean)	0.0013	0.0018	0.0011	0.0028	0.0011	0.0027

- in terms of mean ΔE_{00}, of four derived Models for transform processes of both the forward (denoted as F) and the reverse (denoted as R) under the D_{50} condition.

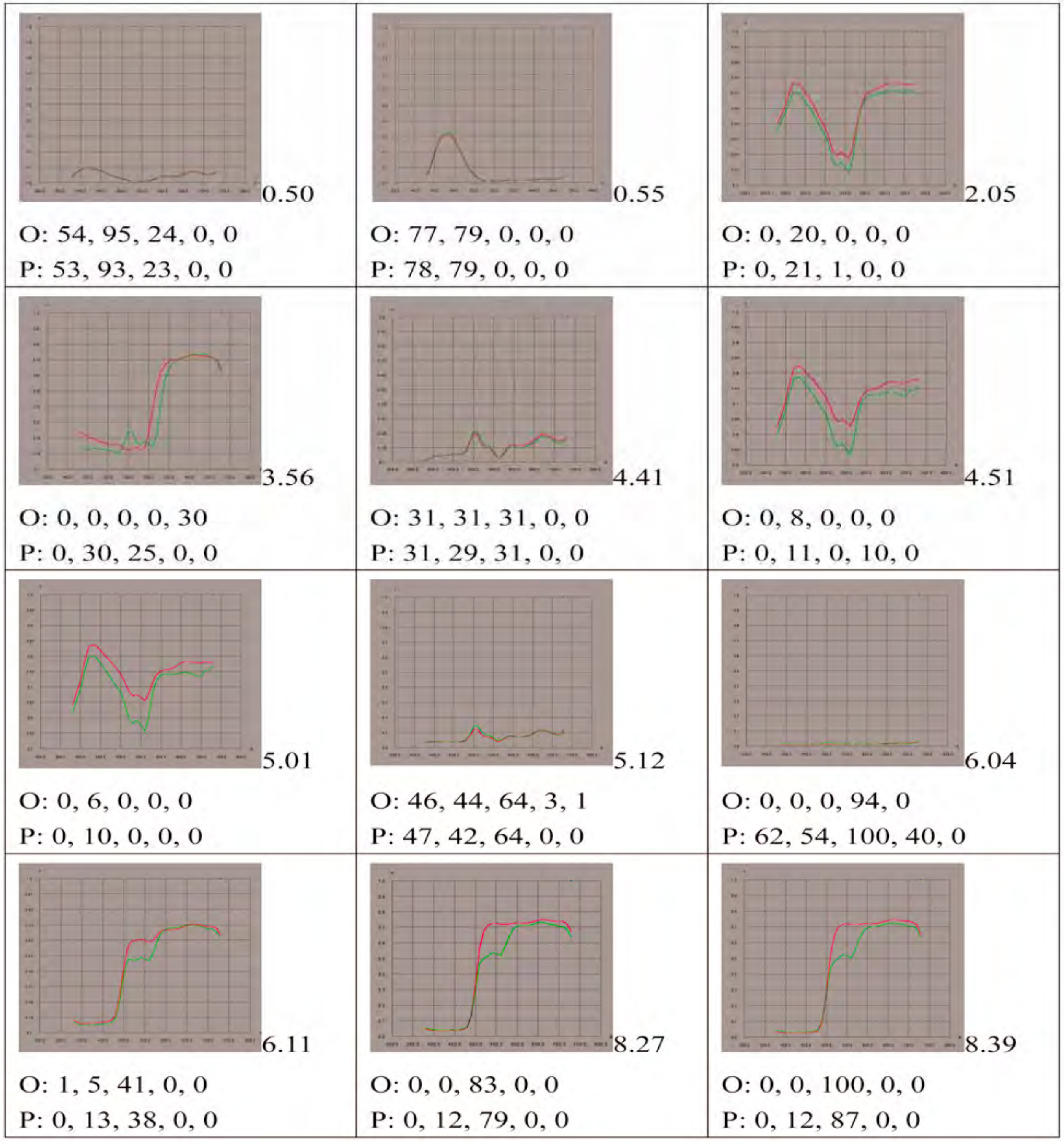
Summary of Prediction performances of the multi-spectral 2nd-SVD model (CMYKRGB)

Subset	CMYKB	
Process	F	R
Max	6.47	4.94
Average	1.00	1.61
ΔE_{00} >6 Count	1	0
RMSE (Mean)	9.78 E-4	0.0026

- in terms of mean ΔE_{00}, of four derived Models for transform processes of both the forward (denoted as F) and the reverse (denoted as R) under the D_{50} condition.

Sample Comparisons & Patches Analysis

Examples of spectral reflectance (SR) estimated, and comparisons between the original and the predicted (CMYKO set; red line: the Originals; green line: the Predicted)



Multispectral CIEXYZ Sensing Model

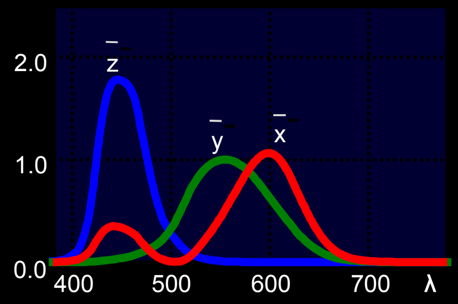
~ Ideal CIE Camera Model

~

Ideal CIE Camera Model

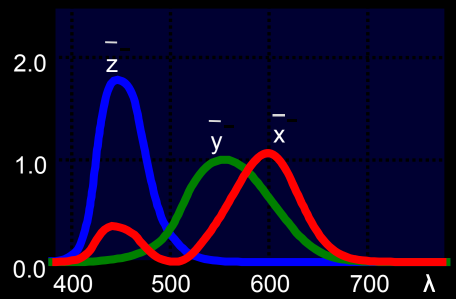
A spectra sensing model, virtually equipped with the simulated CIEXYZ three-band filters (with a set of ideal spectral responses)

- i.e. CIE 1931 Color Matching Function.



Ideal CIE Camera Model

1. An appropriate real spectral color dataset
   - Munsell Book Glossy was used in this research
2. SVD and Winner Method
   - Basis vectors: using *SVD method*
   - Coefficients: *approximated by using the well-known Winner-inverse solution*



Ideal spectral responses

Munsell Book Glossy

Multispectral Hi-Fi 6-colorant/7-ink Separation Algorithm

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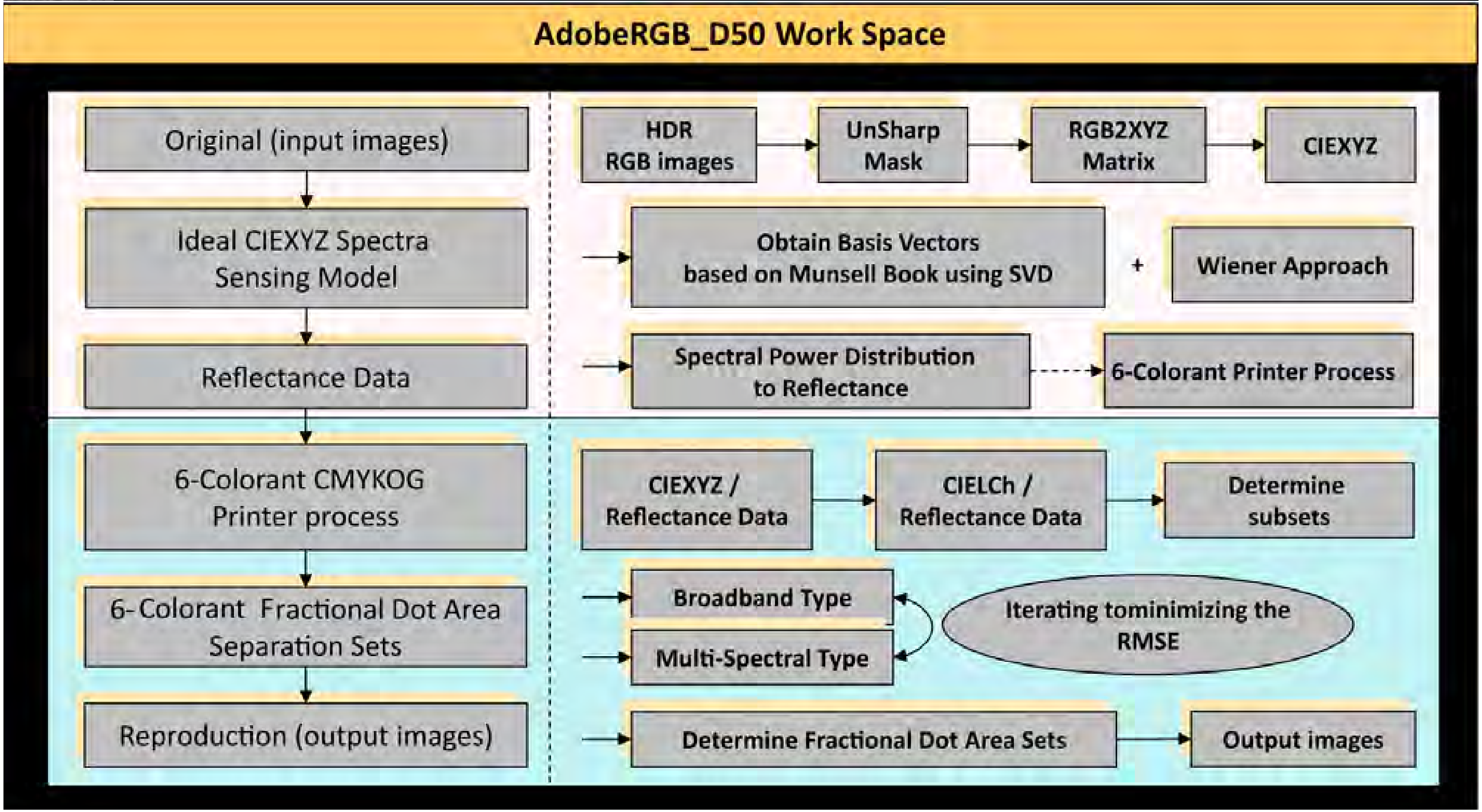
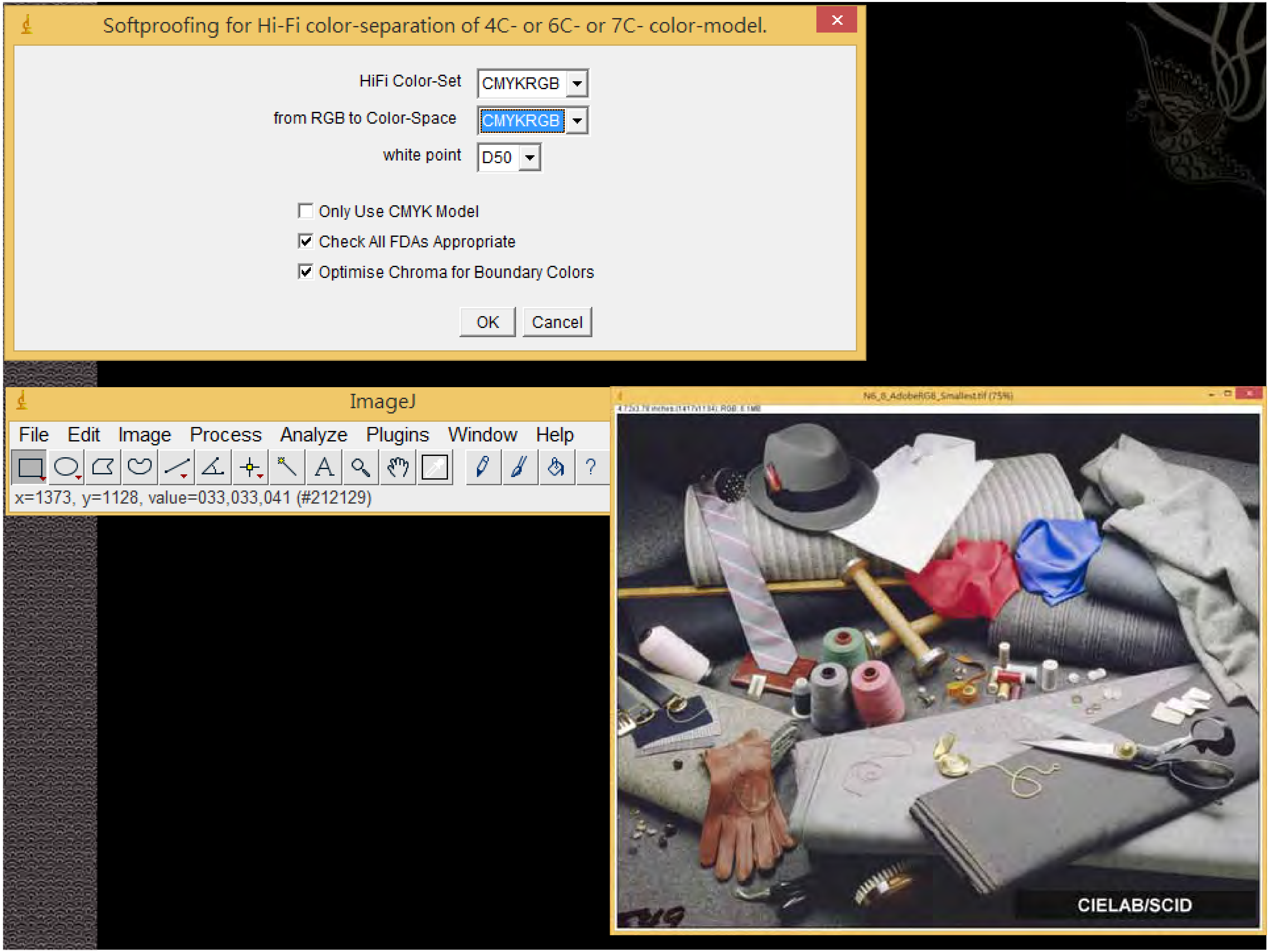
Computational Procedures of Spectral Hi-Fi 6-colorant/ink Separation Algorithm




Softproofing for Hi-Fi color-separation of 4C- or 6C- or 7C- color-model.
HiFi Color-Set
CMYKRGB
from RGB to Color-Space
CMYKRGB
white point
D50
Only Use CMYK Model
Check All FDAs Appropriate
Optimise Chroma for Boundary Colors
OK
Cancel
ImageJ
File
Edit
Image
Process
Analyze
Plugins
Window
Help
x=1373, y=1128, value=033,033,041 (#212129)
CIELAB/SCID


7C
CIELAB/SCID


6C
CIELAB/SCID


4C Optimization
CIELAB/SCID


4C no Optimization
CIELAB/SCID

Original

7C

4C

6C

Soft-proofing Using Adobe-Type Display (BenQ)

Via Halftone Palletter Dithering

http://en.literateprograms.org/Floyd-Steinberg_dithering_(Java)

Sample code

The following sample code reads in an RGB image in a raw image file format, dithers it to a specific optimized 16-color palette found using Photoshop, and writes the output to a raw image file. The original image and dithered result are shown below. The raw input image file for this sample can be downloaded at Image:Amorphophallus titanum USBG small.raw.

Implement the core algorithm

Based on the concept of *error diffusion*

- The nearest palette color is chosen to the current pixel in question, and
- Then compute the difference of that color from the original color in each RGB channel.
- Pieces of this difference are dispersed throughout several adjacent pixels not yet visited.

SO: in MY APPROACH:

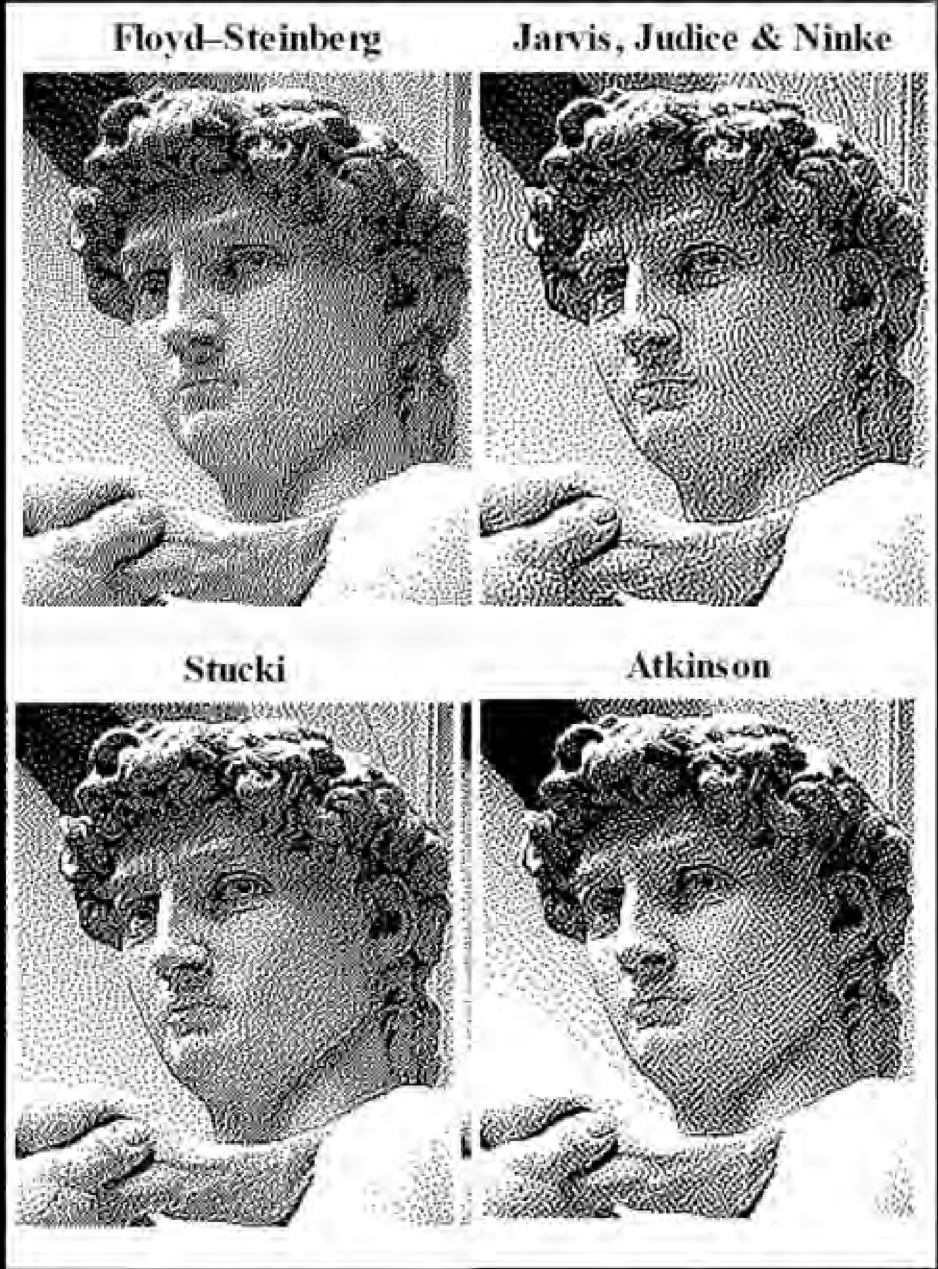
- **Using ΔE_{00} instead of the difference of RGB**
- **CMYKRGB→2^7=128 palettes**
- **CMYKROG→2^6=64 palettes**

Implement the core algorithm

```
<<FloydSteinbergDither definition>>=
public static byte[][] floydSteinbergDither(RGBTriple[][] image, RGBTriple[] palette)
{
        set up result image
        loop over all pixels
                RGBTriple currentPixel = image[y][x];
        find nearest color to current pixel
        compute and disperse error close loop over all pixels
        return result;
}
```

4 Dithering Methods

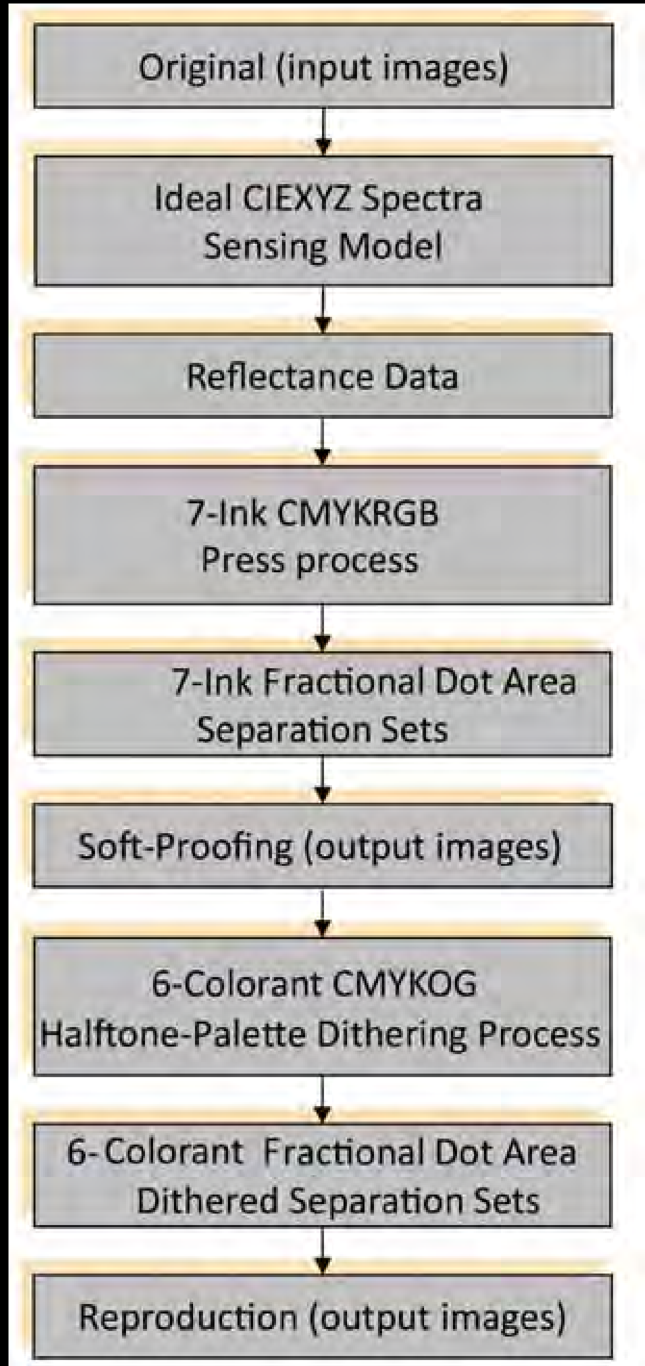
- Floyd-Steinberg
- Jarvis, Judice & Linke
- Stucki
- Atkinson

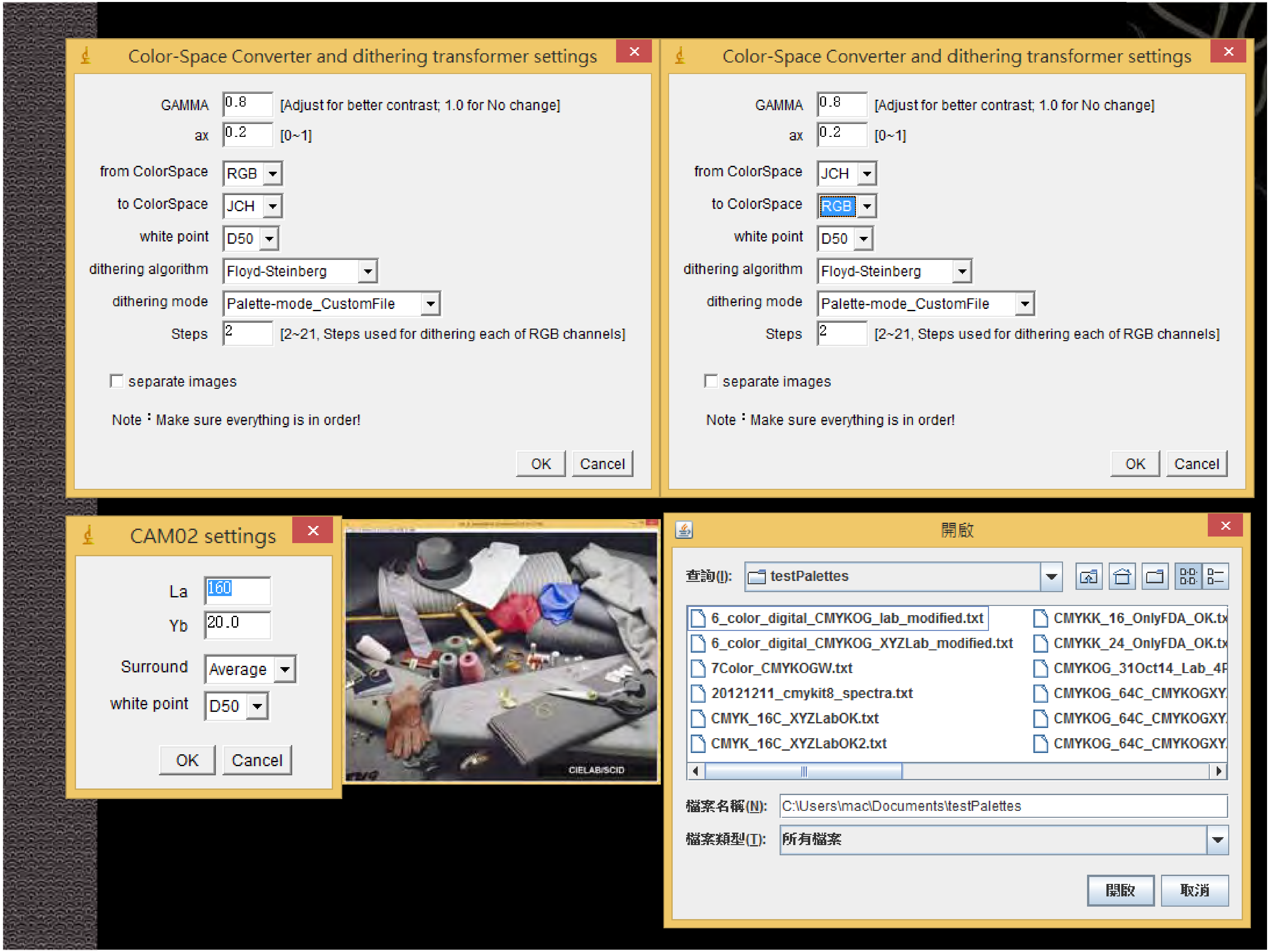


Based on the concept of *error diffusion*

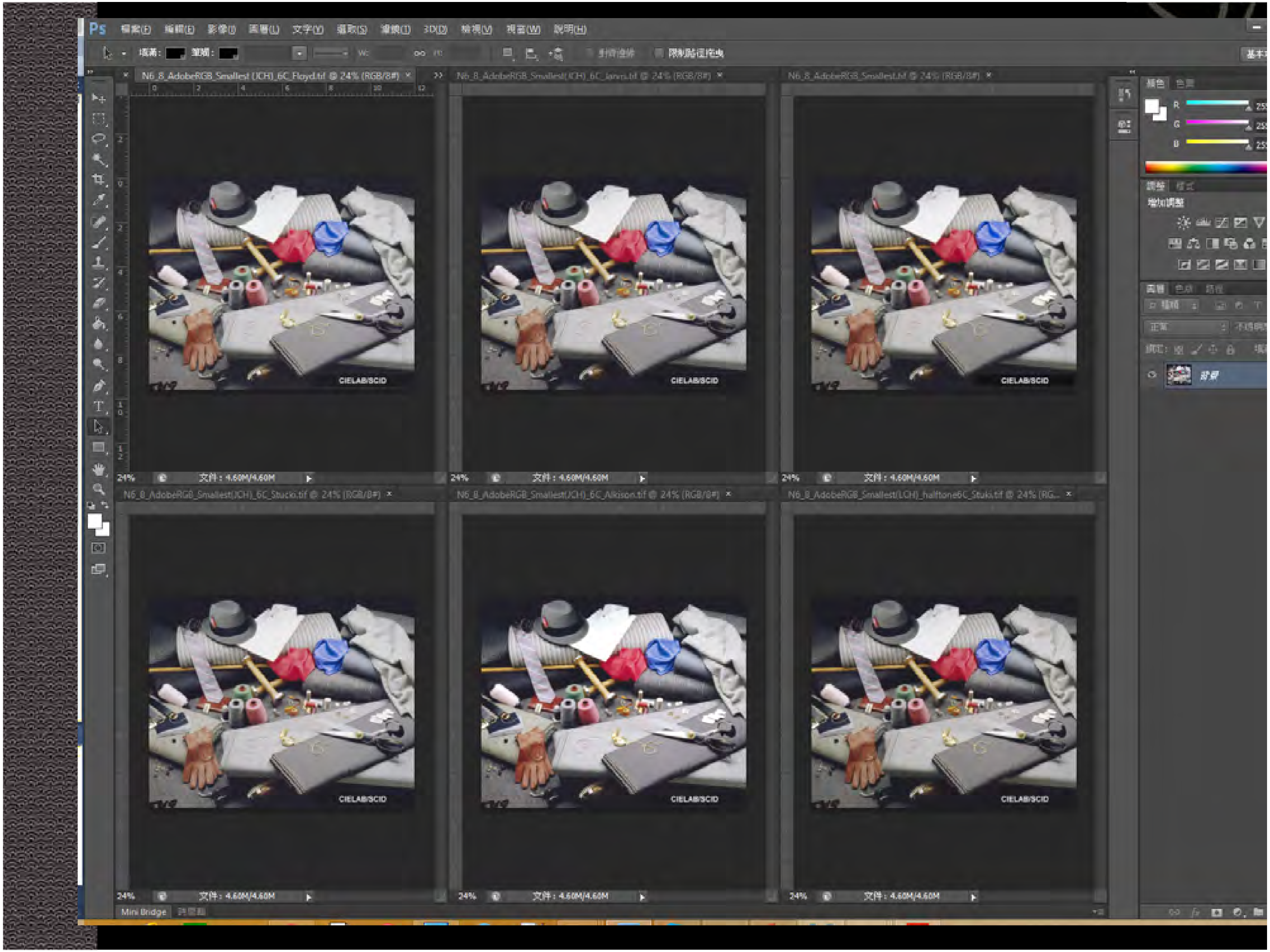
7Cto6C_DitheringProcess

Soft-proofing Computational Procedures from Spectral 7-ink Separation Algorithm to 6-colorant Dithering Process




Color-Space Converter and dithering transformer settings
GAMMA 0.8 [Adjust for better contrast; 1.0 for No change]
ax 0.2 [0~1]
from ColorSpace RGB
to ColorSpace JCH
white point D50
dithering algorithm Floyd-Steinberg
dithering mode Palette-mode_CustomFile
Steps 2 [2~21, Steps used for dithering each of RGB channels]
separate images
Note : Make sure everything is in order!
OK
Cancel
Color-Space Converter and dithering transformer settings
GAMMA 0.8 [Adjust for better contrast; 1.0 for No change]
ax 0.2 [0~1]
from ColorSpace JCH
to ColorSpace RGB
white point D50
dithering algorithm Floyd-Steinberg
dithering mode Palette-mode_CustomFile
Steps 2 [2~21, Steps used for dithering each of RGB channels]
separate images
Note : Make sure everything is in order!
OK
Cancel
CAM02 settings
La 160
Yb 20.0
Surround Average
white point D50
OK
Cancel
CIELAB/SCID
開啟
查詢(I): testPalettes
6_color_digital_CMYKOG_lab_modified.txt
6_color_digital_CMYKOG_XYZLab_modified.txt
7Color_CMYKOGW.txt
20121211_cmykit8_spectra.txt
CMYK_16C_XYZLabOK.txt
CMYK_16C_XYZLabOK2.txt
CMYKK_16_OnlyFDA_OK.tx
CMYKK_24_OnlyFDA_OK.tx
CMYKOG_31Oct14_Lab_4P
CMYKOG_64C_CMYKOGXY
CMYKOG_64C_CMYKOGXY
CMYKOG_64C_CMYKOGXY
檔案名稱(N): C:\Users\mac\Documents\testPalettes
檔案類型(T): 所有檔案
開啟
取消


N6_8_AdobeRGB_Smallest.tif (JCH) (75%)
4.72x3.78 inches (1417x1134); RGB; 6.1MB
CIELAB/SCID


Ps
N6_8_AdobeRGB_Smallest(JCH)_6C_Floyd.tif @ 24% (RGB/8#)
N6_8_AdobeRGB_Smallest(JCH)_6C_Jarvis.tif @ 24% (RGB/8#)
N6_8_AdobeRGB_Smallest.tif @ 24% (RGB/8#)
N6_8_AdobeRGB_Smallest(JCH)_6C_Stucki.tif @ 24% (RGB/8#)
N6_8_AdobeRGB_Smallest(JCH)_6C_Atkison.tif @ 24% (RGB/8#)
CIELAB/SCID
24%
文件：4.60M/4.60M
Mini Bridge

Conclusions

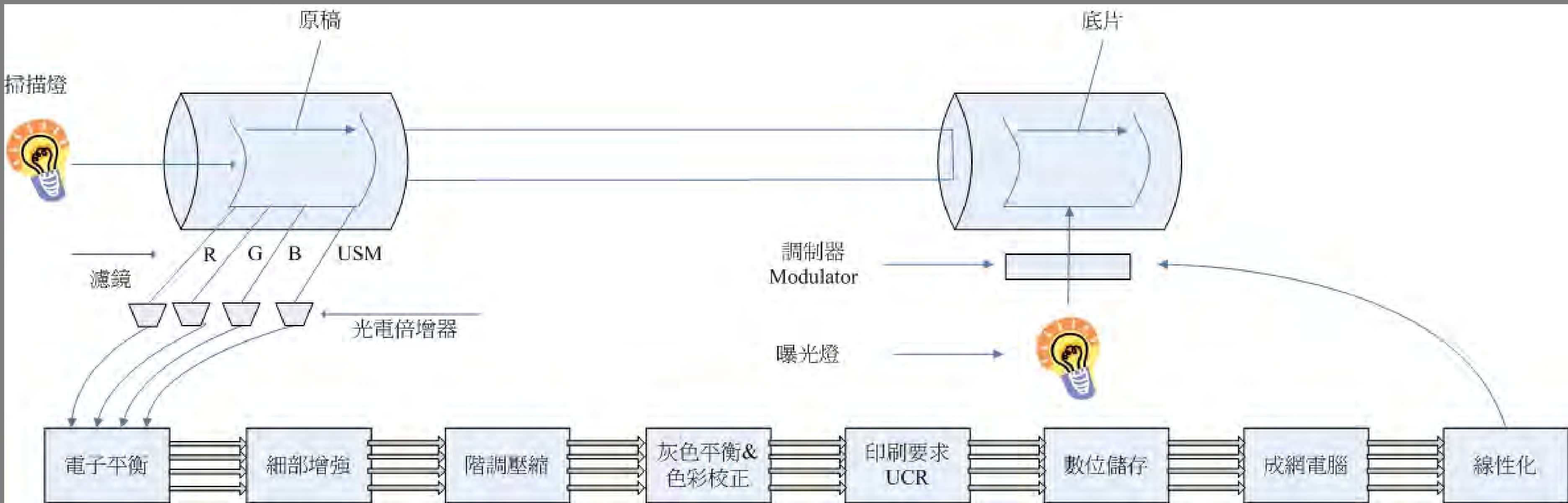
Satisfactorily derived:

1) An HDR contone to Hi-Fi halftone-conversion model, via fitting spectral reflectance approach.
2) The CIEXYZ type of camera (sensing) model
3) Both Contone and Halftone-palate types of image display models, for soft-proofing of simulation of high-fidelity printing system,

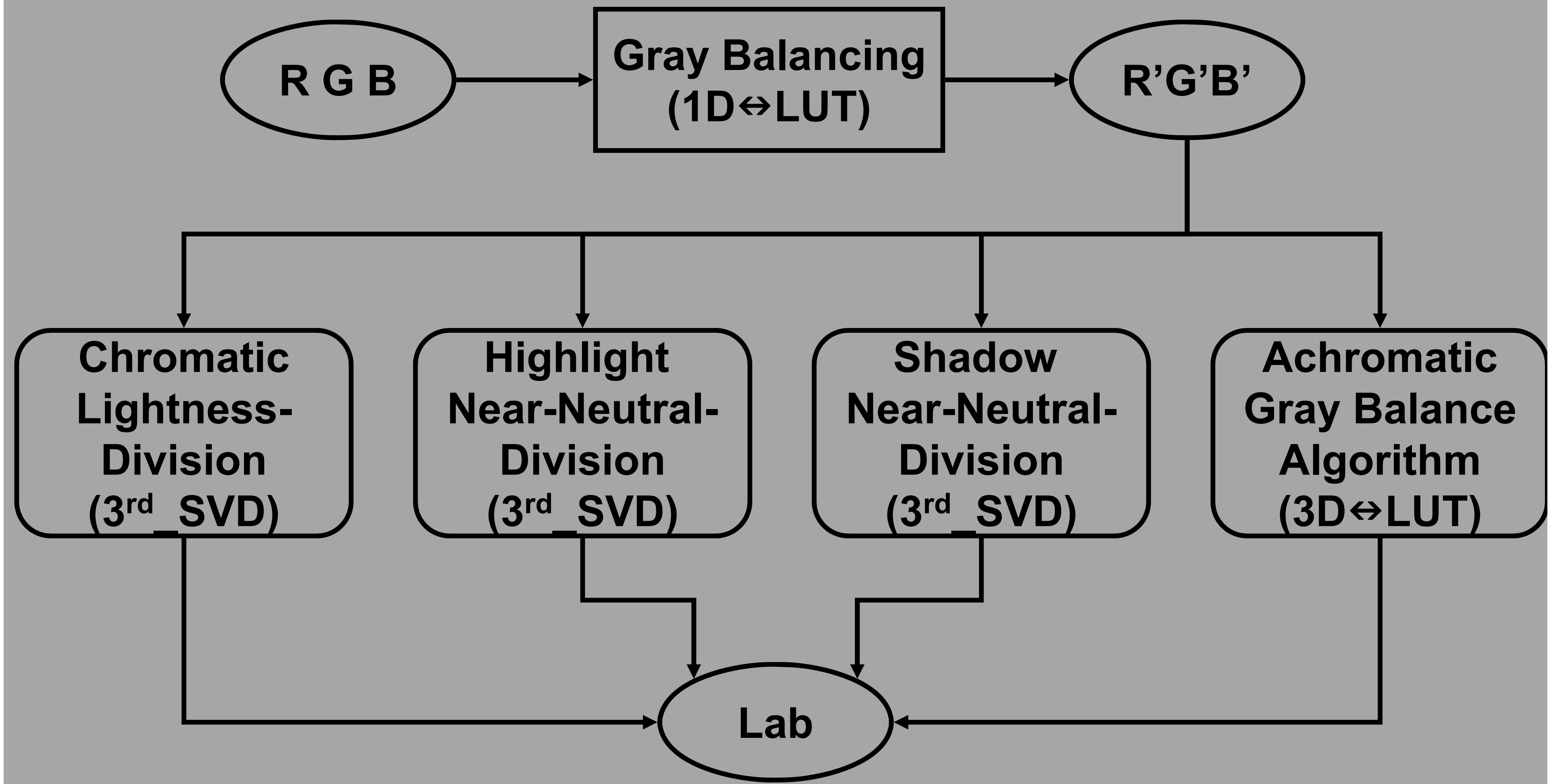
Using CMYKRGB and CMYKOG colorants.

➢Future Work

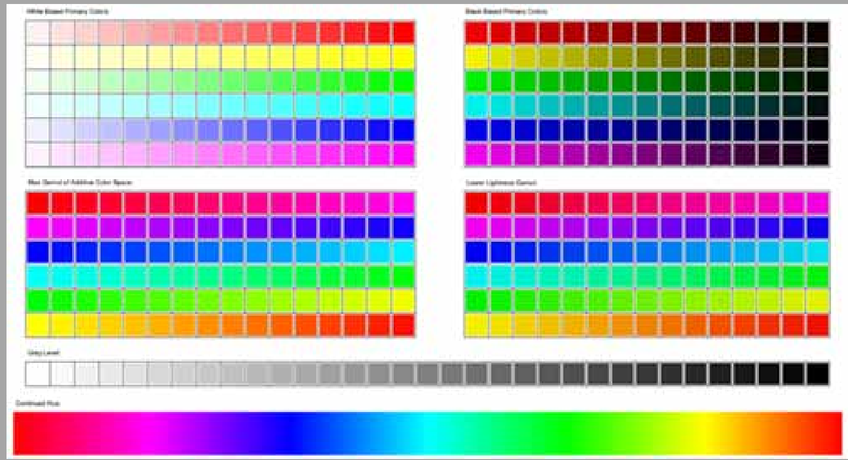
Process of Scanner



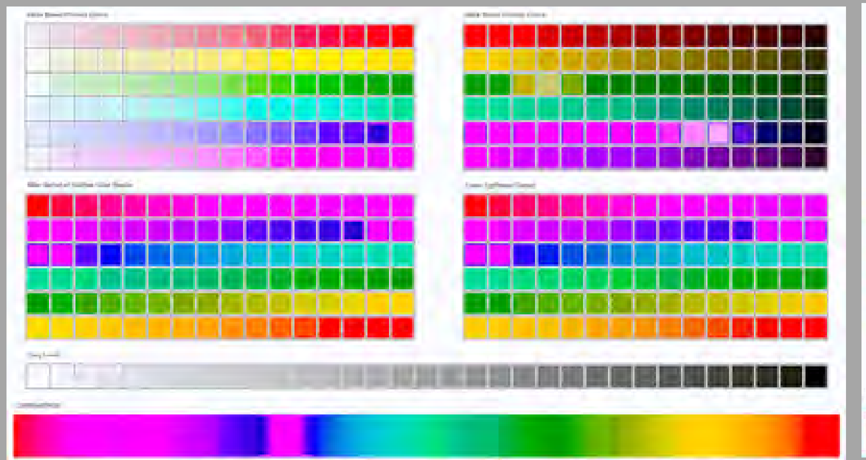
Scanner/Camera Characterization

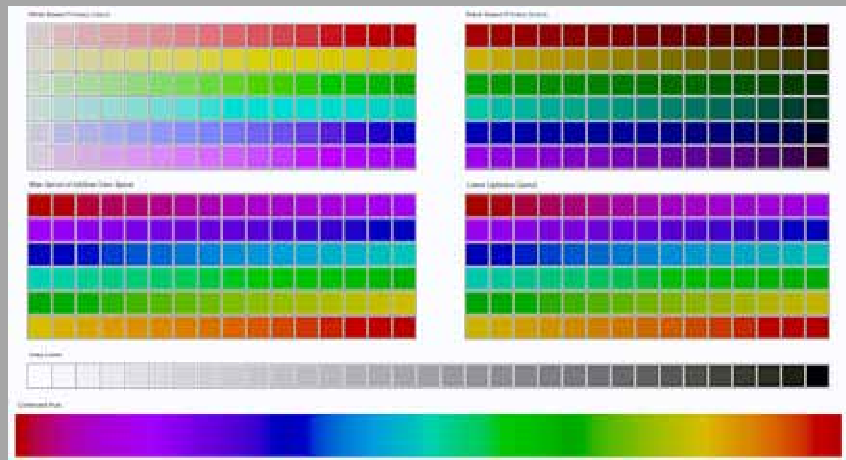


Refined
Device Characterization Model



Original





(before refined)   (after **GB** refined)

Approach	No_GB	GB	L 4	L7	GM
Mean ΔE	2.76	2.31	1.53	0.96	1.17