High Color-Fidelity Imaging System Using B/W Digital Camera and Rotary Color Filters

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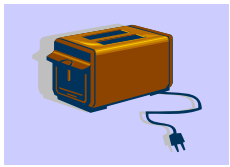
Note
This research was organized in part by the New Energy and Industrial Technology Development Organization, Japan(NEDO).

Part 1: To develop NEDO-DSC to aquire a high-resolution colorimetric image to reproduce an actual scene.
Part 2: Its applications

Part 1 : Background

use case : RAW-DSC for professional user



Scene

Capturing

Colorimetric color reproduction

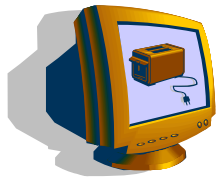
XYZ

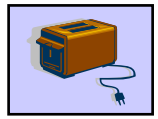
Appearance conv.

X’Y’Z’

Mapping to device

RGBorCMY





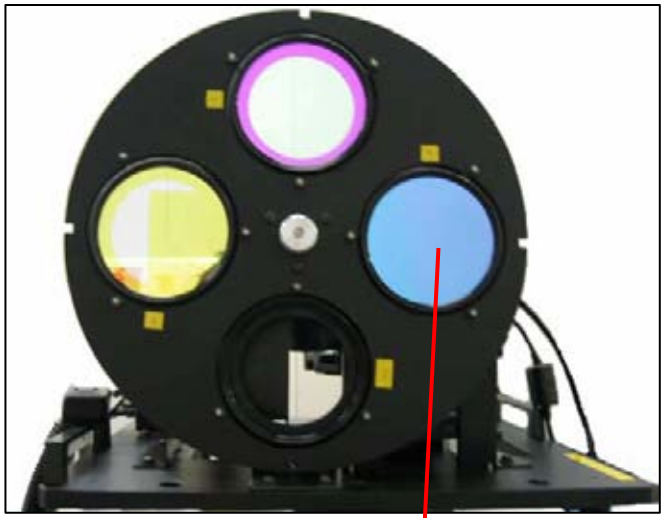
Monitor

Print

Capturing device

High accurate and high fidelity color capturing system

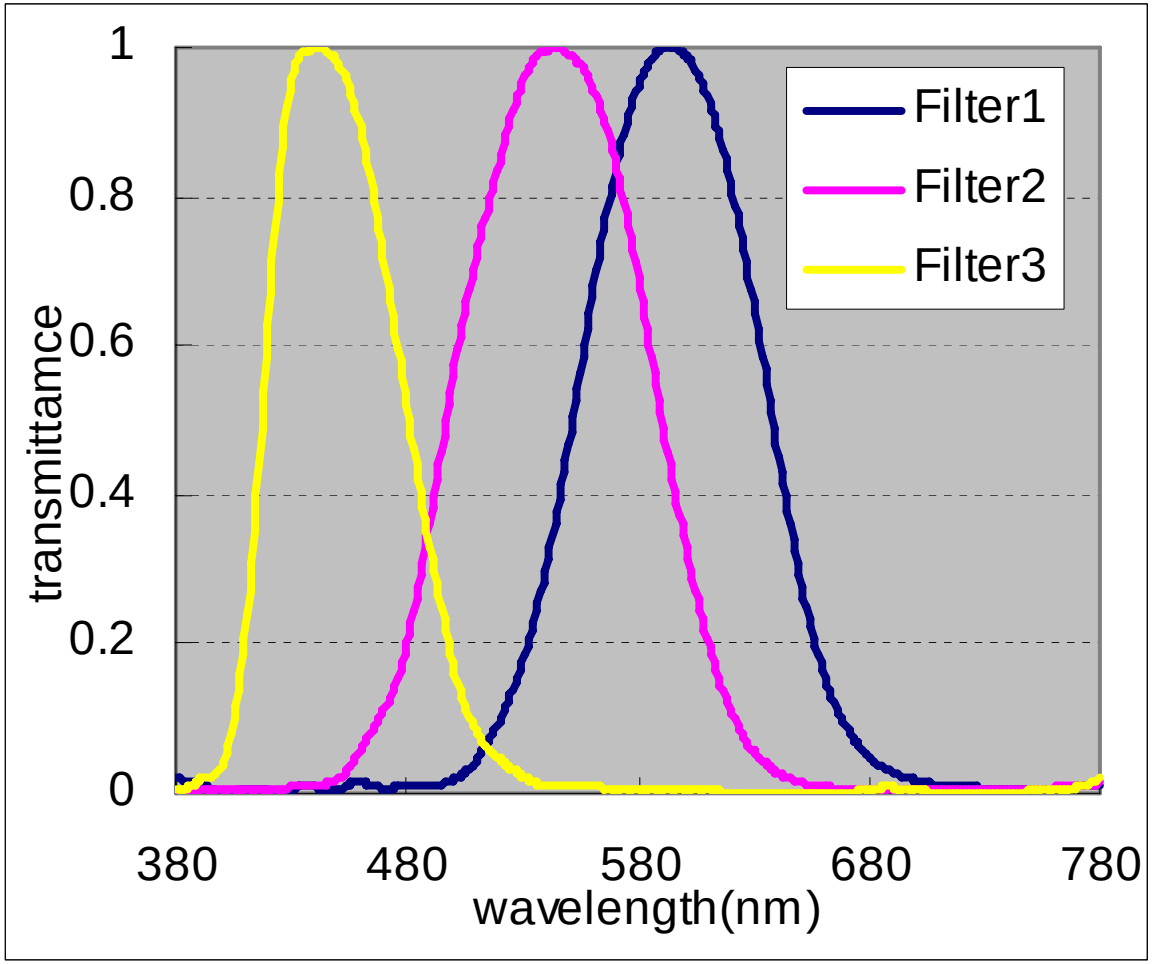
B/W DSC with rotary color filters

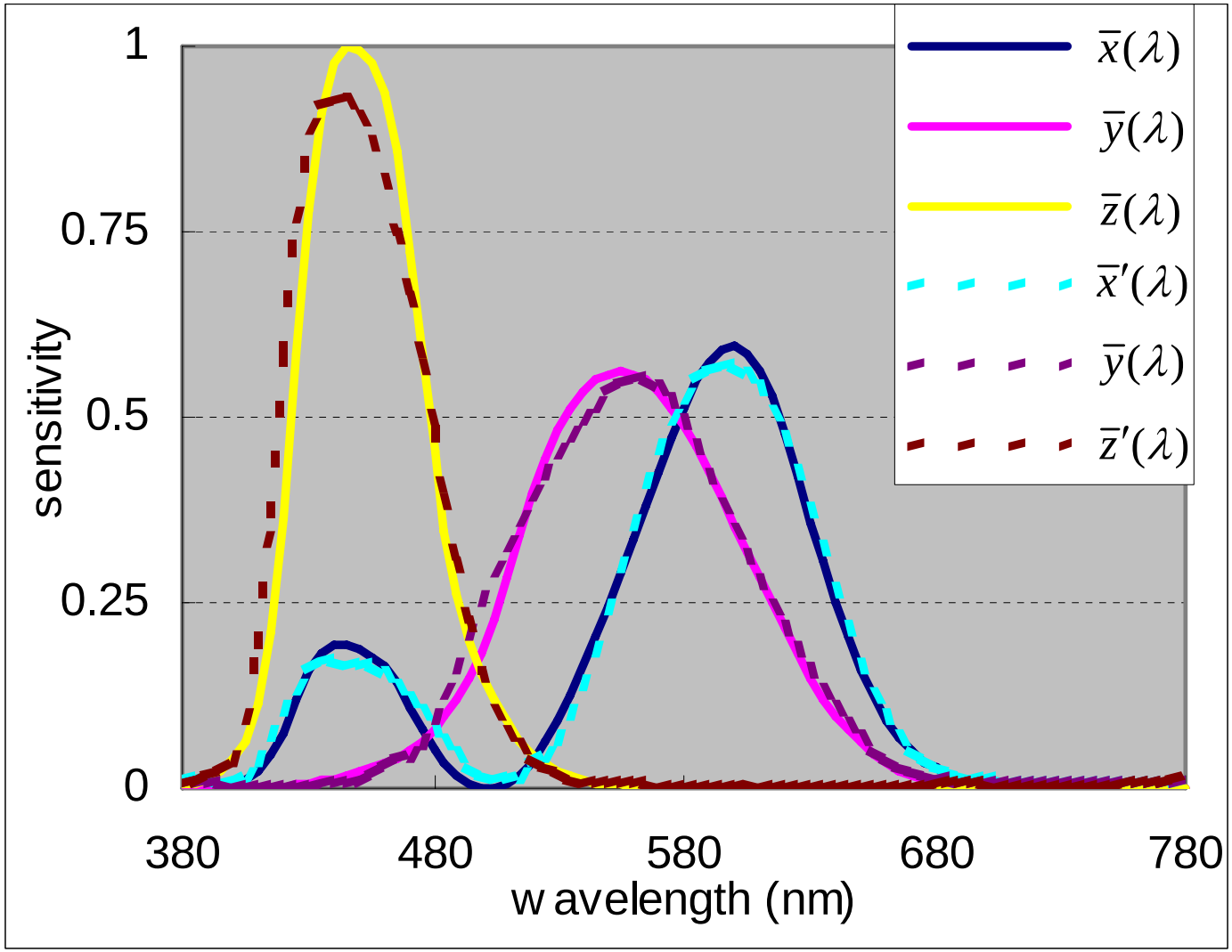


Color Filter

B/W DSC

Transmittance spectra of the color filters




1
0.75
0.5
0.25
0
sensitivity
380
480
580
680
780
w avelength (nm)
$\bar{x}(\lambda)$
$\bar{y}(\lambda)$
$\bar{z}(\lambda)$
$\bar{x}'(\lambda)$
$\bar{y}(\lambda)$
$\bar{z}'(\lambda)$

Evaluation of the spectral sensitivities

Neugebauer's quality factor

$$q = \sum_{i=1}^{3} a_i^2 \Big/ \left|\bar{s}\right|^2$$

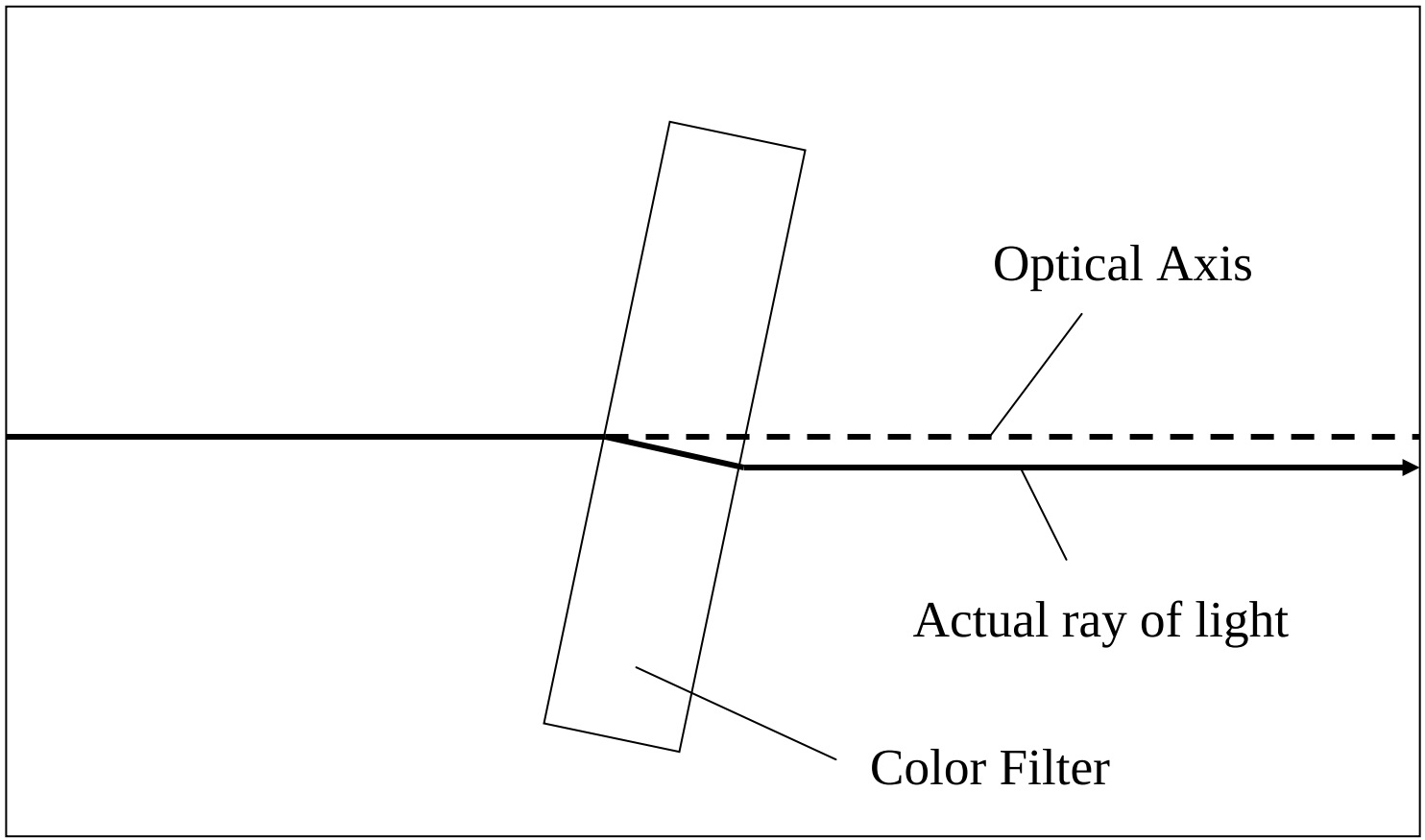
Measure of Goodness by Vora and Trussell

$$\nu \equiv \sum_{i=1}^{3} q_i \Big/ 3$$

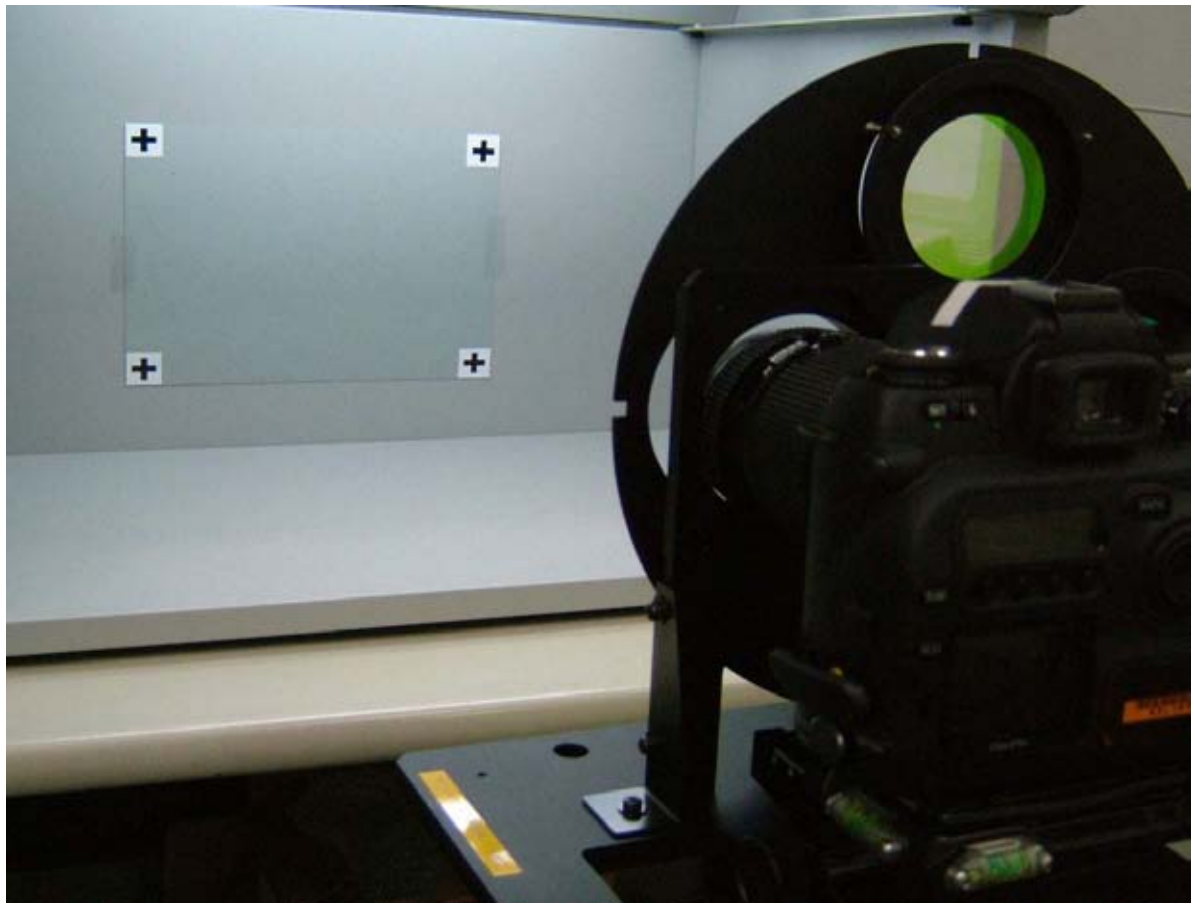
Q-factor and ν

DSC	R	G	B	ν
NEDO-DSC	0.999	0.992	0.983	0.991
DSC（Company A）	0.776	0.996	0.874	0.882
DSC（Company B）	0.813	0.941	0.848	0.867

Color registration



Registration check



Registration error

Type	Filter	X(pixel)	Y(pixel)	Rotation(deg.)
A	R B	0.025514 -0.024398	0.099484 0.014183	0.0010 0.0005
A	R B	-0.033403 -0.074217	0.038653 -0.020859	-0.0001 -0.0002
B	R B	0.012775 -0.067492	0.029657 -0.016036	-0.0005 -0.0005
B	R B	-0.032086 -0.087687	0.011866 0.055662	-0.0002 -0.0001

Data processing procedure

RAW images

Honeycomb interpolation

Interpolated image

XYZ conv.

Calibration data

XYZ image

Calibration method

Scene :
Macbeth&NCS chart
& white plate

Spectroradiometer

Chart: R_n, G_n, B_n
Plate: R_w, G_w, B_w

Tristimulus values

B/W DSC with R-CF

Chart: X_n, Y_n, Z_n
Plate: R_w, G_w, B_w

Image data

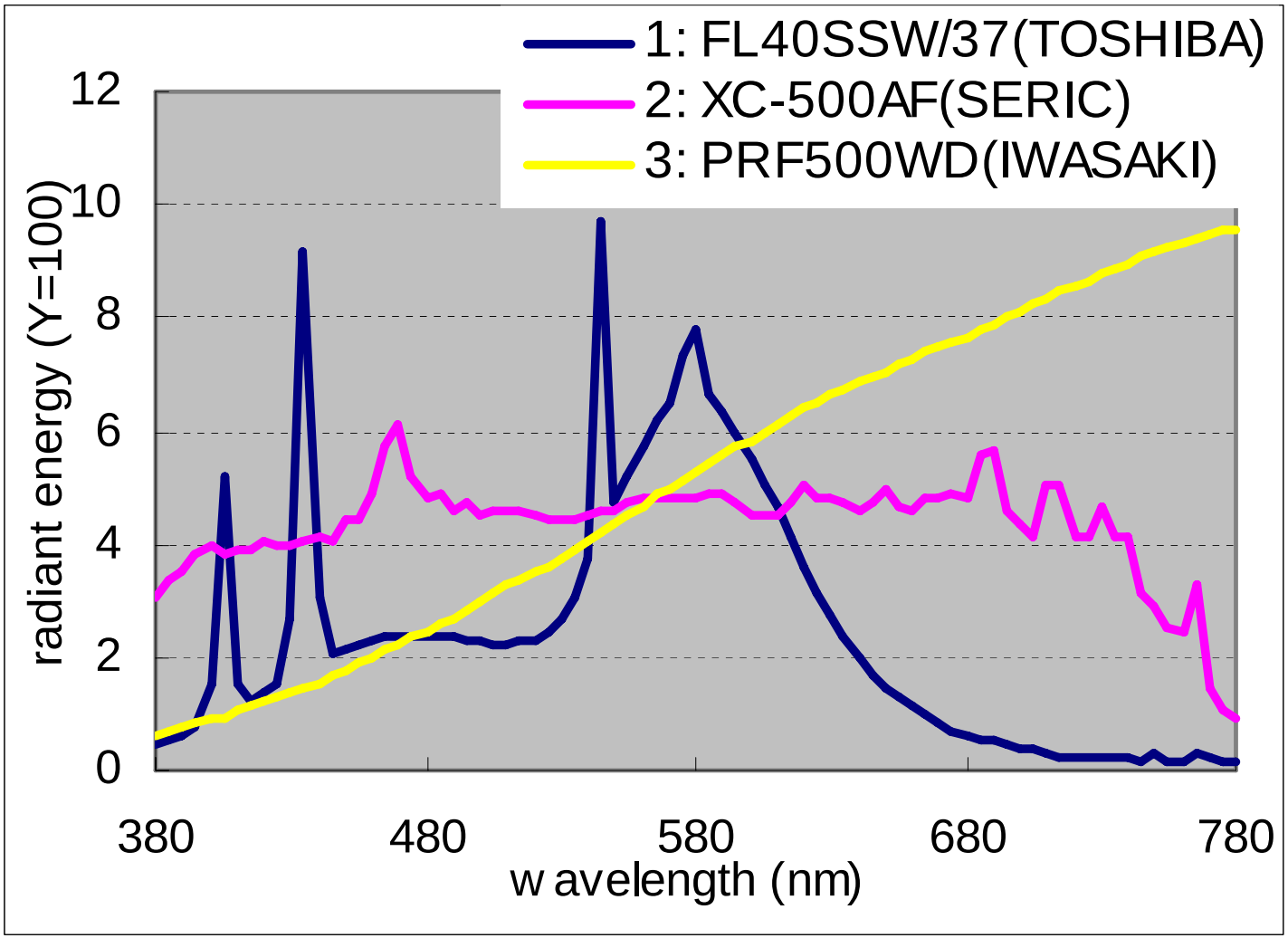
$$\begin{cases} R_n' = (R_n - \alpha)/(R_w - \alpha) \\ G_n' = (G_n - \beta)/(G_w - \beta) \\ B_n' = (B_n - \gamma)/(B_w - \gamma) \end{cases}$$

$$A = \begin{pmatrix} X_1 & \cdots & X_n & X_w \\ Y_1 & \cdots & Y_n & Y_w \\ Z_1 & \cdots & Z_n & Z_w \end{pmatrix} \begin{pmatrix} R_1' & \cdots & R_n' & R_w' \\ G_1' & \cdots & G_n' & G_w' \\ B_1' & \cdots & B_n' & B_w' \end{pmatrix}^{-1}$$

3×3 MTX: A
Correction terms: α, β, γ

Calibration data

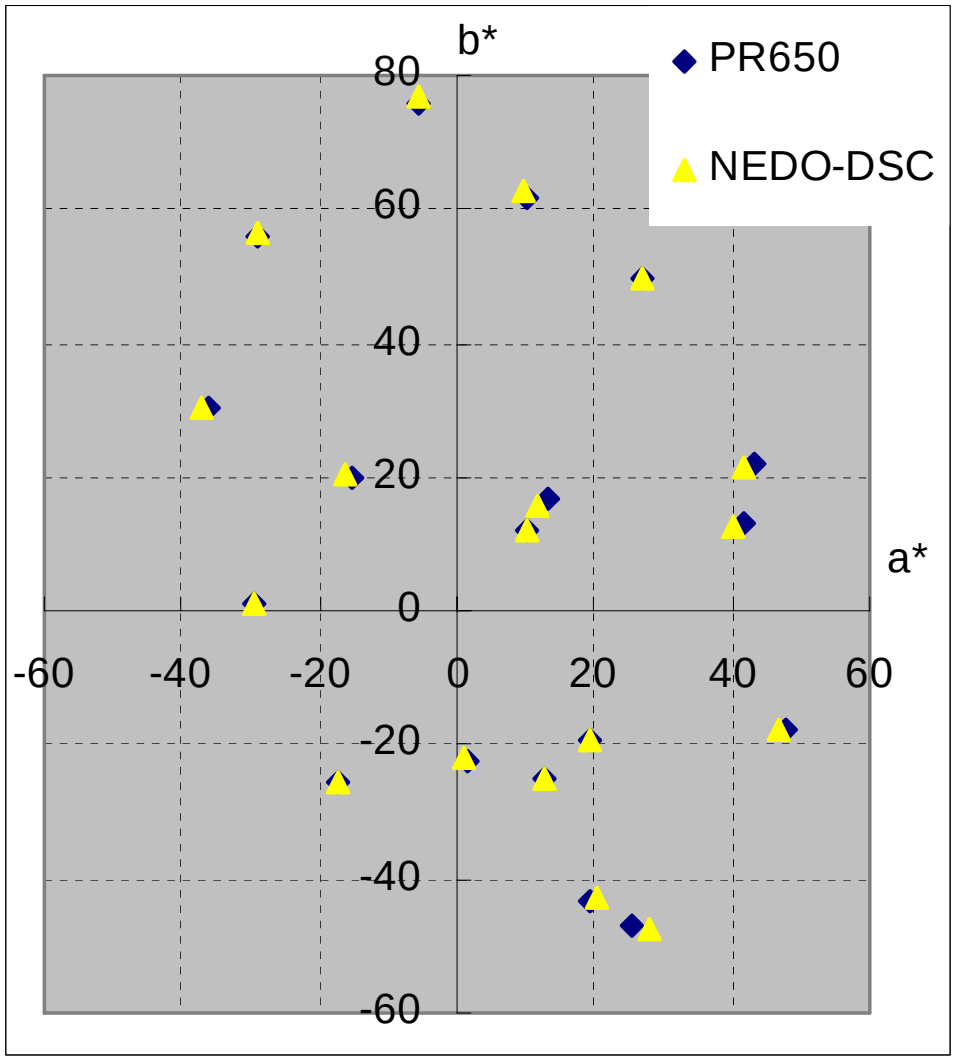
Spectra of the illuminants



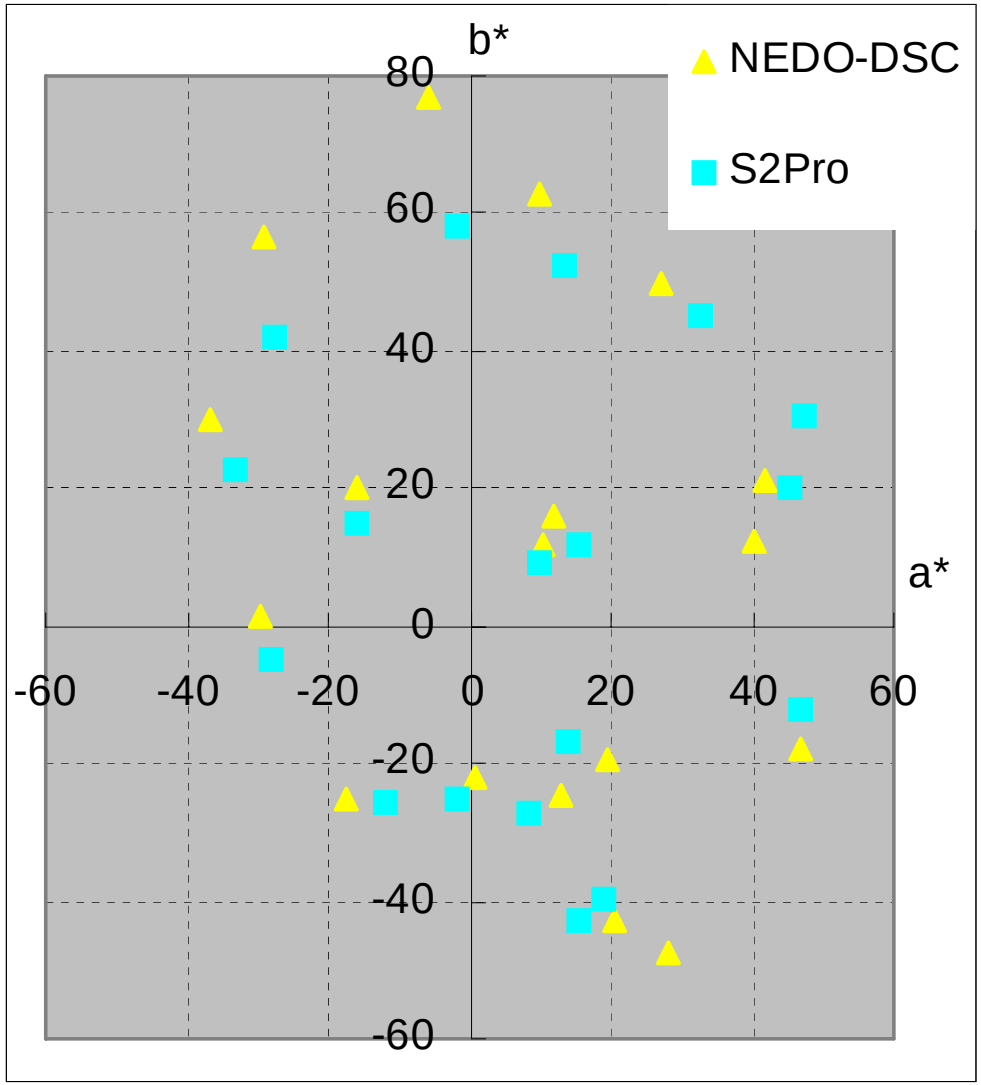
Colorimetric accuracy of NEDO-DSC

Illuminant	$\Delta\overline{E}$	$\Delta\overline{E}_g$	$\Delta E_{\max}$
1(FL40SSW/37)	1.77	0.38	6.27
2(XC-500AF)	1.86	0.54	6.25
3(PRF500WD)	2.08	0.72	7.44

Comparison between NEDO-DSC and Spectro-radiometer

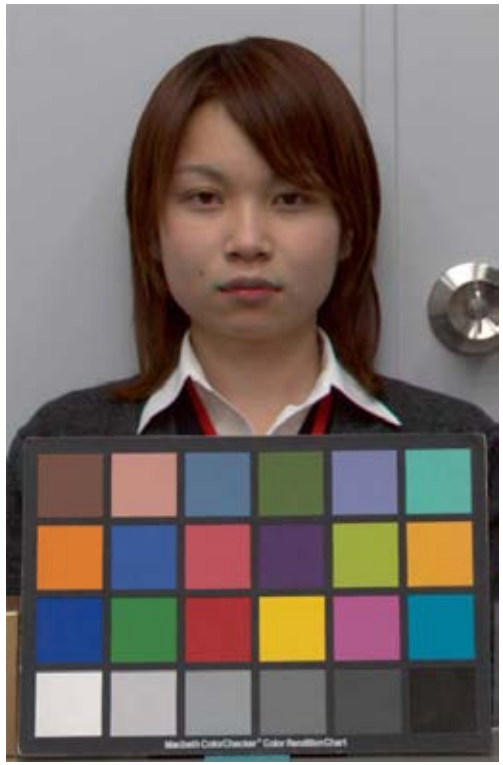


Comparison between NEDO-DSC and commercially available DSC(S2Pro)



sRGB image appearance

DSC(S2Pro)



NEDO-DSC

Conclusion

NEDO-DSC has good results as follows.

(1)Average delta-E = 1.86
to MacBeth 24 and NCS 40 colours and
Average delta-E = 0.54 to MacBeth 6 grays
under XC-500AF（SERIC） illuminant.

(2)Much better than commercially available DSC(S2Pro)
in terms of Colorimetric reproduction.

Part 2 : Its applications.
Actual scene-referred colour space using NEDO-DSC

Color gamut of actual scenes

Procedures

Scene : 5 scenes were captured using NEDO-DSC.
Each scene has extremely saturated objects including plastics, textiles and so on.

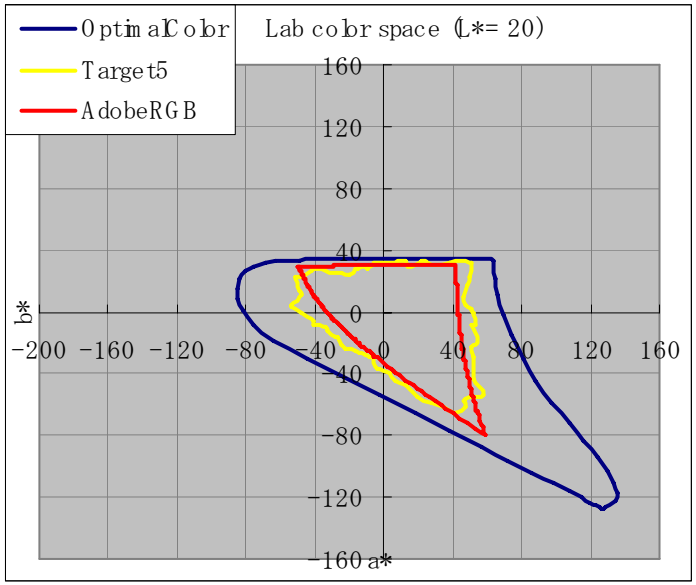
Calibration targets : Macbeth(24), NCS(40) and W-plate

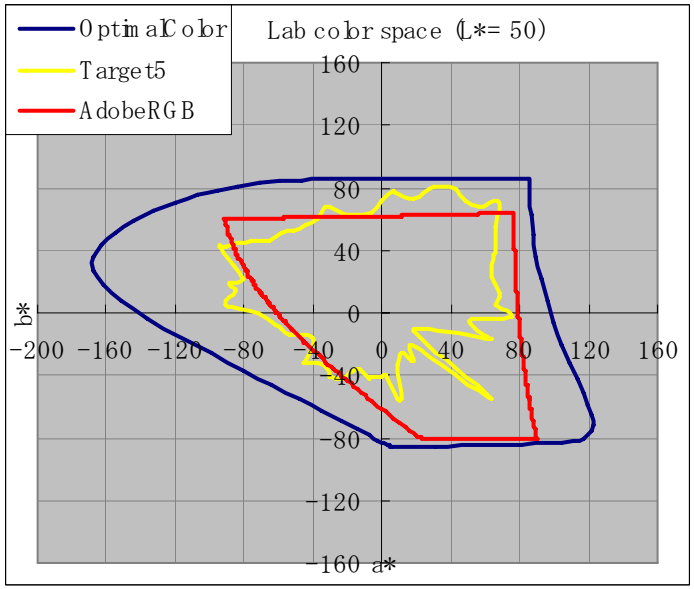
Calculation : Most saturated colors of each scene were calculated in L* in every deltaL*=10 and Hue in every 10 degree.

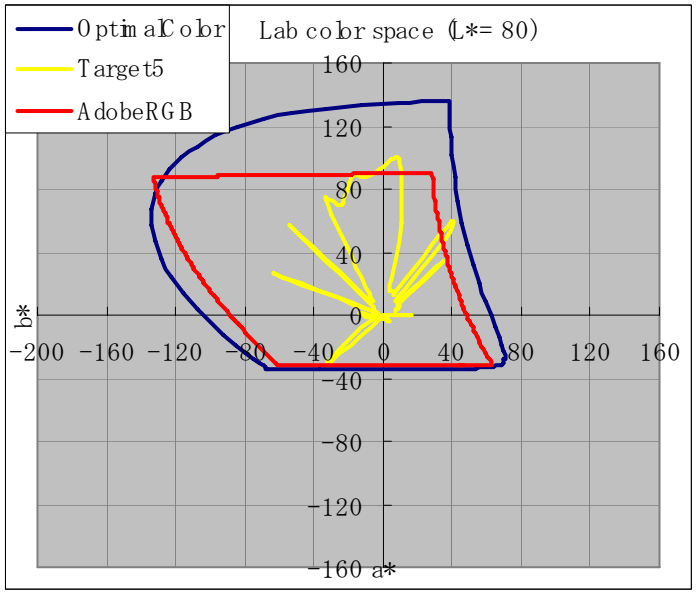
Then, outer most boundary(Maximum C* of 5 scenes) were calculated and plotted in next slides.

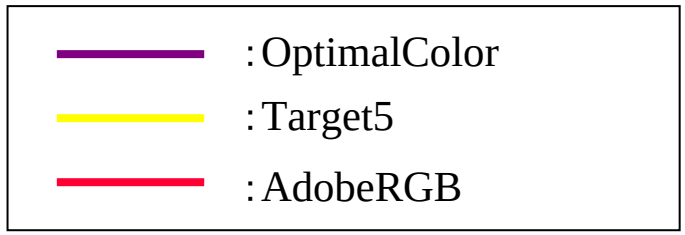
Five scenes

Actual scene-referred color gamut（D65）

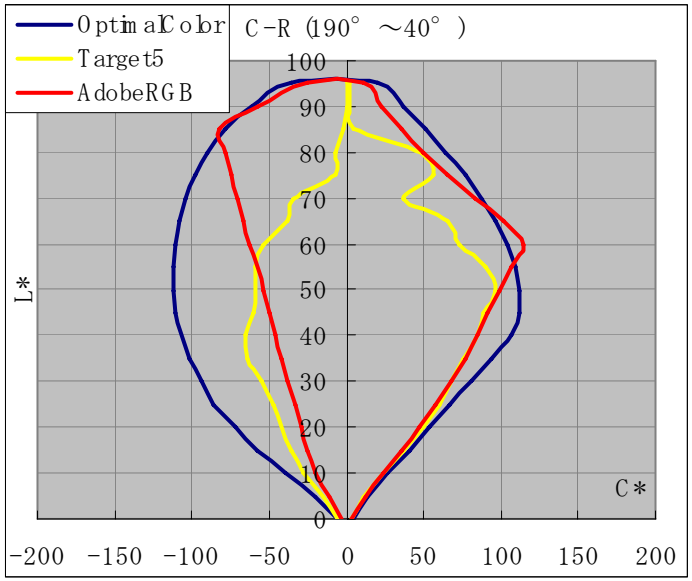


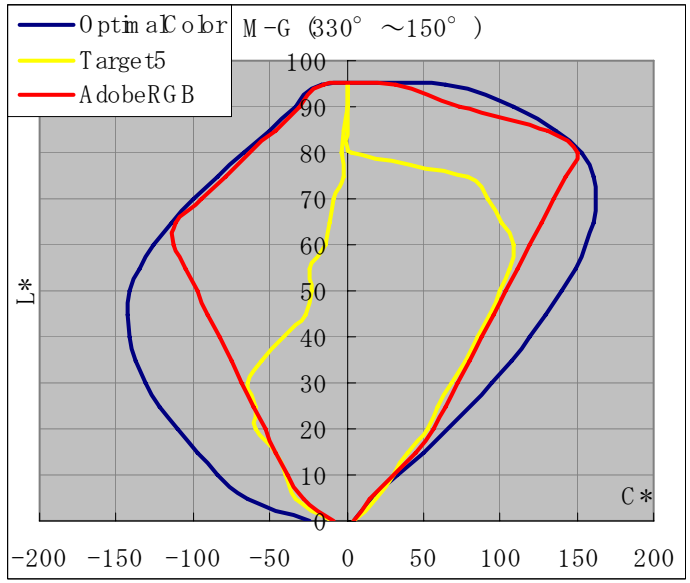


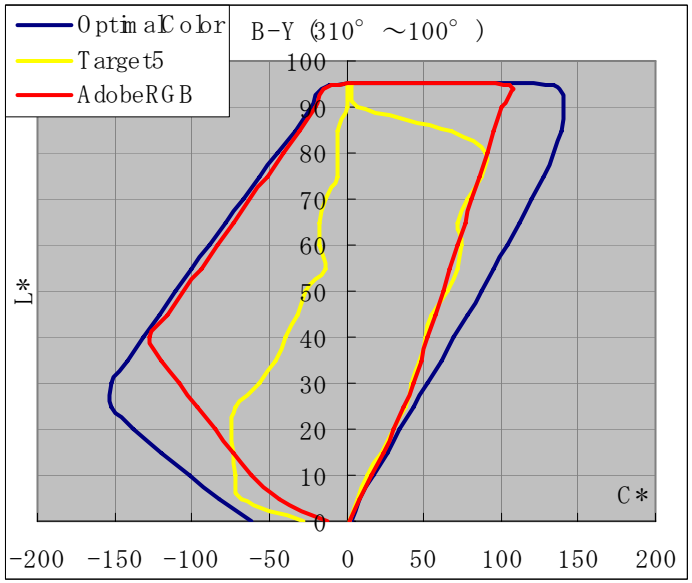


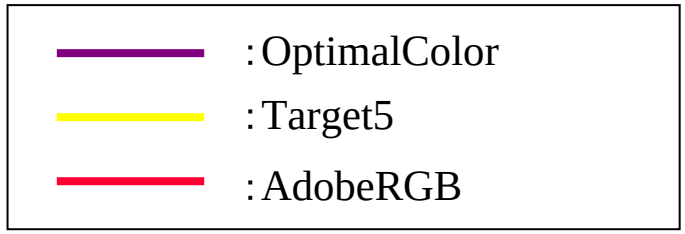


Actual scene-referred color gamut（D65）









Part 2 : Its applications.
In case of transmissive and fluorescent objects

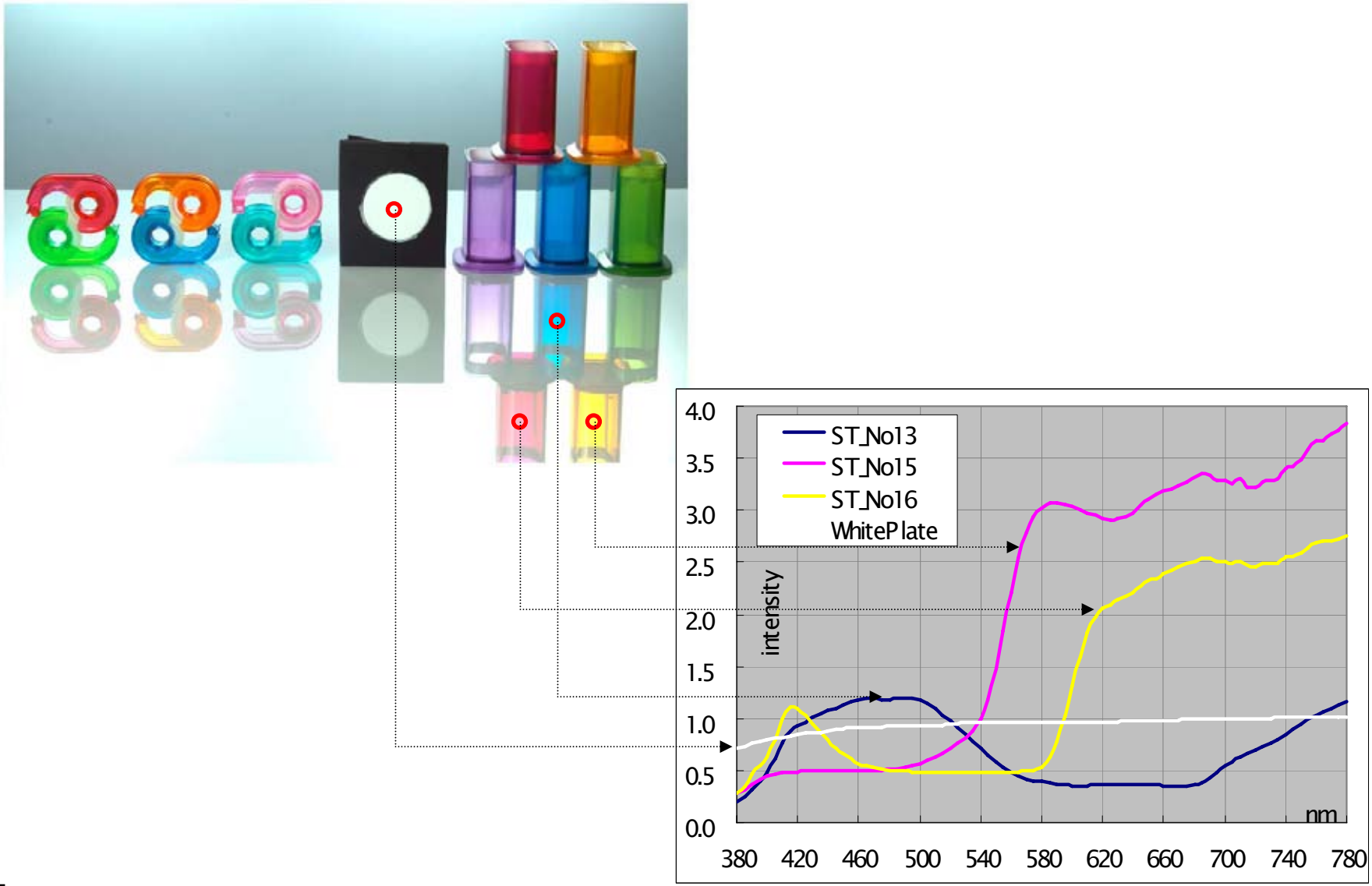
Eight semi-ransmissive scenes





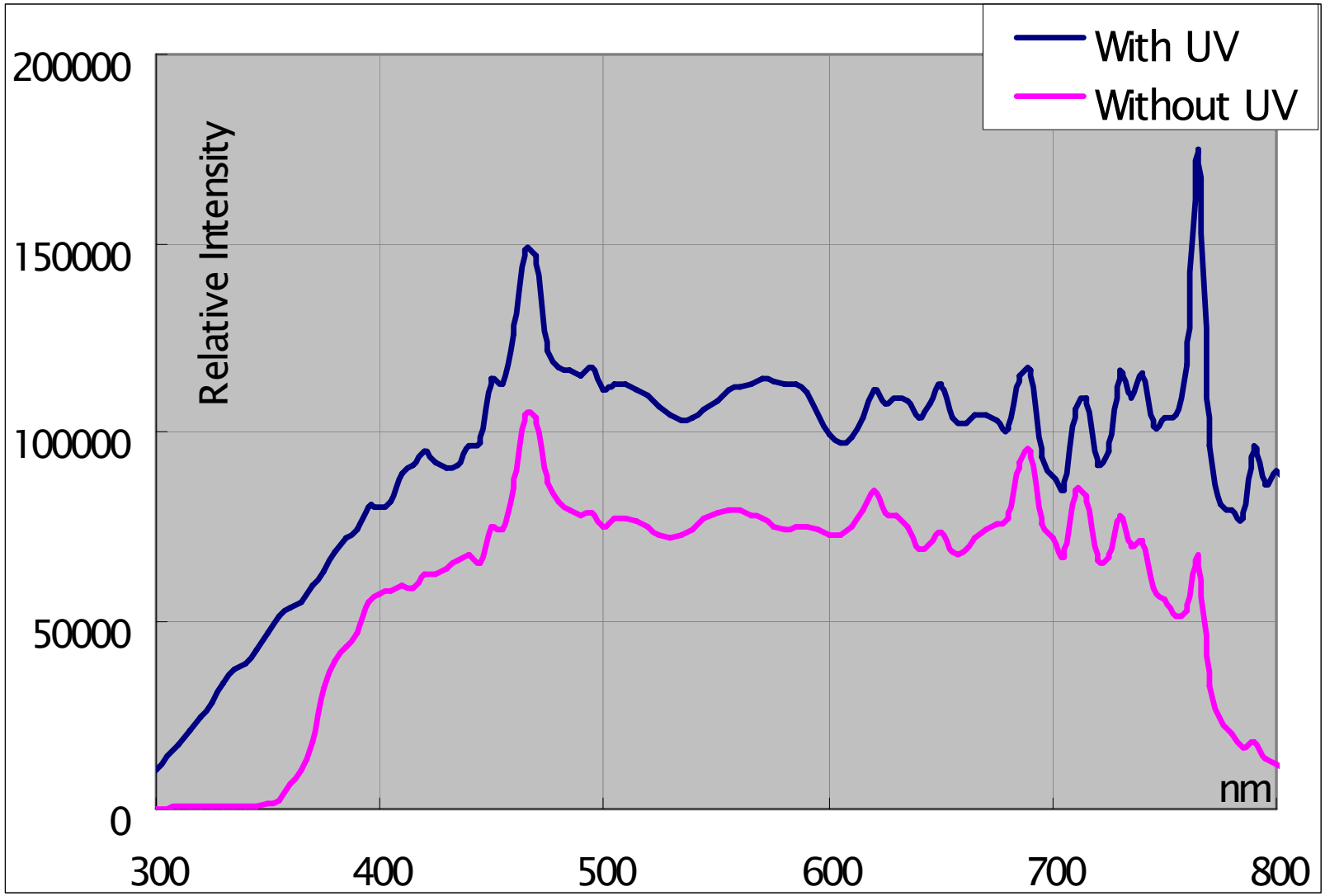



Spectral distribution of semi-transmissive objects



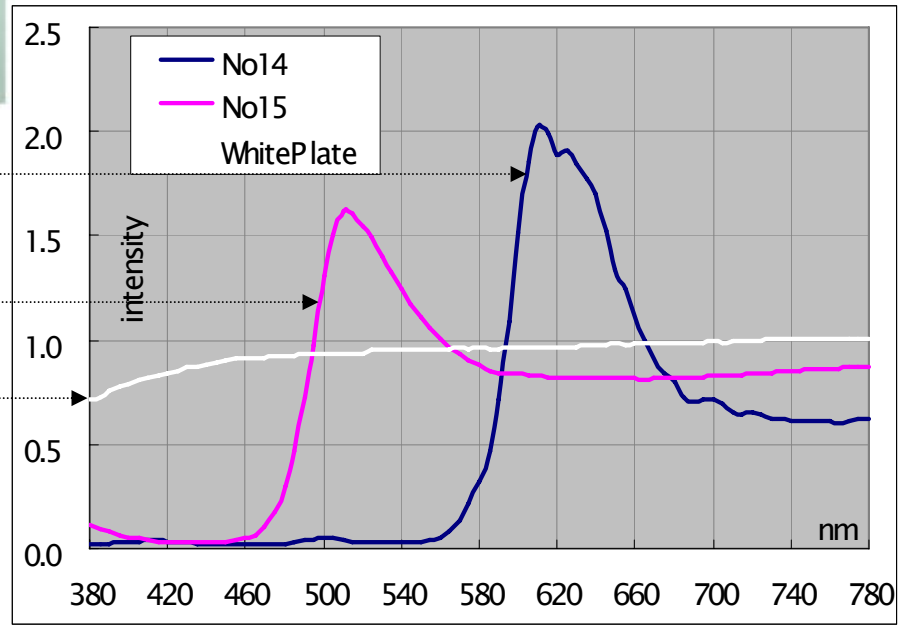
Part 2 : Its applications.
Actual scene-referred colour space using NEDO-DSC

Spectral distribution of UV illuminant



Four fluorescent scenes

Spectral distribution of fluorescent objects



Future Challenges

To define actual scene-referred colour gamut

To develop estimating method of colorimetric characteristics of high-end RAW-DSCs

Acknowledgement
This research was organized in part by the New Energy and Industrial Technology Development Organization, Japan(NEDO).

Thank you for your attention.