The Effect on Gamut Expansion of Real Object Colors in Multi-primary Display

Chang, Chun-Kai

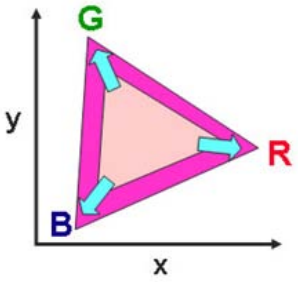
Chiba University

Feb. 1, 2013

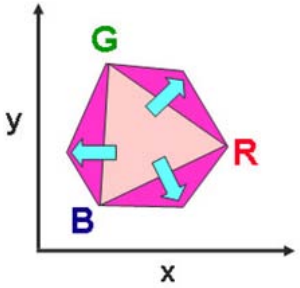
Background

- There are two main techniques to extend a LCD's color gamut:

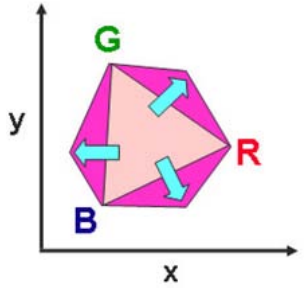
1. **Improving purity of RGB primaries**

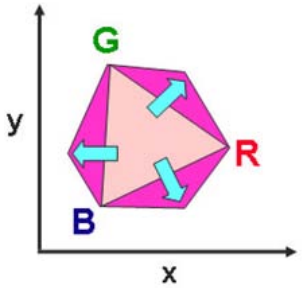


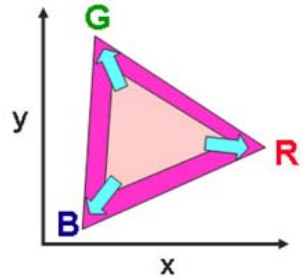
2. **Adding more color primaries other than RGB.**



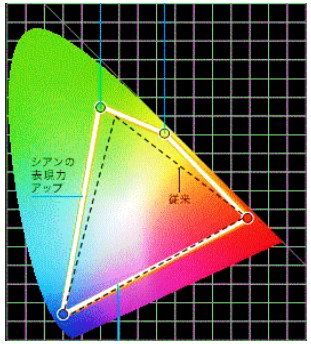
Introduction

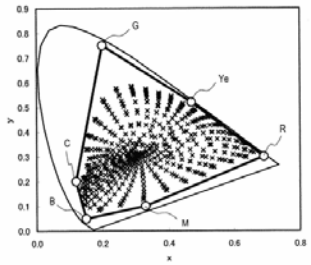




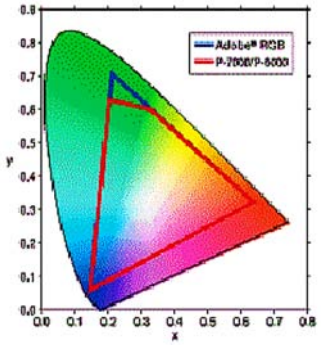


Sharp

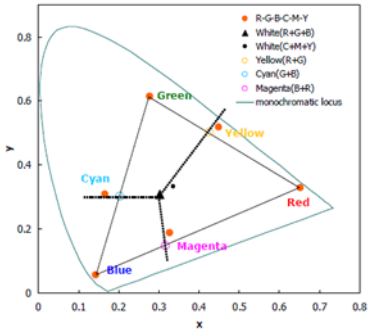




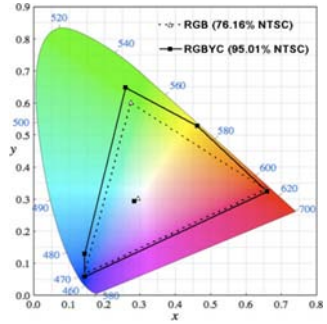
Epson

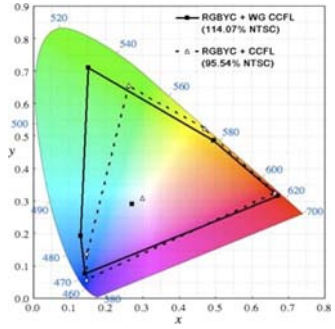


Samsung



Five primary





Topics

1. The introduction of six-primary algorithm.
2. The optimization method of six-primary.
3. The evaluation of gamut expansion in Real object colors.

- The introduction of six-primary algorithm.
- The optimization method of six-primary.
- The evaluation of gamut expansion in Real object colors.

Sun, P. L., H. S. Chen., C. K. Chang. 2008. Six-primary LCD color separation for wide-gamut xvYCC images. The 15th International Display Workshops: 1425-1428

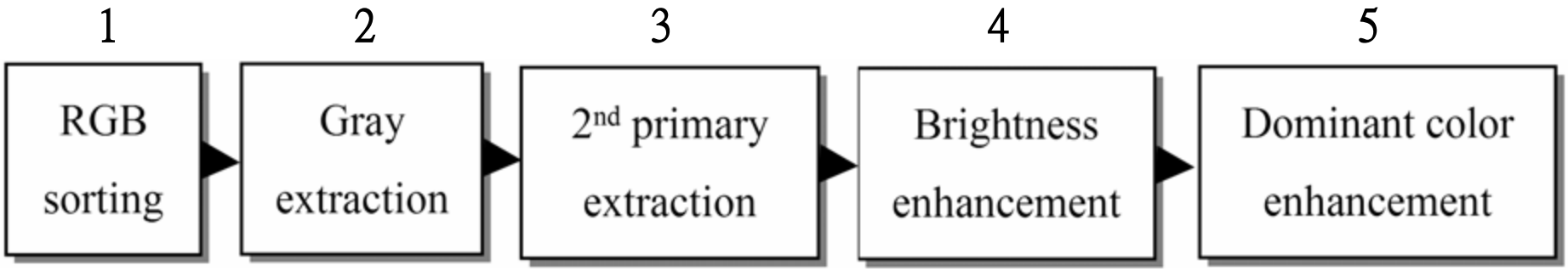
Purpose

- We propose a method developing six-primary color signals.
  - It contains two stages:

    (1) RGB-to-RGBCMY conversion

    (2) a optimized transform matrix based on above data.

Color separation flowchart



- Five major steps in the RGB to RGBCMY conversion.

Multi-primary environment transfer

Three-primary (*R,G,B*) → six-primary(H',E',L',H_c',E_c',L_c')

RGB sorting

$$H = \max(R,G,B)$$
$$E = \text{median}(R,G,B)$$
$$L = \min(R,G,B)$$

Equation1

$$if\ H = L\ then \begin{cases} R' = G' = B' = L \\ C' = M' = Y' = p \cdot L \end{cases}$$

Gray extraction

$$otherwise \begin{cases} L_C = E - L \\ H' = H - (1-p) \cdot L_C \\ E' = L + p \cdot L_C \\ L' = L \end{cases} \quad \begin{cases} H_C' = p \cdot L \\ E_C' = 0.5p \cdot (H + L - L_C) \\ L_C' = E_C' + L \end{cases}$$

2nd primary extraction

R, G, B

Equation2

C, M, Y

- When *H=L* , the color is shown as achromatic color.

RGB-to-RGBCMY conversion

Color Primaries

Brightness enhancement

- Both RGB and CMY white points are D65.
- Luminance ratio of RGB and CMY white points are **1:1.5**.

- RGB: Adobe **RGB**.
- CMY: Increase purity of secondary colors on (x,y) chromaticity diagram.
  1.4, **1.2** and **1.1** for C, M and Y respectively.

Dominant color enhancement

White Point Mapping

- We define the p as follows

p=0

- six-primary display will be much darker than normal RGB displays

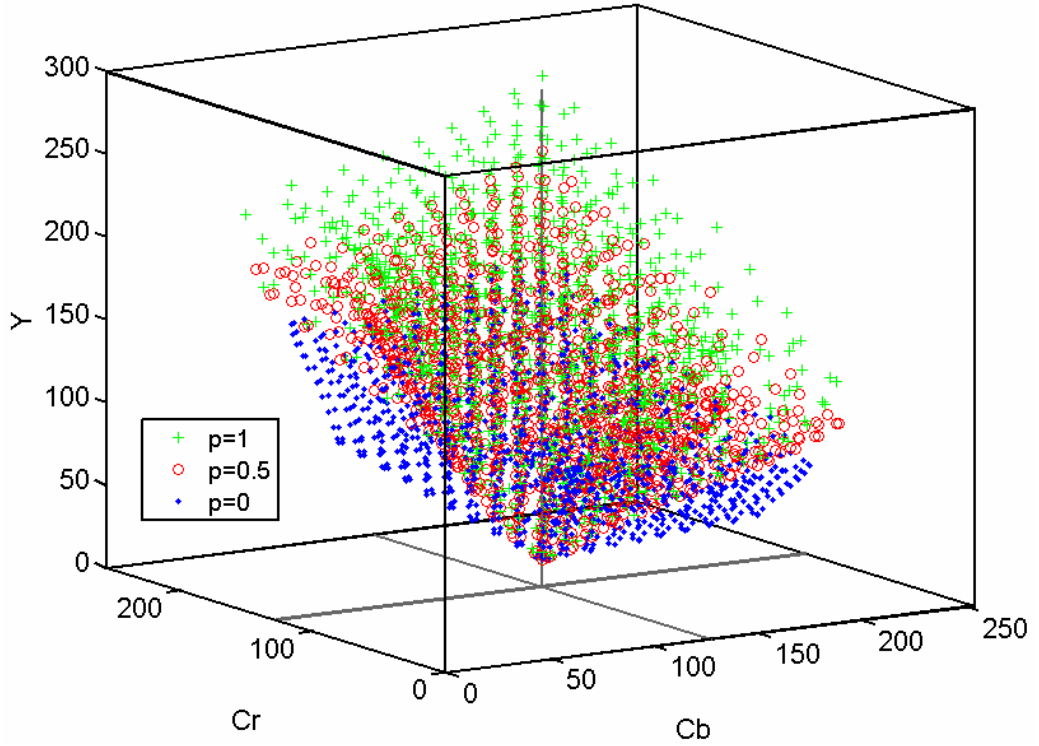
p=1

- will result in great gamut mismatch between the six-primary display and the sRGB standard.

p=0.25

- In this condition, our full 3D six-primary display gamut volume is 168% to sRGB in LAB space.

Sub-gamut in xvYCC space



Bright(P=1)

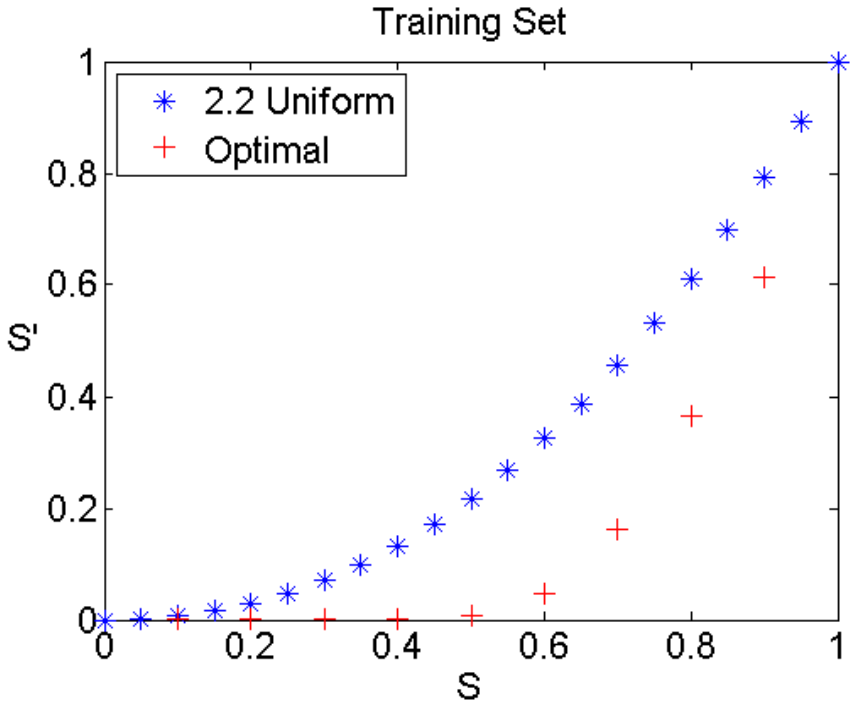
Saturate(P=0)

The p-factors are 0, 0.5 and 1 for saturate to bright sub-gamut.

Optimal Training Set

$$S' = 0.8 \cdot S^{11.5-10p}$$

Equation 3



- Applying this equation instead of the 2.2 gamma, using p=0.1 to 0.9 at 0.1 interval.
- The **mean** and **maximum** errors can be reduced to **0.8** and **6.8**.
  - S represents RGB signal with [0 1] range and S' is its modification.

Multi-Transfer Matrices

Single transfer matrix, gives bad results. → Multi matrices

1. K matrices for transformation

2. The i-th matrix was derived by the sub-gamut with

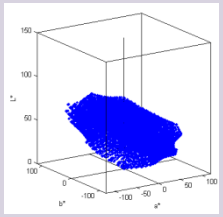
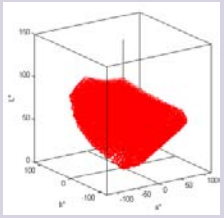
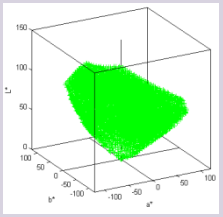
   p =(i-1)/(K-1) , $i \in [1,2,\cdots,K]$

Example : K=3

1st matrix using p=0

2nd matrix using p=0.5

3rd matrix using p=1

p= 0	p=0.5	p=1
		

Result

When k=3, the p=[0, 0.5, 1].

When k=6, the interval of p from 0 to 1 is 0.2.

When k=11, the intervals is 0.1 the multi-matrieces models are slightly better than the single-matrix model.

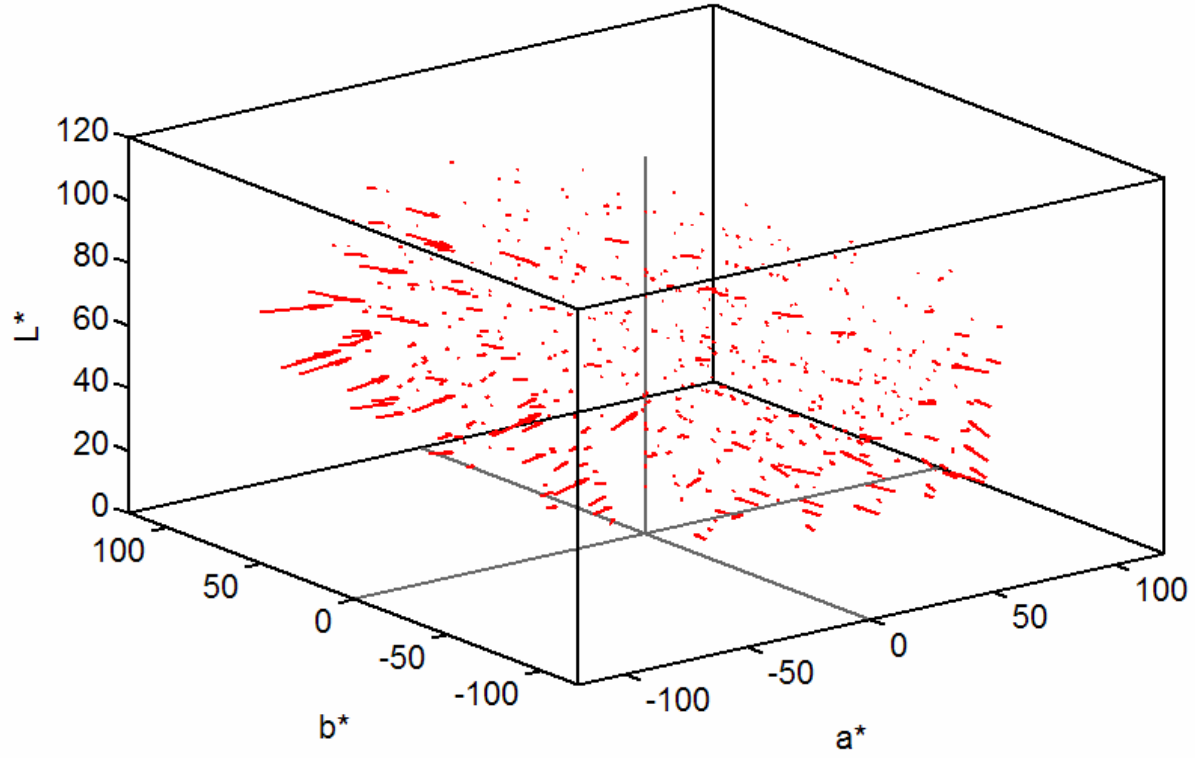
The errors slightly reduce when the number of "k" increase.

Unit: CIEDE2000		Mean	SD	Max.
Single matrix		0.86	0.78	6.89
Multi-matrices	*k*=3	0.89	0.85	6.60
	k=6	0.79	0.72	6.18
	k=11	0.77	0.71	5.90

Decrease

Conclusion

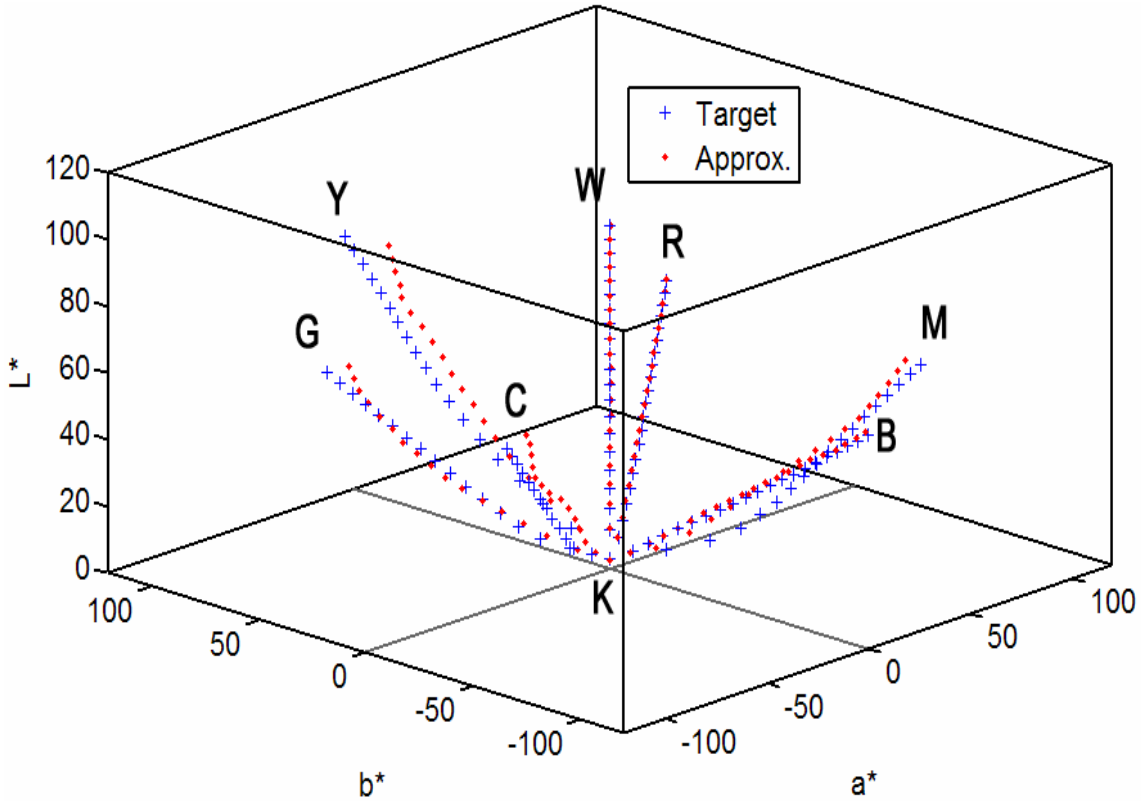
1.Accuracy in matrices model



The start and the end points of the arrows represent target and approximate colors respectively.

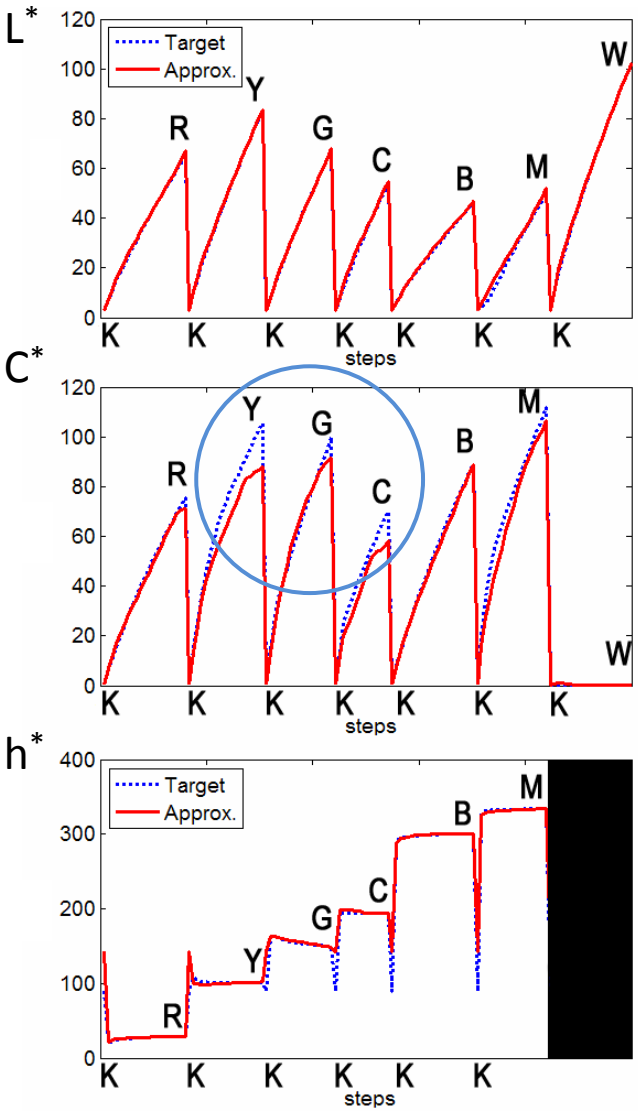
Conclusion

2.Accuracy of seven tones



Seven tones from black to RGBCMYW primaries in p=0.5 sub-gamut.

3.Seven tones in CIELCH color space



The accuracy and smoothness of the seven tones.

- The introduction of six-primary algorithm.
- The optimization method of six-primary.
- The evaluation of gamut expansion in Real object colors.

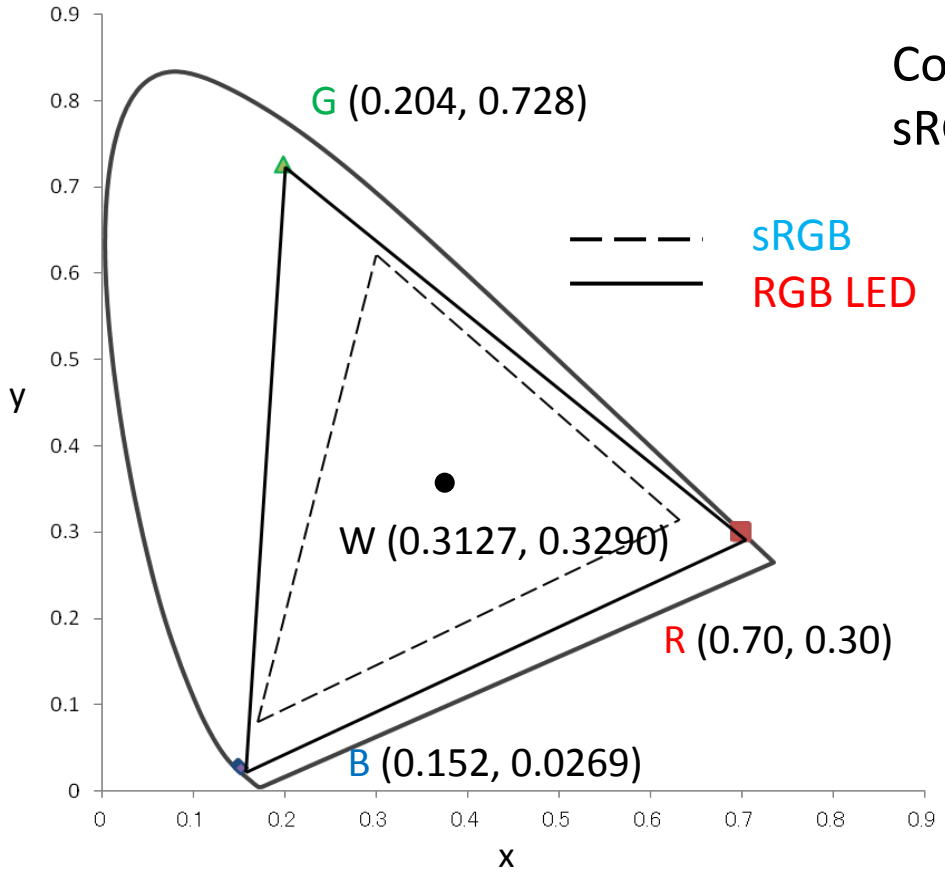
C. K. Chang, H. Yaguchi, Y. Mizokami 2011. Enhancement Methods in sRGB to Six-primary LCD color space. The 18th International Display Workshops: 1307-1311

Purpose

- Simulating a LED as a backlight to expand the whole gamut of six-primary display.
- Deriving some algorithms to optimize the colors of six-primary.

sRGB color gamut expansion

4.Result



Comparison between sRGB & RGB LED

Comparison of sRGB and LED

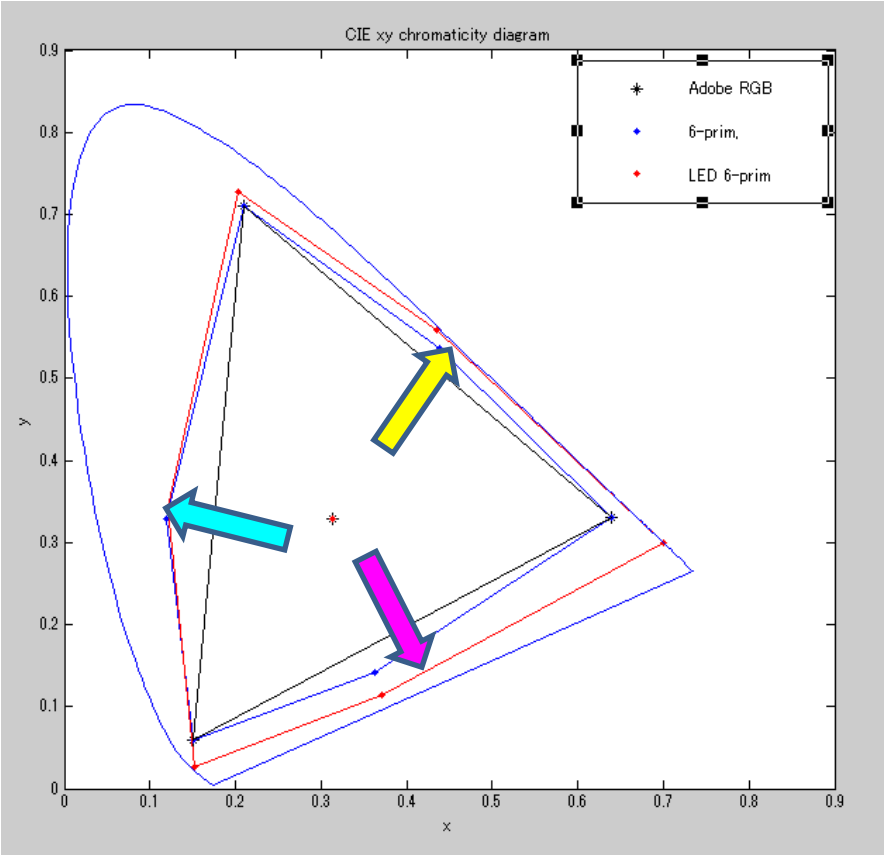
sRGB original

LED RGB

Six-primary comparison

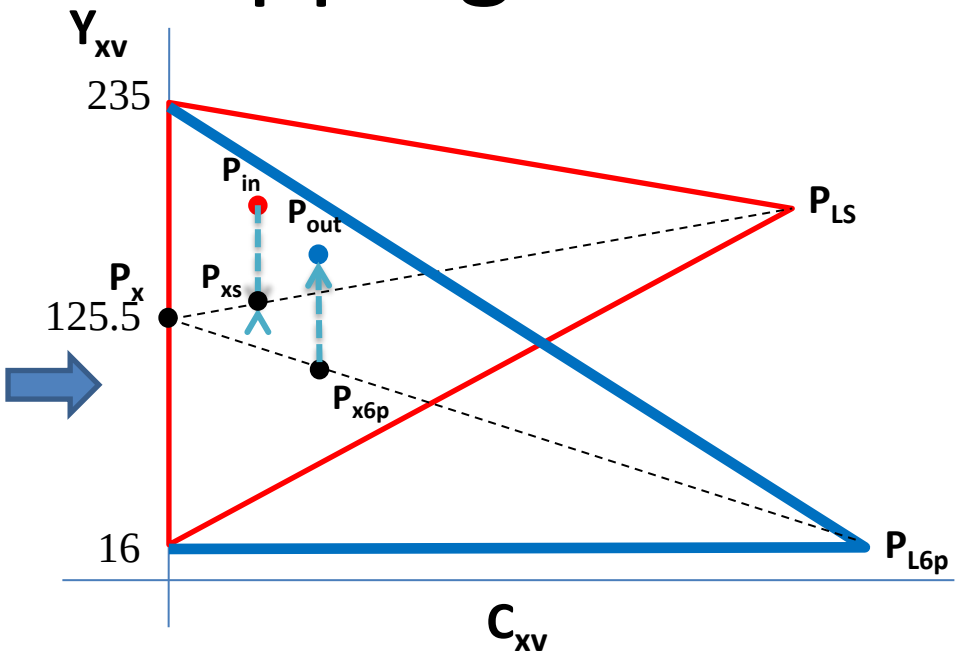
Six-primary & LED Six-primary

Gamut



Gamut mapping

$$\begin{cases} L = Y \\ C = \sqrt{(C_b - 128)^2 + (C_r - 128)^2} \\ H = \text{Arctan}\left(\dfrac{C_r - 128}{C_b - 128}\right) \end{cases}$$



- Using xvYCC color space to simulate CIELAB color space, then convert into CIELCH color space
- Finding the cusp of two color spaces, it can easily derive the new colors according to proportional relationship

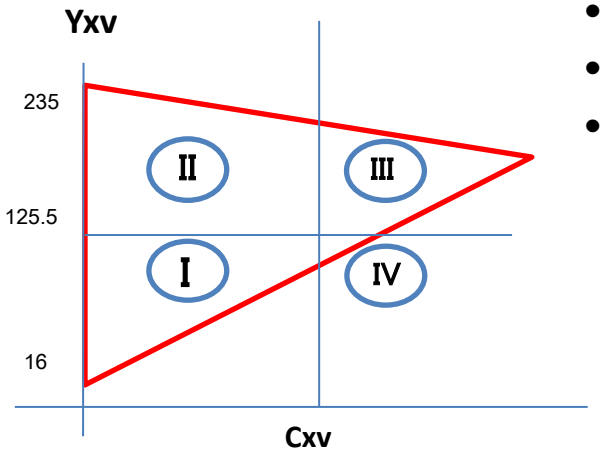
$P_{in} \rightarrow P_{xs} \rightarrow P_{x6p} \rightarrow P_{out}$

Specialized Gamut mapping

II High lightness and low chroma

- White, light gray.
- Set the factor as 0.9

$$G * Factor$$



III High lightness and high chroma

- Cyan, yellow, magenta,
- human eyes always pay attention
- Set the factor as 0.8

I Low lightness and low chroma

- Black, dark brown.
- Can't easily make differences.
- Set the factor as 1.0

IV Low lightness and high chroma

- Dark blue, dark purple.
- Low lightness, changes can't easily be detected.
- Set the factor as 1.1

Result

Original

Enhanced methods

Conclusion

- The result suggests that our proposing method is better.

  -But there are also some problems need to solve.
- Such as the lightness problem and so does the skin color problem.
- We think multi-primary display is a high-end technology and we hope that it will became prevalent in one day.

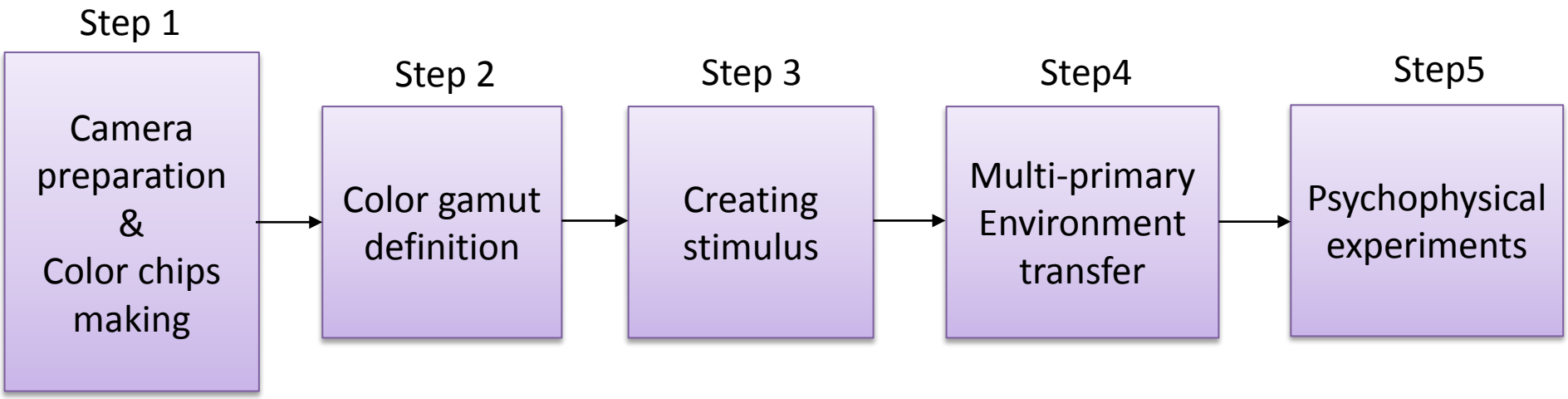
- The introduction of six-primary algorithm.
- The optimization method of six-primary.
- The evaluation of gamut expansion in Real object colors.

C. K. Chang, H. Yaguchi, Y. Mizokami. 2012. The Effect of Gamut Expansion Ratio on Delicious-looking. Journal of Color Science Association of Japan 36: 218-219.

Purpose

- We investigate the delicious-looking foods under multi-primary environment.
  - By examining relationship between color enhancement and delicious-looking foods under six-primary environment.

Experiment flowchart



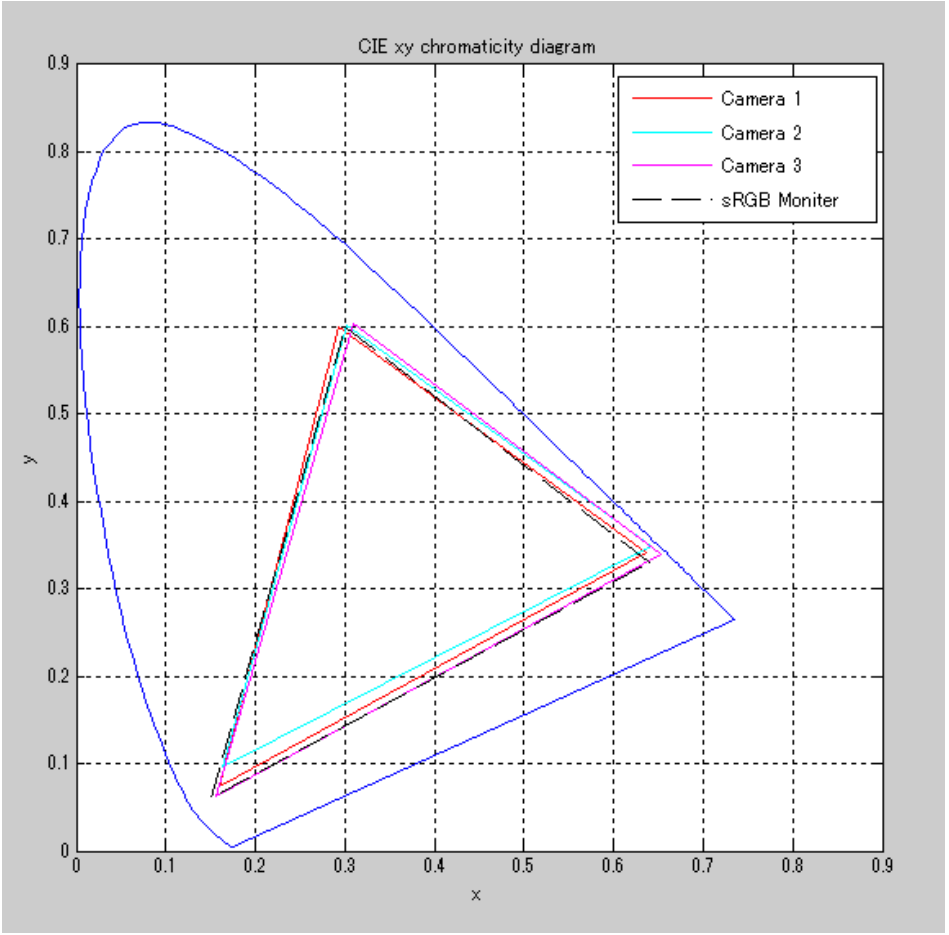
Cameras and each color gamut

AdobeRGB sRGB

Camera 1

Camera 2

Camera 3



Creating Stimulus

Stimulus-type

Pineapple Loquat Wax apple Peach

Plum Carambola Guava

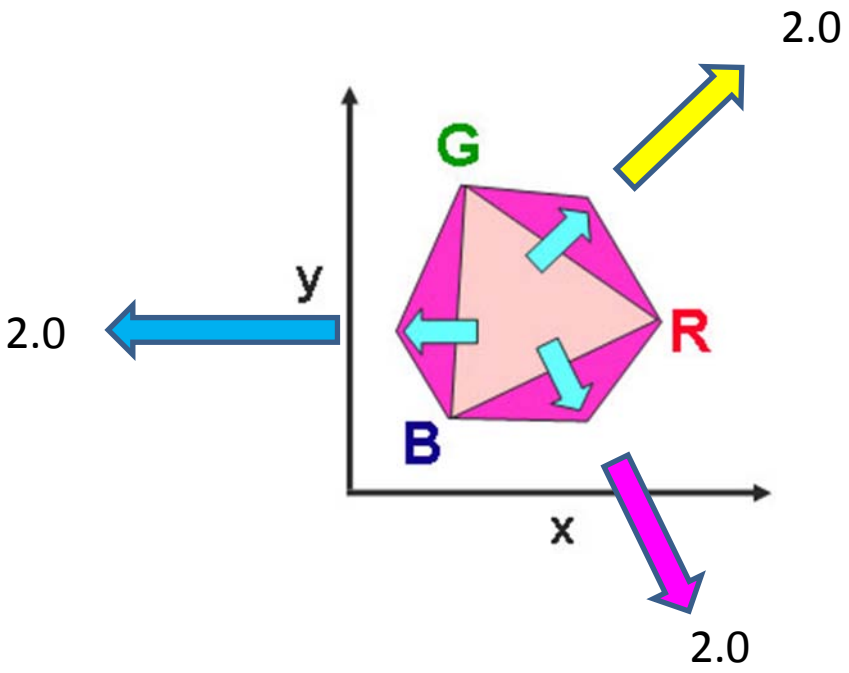
D65

45°

- Each image was taken under the same illumination, the same angle.

- Ratio expansion

We expanded each rate of gamut in Y,C,M directions in 1.2-2.0 times (k = 1.2, 1.4, …, 2.0)



- Ratio expansion

RGB image

Six primary image

k= 1.2

k= 1.4

k= 1.6

k= 1.8

k= 2.0

- Psychophysical experiments

  Interface

Better

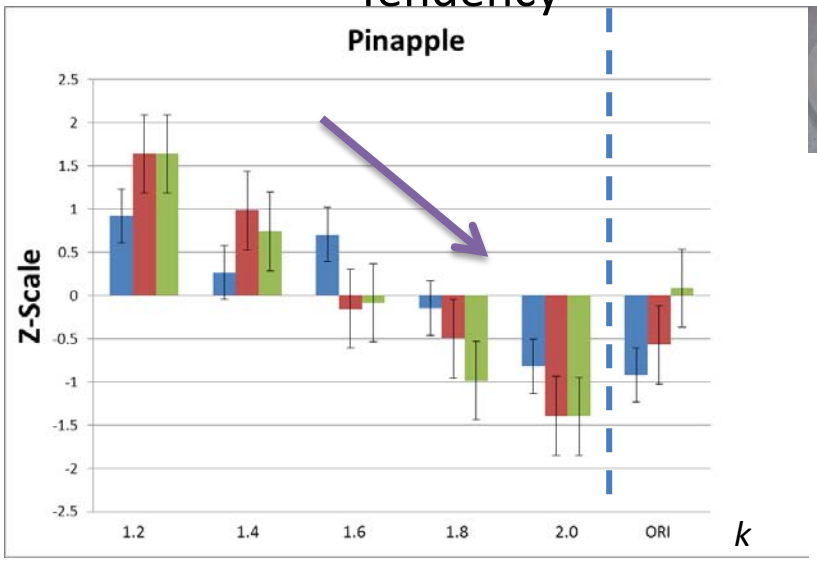
Undo

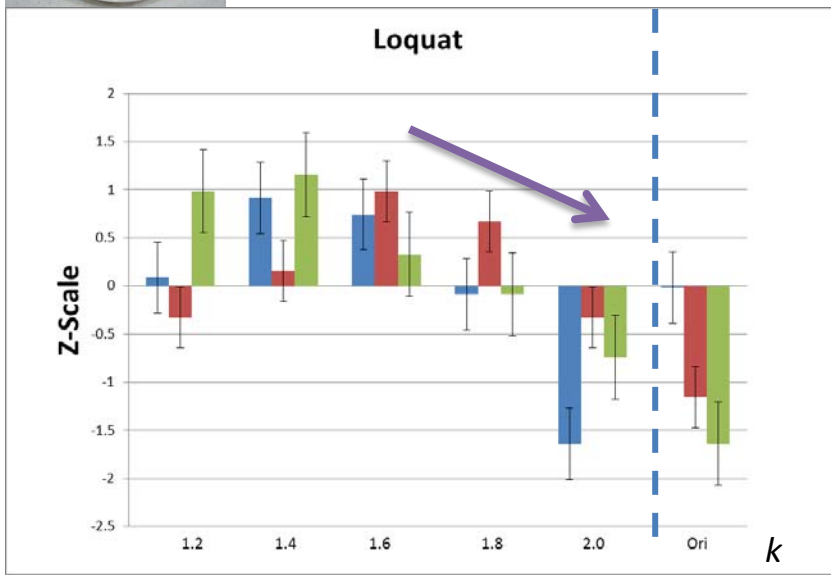
Better

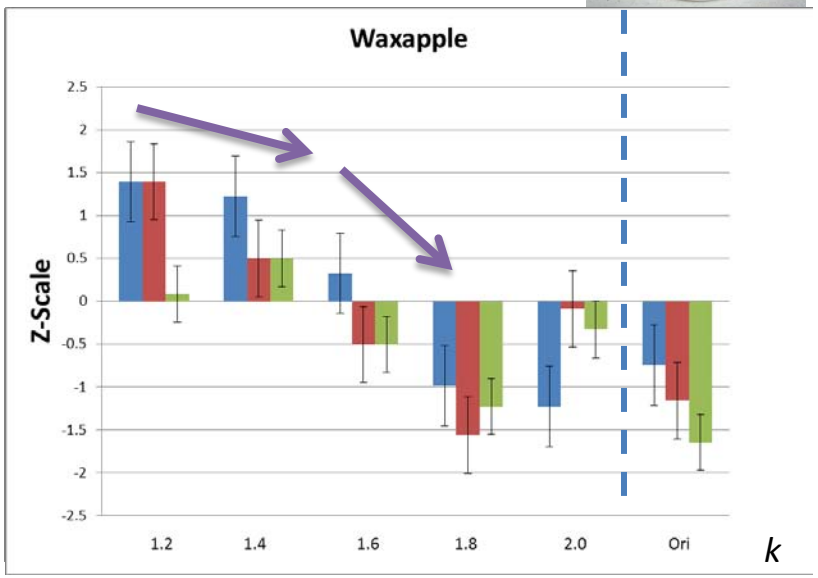
Result & discussion

Tendency

Camera 1
Camera 2
Camera 3

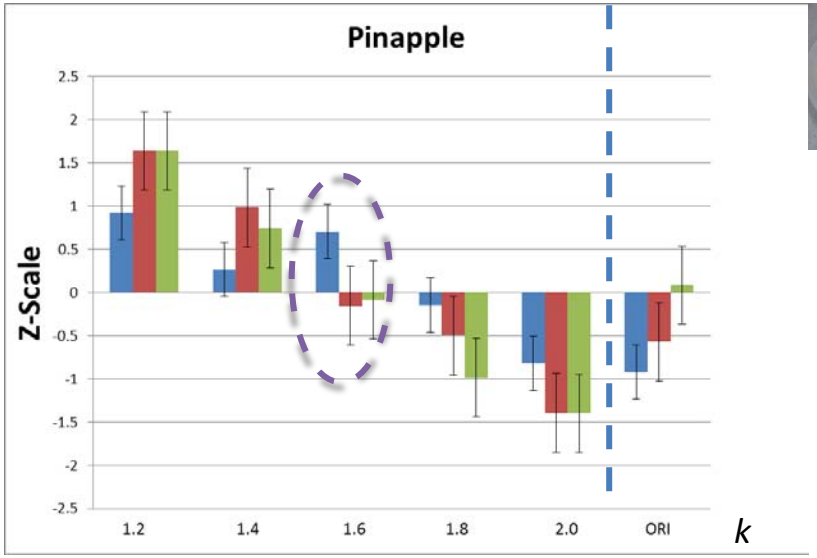


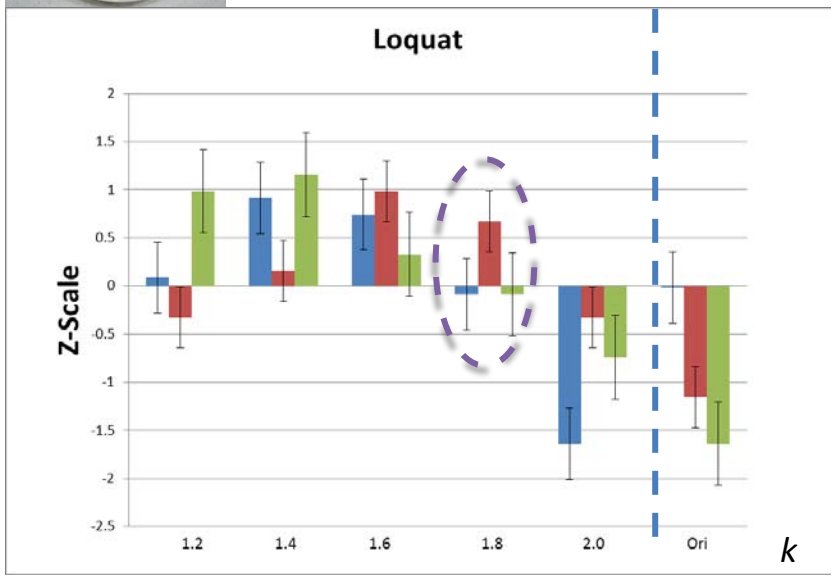


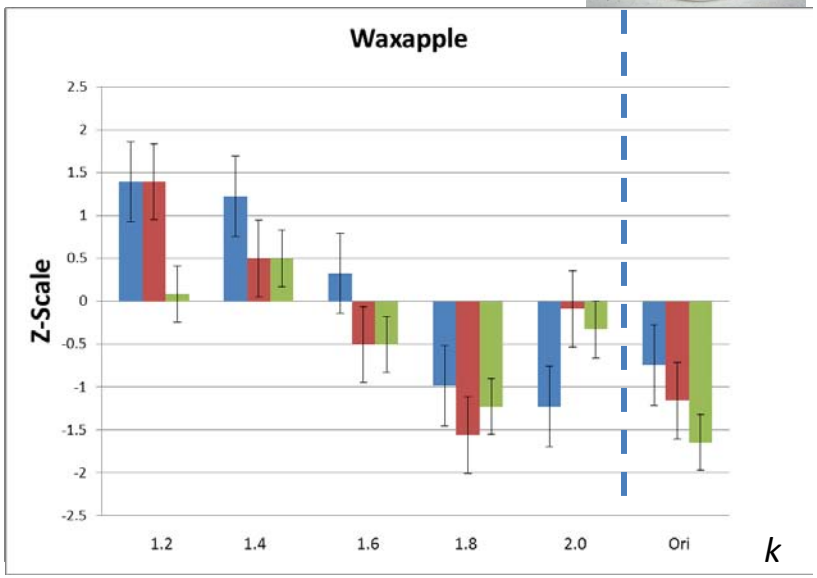


Camera sensitivity

Camera 1
Camera 2
Camera 3

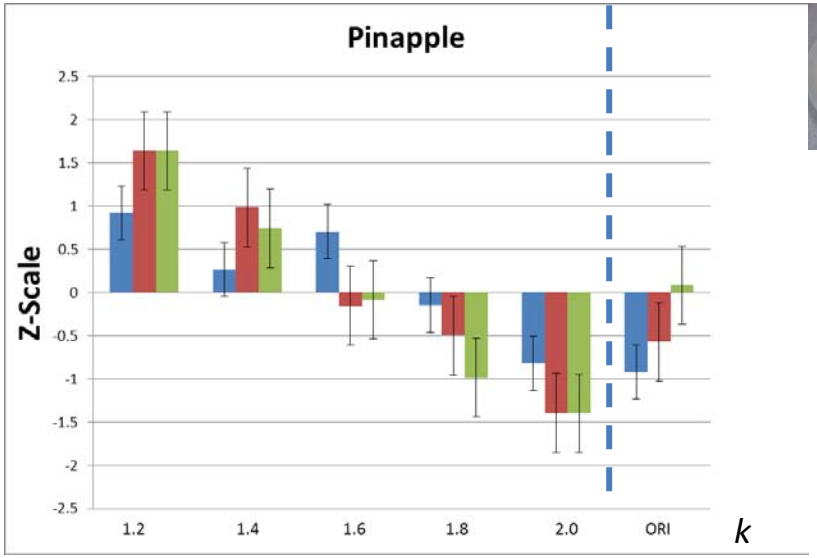


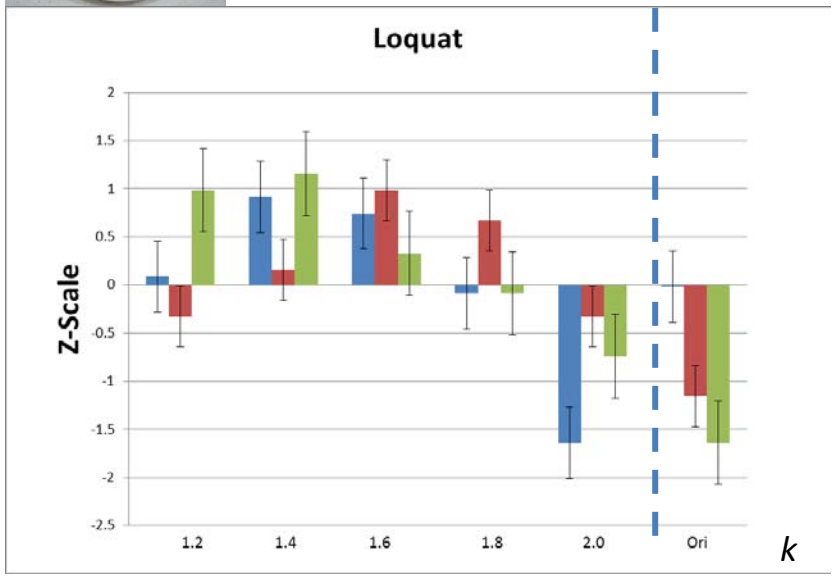


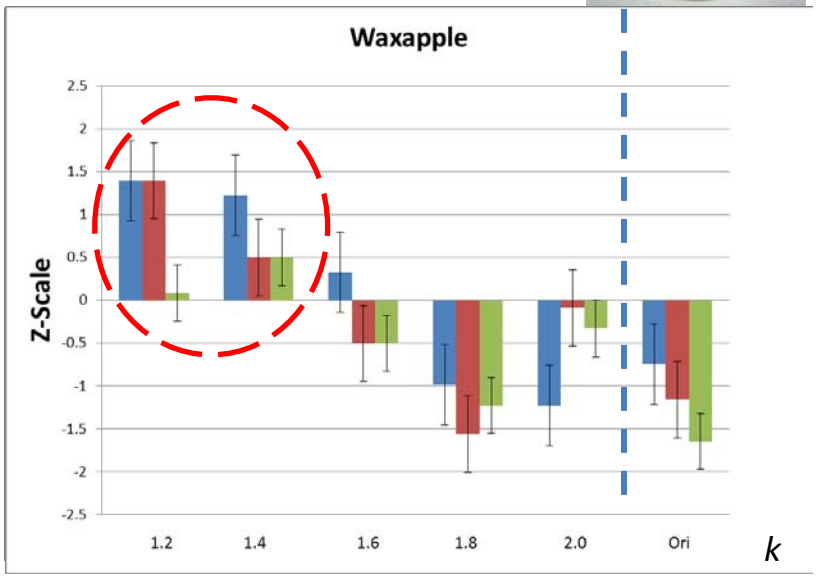


Effect of memory color

Camera 1
Camera 2
Camera 3

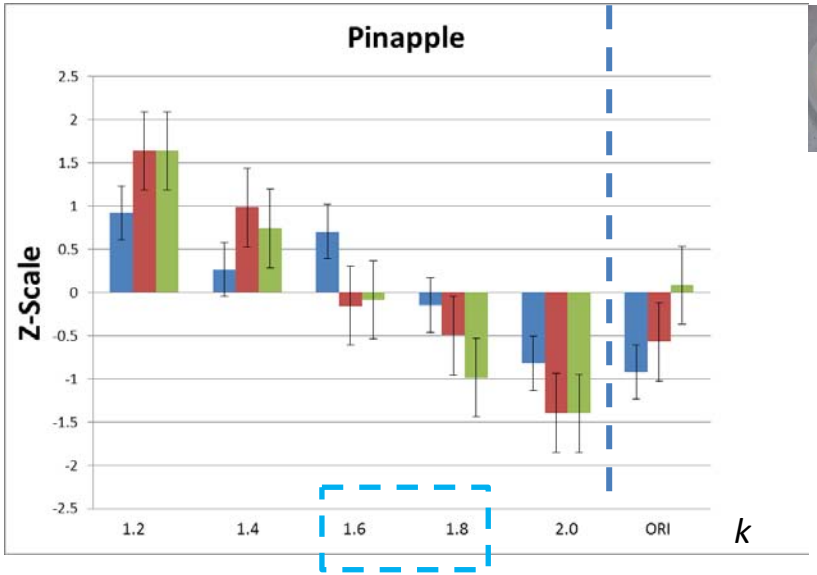


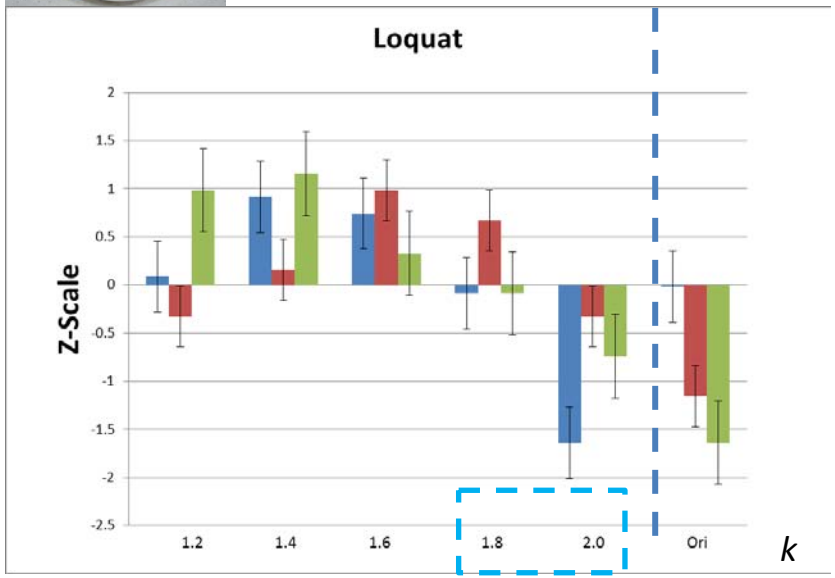


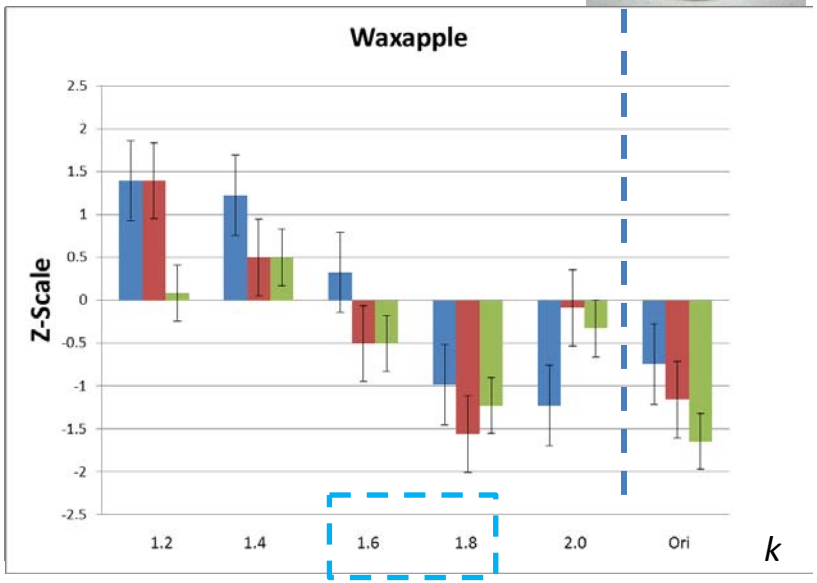


Range threshold

Camera 1
Camera 2
Camera 3







Conclusion

- The result of psychophysical experiment showed the relationships between color enhancement and delicious-looking foods under multi-primary environment.
- There are a certain degree of correlation between delicious-looking and its own colors.
- Especially in red, yellow and green colors, after enhancing a certain degree of chroma, the effect is more significant than the other colors

Thanks for your attention