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CCAD： A Basic Sample Database for Modeling Common Color Appearance

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Preface

This Master thesis is a topic which name is “CCAD: A Basic Sample Database for Modeling Common Color Appearance” at NTNU and SCUT. This thesis was carried out during the Spring semester of 2016. This thesis topic is originated from the inter report about the common color appearance from the ICC. The first topic is a common color appearance model given by the primary supervisor Philip Green, but it was to broad to a master thesis topic. With further discussion, it has changed as this current topic. Most experiments were conducted at SCUT in China and based on Chinese observers, so these achieved data sets were good for Chinese applications. For this report, each reader with the backgrounds of color science and Matlab will be good for reading and understanding freely.

15-05-2016

Acknowledges

I would like to express my sincere appreciation to all those who helped me during the dual master degree between NTNU(Gjøvik) and South China University of Technology(SCUT). My deepest gratitude goes first and foremost to my parents and litter sister who have provided all their best to realize all my thoughts and targets. Each chart and call with you did give me more happiness and confidence to deal with all the challenges and difficulties successfully.

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Abstract

The consistency assessment of a set of cross-media color reproductions is an urgent research topic in color application field. This is enhanced by the various gamut devices which make it impossible to match exactly using conventional colourimetry metrics, which existed metrics for color consistency were developed for small gamut differences. When a set of color reproductions provided by fewer gamut interaction between sample and reference media are judged to show a high degree of similarity, they are usually regard as sharing a 'Common Color Appearance'. This degree of similarity is just scaled by subjective assessment efficiently. In order to achieve and measure common color appearance, some offered metrics based on their private small and special color samples, which had restricted the applicability and evaluation of common color appearance metrics. On the basis of the adjustment & feedback frame, the proposed common color appearance databases (CCAD) including single-patch mode and image-patch model were implemented to provide a new solution for this issue.

In this project, CRPCs data from ISO/PAS 15339 standard were selected as the standard data source. Firstly, ten specific color centers were selected from CRPC4 as primary references, meanwhile the corresponding color centers with same CMYK values in CRPCs (s set 1, 2, 3, 5, 6, 7) selected as the secondary references. Secondly, in each CRPCs gamut, twenty samples were generated by small adjustments of attributes including different combination between lightness, colorfulness and hue angle. Thirdly, similarity scaling values were achieved from category judgment method under the standard viewing condition, and color patch samples with highest similar degree were summarized by Mean-Opinion-Scores and Z-scores together. According to evaluation results, various similarity degree of color patch set and common color appearance set were both achieved with 95% confident interval. At last, using closeness trend line method, the adaptability and scalability of the proposed CCAD were verified to provide a basic data references for common color appearance metrics.

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1 Introduction

As an integral part of color science, color reproduction plays a key role on the conventional and modern color communication, especially on cross-media reproduction [1,2]. With the increasing variety of materials and devices used in graphic arts industry and digital display field, the main content of color reproduction should be consistent among various mediums and real-world conditions. This is hard to achieve but implement urgently by developing one or more powerful metrics. For this big issue, the first question is how to achieve and evaluate the consistent content using visual similarity degree. In conventional printing, color metrics which based on the reproduction of the tristimulus values recommended by the international commission in illumination(CIE) , are the basis of current printing reproduction techniques [3,4]. In the conventional printing, the reproductions quality on different printers are usually checked by the side-by-side comparison, where reference and sample are contrasted under the same viewing conditions [5]. The reproductions would be shared the higher similarity using this assessment approach, because the different printing conditions can be characterized by color gamuts within few differences in size and shape.

However, in digital printing, the variety of device gamuts are too huge and make it difficult to exact match, which can exploit some looser relationship with reference to keep consistent content with acceptable similarity. In addition, for the color reproduction of digital display, the conventional characterization approach is also not well-estimated. Since those conventional color metrics are focused on accurate color match within similar device gamut features. They are limited to the strict match of smallest color difference among devices with various gamuts in size and shape, and not ideal for color reproduction among devices accompanied with large gamut difference [6,7]. One potential solution is expected to exploit the full color gamut, which is unlikely to cover all device gamuts for the moment. Fortunately, a good alternative which described as consistent color appearance or common color appearance(CCA), were used for achieving the consistent content with acceptable similarity among a set of reproductions given various device gamuts. This concept is to exploit special looser relationship with reference in a set of color reproductions which share common color appearance. Lots of scaling metrics to achieve and measure CCA based on private small sample data sets had been proposed recently. For these sample data sets, their applicability and generality still need to be assessed with detailed benchmark and enlarged with large device gamut differences. Thence, a basic sample database for modeling common color appearance is developed for this issue.

1.1 Motivation

For the common color appearance, its motive is to identify a suitable method that will allow us to produce a reference image across a range of media given different color gamuts that provides a consistent color appearance. This concept was described firstly by Jam Morovic as consistent color appearance, and proposed common color appearance term publicly by Philipp Trösters et.al from Fogra color group in 2014th ICC Heidelberg meeting [8]. Lately, many ICC core membership begin paying more attention to this topic. Consequently, the standard work of common color appearance became an urgent issue listed into the ICC research schedule. At the same time, the CIE had established a reportership on common color appearance which named R8-13 focus group. The first teleconference on common color appearance had been hold on 7th Dec. 2015 successfully [9]. In this teleconference, eleven presenters shared their ideas about the common color appearance and coming jobs in special domains. What's more, Gregory High from The Norwegian Colour and Visual Laboratory had presented his PhD topic about a completed frame of common color appearance model(CCAM) [10], which supervised by Associate Professor Philip Green. As a master member of this team, the common color appearance is also an interesting and challenging topic for my thesis topic. As a dual master candidate between NTNU(Gjøvik) and SCUT(China), a topic which named a basic sample database for modeling common color appearance is ideal for me, based on previous course projects and apparatus of the Digital Printing and Green Packaging Laboratory in SCUT. Main contributions of this thesis project will provide original data and samples for other researchers to propose new CCA metrics.

1.2 Aims

The main work is to develop a new basic sample database for modeling common color appearance which named Common Color Appearance Database(CCAD), and show detailed assessment for each sample. Common color appearance is proposed to solve the similarity scale of a set of reproductions across a series of media with different gamuts. When a set of color reproductions are judged the highest similar degree with reference, they are considered to share common color appearance. That is to say, the common color appearance can be achieved by subjective experiment and statistic method[11]. Specifically, similarity scaling and small adjustment method will be used for CCA subjective achievement even though the objective metrics are intent to develop currently. Based on the existing color metrics and color data sets, the proposed CCAD will include single color patch mode and single composite image mode, which consisted of samples set, Mean-Opinion-Score(MOS) matrix, Z-score matrix, DE94 color difference matrix and DE00 color difference matrix. A special common color appearance model (CCAM) frame is expected to propose based on color patch based CCAD. Subjective experiments are conducted under the CIE recommend standards and designed test Matlab GUI. The implemented CCAD based on Chinese observers is to attract more Chinese color researchers to know and promote CIE common color appearance standard work.

1.3 Research methods

Since CCAD is based on the subjective similarity scaling matrix, then psychophysical scaling experiments including category judgment method will be conducted, respectively. In order to make sure color patch sample located into the given data-set gamut, Matlab software were applied to process and analyze all samples and data. In addition, generating LCh attributes small adjustments of samples, recording and processing category judgment experiment data, measured color difference calculation of samples. Statistic methods including qualitative approach and quantitative approach were both used for the CCAD achievement and assessment. The quantitative approach is useful for understanding the internal and potential correlations [12]. Correspondingly, more comprehensive and significant features can be extracted from the qualitative approach [13].

1.4 Research contents

The proposed CCAD is consisted of sample sets sharing CCA with CI 95% and a range of sample sets with different similarity scaling degree. Based on the reference characterization, all the references and samples of the CCAD are including single color patch based mode and single composite image based mode. In the single color patch based mode, ten color centers from CRPC4 data set were selected as the primary references, and the corresponding ten color centers from CRPCs(s=1, 2, 3, 5, 6, 7) data set were selected as the secondary references. Then secondary references were processed by Matlab codes to generate samples with small adjustments among LCh attributes randomly. These samples should be optimized continually until all samples belong to the relative CRPCs gamut. Then, category judgment experiments were conducted in standard viewing condition using the designed Matlab GUI. Furthermore, three research questions including whether is there common agreement on the closeness of color appearance across a set of given reproductions, whether CCA is dependent on the color centers and observers, how is the applicability of the proposed CCAD. In single composite image based mode, the primary references were selected from CID:IQ database which developed by the Norwegian Colour and Visual Laboratory. Their samples were processed as well as color patches but different scale. Considering that the amount of all samples is huge, the analysis and assessment of CCAD based single color patch mode will be only shown in detail in this thesis report.

The section 1 will introduce where is this topic originated from, why choose this topic, how to implement this topic. The section 2 will introduce the theory background of common color appearance and color metrics. The section 3 will show literature survey about common color appearance. The section 4 will focus on the common color appearance database implementation based on subjective similarity scaling experiment. The section 5 will analyze and assess the proposed CCAD using MOS value and Z-score values. The section 6 will show the main conclusions and contributions of CCAD.

2 Background

2.1 Common color appearance

The quantitative description of color is an important branch of color science, which consisted of two famous standard colorimetric systems recommend by CIE, such as CIE1931 standard colorimetric system and CIE1964 supplementary standard colorimetric system [14, 15]. In the basic colourimetry phase, the CIELab color space and corresponding color difference metrics were developed and published consequently [16-18]. These can provide a good solution for the color quantitative issue under standard illuminants and viewing condition while is still hard to meet the real-world color applications [19]. Based on human visual system, the color samples with same tristimulus values may look different under various viewing conditions [20]. This is a famous color phenomenon which defined as color appearance phenomena. Then many classical mathematical models to explain different color appearance phenomena were developed and promoted the advanced color appearance model[21-24]. According to the color appearance model defined by CIE TC1-34, the proposed model should predict the relative color attributes including LCh attributes and the CIECAM02 model that shows more uniform color space was recommended widely [25, 26].

From the view of CCA, it is short for common color appearance or consistent color appearance, which focused on the consistent degree of a set of color reproductions given various device gamuts. The CIE R8-13 TC also prefer the common color appearance term to communicate and exploit new metrics. It is a pity that this term is not well-defined yet even though it had been discussed recently. There are some practical descriptions which can help us to understand the common color appearance concept. Po-Chieh Hung had regard the CCA as image attribute which gives a sense of identity among a set of images which have different tone color [27]. Fogra color group thought that it could be described as the similarity degree of visual consistency among a set of stimuli from device gamuts that differ both in size and shape against a given reference [28, 29]. Philip Green would describe the common color appearance as an color appearance that is accepted by an observers as the closest possible to a reference,which given the differences between the color gamuts of sample media and reference media [30]. In short, the common color appearance can be regarded as color appearance of reproduction sharing consistent content with reference, also can be a similarity scale to judge whether a set of reproductions keep consistent degree. Then they are the just right direction that achieve common color appearance and potential objective metrics. For color gamut, it can provide correlation tools for the objective achievement of CCA. Meanwhile it is a good term to limit and stimulate the color appearance characterizations in special printing workflow and real-world viewing conditions.

2.2 Color difference metrics

Color difference formula is an useful metric that describes the color perception differences between different color samples [31-33]. In the uniform color space, the Euclidean distance between two colors is usually defined as the color difference [34]. Along with the continuous improvements of uniformity of developed color spaces, many classical color difference metrics, such as CIELa*b* color difference metric [35], CIEDE94 color difference metric [36] and CIEDE00 color difference metric [37] were updated and recommended by the CIE consequently. These color difference metrics were still the hot research topics. In order to optimize their prediction performances, the key parameters of color difference metrics were adjusted and tested to find a better correlation between color difference and visual perception difference using the magnitude estimation method given their designed color samples [38]. For the recent CAM02-UCS color difference metric, it was developed by Luo et al [39] based on the uniform color space in CAM02 model. Considering its complexity and conditions, the CAM02-UCS color difference metric was not applied to assess the CCAD directly in this report even though it also showed an excellent prediction performance. CIELa*b* color difference metric, CIEDE94 color difference metric and CIEDE00 color difference metric are introduced below in detail.

2.2.1 CIEL*a*b* color difference metric

CIELa*b* color difference metric is based on the CIE1970Lab color space which is also the device independent color space [35]. CIELa*b* color space is also good uniform color space that the Euclidean distance of two colors can show the color difference,which defined as ΔE*ab. The formula and derivation of ΔE*ab are shown in Equation2.1 and Equation2.2, where a*、b*、ΔL*、ΔC^*_{ab}、ΔH^*_{ab}、Δh_{ab} are short for red-green component axis, yellow-blue component axis, lightness difference, chroma difference, hue difference and hue angle difference, respectively.

$$\Delta E^*_{ab} = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{0.5} = \left[(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2\right]^{0.5} \quad (2.1)$$

$$\begin{cases} \Delta L^* = L_1^* - L_2^* \\ \Delta C_{ab}^* = C^*_{ab,1} - C^*_{ab,2} \\ \Delta H_{ab}^* = 2(C^*_{ab,1}C^*_{ab,2})^{0.5} \times \sin(\Delta h_{ab}/2) \\ C^*_{ab} = [(a^*)^2 + (b^*)^2]^{0.5} \\ \Delta h_{ab} = h_{ab,1} - h_{ab,2} \end{cases} \quad (2.2)$$

2.2.2 CIEDE94 color difference metric

CIEDE94 color difference metric is developed by Berns et al in RIT based on three small color difference data sets including RIT-DuPont set [46], Luo-Rigg set [47] and Witt set [48]. Moreover, the CIEDE94 color difference metric had been recommended as the industrial color difference evaluation criteria by the CIE TC1-29. Comparing to the CIELa*b* color difference metric, three scale factors and three weighted parameters were added to consider different colorimetric attributes effect on whole color difference. The formula and derivation of ΔE^*_{94} are shown in Equation2.3 and Equation2.4, where k_L, k_C, k_H, S_L, S_C, S_H are short for lightness scale factor, chroma scale factor, hue scale factor, lightness weighted value, chroma weighted value, hue weighted value.

$$\Delta E^*_{94} = \left[\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H S_H}\right)^2 \right]^{0.5} \quad (2.3)$$

$$\begin{cases} S_L = 1 \\ S_C = 1 + 0.045 \times C^*_{ab} \\ S_H = 1 + 0.045 \times C^*_{ab} \\ C^*_{ab} = (C^*_{ab,1}C^*_{ab,2})^{0.5} \end{cases} \quad (2.4)$$

2.2.3 CIEDE00 color difference metric

CIEDE00 color difference metric was the latest color difference metric recommended by the CIE to show a better prediction performance in most domains [37, 38]. The completed CIEDE00 color difference metric is also also involuted for industrious customers. Comparing to the CIEDE94 color difference metric, four functions had improved in the CIEDE00 color difference metric. First one is the optimization of prediction performance of neutral colors; second one is that the V shape functions was used for the lightness weighted function; third one is the application of hue angle factor in hue weighted function; the last one is the optimization of rotation factor of blue area. The formula and derivation of ΔE^*_{00} are shown in Equation2.5, Equation2.6 and Equation2.7. Fortunately, all these color difference values can be calculated directly by Matlab codes based on the Color Engineering Toolbox which developed by Philip Green [50].

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right) \right]^{0.5} \tag{2.5}$$

$$\begin{cases} L' = L^* \\ a' = (1+G)a^* \\ b' = b^* \\ C' = \left[(a^*)^2 + (b^*)^2\right]^{0.5} \\ h' = \tan^{-1}\left(\frac{b'}{a'}\right) \end{cases} \quad \begin{cases} \Delta L' = L'_b - L'_s \\ \Delta C' = C'_b - C'_s \\ \Delta H' = 2(C'_b \times C'_s)^{0.5} \times \sin(\Delta h'/2) \\ \Delta h' = h'_b - h'_s \\ G = 0.5\left[1 - \left(\frac{[(C^*_{ab,1} + C^*_{ab,2})/2]^7}{([(C^*_{ab,1} + C^*_{ab,2})/2]^7 + 25^7)}\right)^{0.5}\right] \end{cases} \tag{2.6}$$

$$\begin{cases} S_L = 1 + \frac{0.015[(L'_1 + L'_2)/2 - 50]^2}{\left\{20 + [(L'_1 + L'_2)/2 - 50]^2\right\}^{0.5}} \\ S_C = 1 + 0.045[(C'_1 + C'_2)/2] \\ S_H = 1 + 0.045[(C'_1 + C'_2)/2]T \\ R_T = -\sin(2\Delta\theta)R_C \\ \Delta\theta = 30\exp\left\{-([(h'_1 + h'_2)/2 - 275]/25)^2\right\} \\ RC = 2\left(\frac{[(C'_1 + C'_2)/2]^7}{[(C'_1 + C'_2)/2]^7 + 25^7}\right) \\ T = 1 - 0.17\cos[(h'_1 + h'_2)/2 - 30^o] + 0.24\cos(h'_1 + h'_2) - 0.2\cos[2(h'_1 + h'_2) - 63^o] \end{cases} \tag{2.7}$$

2.3 Subjective evaluation of color reproduction quality

For a set of color reproductions, they are said to share the common color appearance when judged to be closest possible with reference by observers. As a result, subjective scaling method would be used for color reproduction quality evaluation. Similarity and preference are the two important independent attributes of color reproduction quality evaluation. Subjective scaling method is usually based on certain psychophysical experiments which observers need to give their scaling values under the specific test question. Subjective scaling experiment is a crucial step for obtaining the accurate similarity scaling values to implement the common color appearance database. Subjective scaling evaluations is correlated measured colorimetric data with visual perception to create the effective numerical relationships [51]. The objectivity of perception measurement under specific designed rules can be equivalent to general physical measurement, although the perception measured data are considered to have potential subjectivity [52]. In subjective scaling experiment, three factors including test instruction, test accuracy and test time should be kept in a good balance. There are three popular categories of approaches including threshold test method [53-55], matching test method [56, 57] and psychophysical scaling method [58-61].

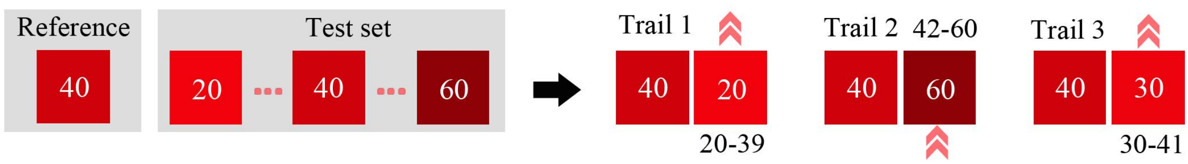


Figure 1 Adjustment experiment case

Threshold test method is based on Weber's law to determine the visual sensitivity of small changes of tested color samples, also defined as the just-noticeable difference method [53]. For the designed principle and cases, there are three main approaches to rate subjective thresholds including adjustment method, limit method and constant stimuli method [54]. In the Figure 1, the principle of adjustment experiment case was shown and derivated step by step given some color samples [55]. Matching test method is mainly to adjust the color sample to match the reference accurately, which including haploscopic matching approach and memory matching approach[56, 57]. Two approaches case are shown in Figure 2, respectively.

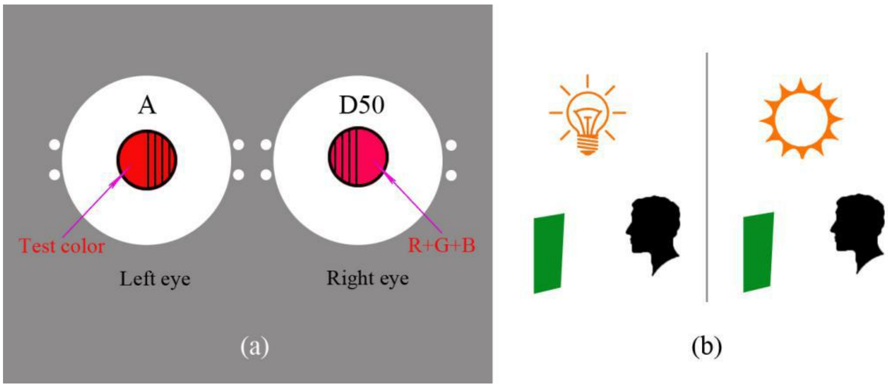


Figure 2 Test matching case：(a)Haploscopic Matching；(b)Memory Matching

Psychophysical scaling method is used for determining the quantitative relationship between the physical properties of tested color samples and observer's visual perception[58]. The dimensions of color attributes can be selected freely in psychophysical scaling method[59]. The single attribute assessment of color patch can be regarded as one dimensional scaling method. Meanwhile the LCh attributes of tested sample are all changed case should belong to the multidimensional scaling method. Furthermore, there are some various numerical approaches including category judgment method, pair comparison method, rank order method, magnitude estimation method, ratio estimation method and so on[60, 61]. For subjective similarity scaling experiment, one detailed approach is generally selected from the first four method according to the test target and test question.

2.3.1 Category judgment method

Category judgment method is a kind of subjective evaluation method based on range frequency theory or model for obtaining the order or weight of a large number of test samples[62]. In the category judgment method, the observers were asked to classify each test sample in the large sample set according to the specific rules. Classification rules can be the similarity of the tested sample comparing to reference sample or the preference of the observer. There are three categories including five-level method, seven-level method and nine-level method [63]. The times that each color was placed in a particular category by all observers is recorded into scaling judgment matrix. The category judgment method has the advantages of moderate experimental time and high accuracy, so it is often used in the evaluation of large or super large sample sets. Figure 3 shows the nine-level based category judgment method of test cases.

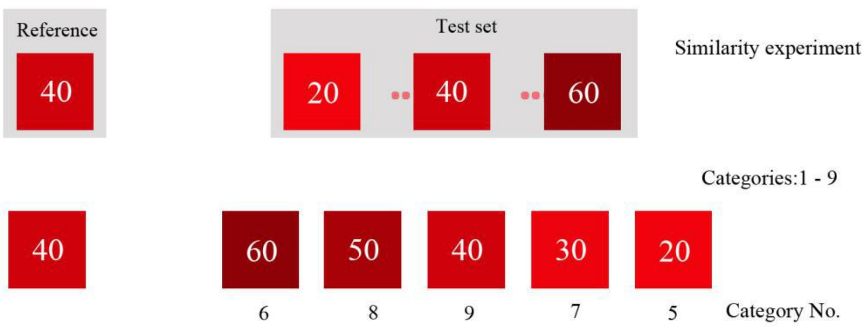


Figure 3 Category judgment experiment case

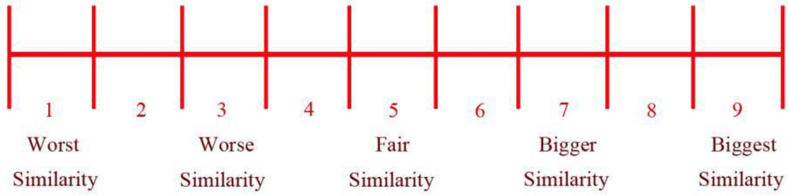


Figure 4 Nine categories of similarity scaling value

In the above case, the nine-level based category judgment method is used, which add an intermediate scale to the five-level based method sequentially. The quantitative accuracy has been increased which also require the observers a higher ability to distinguish the smaller differences. In the similarity scaling experiment shown in Figure4, when the similarity value is 9 which indicates this sample is judged the highest similarity, which 1 represents the lowest similar to reference. In order to demonstrate the quantification principle of the category judgment method, taking five observers and four reproductions (I, II, III, IIII) as an example, the Table1 is established to record twice scaling results of each observer for each reproduction.

Table 1 Raw data of five observers in category judgment experiment case

	(a) Observer 1					(b) Observer 2					(c) Observer 3					(d) Observer 4					(e) Observer 5				
	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
I	0	0	1	1	0	0	0	0	1	1	0	0	0	2	0	0	0	0	0	2	0	0	0	1	1
II	0	1	1	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	1	1	0
III	0	2	0	0	0	0	2	0	0	0	0	1	1	0	0	1	1	0	0	0	0	1	1	0	0
IIII	1	1	0	0	0	2	0	0	0	0	0	2	0	0	0	1	1	0	0	0	0	2	0	0	0

In Table 1, each value in the data area represents the frequency that corresponding reproduction is judged as a specific category. In Table 1, the column is for the similarity scaling degree in descending order, meanwhile the row is for each reproduction. All the raw values scaled by each observer were summed correspondingly to establish a 4×5 summed frequency matrix which shown in Table 2 (a). Then it was transformed continuously to cumulative frequency matrix which shown Table 2 (b). Lately, all the cumulative frequency values were divided by the total observers (hear it is 10) to achieve the cumulative proportion matrix which shown in Table 2(c).

Table 2 Steps for calculating cumulative percentage matrix

	(a) Summed frequency matrix					(b) Cumulative frequency matrix					(c) Cumulative percentage matrix				
	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
I	0	0	1	5	4	0	0	1	6	10	0	0	0.1	0.6	1
II	0	1	6	3	0	0	1	7	10	10	0	0.1	0.7	1	1
III	1	7	2	0	0	1	8	10	10	10	0.1	0.8	1	1	1
IIII	4	6	0	0	0	4	10	10	10	10	0.4	1	1	1	1

By using equation 2.8, the summed frequency matrix is converted into the logical function matrix (LFM) which is shown in Table 3(a). The partial Z-score sample values can be calculated by solving the the inverse of the standard normal cumulative distribution for cumulative percentage matrix. This is easy to implement by using function "norminv" in Matlab or function "normsinv" in Microsoft Excel. When the Z-score sample values had gathered, then they were correlated with corresponding LFM values to calculate the scaling coefficient α by using linear regression analysis. The scaling coefficient α is the slope of linear trend line which shown in Figure 5. In the LFM conversion equation 2.8, where F is the frequency value from the summed frequency matrix with possible modifications to keep all the data in standard normal distribution, n is for the total observations of each observer (hear set 10), C is any additional coefficient (here set 0.5 according to the Bartleson's empirical formula) [64]。

$$LFM = \ln\left(\frac{f+c}{N-f+c}\right) \tag{2.8}$$

Table 3 LFM matrix, Z-score matrix and Difference matrix

	(a) LFM matrix					(b) Original Z-score matrix					(c) Difference matrix			
	5	4	3	2	1	5	4	3	2	1	5	4	3	2
I	-3.04	-3.04	-1.85	0.00	3.04	-2.47	-2.47	-1.50	0.00	2.47	0.00	0.97	1.50	2.47
II	-3.04	-1.85	0.37	-0.76	3.04	-2.47	-1.50	0.30	-0.62	2.47	0.97	1.79	-0.92	3.08
III	-1.85	0.76	-1.22	3.04	3.04	-1.50	0.62	-0.99	2.47	2.47	2.11	-1.61	3.46	0.00
IIII	-0.37	0.37	3.04	3.04	3.04	-0.30	0.30	2.47	2.47	2.47	0.60	2.17	0.00	0.00

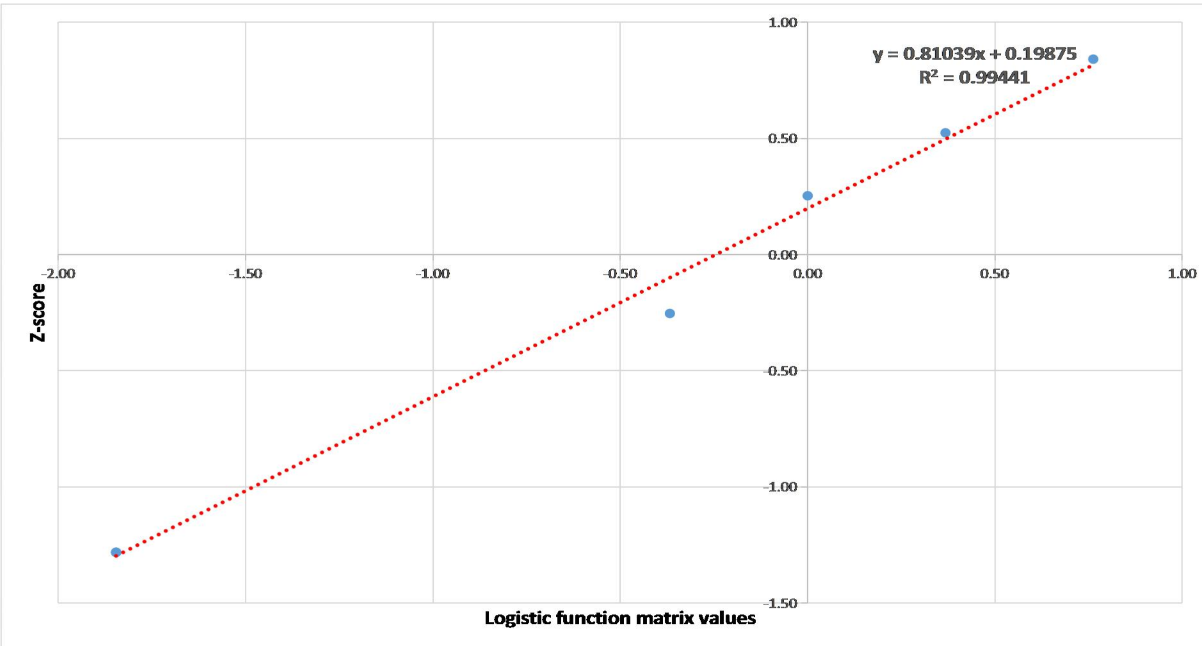


Figure 5 Scaling coefficient α: the slop of linear regression line

Then the whole Z-score values can be achieved by the scaling coefficient α multiplying all the values in LFM to establish the original Z-score matrix which shown in Table 3(b). The next step is obtain the new 4×(5-1) difference matrix by the previous value replaced by it subtracted the next value in same row which shown in Table 3(c). Furthermore, the difference average values of each reproduction were calculated to determine the boundary value of each scaling degree category which shown in Table 4(a) and Table 4(b). Each boundary value is calculated by the cumulative sum of difference average value based on a given initial value. At last, the final Z-score value matrix is calculated by taking the boundary value to subtract the original Z-score value successively. At the same time,in the Table 5, the average and rank order of final Z-score values were both shown together. The average Z-score value is proportional to the subjective scaling prefer. In order to visualize the scaling results, the average Z-scores were plotted with error bar shown in Figure 6. The average Z-score value is indicated by the center cycle, and the whisker on each line is for the 95% Confidence interval. The 95% Confidence interval can be calculated by the equation 2.9[65], where σ is set 1 and N is the number of observations(hear it is 10).

$$CI = 1.96 \times \frac{\sigma}{\sqrt{N}} \tag{2.9}$$

Table 4 Difference average matrix and boundary value matrix

	(a) Difference average matrix					(b) Boundary value matrix				
	5	4	3	2		T1	T2	T3	T4	T5
DA	0.92	0.83	1.01	1.39	Boundary	0	0.92	1.75	2.76	4.15

Table 5 Final Z-score matrix

	5	4	3	2	Average	Rank
I	2.47	3.39	3.25	2.76	2.96	1
II	2.47	2.42	1.45	3.38	2.43	2
III	1.50	0.30	2.74	0.29	1.21	3
IIII	0.30	0.62	-0.72	0.29	0.12	4

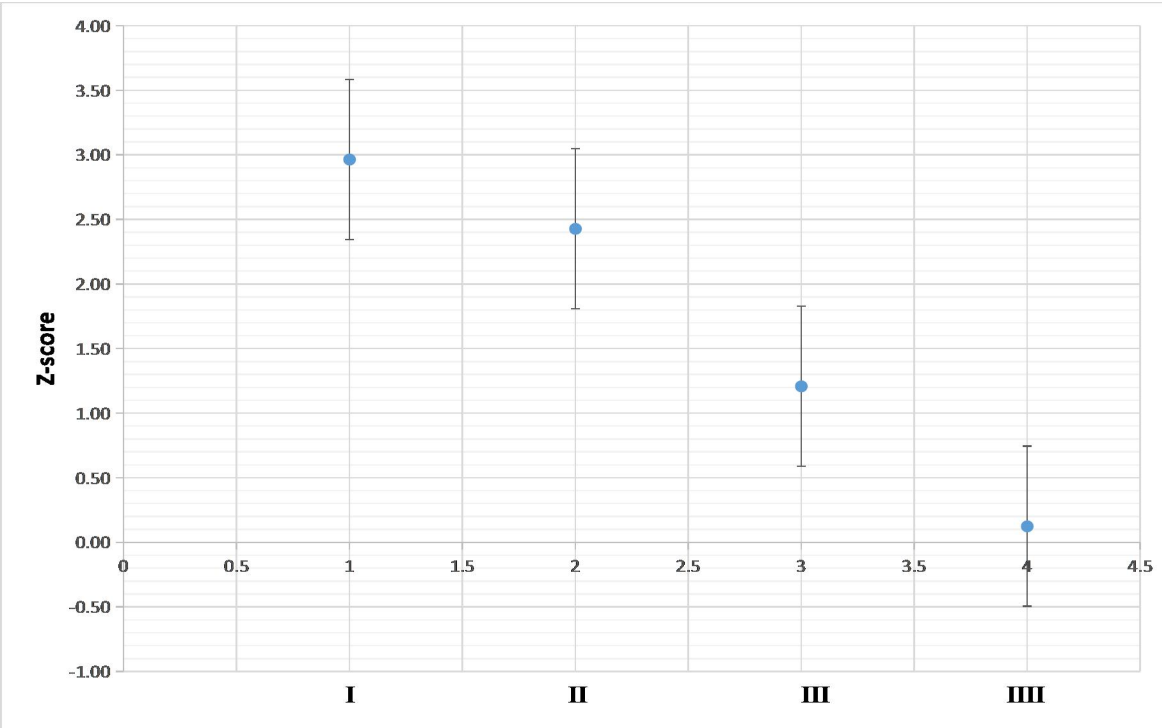


Figure 6 Z-scores with 95% confidence interval from category judgment experiment case

As seen in Table 4 and Table 5, combining average Z-score value of each reproduction with the boundary value, this reproduction can be judged into the specific category. From the Figure 6, it is an easy way to determine the significantly difference of each reproduction. The reproduction I is significantly different from the reproductions III and IIII, meanwhile the reproduction IIII is also significantly different from the reproductions I and II. So the category judgment approach is not only to provide the subjective scaling value with 95% Confident interval, but also indicate that the sample would be judged into a specific category[66]. The subjective scaling values will be more credible in the case of enough observers. The category judgment experiments will be designed and conducted for similarity scaling evaluation using the Matlab GUI.

2.3.2 Pair comparison method

Pair comparison method is also a common subjective evaluation method in psychophysical scaling experiments [67]. Compared to category judgment method, the accuracy of pair comparison method is better but will take so long time when the amount of samples are large. It is suitable for small samples set evaluation, such as CIE guide for color gamut mapping algorithm assessment [68]. In the pair comparison experiment, observers were requested to select a reproduction shown the higher or lower attribute in given each pair of samples, such as higher similarity or better preference. The similarity scaling case is shown in Figure 7. In order to avoid the bias of test sample position, the sample position in given test pair will be changed from left to right randomly. At the same time, the observers will evaluate all the random combinations of the test samples, and the scaling results are automatically recorded in the raw contrast matrix. For example, when the test sample I and II was presented simultaneously to each observer, and if select the I for better, then the column I row II position in raw contrast matrix is recorded "1", and the row I column II position is recorded "0"; if test sample I and II are regarded as same, then the corresponding positions will be both recorded "0.5" until all observers completed all of the test sample. In this paper, four observers and four test samples were taken as a pair comparison experiment case, and their raw data are shown in Table 6.

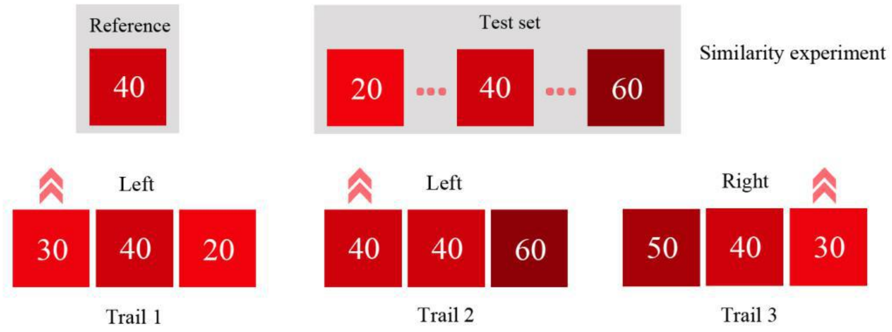


Figure 7 Pair comparison experiment case

After gathering all the raw scaling data from observers, they are summed to establish the summed frequency matrix shown in Table 7(a). The next step is that all frequency values are divided the number of observers to obtain the percentage matrix shown in Table 7(b). The rest steps to achieve the final Z-score matrix and error bar plot is same as that of category judgment method. In the Table 7(c) and 7(d) are shown the logistic function matrix and final Z-score matrix, respectively. From the Figure 8, it is indicated that all Z-score values with 95% Confident interval for four reproductions. The reproduction I and III are significantly different from the reproduction IIII with 95% Confident interval, but the reproduction I, II and III are not significantly different from each other.

Table 6 Raw data of four observers in pair comparison experiment case

	(a) Observer 1				(b) Observer 2				(c) Observer 3				(d) Observer 4			
	I	II	III	IIII	I	II	III	IIII	I	II	III	IIII	I	II	III	IIII
I	*	0	0.5	0	*	0	0	0	*	0.5	0	0.5	*	0.5	1	0
II	1	*	1	0.5	1	*	0.5	0.5	0.5	*	1	0	0.5	*	1	0.5
III	0.5	0	*	0	1	0.5	*	1	1	1	*	0	0	0	*	0.5
IIII	1	0.5	1	*	1	0.5	0	*	0.5	1	1	*	1	0.5	0.5	*

Table 7 Z-score transform matrix

	(a)Summed frequency matrix				(b) Percentage matrix				(c) Logistic Function matrix				(d) Final Z-score matrix			
	I	II	III	IIII	I	II	III	IIII	I	II	III	IIII	I	II	III	IIII
I	*	1	1.5	0.5	*	0.25	0.375	0.125	*	-0.85	-0.41	-1.39	*	-0.7	-0.34	-1.14
II	3	*	3.5	1.5	0.75	*	0.875	0.375	0.85	*	1.39	-0.41	0.7	*	1.14	-0.34
III	2.5	0.5	*	1.5	0.62	0.125	*	0.375	0.41	-1.39	*	-0.41	0.34	-1.14	*	-0.34
IIII	3.5	2.5	2.5	*	0.87	0.62	0.625	*	1.39	0.41	0.41	*	1.14	0.34	0.34	*

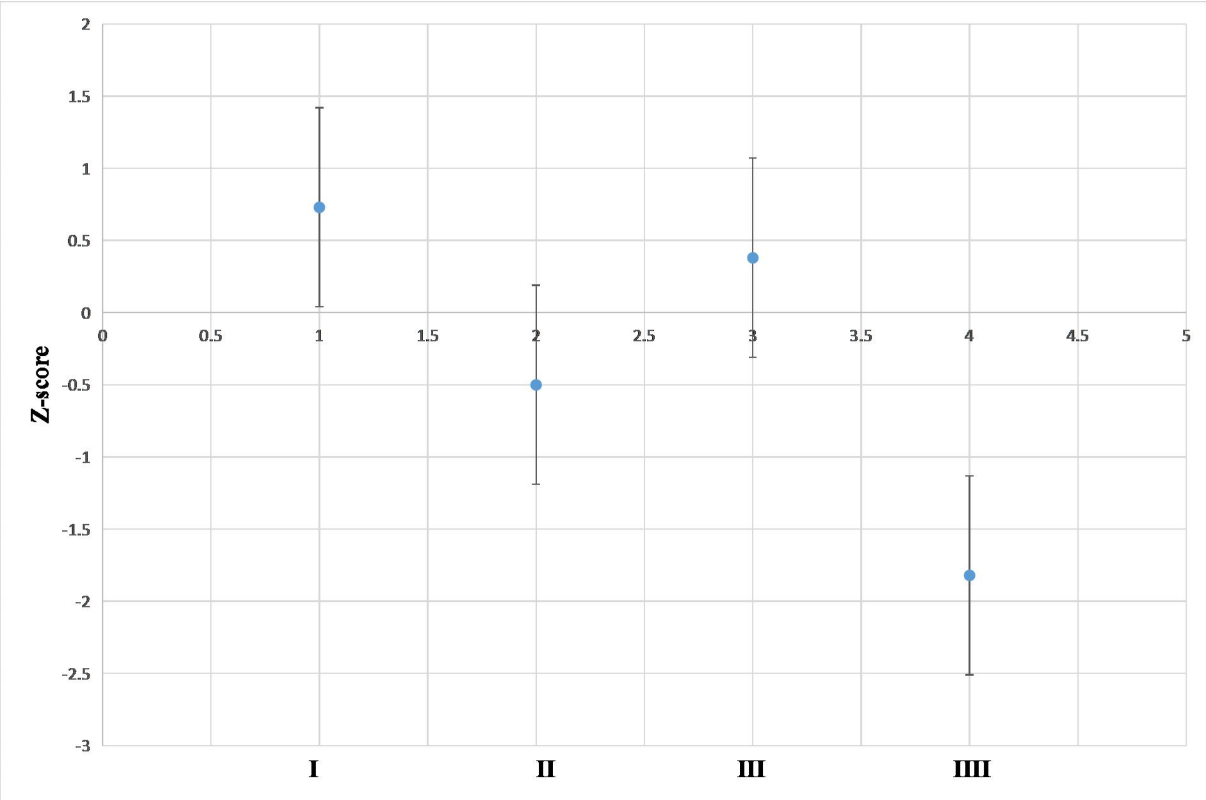


Figure 8 Z-scores with 95% confidence interval from pair comparison experiment case

2.3.3 Rank order method

Rank order method is a fast and simple subjective evaluation approach in psychophysical scaling experiments where the sample set is large [69]. In the rank order experiment, each observer is requested to give a ascending or descending order to a set of reproductions based on the reference and some specific judgment rules. The principle of rank order experiment case is shown in Figure 9. The order number of each sample will be recorded as well as its index number in raw order data matrix. The raw scaling data of eight observers are shown in Table 8(a).

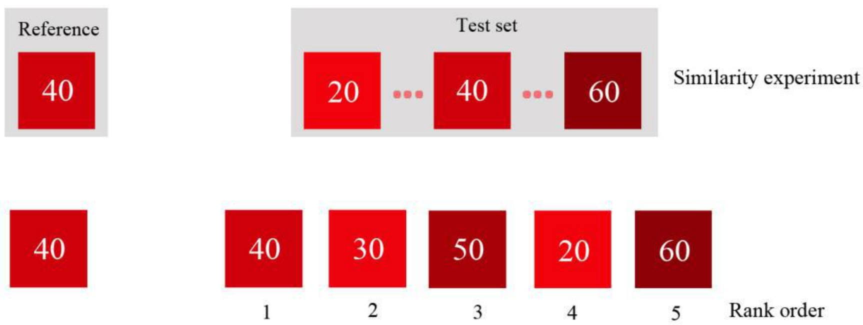


Figure 9 Rank order experiment case

The raw scaling data cannot be converted into the summed frequency matrix directly. The frequency matrix should be established firstly by using the comparative pair comparison modeling proposed by Cui et al [70]. This transform model can convert the raw rank order data into raw pair comparison data which called raw frequency values using the equations 2.10 and 2.11. Table 8(b) is shown the summed frequency matrix. After the summed frequency values achievement, the same steps and functions as pair comparison method were used to analysis all the scaling results. In the equation 2.10, the RS_i is the rank order number of observer i in raw order data matrix, z(i, j) is a indicator to convert the proportion of choices into Z-scale values, P_{mij} is a binary value corresponding to the scaling preference data, S_i is the scale value, n is the number of test reproductions.

$$RS_i = \frac{1}{n(n-1)} \sum_{m=1} n \sum_{j=1} np_{mij} = \frac{1}{n-1} \sum_{j=1}^{n} z\left(\frac{\sum_{j=1} np_{mij}}{n}\right) \tag{2.10}$$

$$S_i = z\left(\frac{1}{n-1} \sum_{j=1}^{n} \left[\frac{\sum_{m=1}^{n} p_{mij}}{n}\right]\right) \tag{2.11}$$

Table 8 Raw data and summed frequency matrix of rank order experiment case

	(a) Raw order data matrix								(b) Summed frequency matrix			
	O1	O2	O3	O4	O5	O6	O7	O8	I	II	III	IIII
I	1	1	1	2	2	1	1	2	*	2	1	0
II	2	3	2	1	1	2	3	3	6	*	3	0
III	3	2	4	3	4	3	2	1	7	5	*	2
IIII	4	4	3	4	3	4	4	4	8	8	6	*

2.3.4 Magnitude estimation method

Magnitude estimation method is an efficient subjective evaluation approach using the obvious magnitude value in psychophysical scaling experiment [71]. In magnitude estimation experiment, the magnitude criteria is set firstly by using the biggest or smallest attribute of reference. For example, the lightness degree of white reference is set 100, or the lightness degree of black reference is set 0, then the lightness degree of other samples can be judged from 0 to 100 range. In the Figure 10, the reproduction copy is set as the reference criteria, which given the similarity degree is 100. The data process of magnitude estimation method is same with the Mean Opinion Score(MOS) method. The MOS method is recommended firstly by the International Telecommunication Union(ITU) for the audio quality assessment, and lately extended into visual perception evaluation [72].

In the MOS experiment, observers are requested to give a scaling value from 1 to 5 range for one specific attribute (similar to category judgment approach to some degree). For the scaling value, the 5 is for the best quality, in turn the 1 is for the worst quality, which shown in Figure 11. The magnitude estimation method can regarded as the scaling range changed from [1, 5] to [0, 100]. The mean magnitude estimation score(MMES) can be calculated by using the equation2.12, where S_i is the scaling value given by each observer for test reproduction i, n is the number of observations.

$$MMES = \frac{1}{n} \sum_{i=1}^{n} S_i \tag{2.12}$$

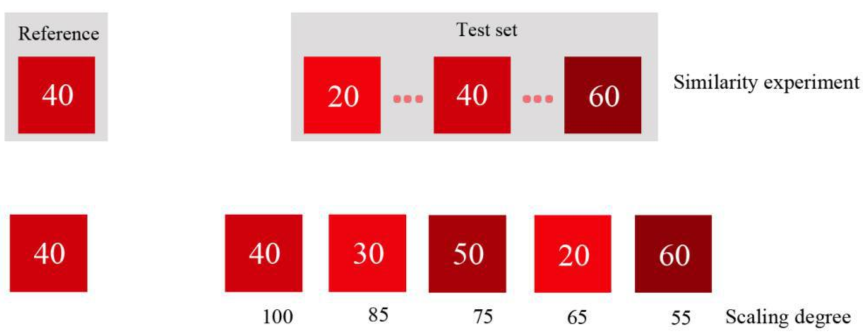


Figure 10 Magnitude estimation experiment case

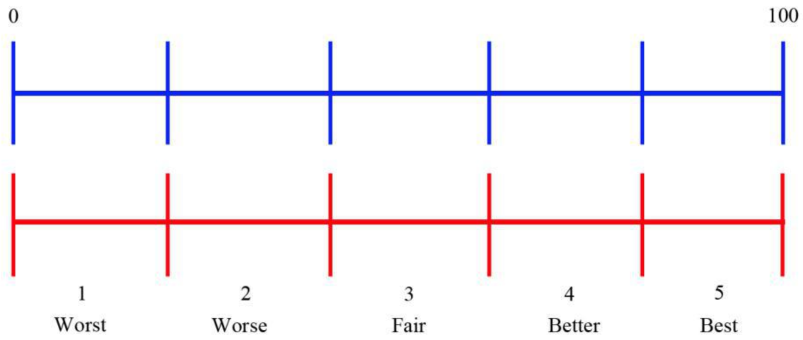


Figure 11 Conversion from magnitude estimation values to Z-scores

Magnitude estimation method is not only a subjective evaluation approach with high efficiency, but also provided detailed loci of all the samples compared to reference criteria. The magnitude estimation scores can also be converted into the scaling values of category judgment approach by using the numerical model in Figure 11. For the MOS and MMES values, it is a big pity that them can not been show their obvious credibility criteria. So the repeatability and accuracy of subjective scaling values should be certified by adding other functions or approaches together. Likewise, based on the specific category criteria, the MMES values of raw scaling data can be converted into frequency values of the five-level category judgment method. For the optimization of color difference metrics, many scholars have discussed the applicability of magnitude estimation method and shared their good preference [73-75]

2.4 Setups of subjective experiment

In order to improve the accuracy of evaluation experiment, some factors including observer type and amount, test question and viewing condition should be paid more attention on. For the view of professional level, observers are consisted of expert type and naive type. The expert type is the observer who may know the test experiment well or guys who have some backgrounds about test samples. Then they may distinguish more fine or potential information based on the designed criteria and their experience than naive type. Generally speaking, the more expert types at the certain ratio, the better accuracy of scaling result required powerful distinctions. However, the expert types are not easy found and interested in subjective evaluation experiment. So the ratio of expert type and naive type which is kept in the range from 1:1 to 1:3, would be acceptable. It is so important that making a balance between expert type and naive type based on the observer task instruction.

The amount of observers should be invited is a thorny problem to conduct the subjective evaluation experiment. Currently, there is no standard guides about the amount of observers in color reproductions quality evaluation. There is also a trade off between the number of observers and the test time depending on the observer task instruction. Because the increasing amount of observers will lead more test time and processing time even though it will also enhance the statistic accuracy. Engeldrm had proposed the number of observers is from 4 to 50 for the image quality evaluation in his book which name is psychophysical experiment, as well as the prefer range from 10 to 30 [61]. At least 15 observers are invited in a common image quality evaluation experiment according to CIE's guide on gamut mapping algorithm assessments [63].

Test question is one of kernel factors to achieve the accurate and useful subjective scaling results. The test question is that what observers are expected to do under the words description. For instance, what is the test attribute, how to assess the given attribute based on the specific criteria or definition. These contexts are a core to any successful experiment.

Viewing condition is also the key factor to influence the efficient and precise subjective scaling results. Good consideration for viewing conditions is that a quiet and comfortable environment should be provide for observers. In case of visual fatigue, observers should be told the test time in dark room before the formal experiment. For experiments required specific illumination, the illumination intensity of experimental room should be measured and controlled at the stable range. For the LED display experiment, the required white point, color temperature and expected lightness of monitor should be calibrated periodically. At the same time, the monitor should be warming up 30 minutes before the formal experiment. CIE also recommended two light sources including D65 and D50, but the D65 is mainly recommended in China.

Viewing distance is also an important factor to control the precision and accuracy of subjective scaling experiment. The viewing distance is defined as the horizontal distance between the eye and test samples. In general, the task instructions required a very fine distinction are easily influenced by the viewing distance. When the viewing distance is small, the graininess and raggedness become more obvious. When the viewing distance is large, the sharpness will decrease. Therefor, the viewing distance is also dependent on the task instruction. In the development of color space system, CIE had recommended 2° viewing field and 10° viewing field for color comparison. Then the viewing distance range changed from 50 cm to 120 cm would be meet most color evaluation experiments.

2.5 Common color appearance database

Common color appearance database is a color sample database which mainly included a set of samples with possible closest with reference on the basis of gamut features of standard color database source. Considering the feature of color sample, the sample database which share common color appearance can be divided into the single color patch mode and composite image model. For these two model CCAD, all the test samples are designed in CIELa*b* color space and transformed into sRGB mode to display in subjective similarity scaling experiments. For the composite image mode CCAD, it is just to show the sample design process in this paper. In addition, the workflow and analysis of the single color patch model CCAD had presented and summarized in detail.

2.5.1 Color -patch-based CCAD

As an useful data source for colourimetry metrics, color patch data sets with the specific features always provide a basic color tool to develop and improve the uniform color spaces, color difference metrics and color appearance models [76]. In order to measure the uniformity of CIELab color space, the Munsell data set and Natural Color System (NCS) data set were firstly developed and applied by color experts [77, 78]. There are also other classical color difference sample sets were developed and published to assess the color difference formula in recent years, such as RIT-DuPont data set, Luo-Rigg data set and Witt data set. To develop a large color difference formula based on CIECAM02, current seven data sets were introduced and contrasted by Luo et al [39]. In addition to the color characteristics, the physical properties of color patches had also effected on the accuracy and precision of psychophysical evaluation experiments, such as the size and shape of color patch [79, 80]. For this project, the size of color patch is prior to design as 100 pixel ×100 pixel. It is easy for the management and measurement of whole sample set, and suitable for the sample display as a pair of samples on the monitor in subjective scaling experiments. The color attributes of color patches were depended on the standard CGATS21-CRPCs (s is from 1 to 7) data set. Considering the amount of color centers and test time, then ten primary color centers were selected that data set. The small adjustments of color centers are designed randomly as many as twenty kinds of changes. Form the moment, all samples were scaled by observers under one standard viewing condition, and record into the special worksheet.

2.5.2 Image-based CCAD

Image sample set is usually a database which is intent to the quality evaluation of advanced and transformed images. It can be divided into two main databases including gray image set and color image set. For the classical gray image database, there are IRCCyN/IVC Watermarking Databases which included images embedded in watermarking features [81], and the Wireless Imaging Quality

Database just accompanied with gray scale attribute. For the popular color image databases, there are general recommended color image sets and private color image sets. For example, the Categorical Subjective Image Quality Database [83], Tampere Image Database 2013 [84] and Live Image Quality Database (Release 2) [85] are general cases. Pedersen's printing quality of color image database [86], Simone's perception quality of distorted image database [87] and Liu's CID:IQ image database [88] are private cases. All above image databases were designed on the basis of single image sample. In some experiments, the results will be dependent on the content of selected single image sample actively. For this issue, specified items will attached into the single image sample to obtain a kind of composite image sample, such as color checker, black printed reticles and gradient color rings. The additional items can be also the different scene content. In Figure12, four scenes and two color checkers are consist of a composite image sample. For these composite images, the raw scaling results can't been correlated with the features of different scenes directly. For the composite image mode CCAD, all the primary image samples are designed with four different scenes selected from the CID:IQ image database which can provide 23 different scenes. As for the processing step, it is similar to that of single color patch mode CCAD.

Figure 12 Composite image sample with checked features

In this section, based on the colourimetry principles, the common color appearance and common color appearance database were introduced consequently, as well as the subjective similarity scaling experiments. For the psychophysical experiments, the detailed designing rules are presented to control the accuracy and efficiency of subjective experiments. Design concepts about single color patch mode CCAD and composite image mode CCAD also share some hints for each sample applied into subjective scaling experiments.

3 Literature survey

3.1 A survey of common color appearance applications

Common color appearance is an useful term that described the visual consistent degree of a set of reproductions provided by various printing mediums and media. In most color reproduction usage cases, the common color appearance plays more and more role on enhancing the color reproduction quality, such as color reproduction optimization, customer brand management and so on. For the conventional fields, it is required to an efficient objective metric to achieve and measure common color appearance. This will provide an available communication tool for printing providers, designers and customers from different industries such as conventional printing, digital printing, multimedium cases and so on. In particular, the promotion of ICC color management, and a series basic databases under characterized reference printing conditions can be provided basic data for implementing the common color appearance metrics.

3.1.1 Traditional printing case

Traditional printing has been occupied a significant market share in the color reproduction field, which has distributed many printing standard processes and preferred materials [89]. For the traditional offset printing, the ISO/PAS15339 standard had been developed by defining the specific printing databases based on seven substrates which could include most potential printing services [90]. On the basis of these printing databases, the color reproductions given from different printing medium can share the common color appearance, the usage case with designed composite image sample shown in Figure 13. Due to the diversity of traditional printing, seven CPRC data sets are still far from enough, but for providing intermediate platform to achieve the consistent similarity of a set of reproductions under different and limited printing conditions. Then it shows a feasible way to correlate color attributes of reproductions shared common color appearance with gamut feature of given printing media, this is further implemented by the proposed adjustment and feedback scaling frame.

Figure 13 ISO/PAS 15339 CRPCs case sharing CCA

For the CCA achievement based on the CRPCs database, it should ensure that the consistent hue produced by solid yellow ink, cyan ink and magenta ink in different printing systems which their color gamuts shared similar shape and different size to do degree. In the reference printing systems, the same combination of above three basic inks would produce its black scale and black scale which had been calibrated to possible closest to target neutral scale. This is the key principle to achieve a consistent appearance for a CMYK image on given different printing systems. In addition, for the conventional printing, Jam Morovic had also offered an ideal case to achieve CCA of CMYK images by using a senior and smart gamut mapping strategy, which his typical case shown in Figure 14 [91]. In Figure 14, the left side is the reference image, right side is the reproductions on different printers. The first column shows the native color approach which the reference is reproduced by its original CMYK data without considering any color calibrations, and it is easy to find the reproductions are different in sky color. The second column shows the color match approach which applied gamut mapping algorithm based on minimum ΔE in gamut intersection, and it is not pleasant yet for the consistency. The third column shows a smart and senior gamut mapping approach which would provide a consistent color appearance of references. However, this intelligent gamut mapping strategy had not been developed yet. From the view of Jam Morovic, the gamut mapping method is the combination of art and science, which depended on the ongoing specific motives [92].

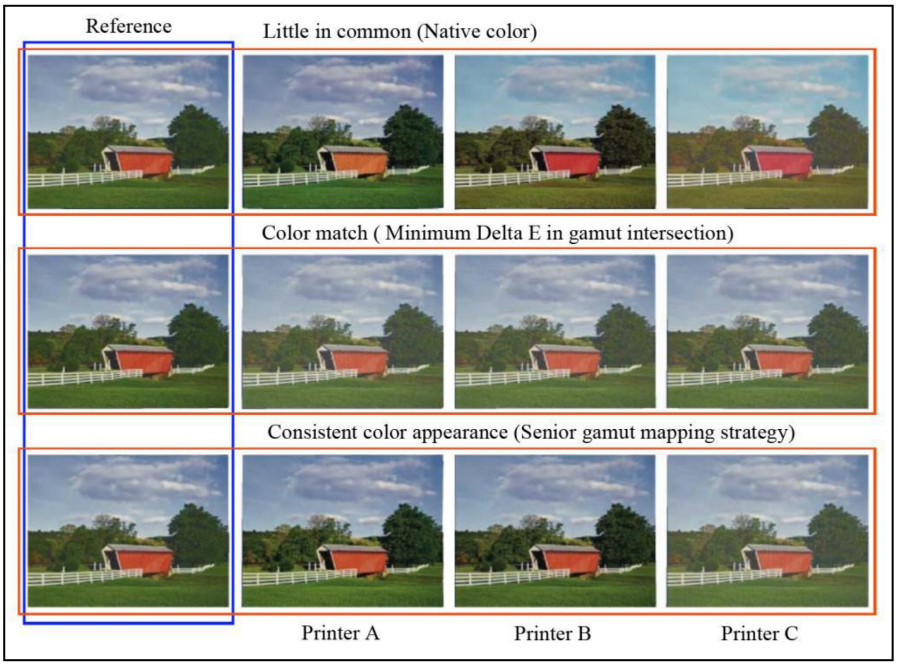


Figure 14 Jan Morovic's three gamut mapping strategies to display reference image

3.1.2 Digital printing case

The biggest difference between digital printing and traditional printing is the variety of substrates and supplement materials, which lead few interaction between the various color gamuts. This would cause the reproductions which are significant different from each printing provider, hardly to maintain the consistent color appearance of a set of reproductions. An typical case of digital printing application is the digital proofing, which can provide a quality confirmation for printing service providers to obtain business contracts. To achieve the consistent color appearance among a range of reproductions based on signed digital proofing draft, a digital master document is expected to develop to control the whole workflow, which had been partial standardized by the ISO 16760:2014 documents [93].

ICC color management is also popular among digital printing service providers. The ICC profiling software solution is not the only one and had been published different business versions from ICC member enterprises. This had been presented by Fogra color group in detail, and assessed by creating five ICC profiles solutions for test printing systems [94]. In the Fogra assessment of ICC perceptual rendering intent case, the specific reference is consist of color wheel given concentric rings and gray gradient scales under five ICC profiles. These reproductions are created by six different profiling software solutions. Then observers were requested to rank all the above reproductions from the most similar to least similar to reference, which shown in Figure 15. For the case of specific reference, Fogra applied 24 kinds of color centers and 10 kinds of gray centers under five ICC profiles. These ICC profiles were just used CRPC1 profile and CRPC4 profile. Since the reference and samples are the composite image mode, then it will be hard to correlate each single concentric ring with the scaling order value even though it can avoid the scaling results depending on the selected color center. Fortunately, this is an efficient and convenient way to verify general agreements about the common color appearance in digital printing workflow from the observers.

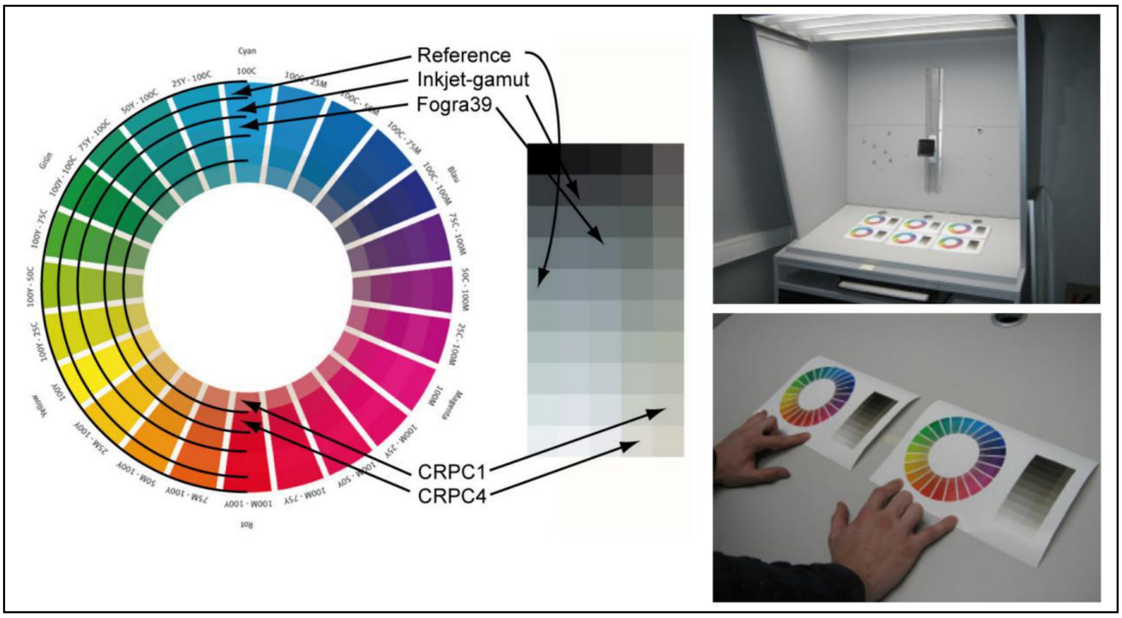


Figure 15 Fogra case based on ICC perceptual rendering intents

Figure 16 Brand management based on multimedia case

3.1.3 Multimedium case

The biggest goal of common color appearance topic is to provide the objective metrics to achieve and measure consistent appearance of a set of reproductions under different printing media. This is more powerful for the brand managers now. For the visual identity system of enterprise, brand color is the core element for its design and management. Because brand color will be printed on different medium under the various viewing conditions. So it is possible to maintain the consistent appearance in real world when the color data is managed carefully and continually. In Figure 16, it is indicated that the visual consistency required in different circulation environment. This is the issue that the general common color appearance model is going to solve completely. Then the common color appearance should be able to match each other, but the colourimetry value is not necessarily constant. The brand integrity is highly perceived by observers can be regarded as the scaling index which maybe a good alternative for the similarity in subjective evaluation experiments. However, there are not recognized objective metrics to be applied directly into brand management. This will be possible solved by the ongoing closeness trend line scaling method [95]. Based on the frame proposed by Gregory's PhD project plan, the constant visual evaluation in viewing modes described the real world conditions were contrast using the retargeting method and repurposing method, which may gives more guide for achieve common color appearance in brand management when his completed model is implemented eventually [10].

3.1.4 Display case

Common color appearance is regarded as the similarity degree of a set of color reproductions given different device with various color gamuts in size and shape. That device is not only referred to the printing media, but also display media. With the advanced luminescent materials development, the color gamut difference between new display media and printing medium is increasing fast in recent ten years. For example, in the international exhibition, the company logo will be displayed on different devices such as LCD, LED and OLED monitors, and as far as possible required the consistent color appearance. The ITU Rec.2020 is the new standard for the huge gamut transmission of broadcast television [96]. In Figure 17, it is shown four display gamuts and their potential display scenes.

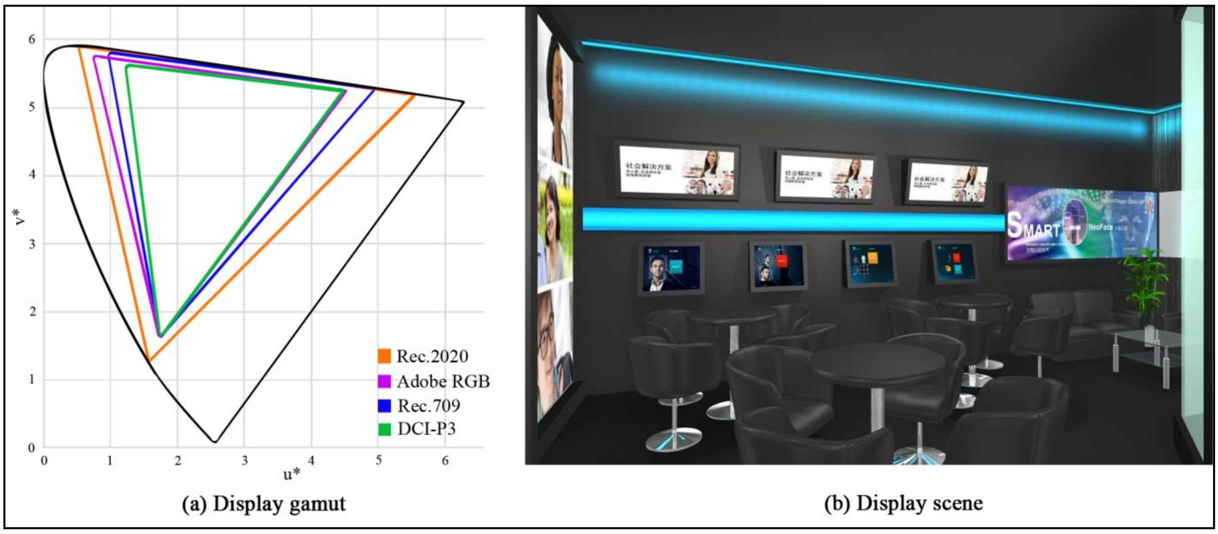


Figure 17 Display case required CCA: (a) display gamut; (b) display scene

3.2 Common color appearance reference source

In conventional printing, the ISO/PAS 15339 can provide a feasible case for reproductions sharing common color appearance based ICC profiles created with seven CRPC databases under offset printing systems. However, the objective evaluation on other printing systems is necessarily developed by some practical metrics. Mike Rodriguez (independent color consultant) had presented the development history of seven CRPC databases, and discussed the principles achieving common color appearance based on hue adjustment of primary color and neutral scale calibration in the first teleconference about common color appearance [97]. For hue adjustments, the CMY hue tonality curve had been aligned to the constant color tonality curve under the characterized reference printing conditions. For different printing systems, the neutral gray are calibrated by the similar tonality curves for the CMY scale and K scale. So, in digital printing, the color data sets of corresponding characterized reference printing conditions are necessarily developed according to above principle. However, this is not easy implemented because the substrates and digital inks varied from different digital printing systems.

In this project, the primary references were selected from the CRPC4 data set, and the secondary references were selected the corresponding color centers from the rest CRPCs data sets. The features and quantitative relationships were summarized from the designed color sample set generated by small adjustments among the LCh attributes using Matlab functions.in Figure 18, the color gamut features of CRPCs data sets are shown in 2D plane and 3D space respectively. It can be found that their color gamut volumes are increasing with the s value, but share the similar overall shape. The CRPC4 data set is selected as the primary reference data set, because its color gamut size is located the middle of whole CRPCs data set gamut distribution in 2D plane. The secondary references are selected from the rest CRPCs data sets, which both explore gamut feature change trend from large to small and from small to large. The processed color centers are all inside the gamut boundary of the corresponding CRPCs data set, which contributed to implement intelligent color gamut mapping algorithms. This maybe provide a feasible way to carry out Jam Morovic's strategy, which is also a goal for common color appearance metric development.

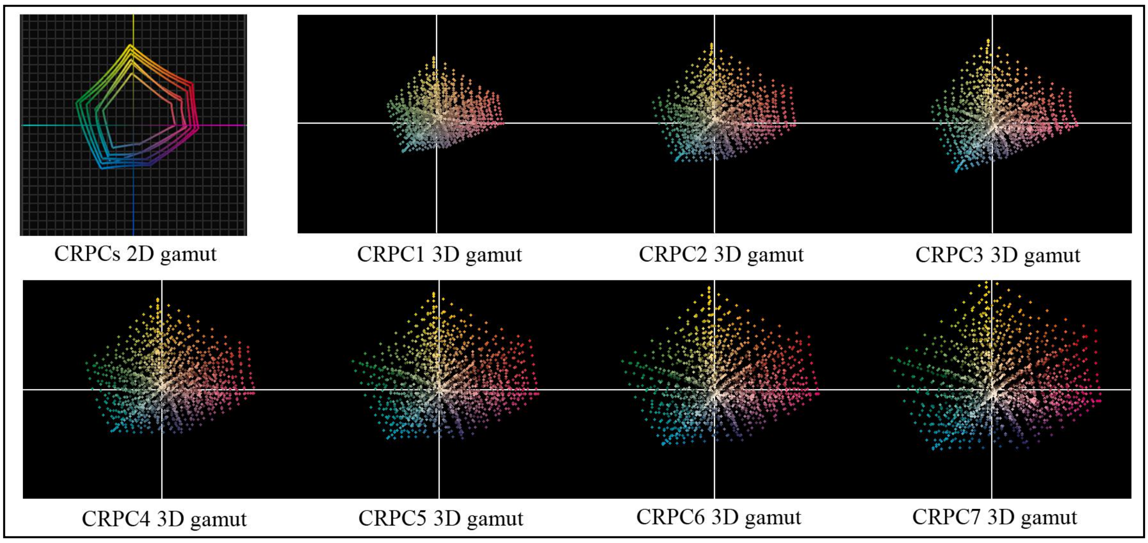


Figure 18 CRPCs(s=1~7) gamut in 2D and 3D display

In addition, for the common color appearance source, Jürgen Seitz (from GMG) think that digital proof is the most reliable tool to create physical color references, and establish new color space to replace Fogra39 in a relative color communication [98], which shown in Figure 19. However, such a reference is more suitable for relative match of the digital image quality, but further from the absolute match of printing reproductions. This did contribute to develop an alternative space for a wide and new common color appearance source.

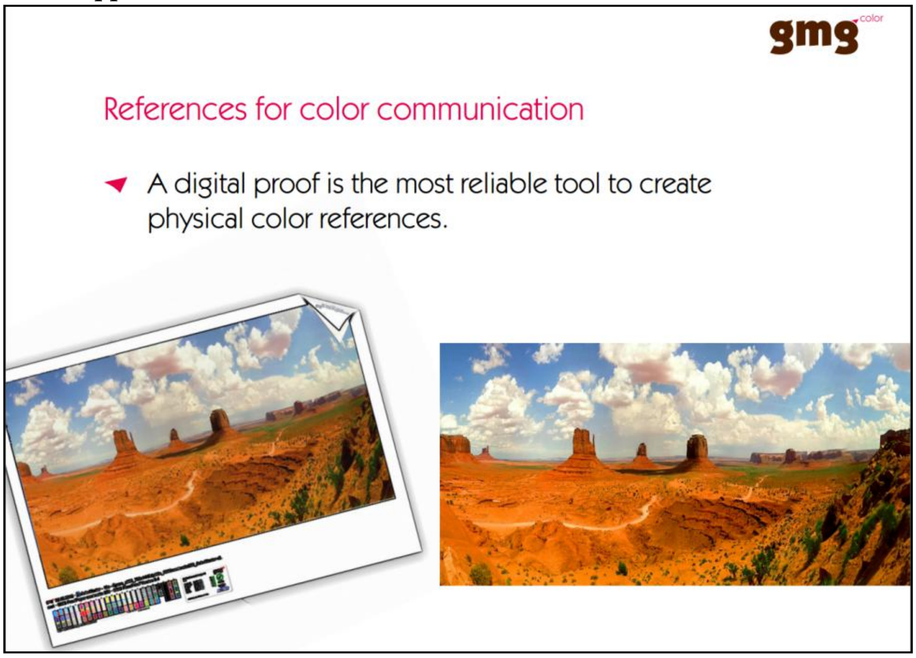


Figure 19 GMG theory for reference selection in color communication

3.3 Common color appearance achievement

Common color appearance can be regarded as the consistent color appearance which accepted generally by observers based on the different device gamuts. The key point is how to determine the similarity degree of accepted consistent color appearance of a set reproductions for all observers. Currently, the common color appearance can be achieved from the calibrated reproduction with the ICC profiles based on CRPCs data set. This is a standard and easy way to achieve common color appearance in offset printing, and its principle is also originated from the adjustment and feedback approach. That is to say, given different reference media and sample media, the samples generalized by small adjustments among LCh attributes which are scaled the highest similarity by observers under the specific viewing condition, can be regarded as a set of reproductions sharing common color appearance. This is a time-consuming and practical subjective approaches before the objective methods are to be developed by ICC. The weighted parametric approach is one potential objective metric for achieving common color appearance. However, it is also difficult to determine the useful and enough key parametric to create a completed formula or model. From the view of image quality, Po-Chieh Hung had selected specific factors such as image complexity, smoothness, color balance, gamut mapping, color rendering, light source and others [99] , which both shown in Equation 3.1 and Figure 20. The weighted coefficients are determined by the subjective scaling results.

$$F_{cca} = w_{ic}I_c + w_{sm}S_m + w_{cb}C_b + w_{gm}G_m + w_{cr}C_r + w_{ls}L_s + O \tag{3.1}$$

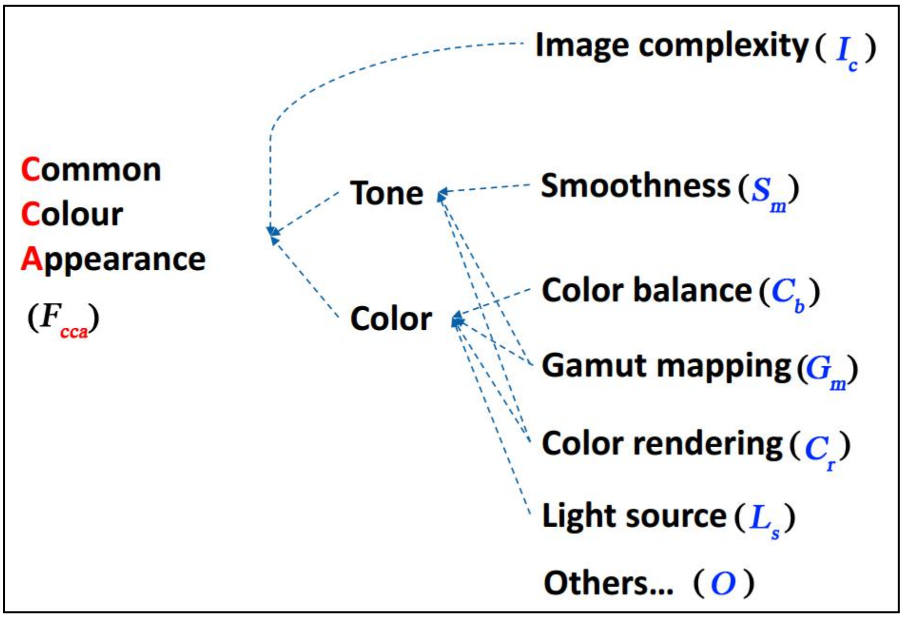


Figure 20 Weighted parametric method frame

3.4 Common color appearance metric

The approaches and objective tools to achieve the common color appearance are worth exploiting, even though its definition is not recommended by ICC yet and other organizations. This common color appearance is a special concept that described similarity degree of reproductions on given different device gamuts while traditional color appearance is the visual consistency of reproductions on one specific device gamut under different viewing conditions. From the view of conversion workflow, the common color appearance metric can be defined as the forward common color appearance model. Given specific inputs and boundary constraints, the outputs can directly implemented by quantitative models. This model frame is similar to the CIECAM02 model. According to the viewing condition variations, it can be divided into two models including generalized CCAD and special CCAD. The CCA and CCAM has more in common with gamut mapping, which can provide the potential acquisition tool for the former and create the transformed formula for the latter. For example, Yasuki Yamauchi team from Yamagata university had offered a closeness trend line method which showed the potential frame to explore the CCAM [100]. From the view of effect evaluation, it can be regarded as the backward common color appearance. For instance, the color naming method which proposed by Philipp Tröster team, was a good approach to evaluate the common color appearance model [95]. In addition, combining sophisticated statistical analysis method with color difference matrix of consistent samples, Robert Chung team from the RIT had presented their considerations and frame of common color appearance metrics by discussing the color consistency and visual consistency topics [101]. Further, Elena PhD shared her research questions about consistent visual metrics with specific factors including memory colors, expanse colors, daylight locus and other color space. It is also a pity that there is no completed metric frame for common color appearance yet.

3.4.1 Closeness trend line scaling approach

Closeness trend line scaling approach is the closeness degree of two color under different device gamut from the view of visual perceptual match. Minimum color difference approach didn't always match the visual perceptual difference of the color data sets produced by different device gamuts. This issue maybe cause by the few gamut interaction between reference media and sample media. Then Yasuki proposed an alternative to express the visual perceptual difference using the distance between the test sample and closest sample to the reference sample in corresponding device gamut, which shown in Figure 21. The workflow of closeness trend line scaling approach is consist of two steps including trend lines determination and closeness distance calculation. This trend line is the loci distributed by a set of closest colors under different device gamuts. This closeness distance is the shortest distance calculated from the test sample to the corresponding consistent color on the trend line loci rather than that from test sample to reference color.

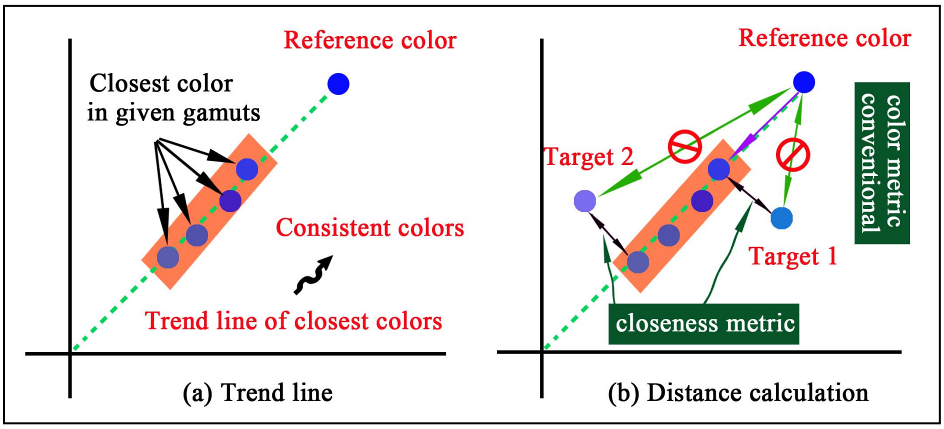


Figure 21 Closeness trend line method: (a) Trend line; (b) Distance calculation

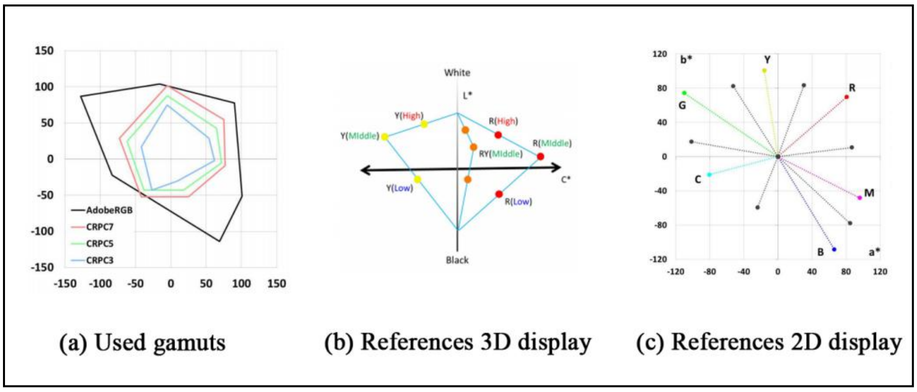


Figure 22 Setups of Yasuki's scaling experiment

At present, the main three features of closeness trend line scaling approach proposed by Yasuki are shown the following sentences:

Firstly, twelve reference colors were selected from the AdobeRGB gamut which located outside of gamut boundaries of test color sets. The selected test sample gamuts were three CRPC color sets including CRPC3, CRPC5, CRPC7, which shown in Figure 22. From the source color selection, it is main considered the color centers located outside of gamut boundaries of seven CPRC color sets, while inside color centers and neutral colors were not taken into account in the setups of Yasuki's subjective scaling experiments.

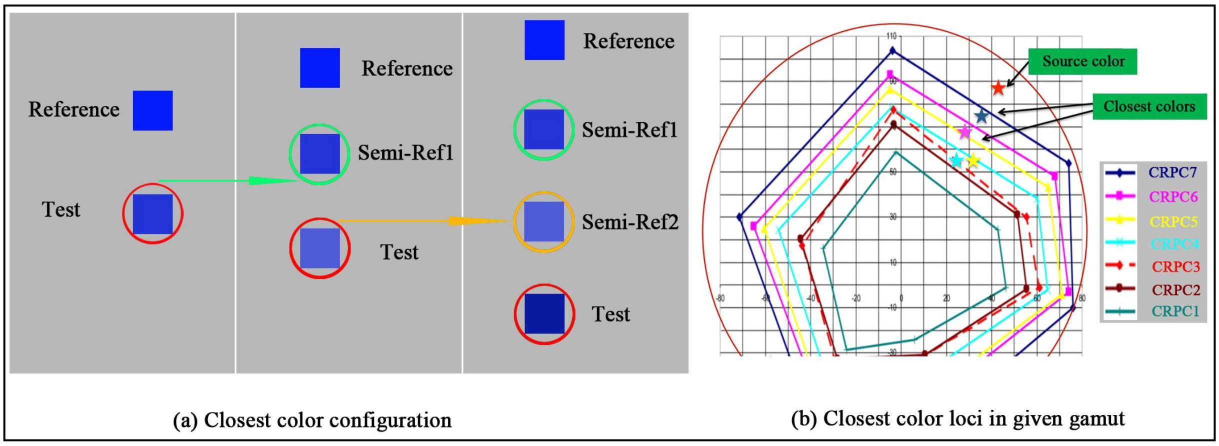


Figure 23 Closest color configuration and loci display

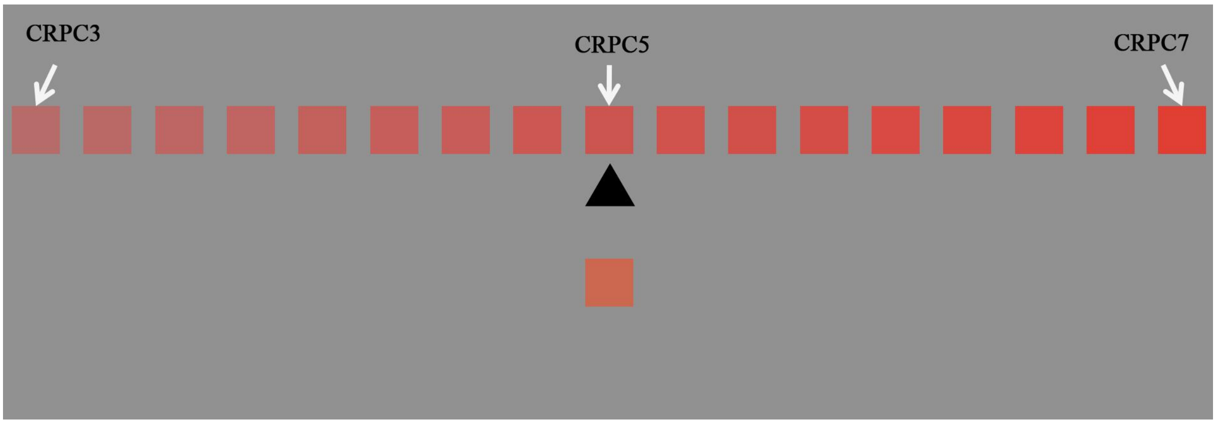


Figure 24 Stimulus configuration case

Secondly, the corresponding consistent colors were configured from the outermost gamut to adjacent interior color gamuts. In this case, the first corresponding consistent color was configured from the CRPC7 gamut based on source color, then the second corresponding consistent color was configured from the CRPC5 gamut based on the first corresponding consistent color, lately the third corresponding consistent color was configured from the CRPC3 gamut based on the second corresponding consistent color. All the corresponding consistent colors were plotted in a*b* plane to fit different closeness trend scaling lines for different reference colors. For each corresponding consistent color was configured by subjective scaling experiments, which one case shown in Figure 23. This configuration approach can provide a fast way to find the corresponding consistent colors, and guarantee a good accuracy for single color attribute dimension. However, this approach is not ideal for combination variations of three color attributes, which will seriously deviate from the source color. Moreover, this deviation phenomena was also found in Yasuki's scaling results.

Thirdly, the configuration of corresponding consistent color under different color gamuts were basically found among test stimulus including nine degrees in chroma dimension and fixed hue attribute, which shown in Figure 24. The chroma attribute of test stimulus were designed as nine degrees in ascend order with the same interval, which is not always to provide all samples including enough nine degrees for various color centers under given device gamuts. Therefore, linear color set may not more easy than cluster distribution of multi-dimensional attributes to configure the corresponding consistent colors. At the same time, Yasuki's results had shown that some consistent color loci of color centers were not always along with hue angle direction, which indicated the only hue attribute maybe not enough for color center configuration.

3.4.2 Color naming approach

Color naming approach is a method proposed by Philipp Tröster team from Fogra color group based on three famous color naming experiments, which expressed the similarity degree of common color appearance using the amount of color names contained in color difference space between reference sample and test sample [94, 100]. Their theoretical hypothesis is that the color patch of reference image can be described as the same color name should be more consistent than that described as different color names when it was mapped to one or multi-reproductions. Their initial results had shown that this approach was a potential correlation between color names and common color appearance. The first color names database was based on the unconstrained web-based experiment, which conducted by Giordano Beretta and Nathan Moroney, and offered a list of 400 color names and their CIELa*b* values [102]. The second color names database was based on the monitor-based experiment, which shared by Xkcd-color-survey, and offered 954 color names and the associated RGB values. The third color names database was a database from the Colorhexra.com where offered 746 color names and the associated CIELa*b* values. The density of color names of three famous color name databases in CIEa*b*-plane are shown as histograms with the dimension of the bins is (25×25) in Figure 25.

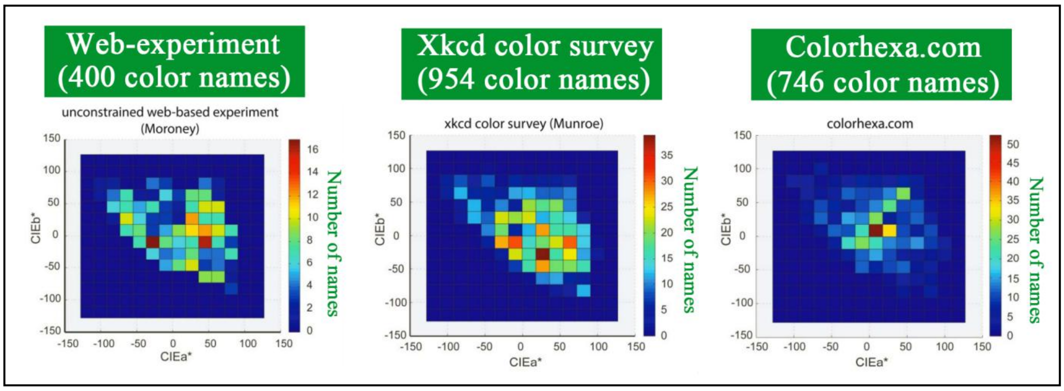


Figure 25 The density of color names of three famous color name databases in CIEa*b*-plane

According to color names and the corresponding position in CIELa*b* color space, the distance between the reference and target reproduction is measured by the CIELa*b* color difference. However, their color difference magnitude is not just expressed by this distance, but the amount of its similar color names contained in color difference cuboid (ΔL^*-Δa^*-Δb^*) with depicted Lab-points, which shown in Figure 26.

Interestingly, Philipp Tröster et al proposed two different CCA evaluation metrics for two main psychophysical experiments including CCA assessment of composite images using perceptual mapping strategies and CCA assessment of color rings using ICC perceptual rendering intents. In the CCA assessment experiments of composite images, the consistent scaling values of a set of reproductions were calculated directly by the proposed Φ_{CA} formula which shown in Equation 3.2 in detail. Where N_{CN} is the average amount of color names in each bin indicated scaling index, N_{ij} is the number of comparisons between the samples i and j for each designed group. The second sum is used for the color checker and N_k^{ij} sums up all the crossed color boundaries between color names. However, in the CCA assessment experiments of color rings, the consistent scaling values of color patch is expressed by the N_{fn} formula which shown in Equation 3.3 clearly. Where Lab_i and Lab_j is for the Lab-point of reference color and the Lab-point of sample color, and N_{ff} is the average amount of color names of specific color difference interval, and N_g is the number of test gamuts. The intermediate threshold function is to calculate the distance between the farthest color name point within the crossed color boundaries to the connected line of color centers. The form and feature of threshold function is depicted in Figure 27, as well as the principle of color naming cylinder model.

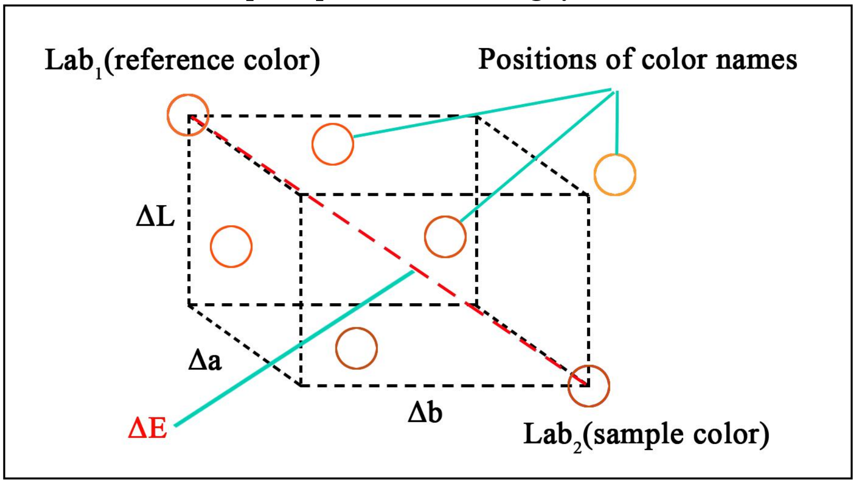


Figure 26 Principle of cuboid model correlated color names and their positions

$$\Phi_{CA} = \frac{N_{CN}}{N_{ij}} \sum_{\substack{i,j \in G \\ j \neq i}} \left[\sum_{k \in CB} N_k^{ij} \right] \tag{3.2}$$

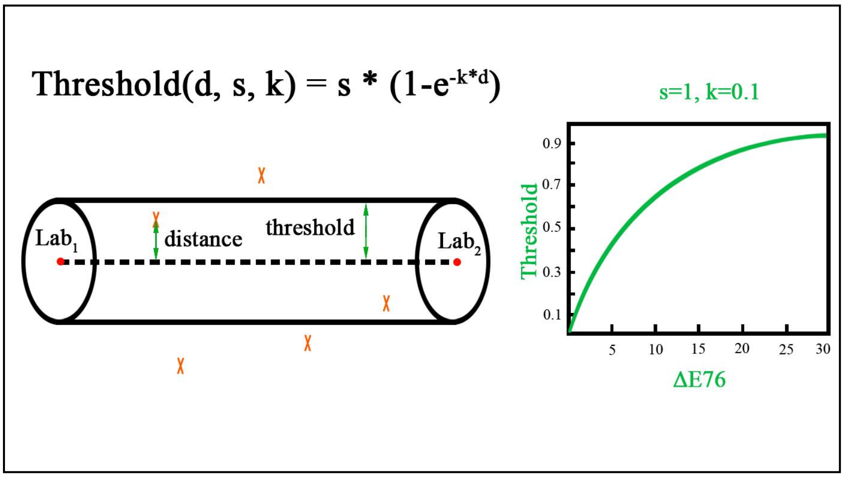


Figure 27 Principle of cylinder model using special threshold function

$$N_{fn} = \sum_{1}^{N_{ff}} \sum_{i=1}^{N_g - 1} \sum_{j=i+1}^{N_g} threshold\,(Lab_i, Lab_j) \tag{3.3}$$

The numerical model of color naming approach had been developed from the cuboid model to cylinder model for more comprehensive applications. However, there is a far way to optimize this approach to meet the standard CCA measurement metrics recommended by ICC R8-13 TC, although it had some potential practical correlations. For Philipp's initial experiments, it had not excluded the dependence of sample colors on the correlated result. For example, the color centers were not considered other special colors such as memory colors. For the threshold function with s=1 and k =0.1 case, it can can be found the nonlinear relationship between threshold values and ΔE values, which indicated that the inhomogeneity of color names density among union color difference bin. This is shown that it maybe impossible for avoiding the dependence of color centers in the CIELa*b* color space, and maybe required to use more uniform color space such as IPT color space or develop others. Then the applicability of color naming approach in CCAD is not discussed in this paper.

4 CCAD implementation

The proposed CCAD is a color sample database for modeling and assessing common color appearance. Whether the CCAD is created by single color patch mode or composite image mode, the color centers should include all possible primary color and secondary color samples. The typical workflow of CCAD implementation is shown with five features in Figure 28. Firstly, the sample sets of CCAD is consist of reference set and test sample set which generated by small adjustments among combinations of LCh attributes. Secondly, all the reference colors are selected from the various CRPC data sets. Thirdly, all the sample colors are created by Matlab software randomly under the specific gamut. Fourth, the nine degree category judgment approach is applied into the subjective similarity scaling experiments. Fifth, all the observers has checked and passed the color blind test and visual sensitivity test before subjective scaling experiments.

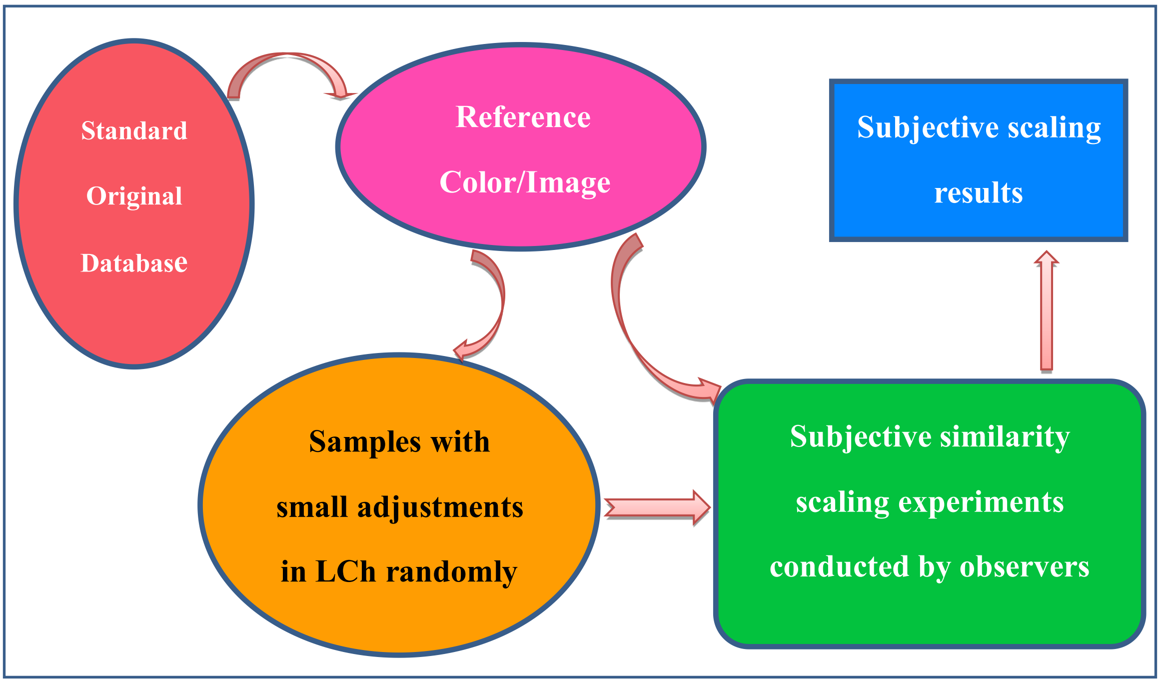


Figure 28 Workflow of CCAD implementation

4.1 References design

Reference sample is the source color which had significant effect on psychophysical experiments. For the reference design, the individuality and generality of source colors should be considered together, which can be easy achieved from the standard color data set or the database recommended by famous national organizations. The number of reference colors is necessary to match the number of observers and the whole test time. In addition, in the setups of some current image databases, they also had offered some guides about the least amount of reference colors. For example, Keelan et al proposed at least three reference images used in relative evaluation of just noticeable color difference experiment, and at least six reference images applied into absolute assessment of standard image quality. A similar recommendation can be found in ISO 260462-1 standard document. So, at least five references will be selected in this project.

4.1.1 Color-patch-based references

The primary source colors of CCAD based on single color patch mode were ten color centers chosen from the CRPC4 data set. All the reference colors are designed as solid color patches with 100 pixel×100 pixel square. The CMYK values and Lab values of reference colors are listed in Table 9. The format of all values are rounded as the integer statistics, which is convenient to design the specific color patch using the Photoshop software in Lab mode. This transform maybe lead loss of accuracy of the final scaling results. These ten color centers are located on the gamut boundaries of CRPCs color data sets, which behave more sensitive to the any change of LCh attributes, and shown in Figure 29.

Table 9 The CIELa*b* and CMYK of CRPC4 reference color patches

Sample_ID	Test_ID	C	M	Y	K	L	a	b
1	1	0	0	0	0	89	0	3
1008	2	40	40	40	40	42	3	3
1286	3	100	100	100	100	15	0	1
73	4	100	0	0	0	55	-36	-38
9	5	0	100	0	0	47	66	-3
649	6	0	0	100	0	83	-3	83
1260	7	0	0	0	100	23	1	2
81	8	100	100	0	0	28	14	-39
657	9	0	100	100	0	46	62	39
721	10	100	0	100	0	49	-54	24

*Reference white point and reference black point of CRPC4 data set are(89.00, 0.00, 3.00)and(15.29, 0.29, 1.34).

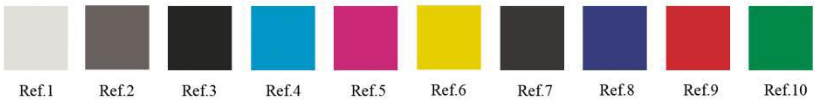


Figure 29 CRPC4 reference color patches displayed in sRGB mode

Table 10 The CIELa*b* values of CRPCs(s=1, 2, 3, 5, 6, 7) reference color patches

	CRPC1(No.1)			CRPC2(No.2)			CRPC3(No.3)			CRPC5(No.5)			CRPC6(No.5)			CRPC7(No.6)		
	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b
1	85	1	5	87	0	3	95	1	-4	92	0	0	95	1	-4	97	1	-4
2	47	3	5	43	3	3	48	2	1	42	3	2	43	3	1	42	3	2
3	32	0	1	22	1	1	27	0	1	9	0	2	9	0	0	4	0	3
4	59	-24	-26	57	-28	-34	60	-26	-44	57	-37	-44	56	-37	-50	54	-42	-54
5	56	48	0	52	58	-2	56	61	-2	48	71	-4	48	75	-4	47	78	-10
6	80	-2	60	82	-2	72	89	-3	76	87	-4	88	89	-4	93	90	-4	103
7	37	1	4	30	1	2	32	1	1	19	0	1	16	0	0	14	0	0
8	42	7	-22	35	9	-32	38	10	-31	27	17	-44	25	20	-46	20	26	-53
9	54	44	25	51	55	32	54	56	28	48	65	45	47	68	48	47	75	54
10	55	-35	17	51	-44	19	54	-43	15	51	-62	26	50	-66	26	50	-72	29

Table 11 The CIELa*b* values of reference white ans reference black of CRPCs(s=1, 2, 3, 5, 6, 7) database

	CRPC1(No.1)			CRPC2(No.2)			CRPC3(No.3)			CRPC5(No.5)			CRPC6(No.5)			CRPC7(No.6)		
	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b
Ref_W	85.0	1.00	5.00	87.0	0.00	3.00	95.00	1.00	-4.00	92.00	0.00	0.00	95.0	1.00	-4.00	97.0	1.00	-4.0
Ref_K	31.7	0.09	0.80	22.0	0.80	1.26	27.08	-0.19	1.07	9.20	0.00	1.86	9.05	0.20	0.39	4.41	-0.16	2.77

For the secondary reference colors were selected from color centers shared the corresponding

CMYK values in CRPCs data sets, where s is set (1, 2, 3, 5, 6, 7). The CIELab values of selected secondary colors are depicted in Table 10 in detail. The reference white point and reference black point of rest six CRPC data sets are shown in Table 11, respectively. Moreover, all the secondary color patches are displayed in sRGB mode which shown in Figure 30.

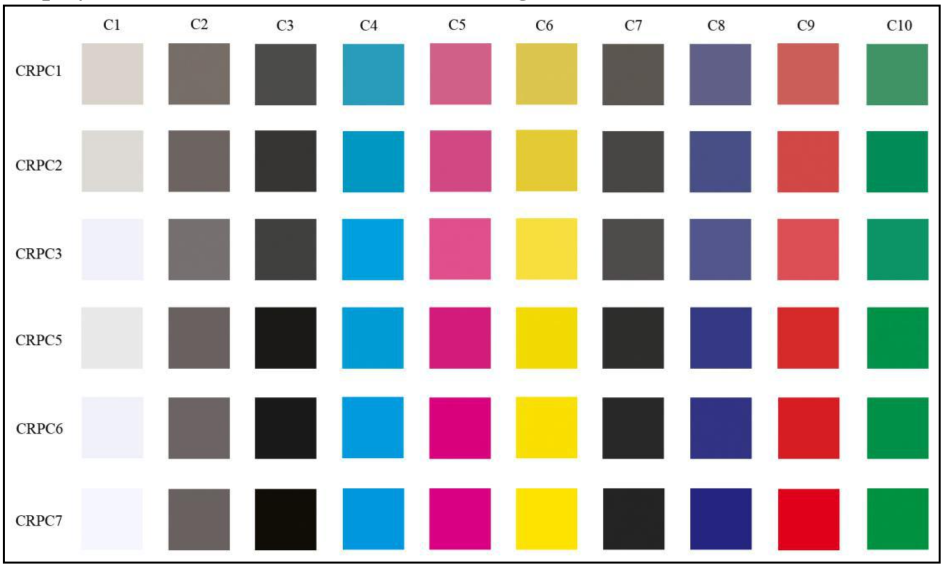


Figure 30 CRPCs(s=1, 2, 3, 5, 6, 7) reference color patches displayed in sRGB mode

Figure 31 Five composite reference images displayed in sRGB model

4.1.2 Image-based references

Reference images of CCAD based on composite image mode were selected twenty scenes from the CID:IQ image database. When conducted the subjective similarity scaling experiment, the similarity scaling values can be correlated with Lab values of each pixel of test image. In addition, it can be also correlated with additional color patch of color checker added into the test image. This is easy to measure the Lab values of color centers on substrates or monitors. Then the specific color checker was added into the reference image by using primary colors and basic neutral colors in NCS data set, which shown in Table 12, respectively. Those color samples can show the color names and specific CIELa*b* values together, and applied into various color industries. In Figure 31, the specific color checker can be easy found and consist of thirty color patches in 2362 pixel×1890 pixel square.

4.2 Sample design

4.2.1 Color-patch-based samples

Sample colors of CCAD based on single color patch mode, were generated by small adjustments of LCh attributes of secondary reference colors using designed Matlab codes. The twenty random small adjustments of LCh attributes matrix is shown in Table 13. At last, 1260 sample color patches were created by specific file name order. The small adjustment magnitude of LCh attributes matrix is always loop to ensure all the sample colors located inside the corresponding gamut boundary of CRPC data set. For the test whether each sample color point is in the specific color gamut of CRPC data set or not, it can be easily achieved by the combination of trigamut.m function and scatter3.m function in Matlab, which shown as colorpoint_ingamut.m program in the supplement code_list documents of thesis file.

Table 12 The CIELa*b* values of special color center references

Deep Pink	L a* b*	62 46 17	Deep Olive Green	L a* b*	18 -11 25	White	L a* b*	100 0 0
Deep Red	L a* b*	30 45 18	Deep Reddish Orange	L a* b*	41 47 42	10% Gray	L a* b*	94 0 0
Deep Orange	L a* b*	53 33 56	Deep Bluish Green	L a* b*	25 -21 -3	20% Gray	L a* b*	88 0 0
Dark Olive	L a* b*	26 -2 18	Deep Greenish Blue	L a* b*	51 -22 -17	30% Gray	L a* b*	81 0 0
Deep Yellow	L a* b*	60 5 61	Deep Purplish Blue	L a* b*	17 14 -32	40% Gray	L a* b*	74 0 0
Deep Green	L a* b*	31 -28 7	Deep Reddish Purple	L a* b*	29 37 -19	50% Gray	L a* b*	66 0 0
Deep Brown	L a* b*	26 16 24	Deep Purplish Pink	L a* b*	61 48 -6	70% Gray	L a* b*	47 0 0
Deep Blue	L a* b*	26 -5 -30	Deep Yellowish Pink	L a* b*	59 48 60	80% Gray	L a* b*	35 0 0
Deep Purple	L a* b*	28 30 -26	Deep Reddish Brown	L a* b*	17 35 21	90% Gray	L a* b*	20 0 0
Deep Yellowish Green	L a* b*	36 -36 23	Deep Yellowish Brown	L a* b*	32 11 27	Black	L a* b*	0 0 0

In Table 13, the ID variable is the identity of each adjustment of LCh attributes, and the Var_Cx (x is set from 1 to 10) is given the adjustment magnitude matrix for the specific color center No.x. When all the sample color patches were created, the positions of each sample color in CIELa*b* color space were all plotted together for each color center using the designed displayall.m function. The sample loci case of color center No.10 in gamut boundary of the CRPC1 data set is displayed in Figure 32. In order to analyze the position feature of secondary reference color and sample colors in CIELa*b* color space, ten color centers within six CRPC data set are depicted from Figure 33 to Figure 42, respectively. In each case, the secondary reference color is marked its detailed position among all sample color set with red dot and green line. All color points are distributed in yellow cycle with relative rate. It should be explained that all the sample color patches were shown in sRGB mode.

Table 13 LCh small adjustments metric of reference color patches

ID	Var_C1			Var_C2			Var_C3			Var_C4			Var_C5			Var_C6			Var_C7			Var_C8			Var_C9			Var_C10		
	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh	ΔL	ΔC	Δh
1	-3	0	0	-3	0	0	4	0	0	2	-5	0	2	-5	0	-1	-3	0	3	0	0	2	-5	0	2	-5	0	2	-5	0
2	-2	-3	0	0	-3	0	1	-2	1	0	-3	-2	0	-3	0	-1	-6	-1	-2	-3	0	0	-3	0	0	-3	0	1	-3	0
3	-1	0	-3	0	0	-3	4	0	-3	0	-5	-2	-1	-6	1	-3	-5	0	-1	0	-3	-1	-6	1	0	-7	-3	0	-5	-3
4	-4	-4	2	0	-4	4	3	2	-3	2	-6	-3	2	-6	2	0	-7	0	-3	-5	1	2	-6	2	2	-6	4	2	-6	1
5	-5	-2	-2	0	-2	-2	5	3	3	0	-4	-4	0	-4	2	-2	-3	-1	5	-2	-2	0	-4	2	3	-8	2	0	-4	-2
6	-7	3	-4	0	-9	-4	8	2	-4	0	-5	-5	3	-7	3	-4	-8	-3	7	3	-4	3	-7	3	0	-5	-4	2	-8	3
7	-6	-1	0	-3	-6	0	0	0	2	3	-6	0	3	-6	0	-3	-7	-2	6	-1	0	3	-6	0	3	-9	0	3	-6	0
8	-2	0	-6	-2	0	-6	5	-1	-6	-2	-4	2	-2	-5	1	-5	-1	1	-2	0	-6	2	-4	2	-2	-1	-4	-2	-6	2
9	-6	0	3	-6	0	3	7	-3	2	-1	-8	3	-1	-8	3	-1	-5	-1	-4	0	3	-1	-8	3	-1	-8	1	-1	-8	3
10	-4	2	-9	-4	2	-9	4	1	3	-4	-9	2	-4	-9	2	-2	-7	-2	4	2	-5	3	-4	-2	-3	-9	-1	5	-1	3
11	-9	0	2	-9	-9	4	6	0	4	4	-8	-1	5	-1	3	-3	-6	-2	5	0	2	5	-1	3	4	-8	4	4	-11	5
12	-2	3	-5	-2	3	-6	2	0	-2	-2	-7	-8	-2	-7	-3	-2	-6	1	2	3	-5	-1	-7	2	-2	-7	0	-2	-7	2
13	-5	-3	1	-3	-3	3	2	-1	3	1	-4	-3	2	-8	5	-5	-9	5	3	-3	1	2	-8	5	1	-4	1	1	-4	1
14	-8	2	-4	3	-6	-4	3	-6	0	3	-7	-4	1	-7	4	-2	-5	0	5	2	-4	4	-7	4	3	-7	3	3	-7	-4
15	-9	4	-9	-9	4	-9	9	4	-8	2	-5	-3	2	-5	3	-7	-9	-1	3	4	-9	2	-5	3	2	-5	2	2	-9	7
16	-4	-4	-2	-4	-4	-2	8	-4	-2	1	-4	-2	1	-4	0	-2	-4	0	-4	-3	2	1	-4	0	1	-6	-1	1	-4	2
17	-6	-5	-3	-2	-6	-3	4	3	-3	-2	-6	-3	-2	-6	-1	-3	-8	-1	6	-5	-3	0	-5	-4	-2	-8	-3	-3	-9	3
18	-3	-2	4	-3	-5	4	3	-2	4	-3	-5	4	-3	-9	-2	-5	-7	-3	-3	-2	4	-2	-9	-2	-1	-6	-4	-3	-8	-1
19	-8	6	2	3	-4	-6	12	-4	-6	3	-9	2	3	-8	4	-6	-9	-3	-2	-5	2	3	-8	4	3	-9	6	3	-9	2
20	-6	2	-3	-6	2	-3	10	2	-3	-4	-9	-5	-1	-3	3	-4	-6	-1	6	-2	-3	1	-3	3	-4	-12	1	-4	-1	-1

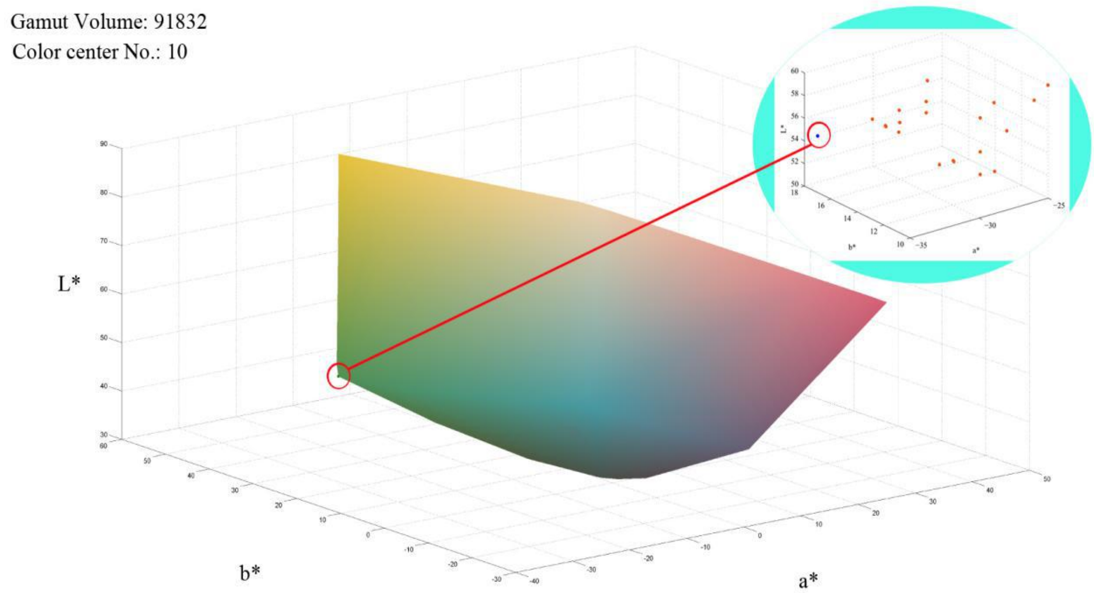


Figure 32 Samples loci of color center No.10 in CRPC1 gamut

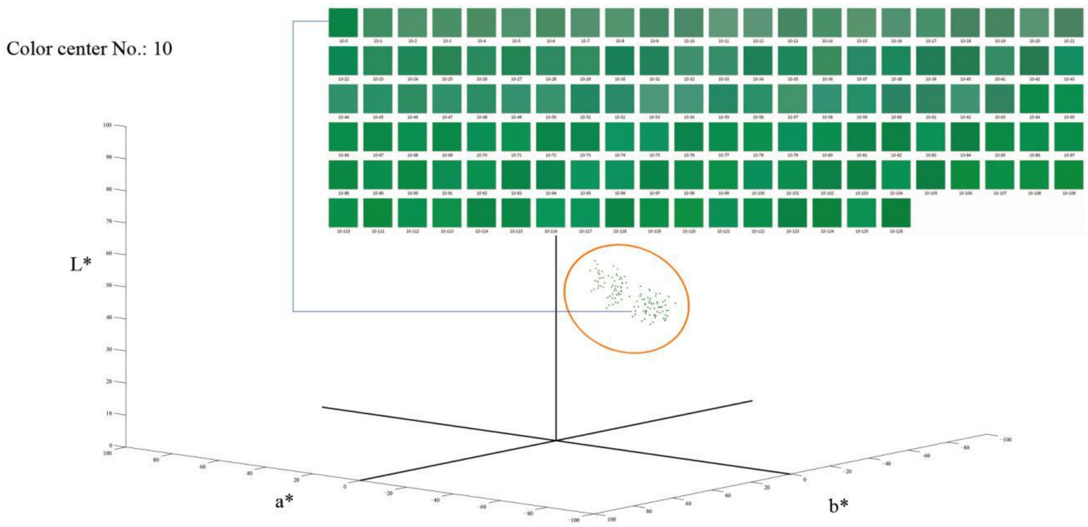


Figure 33 Samples of color center No.10 displayed in sRGB mode and located in CIELa*b* space

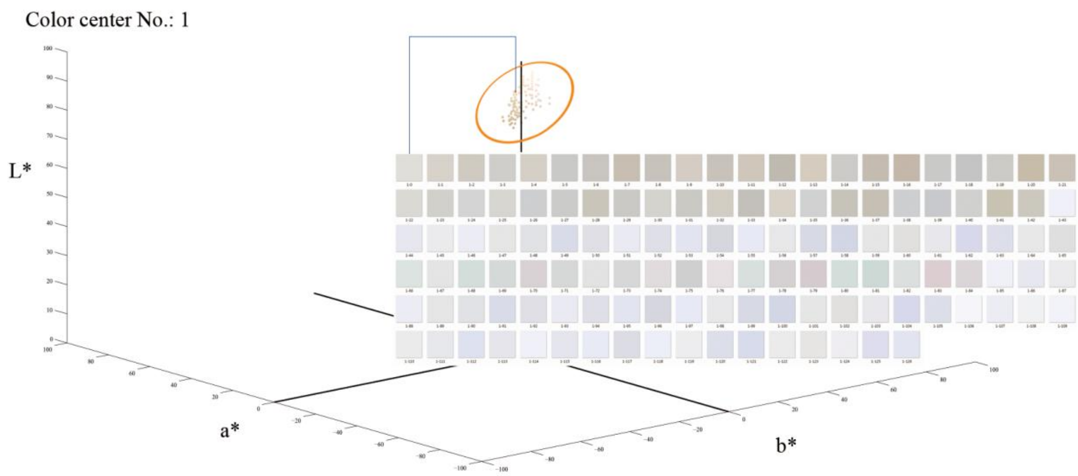


Figure 34 Samples of color center No.1 displayed in sRGB mode and located in CIELa*b* space

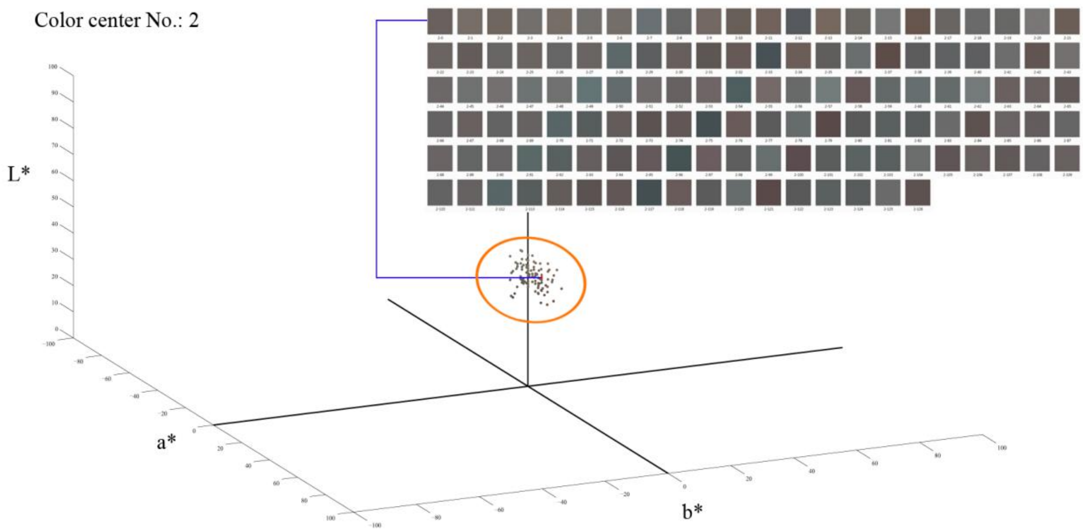


Figure 35 Samples of color center No.2 displayed in sRGB mode and located in CIELa*b* space

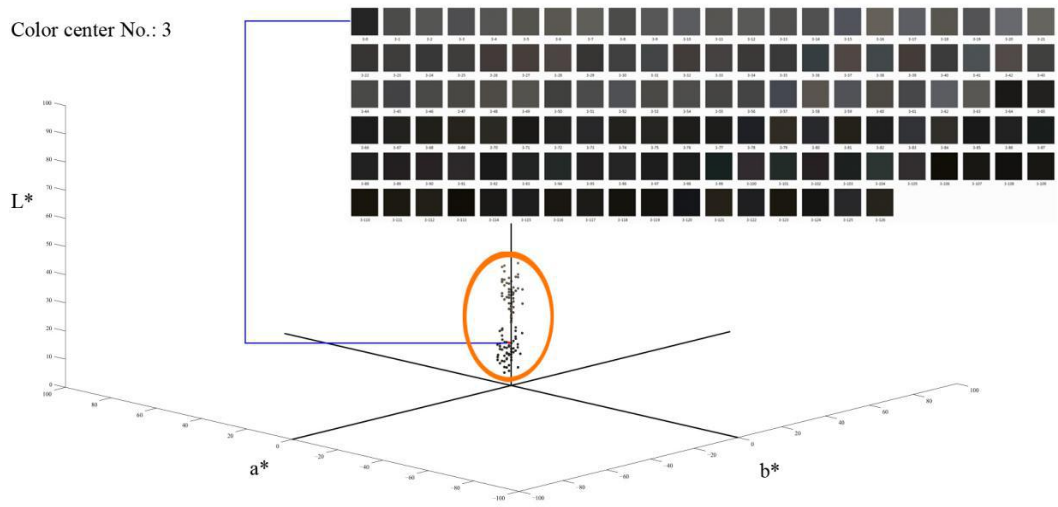


Figure 36 Samples of color center No.3 displayed in sRGB mode and located in CIELa*b* space

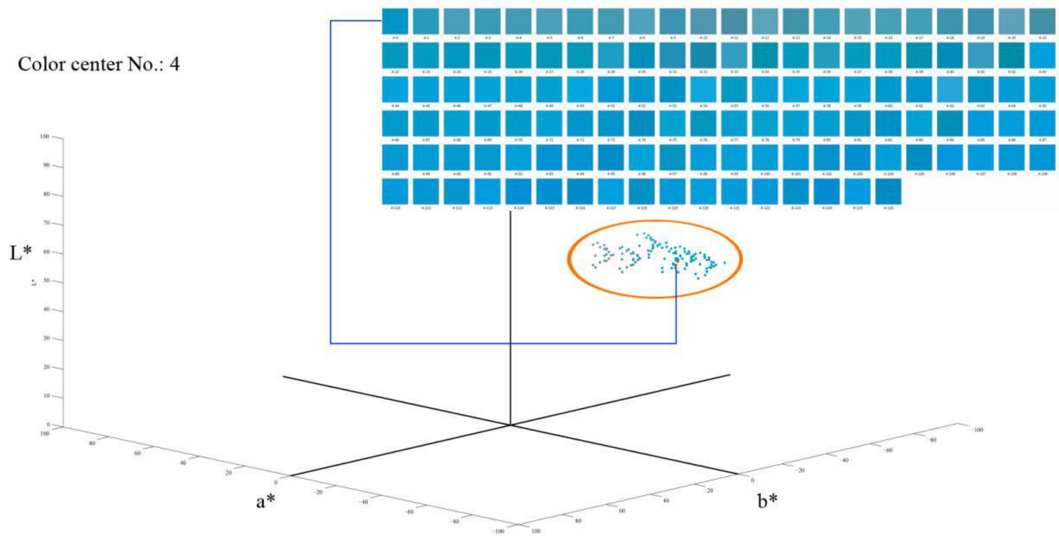


Figure 37 Samples of color center No.4 displayed in sRGB mode and located in CIELa*b* space

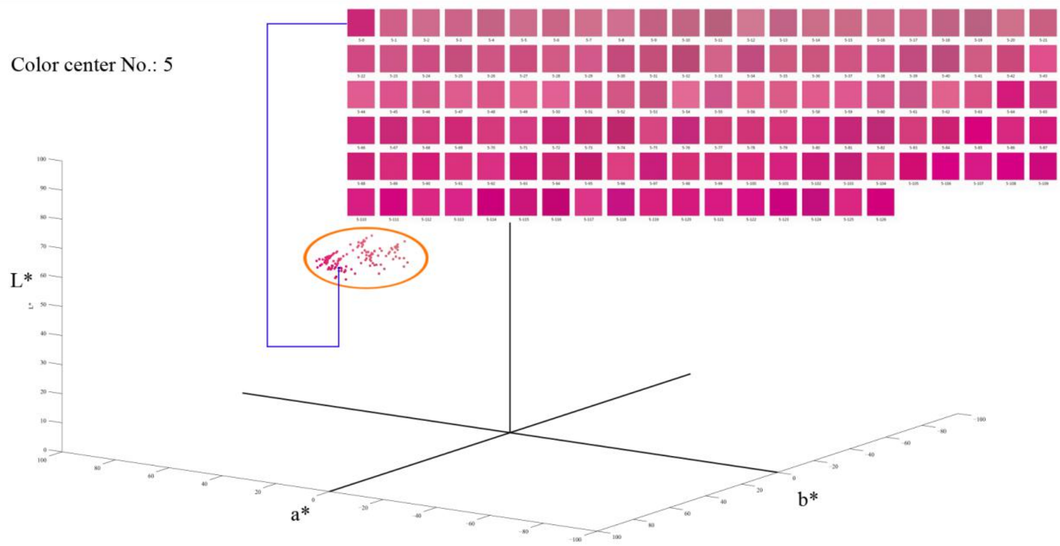


Figure 38 Samples of color center No.5 displayed in sRGB mode and located in CIELa*b* space

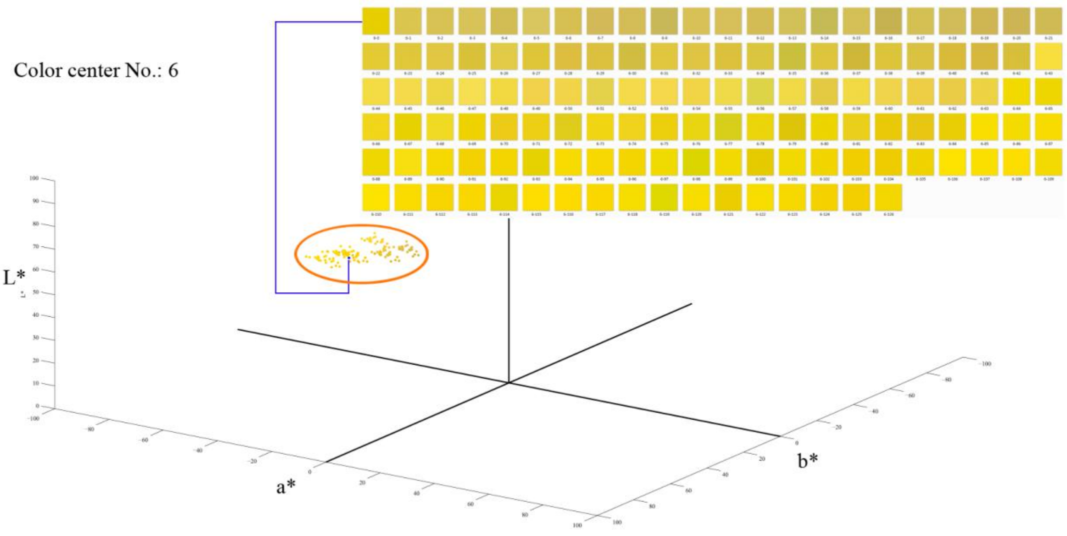


Figure 39 Samples of color center No.6 displayed in sRGB mode and located in CIELa*b* space

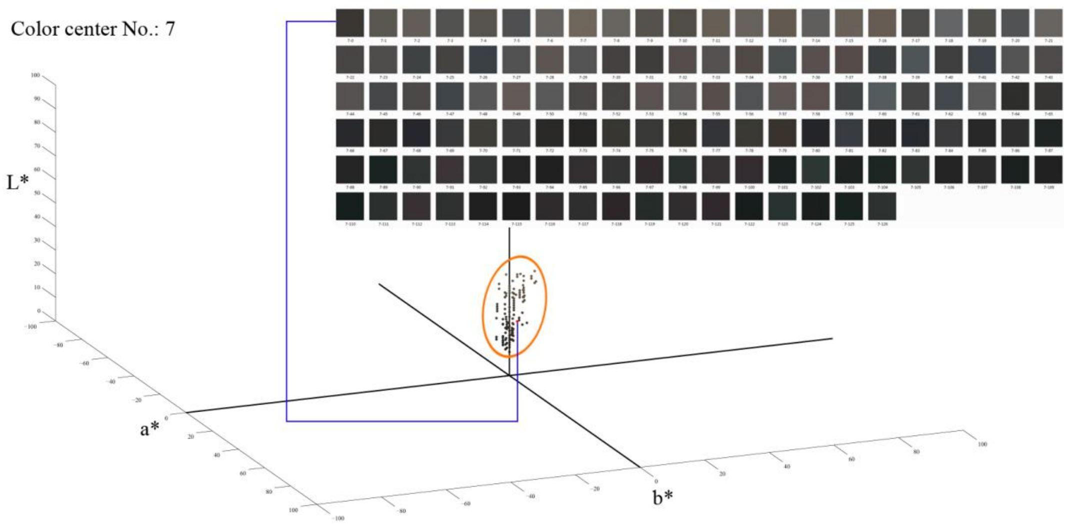


Figure 40 Samples of color center No.7 displayed in sRGB mode and located in CIELa*b* space

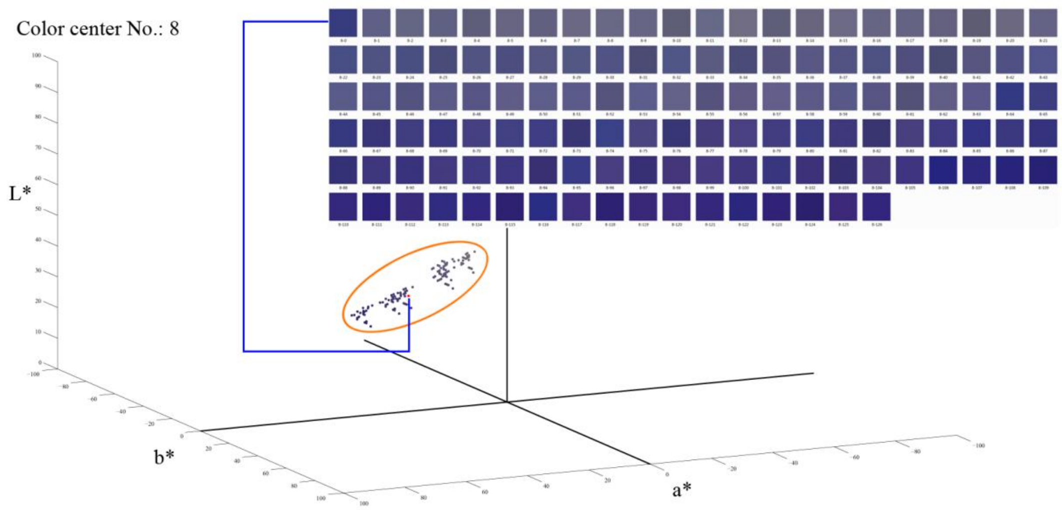


Figure 41 Samples of color center No.8 displayed in sRGB mode and located in CIELa*b* space

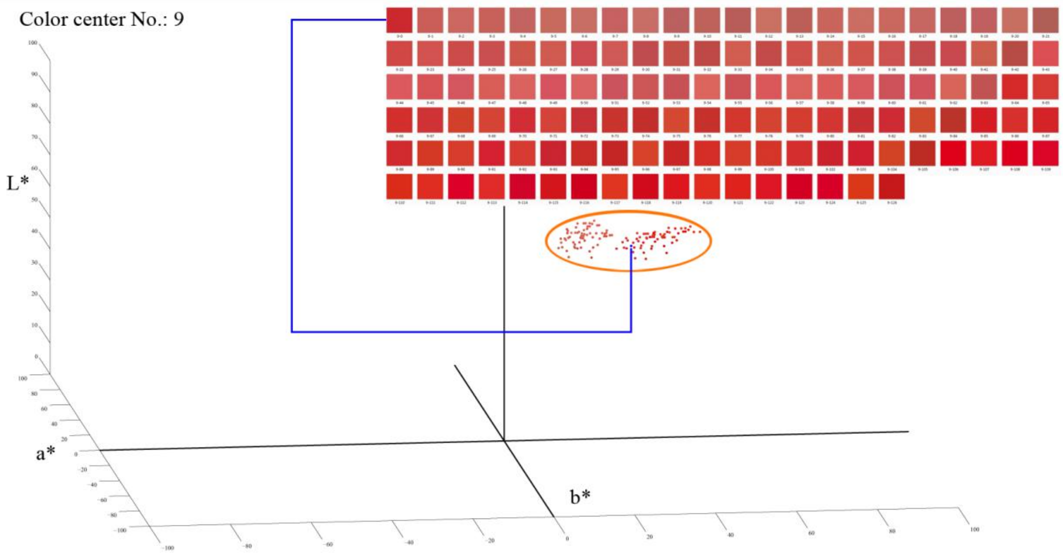


Figure 42 Samples of color center No.9 displayed in sRGB mode and located in CIELa*b* space

4.2.2 Image-based samples

Sample images of CCAD based on composite image mode, were also generated by small adjustments of LCh attributes of reference images using designed Matlab codes. The twenty random small adjustments of LCh attributes matrix is shown in Table 14. At last, 100 sample images were created by specific file name order, which their screenshots of all sample images displayed in sRGB mode are shown in Figure 43.

Table 14 LCh small adjustments metric of reference image

Var_I	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ΔL	5	0	0	0	0	-4	5	-2	6	-4	9	-2	3	3	8	-4	-3	4	3	2
ΔC	0	4	0	5	-4	9	6	0	0	-2	7	9	4	6	-4	-4	6	-2	-5	-7
Δh	0	0	6	4	-5	0	0	6	4	5	-4	6	3	-4	9	-2	3	5	6	-3

Figure 43 Screenshots of all sample images displayed in sRGB mode

4.3 Subjective experiment setups

4.3.1 Viewing condition

According to principles described in section 2.4, psychophysical experiments should be conducted firstly in a quiet laboratory, and the monitor is placed horizontally on the stable table. Observer's binocular and test samples could be adjusted freely in the same horizontal plane by changing automatically bodies on adjustable swivel chair. However, there is no fixed visual device for observers. The indoor brightness recommended by ITU should be kept low level, while ICC gave a recommended range. Using cosine correction photometer, the ambient brightness should be lower than 64 lux when the monitor state is on, while that should be lower than 32 lux when the monitor state is off. The calibrated color temperature of environmental light source should be maintained below or similar to the measured color temperature of monitor white point. The PA272W NEC monitor was used in this project with a 27 inch LCD screen. The other hardware configurations are including NVIDTA Quadro K2200 adapter which provided 2560×1440 resolution, Intel (R) Xeon (R) 1.9 G Hz processor, 16G installed storage and 64 bit Windows 7 ultimate system. Moreover, color measured device is used i1 Pro2. At the same time, CIE standard light source D65 was recommended by the ICC and ITU. The monitor brightness should be not less than 75 cd/m², and the gamma value is selected from 1.8 to 2.2. In this subjective experiment, the ambient brightness was remained at 10 lux. In addition, the target illuminant was selected D65, the monitor brightness was selected 120 cd/m², and gamma value was set to 2.2. Observation distance was set 60 cm (about 20.6 degree view angle). At last, this monitor was calibrated every 15 days. Other parameter settings and calibration results are shown in Figure 44. The adjusted maximum ΔE of PA272W NEC monitor is 0.21 ΔE^*_{ab}, and its white point is (0.313, 0.051).

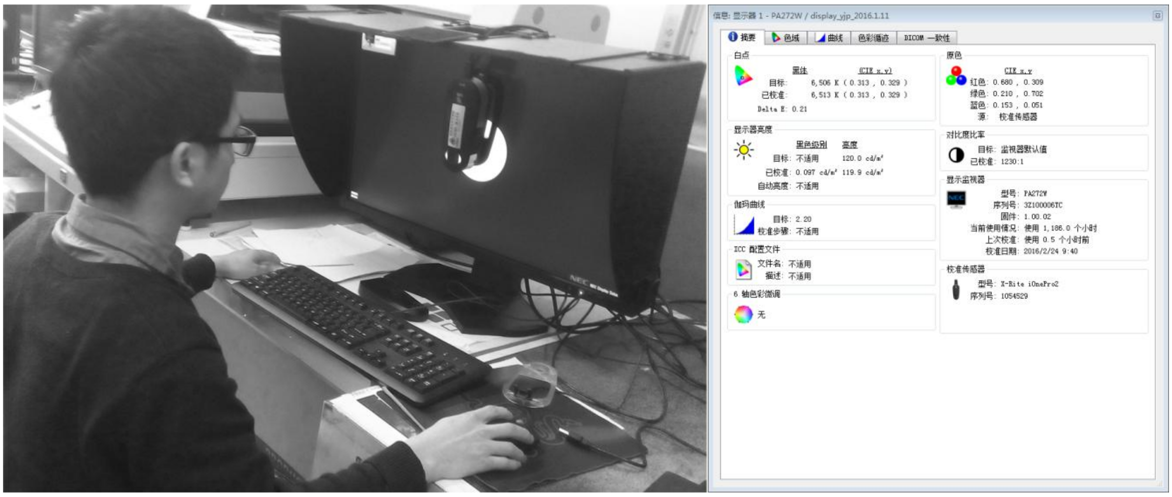
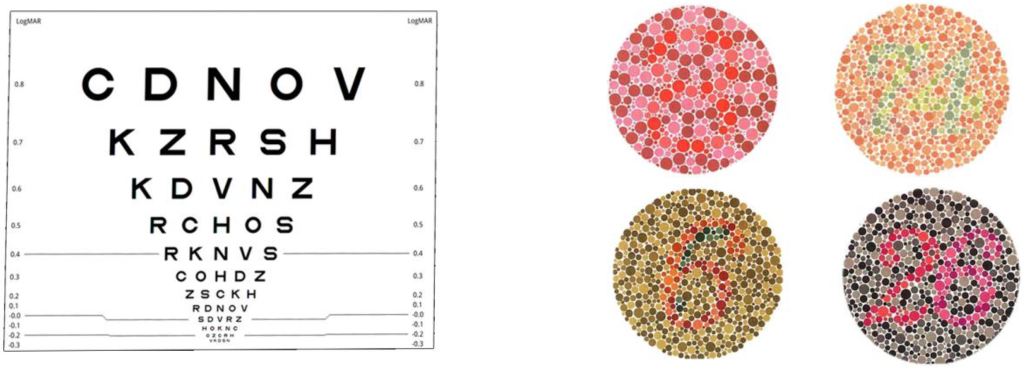


Figure 44 Parameter settings and calibration of Monitor with i1Pro2



a) Snellen Chart b) Ishihara Chart

Figure 45 Visual pretest including Snellen Chart and Ishihara Chart

4.3.2 Similarity scaling experiment

For the similarity assessment of color patch based samples, its amount is up to 1260, which would take much time for observers. So a fast and efficient approach should be considered for similarity scaling experiment. As described in chapter 2, category judgment method is worth for consideration. Moreover, the reduction of test time can decrease the effect of visual fatigue on scaling precision. Despite the five-degree category judgment was recommended by the CIE, this scaling experiment was preferred to choose the nine-degree category judgment method to meet smaller fine details distinction, which introduced in Figure 4. In this project, it was consist of two main experiments such as single color patch based consistent colors assessment test and composite image based consistent images assessment test. The former experiment will cost 40 minutes, and the latter will cost 25 minutes, and the interval will cost 10 minutes break. The total amount of observers is 18, such as 10 men and 8 women. The rate of expert type observer and naive type expert is 6:12. The expert type observer is who has the background of printing color science or experience of color psychophysical experiment. Fortunately, all the invited observers were passed the Snellen visual acuity test and Ishihara color blindness test, which shown in Figure 45. In addition, all observers were given color sensitivity training by using Online Color Challenge test until the score of each observer is lower than 30. This X-rite Pantone Online Color Challenge test is a test to determine the rank order of color patches based on the left reference color and the right reference color [107]. The smaller the score is, the more powerful the ability of color fine distinction is .

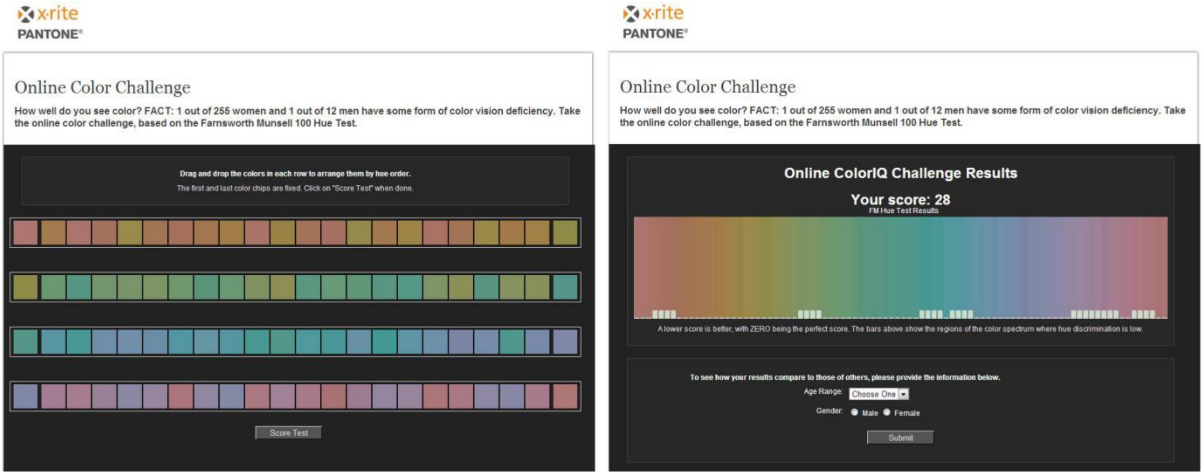


Figure 46 Screenshots of training interface of X-rite Pantone Online Color Challenge

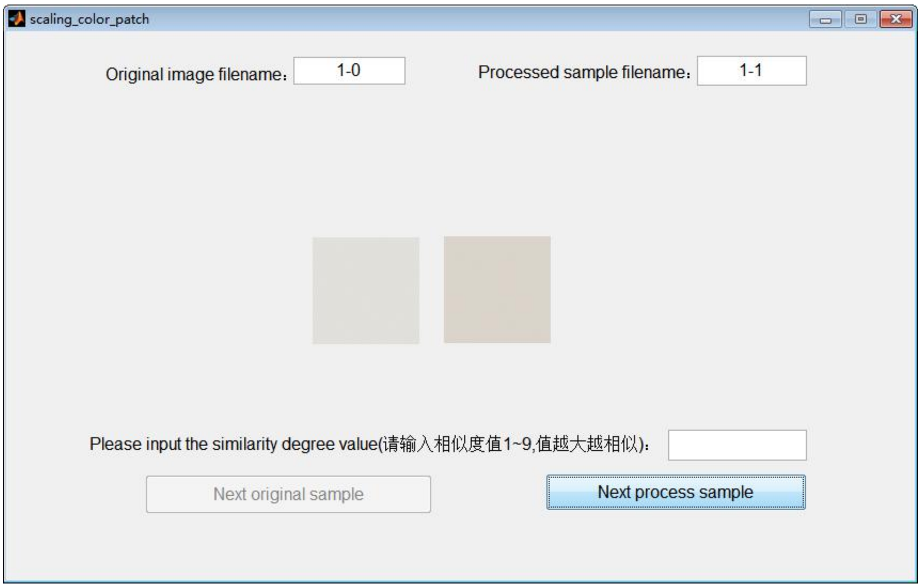


Figure 47 Screenshots of GUI of color patch similarity scaling experiment

The observer task instruction of single color patch based consistent colors assessment test is requested observers to input their scaling values according to the subjective similarity of the right sample color patch compared to the left reference color patch until all samples are completed. The subjective similarity scaling test is based on the developed similarity Matlab GUI which shown in Figure 47. One advantage of this scaling GUI is that each color patch is shown the file-name-number and corresponding visual LCh attributes in Lab mode. After one scaling value was input, the next sample would be displayed by clicking the ‘Next process sample’ button until 126 samples finished. At last, the ‘Next original sample’ button was clicked to display next reference color patch consequently.

The observer task instruction of composite image based consistent images assessment test is requested observers to input their scaling values according to the subjective similarity of the right sample image compared to the left reference image until all samples are finished. The subjective similarity scaling test is based on the developed similarity Matlab GUI which shown in Figure 48. One advantage of this scaling GUI is that each image is shown the file-name-number and corresponding visual LCh attributes in Lab mode. After one scaling value was input, the next sample would be displayed by clicking the 'Next process sample' button until 100 samples finished. At last, observers clicked the 'Next original sample' button to display next reference image according to its hint. Before the formal experiments, on group training test would be conducted, but not recorded into final result.

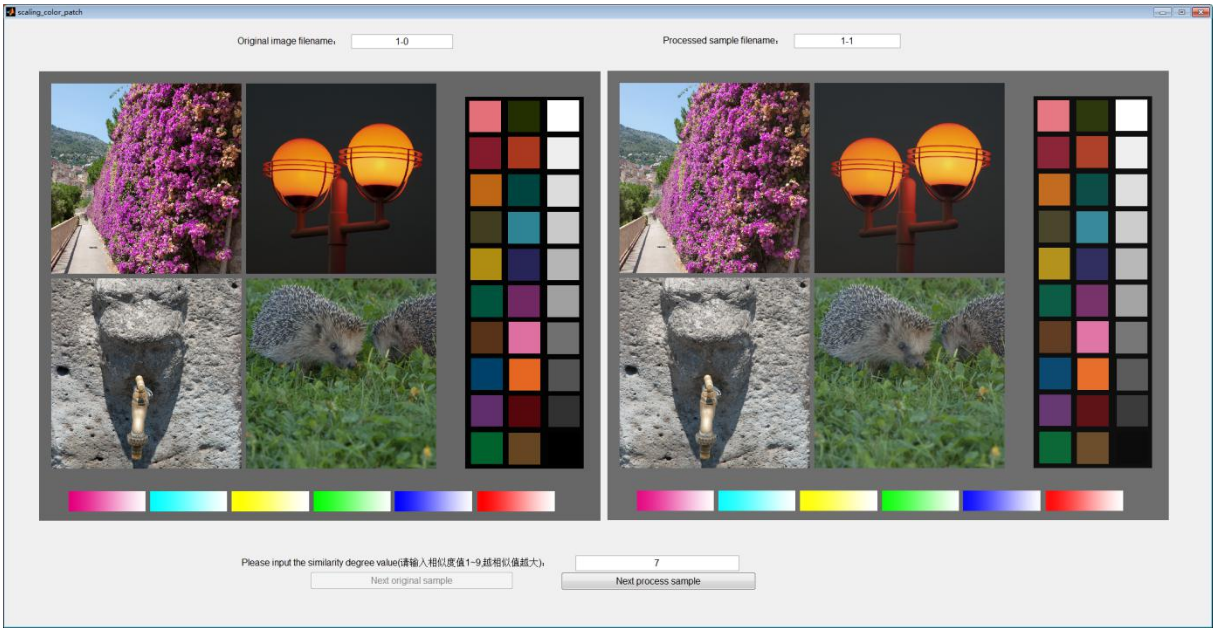


Figure 48 Screenshots of GUI of image similarity scaling experiment

4.4 Data processing method

In order to create and assess the proposed CCAD, all row scaling data should be processed and correlated with the measured ΔE data. The subjective raw data automatically obtained from the designed program are mainly included category scaling data sheet, the observer information, the displayed order and marked number of samples and references and so on. The mat2txt.m function was used to correct some input errors because the scaling data result saved directly as the mat format file, which can not be changed directly in the ongoing experiment. For the visualization of subjective result, the mean opinion score (MOS) transform was used and recommended by the ITU, which shown in Equation 4.1. Where N is the number of observers, and M_i is the score given by observe i. In this case, it is regarded as the category number given in similarity scaling experiment.

$$\overline{M} = \frac{1}{N}\sum_{i=1}^{N} M_i \tag{4.1}$$

The MOS data and Z-score data would be both used for the assessment of agreed consistent colors. The measured color difference matrix can be processed by the CIEDE98 color difference metric and CIEDE98 color difference metric together based on Philip Green's Color Engineering Toolbox. It is can found the Subjective_display.m code in the supplement documents of thesis file.

5 CCAD assessing and modeling

The biggest difficulty for CCAD achievement is the correlation of sample colors between the similarity scaling vale and measured color difference value under the specific gamut. This not only affects the applicability of proposed CCAD, but also limits the accuracy of metrics to achieve and assess CCA such as the narrow CCAM. Eventually, the similarity scaling matrix is obtained from the fifteen groups of useful raw scaling data for the designed 1260 samples. The measured color difference matrix is created by the whole color difference values among primary color, consistent colors and sample colors, using the CIEDE94 color difference metric and CIEDE00 color difference metric together. In order to achieve and characterize the proposed CCAD, the discreteness of subjective similarity scaling total result were used and analyzed, as well as the correlation analysis of twice similarity scaling results. At last, the similarity scaling values and the color difference value were correlated to explain the highest similarity of consistent colors achieved by the judgments of MOS values and Z-score values. For consistent colors inside the different gamut boundaries o f six CRPC data sets, the applicability of the closeness trend line scaling approach was verified a promising result. Based on these correlations and consistent colors, a kind of CCAM frame was introduced .

5.1 Achieved CCAD evaluation

5.1.1 Discreteness of subjective similarity scaling result

Since all the similarity scaling values were obtained from the psychological experiments which were easily influenced by observers. Then the repeatability or discreteness of twice session scaling results were introduced and analyzed for each color center. Considering the amount of similarity scaling values were huge, the discreteness of each color center including 126 samples was calculated directly by the AVEDEV function in Excel, and the whole result was shown in Figure 49. In category judgment experiment, each color patch was usually displayed twice in difference position combination to ensure the repeatability of subjective scaling result for each color patch. This is easily implemented in the case of a small species, rather than for the huge species. Then the whole similarity scaling experiment were divided into two separate sessions with 15 days interval. In addition, other settings and observers were same. In figure 49, the mean deviations of first session and second session were shown similar trend and both smaller than 1 which indicated a good repeatability of twice similarity scaling results. With the exception of samples of color center No.5 and No.6, other mean deviations were fluctuated slightly at 0.8, even some was closed to 0.7. In short, these scaling results could be accepted and applied to exploit the samples with highest similarity.

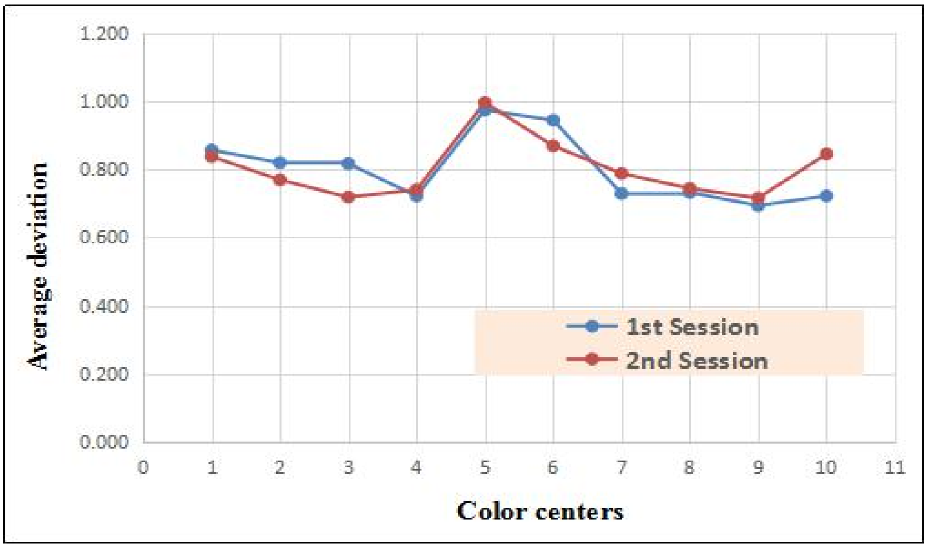


Figure 49 Discreteness of subjective similarity scaling result

5.1.2 Correlation analysis of twice similarity scaling output

In Figure 49, the whole repeatability of each color center including 126 samples can be easily found, but not show the correlation of each color sample. For this feature, it can be used the least square method to fit linearly the twice scaling data for each color sample. All the correlations based on different color center were shown from Figure 50 to Figure 59, where the vertical coordinate is for the similarity scaling value of second session, the horizontal coordinate is for the similarity scaling value of first session, and the red line is the linear fitting line accompanied with an obvious fitting equation.

In Figure 50, it can be found that all samples are distributed symmetrically around the fitting line within the whole range. Its goodness of fit R2 is 0.9732, very close to 1, was indicated a nice correlation between first session and second session. Overall, the similarity scaling values of second session were bigger a bit than that of first session for the color center No.1. In Figure 51, the distribution range of similarity scaling values of samples for color center No.2 is relatively wide, and most samples of first session are focused on the high similarity range. Its goodness of fit R2 is 0.9631, also close to 1, was indicated a good correlation. In Figure 52, the distribution range of similarity scaling values of samples for color center No.3 is relatively short, and most samples of first session are focused on the high similarity range. Its goodness of fit R2 is 0.9726, very close to 1, was indicated a nice correlation. These three color centers were approximate belongs to neutral color set. Their similarity scaling values were close to 9 with certain color samples. For these samples set, it is indicated that some neutral colors achieved the consensus agreement for the samples with highest similarity which would share common color appearance. It is stated that more neutral color samples still need further optimization to a completed neutral color samples set shared the common color appearance.

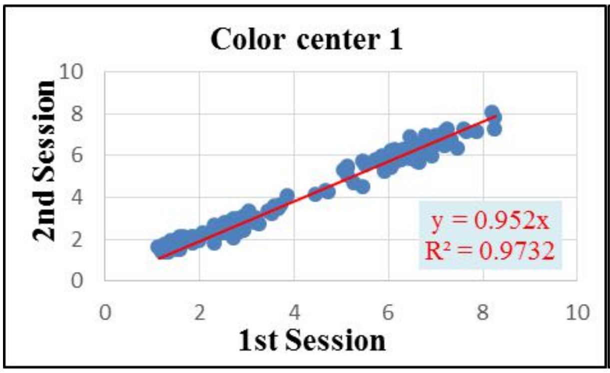


Figure 50 Test result repeatability for color center No.1

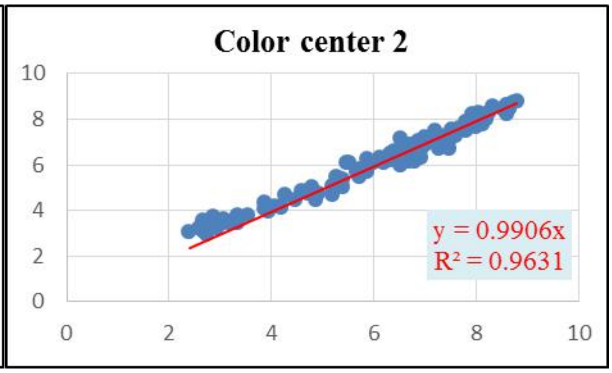


Figure 51 Test result repeatability for color center No.2

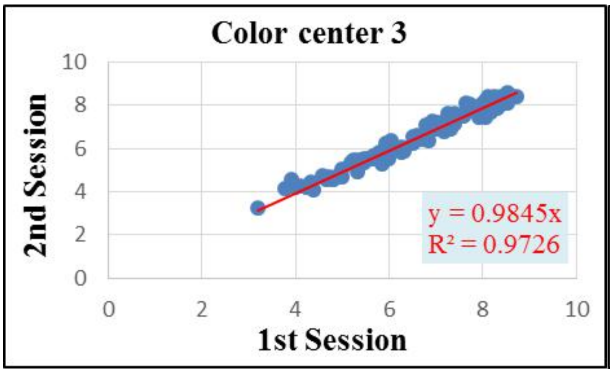


Figure 52 Test result repeatability for color center No.3

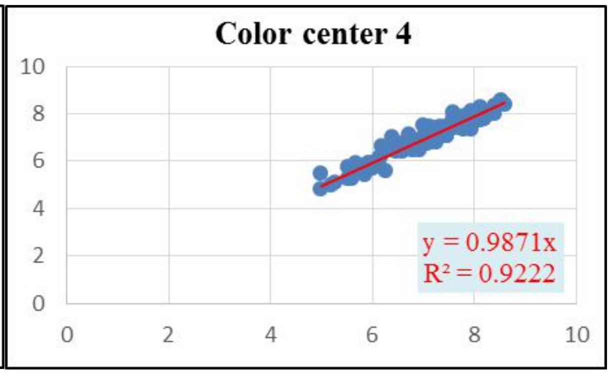


Figure 53 Test result repeatability for color center No.4

In addition to neutral color centers, the rest are the color samples for color centers, which shown from the Figure 53 to Figure 59. For the color centers including No. 4, No.7, No.8 and No.9, their goodness of fit R2 were above 0.922 which indicated a good correlation between first session and second session for these color centers. However, there are some specific features for different color centers, such as the range and symmetry of sample distributions. Taking color center No.4 for an example, the similarity scaling values were focused on the specific range (4~9) with a good symmetric distribution. The samples with highest similarity scaling values also can be found easily in Figure 53. For color centers such as No.5(shown in Figure 54), No.6 (shown in Figure 55) and No.10 (shown in Figure 59), their goodness of fit were about 0.76 which indicated that the general correlation between first session and second session for these color centers. The similarity scaling values of samples in the second session were bigger than that in the first session, especially on small scaling value area. This maybe caused by the relative small magnitudes of LCh attribute adjustments, which partially verified from the short distribution range. Taking color center No.10 for an example, the similarity scaling values of twice sessions were mainly focused on the specific range (6~8). There are still similarity scaling values of some samples closest to 9 although its goodness of fit was just 0.75869. In short, all the color centers shared the acceptable correlation between first session and second session by the linear fit analysis method.

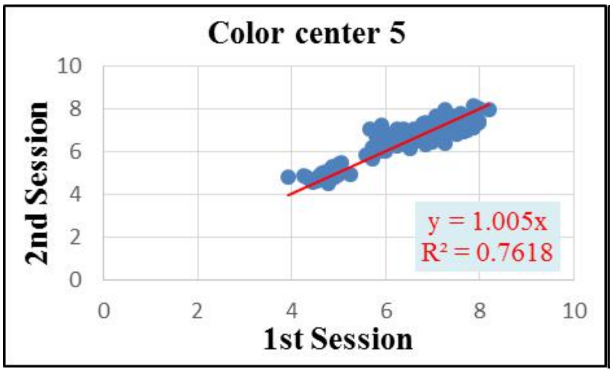


Figure 54 Test result repeatability for color center No.5

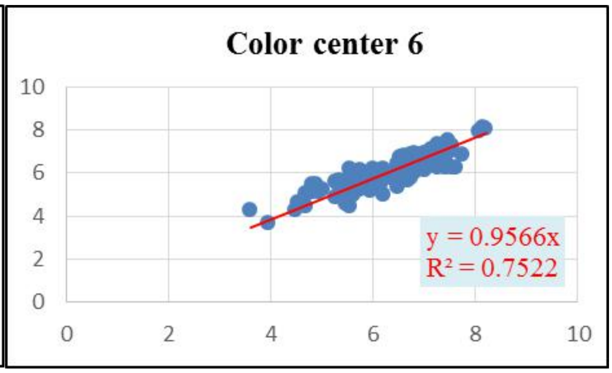


Figure 55 Test result repeatability for color center No.6

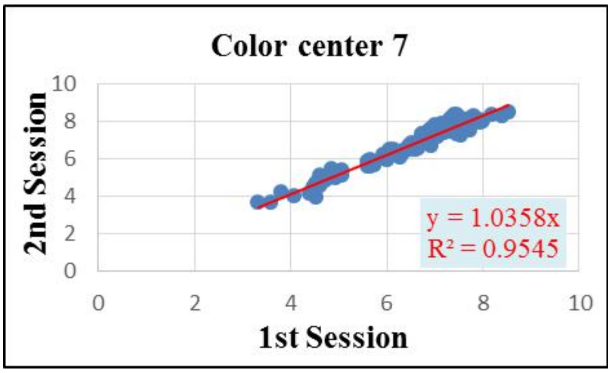


Figure 56 Test result repeatability for color center No.7

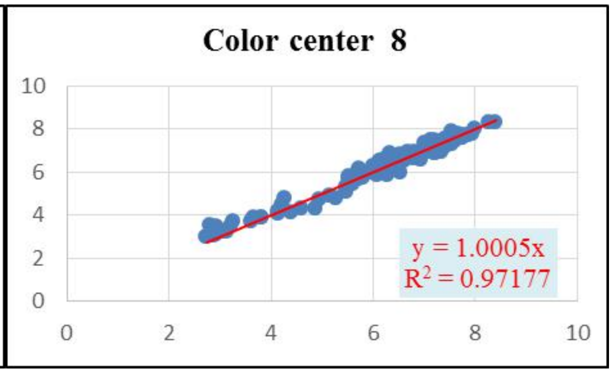


Figure 57 Test result repeatability for color center No.8

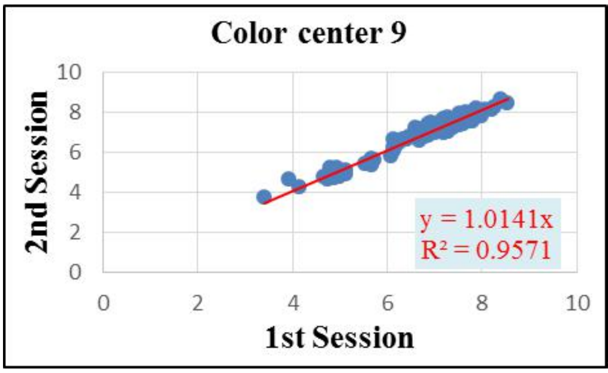


Figure 58 Test result repeatability for color center No.9

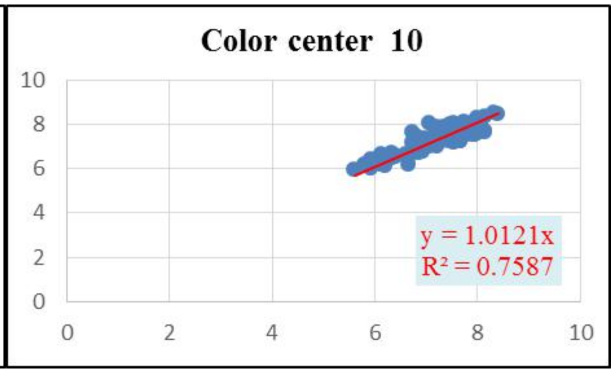


Figure 59 Test result repeatability for color center No.10

5.1.3 Z-score analysis of subjective similarity

The raw subjective scaling data of category judgment experiment can't be used to the consistent colors achievement because of the individual basis. Then Z-scores transformed from those data can be a good index that shows the significant difference between the specific test sample and rest samples of the same sample set. All the Z-scores of color samples for ten color centers were introduced and contrast one by one from the Figure 60 to Figure 119. In the Z-score characterization figure, the vertical coordinate is for the Z-score value including positive and negative format, but its absolute value is just indicated the magnitude deviated from the average value. The Z-score point is plotted with an error bar which usually selected the 95% confidence interval. If two confidence intervals overlap in vertical direction, then two corresponding samples are not considered to be significantly different with a 95% confidence. If two confidence intervals don't overlap each other in vertical direction, then two corresponding samples are considered to be significantly different with a 95% confidence. Where the SX_x is for the color sample set originated from the samples of color center No.X under CRPCs (s is 1, 2, 3, 5, 6, 7) color data set, x is from 1 to 6.

5.1.3.1 Z-score analysis of subjective similarity for color center No.1

The Z-score distributions of 126 color samples for color center No.1 were shown from Figure 60 to Figure 65 respectively. In Figure 60, the confidence intervals of most color samples for color center No.1 under CRPC1 data set overlapped each other, it was indicated that one of test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.11, No.20 and No.21, the color sample No.16 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.1, No.3 and No.4, the color sample No.19 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.16 and No.19 were possible to be the MOS extreme values of color sample set for color center No.1, but it was not enough to be judged which one is the similarity maximum value.

In Figure 61, the confidence intervals of most color samples for color center No.1 under CRPC2 data set overlapped each other, it was indicated that one of test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.18, the color sample No.17 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.1 and No.9, the color sample No.4 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.17, the color sample No.18 can be considered to be significantly different from rest samples with a 95% confidence. Beside above three special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.4 and No.17 were possible to be the MOS extreme values of color sample set for color center No.1, but it was not enough to be judged which one is the similarity maximum value.

In Figure 62, the confidence intervals of most color samples for color center No.1 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.1, No.2 and No.17, the color sample No.4 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.18 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.4 and No.18 were possible to be the MOS extreme values of color sample set for color center No.1, but it was not enough to be judged which one is the similarity maximum value.

In Figure 63, the confidence intervals of most color samples for color center No.1 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.5, No.16, No.17, No.18 and No.19, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.12, the color sample No.2 with smallest

Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.21 can be also considered to be significantly different from rest samples with a 95% confidence. Beside above three special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.2 and No.20 were possible to be the MOS extreme values of color sample set for color center No.1, but it was not enough to be judged which one is the similarity maximum value.

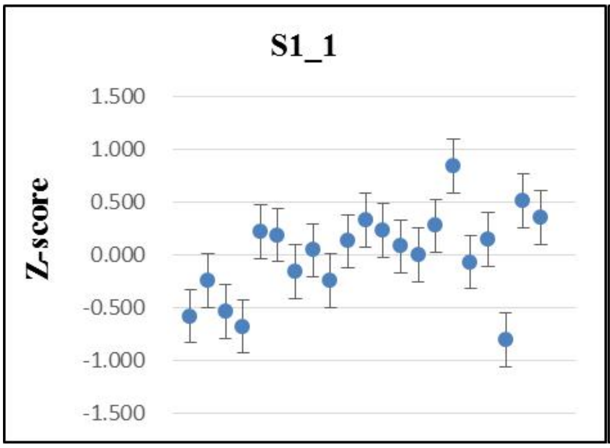


Figure 60 Z-scores of S1_1 samples

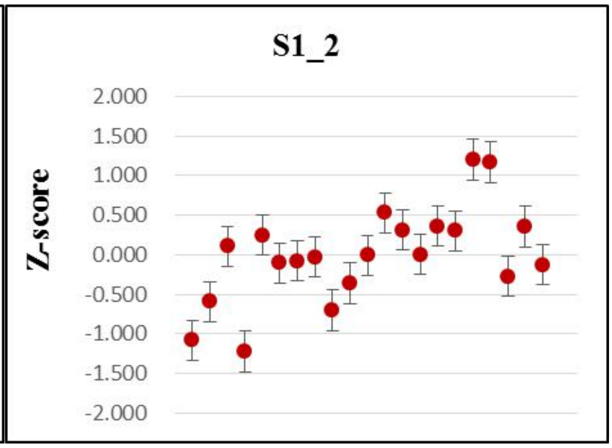


Figure 61 Z-scores of S1_2 samples

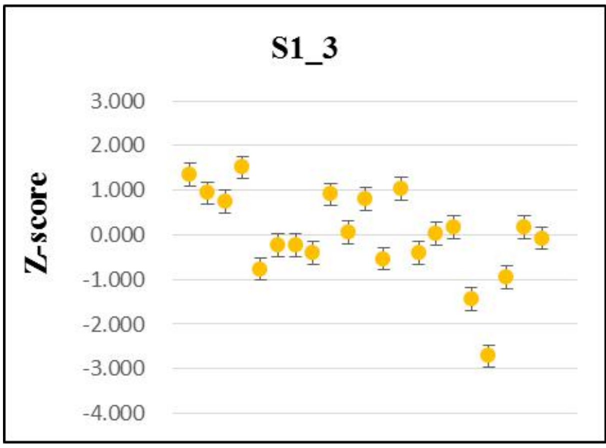


Figure 62 Z-scores of S1_3 samples

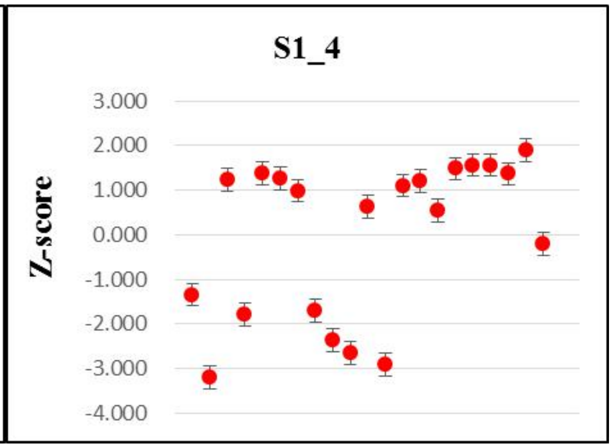


Figure 63 Z-scores of S1_4 samples

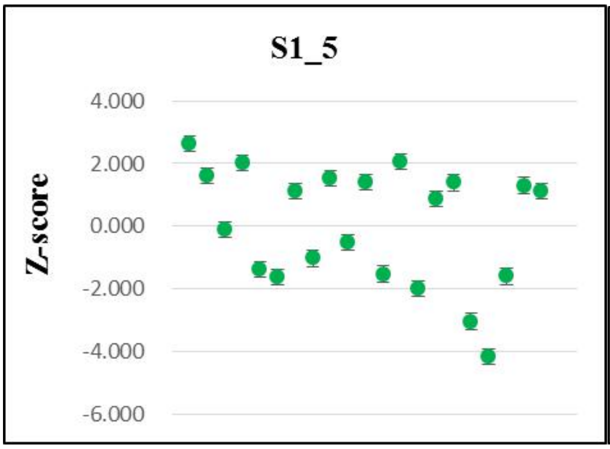


Figure 64 Z-scores of S1_5 samples

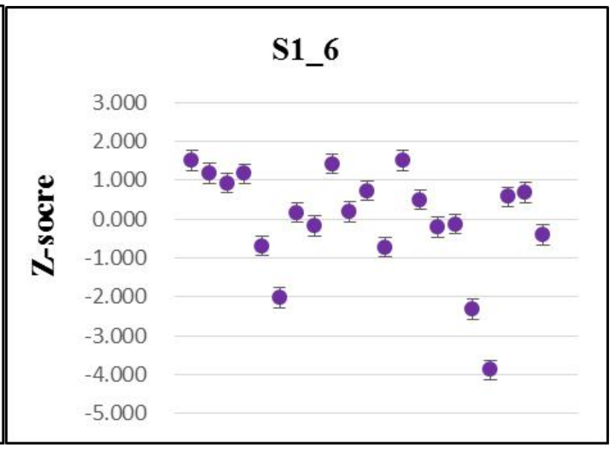


Figure 65 Z-scores of S1_6 samples

In Figure 64, the confidence intervals of most color samples for color center No.1 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be

significantly different from any others with a 95% confidence. The color sample No.1 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.18 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1 and No.18 were possible to be the MOS extreme values of color sample set for color center No.1, but it was not enough to be judged which one is the similarity maximum value.

In Figure 65, the confidence intervals of most color samples for color center No.1 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.2, No.4 and No.9, the color sample No.1 and No.13 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.18 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1, No.13 and No.18 were possible to be the MOS extreme values of color sample set for color center No.1, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.2 Z-score analysis of subjective similarity for color center No.2

In Figure 66, the confidence intervals of most color samples for color center No.2 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.12, the color sample No.7 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.10 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.7 and No.10 were possible to be the MOS extreme values of color sample set for color center No.2, but it was not enough to be judged which one is the similarity maximum value.

In Figure 67, the confidence intervals of most color samples for color center No.2 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.7, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.2, the color sample No.4 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.4 and No.12 were possible to be the MOS extreme values of color sample set for color center No.2, but it was not enough to be judged which one is the similarity maximum value.

In Figure 68, the confidence intervals of most color samples for color center No.2 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.8, No.12 and No.15, the color sample No.7 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.21, the color sample No.11 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.7 and No.11 were possible to be the MOS extreme values of color sample set for color center No.2, but it was not enough to be judged which one is the similarity maximum value.

In Figure 69, the confidence intervals of most color samples for color center No.2 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be

significantly different from any others with a 95% confidence. Except for the No.7, No.15 and No.18, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.1 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1 and No.12 were possible to be the MOS extreme values of color sample set for color center No.2, but it was not enough to be judged which one is the similarity maximum value.

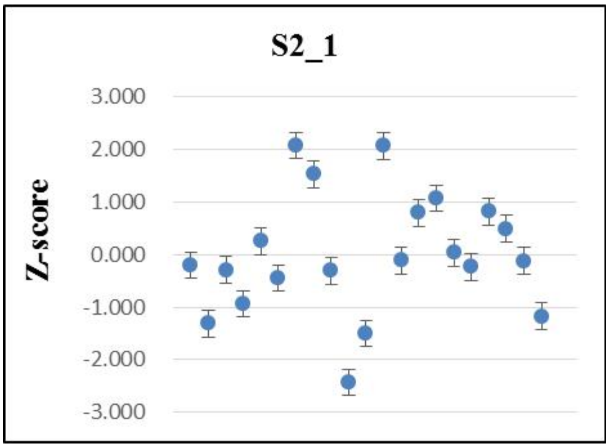


Figure 66 Z-scores of S2_1 samples

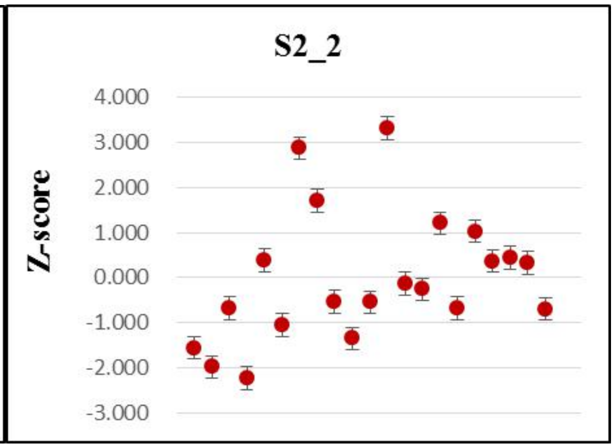


Figure 67 Z-scores of S2_2 samples

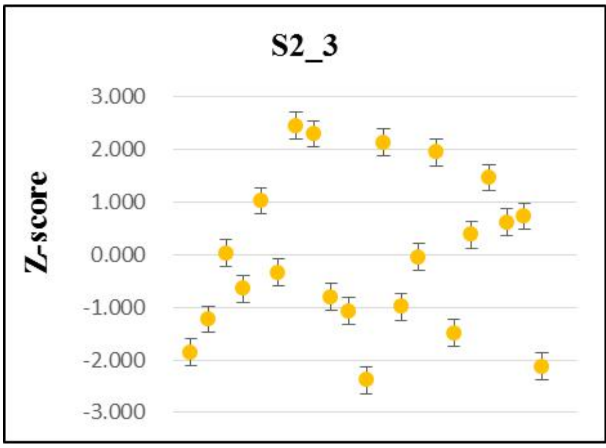


Figure 68 Z-scores of S2_3 samples

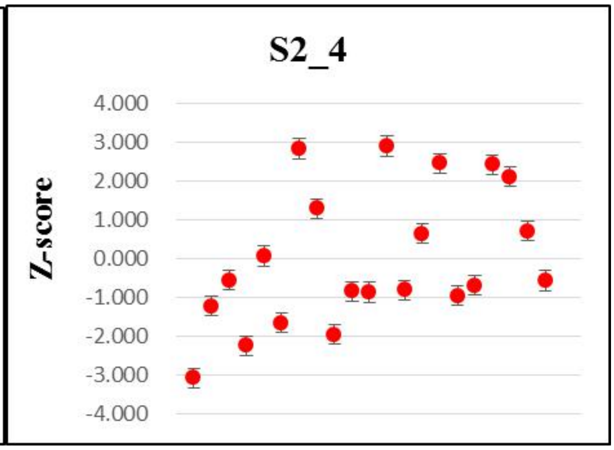


Figure 69 Z-scores of S2_4 samples

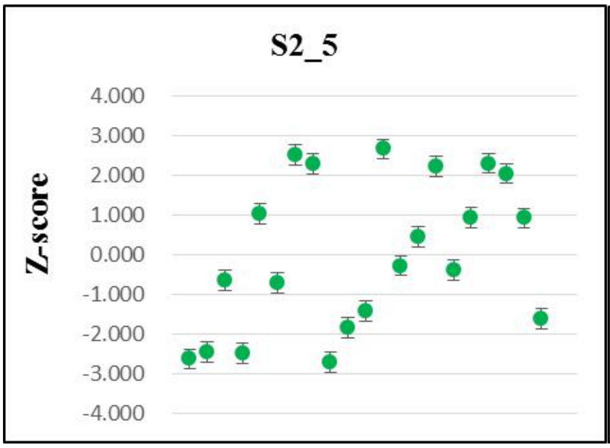


Figure 70 Z-scores of S2_5 samples

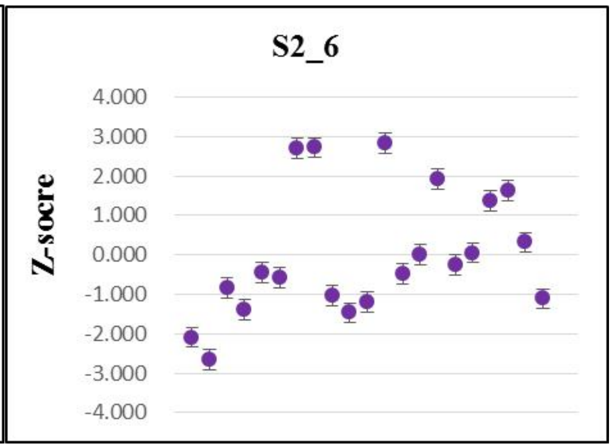


Figure 71 Z-scores of S2_6 samples

In Figure 70, the confidence intervals of most color samples for color center No.2 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.7, No.8, No.15 and No.18, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.1, No.2 and No.4, the color sample No.9 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.9 and No.12 were possible to be the MOS extreme values of color sample set for color center No.2, but it was not enough to be judged which one is the similarity maximum value.

In Figure 71, the confidence intervals of most color samples for color center No.2 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.7 and No.8, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.2 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.2 and No.12 were possible to be the MOS extreme values of color sample set for color center No.2, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.3 Z-score analysis of subjective similarity for color center No.3

In Figure 72, the confidence intervals of most color samples for color center No.3 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.7 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.13 and No.14, the color sample No.3 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.3 and No.7 were possible to be the MOS extreme values of color sample set for color center No.3, but it was not enough to be judged which one is the similarity maximum value.

In Figure 73, the confidence intervals of most color samples for color center No.3 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.16, No.17 and No.18, the color sample No.21 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.8 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.8 and No.21 were possible to be the MOS extreme values of color sample set for color center No.3, but it was not enough to be judged which one is the similarity maximum value.

In Figure 74, the confidence intervals of most color samples for color center No.3 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.16, the color sample No.21 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.8 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.8 and No.21 were possible to be the MOS extreme values of color sample set for color center No.3, but it was not enough to be judged which one is the similarity maximum value.

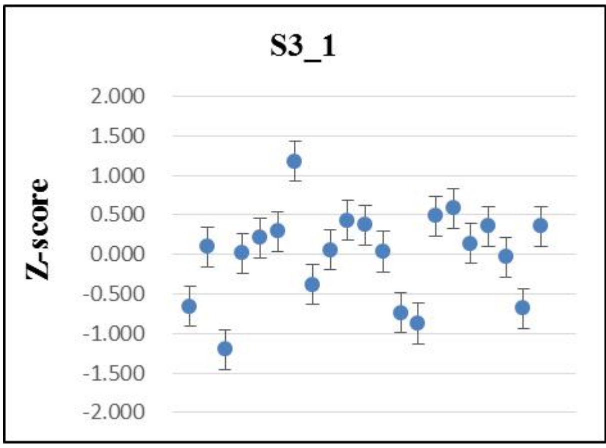


Figure 72 Z-scores of S3_1 samples

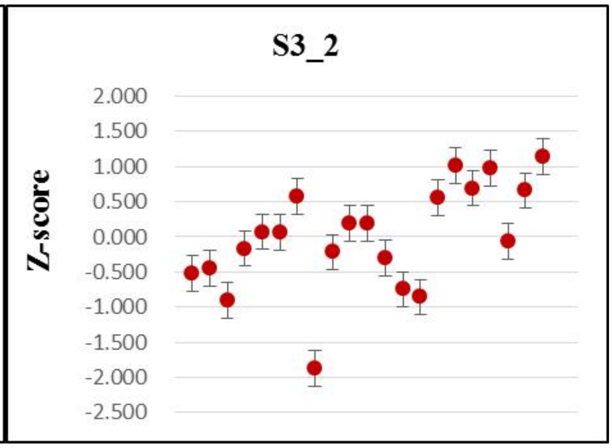


Figure 73 Z-scores of S3_2samples

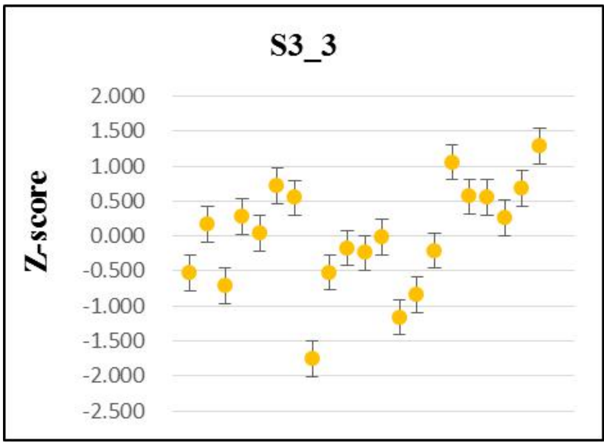


Figure 74 Z-scores of S3_3 samples

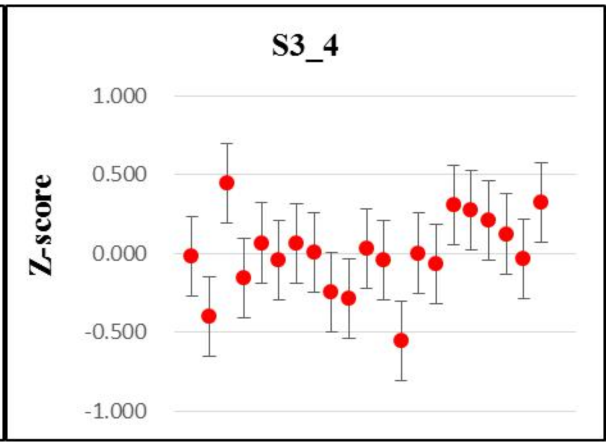


Figure 75 Z-scores of S3_4 samples

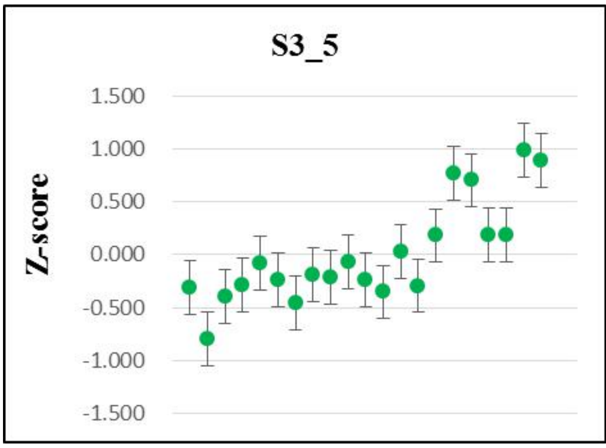


Figure 76 Z-scores of S3_5 samples

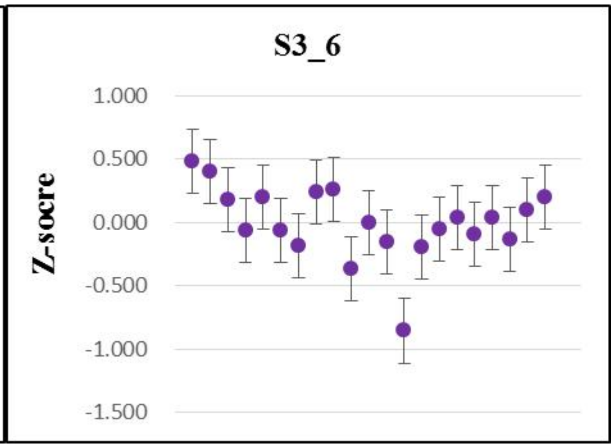


Figure 77 Z-scores of S3_6 samples

In Figure 75, the confidence intervals of most color samples for color center No.3 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.2, No.4, No.9 and No.13, the color sample No.3 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.2, No.9, No.10 and No.15, the color sample No.8 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.3 and No.13 were possible to be the MOS extreme values of color sample set for color center No.3, but it was not enough to be judged which one is the similarity maximum value.

In Figure 76, the confidence intervals of most color samples for color center No.3 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.16, No.17 and No.21, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.1, No.3 and No.7, the color sample No.2 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.2 and No.20 were possible to be the MOS extreme values of color sample set for color center No.3, but it was not enough to be judged which one is the similarity maximum value.

In Figure 77, the confidence intervals of most color samples for color center No.3 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.12, the color sample No.1 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.13 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1 and No.13 were possible to be the MOS extreme values of color sample set for color center No.3, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.4 Z-score analysis of subjective similarity for color center No.4

In Figure 78, the confidence intervals of most color samples for color center No.4 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.1, No.2, No.3, No.10, No.13 and No.15, the color sample No.11 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.5, No.6, No.16 and No.17, the color sample No.18 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.11 and No.18 were possible to be the MOS extreme values of color sample set for color center No.4, but it was not enough to be judged which one is the similarity maximum value.

In Figure 79, the confidence intervals of most color samples for color center No.4 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.21 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.2, No.3, No.4, No.9, No.10 and No.12, the color sample No.1 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1 and No.21 were possible to be the MOS extreme values of color sample set for color center No.4, but it was not enough to be judged which one is the similarity maximum value.

In Figure 80, the confidence intervals of most color samples for color center No.4 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.1, No.2, No.6, No.7, and No.10, the color sample No.8 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.19 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.8 and No.19 were possible to be the MOS extreme values of color sample set for color center No.4, but it was not enough to be judged which one is the similarity maximum value.

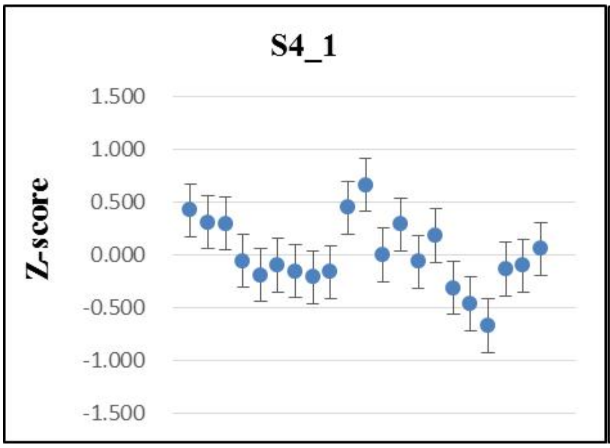


Figure 78 Z-scores of S4_1 samples

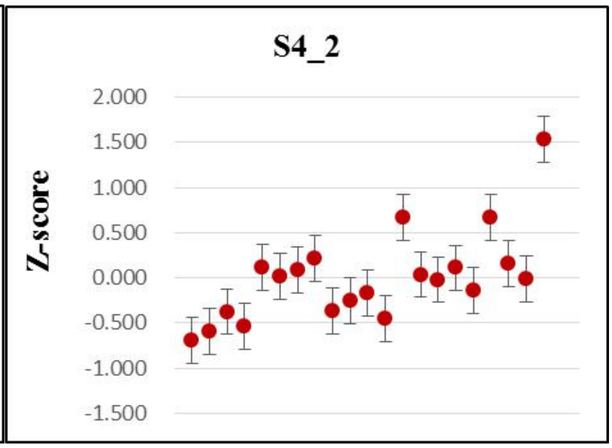


Figure 79 Z-scores of S4_2 samples

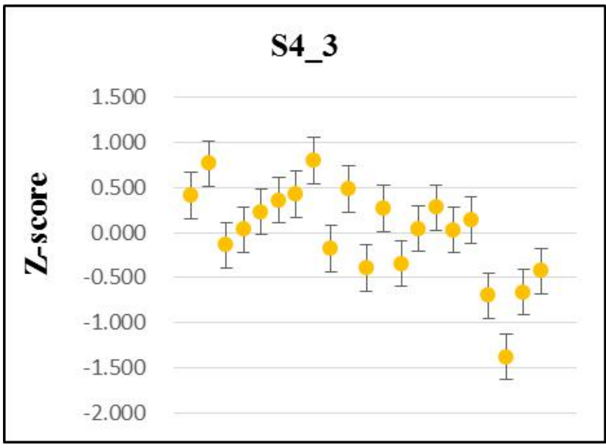


Figure 80 Z-scores of S4_3 samples

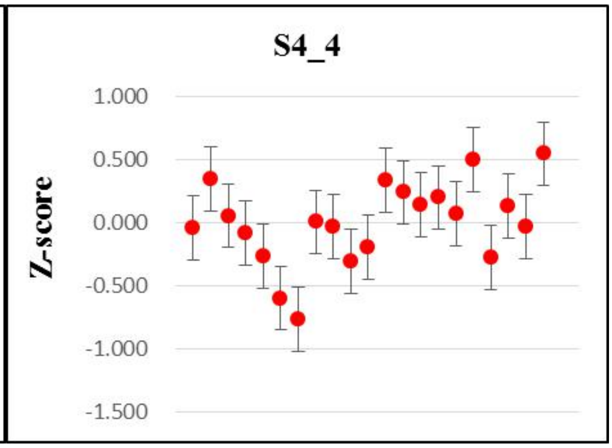


Figure 81 Z-scores of S4_4 samples

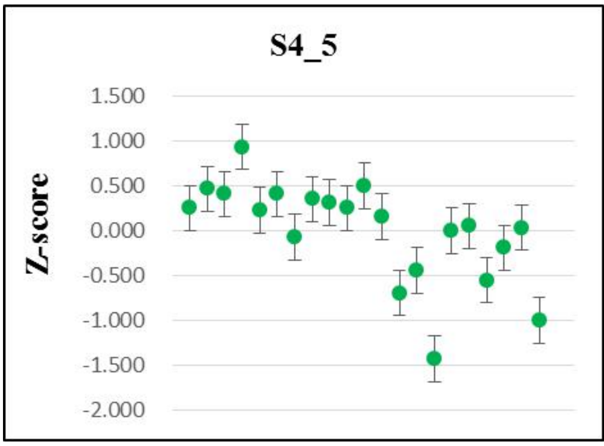


Figure 82 Z-scores of S4_5 samples

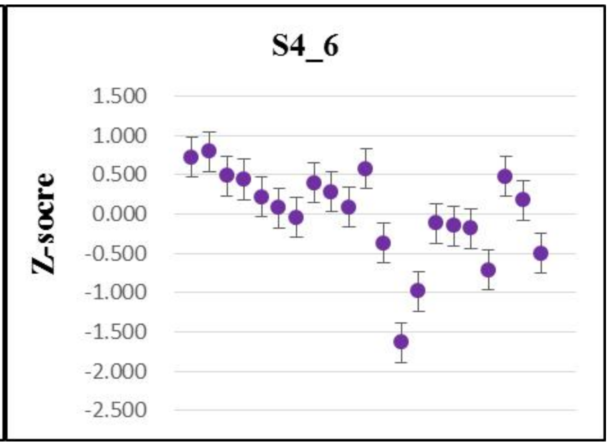


Figure 83 Z-scores of S4_6 samples

In Figure 81, the confidence intervals of most color samples for color center No.4 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.21 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. Except for the No.6 and No.10, the color sample No.7 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.7 and No.21 were possible to be the MOS extreme values of color sample set for color center No.4, but it was not enough to be judged which one is the similarity maximum value.

In Figure 82, the confidence intervals of most color samples for color center No.4 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.2 and No.11, the color sample No.4 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.21, the color sample No.15 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.4 and No.15 were possible to be the MOS extreme values of color sample set for color center No.4, but it was not enough to be judged which one is the similarity maximum value.

In Figure 83, the confidence intervals of most color samples for color center No.4 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.1, No.3, No.4, No.8, No.9, No.11 and No.19, the color sample No.2 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.13 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.2 and No.13 were possible to be the MOS extreme values of color sample set for color center No.4, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.5 Z-score analysis of subjective similarity for color center No.5

In Figure 84, the confidence intervals of most color samples for color center No.5 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.7 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.13 with smallest Z-score can be also considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.7 and No.13 were possible to be the MOS extreme values of color sample set for color center No.5, but it was not enough to be judged which one is the similarity maximum value.

In Figure 85, the confidence intervals of most color samples for color center No.5 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.16 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.4 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.4 and No.16 were possible to be the MOS extreme values of color sample set for color center No.5, but it was not enough to be judged which one is the similarity maximum value.

In Figure 86, the confidence intervals of most color samples for color center No.5 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.16 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.3 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.3 and No.16 were possible to be the MOS extreme values of color sample set for color center No.5, but it was not enough to be judged which one is the similarity maximum value.

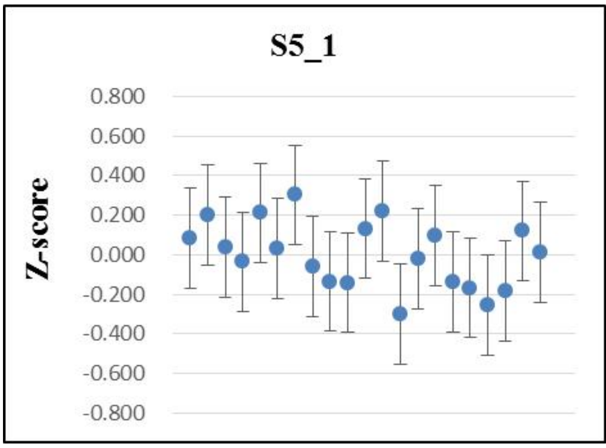


Figure 84 Z-scores of S5_1 samples

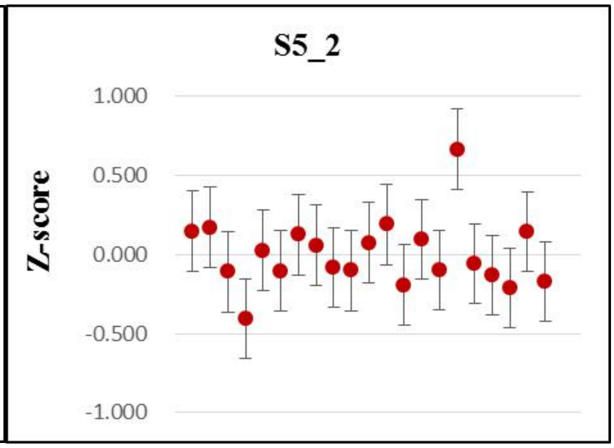


Figure 85 Z-scores of S5_2 samples

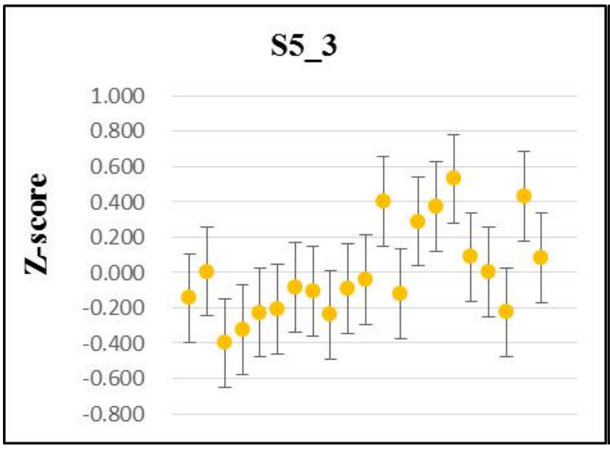


Figure 86 Z-scores of S5_3 samples

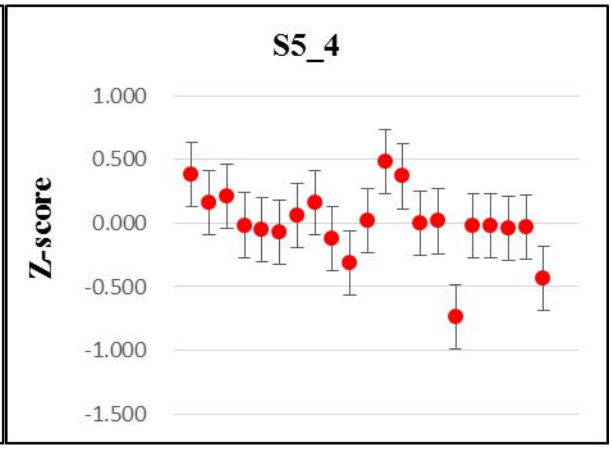


Figure 87 Z-scores of S5_4 samples

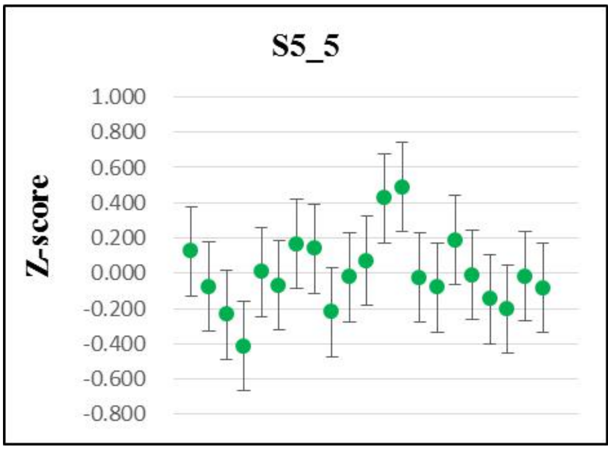


Figure 88 Z-scores of S5_5 samples

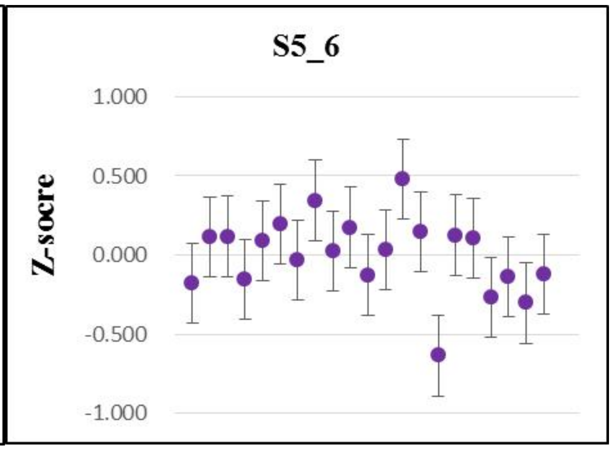


Figure 89 Z-scores of S5_6 samples

In Figure 87, the confidence intervals of most color samples for color center No.5 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.12 with biggest

Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.16 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.12 and No.16 were possible to be the MOS extreme values of color sample set for color center No.5, but it was not enough to be judged which one is the similarity maximum value.

In Figure 88, the confidence intervals of most color samples for color center No.5 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.13 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.4 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.4 and No.13 were possible to be the MOS extreme values of color sample set for color center No.5, but it was not enough to be judged which one is the similarity maximum value.

In Figure 89, the confidence intervals of most color samples for color center No.5 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for No.1, No.4, No.11, No.15, No.18, No.19, No.20 and No.21, the color sample No.13 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for No.1, No.18 and No.20, the color sample No.15 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.13 and No.15 were possible to be the MOS extreme values of color sample set for color center No.5, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.6 Z-score analysis of subjective similarity for color center No.6

In Figure 90, the confidence intervals of most color samples for color center No.6 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.9, No.16 and No.18, the color sample No.14 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.2 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.2 and No.14 were possible to be the MOS extreme values of color sample set for color center No.6, but it was not enough to be judged which one is the similarity maximum value.

In Figure 91, the confidence intervals of most color samples for color center No.6 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.9, No.12, No.15, No.16, No.19, No.20 and No.21, the color sample No.14 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.1 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1 and No.14 were possible to be the MOS extreme values of color sample set for color center No.6, but it was not enough to be judged which one is the similarity maximum value.

In Figure 92, the confidence intervals of most color samples for color center No.6 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.14 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. Except for the No.19 and No.20, the color sample No.21 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.14 and No.21 were possible to be the MOS extreme values of color sample set for color center No.6, but it was not enough to be judged which one is the similarity maximum value.

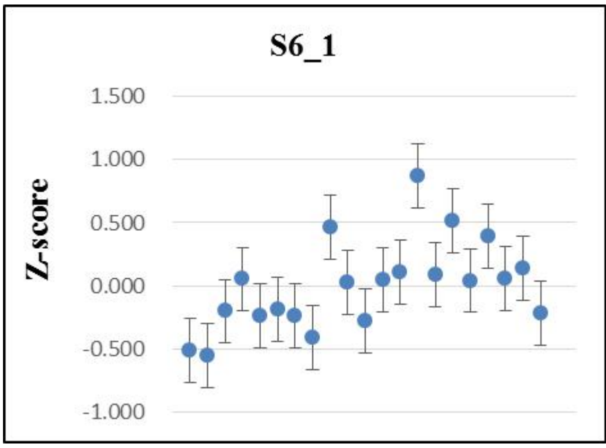


Figure 90 Z-scores of S6_1 samples

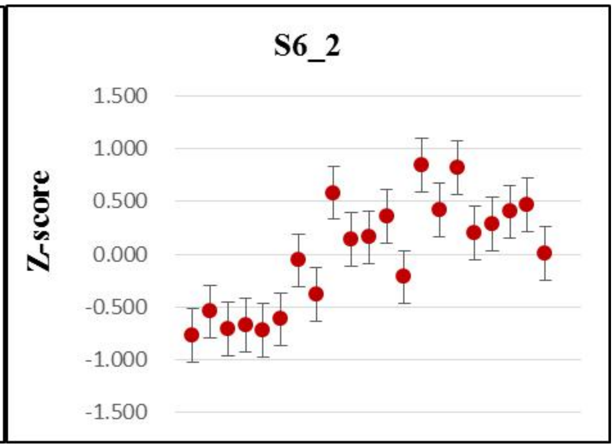


Figure 91 Z-scores of S6_2 samples

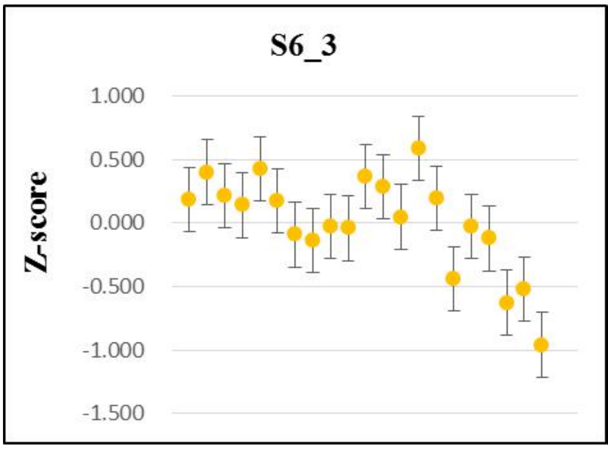


Figure 92 Z-scores of S6_3 samples

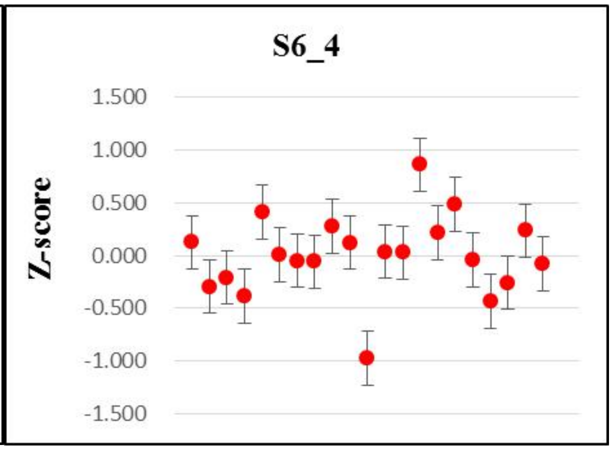


Figure 93 Z-scores of S6_4 samples

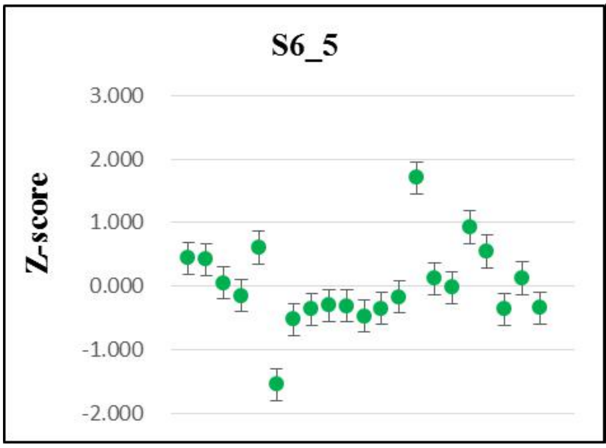


Figure 94 Z-scores of S6_5 samples

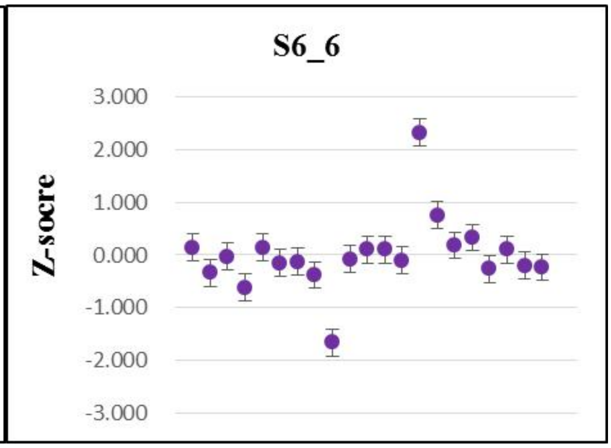


Figure 95 Z-scores of S6_6 samples

In Figure 93, the confidence intervals of most color samples for color center No.6 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.5 and No.16, the color sample No.14 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.11 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.11 and No.14 were possible to be the MOS extreme values of color sample set for color center No.6, but it was not enough to be judged which one is the similarity maximum value.

In Figure 94, the confidence intervals of most color samples for color center No.6 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.14 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.6 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.6 and No.14 were possible to be the MOS extreme values of color sample set for color center No.6, but it was not enough to be judged which one is the similarity maximum value.

In Figure 95, the confidence intervals of most color samples for color center No.6 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.14 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.9 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.9 and No.14 were possible to be the MOS extreme values of color sample set for color center No.6, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.7 Z-score analysis of subjective similarity for color center No.7

In Figure 96, the confidence intervals of most color samples for color center No.7 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.8, the color sample No.7 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.20, the color sample No.17 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.7 and No.17 were possible to be the MOS extreme values of color sample set for color center No.7, but it was not enough to be judged which one is the similarity maximum value.

In Figure 97, the confidence intervals of most color samples for color center No.7 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.18 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.9 and No.19, the color sample No.10 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.10 and No.18 were possible to be the MOS extreme values of color sample set for color center No.7, but it was not enough to be judged which one is the similarity maximum value.

In Figure 98, the confidence intervals of most color samples for color center No.7 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.20, the color sample

No.18 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.3 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.3 and No.18 were possible to be the MOS extreme values of color sample set for color center No.7, but it was not enough to be judged which one is the similarity maximum value.

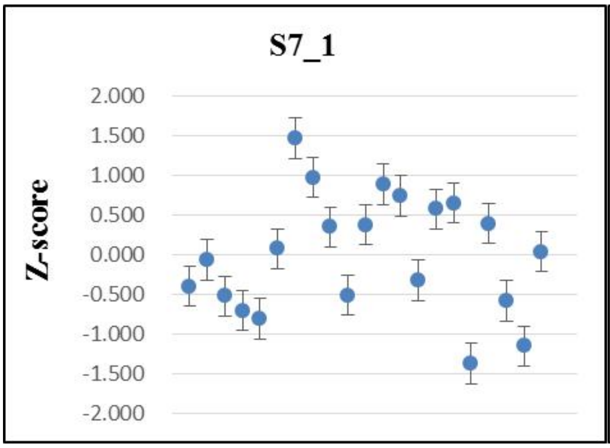


Figure 96 Z-scores of S7_1 samples

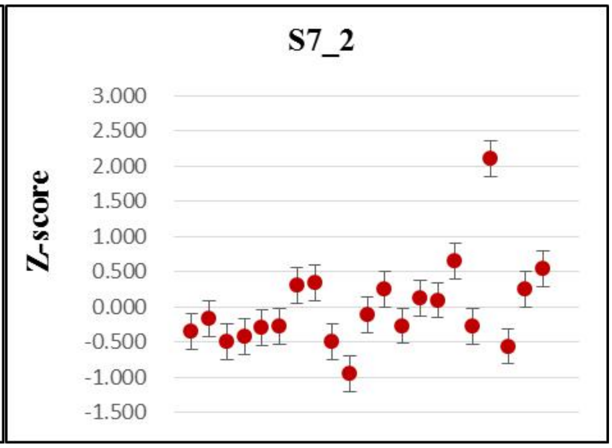


Figure 97 Z-scores of S7_2 samples

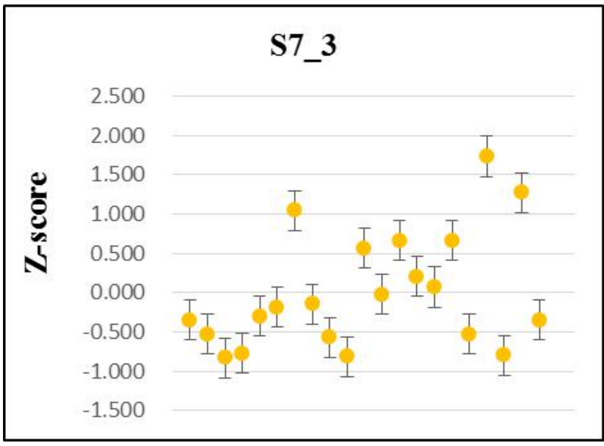


Figure 98 Z-scores of S7_3 samples

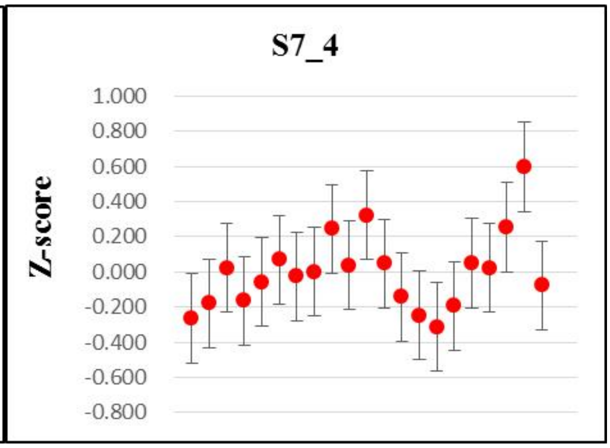


Figure 99 Z-scores of S7_4 samples

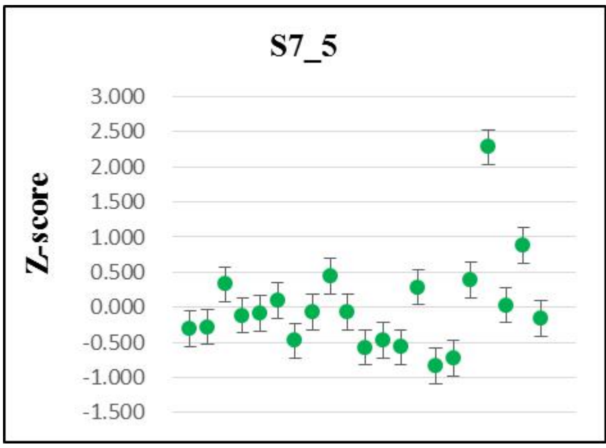


Figure 100 Z-scores of S7_5 samples

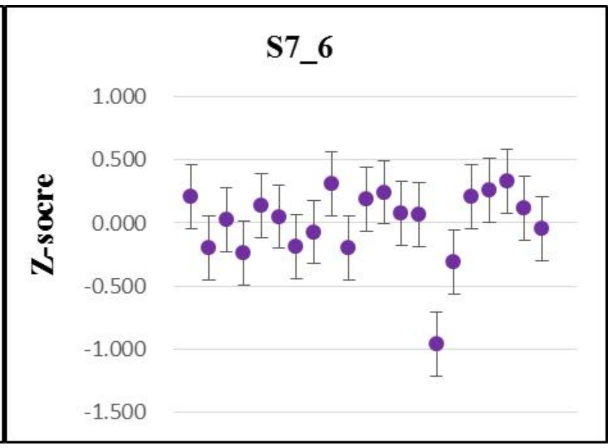


Figure 101 Z-scores of S7_6 samples

In Figure 99, the confidence intervals of most color samples for color center No.7 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be

significantly different from any others with a 95% confidence. Except for the No.6, No.9, No.11 and No.19, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.15 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.15 and No.18 were possible to be the MOS extreme values of color sample set for color center No.7, but it was not enough to be judged which one is the similarity maximum value.

In Figure 100, the confidence intervals of most color samples for color center No.7 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.18 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.7, No.11, No.12, No.13 and No.16, the color sample No.15 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.15 and No.18 were possible to be the MOS extreme values of color sample set for color center No.7, but it was not enough to be judged which one is the similarity maximum value.

In Figure 101, the confidence intervals of most color samples for color center No.7 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.19 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.15 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.15 and No.19 were possible to be the MOS extreme values of color sample set for color center No.7, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.8 Z-score analysis of subjective similarity for color center No.8

In Figure 102, the confidence intervals of most color samples for color center No.8 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.10, No.11, No.12, No.14, No.17, No.18, No.19 and No.20, the color sample No.15 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.1, the color sample No.3 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.3 and No.15 were possible to be the MOS extreme values of color sample set for color center No.8, but it was not enough to be judged which one is the similarity maximum value.

In Figure 103, the confidence intervals of most color samples for color center No.8 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.5, No.9, No.15 and No.20, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.21 with smallest Z-score can be considered to be significantly different from few samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.12 and No.21 were possible to be the MOS extreme values of color sample set for color center No.8, but it was not enough to be judged which one is the similarity maximum value.

In Figure 104, the confidence intervals of most color samples for color center No.8 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.13 and No.15, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.3 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.3 and No.20 were possible to be the MOS extreme values of color sample set for color center No.8, but it was not enough to be judged which one is the similarity maximum value.

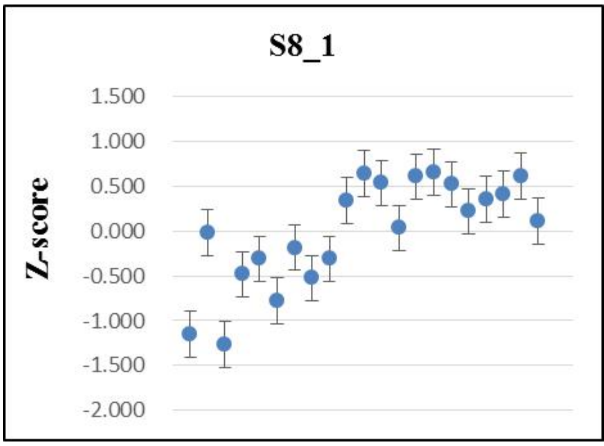


Figure 102 Z-scores of S8_1 samples

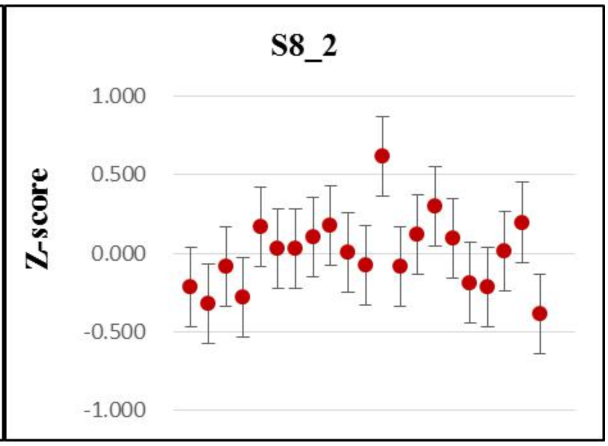


Figure 103 Z-scores of S8_2 samples

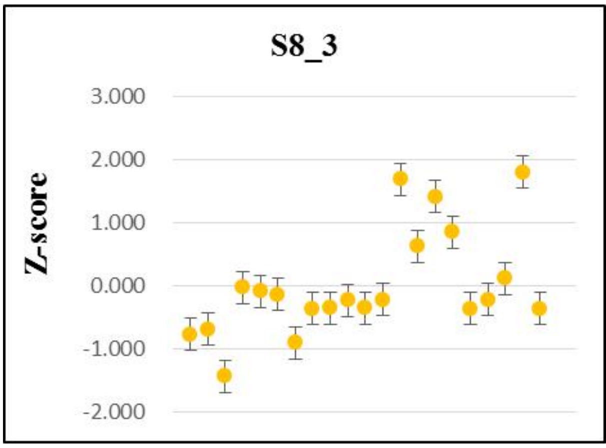


Figure 104 Z-scores of S8_3 samples

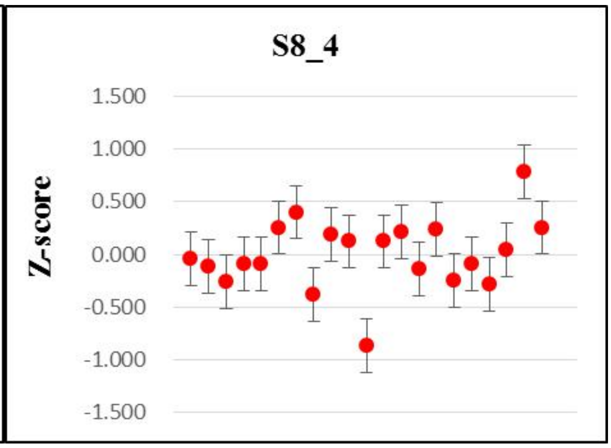
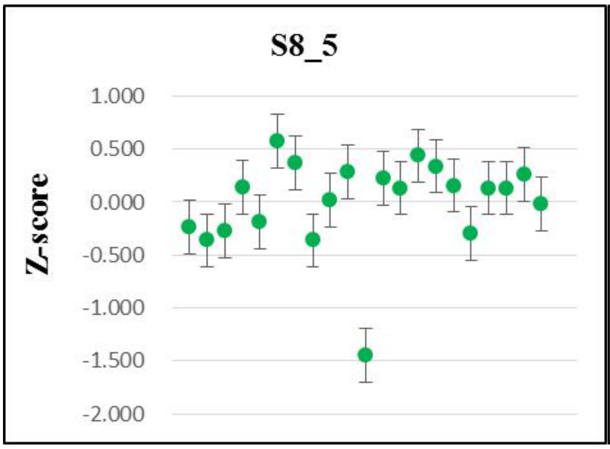


Figure 105 Z-scores of S8_4 samples



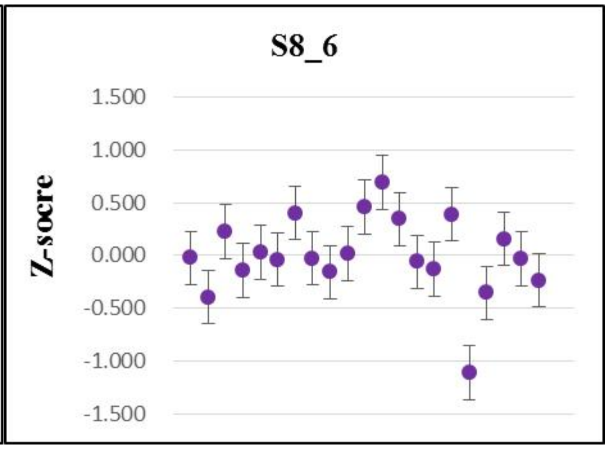


Figure 106 Z-scores of S8_5 samples Figure 107 Z-scores of S8_6 samples

In Figure 105, the confidence intervals of most color samples for color center No.8 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.7, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.8, the color sample No.11 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.11 and No.20 were possible to be the MOS extreme values of color sample set for color center No.8, but it was not enough to be judged which one is the similarity maximum value.

In Figure 106, the confidence intervals of most color samples for color center No.8 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.6 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.11 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.6 and No.11 were possible to be the MOS extreme values of color sample set for color center No.8, but it was not enough to be judged which one is the similarity maximum value.

In Figure 107, the confidence intervals of most color samples for color center No.8 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.3, No.7, No.11, No.13, No.16 and No.17, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.17 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.12 and No.17 were possible to be the MOS extreme values of color sample set for color center No.8, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.9 Z-score analysis of subjective similarity for color center No.9

In Figure 108, the confidence intervals of most color samples for color center No.9 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.8 and No.20, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.11 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.11 and No.12 were possible to be the MOS extreme values of color sample set for color center No.9, but it was not enough to be judged which one is the similarity maximum value.

In Figure 109, the confidence intervals of most color samples for color center No.9 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.1, No.6, No.17 and No.20, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.4, No.10 and No.18, he color sample No.19 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.12 and No.19 were possible to be the MOS extreme values of color sample set for color center No.9, but it was not enough to be judged which one is the similarity maximum value.

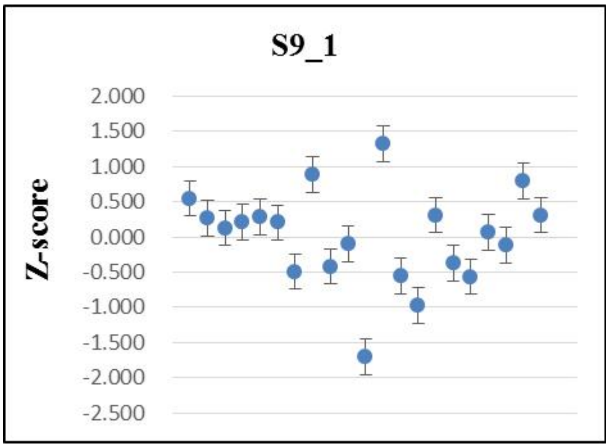


Figure 108 Z-scores of S9_1 samples

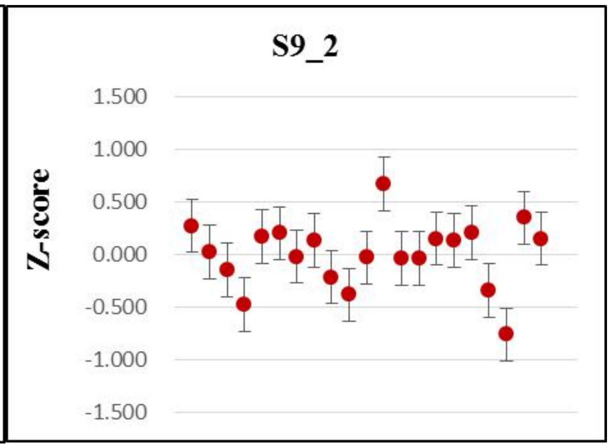


Figure 109 Z-scores of S9_2 samples

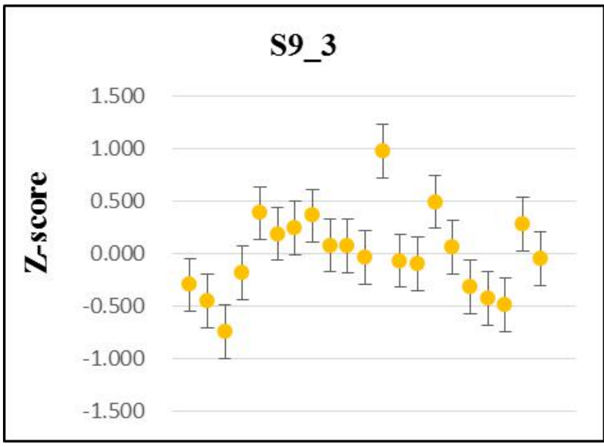


Figure 110 Z-scores of S9_3 samples

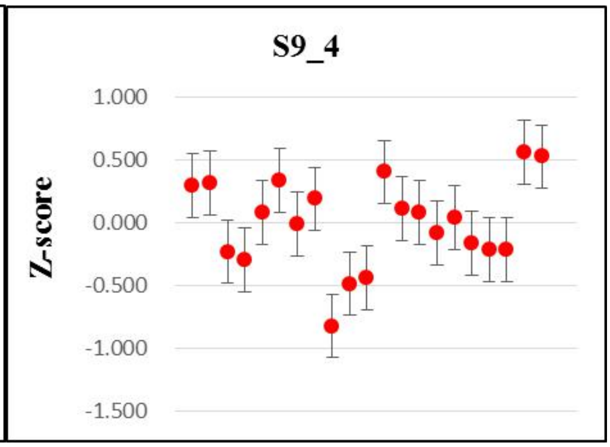


Figure 111 Z-scores of S9_4 samples

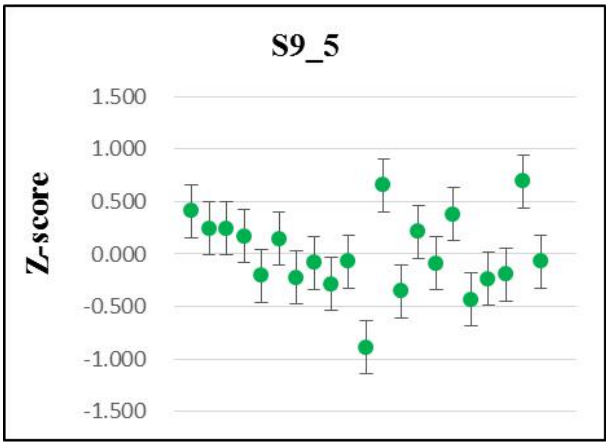


Figure 112 Z-scores of S9_5 samples

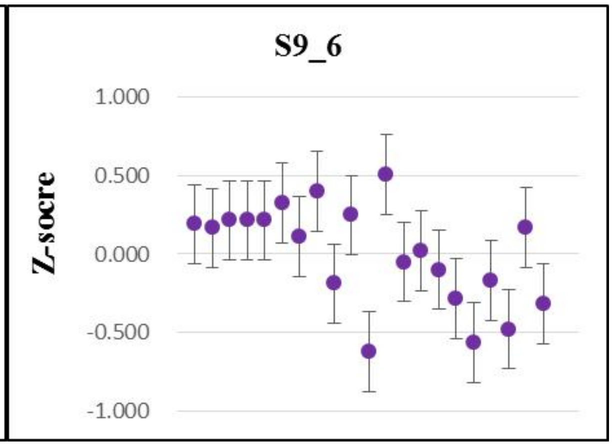


Figure 113 Z-scores of S9_6 samples

In Figure 110, the confidence intervals of most color samples for color center No.9 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.15, the color sample No.12 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.2, No.17, No.18 and No.19, the color sample No.3 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.3 and No.12 were possible to be the MOS extreme values of color sample set for color center No.9, but it was not enough to be judged which one is the similarity maximum value.

In Figure 111, the confidence intervals of most color samples for color center No.9 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.1, No.2, No.5, No.6, No.8, No.12, No.13, No.14 and No.21, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.10 and No.11, the color sample No.9 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.9 and No.20 were possible to be the MOS extreme values of color sample set for color center No.9, but it was not enough to be judged which one is the similarity maximum value.

In Figure 112, the confidence intervals of most color samples for color center No.9 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.1, No.2, No.3, No.12, No.14 and No.16, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.17, the color sample No.11 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.11 and No.20 were possible to be the MOS extreme values of color sample set for color center No.9, but it was not enough to be judged which one is the similarity maximum value.

In Figure 113, the confidence intervals of most color samples for color center No.9 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.12 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. Except for the No.9, No.16, No.17, No.18, No.19 and No.21, the color sample No.11 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.11 and No.12 were possible to be the MOS extreme values of color sample set for color center No.9, but it was not enough to be judged which one is the similarity maximum value.

5.1.3.10 Z-score analysis of subjective similarity for color center No.10

In Figure 114, the confidence intervals of most color samples for color center No.10 under CRPC1 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.11 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. Except for the No.10, No.18 and No.19, the color sample No.9 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.9 and No.11 were possible to be the MOS extreme values of color sample set for color center No.10, but it was not enough to be judged which one is the similarity maximum value.

In Figure 115, the confidence intervals of most color samples for color center No.10 under CRPC2 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.2, No.7, No.9, No.10, No.12, No.13, No.14 and No.16, the color sample No.11 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Except for the No.3, No.5, No.6, No.8, No.15, No.18, No.19, No.20 and No.21, the color sample No.4 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.4 and No.11 were possible to be the MOS extreme values of color sample set for color center No.10, but it was not enough to be judged which one is the similarity maximum value.

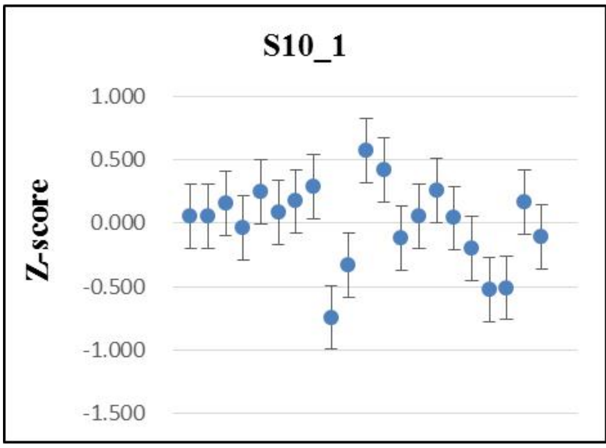


Figure 114 Z-scores of S10_1 samples

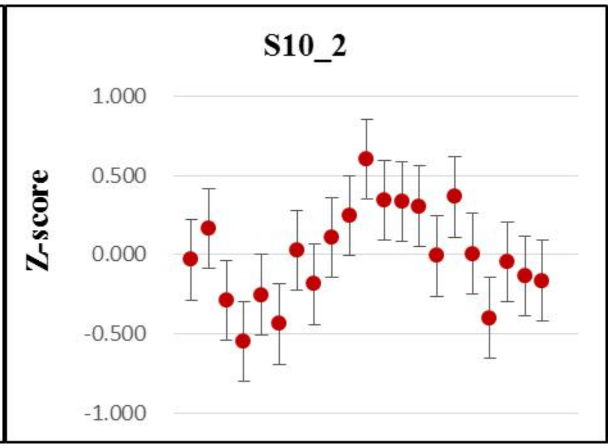


Figure 115 Z-scores of S10_2 samples

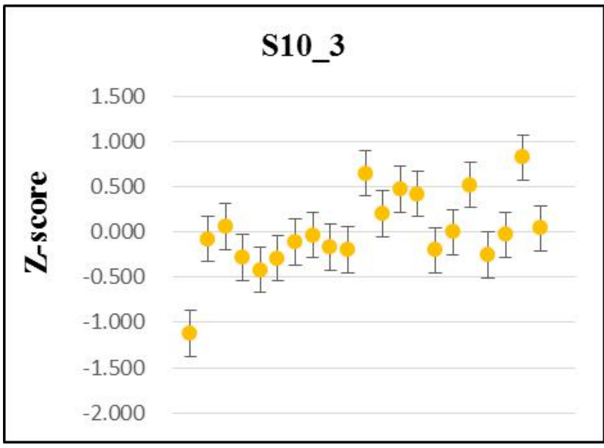


Figure 116 Z-scores of S10_3 samples

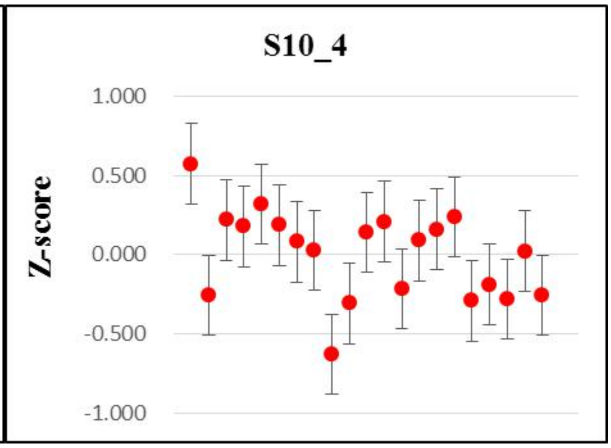


Figure 117 Z-scores of S10_4 samples

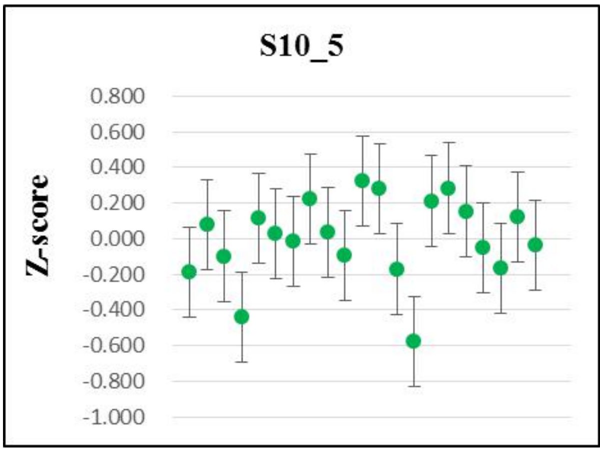


Figure 118 Z-scores of S10_5 samples

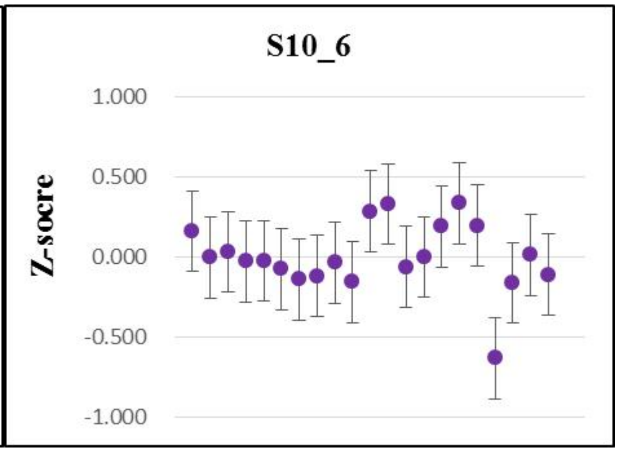


Figure 119 Z-scores of S10_6 samples

In Figure 116, the confidence intervals of most color samples for color center No.10 under CRPC3 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. Except for the No.11, No.13, No.14 and No.17, the color sample No.20 with biggest Z-score can be considered to be significantly different from rest samples with a 95% confidence. The color sample No.1 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1 and No.20 were possible to be the MOS extreme values of color sample set for color center No.10, but it was not enough to be judged which one is the similarity maximum value.

In Figure 117, the confidence intervals of most color samples for color center No.10 under CRPC5 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.1 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. Except for the No.2, No.10, No.13, No.17, No.18, No.19 and No.21, the color sample No.9 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.1 and No.9 were possible to be the MOS extreme values of color sample set for color center No.10, but it was not enough to be judged which one is the similarity maximum value.

In Figure 118, the confidence intervals of most color samples for color center No.10 under CRPC6 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.11 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. Except for the No.4, No.13 and No.19, the color sample No.14 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.11 and No.14 were possible to be the MOS extreme values of color sample set for color center No.10, but it was not enough to be judged which one is the similarity maximum value.

In Figure 119, the confidence intervals of most color samples for color center No.10 under CRPC7 data set overlapped each other, it was indicated that most test samples were not considered to be significantly different from any others with a 95% confidence. The color sample No.16 with biggest Z-score can be considered to be significantly different from few samples with a 95% confidence. The color sample No.18 with smallest Z-score can be considered to be significantly different from rest samples with a 95% confidence. Beside above two special color samples, there are no other color samples to show significant difference each other with a 95% confidence. So, the color sample No.16 and No.18 were possible to be the MOS extreme values of color sample set for color center No.10, but it was not enough to be judged which one is the similarity maximum value.

5.1.4 MOS analysis of subjective similarity

The plotted similarity MOS values which were the average of twice similarity scaling MOS values, were used to analyze the similarity degree of color samples, and shown from the Figure 120 to Figure 129. To contrast the MOS values of color samples under six selected CRPC data set, each color centers were shown and discussed in each figure, which can exploit the trend of color samples among different CPRC data sets.

In Figure 120, the similarity MOS values of color samples for color center No.1 were fluctuated greatly among range from 1 to 8. It can be easily found that the trends of color samples were varied from different CRPC data set. The trend of similarity MOS values of color samples within CRPC1 and CRPC2 data sets had in common with slight fluctuation and main from 5 to 8. The trend of similarity MOS values of color samples within CRPC3, CRPC5 and CRPC7 data set had in common with big fluctuation and main from 1 to 7. Obviously, the trend of similarity MOS values of color samples within CRPC6 data set fluctuated sharply, which maybe caused by the large lightness adjustment in process step. In Figure 121, for the color center No.2 case, the whole trend of similarity MOS values of color samples within different CRPC data sets were same, and all fluctuated sharply at samples marked No.7, No.8, No.12 and No.15. In addition, the whole similarity MOS values were changed from 4 to 9 as well as the previous small adjustments in LCh attributes. Interesting, the CRPC6 case for color center No.2 also showed a sharp fluctuation.

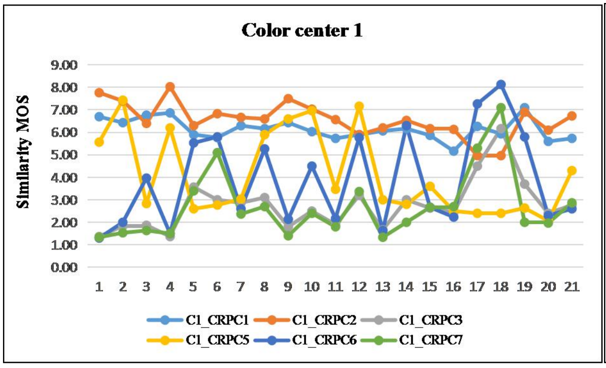


Figure 120 MOS values of samples of color center No.1

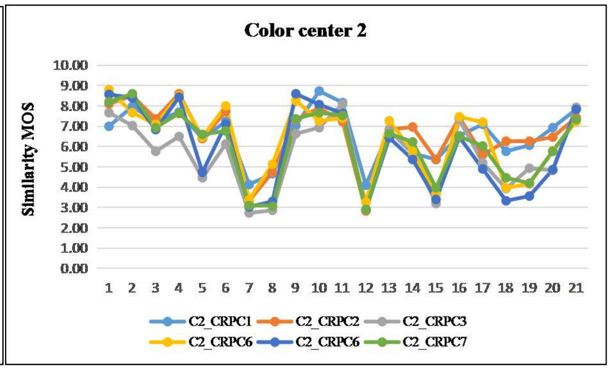


Figure 121 MOS values of samples of color center No.2

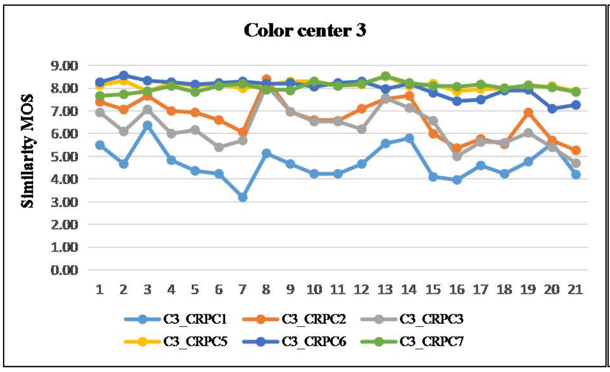


Figure 122 MOS values of samples of color center No.3

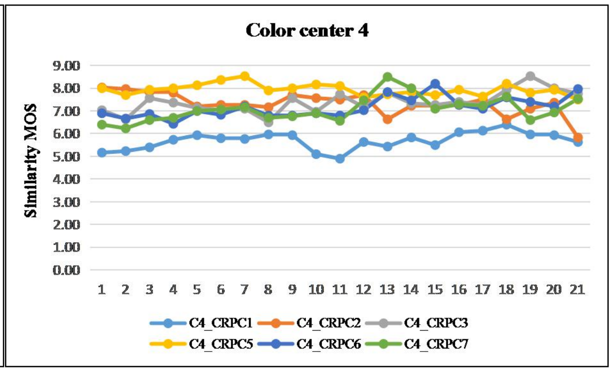


Figure 123 MOS values of samples of color center No.4

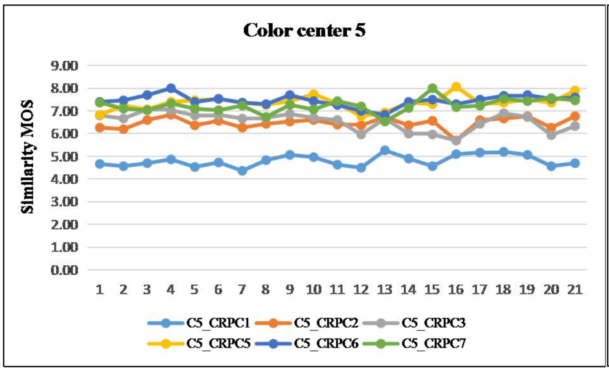


Figure 124 MOS values of samples of color center No.5

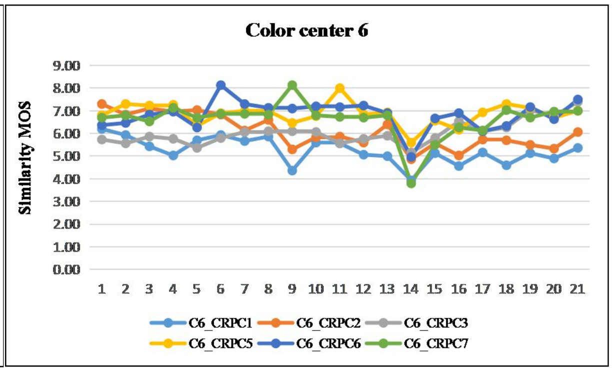


Figure 125 MOS values of samples of color center No.6

In Figure 122, the similarity MOS values of color samples for color center No.3 were distributed in two obvious similarity intervals, and fluctuated slightly. The similarity MOS values of color samples within CRPC1, CRPC2 and CRPC3 data sets had in common with big fluctuation from 3 to 8. However, The similarity MOS values of color samples within CRPC5, CRPC6 and CRPC7 data sets had in common with tiny fluctuation from 7 to 9. In Figure 123, the similarity MOS values of color samples for color center No.4 were distributed in an obvious similarity interval, and fluctuated slightly from 5 to 9. There are some similarity MOS values of color samples within CRPC3, CRPC5, CRPC6 and CRPC7 data sets very close to 9 which showed the highest similarity degree.

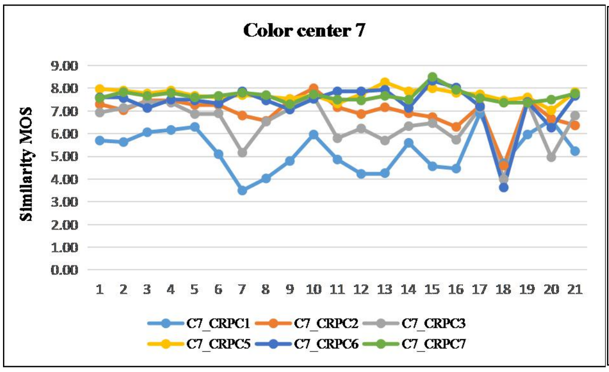


Figure 126 MOS values of samples of color center No.7

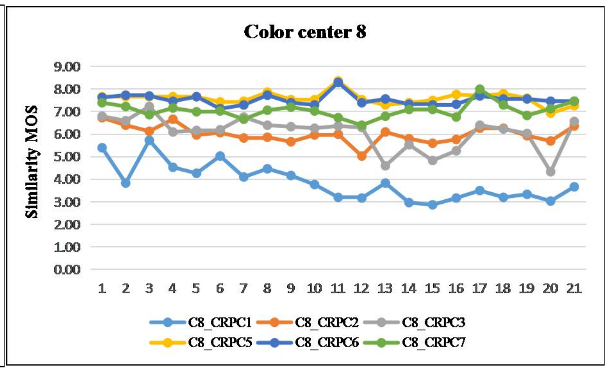


Figure 127 MOS values of samples of color center No.8

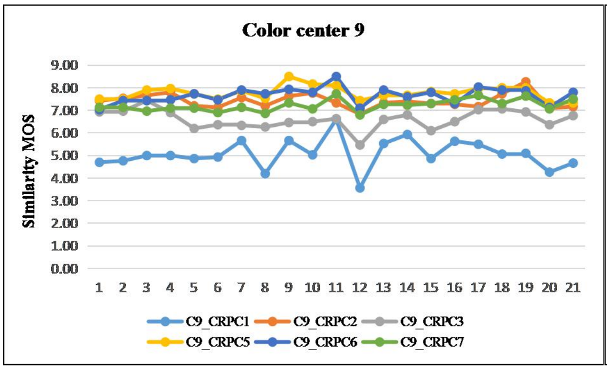


Figure 128 MOS values of samples of color center No.9

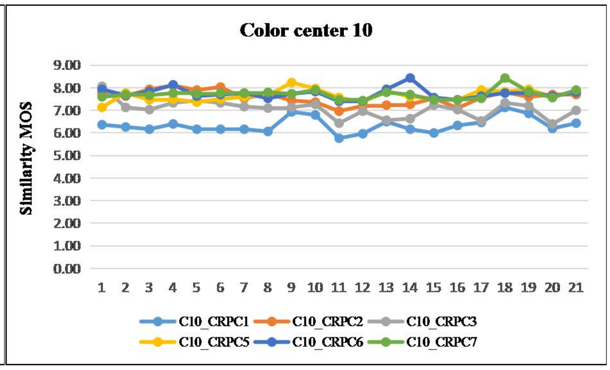


Figure 129 MOS values of samples of color center No.10

In Figure 124, except for the CRPC1 case, the similarity MOS values of color samples for color center No.5 were distributed in an obvious similarity interval from 6 to 8. Correspondingly, the similarity MOS values of color samples within CRPC1 data set showed a slight fluctuation from 4 to 6. In Figure 125, the trend of similarity MOS values of color samples for color center No.6 had in common with similar big fluctuation. Some similarity MOS values of color samples within CRPC5, CRPC6 and CRPC7 data set were very close to 9 which is the highest similarity degree. It was obvious that color samples marked No.6, No.9 and No.14 had fluctuated sharply.

In Figure 126, the similarity MOS values of color samples for color center No.7 were distributed in two obvious similarity intervals. Moreover, the similarity MOS values of color samples within CRPC5, CRPC6 and CRPC7 data sets showed a slight fluctuation from 7 to 9, while those within CRPC1, CRPC2 and CRPC3 data sets showed a sharp fluctuation from 3 to 7. The color samples within CRPC1 data set for color center No.7 influenced easily by the designed small adjustments. In Figure 127, the similarity MOS values of color samples for color center No.8 were also distributed in two obvious similarity intervals. The similarity MOS values of color samples within the CRPC1 data set showed a sharp fluctuation, while other data sets showed a slight fluctuation from 6 to 8.

In Figure 128, the similarity MOS values of color samples for color center No.9 were distributed in two obvious similarity intervals. The similarity MOS values of color samples within the CRPC1 data set showed a sharp fluctuation, while other data sets showed a slight fluctuation from 6 to 9. The similarity MOS values of color samples marked No.12 within all CRPC data sets were changed sharply. In Figure 129, the similarity MOS values of color samples for color center No.10 were distributed in a focused similarity interval from 6 to 9, and showed a tiny fluctuation.

5.1.5 Color difference analysis of subjective similarity

The correlation of color samples between measured color differences and subjective visual differences is an important element to achieve the CCAD and assess the CCA. When that correlation model or metric is developed, it can test the applicability of CCAD, and in turn to optimization of correlation models. For the measured color difference calculation, the CIEDE94 color difference metric and CIEDE00 color difference metric were both used for all color samples based on the DE94.m function and DE00.m function in Philip Green's Color Engineering Toolbox. It should be stated that four indicators including ΔE, ΔL, ΔC and ΔH were introduced and discussed for each color center, respectively.

5.1.5.1 CIEDE94 analysis of subjective similarity

In Figure 130, as for 126 color samples for color center No.1, their four indicators including ΔE94, ΔL94, ΔC94 and ΔH94 were were shown and correlated with the corresponding similarity MOS values. Where the blue solid circle is for ΔE94, the orange solid circle is for ΔL94, the green solid circle is for ΔC94 and the yellow solid circle is for ΔH94. The whole ΔE94 range of color samples was from 0 to 14 NBS. Interestingly, the ΔE94 value of color sample with MOS value set 6 was bigger than that of color sample with MOS value set 2. This maybe caused by the MOS value is an average term, which indicates a more scale or metric to show an useful correlation. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.1, the ΔH94 was an useful index based on the different ratios of ΔL94 and ΔC94 to match the corresponding MOS values. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index.

In Figure 131, as for 126 color samples for color center No.2, the whole ΔE94 range of color samples was from 0 to 13 NBS. There is a nice correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.2, the ΔH94 was also an useful index, when the ΔL94 and ΔC94 were relative small, to match the corresponding MOS values. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

In Figure 132, as for 126 color samples for color center No.3, the whole ΔE94 range of color samples was from 0 to 30 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.3, the ΔL94 was also an useful index, when the ΔC94 and ΔH94 were relative small, to match the corresponding MOS values. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

In Figure 133, as for 126 color samples for color center No.4, the whole ΔE94 range of color samples was from 0 to 28 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.4, the ΔC94 was also an useful index, when the ΔL94 and ΔH94 were relative small, to match the corresponding MOS values. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

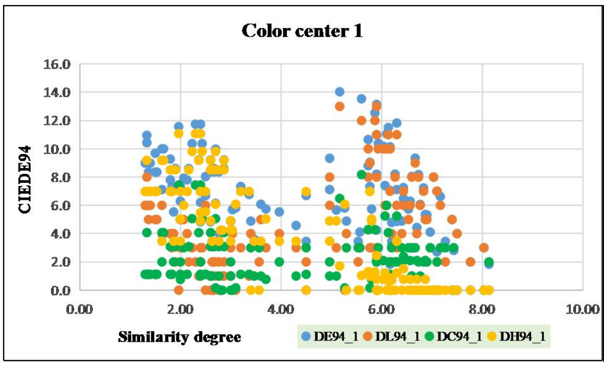


Figure 130 DE94 values of samples of color center No.1

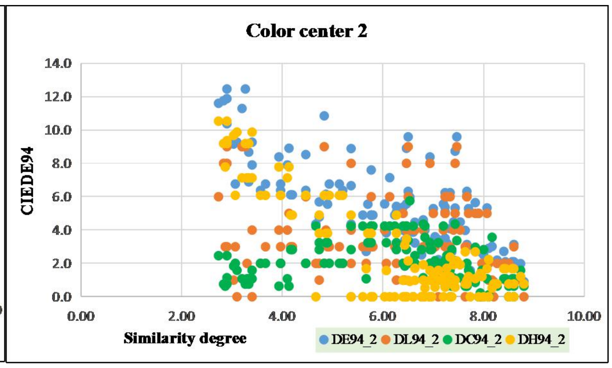


Figure 131 DE94 values of samples of color center No.2

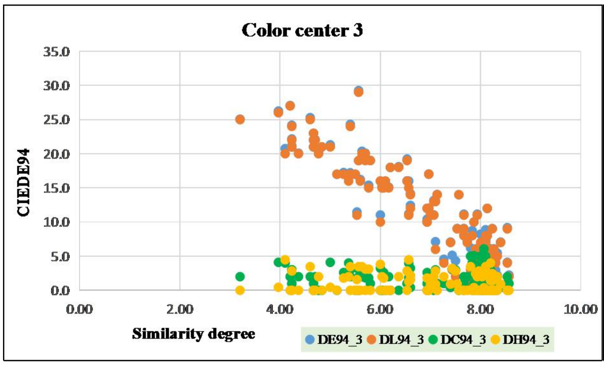


Figure 132 DE94 values of samples of color center No.3

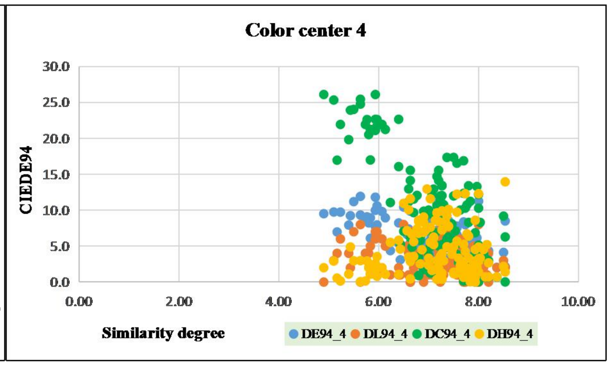


Figure 133 DE94 values of samples of color center No.4

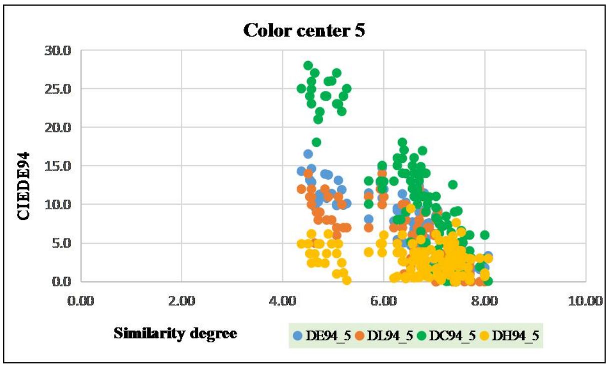


Figure 134 DE94 values of samples of color center No.5

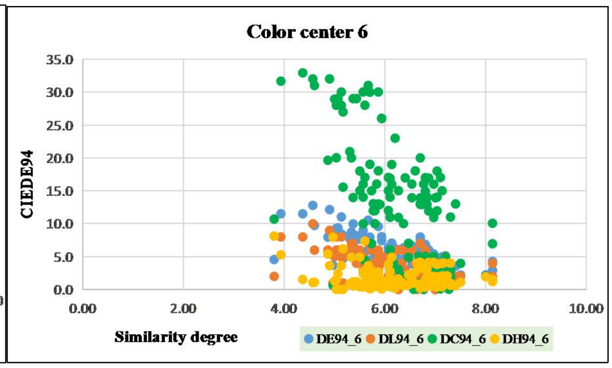


Figure 135 DE94 values of samples of color center No.6

In Figure 134, as for 126 color samples for color center No.5, the whole ΔE94 range of color samples was from 0 to 28 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.5, the ΔC94 and ΔH94 were both correlated with the corresponding MOS values with different linear coefficients, when the ΔL94 were enough small. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

In Figure 135, as for 126 color samples for color center No.6, the whole ΔE94 range of color samples was from 0 to 15 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.6, the ΔL94 and ΔC94 were both correlated with the corresponding MOS values with different linear coefficients, when the ΔH94 were enough small. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

In Figure 136, as for 126 color samples for color center No.7, the whole ΔE94 range of color samples was from 0 to 22 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.7, the ΔL94 was also correlated with the corresponding MOS values, when the ΔH94 and ΔC94 were enough small. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

In Figure 137, as for 126 color samples for color center No.8, the whole ΔE94 range of color samples was from 0 to 25 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.8, the ΔL94 and ΔC94 were both correlated with the corresponding MOS values with different linear coefficients, when the ΔH94 were enough small. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

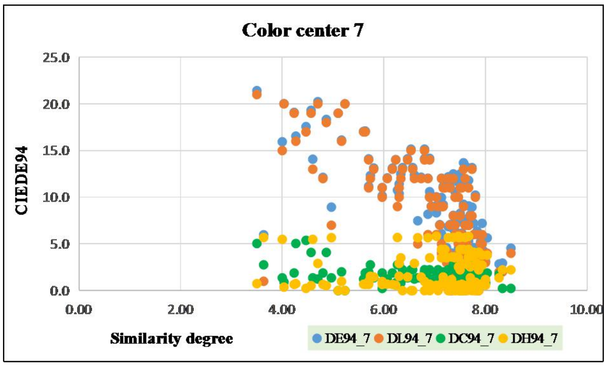


Figure 136 DE94 values of samples of color center No.7

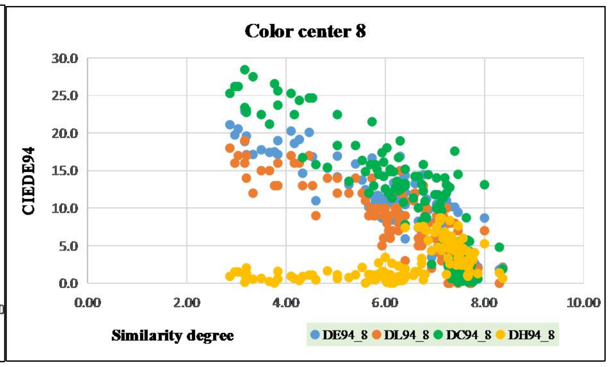


Figure 137 DE94 values of samples of color center No.8

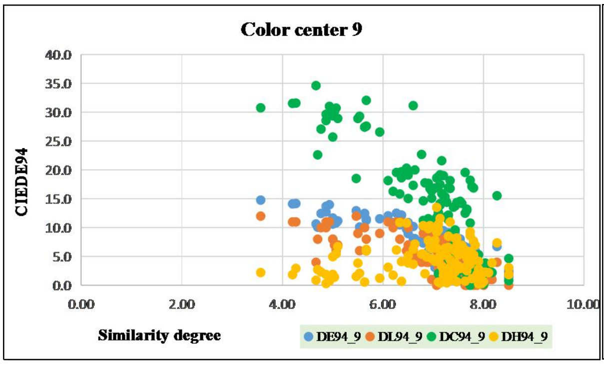


Figure 138 DE94 values of samples of color center No.9

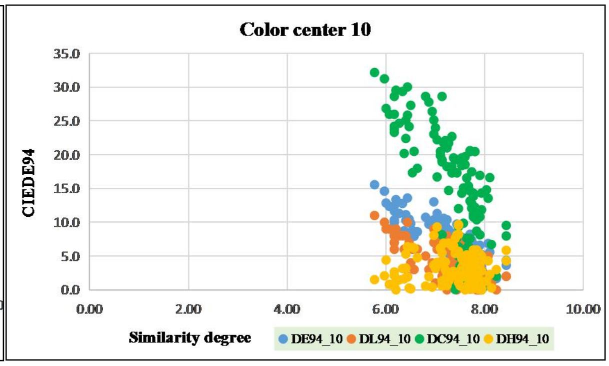


Figure 139 DE94 values of samples of color center No.10

In Figure 138, as for 126 color samples for color center No.9, the whole ΔE94 range of color samples was from 0 to 15 NBS, while the whole ΔC94 range of color samples was up to 35 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.9, the ΔC94 were not obviously correlated with the corresponding MOS values, when the ΔL94 and ΔH94 were fixed. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it would be an useful correlative index by adjusting the ratio of rest two indicators.

In Figure 139, as for 126 color samples for color center No.10, the whole ΔE94 range of color samples was from 0 to 20 NBS, while the whole ΔC94 range of color samples was up to 35 NBS. There is a good correlation between the ΔE94 values and similarity MOS values. At the same time, according to the distributions of ΔL94, ΔC94 and ΔH94 of color samples for color center No.10, the ΔC94 were correlated with the corresponding MOS values, when the ΔL94 and ΔH94 were enough small. It can be found that if one of three indicators including ΔL94, ΔC94 and ΔH94 had change bigger than any others, then it can be an useful correlative index by adjusting the ratio of rest two indicators.

5.1.5.2 CIEDE00 analysis of subjective similarity

The CIEDE00 metric can show a more information in the change direction of color difference of color samples than CIEDE94 metric, which attributed to provide a more accurate correlation in the specific similarity interval. In Figure 140, as for 126 color samples for color center No.1, their four indicators including ΔE00, ΔL00, ΔC00 and ΔH00 were were shown and correlated with the corresponding similarity MOS values. Where the orange solid circle is for ΔE00, the yellow solid circle is for ΔL00, the green solid circle is for ΔC00 and the reddish brown solid circle is for ΔH00. The whole ΔE00 range of color samples was from 0 to 15 NBS, and also showed a good linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.1, the ΔL00 and ΔH00 both correlated with corresponding similarity

MOS values well while ΔC00 was not obvious for color samples in the small MOS range. The ΔL00 and ΔH00 both correlated the corresponding similarity MOS values well while ΔC00 was not obvious for color samples yet in the big MOS range.

In Figure 141, as for 126 color samples for color center No.2, the whole ΔE00 range of color samples was from 0 to 15 NBS, and also showed a good linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.2, the ΔC00 and ΔH00 both correlated the corresponding similarity MOS values with a linear trend while ΔL00 was not obvious for color samples in the whole similarity MOS range.

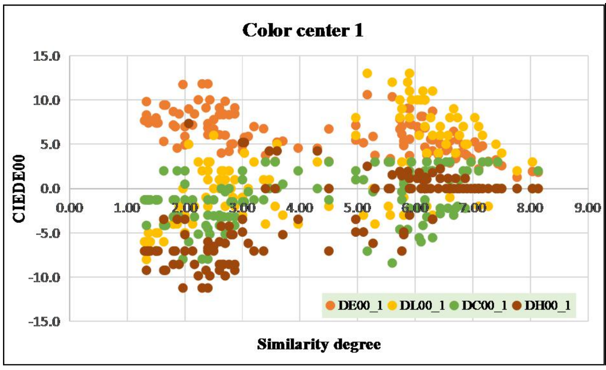


Figure 140 DE00 values of samples of color center No.1

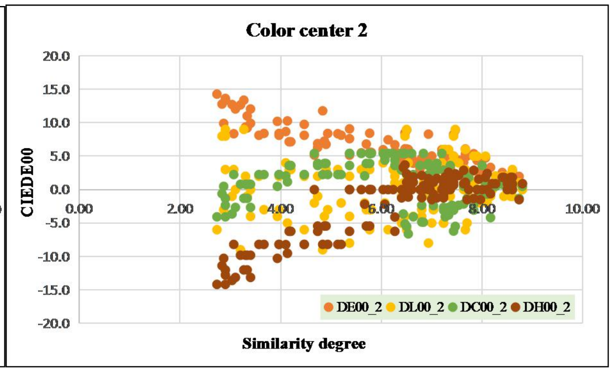


Figure 141 DE00 values of samples of color center No.2

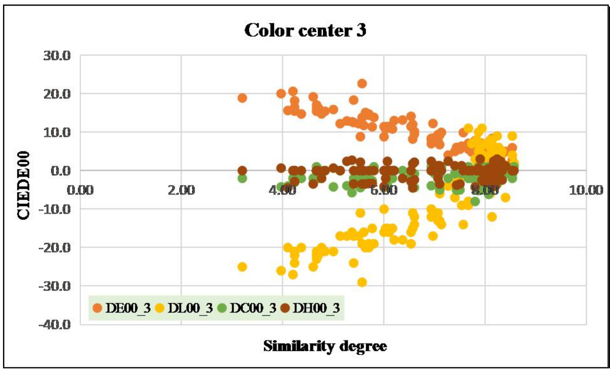


Figure 142 DE00 values of samples of color center No.3

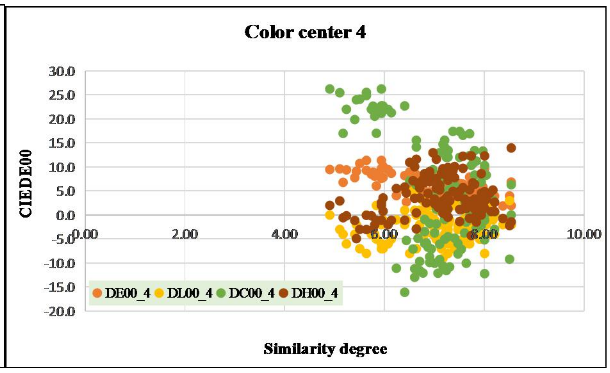


Figure 143 DE00 values of samples of color center No.4

In Figure 142, as for 126 color samples for color center No.3, the whole ΔE00 range of color samples was from 0 to 30 NBS, and also showed a good linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.3, the ΔL00, ΔC00 and ΔH00 of color samples all correlated the corresponding similarity MOS values with a linear trend in the whole similarity MOS range.

In Figure 143, as for 126 color samples for color center No.4, the whole ΔE00 range of color samples was from 0 to 20 NBS, and also showed a general linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.4, the biggest ΔC00 value of color samples was up to 30 NBS. The ΔL00, ΔC00 and ΔH00 of color samples didn't correlate the corresponding similarity MOS values with an obvious linear trend in the whole similarity MOS range.

In Figure 144, as for 126 color samples for color center No.5, the whole ΔE00 range of color samples was from 0 to 20 NBS, and also showed a general linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.5, the biggest ΔC00 value of color samples was up to 30 NBS. The ΔL00, ΔC00 and ΔH00 of color samples didn't correlate the corresponding similarity MOS values with an obvious linear trend in the whole similarity MOS range.

In Figure 145, as for 126 color samples for color center No.6, the whole ΔE00 range of color samples was from 0 to 15 NBS, and also showed a general linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.6, the biggest ΔL00 value of color samples was up to 25 NBS. The ΔC00 and ΔH00 of color samples didn't correlate the corresponding similarity MOS values with an obvious linear trend in the whole similarity MOS range.

In Figure 146, as for 126 color samples for color center No.7, the whole ΔE00 range of color samples was from 0 to 20 NBS, and also showed a general linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.7, the biggest ΔC00 value of color samples was up to 30 NBS. The ΔC00 and ΔH00 of color samples correlated with corresponding similarity MOS values with an obvious linear trend while ΔL00 was not obvious in the whole similarity MOS range.

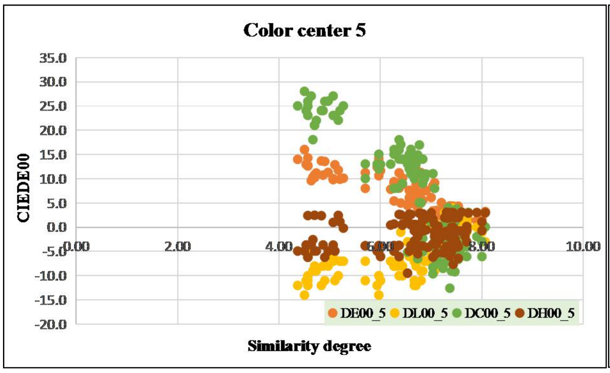


Figure 144 DE00 values of samples of color center No.5

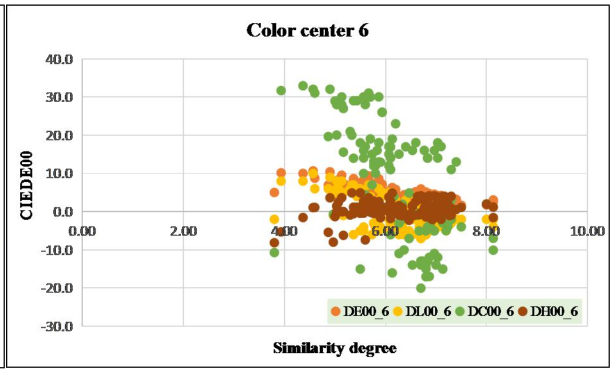


Figure 145 DE00 values of samples of color center No.6

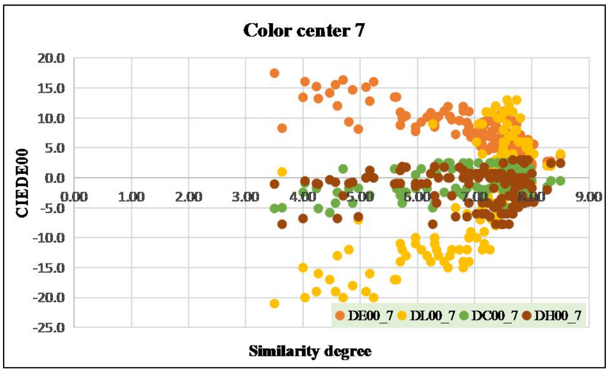


Figure 146 DE00 values of samples of color center No.7

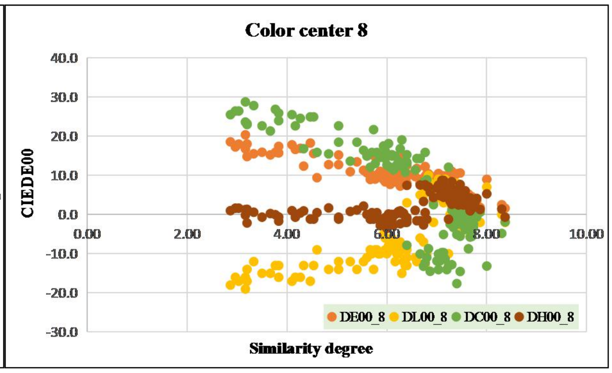


Figure 147 DE00 values of samples of color center No.8

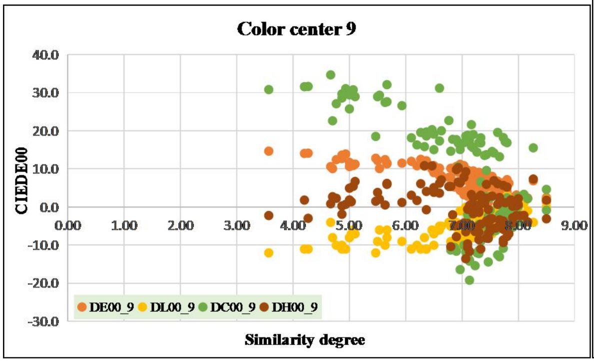


Figure 148 DE00 values of samples of color center No.9

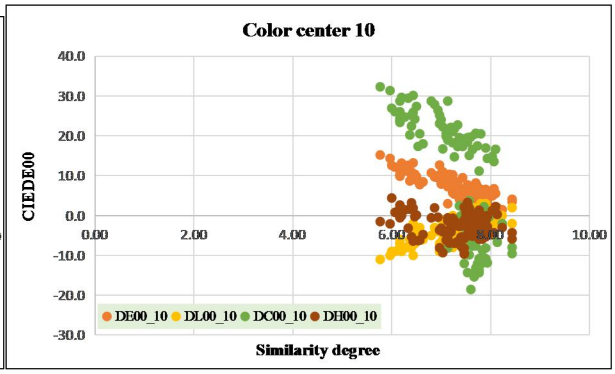


Figure 149 DE00 values of samples of color center No.10

In Figure 147, as for 126 color samples for color center No.8, the whole ΔE00 range of color samples was from 0 to 25 NBS, and also showed a good linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.8, the biggest ΔC00 value of color samples was up to 30 NBS, and the biggest ΔL00 of color samples was up to 20 NBS. The ΔL00, ΔC00 and ΔH00 of color samples didn't correlate the corresponding similarity MOS values with an obvious linear trend in the whole similarity MOS range.

In Figure 148, as for 126 color samples for color center No.9, the whole ΔE00 range of color samples was from 0 to 15 NBS, and also showed a good linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.9, the biggest ΔC00 value of color samples was up to 40 NBS, and the biggest ΔL00 of color samples was up to 15 NBS. The ΔC00 and ΔH00 of color samples didn't correlate the corresponding similarity MOS values with an obvious linear trend while ΔL00 showed an obvious linear trend in the whole similarity MOS range.

In Figure 149, as for 126 color samples for color center No.10, the whole ΔE00 range of color samples was from 0 to 20 NBS, and also showed a good linear correlation with corresponding similarity MOS values. According to the distributions of ΔL00, ΔC00 and ΔH00 of color samples for color center No.10, the biggest ΔC00 value of color samples was up to 35 NBS, and the biggest ΔL00 of color samples was up to 15 NBS. The ΔL00, ΔC00 and ΔH00 of color samples didn't correlate the corresponding similarity MOS values with an obvious linear trend in the whole similarity MOS range.

5.2 CCAD applicability of closeness trend line scaling approach

For the metrics to measure the consistent degree of color sets given different gamut, the closeness trend line scaling approach was regarded as a promising one. The ICC R8-13 memberships both though it should be further improved to create a detailed quantitative formula. On the basis of the proposed CCAD, the applicability of closeness trend line scaling approach was verified by the selected color samples shared common color appearance with 95% confidence interval. According to the Z-score values and MOS values of color samples in section 5.1, the whole 60 consistent colors from ten color centers were shown Table 15, respectively. Where the ID column is for the identify number of color sample, the Z-score column is for the Z-score value of color sample, the MOS column is for the MOS value of color sample, the Z-lowest column is for whether its Z-score is the minimum Z-score of corresponding color sets including positive and negative, the 95%CI is for whether this color sample was shared the highest similarity with 95% confidence interval, and Y is for yes, N is for no, NC is for uncertain. The ID is selected from the test sequence which is shown as X_x, where the X is for the marked number of color center, the x is for the marked number of designed adjustment in each CRPC data set. When the x is set zero, then this color patch is the primary color in CRPC4 data set. If the x is set from 1 to 21, then this color patch is the test color patch including secondary color in CRPC1 data set. If the x is set from 22 to 42, then this color patch is the test color patch including secondary color in CRPC2 data set. If the x is set from 43 to 63, then this color patch is the test color patch including secondary color in CRPC3 data set. If the x is set from 64 to 84, then this color patch is the test color patch including secondary color in CRPC5 data set. If the x is set from 85 to 105, then this color patch is the test color patch including secondary color in CRPC6 data set. If the x is set from 106 to 126, then this color patch is the test color patch including secondary color in CRPC7 data set.

In Table 16, in 60 color patches subsets within six CRPC data sets, all color samples with highest similarity MOS values were listed and correlated with Z-score characterizations and confidence interval. From the statistic view, the scaling similarity MOS value will provide a absolute term with unsettled confidence interval, while the Z-score value can provide a specific confidence interval of each color sample. So, combined Z-score value with scaling MOS value, whether the highest similarity MOS value of each color sample can be judged as the consistent color or not. Based on this judgment rule, for the proposed CCAD, the following combinations of color samples for the specific color center can be used to test the applicability of closeness trend line scaling approach. The combination of color samples for color center No.1 is 1_65, 1_102 and 1_122. The combination of color samples for color center No.2 is 2_10, 2_64 and 2_107. The combination of color samples for color center No.3 is 3_29 and 3_50. The combination of color samples for color center No.4 is 4_61, 4_99 and 4_118. The combination of color samples for color center No.6 is 6_74, 6_90 and 6_114. The combination of color samples for color center No.8 is 8_45, 8_95 and 8_122.

For the selected six consistent colors sets, the color center No.1, No.2 and No.3 are for neutral color set case, and the rest is for color set case. For gamut analysis of select color sample sets, the combination of color samples for color center No.1 included CRPC5, CRPC6 and CRPC7 data set; the combination of color samples for color center No.2 included CRPC1, CRPC5 and CRPC7 data set; the combination of color samples for color center No.3 included CRPC2 and CRPC3 data set; the combination of color samples for color center No.4 included CRPC3, CRPC6 and CRPC7 data set; the combination of color samples for color center No.6 included CRPC5, CRPC6 and CRPC7 data set; the combination of color samples for color center No.8 included CRPC5, CRPC6 and CRPC7 data set. In addition, three any color samples were selected as the test samples from the corresponding CRPC data set and color center. Then the color differences between test samples and consistent colors were calculated by two color difference metrics including the CIEDE94 and CIEDE00. These color difference values were correlated with the corresponding similarity MOS values to compare the previous minimum color difference correlation.

Table 15 The samples share the highest similarity in CCAD

ID	Z-score	MOS	Z-lowest	95% CI	ID	Z-score	MOS	Z-lowest	95% CI
1_19	-0.806	7.10	Y	NC	6_1	-0.508	6.20	N	NC
1_25	-1.222	8.03	Y	NC	6_22	-0.768	7.30	Y	NC
1_60	1.563	6.17	Y	NC	6_63	-0.960	7.40	Y	NC
1_65	1.613	7.43	Y	C	6_74	-0.970	8.00	Y	C
1_102	-3.875	8.13	Y	C	6_90	-1.547	8.13	Y	C
1_123	-3.875	7.10	Y	C	6_114	-1.659	8.13	Y	C
2_10	-2.430	8.73	Y	C	7_17	-1.377	6.90	Y	NC
2_25	-2.231	8.60	Y	NC	7_31	-0.954	8.00	Y	NC
2_53	-2.382	8.10	Y	NC	7_52	-0.814	7.63	N	NC
2_64	-3.074	8.80	Y	C	7_76	-0.142	8.27	Y	NC
2_93	-2.727	8.60	Y	NC	7_99	-0.833	8.33	Y	NC
2_107	-2.651	8.60	Y	C	7_120	-0.957	8.50	Y	C
3_3	-1.203	6.37	Y	NC	8_3	-1.265	5.73	Y	NC
3_29	-1.873	8.40	Y	C	8_22	-0.217	6.73	N	NC
3_50	-1.750	8.13	Y	C	8_45	-1.429	7.23	Y	C
3_76	-0.554	8.53	Y	NC	8_74	-0.867	8.37	Y	NC
3_86	-0.801	8.57	Y	NC	8_95	-1.444	8.30	Y	C
3_118	-0.854	8.53	Y	NC	8_122	-1.111	8.00	Y	C
4_18	-0.672	6.40	Y	NC	9_11	-1.702	6.60	Y	C
4_22	-0.693	8.03	Y	NC	9_40	-0.763	8.27	Y	NC
4_61	-1.381	8.53	Y	C	9_45	-0.744	7.43	Y	NC
4_70	-0.762	8.53	Y	NC	9_72	-0.820	8.50	Y	NC
4_99	-1.426	8.20	Y	C	9_95	-0.890	8.50	Y	NC
4_118	-1.633	8.50	Y	C	9_116	-0.623	7.73	Y	NC
5_13	-0.303	5.27	Y	NC	10_18	-0.524	7.13	Y	NC
5_25	-0.405	6.83	Y	NC	10_27	-0.439	8.03	N	NC
5_45	-0.399	7.07	Y	NC	10_43	-1.125	8.07	Y	C
5_79	-0.739	8.07	Y	NC	10_72	-0.629	8.23	Y	NC
5_88	-0.414	8.00	Y	NC	10_98	-0.580	8.43	Y	NC
5_120	-0.636	8.00	Y	NC	10_123	-0.633	8.43	Y	NC

All the alternative correlation results were shown from the Table 16 to Table 21. All the selected primary colors and consistent colors were plotted on the a*b* plane in Figure 150. In Table 16, for the color center No.1, three test color samples were 1_64, 1_102 and 1_123, which included different similarity MOS values all below 8. For the correlation between similarity MOS value and measured color difference values, firstly the color difference values of primary colors and consistent colors were the minimum color difference values in most cases. There was a good positive correlation between the test colors and primary colors while a good negative correlation between test colors and consistent colors to some degree. For the case of CRPC5, the applicability of closeness trend line scaling approach was general which maybe caused by the designed big adjustments of LCh attributes. Because these neutral color samples are susceptible to be recognized by small adjustments of chroma and hue attributes. Obviously, the cases of CRPC6 and CRPC7 were both shown an excellent result.

Table 16 Closeness trend line applicability of color center No.1

ID_CCA	L_adj	a_adj	b_adj	S_MOS	CIEDE94	CIEDE00	TLDE94	TLDE00	Correlation
1_0	89	0	3						
1_65	89	0	0	7.43	2.8	2.8			
1_102	89	0	1	8.13	1.8	1.8			
1_123	91	0	1	7.1	2.7	2.2			
1_64	92	0	0	5.57	4.1	3.4	3.00	1.87	
1_72	90	0	0	6.6	3	2.9	1.00	0.63	Y+
1_73	86	0	0	6.93	4.1	3.4	3.00	1.92	
1_90	90	0	-2	5.8	4.9	4.9	3.09	2.99	
1_98	92	0	-1	6.3	4.9	4.3	3.59	2.72	Y
1_101	91	0	0	7.27	3.4	3.1	2.23	1.59	
1_111	92	0	-2	5.1	5.7	5.2	3.09	2.99	
1_113	91	1	-3	2.7	6.1	6	3.94	4.06	Y
1_122	93	0	0	5.3	4.9	3.7	2.23	1.57	

Table 17 Closeness trend line applicability of color center No.2

ID_CCA	L_adj	a_adj	b_adj	S_MOS	CIEDE94	CIEDE00	TLDE94	TLDE00	Correlation
2_0	42	3	3						
2_10	41	3	5	8.73	2	2			
2_64	42	3	2	8.8	0.9	0.9			
2_107	39	3	2	8.6	3.1	2.8			
2_2	44	3	5	7.97	2.6	2.5	3.00	2.74	
2_6	47	2	3	7.23	5.1	4.9	6.28	5.95	Y+
2_16	38	6	8	6.53	6	6	4.35	4.64	
2_66	42	1	0	7.1	3.3	3.7	2.59	3.18	
2_69	42	1	1	8	2.5	3.1	2.02	2.75	Y
2_72	40	3	2	8.27	2.2	2	2.00	1.78	
2_110	42	0	0	6.6	3.9	4.8	4.49	5.17	
2_116	38	5	2	7.53	4.5	4.4	1.98	2.53	Y+
2_122	38	0	0	6.03	6	5.6	3.48	4.52	

In Table 17, for the color center No.2, three test color samples within CRPC 1 data set were 2_2, 2_6 and 2_16, three test color samples within CRPC 5 data set were 2_66, 2_69 and 2_72, three test color samples within CRPC 5 data set were 2_110, 2_116 and 2_122. For the correlation between similarity MOS value and measured color difference values, firstly the color difference values of primary colors and consistent colors were the minimum color difference values in most cases. There was a positive correlation between the test colors and primary colors while a negative correlation between test colors and consistent colors to some degree. For the cases of CRPC1 and CRPC7, their applicability of closeness trend line scaling approach were general which maybe caused by the designed big adjustments of LCh attributes. Because these neutral color samples are susceptible to be recognized by small adjustments of chroma and hue attributes. Obviously, the cases of CRPC5 were both shown an excellent result.

In Table 18, for the color center No.3, three test color samples within CRPC 2 data set were 3_25, 3_27 and 3_35, three test color samples within CRPC 3 data set were 3_66, 3_69 and 3_72. For the correlation between similarity MOS value and measured color difference values, firstly the color difference values of primary colors and consistent colors were the minimum color difference values in most cases. It was found that the correlative trend of ΔE00 and ΔE94 of test samples were big different. There was a positive correlation between the test colors and primary colors while a negative correlation between test colors and consistent colors to some degree. Obviously, the cases of CRPC2 and CRPC3 were both shown an excellent result.

Table 18 Closeness trend line applicability of color center No.3

ID_CCA	L_adj	a_adj	b_adj	S_MOS	CIEDE94	CIEDE00	TLDE94	TLDE00	Correlation
3_0	15	0	1						
3_29	22	1	1	8.4	7.1	5			
3_50	27	0	1	8.13	12	8.4			
3_25	26	1	1	7	11	7.8	4.00	2.89	
3_27	27	3	3	6.6	12.4	9.5	5.59	4.78	Y
3_35	24	0	0	7.67	9.1	6.3	2.42	2.25	
3_45	28	0	-1	7.07	13.1	9.4	2.21	2.11	
3_55	29	0	1	7.57	14	9.9	2.00	1.51	Y
3_57	30	0	-5	6.57	16	12	6.30	6.00	

Table 19 Closeness trend line applicability of color center No.4

ID_CCA	L_adj	a_adj	b_adj	S_MOS	CIEDE94	CIEDE00	TLDE94	TLDE00	Correlation
4_0	55	-36	-38						
4_61	57	-21	-41	8.53	8.5	6.9			
4_99	59	-36	-42	8.2	4.4	4			
4_118	52	-44	-43	8.5	4.1	4			
4_43	60	-26	-44	7.03	8.2	6.9	3.79	3.52	
4_58	62	-26	-38	7.4	8.5	7.5	6.07	5.25	Y+
4_62	63	-20	-37	8	11.3	9.6	6.18	5.49	
4_92	59	-33	-45	6.8	5.6	4.9	2.30	1.83	
4_101	57	-36	-46	7.1	3.9	3.5	2.57	2.30	Y+
4_105	52	-35	-40	7.97	3.2	3.1	7.03	6.61	
4_106	54	-42	-54	6.4	5.4	5.1	5.19	4.35	
4_117	58	-38	-47	7.47	4.5	4.1	7.07	6.41	Y+
4_119	55	-42	-49	8	3.7	3.6	4.22	3.79	

In Table 19, for the color center No.4, three test color samples within CRPC 3 data set were 4_43, 4_58 and 4_62, three test color samples within CRPC 6 data set were 4_92, 4_101 and 4_105, three test color samples within CRPC 7 data set were 4_106, 4_117 and 4_119. For the correlation between similarity MOS value and measured color difference values, firstly the color difference values of primary colors and consistent colors were the minimum color difference values except for CRPC6 case. There was a bad positive correlation between the test colors and primary colors while a bad negative correlation between test colors and consistent colors to some degree. It was also found that the correlations between test colors and primary colors were good for all CRPC cases. Obviously, the cases of CRPC3, CRPC6 and CRPC7 were all shown a bad result.

Table 20 Closeness trend line applicability of color center No.6

ID_CCA	L_adj	a_adj	b_adj	S_MOS	CIEDE94	CIEDE00	TLDE94	TLDE00	Correlation
6_0	83	-3	83						
6_74	85	-1	81	8	2.2	1.8			
6_90	87	-2	90	8.13	4.3	3.1			
6_114	85	-5	93	8.13	2.9	2.6			
6_70	83	1	80	7	1.9	2.3	2.21	1.77	
6_81	84	-2	80	7.3	1.3	1.1	1.12	0.90	Y
6_83	81	1	79	6.7	2.8	2.8	4.12	2.95	
6_86	88	-4	90	6.47	5.2	3.6	3.09	1.25	
6_97	87	-5	87	6.9	4.2	2.9	3.59	1.79	Y+
6_105	85	-2	87	7.5	2.2	1.7	2.23	1.44	
6_113	87	0	96	6.83	5	4.1	3.09	3.03	
6_122	88	-4	99	6.13	5.9	4.5	3.59	2.34	Y+
6_123	87	-2	95	7.03	4.7	3.6	2.23	2.11	

Table 21 Closeness trend line applicability of color center No.8

ID_CCA	L_adj	a_adj	b_adj	S_MOS	CIEDE94	CIEDE00	TLDE94	TLDE00	Correlation
8_0	28	14	-39						
8_45	38	9	-28	7.23	11	9.6			
8_95	28	17	-43	8.3	1.8	2.5			
8_122	21	24	-49	8	8.7	9			
8_43	38	10	-31	6.8	10.6	9	1.32	1.31	
8_50	41	8	-25	6.4	14.3	12.6	3.31	2.98	Y
8_61	36	8	-22	6.03	10.9	9.6	3.47	2.93	
8_86	27	18	-41	7.73	2.4	3.3	1.50	1.84	
8_90	25	20	-42	7.13	4.3	5.2	3.53	3.39	Y
8_96	30	18	-36	7.4	3.6	4.1	3.65	2.99	
8_114	22	26	-49	7.2	8.4	9.7	1.42	1.42	
8_118	19	25	-46	6.8	10.5	10.4	2.45	2.06	Y+
8_119	22	26	-44	7.1	8.5	9.9	2.71	2.90	

In Table 20, for the color center No.6, three test color samples within CRPC 5 data set were 6_70, 6_81 and 6_83, three test color samples within CRPC6 data set were 6_86, 6_97 and 6_105, three test color samples within CRPC7 data set were 6_113, 6_122 and 6_123. For the correlation between similarity MOS value and measured color difference values, firstly the color difference values of primary colors and consistent colors were the minimum color difference values only for CRPC7 case. For the cases of CRPC6 and CRPC7, there was a bad positive correlation between the test colors and primary colors while a bad negative correlation between test colors and consistent colors to some degree. Obviously, the case of CRPC7 was shown an excellent result.

In Table 21, for the color center No.8, three test color samples within CRPC 3 data set were 8_43, 8_50 and 8_61, three test color samples within CRPC6 data set were 8_86, 8_90 and 8_96, three test color samples within CRPC7 data set were 8_114, 8_118 and 8_119. For the correlation between similarity MOS value and measured color difference values, firstly the color difference values of primary colors and consistent colors were the minimum color difference values only for CRPC6 case. For the cases of CRPC3 and CRPC7, there was a good positive correlation between the test colors and primary colors while a bad negative correlation between test colors and consistent colors to some degree. Obviously, the case of CRPC7 was shown an excellent result.

In order to illustrate the applicability of closeness trend line scaling approach of consistent colors, the primary reference colors and consistent color samples for six selected color centers were plotted vividly on the a*b* plane, which shown in Figure 150. In Figure 150, the color centers including No.1, No.2, No.3, No.4, No.6 and No.8 were displayed and contrasted, respectively. Where the black arrow was used to mark the primary reference colors among colorful solid circles. It was easily found that the consistent color samples most shared a linear loci, which its slop was varied with the specific color center. Another phenomenon was that the primary reference colors were located one side of the corresponding trend line loci.

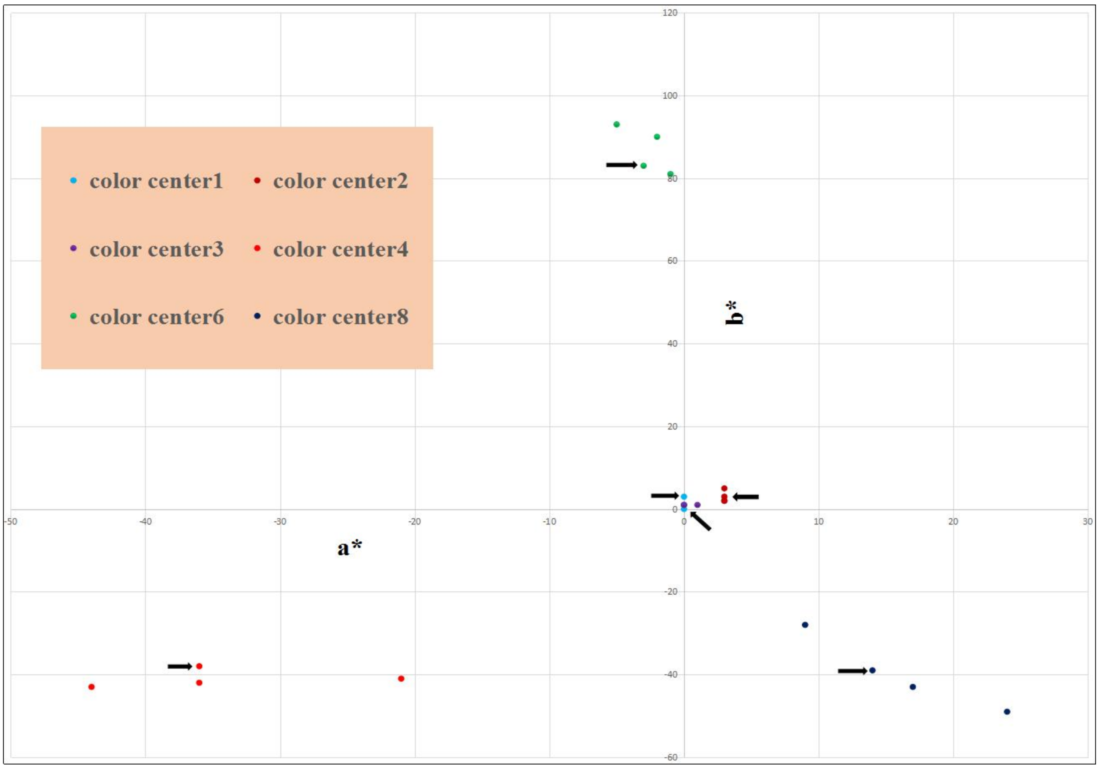


Figure 150 The consistent color loci case

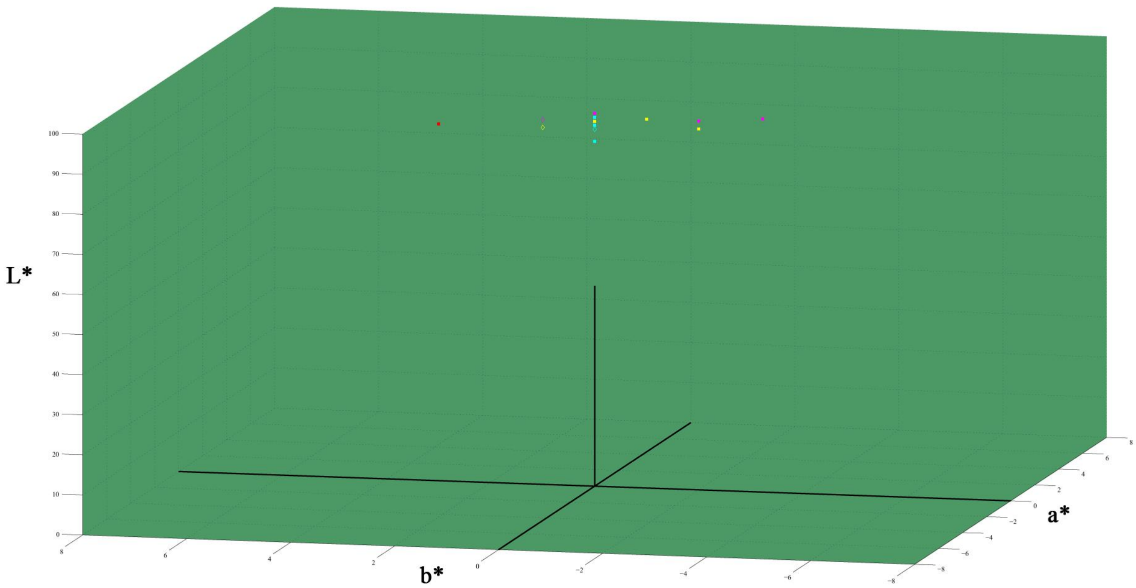


Figure 151 The consistent colors distribution of color center No.1 case

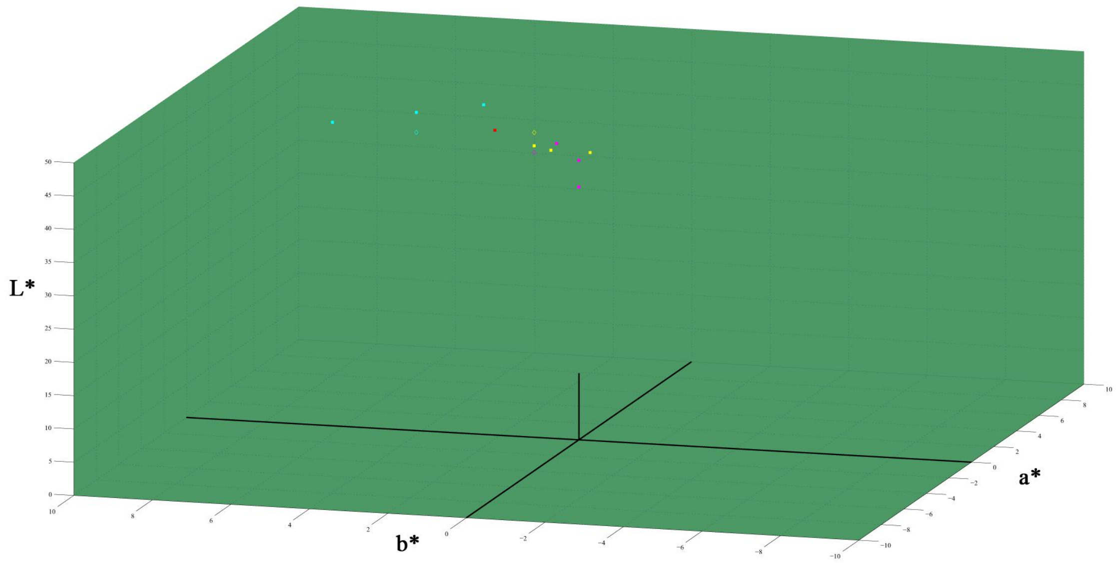


Figure 152 The consistent colors distribution of color center No.2 case

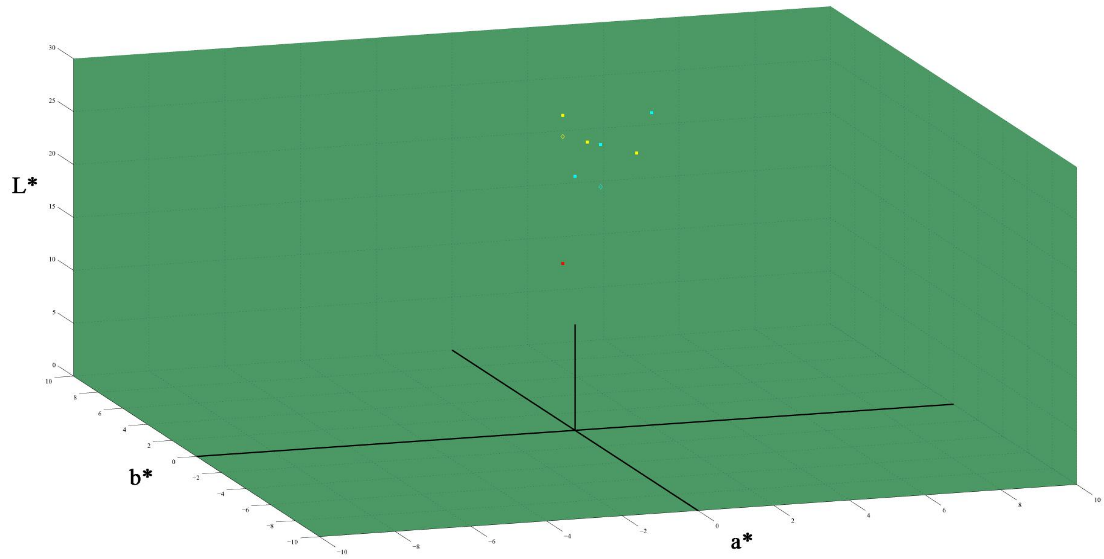


Figure 153 The consistent colors distribution of color center No.3 case

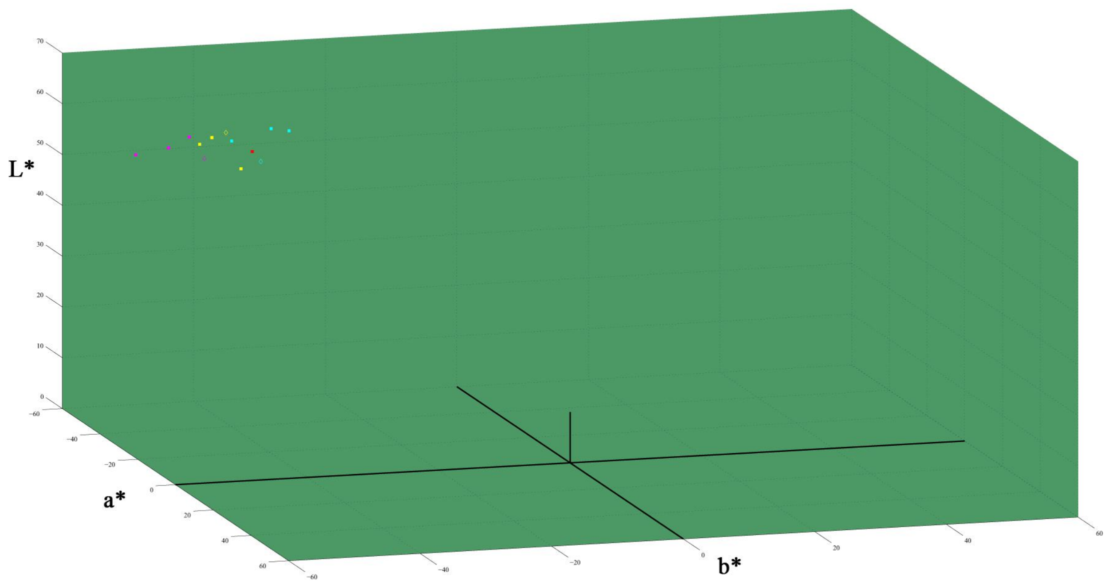


Figure 154 The consistent colors distribution of color center No.4 case

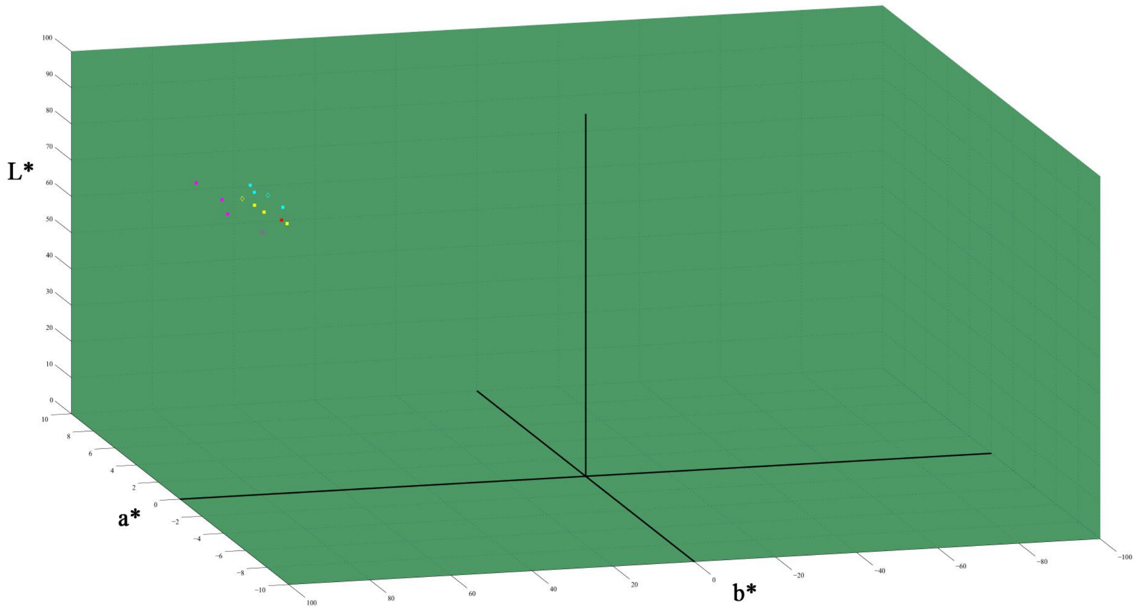


Figure 155 The consistent colors distribution of color center No.6 case

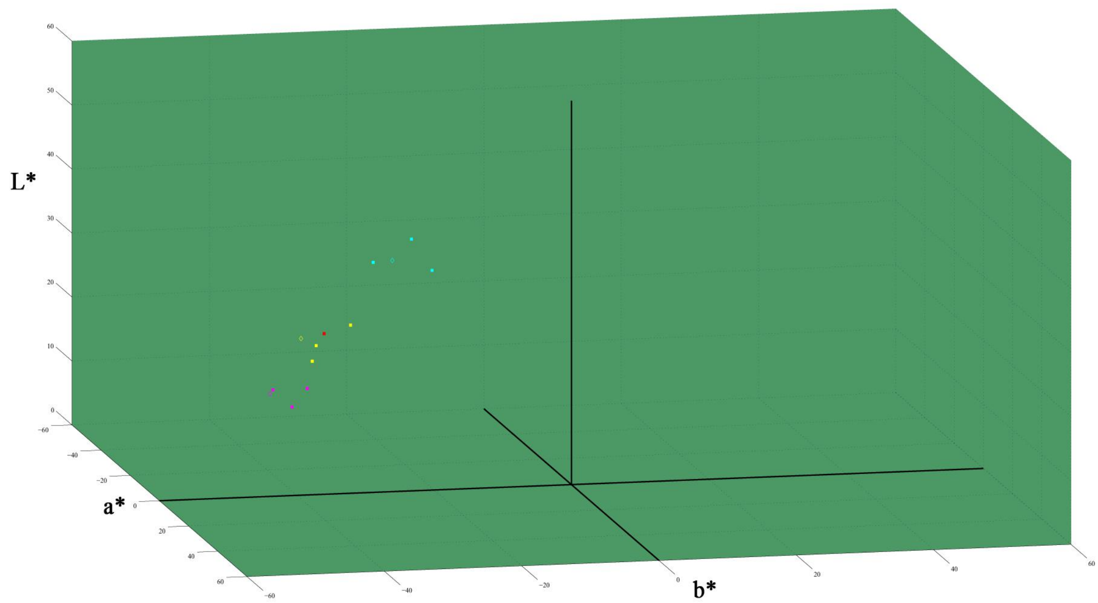


Figure 156 The consistent colors distribution of color center No.8 case

The obvious advantage of this project was that any combinations of LCh attributes were considered, and analyzed in CIELa*b* color space by using the scatter3.m function, which shown from the Figure 151 to Figure 156. Where the red solid squares were for primary reference colors, the yellow, magenta and cyan hollow diamonds were for three relative consistent colors, the yellow, magenta and cyan solid diamonds were for three relative test colors. In Figure 151, the local trend line of consistent colors for color center No.1 can be found and correlated well with the description in Table 16. In Figure 152, the local trend line of consistent colors for color center No.2 can be found and correlated well with the description in Table 17. In Figure 153, the whole trend line of consistent colors for color center No.3 can be easily found and correlated well with the description in Table 18. In Figure 154, the local trend line of consistent colors for color center No.4 can be generally found and correlated well with the description in Table 19. In Figure 155, the local trend line of consistent colors for color center No.6 can be found and correlated well with the description in Table 20. In Figure 156, the local trend line of consistent colors for color center No.8 can be found and correlated well with the description in Table 21. Powerful and practical correlations between consistent colors, primary reference colors and test colors were attributed to develop the narrow CCAM. For this narrow CCAM frame, it should consider the input parameters including colourimetry of pixels of image or color patch, sample and reference medium gamut and viewing condition. The output of narrow CCAM can be the colourimetry of color samples share common color appearance. The practical model is the further research work.

6 Conclusions and Further Work

6.1 Contributions

In this project, the common color appearance sample database based on color patch mode has completely developed with initial aspects. The proposed CCAD is mainly attributed to provide a data set of color samples including consistent colors and associated observations. In the literature survey section, current researches about common color appearance had been introduced and analyzed in detail with vivid cases. Introductions of CCA applications shows the original idea to motivate researchers to focus on the feasible subjective adjustment-feedback frame. Analysis of current CCA achievement and evaluation metrics has shared some optimization solutions to the current specific promising models. When designed the common color appearance sample database, this work not only introduces the single color patch mode, but also offers a new practical guide for composite image mode. For the subjective experiments of CCA achievement, it also provides an useful comprehensive guide for the samples design, test program development, experiment setups and data process. Another key contribution is the applicability assessment of closeness trend line scaling approach by using the determined consistent colors of the proposed CCAD, which can motive others to develop more completed numerical models based on this color data set and the proposed narrow CCAM frame.

6.2 Conclusions

Firstly, in the proposed CCAD, there are certain consistent colors share common color appearance, which generally agreed by all observers with 95% confidence interval. These consistent colors were judged from the color samples with highest similarity scaling values within the specific CRPC data set. These similarity scaling values were mainly characterized by the combination of MOS values and Z-scores with 95% confidence interval. The similarity MOS values were calculated by twice similarity scaling values. The Z-score values were transformed from the raw scaling matrix produced by nine-degree category judgment experiments. Then the subjective adjustment-feedback frame did can produce the consist colors in given different medium gamuts with certain confidence interval.

Secondly, the consistent colors share common color appearance are dependent on the color center. According to similarity scaling results shown in Table 15, it can be found that the neutral samples with consistent colors were more likely to be obtained than that of color samples to some degree. This phenomena maybe caused by the color samples within the given CRPC data set.

Thirdly, the proposed CCAD shows a good applicability for closeness trend line scaling approach. Comparing to consistent color sample sets, the consistent neutral color sample sets show a better applicability. In some cases, for the same color center, consistent colors within different CRPC color data sets also shows the different applicability. The applicability of trend line scaling approach is judged by whether the correlation between test color sample and consistent color sample is good, as well as considering the correlation between test color sample and primary reference color.

At last, this approach and workflow of implemented CCAD based on single color patch mode , are also suitable for the CCAD based on composite image mode. According to the guide for image based reference and samples, the setups and test GUI program of similarity scaling experiment were introduced in this project. The corresponding subjective scaling experiments were also conducted by same observers following the single color patch based experiment. However, the consistent colors were not achieved now because of the color samples were huge. But these can be implemented by those steps and metrics in the single color patch based experiment eventually.

6.3 Further work

The achievement and assessment of common color appearance metrics is a huge topic to be solved. As for one basis of this topic is to provide a practical color data set to exploit the CCA metrics for CIE R8-13 common color appearance reportship. The implemented CCAD based on single color patch mode would be one expected color data set. In this project, the proposed CCAD based on 10 special color centers within six CRPC color data sets has been successfully achieved, while there are three cost time further works based on this project to be exploited.

Firstly, the observer task instruction can be changed from the similarity scaling task to the difference scaling task to match directly the measured color difference sets. For the color samples of proposed CCAD, more consistent colors maybe obtained from current designed color patches with 95% confidence interval. Because the smallest difference can be easily scaled as 0 for observers while it is hard for same observers to scale the biggest similarity as 9. And the confidence interval maybe can be increased to 99% for most obtained consistent colors.

Secondly, the subjective similarity scaling experiment should add the different viewing conditions to propose a completed CCAM. For the common color appearance, it should be considered different viewing conditions even if the current CCAD is implemented in a standard viewing condition.

Thirdly, for the CCAD based on composite image mode, their consistent colors would be obtained by using the workflow of the achieved CCAD based on single color patch mode. Because of the composite image samples were designed with additional color patches from the primary colors of NCS data set, then it will provide more color samples to obtain the consistent colors even if it will cost huge time for calculation and analysis.

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