

# Color appearance and visual measurements for color samples with gloss effect

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We assess the color appearance of the samples with different inks on glossy substrates, five kinds of paper with different gloss levels. The color samples are measured using spectrophotometers under different illuminating/viewing geometries and visually estimated using the psychophysical method of magnitude estimation. The results of the two approaches are compared through the color appearance model of CIECAM02. The experimental data analysis indicates that the 0/45 and 15/0 geometries can be used to describe the two major aspects of gloss effect, the enlargement of color gamut, and the reduction of lightness. The agreement for hue attribute between instrumental measurement and visual assessment is better than those for colorfulness and lightness.

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It is well known that the gloss of printed material has a significant effect not only on its appearance but also on the perceived surface color<sup>[1]</sup>. Matte surface tends to have lower chroma and higher lightness compared to those with gloss effect, when the samples are measured without the specular light<sup>[2]</sup>. While with the presence of specular light, the results tend to be opposite. To assess samples with gloss effect, both measurements with and without specular reflection should be evaluated to give full comprehensions of the gloss factor. In this letter, the color samples with gloss effect are visually assessed and physically measured under different illuminating/viewing geometries. Through the CIECAM02 color appearance model, the results of different geometries against visual data are evaluated and compared<sup>[3,4]</sup>.

Five kinds of paper with different gloss scales were selected to be substrates, which were Niceday recycled plain paper (P), Epson photo quality paper (PQ), Epson premium glossy photo paper (PG), Olmec glossy inkjet paper (OG), and Epson ultra glossy photo paper (UG). All specular gloss values of the five substrates were measured using a Sheen Tri-micro Gloss 160/T gloss meter. As listed in Table 1, the substrates were measured under the geometry of 60° first and those whose gloss values were under 10 were measured again under the geometry of 85°<sup>[5]</sup>.

Both pigment and dye inks were inspected, which were provided by Clariant Co., Ltd. There were five different colors: the CMYK (cyan, magenta, yellow, and key) primaries and a color made by mixing equal amounts of CMY together, all of which had two different concentrations, resulting in 10 colors for pigment and dye inks, respectively. All the 20 ink samples for the two types of

inks were applied on to five different substrates using a K-bar with spiral of 0.1 μm. In total, 100 color samples were prepared, with the size of 3 × 3 (inch).

The visual assessment was performed using a viewing cabinet in a dark room, under the light source of a D65 simulator, by the psychophysical method of magnitude estimation. A panel of eight observers with normal color visions, including four males and four females, participated in the visual assessment, seven of which had academic backgrounds in color science and the other one was well trained before participation. The observers were asked to make quantized estimations of the test samples, which were displayed randomly, for their appearance attributes with maximum gloss effect by comparison with the given references. The references for lightness and colorfulness assessment corresponded to N10 from Munsell color order system and 3040-R20B from NCS (Natural Color System) color order system, respectively. All observers were clearly instructed about their tasks and fully adapted to the illumination of the cabinet. 20 of the 100 samples were assessed twice for the inspection of intra-variation of the observers. In total, each observer made 120 assessments, all of which were divided into two sessions to avoid the fatigue of the observers.

All samples were then measured using three different types of spectrophotometers, Gretag Macbeth CE7000A, X-Rite 939 (0/45), and Datacolor FX10. Specula included (SPIN) and specula excluded (SPEX) geometries for Gretag Macbeth CE7000A, 0/45 for X-Rite 939, and 10 kinds of geometries for Datacolor FX10 were adopted.

The intra- and inter-variation were analyzed firstly, to check the reliability of the collected data. The performance of the observers was reported in terms of STRESS (standardized residual sum of squares) values<sup>[6]</sup>, which can be calculated using

$$\text{STRESS} = \left( \frac{\sum (E_i - F_1 V_i)^2}{\sum F_1^2 V_i^2} \right)^{1/2} \times 100, \quad (1)$$

**Table 1. Gloss Values of Selected Substrates**

Geometry	P	PQ	PG	OG	UG
60°	3.5	2.3	37	29	62
85°	5.5	2.9	—	—	—

$$F_1 = \frac{\sum E_i^2}{\sum E_i V_i}, \quad (2)$$

where  $E_i$  is the target data and  $V_i$  is the reference data. The less the STRESS value is, the better the sample data conform to the target data. If two groups of data are identical, the STRESS value of them would be 0.

Table 2 shows the STRESS values of the observers for intra- and inter-variation of lightness, colorfulness, and hue, respectively. The STRESS values had good linear relationship with coefficient of variation (CV) values<sup>[6]</sup>, so it can be compared with published data for performance evaluation.

For the inter-variation of visual assessments, the performance of observers on hue attribute was better than lightness and colorfulness with an average STRESS value of 10.1, approximately corresponding to the CV value of 11.3. While for lightness and colorfulness, the performance of the observers was slightly worse, with the STRESS values of 18.9 and 23.7, whose corresponding CV values were 20.7 and 25.2, respectively. This is typical for magnitude estimation method when applied for color appearance assessment<sup>[7,8]</sup>, except that the performance of observers on lightness was slightly worse. For the three attributes assessed by the observers, they were all slightly less accurate compared with those found in earlier similar studies<sup>[8]</sup>. When assessing samples with gloss effect, slight changes in viewing geometry could result in large variation in colorfulness, especially lightness; while for hue, such effect is not so obvious. For the intra-variation of each observer, similar trend existed, while with better performance for each of the color appearance attributes.

The overall observer performances indicated that the reliability of this group of eight observers was acceptable. Different performances of lightness and colorfulness for intra- and inter-variation implied difficulties for observers to assess lightness and colorfulness with gloss effect. The mean values from the visual assessment were used for analysis.

The results of visual assessments and instrumental measurements have been compared. CIECAM02 was applied for the data transformation from the instrumentally measured  $XYZ$  to  $J$ ,  $M$ , and  $H$ . The luminance levels of the lightness reference and the background, as the parameters for  $J$ ,  $M$ , and  $H$  calculations, were 362.7 and 130.0 cd/m<sup>2</sup>, respectively, measured by a Minolta CS1000a tele-spectroradiometer. The scatter diagrams of visual assessments against different geometries are plotted in Fig. 1. Table 3 gives the statistical data of the comparison. For FX10, the 15/0 geometry performed the best among the 10 geometries, so only this one of

**Table 2. The Minimum, Maximum, and Mean STRESS for Intra- and Inter-Variation of Visual Assessments**

Parameter	Intra-Variation			Inter-Variation		
	Min	Max	Mean	Min	Max	Mean
Lightness	10.3	23.5	17.9	14.3	20.9	18.9
Colorfulness	16.3	23.6	19.1	15.6	33.5	23.7
Hue	1.3	9.8	6.2	7.5	17.2	10.1

**Table 3. Comparison Between Visual Assessments and Instrumental Measurements Under the Specified Viewing Geometries in Terms of STRESS for Lightness, Colorfulness, and Hue**

Geometry	Lightness	Colorfulness	Hue
SPEX	28.2	24.0	18.1
SPIN	25.9	23.2	16.2
0/45	29.4	23.8	19.2
15/0	26.9	20.2	13.7

**Table 4. Results of Significance  $F$ -Test with the Confidence Level of 95% and the Degree of Freedom of 99**

Lightness	Colorfulness	Hue	FINV(0.95,99,99)
0.915	0.849	0.714	0.717

Numbers in the first three columns are the ratios of STRESS values under the geometry of 15/0 to those under the geometry of 0/45.

FX10 was compared with the other three geometries, i.e., SPIN, SPEX, and 0/45 of the other spectrophotometers.

Hue predictions by CIECAM02 from all of the four geometries gave rather good results, especially for the four primary colors. And the predictions of colorfulness performed the second best. For SPIN and SPEX geometries, the predicted colorfulness values were less than those from visual assessments for less colorful samples; while at medium to high color range, the results tended to be opposite. Similar but less obvious trend could also be seen for the 0/45 and 15/0 geometries. This could be explained that human eyes are sensitive to colors with low chroma, but to high-chroma colors the sensitivity is much lower. For the predictions of lightness, more scattering plots for the medium lightness values could be seen from all of the four geometries, and in general, lightness predictions of the four geometries were similar and did not correspond with the visual results well.

The SPIN and SPEX geometries gave very similar results, and neither was well corresponded to the visual assessment geometry according to CIECAM02. With the integrated sphere for these two geometries, the specular reflection was 'diluted', and eventually contributed only a small portion to the change in the three attributes of color appearance.

$F$ -test with 95% confidence level was performed to check whether the reduction of STRESS value from the geometry of 0/45 to 15/0 was significant. The ratios of lightness (0.915) and colorfulness (0.849) in Table 4 were larger than the critical value (0.717) of the two tailed  $F$  distribution, while the ratio of hue (0.714) was less than the critical value, which indicated that the STRESS value for hue had statistically distinguishable difference between the two geometries. Hereby, compared with the other three geometries, the instrumental geometry of 15/0 corresponded slightly better to the visual results with specular reflection.

The fact that gloss effect affects the perception of color significantly can be verified in this experiment. The insignificant improvement from the geometry of 0/45 to 15/0 against visual data for lightness and colorfulness

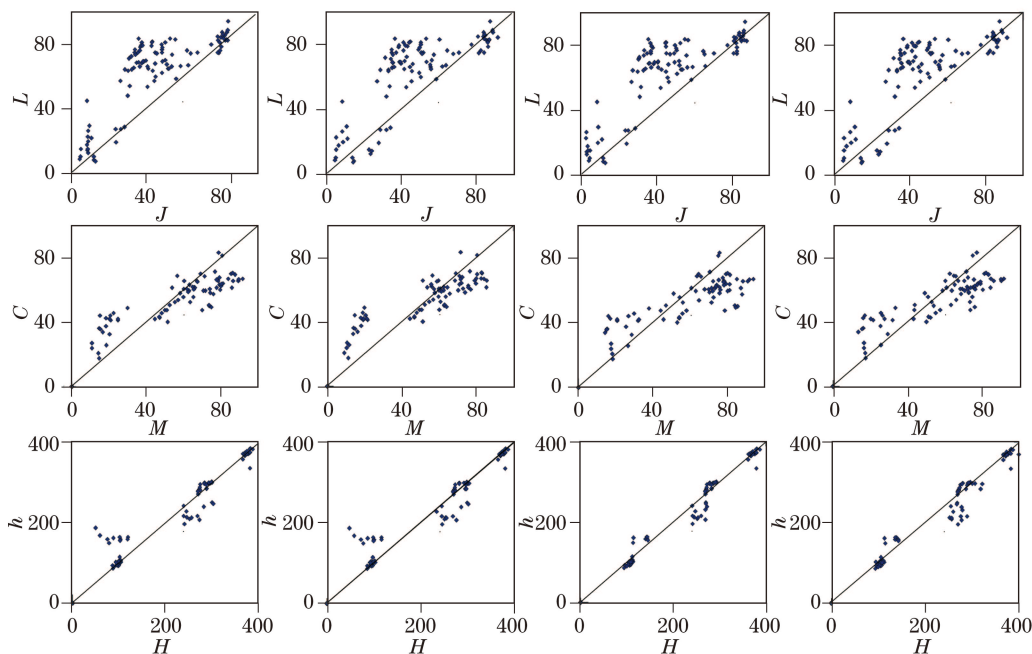


Fig. 1. Comparison between  $J$ ,  $M$ , and  $H$  from instrumental measurements and lightness ( $L$ ), colorfulness ( $C$ ), and hue ( $h$ ) from visual assessment. From left to right are for the geometries of SPEX, SPIN, 0/45 and 15/0; from top to bottom are the comparisons between  $L$  and  $J$ ,  $C$  and  $M$ ,  $h$  and  $H$ .

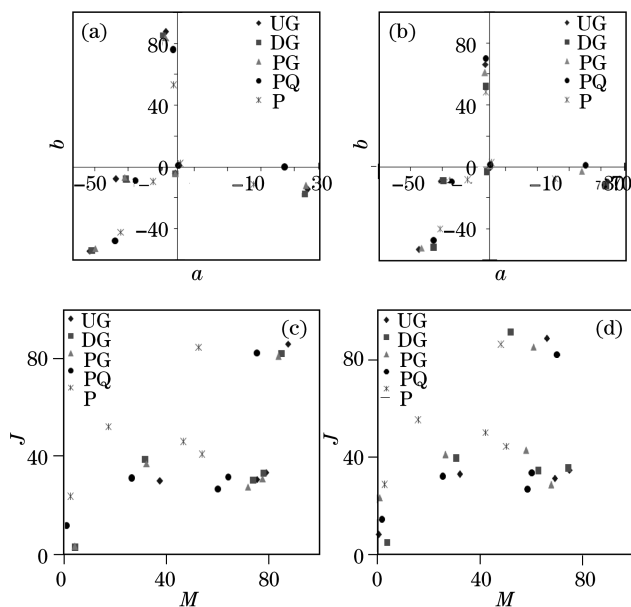


Fig. 2. Results of instrumental measurements of all samples made from pigment-based inks under the geometries of 0/45 and 15/0 plotted in  $a$ - $b$  and  $J$ - $M$  planes of CIECAM02, in which different markers are assigned to samples with different substrates. Plots (a) and (c) for the 0/45 geometry, (b) and (d) for the 15/0 geometry.

can be explained from the following aspects. Most commercial spectrophotometers are following the geometries specified by International Commission on Illumination (CIE) standard. There are barely instruments with geometry that focuses on specular reflection. For samples with gloss effect, small viewing angle variation would result in large reduction of energy from the peak value,

which, to some extent, led to the statistically similar STRESS values of lightness under the geometries of 0/45 and 15/0, and the same with the colorfulness attribute. In addition, with gloss effect, the observers had difficulties to quantify colorfulness and lightness correctly.

The 0/45 geometry was considered to be a good estimation of the viewing condition without specular light<sup>[2]</sup>, and the 15/0 geometry was by far the best estimation of the viewing condition with specular light. Both geometries showed partially the gloss effect on colors as indicated in this study.

Figure 2 illustrates the distribution of points representing the pigment-based colors of each sample in  $a$ - $b$  plane and  $J$ - $M$  plane of CIECAM02. The dye-based inks have the same properties, only with slight differences in the magnitude of the three color appearance attributes.

As shown in Figs. 2(a) and (c), the variation in hue is small compared with the variation in colorfulness. And the colorfulness of those samples decreased towards the origin of the coordinates as the gloss values decreased, except for the samples made from PQ. The results from 15/0 geometry generally had less colorfulness values than those from 0/45 geometry, which was due to the existence of gloss effect.

From Figs. 2(b) and (d), it is shown that the variation of lightness is smaller under the geometry of 0/45, which indicates that less lightness change due to gloss effect is observed under this geometry; while for 15/0, some colors have fairly large variation in lightness. Matte samples made from the substrate  $P$  tend to be steady; while samples with gloss effect tend to shift towards the  $J$  axis, which indicates the reduction of colorfulness, and also different levels of lightness increment could be assigned to samples with different gloss levels. Under the geometry of 0/45, the enlargement of color gamut result-

ing from gloss effect is most obvious. And the change in lightness could be better depicted under the geometry of 15/0. Gloss effect can affect human perception of color in various ways, so both geometries with and without specular light should be considered for better gloss effect descriptions.

In conclusion, the color appearances of samples with different gloss levels have been estimated and compared with visual assessments and instrumental measurement, respectively. The intra- and inter-variation of the observers were generally considered to be acceptable to compare with the corresponding instrumental measured data. The detailed analysis with the color appearance model of CIECAM02 indicates that the geometries of SPIN and SPEX have rather similar performance and are insufficient for gloss effect characterization. The 0/45 geometry can be used to evaluate the enlargement of color gamut for glossy colors; while the 15/0 geometry can be employed to assess the change of lightness resulting from gloss effect, in which the specular reflection is considered.

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