Study of Visual-Instrumental Agreement in Different Color Spaces for Colors Close to Boundary of Quadrants in CIEL*a*b* Color Space

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Abstract

Spot color printing has a significant role in maintaining consistency in shade reproduction on different substrates. For consistency in quality reproduction, the first step is color measurement, but because color is a psychophysical quantity, numerical shade approval is not sufficient. Thus, a shade must be approved visually as well as numerically. Visual-instrumental agreement is very important in color approval. A shade may be reproduced in different sample sizes, and then due to sample size, a viewing field angle must be selected. Viewing field changes may change visual perception of the same shade. Generally, shades that are closer to the boundary of quadrants are more likely to be subject to perceived color changes. This study is carried out for colors that fall near quadrant boundaries in CIEL*a*b* color space. In this work, colors that have a* or b* absolute values less than 2 and change their quadrant after switching field of viewing are considered. Psychophysical experiments were conducted considering 2 ° human observers, and the results show that visual-instrumental agreements are worse at quadrant boundaries. It was found that in the case that

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the shade falls closer to boundary of quadrant, setting tolerance limits becomes very difficult. If the same color is plotted in different color spaces such as LABNHU, LLAB, RLAB or ZLAB and comparison is carried out, the RLAB model seems to be more useful in the spot color approval process.

Introduction

Spot colors are frequently used in printing and packaging industries (Wu, et al 2008). When spot colors are approved on press in the standard-sample comparison manner, visual-instrumental agreement is necessary. In the case of approval, if agreement between customer and supplier has the same acceptable and perceptible values, then only pass/fail decisions can be made (Berns, 2000). In some cases for several reasons, any two persons may not have the same perception for any particular color, then instrumental readings can help in decision making. When a pass/fail decision is made, the pair must pass visually and numerically. An agreement between person to person and person to instrument (numbers) is important. E.g. if numerical analysis shows yellow is reddish then visual perception also shows that yellow is reddish. If perception of that color is yellowish green then in this failure case question arises who is correct, Instrument or person? Decisions can be cross checked by bringing another instrument or person into the experiment but again questions arise about which person is correct or and/or which instrument is correct? These cases can happen if either a*or b* values of color in CIEL*a*b* color space are close to zero. This can happen because of the following reasons.

1) Low CRI of light source (Field, 2004, p3). When calculations of tristimulous values are carried out, the CIE illuminant data are used, but if light emitted from the light source gives far different data than data used in calculation then this leads to error. Difference between illuminant data and data measured from light source is known as color rendering index. Color rendering index of any light source should be as high as possible.

2) Instrumentation parameters. In instrumentation parameters the following parameters are involved.
    a) Type of geometry
    b) Light source used in instrument
    c) Inter-instrument agreement
    d) Number of detectors
    e) Measurement periodicity - 10nm or 20 nm
    f) Aperture size
    g) UV component
    h) Fluorescence
    i) Instrument range- 380 to730 nm
    j) Material backing

Change in single parameters gives different numbers for the same color patch.

3) Variables related to human beings. (Wyszecki and Stiles 2000) Human beings themselves represent an import variable. Along with physical conditions, psychological conditions also impact perception of color. Chromatic adaption and brightness adaption also affect perceptions of color.

Considering all the above variables, visual-instrumental agreement is necessary to decide the location of color in color space and tone for color matching. When colors are close to a quadrant's boundary, one color dimension has a very small tone & it should be noticeable to the eyes.

Literature Review

Field size and observer. In the graphic arts industry, CIE1931 2° observer is used along with D_{50} illuminant (Field 2004, p6). Selection of field size (2° or 10°) is depends on size of sample and distance of viewing (Ohta and Robinson, 2005). Apart from that, two main reasons for selecting 2° observer are given by Ohta and Robertson (2005) on page 71 as

1. The region in retina having the highest visual activity, the fovea, has the viewing angle of about 20°.

2. Because central portion of retina is covered with yellow pigment called the macular pigment color matching functions for this central portion differ from that of peripheral portion in fields larger than 4°.

The CIE 1964 standard colorimetric system can be used where viewing angle is 4° or more (Ohta and Robinson, 2005, p72). In the printing industry, the Pantone™ PMS book is widely used as a shade library. The size of a PMS color patch, and if we consider the average distance of viewing as 60 cm, then the sample size is fit for the 2° observer field. So, theoretically for average working conditions in the graphic art industry, the 2° field size is suitable. But if the sample size is larger, e.g. folding carton with large spot color area, then the 10° standard colorimetric systems can be used. But condition can come where this field size may not show visual-numerical agreement. This condition may occur if the color is close to boundary of a quadrant in color space and this is tested in this experiment.

For those colors as in CIELAB space, it not possible to allocate individual tolerances, so color is plotted in other color spaces such as LABNHU, LLAB, RLAB and ZLAB.

Color Spaces (Field, 2004)

The three dimensional space constructed for using a geometrical expression of color is called a color space (Ohta and Robinson, 2005, p 60). There are many color spaces available for colorimetric calculations. Color spaces are of two types: 1) Non-uniform color spaces 2) Uniform color spaces. But no perfectly uniform color space is available. Color spaces based on opponent theory are considered here because they are claimed to be more uniform. As per opponent theory red & green are opposite hues also blue & yellow are opposite colors (Field, 2004) Following are the color spaces available based on opponent color theory.

- AN Lab (Wyszecki and Stiles, 2000)
- Scofield 1943 Lab (Ohta and Robinson, 2005)
- Glasser, McKinney, Reilley, & Schnell 1958 - Lab (Wyszecki and Stiles, 2000)
- Hunter Lab 1966 (HunterLab, 2008)
- MLab (Sharma, 2003)
- CIE Lab 1976 (Ohta and Robinson, 2005)
- K. Richter – LABNHU 1977 (Ohta and Robinson, 2005, p 60)
- LLAB (Field 2004, p6)
- RLab (Field 2004, p6)
- ZLab (Field 2004, p6)

These are modified color spaces and can be used for calculating color differences Metamerism Indices (MI). But, the CIELAB1976 model is well accepted and it is simple. CIELAB1976 color space does not account for surroundings and background, so further developed color spaces are claimed to be better than CIELAB.(Fairchild, *2005)*

The Formula used for CIELAB1976 color space is as follows.

CIELAB 1976 formula (Field, 2004, Wyszecki and Stiles, 2000)

$$L = 116\, f(Y/Y_n) - 16 \qquad \text{1a}$$
$$a = 500[f(X/X_n) - f(Y/Y_n)] \qquad \text{1b}$$
$$b = 200[f(Y/Y_n) - f(Z/Z_n)] \qquad \text{1c}$$

Where:

$f(r) = r^{1/3}$ for $r > .008856$

$f(r) = 7.787r + 16/116$ for $r \leq .008856$

To calculate CIE XYZ values following equations will be used.

$$X = K\int_{380}^{730}(S(\lambda)R(\lambda)\overline{X}(\lambda)) \qquad 2a$$

$$Y = K\int_{380}^{730}(S(\lambda)R(\lambda)\overline{Y}(\lambda)) \qquad 2b$$

$$Z = K\int_{380}^{730}(S(\lambda)R(\lambda)\overline{XZ}(\lambda)) \qquad 2c$$

LABHNU

This space is claimed to be an improved color space relative to 1976 CIELAB color space. . Wyszecki and Stiles, 2000)

$L = 116\ (Y/100)^{1/3} – 16$ 3a
$A^*=500\ (A'-A'_n)Y^{1/3}$ 3b
$B^*= 500\ (B'-B'_n)Y^{1/3}$ 3c

Where
$A'= \frac{1}{4}\ (x/y + 1/6)^{1/3}$
$B'= {}^{1}/_{12}\ (z/y + 1/6)^{\ 1/3}$

LLAB color space

It was derived by M. Ronnier Luo, Mei-Chun Lo and Wen-Guey Kuo (1996)

It is combination of BFD transform and modified CIELAB color space. It has a surround indicator, lightness indication and colorfulness indication factors.

$L = 116\ f(Y)^z – 16$ 4a
$A= 500\ [f(X) - f(Y)]$ 4b
$B= 500\ [f(Y) - f(Z)]$ 4c

RLAB

It was derived by Mark D Fairchild (2005). It has its own chromatic adaption model. It color space is modified. It accounts a surroundings illumination level factor as σ.

$L^R= 100\ (Y_{ref})^{\ \sigma}$ 5a
$a^R= 430\ [(X_{ref})^{\ \sigma} -(Y_{ref})^{\ \sigma}]$ 5b
$b^R= 170\ [(Y_{ref})^{\ \sigma} -(Z_{ref})^{\ \sigma}]$ 5c

Where σ is surround and X_{ref} $Y_{ref,}$ Z_{ref} are calculated by using its CAT model.

ZLAB

This model was also derived by Mark D. Fairchild (2005)) and it was considered for CIECAM97. It is very simple in construction. Before entering into modified color space, it uses the Bradford (K.M. Lam 1985) matrix with its own transformation equations to calculate new tristimulous values. This space also accounts for surrounding conditions.

$$L^z = 100\ (Yc/100)^{1.45/2\sigma} \quad (6a)$$
$$A^z = 500\ [(Xc/100)^{1/2\sigma} - (Yc/100)^{1/2\sigma}] \quad (6b)$$
$$B^z = 200\ [(Yc/100)^{1/2\sigma} - (Zc/100)^{1/2\sigma}] \quad (6c)$$

Experimental

In this experiment, 36 Pantone™ colors were selected from the Pantone™ PMS coated gloss library. All shades changes its quadrant if field size/observer is changed. All shades are closer (distance less than 3) to the boundary of color quadrant. Then psychophysical tests were conducted and analysis was carried out. Figure1 shows location of all colors in CIEL*a*b* color space.

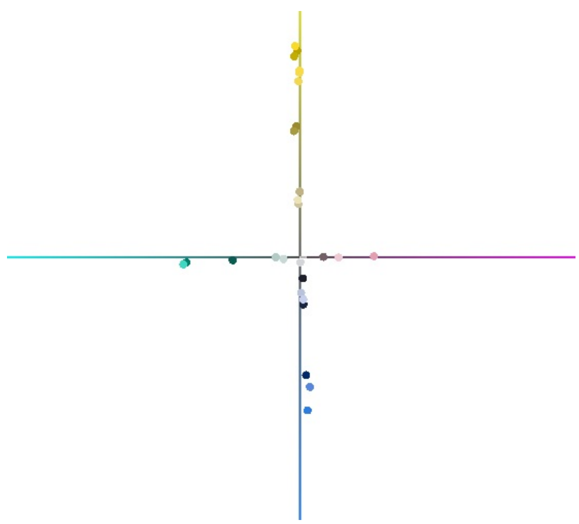

Figure 1. Location of colors in CIELab color space.

Figure 1 shows that all shades are very close to a boundary and very difficult and confusing for deciding its location in color space. All calculations were carried out by using reflectance data from an i1 instrument.

Following are some experimental parameters.

1) Instrument – i1
2) Illuminant/observer – D50/2 and D50/10
3) Viewing booth – X-rite Judge II
4) Sample size 2 x 2 cm
5) Distance – 59.19 cm
6) CRI- 95
7) Inter instrument agreement – 0.1ΔEcmc
8) Software – Xrite ProfileMaker 5
9) Apertures – 3.4mm
10) Measurement Backing – White

Table 1. Pantone™ PMS colors selected for this study.

PANTONE ™	Lab 2 °	Lab 10 °
107	89.14, –1.86, 81.65	87.58, 4.09, 81.66
114	88.63, –0.2, 71.46	87.25, 4.79, 71.45
294	17.42, 2.34, –45.80	20.09, –8.83, –41.11
333	78.59, –45.01, –2.85	79.11, –43.20, 0.05
437	43.9, 9.09, 0.11	43.59, 10.56, –0.6
494	73.73, 28.71, 0.33	73.44, 27.49, –0.57,
532	14, 1.11, –8.23	14.37, –0.79, –7.34
533	16.88, 1.47, –18.38	17.79, –2.85, –16.41
561	35.89, –26.01, –1.19	36.07, –24.05, 0.15
569	46.53, –43.96, –2.08	46.98, –41.72, 0.51
612	72.05, –2.27, 77.80	70.64, 3.19, 78.25
618	64.81, –2.26, 48.82	63,82, 1.46, 48.66
619	59.12, –1.39, 50.65	58.13, 2.30, 50.55
621	86.26, –6.29, –0.79	86.33, –6.28, 0.10
622	80.91, –9.28, –0.13	80.98, –8.94, 0.81
2706	84.11, 1.33, –16.38	84.65, –1.39, –15.03
2718	56.93, 3.93, –50.31	58.95, –4.57, –47.00
2727	52.97, 2.99, –59.40	55.68, –8.42, –54.82
3975	67.87, –1.06, 79.90	66.41, 4.64, 80.19
4525	74.33, –0.04, 25.34	73.77, 1.64, 25.34
4535	79.71, –0.52, 20.49	79.25, 0.83, 20.60
7404	87.71, –0.56, 68.00	86.37, 4.17, 67.78
7422	85.76, 14.94, –0.2	85.74, 13.21, 0.19

7450	79.40, 0.46, –13.79	79.88, –1.99, –12.50
7499	91.03, –0.81, 22.08	90.55, 0.46, 22.35
CG1	86.46, 0.21, –2.00	86.54, –0.57, –1.25
CG2	83.96, 0.21, –2.36	84.05, –0.61, –1.60
CG3	79.58, 0.15, –2.42	79.69, –0.71, –1.69
CG4	75.18, 0.19, –2.91	75.03, –0.73, –2.19
CG5	71.65, 0.15, –3.00	71.78, –0.79, –2.29
CG6	68.52, 0.27, –3.45	68.66, –0.71, –2.78
CG7	62.44, 0.28, –3.75	62.59, –0.76, –3.10
CG8	56.05, 0.14, –4.03	56.22, –0.95, –3.39
CG9	48.86, 0.15, –4.20	49.04, –1.0, –3.55
CG10	41.72,0.00, –4.31	41.91, –1.18, –3.68

In the experiment, 11 yellow, 6 green, 6 blue, 3 red and 10 gray shades were selected. The observer was asked for judging its tone and its quadrant. Psychophysical tests were conducted with 10 clear vision observers for two degree observer settings. All observers were allowed to set their eyes to adapt to conditions and have good knowledge of judging color.

Table 2. Color coordinates in different color space of same color.

	Pantone™ No	CIELab 2°	LABNHU	Llab	RLab	Zlab
1	107	89.14, –1.86, 81.65	89.13, –1.91, 56.95	81.93, –5.95, 72.74	87.93, –10.15, 81	85.96, –4.56, 83.38
2	113	88.77, –0.11, 72.16	88.77, –0.12, 51.60	81.40, –4.34, 68.69	87.53, –7.67, 72.26	85.54, –2.63, 73.53
3	114	88.63, –0.2, 71.46	88.63, –0.21, 51.18	81.20, –4.43, 68.51	87.38, –7.72, 71.58	85.37, –2.70, 72.80
4	294	17.42, 2.34, –45.80	17.41, 2.46, –39.29	(–0.45, 7.08, –35.69)	19.76, 11.10, –38.31	15.70, 5.80, –44.44
5	333	78.59, –45.01, –2.85	78.59, –45.53, –2.28	67.35, –60.04, –2.93	76.69, –46.25, –2.87	73.54, –43.84, –2.9
6	437	43.9, 9.09, 0.11	43.90, 9.38, 0.09	23.06, 17.77, –0.05	42.21, 8.38, 0.08	37.10, 8.77, 0.11
7	494	73.73, 28.71, 0.33	73.72, 29.89, 0.27	59.77, 47.49, –0.22	71.49, 30.21, 0.27	68.08, 28.24, 0.35
8	532	14, 1.11, –8.23	14.00, 1.12, –6.74	(–3.38, 2.22, –9.47)	17.14, 1.82, –6.18	13.16, 1.45, –7.97
9	533	16.88, 1.47, –18.38	16.89, 1.37, –15.32	(–1.23, 3.56, –19.18)	19.33, 3.68, –14.5	15.16, 2.34, –17.85
10	561	35.89, –26.01, –1.19	35.88, –26.32, –0.94	15.05, –35.61, –1.1	35.04, –22.34, –0.97	29.85, –24.86, –1.17
11	569	46.53, –43.96, –2.08	46.52, –43.97, –1.68	26.27, –56.39, –1.93	44.70, –39.51, –1.84	39.48, –42.07, –2.1
12	612	72.05, –2.27, 77.80	72.04, –2.33, 52.37	57.12, –7.18, 85.06	69.77, –9.2, 72.1	65.85, –4.66, 79.17
13	618	64.81, –2.26, 48.82	64.81, –2.32, 35.65	47.61, –7.74, 66.17	62.39, –7.29, 45.61	57.94, –3.99, 49.23
14	619	59.12, –1.39, 50.65	59.12, –1.44, 36.37	40.38, –6.05, 66.77	56.72, –6.24, 45.93	51.92, –3.14,51.03
15	621	86.26, –6.29, –0.79	86.25, –6.46, –0.64	78.34, –12.65, –1.39	84.84, –6.67, –0.83	82.74, –6.16, –0.81
16	622	80.91, –9.28, –0.13	80.91, –9.53, –0.1	70.39, –19.14, –0.01	79.1, –9.84, –0.12	76.32, –9.12, –0.14
17	2706	84.11, 1.33, –16.38	84.11, 1.38, –13.32	75.29, 5.05, –28.13	82.53, 4.21, –17.59	80.27, 2.18, –16.56
18	2718	56.93, 3.93, –50.31	56.93, 4.04, –42.20	38.85, 12.69, –64.57	54.63, 13.66, –51.07	50.17, 7, –50.24

19	2727	52.97, 2.99, –59.40	52.97, –69.37, –50.8	34.28, 12.24, –69.37	50.80, 15.23, –59.99	46.23, 6.94, –59.19
20	3975	67.87, –1.06, 79.90	67.86, -1.07, 52.43	51.47, –5.7, 87.18	65.47, –7.66, 72.30	61.21, –3.4, 81.42
21	4525	74.33, –0.04, 25.34	74.33, –0.04, 19.65	60.60, –3.37, 42.74	72.15, –3.29, 25.34	68.58, –1.13, 25.58
22	4535	79.71, –0.52, 20.49	79.71, –0.52, 16.03	68.31, –3.74, 35.35	77.80, –3.33, 20.98	74.83, –1.42, 20.71
23	7404	87.71, –0.56, 68.00	87.7, –0.57, 49.06	97.81, -4.83, 67.85	86.37, -7.85, 68.16	84.25, –2.96, 69.24
24	7422	85.76, 14.94, –0.2	85.75, 15.47, –0.15	77.37, 26.45, –7.73	84.26, 16.28, –0.24	82.19, 14.74, –0.18
25	7450	79.40, 0.46, –3.79	79.39, 0.49, –11.20	68.3, 3.41, –26.09	77.49, 2.78, –14.57	74.64, 1.19, –13.92
26	7499	91.03, –0.81, 22.08	91.02, –0.82, 17.29	85.33, –3.68, 31.27	90.01, –4, 23.41	88.49, –1.79, 22.41
27	CG1	86.46, 0.21, –2.00	86.45, 0.2, –1.6	78.61, 0.82, –4.33	85.05, 0.52, –2.13	83.01, 0.28, –2.02
28	CG2	83.96, 0.21, –2.36	83.95, 0.21, –1.89	74.84, 0.95, –5.26	82.35, 0.59, –2.50	79.99, 0.31, –2.38
29	CG3	79.58, 0.15, -2.42	79.58, 0.13, -1.93	68.41, 0.81, –5.64	77.68, 0.51, –2.52	74.80, 0.23, –2.43
30	CG4	75.18, 0.19, –2.91	75.17, 0.18, –2.33	62.11, 1.06, –6.96	73.04, 0.63, –3.00	69.68, 0.31, –2.93
31	CG5	71.65, 0.15, –3.00	72.64, 0.14, –1.97	57.20, 0.90, -6.02	69.38, 0.52, -2.50	65.67, 0.25, –2.47
32	CG6	68.52, 0.27, –3.45	68.51, 0.29, –2.77	52.96, 1.45, –8.34	66.16, 0.8, –3.47	62.19, 0.44, –3.46
33	CG7	62.44, 0.28, –3.75	62.44, 0.29, –3.02	45.0, 1.53, –9.0	60.03, 0.84, –3.7	55.60, 0.46, –3.76
34	CG8	56.05, 0.14, –4.03	56.04, 0.16, –3.24	37.05, 1.23, –9.38	53.73, 0.73, –3.88	48.95, 0.34, –4.03
35	CG9	48.86, 0.15, –4.20	48.85, 0.17, –3.38	28.64, 1.23, –9.26	46.84, 0.75, –3.92	41.80, 0.37, –4.18
36	CG10	41.72,0.00, –4.31	41.72, 0.03, –3.48	20.86, 0.88, –8.80	40.23, 0.62, –3.88	35.09, 0.24, –4.27

Results and Discussion

All psychophysical tests were conducted only for 2° observers. With reference to results shown in Table 1, except for shade number 2727, no shade has similar perception for all observers. A random distribution of perceptual agreement shows some observers agree with the instrument and some do not. To analyze data shades, they were categorized into 5 groups. In group I either a* or b* values for 2° observer of shades are closer to an axis and a* & b* value in 10° are farther away from that axis. So, shades 113, 114, 3975 4524, 7404, and 7450 are considered. Analysis for those shades shows that, although a* or b* values in 2° readings are close to an axis, most observer readings followed the 2° data. So an observer can perceive very light tone of opponent colors. In group 2 shades either a* or b* value in 10° observer of shades is closer to an axis and a* & b* value in 2° is farther away from an axis. So shades 333, 532, 561, 569, and 621 fall in this group. Analysis shows that, although tests were conducted for 2°, most observers do not agree with the instrument data. In this group, although a* or b* readings of colors in 2° are farther away from an axis, observers do not agree with the instrument. In group III, shades with either a* or b* values in 2° and 10° close to axis were selected, so shades 437, 494, 7422, 7499, 622 fall in this category. In this case most observers agree with 10° readings. In group IV, a* or b* values of shades are farther away from the axis for both 2° and 10° readings. In this group, shades 107, 294, 533, 612, 618, 619, 2706, 2718, 2727, 4535 are considered. Results show that observers agree with 2° and for a few shades observers agree with 10° data. In group V, all grays were considered and it was found that observer may get confused with gray as grays have much less noticeable color cast. Over all, although tests were conducted for 2° observers, many observers do not agreed with 2° instrument data. So agreement between two observers for many shades was not found.

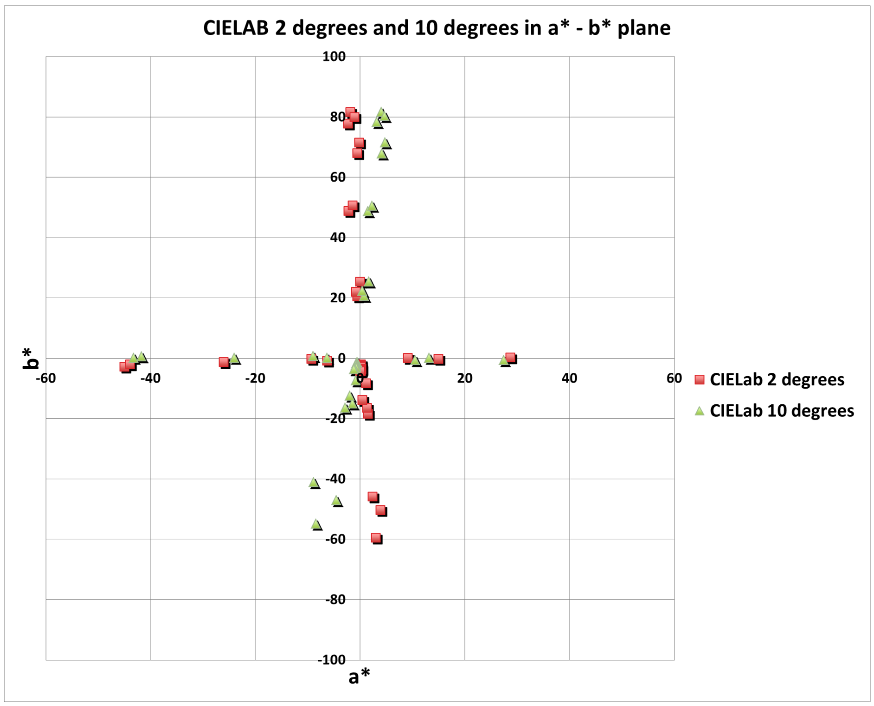

Figure 2. Same color changes quadrant when observer field angle is changed.

Figure 2 shows that when field is switched from 2º to 10º then same shade changes it quadrant and results in change in perception. As yellow shade in 2º is greenish become reddish when observer is selected as 10º. Blue which shows reddish blue tint becomes greenish blue by just switching to 10º field observer. Observer confuses in these types of shades.

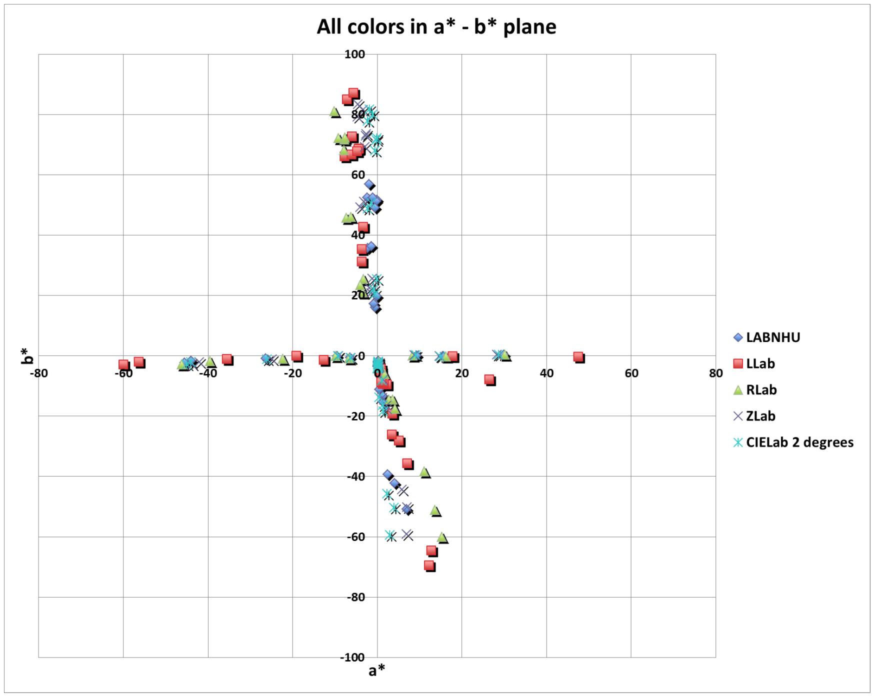

Figure 3. Color location in a a-b* plane for different color space.*

Figure 3 shows that all color spaces behave differently except for LABNHU compared with CIELab color spaces. The RLAB model plots shades away from the axes compared with other models.

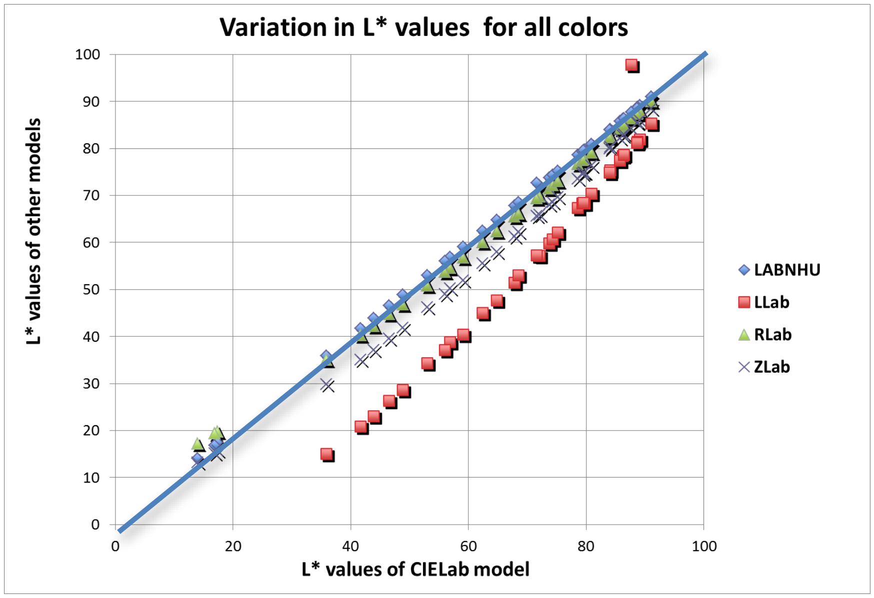

Figure 4. Lightness value comparisons.

When we consider positioning the same color into different color spaces, our results show that CIELAB, LLAB and ZLab behave similarly. In the LLAB model, the lightness value is less when compared with other color spaces, because of its z function. But RLab doesn't behave similarly. In the RLab model, the same color is located quite away from its axis. This phenomenon can be used for assigning individual tolerances to color during reproduction.

Conclusion

If colors are close to quadrant's boundary in CIELab color space, i.e. if either a* or b* values are very small and color changes its quadrant after changing standard colorimetric observer, which results in change in perception of tone of opponent color, then visual-instrumental agreement or visual agreement between two observers may not be found at standard viewing and measuring conditions. LLab space shows different results in lightness scale and RLAB space shows location of color away from axes. This phenomenon can be used for assigning tolerance for color reproduction for colors that fall close to boundaries in CIELAB color space.

Note; Pantone™® is registered tread mark of X-rite Inc.

CIELab values given in table 2 are subject to change with reference to measuring parameters and calculation accuracy. Same values may not be found in all Pantone™ books.

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References

Berns, Roy.
2000, *Billmeyer and Saltzman's Principles of Color Technology*, Wiley, third edition.

Fairchild**,** M.D.
2005, *Color Appearance Models,* Second Edition, Wiley Publication.

Field, Gary G.
2004, *Color & Its Reproduction*, GATF press, third edition

HunterLab.
2008, “Hunter L, a, b Color Scale,” *Insight on Color, Vol. 8, No. 9*, downloaded from http://www.hunterlab.com/appnotes/an08_96a.pdf.

M. Ronnier Luo, Mei-Chun Lo and Wen-Guey Kuo.
1996, *Color Research & Application* Volume 21, Issue 6, pages 412–429).

Sharma, Gaurav.
2003, *Digital color imaging handbook,* CRC Press.

Wu Yu Ju, Pekarovicova A. and Fleming, P.D.
2008. “The Effect of Paper Properties on the Color Reproduction for Digital Proofing have of Gravure Publication Printing,” *TAGA Journal,* 4(2), 72–83.

Günter Wyszecki and Walter Stanley Stiles.
2000, *Color Science: Concepts and Methods, Quantitative data, and Formulae*, Wiley-Interscience; 2nd edition (August 8)