Correlation between colour specification (CIE L*a*b*) and colour perception (colour strength) of prints

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Abstract

In the process of the reproduction control, colour of prints is measured in terms of CIEL*a*b*. However, CIEL*a*b* do not correlate well with the colour specified by the percentages of dot area, which correspond to how the prints are reproduced. Hence, there should be the specification of colour perception to connect between them. This study proposed the term "colour strength" for communication regarding the colour appearance of prints and aimed to investigate the correlation between CIEL*a*b* and colour strength. The grey patches varying the dot area percentages of black ink were used as a reference scale of colour strength, where the colour strength values for each patch were obtained by the magnitude estimation method. The series of colour samples of primary and secondary colours were then matched in colour strength to the reference scale. It was found that when dot area percentages of prints increased, the lightness decreased, and the chroma increased, revealing that the colour strength is perceived as the intensity of colour (chroma) in inverse proportion to lightness. Moreover, the change of colour strength was not the same for different hues.

Keywords: dot area percentage, colour strength, offset printing, colorimetry

Introduction

In printing, images are generated by overprinting halftone dots of cyan, magenta, yellow and black in appropriate proportions. (Kipphan 2001: 1207) Therefore, the percentage of dot area of primary colours (CMYK) is used for communication. However, the colour appearance of images printed with the same dot area percentages of CMYK could differ, owing to various printing parameters such as printing materials and printing processes. ISO 12647-2 (ISO 2004) thus defines the CIEL*a*b* values for the quality control process. With CIEL*a*b* values, the differences between printed reproductions can be quantified. Colour reproductions with the same CIEL*a*b* values will have the same colour appearance under the specified conditions. However, the colour perception terms in CIEL*a*b* do not conform to the colour specified by the percentages of dot area. Hence, there should be the specification of colour perception to connect between CIEL*a*b* and the percentage of dot area. The term *colour strength* is adopted to represent the perceptual attribute of colour that relates to the colour-mixing system in printing. This is because the colour strength is related to the intensity of ink, which is defined by the proportion of area covered by ink on the substrate (Nantakarat 2013). The relationships between the dot area percentages and colour strength were established in Nantakarat et al's study (2013). This study aimed to establish the correlation between CIEL*a*b* and colour strength. Before establishing this correlation, the relationship between colour strength and lightness was investigated. This was done to understand the correlation between the perception of colour strength and the measurement value of lightness. This is because in the previous study, lightness was one of the colour attributes that affected hue and chroma (Nayatani and Sakai 2010).

Relationship between colour strength and lightness

Printed colour samples were produced based on the four-colour process with the conventional offset printing and an AM screen, according to the reproduction process control set forth by ISO 12647-2 (ISO 2004). The grey patches varying the dot area percentages of black ink from 0 to 100 were used as a reference scale of colour strength, where the colour strength values for each patch were obtained by the magnitude estimation method. The resultant colour strength scale had the grey patches from 0% to 100% dot area of black ink, and the results are shown in Table 1.

To find the relationship between lightness (L*) and colour strength, the colour patches were measured in terms of XYZ values and the lightness (L*) values were calculated using XYZ of the 0% patch (no print, thus, the paper white) as the reference white. In Table 1, the inverse L* values were obtained from 100-L*.

Table 1. The values of colour strength and lightness (L*) of grey patches (%dot area of black).

% dot area	**0**	**6**	**10**	**17**	**21**	**27**	**32**	**39**
Colour strength value	0	4	8	12	16	21	25	29
Lightness	100	98	96	93	90	87	84	83
Inverse L*	0	2	4	7	10	13	17	18
% dot area	**43**	**50**	**56**	**62**	**65**	**69**	**74**	**81**
Colour strength value	35	39	44	49	54	59	64	70
Lightness	78	75	73	68	66	62	58	53
Inverse L*	22	26	27	32	34	38	42	47
% dot area	**84**	**90**	**93**	**98**	**100**			
Colour strength value	75	81	87	94	100			
Lightness	47	43	37	31	21			
Inverse L*	53	57	63	69	79			

The colour strength values of black ink were plotted against the lightness values for finding the relationship between colour strength and lightness, as shown in Figure 1.

Figure 1(a) shows the negative relation between colour strength and lightness: colour strength increased with decreasing lightness. This finding conformed to the study on "predicting the colour of trichromatic prints" by Kulube and Hawkyard (1995). They found the method to predict the colour resulting from the overlap of trichromatic dots of cyan, magenta and yellow on printing surfaces. Their study showed the chromaticities x, y and luminance, Y of the dye that was printed on the printing surface. When the percentage of concentrations (intensity) of the dye increased, Y (luminance for the surface colour represented by the Y tristimulus value) decreased.

The negative relation of the lightness value was problematic for deriving the colour strength model of good predictions. Consequently, the lightness value was inverted by subtracting 100 with the lightness value (100-L*). The inverse lightness values were obtained, and the positive relation to the colour strength values could be established, as shown in Figure 1(b). The relation was used to derive the colour strength model in the following step.

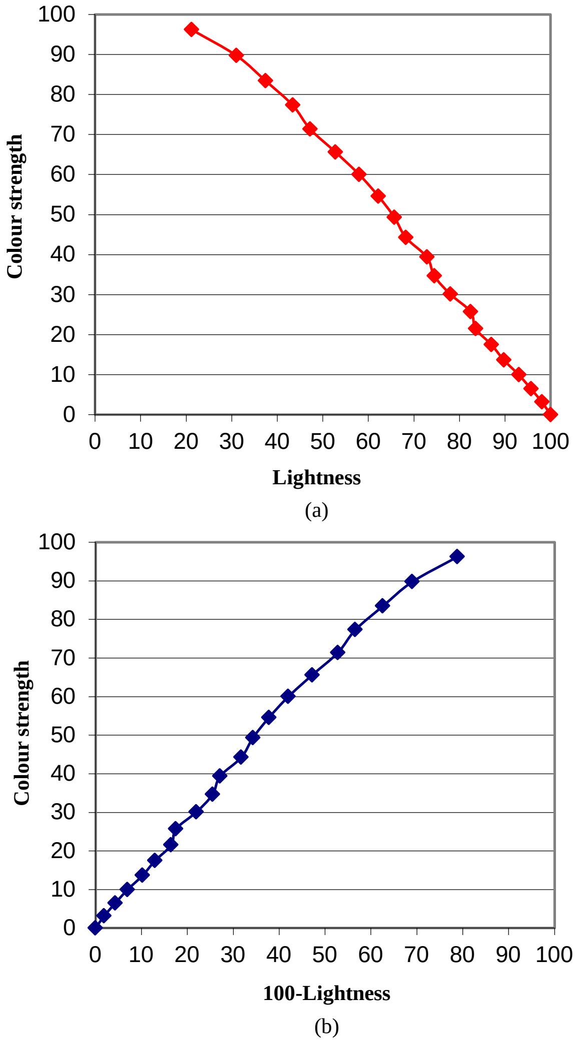

Figure 1. (a) The relationships between colour strength and lightness of black ink. (b) The relationships between colour strength and inverse lightness of black ink.

Deriving a colour strength model for primary and secondary colours

This study derived a colour strength model based on primary and secondary colours. This model converts CIEL*a*b* to colour strength values for the particular prints. To obtain the colour strength values, the series of colour samples with different dot area percentages from 0-100 with 5% intervals of primary colours (C, M, and Y), and secondary colours (M+Y = red, C+Y = green, and C+M = blue) were matched in colour strength to the reference scale. The results are shown in Table 2.

In Table 2, S_C, S_M, S_Y, S_R, S_G, S_B, and S_K represent the colour strength values of cyan, magenta, yellow, red, green, blue, and black, respectively. The values were obtained from the curve fitting method as to convert %dot area of the corresponding black ink to the colour strength of the reference scale.

Table 2. The results of the colour strength values from the visual experiments.

Percent dot area of primary colours	0	5	10	15	20	25	30	35	40	45	50
S_K	0	3	6	10	14	17	22	26	30	35	39
S_C	0	3	7	10	13	17	21	24	28	32	36
S_M	0	4	7	11	14	18	22	26	30	34	38
S_Y	0	4	7	11	15	19	23	27	31	35	39
S_R	0	4	8	12	16	20	24	29	33	37	42
S_G	0	4	7	11	15	19	23	27	31	35	39
S_B	0	4	7	11	15	19	23	27	32	36	40
Percent dot area of primary colours	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	
S_K	44	49	55	60	66	71	77	83	90	96	
S_C	40	44	48	52	56	61	65	70	74	79	
S_M	43	47	51	56	60	65	70	75	79	84	
S_Y	43	47	52	56	61	65	70	74	79	84	
S_R	46	51	55	60	65	70	74	79	84	89	
S_G	44	48	52	57	61	65	70	74	79	84	
S_B	45	49	54	59	64	68	73	78	84	89	

The colours samples were measured in terms of XYZ values, and the CIEL*a*b* values were calculated, using the paper white as the reference white. Thus, at 0% dot area of ink (no print), the L*=100, and a*=b*=0. Figure 2 illustrates the plots of the CIEL*a*b* values of all colour patches. It can be seen that each individual primary (C, M, Y, and K) and secondary (R, G, and B) forms a line, which indicates the change in lightness and chroma with %dot area from 0 to 100. All primary and secondary colours have the same starting point at 0% dot area of prints. The lightness gradually decreases when %dot area of primaries increases. Since colour strength increases with %dot area of primaries, these plots show the relationships between CIEL*a*b* and colour strength.

From Figure2, the lengths of primary colour scales were different, suggesting that the colour strength depended on hue. The black scale had the longest line, showing that the range of colour strength of black covered the ranges of all other colours. Different colour scales pointed to different directions. It was found that when %dot area of prints increased, the lightness decreased, while the chroma increased. This relationship thus described the perception of colour strength. The colour strength is perceived as the intensity of colour (chroma) in inverse proportion to lightness. The results also showed that the change of colour strength was not the same for different hues. This result was also found in the Nayatani's study (1995), where yellow hue had the chroma scale larger than the other hues for constant Munsell chroma.

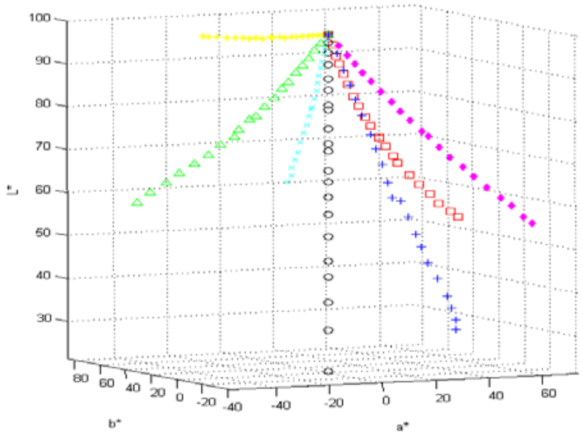

*Figure 2. 3D plot of CIEL*a*b* of the primary and secondary colour scales.*

The positions of colours that have the same colour strength on the primary and secondary colour scales were different regarding the lightness and chroma. This means that all three attributes (lightness, chroma and hue) had an effect on colour strength. When connecting the positions of matching colour strength on the different scales together, the connection roughly formed an ellipsoid. Hence, the relationship between CIEL*a*b* and colour strength should be in a form of ellipsoid function, as given below.

$$S_i = \sqrt{K_{L^*}(100 - L^*_i)^2 + K_{a^*}(a^*_i)^2 + K_{b^*}(b^*_i)^2} \qquad (1)$$

Where S_i is the predictor for colour strength value of the colour i, and K_{L^*}, K_{a^*} and K_{b^*} are the model coefficients of lightness, a* and b*, respectively. $100 - L^*_i$ is the inverse lightness value, a^*_i is the value indicating a position between red and green, and b^*_i is the value indicating a position between yellow and blue.

Using the data in Table 2 and CIEL*a*b* values of all colour samples to substitute the variables in Equation 1, the series of the unknown model coefficients were formed. The model coefficients K_{L^*}, K_{a^*} and K_{b^*} can be estimated by the least square method (LMS), as given in Equation 2.

$$L = \sum_{i=1}^{n}(S_i - (K_{L^*}(100 - L^*_i)^2 + K_{a^*}(a^*_i)^2 + K_{b^*}(b^*_i)^2)^{\frac{1}{2}})^2 \qquad (2)$$

Where L is the response received from the estimates or the sum of square error (epsilon: ε) or sum of the differences between the colour strength values (S_i) and the values estimated from the $L^*a^*b^*$ values, together with the model coefficients.

Using an iterative method for optimising the model coefficients, the equation was solved, and the model coefficients are given in Table 3.

Table 3. The model coefficients in Equation 1.

Coefficient of the relation of CIEL*a*b*	K_{L^*}	K_{a^*}	K_{b^*}
For black colour and primary and secondary colours	1.28	0.91	1.02

By applying the model coefficients in Table 3 to Equation 1, the colour strength model was established and is given in Equation 3.

$$S_i = \sqrt{1.28(100 - L^*_i)^2 + 0.91(a^*_i)^2 + 1.02(b^*_i)^2} \qquad (3)$$

To investigate the accuracy of the model, the colour strength values were calculated by Equation 3, and the results are given in Table 4. These predicted values were then compared with the colour strength values obtained from the visual experiments (Table 2).

Table 4. The predicted colour strength values by Equation 3.

Percent dot area of primary colours	0	5	10	15	20	25	30	35	40	45	50
S_K	0	2	5	8	12	15	19	20	25	29	31
S_C	0	3	6	8	12	14	18	21	24	27	31
S_M	0	5	9	12	15	19	24	28	32	36	41
S_Y	0	6	6	9	13	17	20	24	28	32	36
S_R	0	5	9	13	18	22	28	32	38	42	48
S_G	0	3	6	9	12	15	18	21	25	28	32
S_B	0	6	11	16	20	25	31	36	40	46	50
Percent dot area of primary colours	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	
S_K	36	39	43	48	53	60	64	71	78	89	
S_C	32	35	39	43	47	51	54	58	63	65	
S_M	43	48	53	58	63	68	74	78	84	87	
S_Y	37	43	47	52	57	62	68	75	82	87	
S_R	49	54	60	64	70	75	82	86	91	94	
S_G	34	39	41	46	51	56	61	66	72	77	
S_B	51	56	62	66	70	75	81	85	88	91	

Table 5. The accuracy of the colour strength model's predictions.

The primary and secondary colours	K	C	M	Y
RMS	11.88	7.54	2.10	3.08
%error	25.65	17.80	4.84	7.55
The primary and secondary colours	**R**	**G**	**B**	
RMS	4.46	7.19	6.61	
%error	11.45	17.23	25.84	

The root mean square (RMS) and the percentage of error were used to indicate the accuracy of the predictions. The results are shown in Table 5. It was found that the prediction for blue was the poorest, with an average error of 25.84%. However, the agreement of the visual data between observers was 12 to 43% error (the range of minimum to maximum), which is within the range of the prediction errors by the colour strength model. This means that the performance of the model was acceptable.

Conclusion

The relationships between colour strength and CIEL*a*b* were investigated. The ranges of colour strength were different for different colours. The chroma increased when the lightness decreased and the colour strength increased. But the change was not constant for different hues. This means that all three attributes (lightness, chroma and hue) had an effect on colour strength.

The colour strength model was devised from the measured values based on CIEL*a*b* and the colour strength values obtained from the visual experiments. The model coefficients relating to L^*, a^* and b^* values were optimized by the least square method. The percentages of error of the model's predictions were 25.65, 17.80, 4.84, 7.55, 11.45, 17.23 and 25.84, for black, cyan, magenta, yellow, red, green and blue, respectively.

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