Mathematical Regression Technique to Correlate Visual and Instrumental Colour Analysis for Leather Industry

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Abstract

Colour is the decisive factor in determining a product's quality and appeal. In leather industry, the tanner produces a production lot with large number of leather samples to match a colour provided by a client. However, even when the leathers are dyed/finished with the same colorants under well monitored conditions may show some colour variations. This variation should be characterized and the leathers separated into groups within which the colour difference is considered acceptable. Visual evaluations of shade difference are not consistent when establishing the fine line between acceptable and unacceptable dyeing. A sample that is approved by one person may be rejected by another simply because they perceive colour differently. These differences can be due to age, fatigue, colour vision defects, or experience. Advancements in computer technology have made it possible to replace the subjective visual evaluation by instrumental objective colour evaluation to obtain a repeatable and reliable data that gives consistent pass/fail decisions. There are several colour space options available for implementing a pass/fail tolerance program. In this paper, a useful evaluation of CIELAB76, CMC (1:1), CMC (2:1), CIE94 and CIE2000 colour difference equations and its applicability to different leather substrates is reviewed. Percentage rejection was plotted against visual and instrumental colour formulae. Regression analysis was used to describe the relationship between visual and instrumental colour analysis. Instrumental methods for separating the coloured leather sample lot and determining the tolerance limit for acceptable shade groups was also carried out.

Introduction

Colour is an important property for fashion articles and leather articles are no exception. Colour forecasts for leather products vary depending upon the fashion demand and the colours for different leather products vary from one season to another. Leather manufacturers often need to produce production lots consisting of large number of leathers to match a colour provided by the customer. When leathers are dyed with the same colorants under well controlled process parameters it may lead to colour variation. The colour variation may be due to inconsistencies in raw material selection, pre and post tanning process, dye diffusion rate, etc., When skins are processed and finished with all the necessary sensory and functional properties needed for an end use, the finished leather may be rejected if the colour is not matched to the buyer's sample/swatch. Hence, the colour variation should be characterized

and the leathers need to be segregated into groups within which the colour difference is considered to be acceptable. It is highly challenging today for leather manufacturers and leather goods/ garment producers to shade sort leathers consistently. Visual assessment is the present way to match/sort colours in leather industry.

This visual assessment system is highly subjective (Steen 2002), and differs quite considerably from person to person, the instability over repeated progression results in disputes between the buyer and the seller of the leathers. This variability of visual judgements over the days and with the sensitive demands of the modern day's customers, has increased the need to shade sort materials consistently without any errors.

Reflectance Spectrophotometer interfaced with computer is largely used to quantify colour numerically. CIE colorimeteric mathematical model are used by these spectrophotometers to relate human perception of colour to instrumental responses. From this mathematical model colorimetric scales such as CIE L*a*b* and CIE LCH can be derived and used to communicate as well as quantify colour and its appearance. The colour values obtained from this system describe the magnitude of difference in colour between the standard and sample in a way which is understandable to the human observer. Thus when instruments are used to shade sort materials, they not only provide an objective numerical colour difference but are also more accurate, repeatable and can distinguish even small colour difference when compared to an human expert. When buyer and seller are at different locations they can measure samples at their respective locations and can correlate the reported colour values thus minimizing the inter-instrument variation which leads to a better objective sytem comparing visual assessment by two different human observers.

Tolerances are limits within which a product is considered acceptable. It is general practice to use colour scales or indices such as L*a*b* and LCH when tolerance are established using instrument. There are several colour space options such as CIELAB76, CMC (1:1), CMC (2:1), CIE94 and CIE2000 colour difference equations are available for implementing a pass/fail tolerance program. (Melgosa 2000, Kuehni 1999, McDonald 1990, Luo et al 2000) Determining instrumental tolerance limit is rather difficult process because the acceptance level changes from customer to customer and product to product. Establishing minimum wrong decisions which includes wrong rejection and wrong acceptance using instrumental assessment is required for the leather industry. When a sample is acceptance with higher colour difference value than the tolerance limit it is said to be wrong acceptance, whereas when the sample is rejected with low colour difference value than the tolerance limit it is said to be wrong rejection. However it is seen that the leather industry is less sensitive to completely modernize color matching decisions owing to reasons of congruence in the acceptable level of performance in color difference equations. Which means even with developments like the CMC, CIE94 and CIE 2000 color difference equations , the congruence levels between visual and instrumental color matching decision is low .

Considering the present state of color measurement, and color difference equations, the research reported here in was conducted to explore which CIELAB based color difference equation performs best in predicting visual observations of color matches. Statistical analysis

technique such as regression analysis is used to correlate visual and instrumental colour analysis and determining the tolerance limit for acceptable shade groups.

Experimental

Materials

Good quality full chrome undyed goat crust of size 4-5 sq.ft without any major surface defects were chosen for the study and were processed into suede garment. All the chemicals used for leather processing were of technical grade and the proprietary auxiliaries were from BASF India Ltd. Forty set of coloured suede garment leather were dyed using different synthetic dyes. Then the colour of the leather garment was both measured using a reflectance spectrophotometer and assessed visually by a panel of average human observers.

Visual Observation of Colour

Twenty observers which include both men and women who have experience in colour matching were taken for the study. Participants viewed each colour sample under average daylight conditions. Participants were asked to compare the leather standard against the sample and decide if both leather pieces can be used to stitch a garment. Participants replied zero (does not match) or one (match), pass ratios were calculated (Table1). Logit regression analysis (Berns 1996) were used to convert the binary data to DV using the following equation.

$$DV = 5 + \log_e[Si + 0.5] /[Ni - Si + 0.5] \quad ..... \quad (1)$$

Where Si = number of observers who found the match acceptable and Ni = number of observers.

Instrumental Colour Analysis

All the reflectance measurements were carried out using Premier Colorscan Spectrophotometer interfaced to a digital PC. Before measuring the samples, instrument was calibrated against white MgO tile with illuminant D-65, 10-degree standard observer including UV component and excluding specular component with D^o8 geometry. The reflectance of each sample was measured in the visible range 400nm – 700nm, at 10nm intervals. For reflectance measurement the 8mm aperture was used and four readings were taken. The sample was moved between each reading and the final reflectance data were averaged over these four readings [8]. CIELab color values were calculated from the measured reflectance values for all leather samples and overall colour difference ΔE by employing the below mentioned formulae.

***CIE1976* (ΔE_{ab})**

CIE1976 ΔE_{ab} calculates the Euclidian distance between two points in a 3D space. The mathematical equation is quite simple but the L*a*b* color space is not visually uniform. (ISO / DIS 13655, 1996)

$$\Delta E_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

***CIE1994* (ΔE_{94})**

An attempt has been made by CIE in 1994 to correct for the visually non-uniformity of L*a*b* by weighting lightness, chroma, and hue in different proportions (Habekost, 2007). The mathematic equation provides better correlation to visual difference. (Hunt, 2004)

$$\Delta E_{94} = \sqrt{\left(\frac{\Delta L}{K_L S_L}\right)^2 + \left(\frac{\Delta C}{K_c S_c}\right)^2 + \left(\frac{\Delta H}{K_H S_H}\right)^2}$$

***CIE2000* (ΔE_{00})**

An attempt has been made to improve upon the CIE 1994 equation by adding more weighting factors depending on the hue angle of the color resulted in CIE2000 (Habekost, 2008). The mathematic equation is quite complicated but does not tend to show much improvement in correlation with visual differences. There are still some debate on the data that was used to create this equation but it seems to work (Granger, 2008).

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_c S_c}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{K_c S_c}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

COLOR MEASUREMENT COMMITTEE (ΔE_{cmc})

CMC equation was created by the Color Measurement Committee (of the Society of Dyers and Colourists of Great Britain) and is used primarily in the textile industry. CMC equation is similar to the ΔE_{94} equation in terms of weighting place on the lightness, chroma, and hue of the colors but equation is slightly more complicated. (Habekost, 2007)

$$\Delta E_{CMC} = \sqrt{(\Delta L / I S_L)^2 + (\Delta C / c S_C)^2 + (\Delta H / S_H)^2}$$

RESULTS AND DISCUSSION

Scatterplots of visual data (ΔV) versus each of the colour difference equation suggest that the simple linear regression appears to be appropriate for these data (Fig 1).

Linear models with assumed independent normally distributed errors are among the most common models for data. Using the data given in the table I, simple linear regression model is fitted for the four colour difference equation and the equations are given below.

Fitted model for CIE76 : $3.2470772705132847 - 0.445980559346541x$ .... Eqn 1

Fitted model for CIE94 : $3.6138913594229334 - 0.4916919865193933x$ ....Eqn 2

Fitted model for CIEDE2000 : $3.6166928760978085 - 0.4998943096624735x$ ... Eqn 3

Fitted model for CMC(2:1) : $3.9970594658158487 - 0.5475486940980782x$ . .... Eqn 4

Results of linear regression for data derived from each color difference equation is shown in Table II. The calculated t-statistic value showed each estimate to be significantly different from 0. The p-value for all the models is less than 0.05. The coefficient of determination R Squared (R^2) was used to assess the goodness of fit test and the results for each colour difference equation can be seen in Table III. The goodness of fit assess the ability of each equation to predict colour difference equation equivalent to that of the visual colour difference value given by the observers. The CMC equation yields the smallest R^2 value, and is therefore the best predictor of visual observations. The ranks of equations ordered from best to worst fit are CMC, CIE94, CIEDE2000 and CIE76.

When visual assessment was evaluated, it was observed that the human assessments of colour hue differences are most objectionable. Observers accept to little more differences in chroma than in hue. Similarly they accept lightness difference more easily than difference in chroma and hue. Hence the principles based on elliptical tolerancing followed in CMC, CIE94, CIE2000 correlates better when compared to rectangular tolerancing in CIE76.

In this research, the colour difference equations were compared to generate tolerance limit which will correlate closely to the visual colour evaluation. The overall colour difference value (DE) is used to set the pass and fail data which will minimize the number of instrumental wrong decisions. The DE is to be set in such a way that the color difference value minimizes both the number of passed data falling outside of the tolerance ellipsoid and the number of failed data falling inside the tolerance ellipsoid.

When the colour difference value (DE) is compared to the visual colour evaluation for achromatic or low-chroma the shade difference may be imperceptible when DE is less than 0.5. The shade difference is generally very obvious when DE is above 1.5 in all but high-chroma shades that does not look too much different will not be rejected even with DE is upto 2.5.

CONCLUSIONS

Mathematical models were developed based on the scatter plots for the four colour difference equations. It was found that the simple linear model to be appropriate to fit the experimental data as it gives better overall performance over all the colour pairs compared. Comparison of coefficient of determination (R^2) showed that the ranks of equations ordered from best to worst fit are CMC, CIE94, CIEDE2000 and CIE76. The performance of CMC and CIE94 were quite similar, but CMC equation predict a lightness tolerance twice the magnitude of that predicted by CIE94 when the standard is a light color which correlates with the visual observations. In this study, it has been shown using statistical regression technique that the CMC(2:1) colour difference equations performs best thus yielding similar results to those of the observations made by the humans. Hence this study recommends CMC equation to be used for shade sorting since it gives better correlation with the human observations.

Table I Comparison of Visual and Colour difference values

Sample Number	Specimen ID	Pass Ratio	DV	CIE 76 L*a*b*	CIE 94	CIEDE 2000	CMC(2:1)
1	Std : 38523	--	--	------	------	------	------
2	38529	0.619	5.4626	0.502	0.64	0.532	0.647
3	38361	0.810	6.3551	0.344	0.406	0.37	0.431
4	38436	0.571	5.2744	0.513	0.709	0.563	0.711
5	38437	0.571	5.2744	0.494	0.565	0.544	0.622
6	38440	0.762	6.0986	0.586	0.634	0.662	0.741
7	38441	0.571	5.2744	0.687	0.705	0.717	0.779
8	38541	0.238	3.9014	2.445	2.365	2.47	2.467
9	38542	0.048	2.3850	2.676	2.618	2.785	2.83
10	38498	0.190	3.6419	2.554	2.882	2.865	3.194
11	38499	0.048	2.3850	2.271	2.528	2.52	2.786
12	38438	0.048	2.3850	2.237	2.279	2.542	2.724
13	38439	0.048	2.3850	2.259	2.348	2.558	2.759
14	38400	0.190	3.6419	2.584	2.817	2.937	3.229
15	38392	0.381	4.5374	1.136	1.282	1.385	1.587
16	38393	0.095	2.9459	2.363	2.589	2.654	2.917
17	38394	0.000	1.2388	2.619	3.051	2.911	3.293
18	38336	0.667	5.6592	0.437	0.464	0.482	0.534
19	38347	0.381	4.5374	2.106	2.573	2.239	2.58
20	38349	0.381	4.5374	1.118	1.576	1.254	1.592
21	38357	0.400	4.6143	1.039	1.452	1.155	1.461
22	38411	1.000	8.7612	0.263	0.185	0.24	0.211
23	38496	0.571	5.2744	0.549	0.58	0.656	0.731
24	38497	0.571	5.2744	0.547	0.583	0.628	0.699
25	38394	0.476	4.9090	0.701	0.91	0.803	0.979
26	38383	0.429	4.7256	0.768	1.059	0.853	1.075
27	38517	0.429	4.7256	0.898	1.259	1.008	1.276
28	38515	0.476	4.9090	0.74	0.909	0.803	0.961

29	38516	0.476	4.9090	0.725	0.966	0.814	1.003
30	38512	0.667	5.6592	0.563	0.445	0.576	0.559
31	38513	0.905	7.0541	0.349	0.25	0.31	0.273
32	38492	0.476	4.9090	0.679	0.868	0.739	0.9
33	38493	0.476	4.9090	0.685	0.948	0.774	0.973
34	38315	0.476	4.9090	0.617	0.86	0.682	0.865
35	38491	1.000	8.7612	0.246	0.207	0.24	0.242
36	38490	0.571	5.2744	0.585	0.741	0.621	0.753
37	38311	0.857	6.6650	0.272	0.386	0.303	0.387
38	38526	0.619	5.4626	0.509	0.602	0.592	0.688
39	38528	0.571	5.2744	0.559	0.672	0.65	0.762
40	38527	0.762	6.0986	0.531	0.419	0.48	0.448
41	38525	0.667	5.6592	0.421	0.528	0.442	0.533

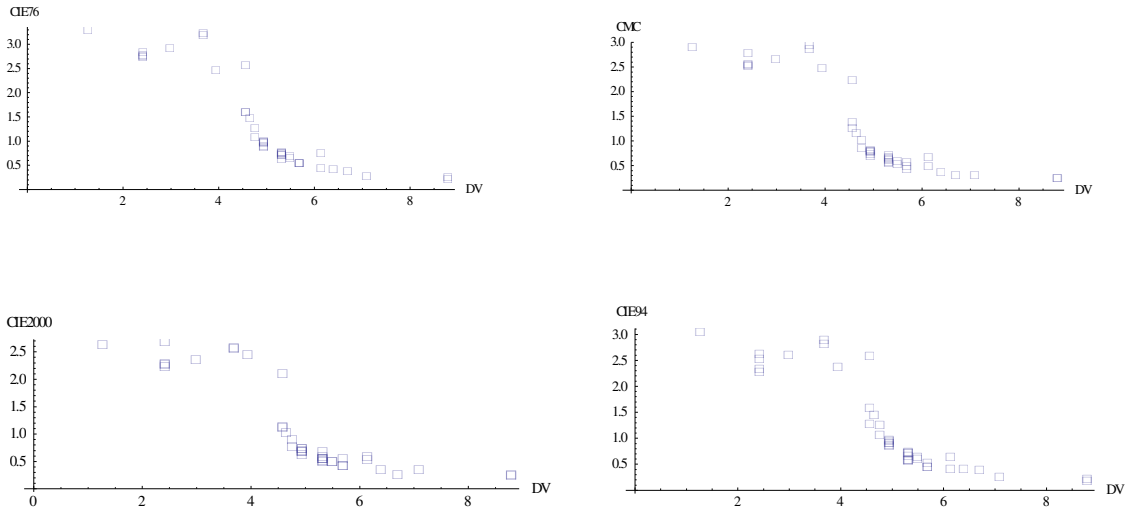

Fig.1 Scatterplots of visual data versus color difference equations

Table II Results of linear regression for data derived from each color difference equation

Predictor	Estimate	Standard Error	t-statistics	p-value
CIE76	-0.4459	0.0471	-9.4510	1.600×10^{-11}
Intercept	3.2471	0.2429	13.367	6.083×10^{-16}
CIE94	-0.4916	0.0477	-10.306	1.464×10^{-12}
Intercept	3.6138	0.2455	14.7158	$2.808 \times 10\text{-}^{17}$
CIE2000	-0.4998	0.0503	-9.928	4.168×10^{-12}
Intercept	3.6166	0.2591	13.953	1.557×10^{-16}
CMC(2:1)	-0.5475	0.0519	-10.5385	7.788×10^{-13}
Intercept	3.9970	0.2674	14.9443	$1.700 \times 10\text{-}^{17}$

Table III Results of R Squared goodness of fit for each colour difference equation

Predictor	R Squared Value
CIE76	0.7015
CIE94	0.7365
CIE2000	0.7217
CMC(2:1)	0.7451

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