Input Device Characterisation: A Comparison between Iteration and Regression Methods Using either XYZ or L*a*b*

H. Izadan and J.H. Nobbs
Department of Colour and Polymer Chemistry, University of Leeds

Abstract
In this study, a scanner has been used to compare the different characterisation methods, iteration and regression, with and without linear RGB and with using either XYZ or L*a*b*. The results show that the iteration method which marginally improves the characterisation accuracy with using XYZ values, has no significant effect in characterisation with L*a*b* values except for the first order polynomial. Also, it was shown that for the regression method either of the L*a*b* or XYZ approaches with an appropriate linearisation method can be used. However, if there is no technological problem, the L*a*b* approach is preferable due to having an optimisation criterion which directly relates to the visual perception of colour difference.

Introduction
Scanner and digital camera characterisations are mostly done with a regression method for transforming RGB of those devices to XYZ tristimulus values [1-2] (XYZ approach).Another approach is transforming RGB to L*a*b* (L*a*b* approach) [3-4]. The non-linear relationship between XYZ and L*a*b* means that the L*a*b* approach requires higher order polynomials which are more susceptible to local maxima and minima. Therefore it has been suggested it would be preferable to use the XYZ approach of characterisation [5].
A drawback of the XYZ approach is that the optimum is the minimum of the sum of the squares of difference between measured and predicted XYZ tristimulus values which has no direct relationship to the visual perception of colour difference [6].
In order to solve this problem researchers have suggested different methods of which the iteration method is an important one [7]. Also, some researchers have used CIELAB weighted least square “to evaluate the rate of change in L*a*b* as a function of change in XYZ” [8] or characterisation directly with L*a*b* approach [3-4].
The aim of this study is to compare the results of characterisation with regression and iteration methods using either XYZ or L*a*b* in order to find the best method of scanner characterisation.

Experiments
In this study, an “Epson Perfection 2400 Photo” scanner has been characterised by regression and iteration in different approaches and with using linear and non-linear RGB. In the XYZ approach, linear RGB was obtained by linearisation to mean reflectance method and in the L*a*b* approach it was obtained by L* method. The method of the RGB linearisation and scanner characterisation with regression method can be found in the previous paper published by the authors [9].
For the iteration method the solver function of EXCEL was used and its starting point was the transformation matrix obtained from an appropriate regression method. The optimisation criteria used for iteration were the sum of the CIELAB colour differences (SDE), the sum of the squares of the CIELAB colour differences (SSDE) and the sum of the squares of the differences between measured and predicted tristimulus values (SSXYZ).

Results and discussion
XYZ approach
Tables 1 and 2 show the results of the characterisation with linearised and non-

linearised RGB in the XYZ approach for regression method (Nreg); and iteration method with different criteria (SDE, SSDE, SSXYZ). These results for average ΔE_{ab}^* are plotted in Figure1.

In this figure SDEno, SSDEno, SSXYZno and Nregno are the results for non-linear RGB.

Figure 1 shows that for non-linear RGB and with all polynomials the order of average ΔE_{ab}^* is as following:

SDEno< SSDEno < SSXYZno= Nregno

and it can be seen that the higher the order of polynomial the lower the difference between the methods.

For the linear RGB and the 1st order polynomial the order of average ΔE_{ab}^* is:

SDE<SSDE<SSXYZ=Nreg

These differences are not significant and for the higher order polynomials all the methods show the same accuracy of characterisation.

Table 1- Average and Maximum ΔE_{ab}^* for XYZ approach using linear RGB

	4th order		3rd order		2nd order		1st order	
	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*
NREG	2.28	13.04	2.75	14.83	3.2	16.98	4.67	20.27
SDE	2.28	13.04	2.75	14.83	3.2	16.98	4.48	19.57
SSDE	2.28	13.04	2.75	14.83	3.2	16.98	4.63	18.20
SSXYZ	2.28	13.04	2.75	14.83	3.2	16.98	4.67	20.27

Table 2- Average and Maximum ΔE_{ab}^* for XYZ approach using non-linear RGB

	4th order		3rd order		2nd order		1st order	
	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*
NREG	2.04	9.12	2.47	10.82	2.84	12.88	7.97	19.25
SDE	1.96	9.49	2.26	13.22	2.59	14.60	7.02	18.62
SSDE	2.02	9.04	2.38	9.75	2.74	11.73	7.06	18.6
SSXYZ	2.05	8.88	2.47	10.83	2.84	12.88	7.97	19.25

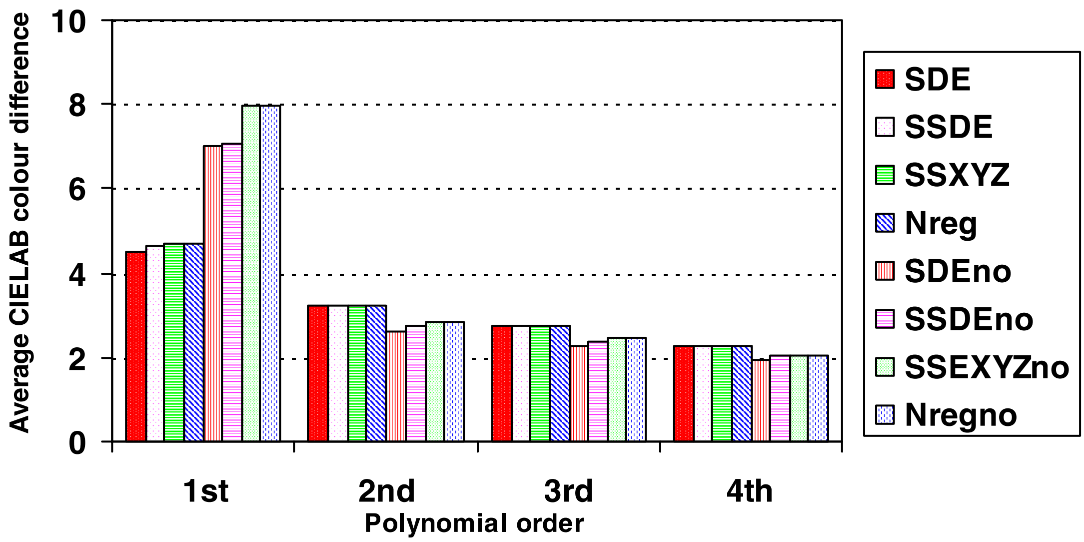

Figure 1- Different optimisation criteria in XYZ approach with linear (e.g. SDE) and non-linear RGB (e.g. SDEno)

L*a*b* approach

The results of the characterisation with the L*a*b* approach are shown in tables 3 and 4.The results for average ΔE_{ab}^* are summarised in figure2.

This figure shows that for the higher order polynomials the results of all methods are approximately the same. For the first order polynomial, however, linearisation has a very significant effect which is expectable.

Both of the Figures 1 and 2 show that the higher the order of the polynomial the lower is the difference between the characterisation accuracy of linear and non-linear RGB.

Comparing L*a*b* and XYZ approaches

To compare the XYZ and L*a*b* approaches the appropriate results from tables 1 to 4 have been selected and plotted in Figure 3.

Table 3- Average and maximum ΔE_{ab}^* for L*a*b* approach using non-linear RGB

	4th order		3rd order		2nd order		1st order	
	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*
NREG	**2.01**	**10.52**	**2.55**	**13.14**	**2.99**	**15.12**	**9.91**	**28.9**
SDE	**1.98**	**10.99**	**2.42**	**15**	**2.84**	**17.25**	**9.81**	**28.98**
SSDE	**2.01**	**10.55**	**2.55**	**13.14**	**2.99**	**15.13**	**9.91**	**28.90**

Table 4- Average and maximum ΔE_{ab}^* for L*a*b* approach using linear RGB

	4th order		3rd order		2nd order		1st order	
	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*	Mean ΔE_{ab}^*	Max. ΔE_{ab}^*
NREG	**1.94**	**8.69**	**2.34**	**10.92**	**2.61**	**12.69**	**4.79**	**19.02**
SDE	**1.94**	**8.69**	**2.34**	**10.92**	**2.61**	**12.69**	**4.67**	**20.26**
SSDE	**1.94**	**8.69**	**2.34**	**10.92**	**2.61**	**12.69**	**4.79**	**19.02**

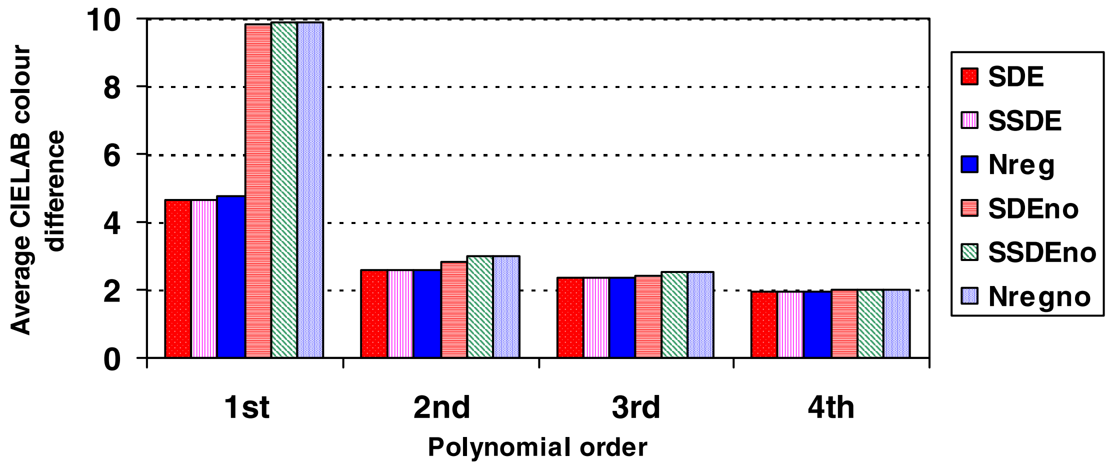

Figure 2- Different optimisation criteria in L*a*b* approach with linear and non-linear RGB

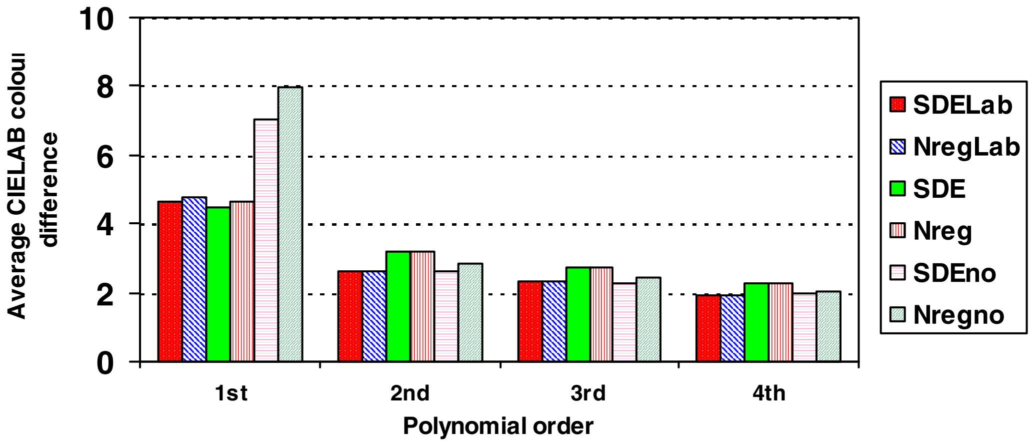

Figure 3- Comparison of XYZ and L*a*b* approaches

The notations SDELab and NregLab are used to show the results of each characterisation method with the L*a*b* approach with linear RGB. Other notations show the results for the XYZ approach with linear and non-linear RGB.

This Figure shows that, for the 1st order polynomial, the XYZ approach with linear RGB is slightly better than the L*a*b* approach with linear RGB and both of them show a significant improvement in comparison to the XYZ approach with non-linear RGB. However, for the higher order polynomials the situation is different and although the differences among all the characterisation methods have been reduced by increasing the polynomial order, the results of the L*a*b* approach with linear RGB are the best and almost the same as the results of the XYZ approach with non-linear RGB.

Conclusion

Input device characterisation with a regression method is often done using the XYZ approach. To solve the problem of the XYZ colour space being not directly related to the visual perception of colour difference, many researches have used the iteration method with an optimisation criterion directly related to the visual perception of colour difference.

In regression method due to the facts that linearisation is not perfect and input devices mostly are not colorimetric, higher order polynomials must be used for characterisation. Some researchers suggest using a second order polynomial, rather than a higher order one, to obtain more reliable characterisation across different materials [10]. Therefore the results of the second order polynomial for the both of the characterisation approaches are compared. With the regression method it can be concluded that either of the L*a*b* or XYZ approaches can be used, however, if there is no technological problem, the L*a*b* approach is preferable due to having an optimisation criterion which directly relates to the visual perception of colour difference.

The iteration method has a marginally improved characterisation accuracy in XYZ approach, but has no significant effect in the L*a*b* approach except for the first order polynomial.

Finally, from the results of this research it can be concluded that the scanner characterisation using a regression method with the L*a*b* approach will lead to the best results.

REFERENCES

1- G., Hong, R. M, Luo, and P.A., Rhodes, A Study of Digital Camera Colorimetric Characterization Based on Polynomial Modelling, Color Research and Application, 26, 1, pg. 76-84 (2001).

2- H. R., Kang, Color Scanner Calibration, Journal of Imaging Science and Technology, 36, 2, pg. 162-170, (1992).
3- J., Hardeberg, Acquisition and Reproduction of Color Images: Colorimetric and Multispectral Approaches, Dissertation.com, USA, 2001.
4- K., Sokolowski, Colour Scanner Calibration- a comparison of different methods, MSc Thesis, Royal Institute of Technology, Stockholm, Sweden, 2003.
5- T., Johnson, Methods for Characterisation of Colour Scanner and Digital Cameras, Displays, 16, 4, pg. 183-191(1996).
6- Berns, R. S., Billmeyer and Saltzman's Principles of Color Technology, 3rd Ed., Jhon Wiley & Sons, New York, 2000, pp 217.
7- Private Communication with Dr C., Li, University of Leeds, UK, June 2005.
8- Funt, B., Ghaffari, R., Bastani, B, Optimal Linear RGB-to-XYZ Mapping for Color Display Calibration, IS&T/SID Twelfth Color Imaging Conference, Scottsdale, USA, pg. 223-227 (2004).
9- Izadan, H., Nobbs, J. H., The Effect of Different Linearisation Methods on Scanner Characterisation, AIC05 Colour Congress, Granada, Spain, pg. 1251-1254(2005).
10- Private Communication with Prof. R. S. Berns, Granada, Spain, May 2005.

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Authors Biography

Hossein Izadan received his BSc and MSc in textile engineering from Isfahan University of technology (IUT) of Iran in 1993 and 1997, respectively. Then he worked in IUT as a lecturer from 1997 till 2003. At the moment He is a third year PhD student in the Department of Colour and Polymer Chemistry at Leeds University.

James Nobbs started his research career as a polymer physicist and, following posts in the UK and Germany, he joined the Colour Chemistry Department at Leeds University in 1980. His research and teaching interests, as the senior lecturer in colour physics, mainly concern the sciences associated with the visual appearance of objects and materials. In December 2004 Jim became the Head of the Department of Colour and Polymer Chemistry.