Analysis of Three Euclidean Color-Difference Formulas for Predicting the Average RIT-DuPont Color-Difference Ellipsoids

Dibakar Raj PANT,[1] Ivar FARUP,[1] Manuel MELGOSA[2]
[1] Gjøvik University College, Norway
[2] University of Granada, Spain

colour difference

ABSTRACT

The RIT-DuPont data set is used to investigate the Euclidean color-difference formulas DIN99d, DIN99o and IPT. The coordinates of the metrics as well as the metrics themselves are transformed to the CIELAB color space, the latter by means of the Jacobians of the coordinate transformations. The RIT-DuPont ellipsoids in the CIELAB space are compared to the Euclidean metrics using two different methods. First, the predicted ellipsoid cross sections in the principal planes of the CIELAB space are compared to the observed data using the ratio of the union to the cross section of the ellipses, giving a single match ratio. Secondly, the full ellipsoids are compared by the method proposed by Schultze. Neither of the methods show a significant difference in the behaviour of the three different color-difference formulas.

1. INTRODUCTION AND METHOD

DIN99d and DIN99o (Cui et al, 2002)[1] and IPT (Ebner and Fairchild, 1998) are important Euclidean color-difference formulas. They were developed using different visual color-difference data sets. All these color-difference formulas have their own associated color spaces which were intended to be perceptually uniform. They have a common aim: to give the color difference given by the Euclidean metric close to the visually perceived color difference. However, this is still challenging due to the non-existence of a perfect uniform color space. Also, it cannot be assured that such formulas are able to predict other sets of visual data which are obtained under different experimental conditions.

It is necessary to do analyses of the above mentioned formulas to know how well they predict color-difference ellipsoids around particular color centers in a common color space. For doing such kind of analyses, we need mathematical models and a reliable color-tolerance data set. The RIT-DuPont data set (Berns et al 1991) is an advanced data set which has been used for testing recent color-difference formulas and uniform color spaces. The experimental average ellipsoids fitted to this data set by Melgosa et al. (1997) will provide us the reference of visual color differences. Study of various color-difference formulas by a Riemannian approach and the Jacobian method was proven efficient by Pant and Farup (2012). It provides a framework to compute metric tensors of different color-difference formulas in a common color space. The coefficients of such tensors give equi-distance ellipsoids in three dimensions and ellipses in two dimensions. The computed ellipsoids can be compared with the experimentally obtained ellipsoids to determine their performance for predicting visual color difference.

In this paper, we have computed ellipsoid cross sections associated to the DIN99d, DI-

1 DIN99o was denoted DIN99b by Cui et al. (2002), but has later been referred to as DIN99o by, e.g., Witt (2005).

N99o and IPT color-difference formulas in the three planes of the CIELAB color space, (a^*, b^*), (a^*, L^*) and (b^*, L^*), respectively. They are compared with the average experimental RIT-DuPont ellipsoid cross sections by using two different methods. The first method, proposed by Pant and Farup (2012) uses the ratio of the union to the intersection of the cross section ellipses to give a single match ratio, R, indicating how well two ellipses with a common center match each other. This is a robust method when we need to account for variations in the size, the shape and the orientation simultaneously for a pair of ellipses. The second method, proposed by Schultze (1972), is a measure for the average deviation of two ellipsoids (V_{AB}). The V_{AB} value expressed in terms of percentage gives the difference between the shapes and orientations of the two ellipsoids. It is also an indicator that tells us the average deviation of color differences.

2. RESULTS AND DISCUSSION

Figure 1 shows the computed ellipsoid cross sections of the DIN99d, DIN99o and IPT in the (a^*, b^*) plane of the CIELAB color space. They are plotted on the top of the cross sections of the ellipsoids fitted at the RIT-DuPont centers in the same plane. The DIN99d ellipsoids are rotated at moderate blue, brilliant greenish blue and dark blue color centers as visually compared with the RIT-DuPont ellipsoids. In the case of DIN99o, they are rotated closely in the same direction as these color centers. However, the sizes of ellipsoids are smaller than the reference. The IPT ellipsoids in the same color centers are better both in the size and the rotation than predicted by previous two color difference formulas. For light brown, moderate reddish brown, and dark reddish orange, the DIN99d and the DIN99o seem to be better than the IPT. Similarly, in the grayish yellow green, moderate yellow and grayish purple centers, the IPT predicted ellipsoids look more similar to the reference than the ones predicted by the DIN99 formulas. In other color centers, the ellipsoids computed by the three formulas are similar.

In Figures 2 and 3, we can see computed ellipsoid cross sections of three formulas in (a^*, L^*) and (b^*, L^*) planes. The DIN99d and the DIN99o ellipsoids are having the same angle in the lightness direction for all 19 color centers, but the IPT ellipsoids have different angles for these color centers in the both planes. The shape and size of the DIN99o and IPT ellipsoids are closer to the reference ellipsoids in the color centers having dominant blue hue than the ones predicted by the DIN99d in the (a^*, L^*) plane. However, in the same plane, the DIN99d ellipsoids perform well to match the reference at brownish and reddish hue centers. For black color, the DIN99o matches well than the IPT and DIN99d. In the (b^*, L^*) plane, the DIN99d and the DIN99o ellipsoid cross sections have a similar pattern of matching with the reference for all color centers.

We have computed matching ratio R of ellipsoid projections of all three planes for these formulas. The resulting R values are in the range $.15 < R < .95$. Figure 4 shows a box plot of the R values of the three metrics. In the plots, the median value is marked by the central horizontal lines. The notch indicates the 95% confidence interval of the median as computed by ANOVA, and the box is bounded by the upper and lower quartiles of the data. The range of data is shown by dashed line. We can see that median values of all three formulas are approximately similar, and that the confidence intervals are overlapping, indicating a non-significant difference between the three metrics. Indeed, the pair-wise statistical sign test of the R values shows that at a 95% confidence level, there is no significant difference between the performance of the DIN99d, DIN99o and IPT metrics in how well they predict the RIT-DuPont ellipsoids.

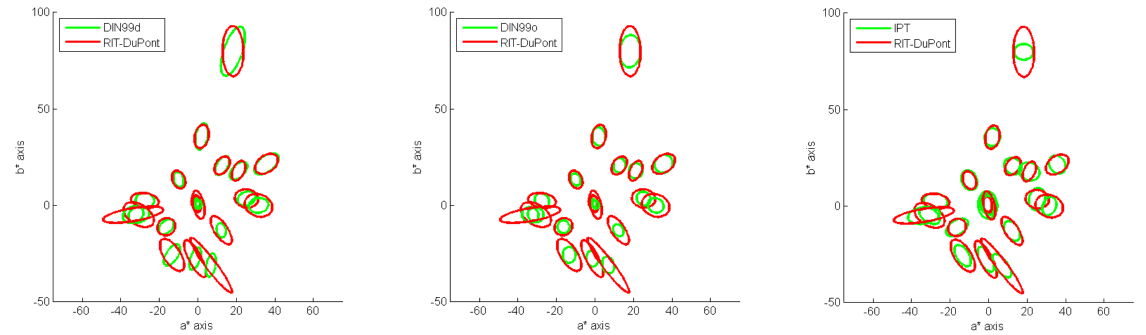

Figure 1. Cross sections of the DIN99d, DIN99o and IPT ellipsoids in the (a, b*) plane.*

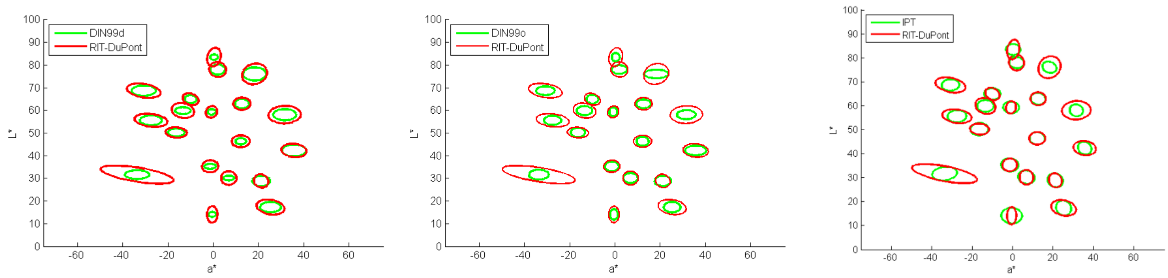

Figure 2. Cross sections of the DIN99d, DIN99o and IPT ellipsoids in the (a, L*) plane.*

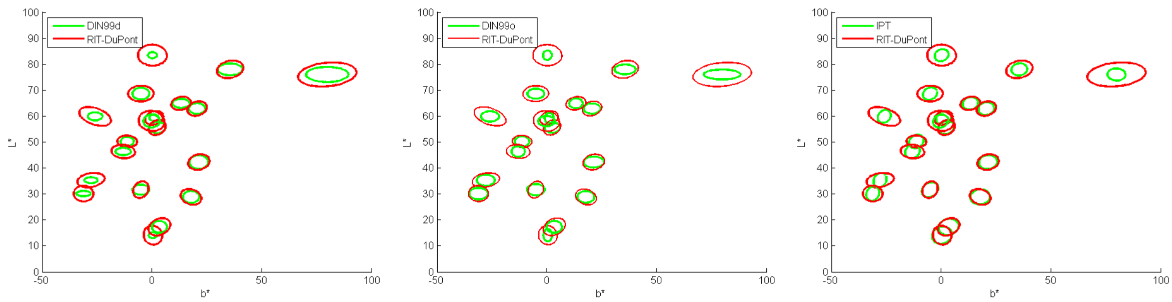

Figure 3. Cross sections of the DIN99d, DIN99o and IPT ellipsoids in the (b, L*) plane.*

Schultze's (1972) measure of deviation, V_{AB}, is calculated between computed ellipsoids and RIT-DuPont ellipsoids for three metrics using a correction factor F = 1. The value expressed in terms of percentage gives the difference between the shapes and orientations of the two ellipsoids. The resulting V_{AB} values of three metrics are close to each other: $V_{AB,DIN99d}$ = 10.12%, $V_{AB,DIN99o}$ = 9.13%, $V_{AB,IPT}$ = 7.93%, Also this indicates that the performances of the three metrics for predicting RIT-DuPont ellipsoids are similar.

3. CONCLUSION

The analysis shows that there is no statistical significant difference between the three Euclidean metrics DIN99d, DIN99o and IPT with respect to how well they reproduce the RIT-DuPont ellipsoids as fitted by Melgosa et al. (1997).

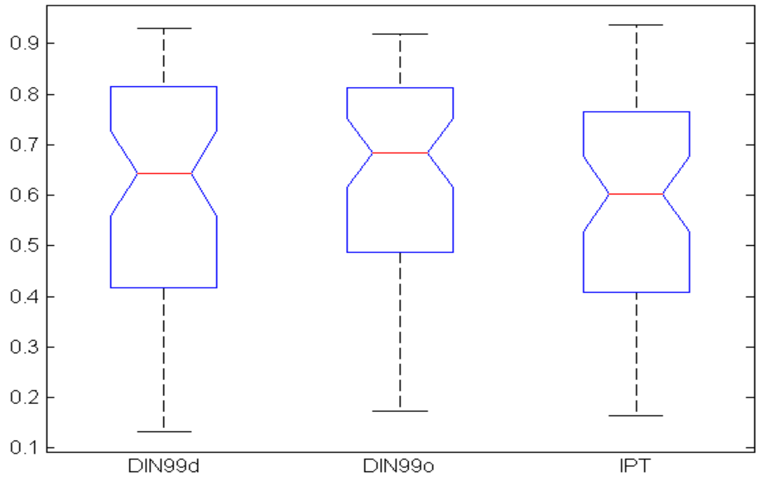

Figure 4. Box plots of matching values R of DIN99d, DIN99o and IPT.

ACKNOWLEDGEMENT

This research was funded by Research Project FIS2010-19839, Ministry of Competitivity (Spain), with European Regional Development Fund (ERDF) and the Research Council of Norway over the SHP programme.

REFERENCES

Berns, R.S., D.H. Alman, L. Reniff, G.D. Snyder and M.R. Balonon-Rosen, 1991. Visual determination of suprathreshold color-difference tolerances using probit analysis. *Color Res. Appl.* 16 297-316.

Cui, G., M.R. Luo, B. Rigg, G. Roesler and K.Witt, 2002. Uniform colour spaces based on the DIN99 colour-difference formula. *Color Res. Appl.* 27 282-290.

Ebner, R., and M.D. Fairchild, 1998. Development and testing of a color space (IPT) with improved hue uniformity. In *The Sixth Color Imaging Conference: Color Science, Systems, and Applications*, vol. 8.

Melgosa, M., E. Hita, A. J. Poza, D.H. Alman and R.S. Berns, 1997. Suprathreshold color-difference ellipsoids for surface colors. *Color Res. Appl.* 22 48-155.

Pant, D., and I. Farup, 2012. Riemannian formulation and comparison of color difference formulas. *Color Res. Appl.* 37(6) 429-440.

Schultze, 1972. The usefulness of colour difference formulas for fixing colour tolerances. In *AIC Proceedings* 254-265.

Witt, K., 2005. Buntheit mit System. *Farbe und Lack* 3 86.

Address: Prof. Ivar Farup, Gjøvik University College,
P.O.Box 191, N-2802 Gjøvik, Norway
E-mail: ivar.farup@hig.no