Preliminary Comparative Performance of the AUDI2000 and CIEDE2000 Color-difference Formulas by Visual Assessments in a Directional Lighting Booth

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ABSTRACT

The calculation of color differences has been developing over the years with the aim of getting robust and adapted models for new colorimetric challenges. A clear example is found in the special-effect pigments. For this type of materials is not enough to measure the color in a single measurement geometry but different measuremet geometries are needed to study their complete behavior. For this reason, the aim of this study is to compare two color difference formulas commonly used in the automotive sector (CIEDE2000 and AUDI2000). Preliminary results indicate that, for measurement geometries closer to the specular direction, AUDI2000 performs better than CIEDE2000 with STRESS rates of 55, 34.21 and 46.33 respectively; on contrast, for measurement geometries away from the specular direction, CIEDE2000 performs better than AUDI2000 with STRESS rates of 34.27, 39.97 and 39.19 respectively.

1. INTRODUCTION

Nowadays, it is possible to do color measurements and color quality control in any situation. However, in many industrial applications, it is not only important to know the color of a given material, but it is also important to evaluate color differences between samples. The classic form to evaluate color differences is by using a gray scale formed by different gray pairs with specific contrasts according to the Adams-Nickerson color difference formula. During the last years, this method has been proven to be effective, so it is universally spread. However, to measure color differences it would be ideal to use any color difference formula, establishing for each case appropriate scales. For this reason, the International Standards Organization (ISO) has published a large number of recommendations. Logically, we should agree with the scales to use on each field, but once they are established, everybody would be able to use the same formulas (Artigas et al. 2002). In this paper, we use the gray letter pairs of the Society of Dyers and Colourists.

In many coloring materials industries, it is important an exhaustive color quality control and specifically, it is important to be able to replicate colored materials in the same way. In the automotive industry, the reference mathematical model used for predicting color differences is the AUDI2000 color difference formula (Eq. 1). Before this formula, and always based on the CIELAB color space, the AUDI95 color difference formula was developed. However, AUDI95 formula was not adequate to predict correctly the tolerance weights for some effect colors, thus Audi was forced to develop a new model to predict tolerances for both solid and effect colors. The new color tolerance model, AUDI2000, solved the problem by using the characteristic flop to predict tolerances (Dauser 2012). On the other hand, since several years the International Commission on Illumination (CIE), recommends to be used the CIEDE2000 color difference formula (Eq. 2). This formula provides an improved method to calculate color differences and it is based on statistical optimization of several visual assessments databases of numerous colors pairs

$$dE_{\gamma} = \sqrt{\left(\frac{dL_{\gamma}}{S_{dL,\gamma}g_{dL}}\right)^2 + \left(\frac{dC_{\gamma}}{S_{dC,\gamma}g_{dC}}\right)^2 + \left(\frac{dH_{\gamma}}{S_{dH,\gamma}g_{dH}}\right)^2} \qquad \text{(Eq. 1)}$$

$$\Delta E_{00} = \sqrt{\left(\frac{dL}{S_{dL}k_{dL}}\right)^2 + \left(\frac{dC'}{S_{dC}k_{dC}}\right)^2 + \left(\frac{dH'}{S_{dH}k_{dH}}\right)^2 + R_T\left(\frac{dC'}{S_{dC}k_{dC}}\right)^2\left(\frac{dH'}{S_{dH}k_{dH}}\right)^2} \qquad \text{(Eq. 2)}$$

CIEDE2000 predicts visual assessments without taking into account different measurement geometries. By contrast, AUDI2000 predicts color differences for six measurement geometries (45as-15 45as15, 45as25, 45as45, 45as75, 45as110). However, to develop AUDI200, it was not used an optimization and testing phase based on visual assessments.

The objective of this work is to evaluate the preliminary performance of CIEDE2000 and AUDI2000 color difference formulas by using different pairs of normal and gonio-apparent colors by doing visual evaluations in a specific lighting booth.

2. METHOD

A set of 13 different color pairs were selected with three different kinds of colors: solid, metallic, and pearlescent. To measure the colorimetric behavior of these goniochromatic samples a multi-angle spectrophotometer, named BYK-mac, was used. From CIELAB values and every measurement geometry, it was calculated the total and partial color differences according to each color difference formula (AUDI2000 and CIEDE2000).

A directional lighting booth was used for the visual assessments to test both color differences formulas, AUDI2000 and CIEDE2000. This cabinet was the byko-spectra effect cabinet (Figure 1), which allows color comparisons in the six measurement geometries of the BYK-mac multi-angle spectrophotometer. Visual assessment data (ΔV) were obtained by placing each pair of samples in the cabinet and by using as reference the card SDC Color Change with 9 gray pairs.

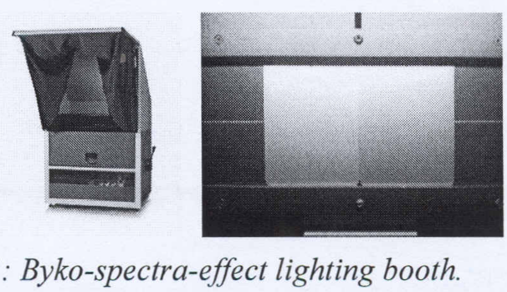

Figure 1: Byko-spectra-effect lighting booth.

To assess the correlation degree between the visual color difference and the instrumental color difference was used the STRESS parameter (García et al. 2007, Huang et al. 2012). It is a statistical parameter that evaluates both the degree of adjustment between two data sets and the statistical inference. The lower STRESS value, better the correlation degree. STRESS is calculated using the following equations:

$$STRESS = \sqrt{\frac{\sum_{i=1}^{N}(\Delta E_i - F_1 \cdot \Delta V_i)^2}{\sum_{i=1}^{N}\left(F_1^2 \cdot \Delta V_i^2\right)}} \quad \text{(Eq. 3)}$$

$$F_1 = \frac{\sum_{i=1}^{N}\Delta E^2}{\sum_{i=1}^{N}(\Delta E_i \cdot \Delta V_i)} \quad \text{(Eq. 4)}$$

3. RESULTS AND DISCUSSION

Preliminary results, but obviously with very few pairs of colors, indicate that:

1. for measurement geometries closer to the specular direction, i.e. 45as-15, 45as15 and 45as25, AUDI2000 performs better than CIEDE2000 with STRESS rates of 55, 34.21 and 46.33 respectively;
2. for measurement geometries away from the specular direction, i.e. 45as45, 45as75 and 45as110, CIEDE2000 performs better than AUDI2000 with STRESS rates of 34.27, 39.97 and 39.19 respectively.

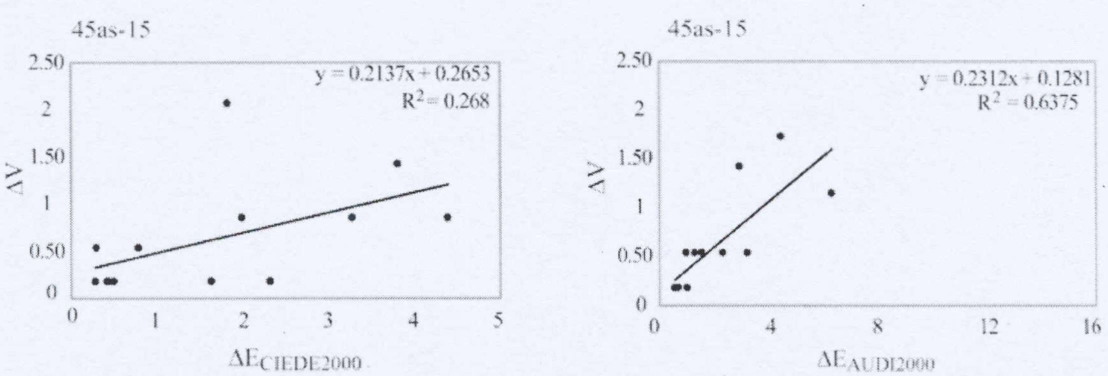

Figure 2: ΔV vs CIEDE2000; ΔV vs AUDI2000 for the measurement geometries 45as-15 (left) and 45as-15 (right).

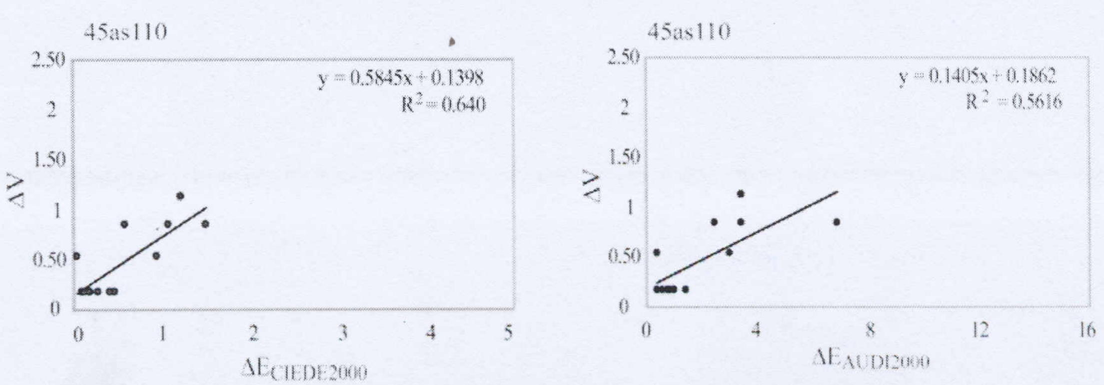

Figure 3: ΔV vs CIEDE2000; ΔV vs AUDI2000 for the measurement geometries 45as110 (left) and 45as110 (right).

Obviously, the worst perceptual prediction results always correspond to metallic and pearlescent colors. In general, there are over-estimates of the visual evaluations, i.e. $\Delta V < \Delta E$ (linear correlation slope ΔV vs ΔE less than 1) – see Figure 2 and 3.

4. CONCLUSIONS

Therefore, from this work, despite its small amount of data, it is possible to conclude that it is necessary to unify the strengths of both color-difference formulas to predict better color differences between gonio-apparent colors for any measurement geometry, which is demanded by several industrial sectors, such as the automotive sector.

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REFERENCES

Artigas, J.M., P. Capilla, and J. Pujoli 2002. *Tecnología del Color*. Publications of the University of Valencia.

Dauser, T., March 2012. *Audi Color Tolerance Formulas*. Personal communication, AUDI AG: Ingolstadt - Germany.

García, P.A., R. Huertas, M. Melgosa, and G. Cui, 2007. Measurement of the relationship between perceived and computed color differences, *JOSA A*, 24:1823-1829.

Huang, M., H. Liu, G. Cui, M.R. Luo, and M. Melgosa, 2012. Evaluation of threshold color differences using printed samples, *JOSA A,* 29(6).

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