Calculating Verbal Descriptions of Color Difference Components

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ABSTRACT

For many applications, it would be helpful if the various components of an observed color difference could be described verbally, based on reflection measurements. However, earlier studies show that existing descriptor methods are difficult to understand even for well trained observers. We propose a new system for describing the components of color and texture differences. It includes a modification of Hansen's method to distinguish main color categories. The new method also uses a variation of Cooper's description of hue-differences, which is better understandable for painters. In the proposed system, the components of the difference are specified as differences in four parameters: lightness, colorfulness, hue (using the three primary colors of traditional artists) and texture. The new system was shown to provide correct descriptors of observed color and texture differences in 73 to 94 percent of the cases, when compared to judgments by observers. This is comparable to assessments by an average observer, and equal or even slightly better than results from previous publications.

1. INTRODUCTION

In the car repair industry, there is a need for using a standardized system for describing color differences. For example, when the painted chip in color documentation is not perfectly matching the color of the car that needs to be repaired, a description of the remaining color difference could be helpful in identifying the exact car color in a numerical database. This description should be in terms of verbal expressions rather than in numerical values, and the vocabulary should be understandable also for those not familiar with colorimetry. Also in many other business areas users would benefit from a specification of the different components underlying the color difference observed between two samples. Colorimetric software easily produces the magnitudes of e.g. **ΔL^*, Δa^* and Δb^*, but such numerical data are diffi**cult to understand for many users (Smith, 1997). They would probably prefer software that is able to specify the components of measured color differences in terms of verbal descriptors. Therefore there is not only a need for a standardized, easily understandable system for describing the components of color differences, but also for a calculation method that produces such descriptions based on measured color differences.

Such a system may also be beneficial to people who are familiar with colorimetry. Previous studies have shown that even for experienced observers with a colorimetric background it is difficult to distinguish which color dimension is dominant in an observed color difference (Melgosa *et al.*, 2000). The rectangular CIE-Lab system is clearly not suitable for this goal. Describing color differences in terms of cylindrical coordinates ΔL^*, ΔC^* and Δh^* is much better, but often not straightforward even for well trained observers (Smith, 1997). Melgosa et al. (2000) found that when observing color pairs that differ in one color attribute, only 60.2% of the observers could identify the correct color parameter. For experienced observers this was only slightly better (72.4%), where it should be remarked that the random probability is 33.3%. These results were confirmed by Zhang and Montag (2006).

Identifying the color parameter that is dominating an observed color difference becomes even more difficult when the color difference is small. Zhang and Montag (2006) showed that even for experienced observers, the percentage of correct identifications of the dominant color attribute in a color difference drops to below 55% for sample pairs with small color difference (CIEDE2000 =8.05). In most of these studies, especially the term chroma has been found to present difficulties. Therefore in our tests we introduced the term "colorful", as we found that it is more clear to people even when not having a background in colorimetry. As mentioned below, we tested several identifications for this word colorfulness with parameters known in the CIE-Lab system, in CIECAM02 *etc*.

Another source of confusion is the method in which to characterize hue differences. As shown by Smith (1997), for colourists the most straightforward system is by using a limited number of main colour categories (such as red, yellow, green and blue), and describe each hue difference as a trend towards one of these terms (i.e.: redder, yellower, greener, bluer). In a system derived by Cooper and McLaren (1973) and McLaren and Taylor (1981), eight different main color categories are used (red, orange, yellow, lime, green, turquoise, blue and violet). In this system hue differences are expressed referring only to the four color categories just mentioned. Thus, one turquoise color may differ from another turquoise color by being either greener or bluer. One blue color may differ from another blue color not by being "more turquoise", but by being greener (or redder).

We found that a disadvantage of the system of Cooper and McLaren is that it does not relate to the traditional artists' primaries of red, yellow and blue (complemented by the three secondary colors orange, green and purple) that are familiar to most painters (Pridmore, 1991). Cooper's method is based on the four opponent colors red–green, yellow-blue. By referring in our new method to the traditional artists' primaries, we have modified Cooper's method in order to make it more intuitive for painters.

In this article, we discuss how we derived an algorithm that converts a measured color and texture difference into a verbal description of its various components, using the new system. The algorithm should: (a) produce a specification of the main color group, from a list of six color categories: red, orange, yellow, green, blue and purple; (b) specify if there is a significant difference in lightness, hue, colorfulness and/or coarseness, and if that difference is large. We also indicate which of the specified differences is most salient.

2. PRELIMNARY TESTS

2.1 Specify color group

Based on the results from preliminary tests we found that for establishing the color group, a good starting point is provided by the Hansen method (Hansen, Walter and Gegenfurtner, 2007). Based on hue values it distinguishes seven chromatic groups apart from an achromatic "Gray" group. However, since we wanted the main color categories to be consistent with the names used in the conventional painter's color wheel, we modified Hansen's method. The turquoise color group name was eliminated, and its colors were assigned to the green group. With 7 observers assessing the color group of 109 paint samples, we found that the definitions from Hansen's method worked well, except for the separation line between the green and blue color category, which needed a hue shift over 5° as compared to Hansen's results. Also, we found that the color group Neutral colors refers to cases with measured chroma value C*<5, and to colors with 5<C*<13 and L*>70.

With the definitions just given, we found that in 87.5 percent of the cases the same color group is found as in the visual tests. The highest scores are found in the red and yellow color groups (100%) and in the green (96.4%) and blue (94.7%) color group. Lowest scores are found for the neutral (77.9%) and purple (81.3%) color groups. We conclude that the main color group can be determined well based on reflection measurements.

2.2 Specify components of color and/or texture difference

For each of the components of color and/or texture differences, we performed preliminary visual tests to choose between several parameters that could be used to describe these components. Thus, for lightness differences we correlated visual data for this difference component with calculated values based on either the CIELab parameter ΔL*, or on one of the CIECAM02 parameters ΔJ (lightness) and DQ (brightness). For the magnitude of hue differences, we used the CIELab parameter ΔH. The direction of hue differences was calculated by the CIELab expression Dh_{ab}. We tested several different parameters to quantify "differences in colorfulness", based on parameters from CIELab and CIECAM02.

In a test we let five observers assess 92 pairs of metallic samples, and describe the color difference. From all parameters tested, we found that the best correlation with the descriptions from the observers was found if we use the different components in the dE_{CMC} equation. Thus, the value of $\Delta L^*/(lS_L)$ correlated best with observed lightness differences, the value of $\Delta C^*/(cS_C)$ with observed differences in colorfulness, and the value of $\Delta H^*/(S_H)$ with observed hue differences.

Our results confirm earlier studies stating that the component that is most difficult to assess is colorfulness (*i.e.* chroma, in earlier studies). We found correct assessment of differences in colorfulness in 60 to 80 percent of the cases, comparable to percentages from 50 to 80 percent reported before (Melosa *et al.*, 2000, Zhang and Montag, 2006). In comparison, lightness differences are correctly predicted by the algorithm in 80 to 90 percent of the cases.

3. MAIN TEST: EXPERIMENTAL

We selected 222 pairs of metallic coating samples, covering color space as good as possible. The average color difference between pairs is ΔE_{CMC} (1.5:1)=3.4 for the face angle. In this set, the ten percent smallest and largest color differences occurr for ΔE_{CMC} (1.5:1)=1.3 and 6.6, respectively. All pairs were visually assessed by 5 trained observers with normal color vision, in individual sessions of the test. After finishing the test, all five observers participated in a group session. In the group session, the visual assessments for every sample pair were discussed among all observers until a group assessment was formulated. Obviously, the group assessment did not necessarily agree with the average value of all five assessments from the individual sessions.

2. RESULTS AND DISCUSSION

Our results show that based on reflection measurements we are able in 73 to 94 percent of the cases to produce the same descriptors for the components of color differences as a trained group of observers. This performance is very similar to the performance of an individual observer doing a visual examination. For the components of the color difference, this performance is comparable or even slightly better than the results published before, cited in the introduction.

For example, lightness differences were predicted by the algorithm as equal to the group session result in 73% (face angle) and 85% (flop angle); for individual observers this varied between 69% and 86% (face angle), and between 68% and 86% (flop angle). Results for other parameters are presented in Table 1. For texture differences, no results from previous investigations have been published, but our results show that observed texture differences can be predicted with a performance very similar to that for the components of color differences.

Table 1. Percentage agreement in specifying color difference components, compared to result from group session. Li : lightness, Cf : colorfulness, Hu : hue, Tx : texture.

	Face				Flop			
	Li	Cf	Hu	Tx	Li	Cf	Hu	Tx
Individual observers	69-86	66-78	68-84	76-86	68-86	67-86	62-81	89-98
New algorithm	73	80	83	76	85	82	77	94

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