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Quality Measurement of Existing Color Metrics using Hexagonal Color Fields

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Resumen. En este trabajo varias formulas están introducidas que permiten calcular la medir la diferencia entre colores de forma perceptible, utilizando el espacio de colores YIQ. Las formulas clásicas y sus derivados que utilizan los espacios CIELAB y CIELUV requieren muchas transformaciones aritméticas de valores entrantes definidos comúnmente con los componentes de rojo, verde y azul, y por lo tanto son muy pesadas para su implementación en dispositivos móviles. Las formulas alternativas propuestas en este trabajo basadas en espacio de colores YIQ son sencillas y se calculan rápidamente, incluso en tiempo real. La comparación está incluida en este trabajo entre las formulas clásicas y las propuestas utilizando dos diferentes grupos de experimentos. El primer grupo de experimentos se enfoca en evaluar la diferencia perceptible utilizando diferentes formulas, mientras el segundo grupo de experimentos permite determinar el desempeño de cada una de las formulas para determinar su velocidad cuando se procesan imágenes. Los resultados experimentales indican que las formulas propuestas en este trabajo son muy cercanas en términos perceptibles a las de CIELAB y CIELUV, pero son significativamente más rápidas, lo que los hace buenos candidatos para la medición de las diferencias de colores en dispositivos móviles y aplicaciones en tiempo real.

Abstract. In the area of colorimetry there are many color metrics developed, such as those based on the CIELAB color space, which measure the perceptual difference between two colors. However, in software applications the typical images contain hundreds of different colors. In the case where many colors are seen by human eye, the perceived result might be different than if looking at only two of these colors at once. This work presents an alternative approach for measuring the perceived quality of color metrics by comparing several neighboring colors at once. The colors are arranged in a two dimensional board using hexagonal shapes, for every new element its color is compared to all currently available neighbors and the closest match is used. The board elements are filled from the palette with specific color set. The overall result can be judged visually on any monitor where output is sRGB compliant.

Keywords: color metric, perceptual quality, color neighbors, quality estimation.

1 Introduction

In the software applications there are applications where several colors need to be compared in order to determine the color that better matches the given sample. For instance, in stereo vision the colors from two separate cameras are compared to determine the visible depth. In image compression algorithms the colors of neighboring pixels are compared to determine what information should be discarded or preserved. Another example is color dithering – an approach, where color pixels are accommodated in special way to improve the overall look of the image. For instance, in Floyd-Steinberg dithering [1] and Riemersma dithering [2] the color is compared to several existing matches and closest match is used; the difference between original color and used match is calculated and propagated to other pixels.

In order to measure the difference between the given colors, each of them has to be specified in a common system, usually referred to as color space. In computer applications it is very common to use RGB color space. However, since RGB color space is rather subjective in terms of specification, of which several exist (such as sRGB, see Rec. 709 [3]), several other color spaces were developed that are also thought to be more perceptually uniform (an important property for measuring color differences). The most commonly used formal color spaces are CIE XYZ, CIELAB and CIELUV [4]. If the original color is specified in RGB color space and that specification is known, the color can be converted to CIE XYZ without losing precision through gamma correction and linear transformation [5]. The transformation from CIE XYZ to CIELAB and/or CIELUV is made through a series of transforming functions (see [4] or [5]). Once the colors have been represented in CIELAB color space, several color difference equations exist (see [6], [7], [8] and [9]).

Alternatives to CIELAB and CIELUV in terms of perceptual accuracy exist, such as DIN99 color space [10] with its associated color difference formulas [11], ATD95 color space [12] and HCL color space [13].

The aforementioned color spaces and their associated metrics have their strengths and weaknesses (see [5] and [14]) in terms of quality and performance. In this work the focus is made on the quality factor in practical applications – where color metrics are used in typical software applications. There are recent works that evaluate the quality of the different color metrics based on specific sample data (see [6] and [15]). However, as much as scientific background is important for a given color metric, its practical application's strengths and weaknesses are of high priority to a software engineer. The experiments described in this work provide insight on how each color metric performs when working with colors typically displayed on a standard computer display. In the reality the human eye perceives a large variety of colors simultaneously and this work provides an alternative approach for testing the existing colors metrics with three or more colors at the same time.

1 Palette Exhaust on Hexagonal Field

In order to measure the quality performance of the given metric, a fixed palette of colors is given. The color values were specified using two techniques – first involved uniform distribution of red, green and blue values in sRGB color space and second using random color generation using linear number distribution. The colors were extracted from the palette one by one depending on the quality comparison described later on until all colors have been exhausted. The initial color that was looked for on the palette is gray (CIELAB coordinates corresponding to L*=50, a*=0 and b*=0). The different choice for the initial color produces different results and middle gray was selected as a reasonable average between the entire set of all possible colors.

The colors were filled on a hexagonal two-dimensional field. The hexagonal shape of field cells was chosen over triangular or square shapes because it has the largest entropy of all three. The different entropy levels are illustrated on the Fig. 1.

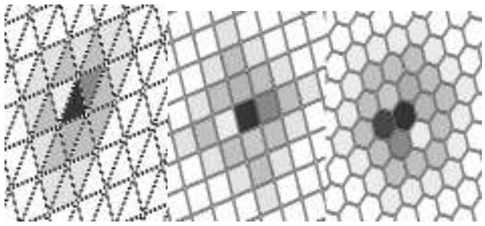

Fig. 1. The entropy of triangular (a), square (b) and hexagonal (c) cell shapes. The number of neighbors is marked with different colors to the given red cell in the middle.

In the above figure it can be seen that the red cell has different number of neighbors depending on the shape. In the last image the hexagonal cell has six neighbors – the largest entropy that can be seamlessly fit on a two-dimensional field. The largest entropy is important for the context of this work as it allows measuring the visual difference between seven colors at once (one at the middle and six neighbors).

In the hexagonal field the order at which the cells are filled with the colors from the source palette is important and affects the final result. There is a finite but significantly large number of all possible ordering schemes on two-dimensional field, starting from linear schemes (from left to right, from top to bottom) to pseudo random ordering such as Hillbert Curve [16]. In this work a radial ordering scheme was used – the initial cell was considered to be in the middle and its neighbors were filled in clockwise manner until the entire field has been filled or the colors from the source palette have been exhausted.

2 The analysis of resulting fields

Once the hexagonal color field has been generated using the approach described earlier, the resulting image was analyzed by several human observers with healthy vision on the standard computer monitor that fully complies with sRGB color standard under such environment conditions, where the external illumination has little significance and can be neglected. It is important to note that although there were very few human observers involved in the experiments to be considered statistical evidence (for that matter, a more extensive study is recommended in the future works) and due to the fact that human color perception is rather subjective, the results should not be considered as statistics. The statistical analysis is beyond the scope of this work.

Since the human color comparison is subjective to individual person each observant was given a complete freedom in terms of metrics and time to observe each of the generated images and then give each image a quality mark between 0 (unordered colors – all cells are different from their neighbors) and 100 (no defects or "jumps" between neighboring colors). The first set of experimental images is illustrated on the Fig. 2.

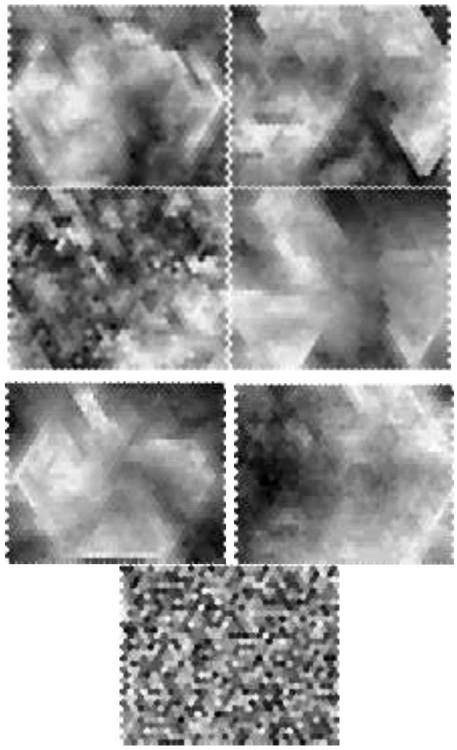

Fig. 2. Experimental Image Set 1 (from left to right, top to bottom) using CIELAB (a), CIELUV (b), HCL (c), DIN99 (d), CIEDE2000 (e) and ATD95 (f) color metrics with the reference palette (g).

The above set of images was generated with the source palette with 1280 random colors on hexagonal field of dimensions 32x32. The experiments used the color metrics based on CIELAB [4], CIELUV [17] and HCL [13], and color difference formulae DIN99 [10], CIEDE2000 [9], and ATD95 [12]. The hexagonal field with unsorted reference palette is shown in the last image (only the first 1024 colors shown). The images were created by extracting colors from the original palette and filling the destination grid, starting from the center. Each color from the input palette is compared to the neighbor colors of the location where it will be placed and the best match is selected.

It can be observed that the overall color distribution varies depending on the chosen color metric, although the observed image is similar (looks like a series of colored patches). The best color matching results appear closer to the center of the image and become worse to the edges as the remaining color options left in the source palette become sparse. The final score chart made by calculating the average of the human observant scores is illustrated on the Fig. 3.

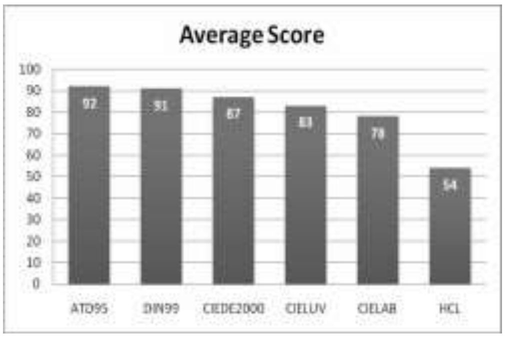

Fig. 3. Average score for the different color metrics using the experimental image set 1 as judged by 10 human observers.

Although it is difficult if not impossible to rule out the subjectivity of human judgment by observing the experimental images, the chart on Fig. 3 shows that color metric based on ATD95 and DIN99 generated the best results when comparing more than two colors at once. In this experiment the colors were generated randomly, which resulted in some colors being very similar to each other and some colors very different. Observing the results on the Fig. 3 it can be concluded that all the tested color metrics can detect similar colors in groups to a different degree. The average score numbers cannot be used as an exact quality measurement for each of the color metrics but they show which color metric performed better than the rest.

The second experimental image set consisted of source palette with 1331 colors distributed uniformly in sRGB color space with 11 levels for each component of red, green and blue, with hexagonal field dimensions of 32x32. The results are illustrated on Fig. 4.

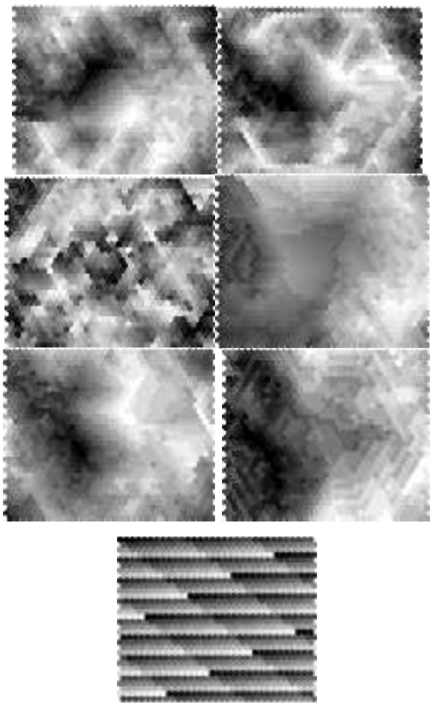

Fig. 4. Experimental Image Set 2 (from left to right, top to bottom) using CIELAB (a), CIELUV (b), HCL (c), DIN99 (d), CIEDE2000 (e) and ATD95 (f) color metrics with the reference palette (g).

The peculiar property of this experimental set is that the difference between colors in the source palette is relatively constant in sRGB color space, so there is no such color pair where color difference is too small as in the previous experimental set. In the previous set of images the color distribution was somewhat similar with different color metrics, while in this set the distribution is quite different for each color metric.

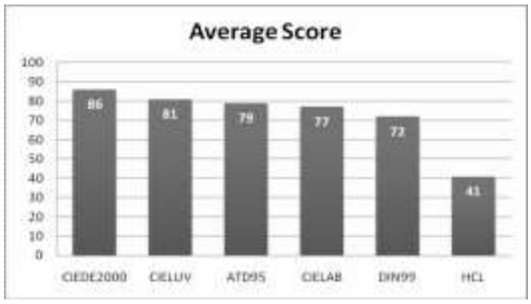

Fig. 5. Average score for the different color metrics using the experimental image set 2 as judged by 10 human observers.

In the chart on Fig. 5 the average scores given by the jury are shown for the second experimental set of images. It can be observed that the scores are generally lower than in the previous experimental set with CIEDE2000 color metric's generated image being the best observed. Although the different color metrics are placed differently on the chart, the consensus from both experiments is that ATD95-based color metric is better than DIN99 and CIELUV is better than CIELAB, with the color metric based on HCL color space being the worst in both cases.

3 Conclusions and future work

In this work an alternative approach for measuring the perceived quality of different color metrics has been presented where three or more colors are compared at the same time as opposed to color pairs. The motivation behind this is that the reality is filled with many different colors which are viewed simultaneously by human eye. In the experiments, the colors were extracted from a fixed color palette one by one and were placed on two-dimensional field with hexagon-shaped cells. The colors from the palette were compared to all existing neighbors on the field and the best match was selected. The resulting images were presented to various human observes with healthy vision on a computer display compliant with sRGB standard for the judgment. The average scores provided by the jury were presented in this work, which indicate the tendency of certain color metrics performing better than others when working with several colors at the same time.

Since the experiments described in this work can hardly be considered definitive for determining which metric performs better, further tests are required with more extensive color sets and different filling strategies on the two-dimensional field. In addition, triangular and square shaped fields with less entropy are to be assessed as potential alternatives to hexagonal fields. The entropy can be further increased by modeling the color cells each in three-dimensional fields where each color can have a certain shape such as a pyramid or a cube, although these fields can be more difficult to visualize and judge.

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