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HOW TO OPTIMIZE THE USE OF THE $L^*H^*C^*$ COLOR SPACE IN COLOR IMAGE ANALYSIS PROCESSES

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ABSTRACT

In this paper, we will discuss about why the *RGB* color space is nowadays always used in color image analysis and how the $L^*a^*b^*$ and the $L^*H^*C^*$ color spaces can be best used in computer processes. Then, we will propose several solutions to digitize these color spaces and to best characterize relevant information on each color histograms.

Key words : color histogram analysis, color digitization, color space.

THE $L^*a^*b^*$ COLOR SPACE

Several psychophysical studies have proved that the $L^*a^*b^*$ color space correlates more efficiently the *human color perception* than the *RGB* color space because in the $L^*a^*b^*$ color space numerical differences are directly proportional to perceptual differences (Pointer, 1981; Berns and Alman, 1991). In the same way several studies linked to image analysis field have demonstrated that color image processing techniques lead to better results when they are carried out in the $L^*a^*b^*$ color space (Ohta et al., 1980; Schwartz et al., 1987). This system approximates a uniform color space in terms of the tri-stimulus values X, Y, Z. Most of researchers are conscious that the use of an *uniform color space* will improve substantially their processes. Nevertheless few of them have generalized their processes to these color spaces.
Equ. 1 below, gives the conversion formulas from XYZ to $L^*a^*b^*$ color space :

$$\begin{cases} L^* = 116\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} - 16 \\ a^* = 500\left(\left(\frac{X}{X_0}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_0}\right)^{\frac{1}{3}}\right) \\ b^* = 200\left(\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_0}\right)^{\frac{1}{3}}\right) \end{cases} \quad (1)$$

where the constants X_0, Y_0 et Z_0, are the tri-stimulus values of the standard white.

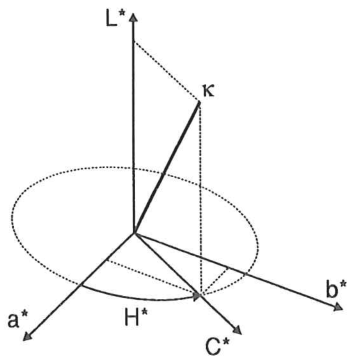


Fig. 1. representation of a color κ in the $L^*a^*b^*$ and $L^*H^*C^*$ color spaces.

DIGITIZATION OF THE $L^*a^*b^*$ COLOR SPACE

Generally the *RGB* color space is digitized with 8 bits per component represented by integer numbers in the range [0,255]. Inversely the $L^*a^*b^*$ color space is represented by real numbers in the range $[0, 100]$ for L^*, $[-130, 200]$ for a^* and $[-160, 160]$ for b^*. Consequently, to code colors, the $L^*a^*b^*$ color space needs 96 bits (3 simple precision real numbers each coded with 4 bytes) per component when the *RGB* color space needs only 24 bits per color component. In order to reduce the amount of memory necessary to code the *RGB* color space and to reduce computing time especially color information access times, it has been suggested to reduce the *RGB* color space digitizing to 5 bits per component (Heckbert, 1977). Thanks to this early processing, we can code the *RGB* color space with only 15 bits per color component. We propose to extend the digitizing principle to the $L^*a^*b^*$ color space. We have computed the minimal value $\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$ corresponding to a digitizing step of one unit in the *RGB* color space, i.e. for two consecutive colors for which one of the components R, G or B differs of one unit. We have then obtained a value of 0.04 units. It seems possible to extend the digitization of $L^*a^*b^*$ color space to a digitizing step of 0.2 unit. Beyond this threshold color differences are perceptible to the human visual system (Haydn and Oulton, 1994). Thus, the $L^*a^*b^*$ color space can be digitized without perceptual degradation with 31 bits (9 bits for L^*, 11 bits for a^* and b^*).

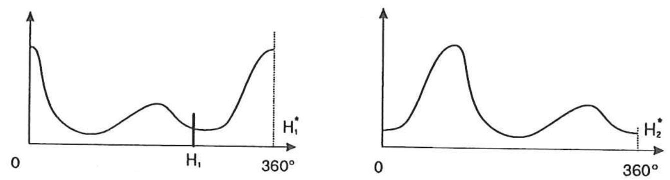
Likewise, it has been shown in several experimental studies, that just noticeable difference can be reliably represented in the *RGB* color space, only if the color definition of that color space is at least scaled on 0 to 1024 steps (Haydn and Oulton, 1994).

COLOR DISCRIMINATION IN THE $L^*H^*C^*$ COLOR SPACE

Secondly, rather than using the $L^*a^*b^*$ color space it seems more appropriated to use the corresponding $L^*H^*C^*$ cylindrical color space (Fig. 1), where H^* corresponds to the angular coordinate of a color in the (a^*,b^*) chromatic plane :

$$\begin{cases} C^* = (a^{*2} + b^{*2})^{\frac{1}{2}} \\ H^* = \begin{cases} 0 & \text{if } a^* = 0 \\ \arctan(b^*/a^*) & \text{if } a^* > 0 \text{ and } b^* >= 0 \\ \arctan(b^*/a^*) + 2\pi & \text{if } a^* > 0 \text{ and } b^* < 0 \\ \arctan(b^*/a^*) + \pi & \text{if } a^* < 0 \end{cases} \end{cases} \quad (2)$$

This latter describes colors in terms of *luminance, chroma* and *hue* like the human visual system. This leads to two computing problems when we analyse the $L^*H^*C^*$ color space not as a three-dimensional representation (3-D) but as the sum of three one-dimensional representations (3×1-D) L^*, H^* and C^*. It is interesting to underline that most of processing methods which work with this color space proceed separately or sequentially on each one-dimensional histograms.
Several processing methods are based on a recursive subdivision of this color space. A widely used method consist in the determination of a 2D-plan which split the current cluster into two sub-clusters. This plan is chosen by examining the three one-dimensional histograms of the current cluster, and by computing a threshold on one of these histograms. The threshold is given by : (method 1) computing the median (Heckbert, 1977), (method 2) computing the value which maximizes the inter-class variances (Wan et al., 1990), (method 3) detecting the most emergent peak among the 1D-histograms and then cutting in the middle of the valley formed by the first peak and its most emergent neighbor (Celenk, 1990).
We can show that among the 1D-histograms the H^* histogram needs to be analysed more specifically than the others because it is defined modulo $2\pi(H^*_{max})$. That is the first problem that we have to face.
As example consider Fig. 2 and Fig. 3. The shifting process of Fig. 3 can be used to

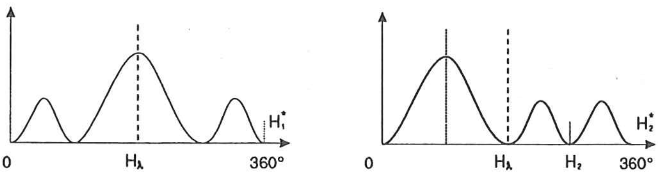


(a) worst case of study for each method.

(b) best case of study for each method.

Fig. 2. shifting of the H^* histogram ($H_2^* = (H_1^* + (2\pi - H_1)) \ mod \ 2\pi$) to preserve the continuity of the hue distribution (modulo 2π).

best detect peaks on the H^* histogram and to best separate two consecutive clusters. To illustrate our purpose, let consider the case of study for which the H^* histogram needs to be splitted in two clusters. In Fig. 3, the H_λ threshold value minimizes the intra-class variance of the two detected clusters. The splitting is more relevant in the second case (Fig. 3(b)) than in the first case (Fig. 3(a)) because it best isolates the most important peak from the others. Moreover, this process can be iterated in a second time to split the two remaining peaks.
Several solutions linked to signal processing field can be used to characterize relevant information on an histogram. In this article, we only deal with the problem of separating



(a) worst case of study for method 3.

(b) best case of study for method 3.

Fig. 3. shifting of the H^* histogram ($H_1^* = (H_2^* + (2\pi - H_2))\ mod\ 2\pi$) to best discriminate hue information.

consecutive clusters on the H^* histogram. Two examples of processes have been given to illustrate our approach. These solutions depend essentially on the criteria used to analyse histograms.

DIGITIZATION OF THE $L^*H^*C^*$ COLOR SPACE

In a first time, we have computed for different values of C^*, scaled according to a step of one unit, the value ΔH^*_{max}. ΔH^*_{max} is the maximal value of ΔH_1^* hue differences for two consecutive colors for which one of the color components R, G or B differs of one unit. As example, consider the following values at $L^* = 50$, for $C^* = 10, \Delta H^*_{max} = 1.86$, for $C^* = 20, \Delta H^*_{max} = 0.68$ and for $C^* = 30, \Delta H^*_{max} = 0.39$, $C^* = 40, \Delta H^*_{max} = 0.25$ $C^* = 50, \Delta H^*_{max} = 0.14$. We can observe that there is no systematic rule which permits to modelize the ΔH^* distribution, except that the minimal value of ΔH_1^* is reached for C^* ranging between 150 and 200, and that the maximal values of ΔH_1^* are reached for C^* "near-zero" (C^*_{min}) and for $C^* = 240$ (C^*_{max}), whatever the L^* values.
Two conclusions can therefore be done. First, since the maximum of the ΔH_1^* values is higher than the threshold of noticeable color difference, the digitizing of the $L^*H^*C^*$ color space is not enough finer to best characterize short color differences. Secondly, since the minimum of the ΔH_1^* values is sometime lower than the threshold of noticeable color difference, we can reduce the step of digitizing of this color component as we have done previously for the $L^*a^*b^*$color space, this without generating additional loss of sensibility in color difference perception. We propose that the digitizing step on the H^* component (d_{H^*}) will be equal to 0.5°.

The second problem that we have to face concerns the width of the digitizing step used to represent the H^* component.
The diagram of Fig. 4 is constructed as follow :

- Let x_1 and x_2 be two colors on the chromatic plane such as :
  $\Delta H_1^* = H^*_{x_2} - H^*_{x_1}, \Delta C_1^* = 0$ and $\Delta L_1^* = 0$.
- Let x'_1 and x'_2 be two colors on the chromatic plane such as :
  $\Delta H_1'^* = H^*_{x'_2} - H^*_{x'_1}, \Delta C_1'^* = 0$ and $\Delta L_1'^* = 0$, and $\Delta H_1'^* = \Delta H_1^*$.

In this figure we can see that a same color deviation on the H^* component does not involve a same color difference. The higher the C^* component is, the more the color deviation on

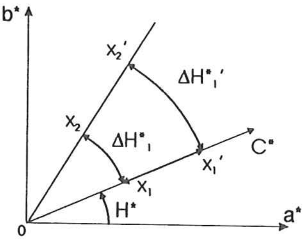


Fig. 4. accurate relationship between visual color difference perception and color measurement values on the H^* component.

the H^* component represents a higher color difference. Consequently, we can not analyse separately the H^* and the C^* component, such as in one-dimensional histograms analysis, except if we adjust the digitizing step of the H^* component in accordance with the value of the C^* component.
To do that, we propose to use the following functions :

$$d_{H^*}(C^*) = (H^*_{max} - d_{H^*}) \frac{B_{1-c'}(\alpha,\beta)}{B(\alpha,\beta)} + d_{H^*} \tag{3}$$

where $d_{H^*}(C^*)$ is the digitizing step of the H^* component associated to the C^* value.
With :

$$B_x(\alpha,\beta) = \int_0^x t^{\alpha-1}(1-t)^{\beta-1}dt \tag{4}$$

which represents the incomplete beta function defined between the two limiting values 0 and 1, thanks to $x = \frac{C^*}{C*_{max}}$.

$$B(\alpha,\beta) = \int_0^1 t^{\alpha-1}(1-t)^{\beta-1}dt \tag{5}$$

which represents the beta function.
(α,β) are two arguments which parameterize the beta function. In our case of study, we use $\alpha = 2.5$ and $\beta = 0.5$. Except for high levels of lightness where the visual sensitivity is saturated. Or, for low levels of lightness where the power of visual discrimination is very poor (Hurvich and Jameson, 1966). In these cases we use $\alpha = 0.5$ and $\beta = 2.5$.
So, for $C^* = 0, d_{H^*}(C^*) = 360°$. Then, $d_{H^*}(C^*)$ decreases quickly according to the increasing of C^* and rises 0.5° at $C^* = C^*_{max}$.
This process leads to a reduction of memory size necessary to code the $L^*H^*C^*$ color space.

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