HCL: a new Color Space for a more Effective Content-based Image Retrieval

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RESEARCH REPORT

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Abstract

Color analysis is frequently used in image/video retrieval. However, many existing color spaces and color distances fail to correctly capture color differences usually perceived by the human eye. The objective of this paper is to first highlight the limitations of existing color spaces and similarity measures in representing human perception of colors, and then to propose (i) a new perceptual color space model called HCL, and (ii) an associated color similarity measure denoted D_{HCL}. Experimental results show that using D_{HCL} on the new color space HCL leads to a solution very close to human perception of colors and hence to a potentially more effective content-based image/video retrieval.

Keywords: Color spaces, similarity color measures, content-based image retrieval.

1 Introduction

In image processing and computer vision, color analysis (e.g., dominant color identification, color-based object detection) is a low-level operation which plays an important role in image/video retrieval. A variety of color spaces have been developed for color representation such as RGB, perceptual color spaces HSL (hue, saturation, luminance), HSV/HSB (hue, saturation, value or brightness) [1] and HSI (hue, saturation, intensity) as well as perceptually uniform color spaces like L*u*v*, and L*a*b* (luminance L*, chrominance u*, v*, a*, and b*) and CIECAM02 [2, 3]. We recall that perceptual uniformity in a given color space means that the perceptual similarity of two colors is measured by the distance between the two color points. The objective of this paper is to first illustrate the limitations of existing color spaces and similarity measures in representing human perception of colors, and then to propose (i) a new color space model which aims at capturing the real color difference as perceived by human eye, and (ii) a new color similarity measure. The proposed space is inspired from HSV (or HSL) and L*a*b*.

The paper is organized as follows. Section 2 is a brief description of color spaces, their strengths and limitations. Section 3 presents a new color space called HCL while Section 4 presents a set of existing color distances, proposes a new similarity measure and provides a performance analysis of color distances applied to a set of color spaces. A conclusion is given in Section 5.

2 Color Spaces

The most commonly used and popular color space is RGB. However, this space presents some limitations. Color spaces like HSV and HSL are also commonly used in image processing. As opposed to the RGB model, HSL and HSV are considered as natural representation color models (i.e., close to the physiological perception of human eye). In these models, color is decomposed according to physiological criteria like hue, saturation and luminance. A great advantage of HSL/HSV models over the RGB model lies in their capacity to recognize the presence/absence of colors in a given image. However, the main drawback of HSL and HSV models concerns their luminance variation which does not correspond to human perception.

The CIE (*Commission Internationale de l'Eclairage*) has defined two perceptually uniform or approximately-uniform color spaces $L^*a^*b^*$ and $L^*u^*v^*$. Further, the $L^*C^*H^*$ (Lightness, Chroma, and Hue) color space has been defined as a derivative of $L^*a^*b^*$ [4]. The L*a*b* and L*C*H* color models are represented in Figure 1. Figure 1-a shows color distribution in these models while Figure 1-b illustrates the variation of chroma C^* and luminance L^* for six different hue values H^* (red, yellow, green, cyan, blue and purple). $L * C * H *$ color model has the luminosity of a hue (respectively the chroma) and grows (respectively decreases) slowly according to the increase in the percentage of white. This variation corresponds to human perception and hence represents a good feature in L*a*b* and L*C*H* color models.

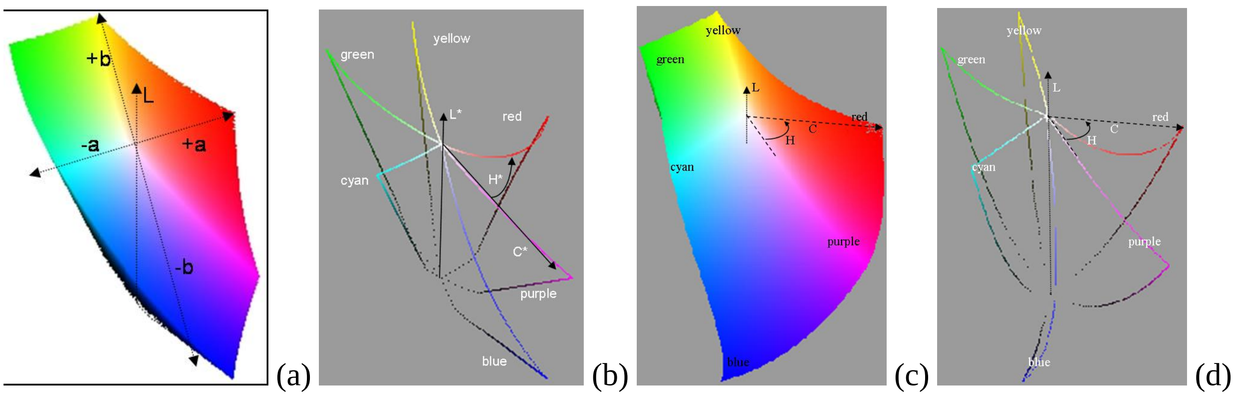


Figure 1. a) L*a*b* color models. b) Chroma and Luminance variations for six hue values. c) CIECAM02 color model. d) Chroma and luminance variations for six hue values.

As pointed out by [2], the spaces L*a*b* and L*C*H* have a significant deficiency since they have weak hue constancy for blues as illustrated by Figures 1-a and 1-b. Indeed, blue hue angle varies between 290^0 to 306^0. In order to get such constancy, another color space called ”CIE Color appearance model” (CIECAM02) has been proposed in [2]. Figures 1-c and 1-d show that CIECAM02 improves hue constancy for almost all colors except the blue hue angle which varies between 257^0 and 274^0.

3 A New Color Space

While in [5] propose new similarity semi-metric distances based on color histograms, the present paper investigates color pixel similarity analysis on a new perceptually uniform color space that we call HCL (Hue, Chroma and Luminance). Such a new color space exploits the advantages of each one of the color spaces: HSL/HSV and $L^*a^*b^*$ and discards their drawbacks.

3.1 RGB to HCL Color Space Convertion

We assume that the chroma and the hue of any color can be defined as a blend of the three chrominance elemental sensations: R-G (from red to green), G-B (from green to blue) and B-R (from blue to red). Based on this assumption and the Munsell color system with the three color attributes closed to human perceptions: hue (H), chroma (C) and luminance (L), we define below a mapping from RGB space to HCL space.

Based on the proportionality law of Von Kries, we define luminance L as a linear combination of $Max(R,G,B)$ and $Min(R,G,B)$ as follows :

$$L = \frac{Q.Max(R,G,B) + (Q-1).Min(R,G,B)}{2} \tag{1}$$

where $Q = e^{\alpha\gamma}$ is a parameter that allows a tuning of the variation of luminosity between a saturated hue (color) and a hue containing a great amount of white, with $\alpha = \left(\frac{Min(R,G,B)}{Max(R,G,B)}.\frac{1}{Y_0}\right)_{Max(R,G,B)>0}$ and $Y_0 = 100$. Parameter γ ($1 \leq \gamma \leq 31$) is a corrective factor that corresponds to the luminous efficacy of the normal human eye, *i.e.*, the response of the eye as a function of wavelength (frequency) under light-adapted (photopic and scotopic vision) conditions. It should be noted that when $Min(R,G,B) = 0$ and $Max(R,G,B)$ varies between 0 and 255, luminance L takes a value between 0 (black) and 128. When $Max(R,G,B) = 255$ and $Min(R,G,B)$ varies between 0 and 255, luminance takes a value between 128 and 130 for $\gamma = 1$, between 128 and 154.5 for $\gamma = 10$ and between 128 and 216.5 for $\gamma = 30$.

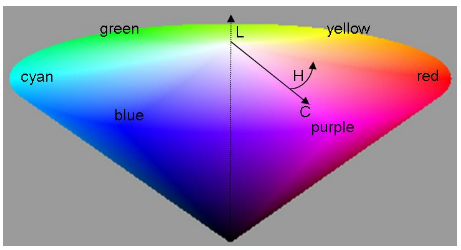
In a similar way, we define chroma $C = Q.C_n$ where C_n represents a mixture of three different combinations of R, G, and B components: red-green, green-blue and blue-red. The proposed formula for C (Equation 2) ensures linearity within lines/planes of hue (see Figure 2).

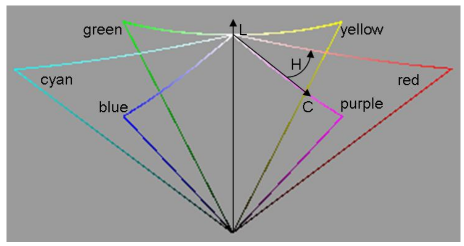
$$C = \frac{Q}{3}.\left(|R-G| + |G-B| + |B-R|\right) \tag{2}$$

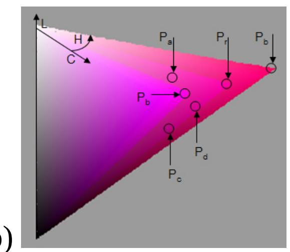
$$H = \arctan\left(\frac{G-B}{R-G}\right) \tag{3}$$

The hue value can be computed using Equation 3. However, hue values vary between -90^0 and $+90^0$ only. To allow hue values to vary in a larger interval going from -180^0 to 180^0 we propose the following formulae :

$$
\begin{aligned}
&\text{if } ((R-G) \geq 0 \text{ and } (G-B) \geq 0), \text{ then } H = \tfrac{2}{3}H \\
&\text{if } ((R-G) \geq 0 \text{ and } (G-B) < 0), \text{ then } H = \tfrac{4}{3}H \\
&\text{if } ((R-G) < 0 \text{ and } (G-B) \geq 0), \text{ then } H = 180 + \tfrac{4}{3}H \\
&\text{if } ((R-G) < 0 \text{ and } (G-B) < 0), \text{ then } H = \tfrac{2}{3}H - 180.
\end{aligned}
\tag{4}
$$



(a)


(b)


(c)

Figure 2. a) HCL color space model. b) Variation of chroma C and luminance L for six different hue values. c) a slice of the HCL model

Figure 2 shows the HCL color model using formulae L, C as well as H for $\gamma = 10$. We can notice that the HCL model have a uniform hue angle. The chroma C decreases while the luminance L increases according to an increase of the white color. In Figure 2-b, the following colors: red, yellow, green, cyan, blue and purple have a unique angle whose value is 0^0, 60^0, 120^0, 180^0, 240^0 and 300^0 respectively. Such result shows that HCL model offers a better hue constancy than L*C*H and CIECAM02 models.

3.2 HCL to RGB Color Space Convertion

The conversion from HCL to RGB color space can be done in two stages. The first stage consists to calculate $Q = e^{(1-\frac{3C}{4L}).\frac{\gamma}{Y_0}}$ where the parameters are defined earlier, and compute the maximum value $Max = \frac{4L-3C}{4Q-2} + \frac{3C}{2Q}$ as well as the minimum value $Min = \frac{4L-3C}{4Q-2}$ of the three R, G and B components. The second stage consists to attach the Max value as well as the Min value to one of the three R, G and B components by referring to the following six cases of the hue angles H. The H value is computed using Equation 3.

Case 1: $0^o \leq H \leq 60^o$: R=Max, B=Min and $G = \frac{R\left(tan(\frac{3}{2}H)\right)+B}{1+tan(\frac{3}{2}H)}$

Case 2: $60^o < H \leq 120^o$: G =Max, B =Min and $R = \frac{G\left(1+tan(\frac{3}{4}(H-180^0))\right)-B}{tan(\frac{3}{4}(H-180^0))}$

Case 3: $120^o < H \leq 180^o$: G=Max, R=Min and $B = G\left(1+tan(\frac{3}{4}(H-180^0)\right) - R.tan(\frac{3}{4}(H-180^0))$

Case 4: $-60^o \leq H < 0^o$: R=Max, G=Min and $B = G\big(1 + tan(\frac{3}{4}H)\big) - R.tan(\frac{3}{4}H)$
Case 5: $-120^o \leq H < -60^o$: B = Max, G = Min and $R = \frac{G\left(1+tan(\frac{3}{4}H)\right)-B}{tan(\frac{3}{4}H)}$
Case 6: $-180^o < H < 120^o$: B = Max, R = Min and $G = \frac{R\left(tan(\frac{3}{2}(H+180^0))\right)+B}{1+tan(\frac{3}{2}(H+180^0))}$

4 Color Similarity Measures

The notion of uniform color perception is an important criterion for classification and discrimination between color spaces. In order to capture perceptual uniformity in a color representation space, it is crucial to rely on the distance criterion which states that the distance $D(c_1, c_2)$ between two colors c_1 and c_2 is correct if and only if the distance value is close to the difference perceived by the human eye [6].

Many distances have been proposed based on the existing color models. The Euclidean distance (denoted by $\triangle E$) is frequently used in cubic representation spaces such as RGB and L*a*b*. Another $\triangle E_{94}$ distance was intensionally proposed for L*C*H [7]. A cylindric distance (denoted by D_{cyl}) [8] is used for cylindric and conic spaces like HSL, HSV and L*C*H*. Recently, another formula for computing color difference (denoted by $\triangle E_{00}$) has been proposed in [9].

4.1 A New Color Similarity Measure

In the following we define a new color similarity measure called D_{HCL} and based on the cylindric model with parameters A_L and A_{CH}. This measure is particularly adapted to the new color space defined in this paper.

$$D_{HCL} = \sqrt{(A_L \triangle L)^2 + A_{CH}({C_1}^2 + {C_2}^2 - 2C_1C_2\cos(\triangle H))} \tag{5}$$

where A_L is a constant of linearization for luminance from the conic color model to the cylindric model, and A_{CH} is a parameter which helps reduce the distance between colors having a same hue as the hue in the target (reference) color.

In order to determine these two parameters, we consider a slice of the HCL model (see Figure 2). For example, let us take a reference pixel P_r of saturated purple (see figure 2-c). We can see that a pixel P_a with the same hue ($\triangle H = 0$) and the same luminance ($\triangle L = 0$) with a difference in chroma equal to

$\triangle C = 50$ is more similar to pixel P_r than pixel P_b having $\triangle L = 0$, $\triangle C = 0$ and $\triangle H$ close to 8^0. But, if one uses the existing distance metric, the pixel P_b will have a smaller distance (more similar to pixel P_r) than pixel P_a. Then, we can determine A_{CH} as $A_{CH} = \triangle H + 8/50 = \triangle H + 0.16$. Moreover, the pixel P_b is more similar to pixel P_r than the pixel P_c having $\triangle H = 0$ and $\triangle C = 50$, and being darker ($\triangle L = 45$). However, the pixel P_d with $\triangle H = 0$, $\triangle C = 50$ and a greater luminance ($\triangle L = 25$) is more similar to pixel P_r than pixel P_b does. Due to this luminance effect, we proceed to a triangulation computation which leads to a correction factor equal to $A_L = 1.4456$.

4.2 Empirical Analysis

We have conducted an experimental study to first analyze the compatibility between the existing distances (e.g., $\triangle E$, $\triangle E_{94}$, $\triangle E_{00}$ D_{cyl}) and the color spaces HSV, L*C*H* and CIECAM02 (see Figure 3), and then contrast these distances against human perception. To that end, we have selected ten different colors as reference (target) colors. Each one of them is compared to a collection of randomly generated colors using each one of the proposed similarity measures. Colors are generated automatically by a variation of R, G and B values ($0 \leq R, G, B \leq 255$) using an increment equal to 15. This leads to a set of 4913 colors for each color space.

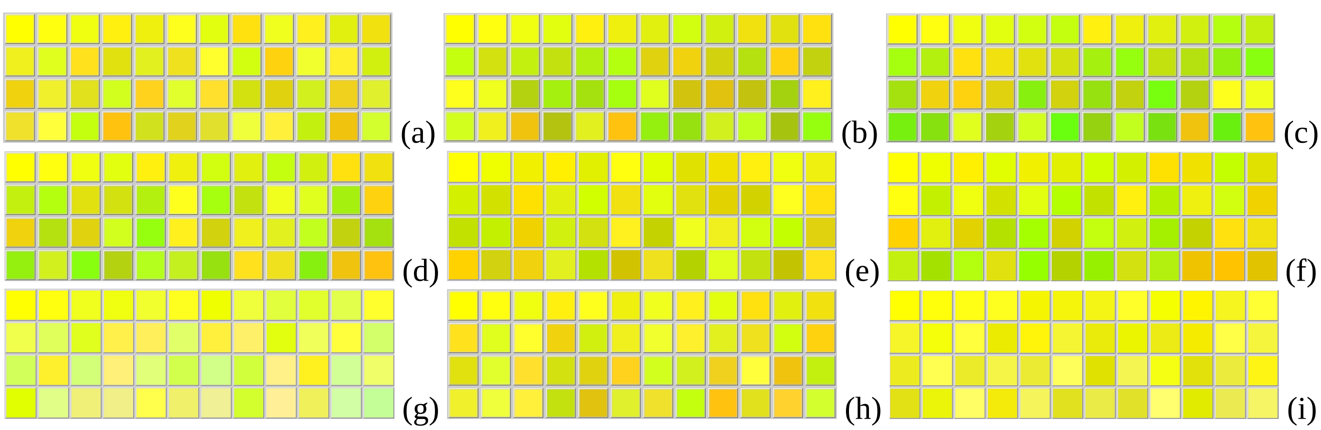


Figure 3. a), b) and c) Distance $\triangle E$ applied to RGB, L*a*b* and L*C*H* spaces respectively. d) and f) Distance $\triangle E_{94}$ applied to L*C*H* and CIECAM02 spaces respectively. e) and g) Distance $\triangle E_{00}$ applied to L*C*H* and CIECAM02 spaces respectively. h) Cylindric distance D_{cyl} applied to HSV space. i) New distance D_{HCL} applied to HCL space.

In order to compare the sequence of colors returned by the computer system (according to different color spaces and distances) with the list returned by the human system, seven subjects were asked to evaluate the output. For each one of the ten cases corresponding to pairs of a given color space and a color distance, there are 48 cells: the reference color cell (leftmost top cell) and 47 (returned) color cells. Every subject has to choose and rank the top ten colors that are most similar to the reference color. If less than ten colors are selected by a subject for a given combination of color distance and space (e.g., Euclidean distance and RGB), then the rank of missing colors is given the value 48. At the end of the experimentation, all subjects concluded that using D_{HCL} on HCL leads to better results than the other combinations of distance and space. Indeed, the combination of D_{HCL} and HCL returns much more colors that are similar to the reference color than any one of the other combinations.

Figure 4-a exhibits five rows corresponding to different colors. The first cell in each row identifies the reference color (red, yellow, green, blue and purple) while the remaining cells have a rank from 1 to 12 where rank 1 corresponds to the color which is the most similar to the reference color. The ranking is computed as the average judgment of seven subjects, three of them are experts in image processing.

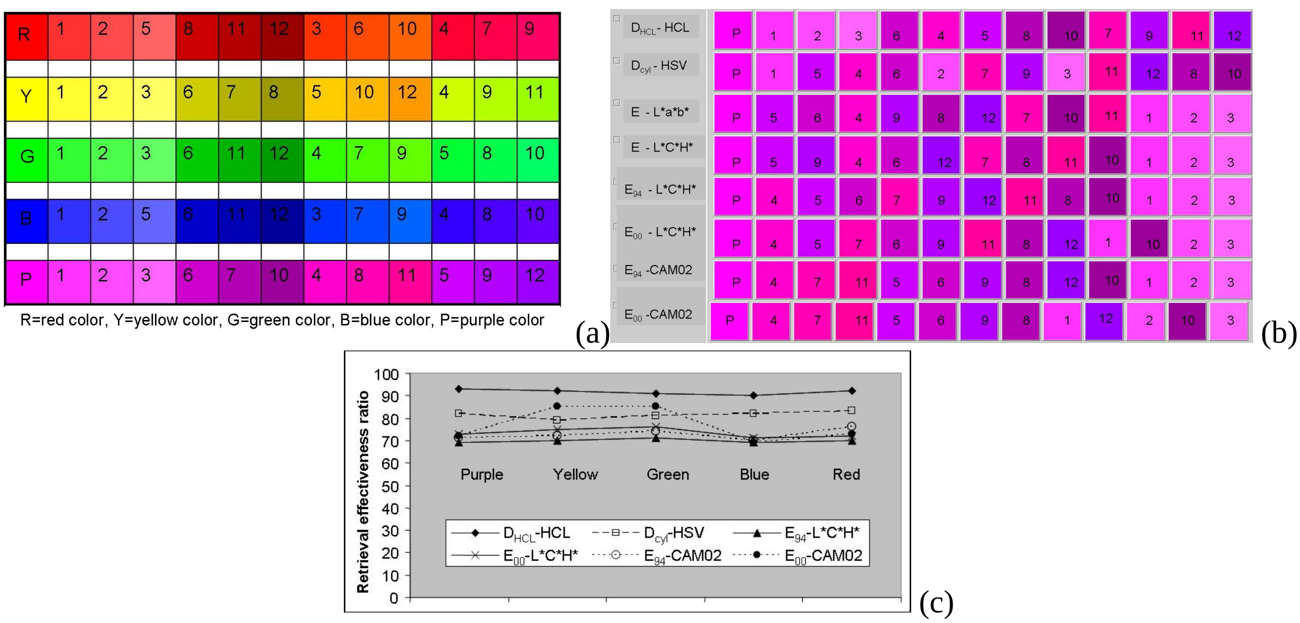


Figure 4. a) Five reference colors with the average ranking of similar colors (from 1 to 12). b) Ranking according to eight pairs of distances and color spaces. c) Retrieval effectiveness of six combinations of distances and color spaces.

Figure 4-b provides the ranking for the purple color. The first row corresponds to the ranking (from the most similar to the less similar) using the distance D_{cyl} and the HCL space defined in the paper. The remaining rows give the ranking returned by the pairs D_{cyl} and HSV, $\triangle E$ and L*a*b*, $\triangle E$ and

L*C*H*, $\triangle E_{94}$ and L*C*H*, $\triangle E_{00}$ and L*C*H*, $\triangle E_{94}$ and CIECAM02, and $\triangle E_{00}$ with CIECAM02, respectively.

To quantify the potential of each distance to return the colors that are close to human perception, we have applied the following effectiveness measure (see [5] for more details).

$$Eff_{sys} = \frac{1}{1 + log(\frac{R}{R_c})} \frac{\sum_{i=1}^{R_c} i}{\sum_{i=1}^{R_c} i + \sum_{i=1}^{R_c} |i - r_i|}. \tag{6}$$

where R_c is the total number of relevant colors (according to the user's judgment) in the color set, R is the total number of retrieved colors ($R \geq R_c$), i ($= 1, 2, \cdots, R_c$) is similarity image ranking by human judgment and r_i corresponds to system image ranking (in a decreasing relevance order).

The curves in Figure 4-c illustrate the retrieval effectiveness ratio of color distance and space combinations for five reference colors where the ordinate represents the average effectiveness computed from the judgment of seven subjects. One can see that the combination of D_{HCL} and color space HCL outperforms the other combinations of color distances and spaces. The pair $\triangle E_{00}$ and CIECAM02 provides good results for yellow and green but the worst effectiveness ratio for the three other colors. The pair $\triangle E_{94}$ and L*C*H* gives the worst retrieval effectiveness for all the selected colors.

Moreover, we conducted additional empirical studies to compare the proposed color space HCL against L*C*H* and CIECAM02 on an image data set of 75000 images representing photographs and paintings of small, medium or high resolution. This includes 50000 images from the database of the Info-Muse network [10] containing museum collections in Québec (Canada) as well as images from different web sites [11]. The first set contains art images related to paintings, statues, medals and ancient clothing items. The whole collection is grouped under four overlapping semantic classes: painting, close-up, indoor and outdoor images. Each class (e.g., Outdoor) is further split into subgroups (e.g., city, landscape, etc.).

Based on a previous work on similarity analysis [5], the comparison between two images makes use of color histograms and a similarity distance involving the Dirichlet distribution. Figures 5-a through 5-c illustrate the retrieval output provided by the system when CIECAM02, L*C*H* and HCL color spaces are used, respectively. When an image query (leftmost top image) is submitted, the system returns images in a decreasing order of similarity. A careful look at the three figures indicates that HCL outperforms the two other spaces. For example, one can see that the first two rows in Figure 5-c contain images with colors closer to those in the image query than images in the same rows of Figures 5-a (CIECAM02) and 5-b (L*C*H*).

(a)

(b)

(c)

Figure 5. a) Image retrieval using CIECAM02 color space. b) Image retrieval using L*C*H* color space. c) Image retrieval using HCL color space.

5 Conclusion

In order to overcome the limitations of existing color spaces and color distances in correctly capturing color differences perceived by the human system, we have presented a new color space called HCL inspired from HSL/HSV and L*a*b* spaces as well as a new similarity measure labelled D_{HCL} and tailored to the HCL space. Experimental results show that using D_{HCL} on HCL leads to a solution very close to human perception of colors and hence to a potentially more effective content-based image/video retrieval.

We are currently studying the potential of our findings in three fields of image/video processing, namely : image segmentation, object edge extraction, and content-based image (or sub-image) retrieval.

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