3D Visualization of Color Data To Analyze Color Images

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Abstract

3D Virtual Reality tool makes color analysis intuitive. Indeed color data are much easier to analyze using 3D diagrams than using 2D sections or inspecting directly the ASCII data files. The aim of this study is to propose a set of tools based on 3D Virtual Reality to display color information in differents color spaces and different color representations, first in order to analyze which color space is the most relevant in regards to a computer vision process and a given image, and next to test in realtime differents algorithms to select the most relevant algorithms, or to understand why an algorithm or a color space gives better results than another, in regards to a given process (segmentation, quantization, indexing, ...) and a given image.

1. Introduction

The aim of this study is to propose a set of tools based on 3D Virtual Reality to display color information in differents color spaces and different color representations, first in order to analyze which color space is the most relevant in regards to a computer vision process and a given image, and next to test in realtime differents algorithms to select the most relevant algorithms, or to understand why an algorithm or a color space gives better results than another, in regards to a given process (segmentation, quantization, indexing, ...) and a given image.

This 3D Virtual Reality tool makes color analysis intuitive. Indeed failures or anomalies of color data or gamut data are much easier to detect and to analyze using 3D diagrams than using 2D sections or inspecting directly the ASCII data files.

Let us introduce the following notations:

- at each pixel (i,j) of an image corresponds a color **C** of coordinates (R,G,B); a color image can be displayed in a color space of 3 dimensions, e.g. the R,G,B color space.
- at each color **C** of an image corresponds one or several pixels, i.e. an occurrence f(**C**); a color image can be characterized by a color histogram of 3 dimensions, e.g. the R,G,B dimensions.
- at each region R_i of an image corresponds a set of adjacent pixels and a color cluster N_i (i.e. a set of color colorimetrically closed); a color image can be characterized, in a color space of 3 dimensions, by its graph of adjacency of colors (CAG) such as:
  – at each vertice N_i corresponds a region R_i and two color values: the mean $(\vec{\mu}_i)$ and the standard deviation (σ_i) representatives of the color distribution of this region,
  – at each edge e_{ij} corresponds a pair of color clusters representatives of two adjacent regions $\{R_i, R_j\}$ and a color distance $d^2(N_i, N_j)$ which can be used to compare the color distribution of these two regions.

2. Visualization of Color Data

In order to visualize color data of a color image, we have developed different tools based on 3D Virtual Reality,* such as:

- a viewer. Themain windowis an image reader/viewer. It can be used to read an image file using: a command line, a “File/Open” menu or by a drag and drop process from the file explorer of Windows. Dealing with color accuracy, this viewer has been designed to load and display color images using 16 bits per channel coding. A selection mechanism using color transparency has been included in the image viewer. This allows the user to select different regions of interest (RoI) in the image. At each of these RoI corresponds one transparency color. This selection process has been chosen in order to build non-connected pixels set.
- a window to display colors in different spaces of representation. The user can select:
  – either a color space (3D) representation. The main aim of this toolbox is to propose an interactive method to visualize the 3D dimensional aspect of the color information. For this purpose we have built a specific interface adapted for color space visualization.
  – either a color image (2D) representation. This 2D color representation enables the user to display the image conversion content. Each channel is mapped respectively to the red, green and blue channels of the displayed image. These channels can be displayed separately using different look up tables (LUT).

*Most of these tools can be accessed at the following http address http://www.couleur.org/colorspace.html

- a window to select a color space. The color space converter window is a selector which includes three menus associated to different display methods of color data images. The main component of the window is dedicated to the color space selection and configuration. All the color transforms processing done in this software use a floating point color data internal representation.

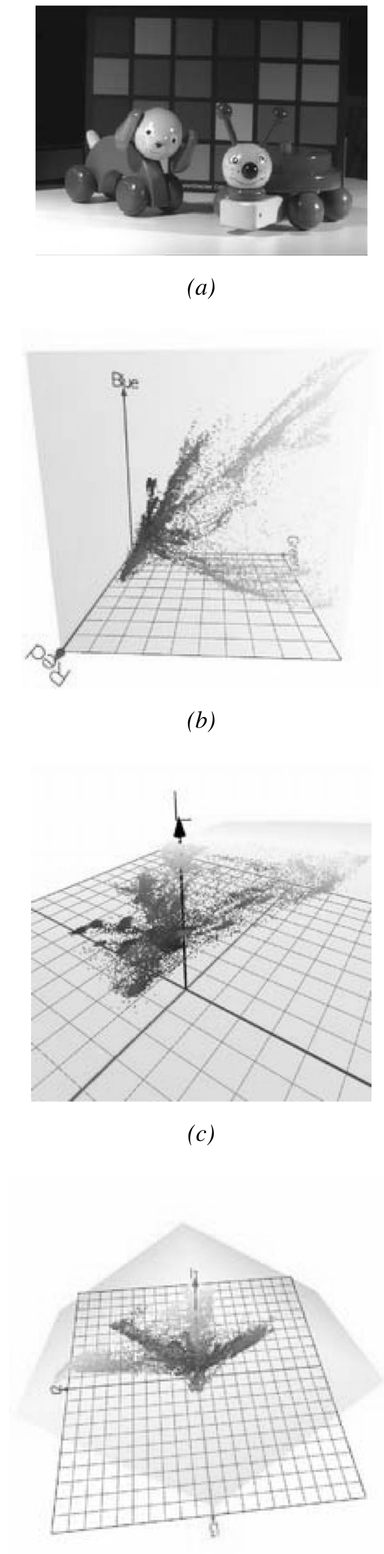
  This window is the control center of this software; it has been designed to launch the different windows used to display the color information: (1) within an image (2D) where each color channels of the original color space are associated with the red, green and blue channels of the displayed image, (2) within a 3D viewer where colors are represented by their 3D coordinates. For color spaces using XYZ as intermediate color space, the primaries, the XYZ offset and the reference white/illuminant can be changed directly or by using some predefined values.

- a 3D navigation interface. The 3D navigation interface uses a virtual camera which allows the user a 3D environment interaction using the mouse or a 3D camera window. The 3D camera window can be used to define precisely the 3D point of view (position of the camera and its target in Cartesian coordinates or in spherical coordinates, field of view of the virtual camera, visualization mode: perspective or orthographic projection).

Several visualization options have been included in order to customize the display : (1) 3D primitive selection (sphere, cube, tetrahedron), (2) primitive display mode: point, wireframe, flat, smooth, (3) CIE standard observer visualization: CIE 31 and/or CIE 64 (for color spaces that use XYZ as intermediate color space). According the options used in the color space selection windowthe user will be able to display : (1) a direct 3D representation of all the selected colors; (2) the 3D histogram of these colors where the 3Dprimitive size are used to define the color frequency. This software uses :

- the Gtk+ library as graphic user interface (GUI), this library originally developed for X-Windows graphic interface is now available on Windows systems. By usingGtk+ (http://www.gtk.org), we are able to build, without code modification, UNIX andWindows versions of this software. One characteristic of this visualization library is its accuracy and efficiency which controlled by the number of polygons (solid volumes or edge lines) used to represent the color gamut of an image. Another characteristic of this 3D Virtual Reality library is its interactivity, since the user can select in realtime multiple windows for different data, or multiple windows for same data (different representations).

- the ImageMagick library, this library has been used to read image files (image with 16 bits by channel are accepted). This library can read a tremendous variety of file formats (http://www.imagemagick.org).



(a)

(b)

(c)

(d)

*Figure 1. Representation of color data of image (a), in different color spaces : RGB (b), L*a*b* (c) and I1I2I3 (d).*

- the OpenGL toolbox, this toolbox has been used to display the 3D color information (http://www.opengl.org)

3. Computation of Color Data

Spaces used in image processing are derived from visual system models (e.g. RGB, opponent color space, IHS, *etc.*); adopted from technical domains (e.g. colorimetry, *XYZ*, television, *YUV*, *etc.*) or developped especially for image processing (e.g. $I_1I_2I_3$ (Ohta) space, *YCC* (Kodak Photo) space, *etc.*).

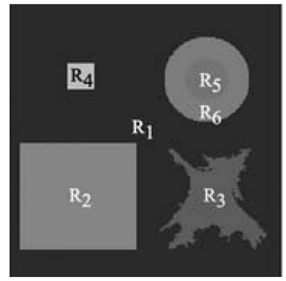
In a general way, we consider that there is four families of color spaces : (1) Primaries color systems *RGB*, *CMY*, *XYZ* (*xyY*), *LMS*; (2) Luminance-chrominance color systems *YUV*, *YIQ*, YC_bC_r, *HSV*, *HSI*, *LHS*; (3) Perceptual color systems *UVW*, *L*a*b**, *L*u*v**, *LHC*; (4) Non-correlated color systems $X_1X_2X_3$, $I_1I_2I_3$; (5) Hybrid color spaces.[1] The reasons for applying color spaces transformations are very varied. The choice of an appropriate color space can be an important factor determining the results of an algorithm on a color image (e.g. the quality of image segmentation, compression ratio, etc.). In practice there is no ideal color space for all image processing applications. The decision on which color space to use depends on the processing task. An optimal decision can be very hard to find. However, knowledge of the properties of the various color space makes the choice easier.

Some of the properties of the various transformations between *RGB* and other color spaces described in this paper are summarized in table 1:**

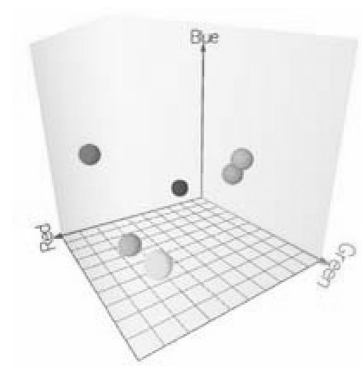
Table 1. Properties of Color Transformations Between RGB and Other Color Spaces.

Color space	Linearity of transformation	Stability of calculations	Perceptual uniformity
rgb	No	No	No
XYZ	Yes	Yes	No
xyz	No	No	No
*L*a*b**, *L*u*v**	No	Yes	Yes
YUV, *YIQ*, YC_bC_r	Yes	Yes	No
AC_1C_2, Opponent	Yes	Yes	No
$X_1X_2X_3$, $I_1I_2I_3$	Yes	Yes	No
IHS, Perceptual	No	No	No
Munsell	No	Yes	Yes

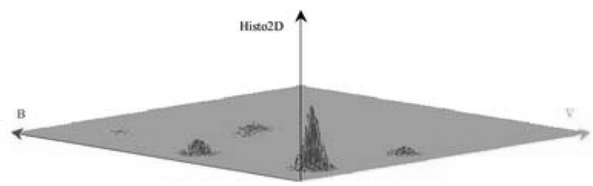
**N.b. Non-linear transformations like hue, saturation, and normalized color have non-removable singularities, near which a small perturbation of input *R*, *G*, and *B* can cause a large jump in the transformed values. Moreover, the distribution of the non-linearly transformed values can shows spurious modes and gaps. By these reasons and from the computational point of view, linear transformation such as *Y*, *I*, and *Q* would be more preferable than nonlinear ones.



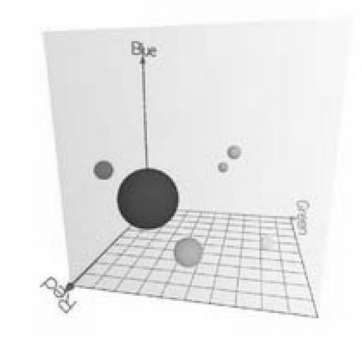
(a)



(b)



(c)



(d)

Figure 2. (a) Image studied. (b) Colors represented in RGB. (c) Histogram (2D) of color componants G, B. (d) 3D Representation of colors histogram in RGB.

3.1. Visualization of Color Data

One objective of this study is to enable the user to display color image data in different color spaces (cf. Figure 1). One reason which justifies this objective is that there is no “universal” color space which is well-adapted for all image processing applications. Sometime, none color space does not satisfy to none processing searched.

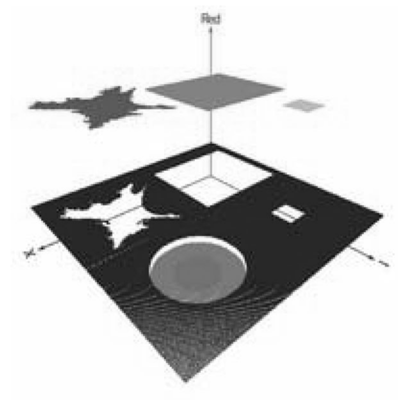
Considering that at each region of an image corresponds a set of colors more or less dispersed in the color space studied; it is interesting to analyze: (1) how, from one color space to another one, are distributed color clusters the ones comparatively to the others, in an objective of discrimination for example, or (2) how are distributed each of these clusters taken separately, in an objective of recognition. The interest of such a tool is to help the user to select the color space, or by default the color components, which are *a priori* the most relevant in regards to a computer vision process and a given image, knowing that in a general way:

- there is no ideal color space for all image processing applications.
- if a color space gives better results in regards to a given application, that does not imply necessarily that this color space will give better results in all cases of study; that depends of images sets studied.
- from one application to another, parameters of study are not the same, sometimes they are linked to numerical criteria sometimes they are linked to visual criteria, this sets the problem of color space quality assessment in reference to image processing quality assessment. Consequently, considering that from one color space to an another one the difference of quality is small, according to criteria of study used, sometimes a color space could give better results than other one, sometimes it could give worse results.

This tool enables to assess the quality of a color space, this in order to help the user to select its space of study.

4. Representation of Color Histogram

The main difficulty we have to face when we compute a color histogram is due to the fact that: (1) a color histogram requires a 3 dimensional representation and that: (2) each of its dimensions is generally coded with at least 256 values. Consequently a color histogram requires at least 256^3 cells.



(a)

(b)

Figure 3. (a) Projection, and (b) section, 3D of histogram 5D ((R,G,B), (i,j)) of Figure 2 (a).

The second difficulty we have to face when we compute a color histogram is due to the fact that most of histogram cells have a frequency of occurrence very small. So, for a color image of size $n*m$ the smallest probability to have a cell with no occurrence is

$$1-\frac{n*m}{256^3}.$$

To solve these difficulties some solutions have been developed[2-4] nevertheless none is really optimal.

In order to visualize 3D color histogram, we have developed a new strategy which consists:

- either, first to compute color histogram (and color statistics), next to visualize color histogram in 3D representation. In such representation the size of geometric primitives is proportional to the color densities (cf. Figure 2).
- either to visualize spatiocolor data (i.e. (RGB) with (i,j) in 5 dimensions (i.e. in high-dimensional environment[5,6]) through 3D cross-sections (cf. Figure 3).

5. Quality of a Color Space

In order to assess the "quality" of the color space used by a user, the software enables to compute and to display, from 3D color representation, several features characteristic of the color distribution studied, such as: (1) global and local (from RoI selected) first statistical moments, (2) principal component axes (PCA) and their first statistical moments, (3) color densities and convex hull of each color cluster selected, (4) color distances between each pair of color clusters corresponding to each pair of RoI selected,

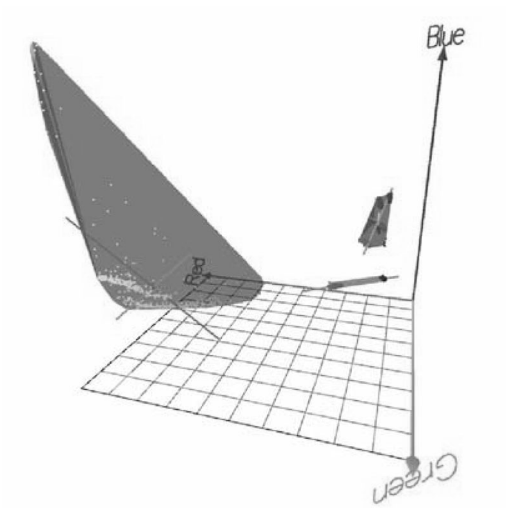


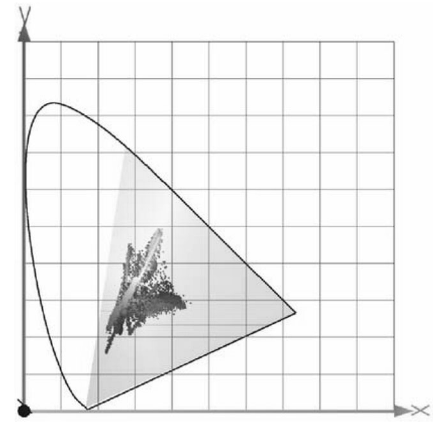
Figure 4. Convex hull and first two principal components of the 3 color clusters the most distants of Figure 1 (a).

These features can be used either to compute similarity metric between images, or to study the invariance, the robustness, of these features to change of scale, rotation, translation, occlusions, etc. Moreover:

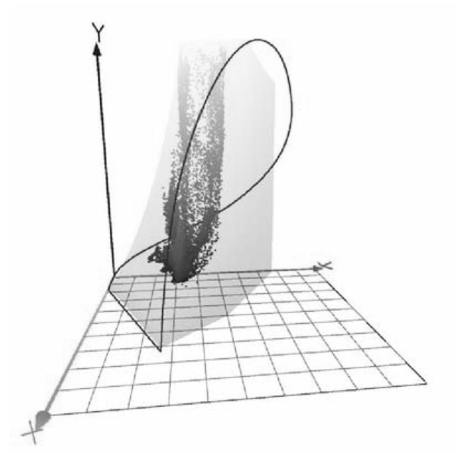
- Color gamut of a given image can be displayed in the 2D chromatic plane *xy* (cf. Figure 5) in order to analyse which are the chromatic changes that a user can do, or not, to enhance color contrasts in the studied image.
- Principal axes can be displayed in the 3D color space in order to analyse which clusters can be better discriminated by such axes than with other axes (cf. Figure 4).
- Convex hull can be displayed in the 3D color space in order to analyze if color clusters can be easily discriminated, or if they overlap, in regards to one or several color components.

5.1. Simulation of Chromatic Changes

In order to use the *RGB* to *XYZ* transformation, the user have to specify both the reference white used and the primaries of the technology used. Unfortunately, in most of computer vision applications, the user do not know these data, nevertheless he can predict these data by using a color constancy algorithm.



(a)



(b)

Figure 5. Representation in the chromatic plane xy, or in the color space xyY, of colors of Figure 1 (a).

In order to analyze color effectswhich result of a change of lighting conditions (i.e. change of reference white, for example between *A*, *C* and D_{65} standard illuminants), or a change of technology (i.e. change of primaries, for example between standards EBU, CIE and NTSC), a visualization toolbox have been developped (cf. Figures 6 and 7). In order to simplify the representation of chromatic changes induced by such changes, the user can select one or several RoI, i.e. one or several color clusters.

This toolbox enables, as the 3D representation toolbox, to analyze if colors of an image are globally or in part, i.e. only for some of them, better discriminated with one features or with another one.

Likewise, this toolbox can be used to analyze either global chromatic changes, or local chromatic changes associated to color clusters selected, which appear between one image and another one. This toolbox can be useful for differents applications, e.g. video image retrieval and indexing applications.

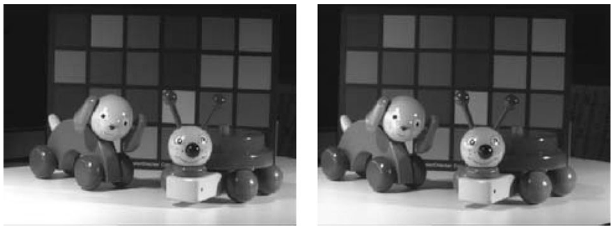


Figure 6. Chromatic changes due to a change of spectral signature of the illuminant.

6. Conclusion and Perspectives

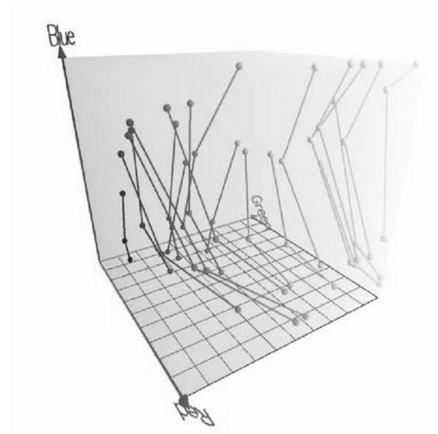
The main characteristic of this work has been to gather in one toolbox several color image analysis tools based on 3D visualization of color data. Another characteristic of this work has been to propose new tools devoted to color imaging.

One aim, at most long term, will be to develop a more sophisticated assessment toolbox of color space quality in order to assess the quality of image processing algorithms. This in order, for example, to optimize the adjustment of threshold values of algorithms in regards to the color space selected.

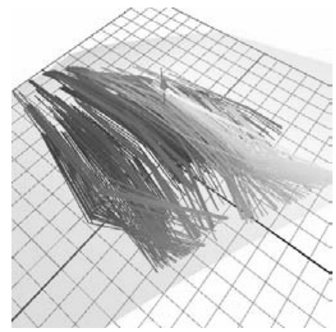
Another aim will be to add a chromatic analyze toolbox which, in lack of *a priori* knowledge, will compute the reference white of a given image. Several techniques have been proposed by Graham Finlayson or David Brainard. Among them, we will use the "color by correlation" technic introduced by Finlayson which, in the chromatic plane *xy*, analyze where is localized the set of colors of the studied image.

Among the differents applications on which we are working now, let us cite:

- image indexing, the aim is to test the robustness of several features to changes of illuminant, changes of viewing direction, occlusions, changes of scale, etc. In the current version of the image retrieval toolbox that some of our colleagues have developed (see "icobra" toolbox at http://www.ligiv.org/icobra), the user has only the possibility to select some low level color features. In the next version, the user will have the possibility to select high level color features.
- image watermarking, the aim is to test the invisibility of some signatures and their robustness to changes of illuminant, changes of scale, etc.
- image segmentation, the aim is to develop a new method of clusters merging in the color space from the graph adjacency of colors based on several color spaces, considering the hypothesis that some color clusters are better discriminated in some color spaces rather in others.



(a)



(b)

*Figure 7. Chromatic changes between images of Figure 6 and Figure 1 (a). In the RGB color space (a), for different color clusters pre-selected. In the L*u*v* color space (c), for color of highest frequency.*

7. References

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