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Color Image Transformations and Spaces: An Application to Color Image Segmentation

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Abstract— **This paper presents color concepts and all the mathematic relationsused in ColorSpace.Acolor image transformation refers to processing of components ofa color image within a single color model.**

Keywords— **Color image segmentation, color space transformations, RGB color space, HSI color space, CIELAB**

I. INTRODUCTION

Image segmentation is the first step in image analysis and pattern recognition. It is a critical and essential component of image analysis and pattern recognition system, is one of the most difficult tasks in image processing, and determines the quality of the final result of analysis. Image segmentation is a process of dividing an image into different regions such that each region is, but the union of any two adjacent regions is not, homogeneous. According to [1], "the image segmentation problem is basically one of psychophysical perception and therefore not susceptible to a purely analytical solution". There are many papers and several surveys on monochrome image segmentation techniques. Color image segmentation attracts more and more attention mainly due to the following reasons: 1] color images can provide more information than gray level images 2] the power of personal computers is increasing rapidly and PCs can be used to process color images.

Now, the segmentation techniques for monochrome images can be extended to segment color images by using R, G and B or their transformations linear nonlinear. However, comprehensive surveys on color image segmentation are few, analyzed the problem when applying edge based and region based segmentation techniques to color images with complex texture and discussed the properties of several color representations the segmentation methods and color spaces.

This paper provides a summary of color image segmentation techniques available at present and describes the properties of different kinds of color representation methods and problems encountered when applying the color models to image segmentation. Some novel approaches such as fuzzy and physics based approaches will be discussed as well. Section 1 briefly introduces this paper. Section 2 reviews some major color representations and color spaces. Section 3 represents experimental results using different color representations and the conclusion is given in section

II. COLOR SPACES

Color Spaces and Distances

The world of color spaces and metrics is far wider than one could imagine at first glance[2]. There are literally dozens of them, usually in a straight relation to their specific use. Thus, there are color spaces for the fabric industry, paper industry, press, psychology, television, computers, physics, and even for foods. Despite the numerous efforts to find a definitive one, there is no single all-terrain color space or even a simple way to compare colors valid enough to everyone.N. Vandenbrouke et al. [3] described a new approach for color image segmentation which is considered as a problem of pixels classification. They show how the colors of the pixels of digital color images can be represented in different colorspaces for color image analysis applications.One of the most important problems in color image analysis is that of segmentation [4].

Here, we are not going to rehash them all over again, not even some of them. We just summarize those found essential for our interests and means, basically digitalized color images given in RGB coordinates. For a more extensive study on color, we suggest Wyszecki and Stiles' book [5].

RGB

These are the color coordinates provided by most capture and imaging sets nowadays. They consist basically in the sensor response to a set of filters. Those filters are an artificial counterpart of the human mechanism of color perception and reproduction of most colors can be achieved by modulating three channels roughly corresponding to colors red, green, and blue.

Nevertheless, some problems arise when trying to emulate the human judgement of color differences. First, we are more sensitive to some colors than others, which mean that for them our sense of difference is finer. This is not the case when using the above distance. Moreover, some color changes affects differently on some areas of the color space. Nonetheless, since the Euclidean distance is homogeneous and isotropic for the RGB color space, the aforementioned kind of nuances in the differences between colors cannot be reproduced. Next, we consider three possible alternatives coping with those difficulties, namely, HSI, Lab, and Luv color spaces. All of them try to translate the human perception of color into figures. Besides, both Lab and Luv aspire to define a space where the Euclidean metric can be used straight away to estimate subtler color differences.

In addition to these approaches, there also exists a number of other works on color representation being the most important among them those of Smeulders and Gevers. The authors try to generate there a set of color invariants by all sorts of derivatives of a fundamental color invariant extracted from certain reactance model. We are not considering those endeavours in our work because their involvement limits a practical application as well as results only show their performance on a pretty small set of images of too unrealistic and homogeneous objects.

Our greatest objection to these classes of invariants, however, has to do with the way a given color is transformed independently of what happens in the rest of the color space and of the illuminated conditions that produced such measure. As a consequence, the invariant will always produce the same result for the same input no matter this color comes from two different surfaces under different light conditions which happen to coincide in this color at least. This problem is usually referred to as mesmerism and is greatly reduced if the whole set of colors is considered instead.

HSI

There are many color models based on human color perception or, at least, trying to do so. Such models want to divide color into a set of coordinate'sdecor relating human impressions such as hue, saturation, and intensity. Next expressions compute those values from raw sensor RGBquantities

$$I = \frac{1}{3}(R+G+B)$$

$$S = 1 - \frac{\min\{R,G,B\}}{I}$$

$$H = \arctan\left(\frac{\sqrt{3}(G-B)}{2R-G-B}\right)$$

I model the intensity of a color, i.e., its position in the gray diagonal 5. Saturation S accounts for the distance to a pure white with the same intensity, that is, to the closest point in the gray diagonal. H is an angle representing just a single color without any nuance, i.e., naked from its intensity or vividness. Some approaches erroneously to our taste use the Euclidean directly to compute color differences in HSI coordinates forgetting that hue is an angle and not strictly a spatial measure. A better distance would be the following expression

$$\Delta C = \sqrt{(I_2 - I_1)^2 + {S_2}^2 + {S_1}^2 - 2S_2S_1\cos(H_2 - H_1)}$$

At small intensities or saturations, hue is very imprecisely determined with those expressions and it is a better idea to compare colors by means of their intensity in that case.

CIELAB

The CIE6 1976 (L*; a*; b*) is a uniform color space developed as a space to be used for the specification of color differences. It is defined from the tristimulus values normalized to the white by next equations

$$L^* = 116\left(\frac{Y}{Y_w}\right)^{\frac{1}{3}} - 16$$

$$a^* = 500\left[\left(\frac{X}{X_w}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_w}\right)^{\frac{1}{3}}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_w}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_w}\right)^{\frac{1}{3}}\right]$$

The line from (0; 0; 0) to (Rmax; Gmax; Bmax), where the maximum coordinate value is 255 or 1, if normalized coordinates are used. In these equations (X; Y; Z) are the tristimulus values of the pixel and (Xw; Yw;Zw) are those of the reference white. We approximate these valuesfrom (R; G; B) by the linear transformation

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.607 & 0.174 & 0.200 \\ 0.299 & 0.587 & 0.114 \\ 0.00 & 0.066 & 1.116 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (1)$$

Our reference white is (Rw; Gw; Bw) = (255; 255; 255). L^* represents lightness,a^* approximates redness-greenness, and b^*, yellowness-blueness. These coordinates are used to construct a Cartesian color space where the Euclideandistance is used, i.e.,

$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

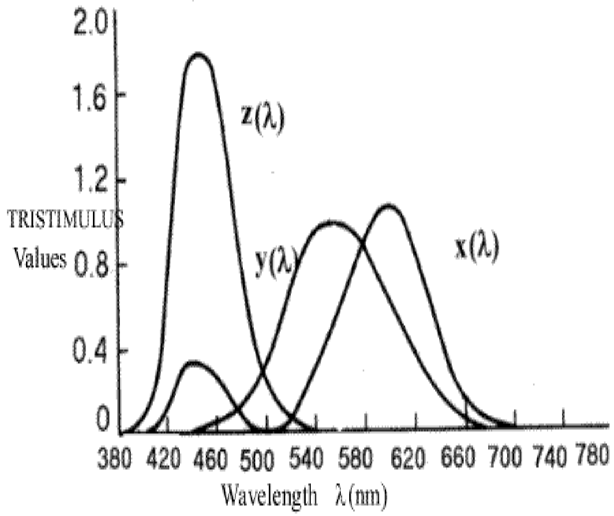


Figure 1 Color matching functions x(λ), y(λ), z(λ), for the 2^0 Standard Observer

CIELUV

The CIE 1976 (L^*; u^*; v^*) is also a uniform color space defined by equations

$$L^* = 116\left(\frac{Y}{Y_w}\right)^{\frac{1}{3}} - 16$$

$$u^* = 13L^*(u' - u'_w)$$

$$v^* = 13L^*(v' - v'_w)$$

In these equations u0 and v0 are the chromaticity coordinates of the stimulus

and u0w and v0w are those of the reference white. These values actually are the

CIE 1976 Uniform Chromaticity Scales (UCS) defined by equations

$$u' = \frac{4X}{X + 15Y + 3Z}$$

$$v' = \frac{9Y}{X + 15Y + 3Z}$$

As before, (X; Y; Z) are the tristimulus values of a pixel computed fromRGB values with Eq. (1). Analogously to (L^*; a*; b*) coordinates, those coordinates also construct a Cartesian color space where to use the Euclidean distance

$$\Delta E^*_{uv} = \sqrt{\Delta L^{*2} + \Delta u^{*2} + \Delta v^{*2}}$$

We must state that in [Fai97] is argued that (L*; a*; b*) are better coordinatesthan (L*; u*; v*) since the adaptation mechanism of the latter {a subtractive shift in chromaticity coordinatesrather than a multiplicative normalization of tristimulus values, (X=Xw; Y=Yw;Z=Zw) {can result in colors right out of the gamut of feasible colors. Besides, (L*; u*; v*) adaptation transform is extremely inaccurate with respect to predicting visual data. However, what is worst for our purposes is its poor performance at predicting color differences.

We consequently prefer to use Lab coordinates, whenever an alternative to the RGB space is needed.

CIE System of Color Specification:

- Standard observer
- CIE primaries.

Another specification of color that is also popular was generated by CIE (commission International de L' E clairage) an international body of color scientists in 1931.

Standard Observer

The CIE defined a standard observer by averaging the color matching data of a large number of observers having normal color vision. This standard observed data consists of color matching functions for primary stimuli of wavelengths *700 (R_o), 546-1(G_o)* and *435-8(B_o)* nm with units normalized in the standard way i.e. equal amounts of the three primaries are required to match the light from the equal energy illuminant E.

Using these curves shown in Fig(1) and given the spectral distribution of any color, we can use equation(1) to calculate the tristimulus values required by the standard observer to match that color.

CIE Primaries:-

CIE defined three new primaries *x*, *y*, and *z* in which standard observer results can be expressed. It is possible to calculate the amounts of **X,Y,Z** needed to match any color, given its tristrimulus values corresponding to any other primaries such as R_o, G_o and B_o. In order to do this, CIE has defined the transformation equations relating two primary systems as:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.365 & -0.515 & 0.005 \\ -0.897 & 1.426 & -0.014 \\ -0.468 & 0.089 & 1.009 \end{bmatrix}$$

Properties of CIE Coordinate System:-

(1) The trisimulus values X, Y, Z are normalized to equal energy white.

(2) The Y tristimulus value corresponds to the luminance of the color. The color matching function for Y is proportional to the relative luminous efficiency shown earlier.

(3) Unlike R, G, B system, where sometimes certain tristimulus values must be negative for match, the tristimulus value and the color matching functions in CIE-XYZ system are always positive as shown is Fig (2).

This positivity makes X, Y, Z primaries non-real or imaginary i.e. they cannot be realized by any actual color stimuli. In X, Y, Z tristimulus vector space, the primaries are represented by vectors outside the domain representing real colors. This will be clear from the following section.

Chromaticity coordinates in CIE-XYZ system.

For tristimulus value X, Y, Z the chromaticity coordinates are given by

$$x = X / X + Y + Z$$

$$y = Y / X + Y + Z$$
$$z = Z / X + Y + Z$$

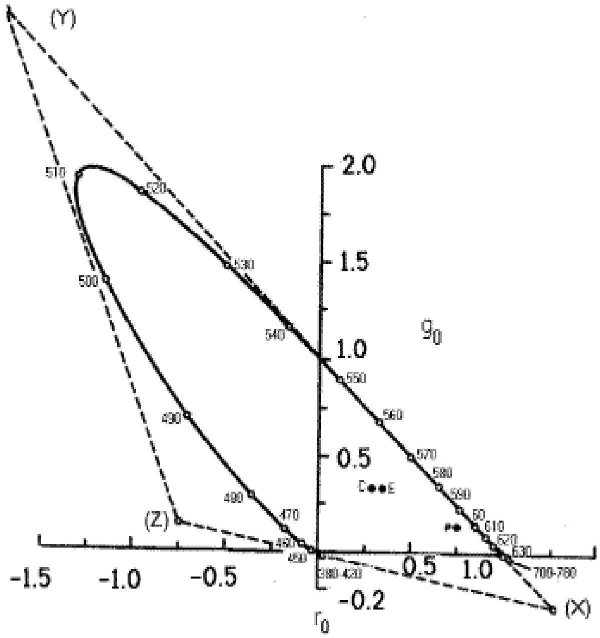


Figure 2 The (r_0,g_0) chromaticity diagram for the Standard Observer.

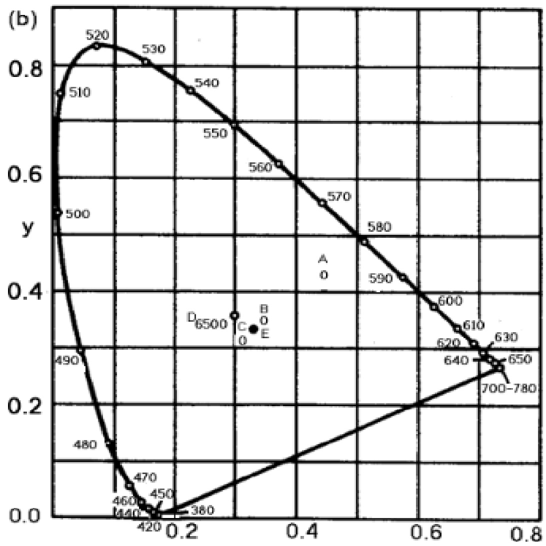


Figure 3 The (r_0,g_0) chromaticity diagram

Thus, a color is specified by two chromaticity coordinates (*x*, y) and the <u>*Y*</u> where <u>*Y*</u> is the luminance and (*x*, *y*) can be thought of as color of the stimulus devoid of brightness.

A plot of chromaticity coordinates for the physical colors forms a chromaticity diagram. Two such diagrams are shown in Fig (3) for chromaticity (r_0, g_0) and (*x*, *y*).

These chromaticity diagrams also show the chromaticity coordinates of each spectral color. The pure spectral colors are plotted on the elongated horse-shoe shaped curve called spectral-locus. The straight line joining the two extremes of the spectral locus is called the line of purples.

In (r_0, g_0) chromaticity diagram, the spectral locus extends outside the triangle formed by three primaries (R_0, G_0, B_0) which are located at (1,0), (0,1) and (0,0). The region within this triangle is referred to as a color gamut of primary sources i.e. contains all colors reproducible by R_0, G_0 and B_0.However as observed, there is a large range of spectra colors that cannot be synthesized by non-negative amounts of R_0, G_0, B_0.

In (x, y) chromaticity diagram, on the other hand, all spectral colors including the line of purples lie within the triangle with vertices (0,0), (1,0) and (1,1). Therefore, all real colors can be synthesized by positive amounts of X, Y, Z primary colors. But, all three vertices are outside the spectral locus, thus making them non-real. It is sometimes useful to indicate the qualitative color appearance in terms of the specification (*x*, *y*).

For this, we plot the chromaticity coordinates of the spectral colors individually for each wavelength. This is shown in Fig (4). These chromaticity plots are different from color matching functions of Fig (1), and should not be confused with them.

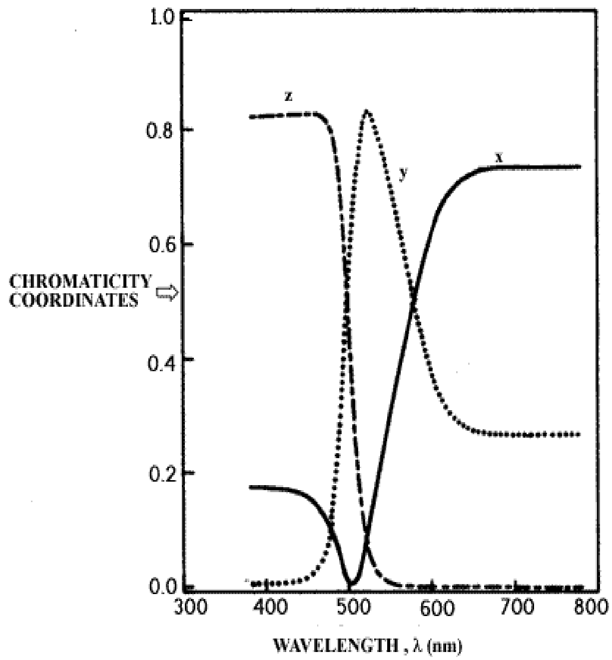


Figure 4 Chromaticity coordinates (x,y,z) of spectral colors.

From the (*x, y, z*) plots of the spectral colors, we observe that a large value of x indicates a substantial amount of red light that can be matched by colors that appear orange, red or reddish purple.If y is large, the color appears green, bluish-green or yellowish-green. A small value both for x and y indicates chromaticity z is large and such a color is matched by colors appearing blue, violet or purple. Note from Fig (4) that unlike the chromaticity coordinates (r_0, *g0, b0*) the chromaticity coordinates (*x, y, z*) shown in the same figure are always positive. Summarizing we can say that color images and its representation for human vision play an important role in image and video compression and coding. Present day image and video coding standards such as JPEG 2000, MPEG 2, 4 etc. employ various color spaces to achieve high compression ratios.

Color Mixtures

One important objective of colorimetry is to be able to specify the color of a mixture in terms of the components of the mixture. Any technique by which, an unknown color is evaluated in terms of known colors. Colorimetry may be visual, photoelectric, or indirect by means of spectrophotometry. These techniques are widely used in scientific studies involving the appearance of objects and lights, but are of greatest importance in the color specification of the raw materials and finished products of industry.

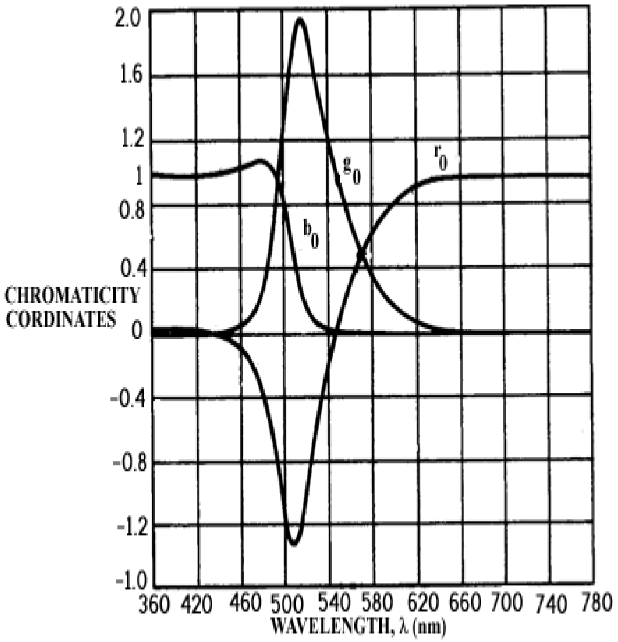


Figure 5 Chromaticity coordinates (r_0,g_0,b_0) of spectral colors for the 2^0 Standard Observer Primaries R_0,G_0,B_0 at wavelengths 700.0nm, 5461.1 nm and 435.8nm respectively

In visual colorimetry, the unknown color is presented beside a comparison field into which may be introduced any one of a range of known colors from which the operator chooses the one matching the unknown. To be generally applicable, the comparison field must not only cover a sufficient color range but must also be continuously adjustable in color.

In indirect colorimetry, the light leaving the unknown specimen is split into its component spectral parts by means of a prism or diffraction grating, and the amount of each component part is separately measured by a photometer. The quantity evaluated is spectral radiance of a light source, spectral transmittance of a filter (glass, plastic, gelatin, or liquid), or spectral reflectance of an opaque body.

In photoelectric colorimetry, the light leaving the specimen is measured separately by three photocells. The spectral sensitivity of these photocells is adjusted, usually by color filters, to conform as closely as possible to the three color-mixture functions for the average normal human eye (CIE standard observer). The responses of the photocells give directly the amounts of red, green, and blue primaries required to produce the color of the unknown specimen for the kind of vision represented by the three photocells.

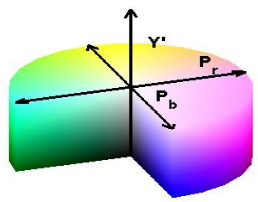
If two objects have the same color because the light leaving one of them toward the eye is spectrally identical to that leaving the other, any type of colorimetry serves reliably to establish the fact of color match. If, however, the two lights are spectrally dissimilar, they may still color-match for any one observer; such pairs of lights are called metamers. Normal color vision differs sufficiently from person to person so that a metameric color match for one observer may be seriously mismatched for another. On this account, the question of color match of spectrally dissimilar lights can be reliably settled only by the indirect method which uses spectrophotometry combined with a precisely defined standard observer. We have already seen that the experimentally observed Grassman's laws state that the tristimulus values of a color mixture are obtained by vector addition of the tristumulus values of the components of the mixture. Thus, if colors $S_1(=X_1,Y_1,Z_1)$ and $S_2(=X_2,Y_2,Z_2)$ are mixed to obtain color $S(=X,Y,Z)$, then

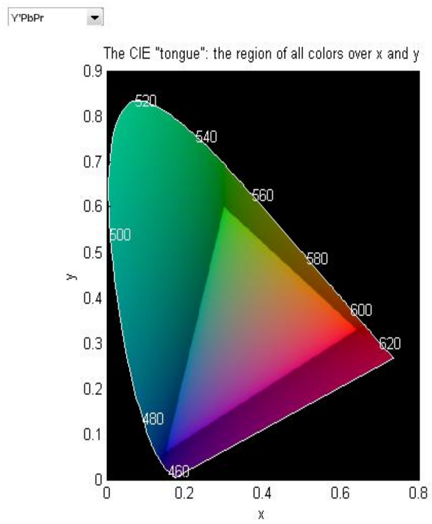
$$X = X_1 + X_2$$

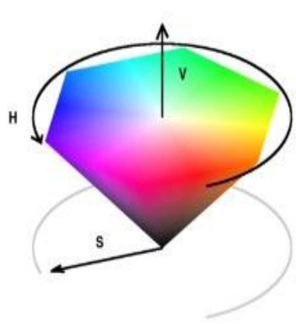
$$Y = Y_1 + Y_2$$

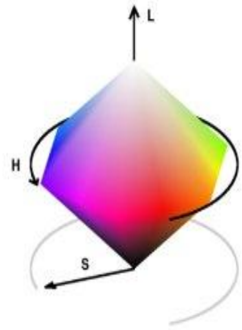
$$Z = Z_1 + Z_2$$

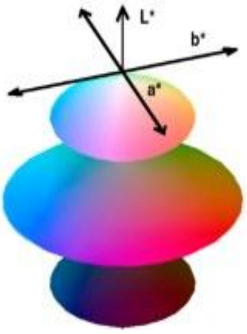
III. EXPERIMENTAL RESULTS

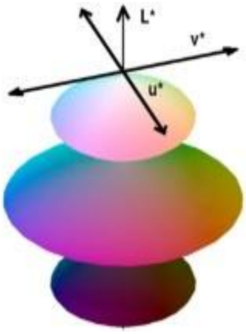


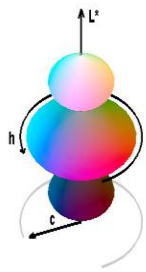




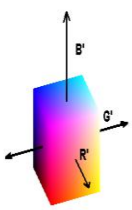




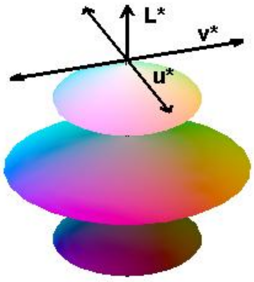




L*ch



sRGB



L*u*v*

IV. CONCLUSION

This paper presents color spaces with RGB and HSV color spaces. By defining different primary colors forthe representation of the system, different color models can be devised. Oneimportant aspect is the color transformation, the change of coordinates fromone color system to another. Such a transformation associatesto each color in one system a color in the other model. Each color model comesinto existence for a specific application in color image processing. Unfortunately, there is no technique for determining the optimum coordinate modelfor all image processing applications. For a specific application the choice ofa color model depends on the properties of the model and the design characteristics of the application.

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