New YHS Color Coordinate System and its Application in Remote Sensing

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Abstract— **A new color coordinate system, which describes color by means of brightness, hue and saturation, is presented. The relative distance from the body diagonal to the nearest surface of the RGB color cube is used as the saturation. The conversions from and to the RGB space are described.**

Keywords— **colour coordinate system, brightness, hue, saturation**

I. Introduction

COLOR can be described by its red (R), green (G) and blue (B) coordinates (the well-known RGB system), or by some its linear transformation as XYZ, CMY, YUV, YIQ, and/or others. The CIE adopted systems CIELAB and CIELUV (summary in [1] and [2]), in which, to a good approximation, equal changes in the coordinates result in equal changes in perception of the color. Nevertheless, sometimes it is useful to describe the colors in an image by some type of cylindrical-like coordinate system, it means by its hue, saturation and some value representing brightness. If the RGB coordinates are in the interval from 0 to 1, each color can be represented by the point in the cube in the RGB space. Let us imagine the attitude of the cube, where the body diagonal linking "black" vertex and "white" vertex is vertical. Then the height of each point in the cube corresponds to the brightness of the color, the angle or azimuth corresponds to the hue and the relative distance from the vertical diagonal corresponds to the saturation of the color.

Importance of such color spaces in remote sensing is described in detail in [2]. The spectral bands in satellite images do not often correspond to the human perception precisely and these color spaces make possible to obtain "natural" color images easily. On the other hand, in some cases we need to create an "artificial" color display from e.g. infrared spectral bands, which emphasizes some observed information. The color manipulations were the principle motivation of this paper.

The present color models have some disadvantages in practical use. E.g. we convert an image in some image processing application into some brightness-hue-saturation model and we would like to work with individual components (coordinates) as with separate images. There is desirable regarding to the back conversion to have all combinations of the values. It means we need such model, where the range of values of saturation is identical for all hues.

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The survey of present color models is in the next section. The description of the new YHS model is given in the Section III. The Section IV deals with the back conversion and an example of color manipulation is presented.

II. Survey of present color models

There were published many brightness-hue-saturation systems, the most important are HSV, HLS, IHS and HSI. HSV and HLS can be found in [3], IHS was published in [1] and HSI in [4].

The HSV model is based on projection of the RGB color cube onto a hexcone and its coordinates can be computed by the following algorithm:

The value representing brightness

$$V = \max\{R, G, B\}, \qquad (1)$$

$$M_2 = \min\{R, G, B\}. \qquad (2)$$

The saturation

$$S = \frac{V - M_2}{V} \qquad (S = 0 \text{ for } V = 0), \qquad (3)$$

$$C_r = \frac{V - R}{V - M_2} \quad C_g = \frac{V - G}{V - M_2} \quad C_b = \frac{V - B}{V - M_2}. \qquad (4)$$

The definition of the hue depends on what RGB coordinate is maximum

$$\begin{aligned} H_t &= \begin{cases} C_b - C_g & R = V \\ 2 + C_r - C_b & G = V \\ 4 + C_g - C_r & B = V \end{cases} \\ H &= 60^\circ \cdot H_t. \end{aligned} \qquad (5)$$

If $S = 0$, H is undefined. If $H < 0, H := H + 360^\circ$.

The HLS model projects the RGB color cube onto a double-hexcone. The following algorithm gives the conversion from the RGB space:

$$\begin{aligned} M_1 &= \max\{R, G, B\} \\ M_2 &= \min\{R, G, B\}. \end{aligned} \qquad (6)$$

The luminance

$$L = (M_1 + M_2)/2. \qquad (7)$$

The saturation

$$S = \begin{cases} \dfrac{M_1 - M_2}{M_1 + M_2} & L \le 0.5 \\ \dfrac{M_1 - M_2}{2 - M_1 - M_2} & L > 0.5\ . \end{cases} \qquad (8)$$

The algorithm for the hue H is the same as in the HSV model, where M_1 is used instead of V. If $M_1 = M_2$, $S = 0$ and H is undefined.

The main disadvantage of both systems is the definition of the brightness, which does not depend on the middle value of R, G and B. The brightness of the HSV model does not depend even on the minimum value.

The IHS system is defined as:

the intensity

$$I = (R + G + B)/3, \tag{9}$$

$$\begin{aligned} V_1 &= (-R - G + 2B)/\sqrt{6} \\ V_2 &= (R - 2G)/\sqrt{6}, \end{aligned} \tag{10}$$

the hue

$$H = \tan^{-1}\left(\frac{V_2}{V_1}\right), \tag{11}$$

the saturation

$$S = \sqrt{V_1^2 + V_2^2}. \tag{12}$$

The intensity is defined by the acceptable way, but the system is not centered, the origin of the $V_1 - V_2$ coordinate system is translated from the gray color.

There is another problem with the saturation. We can substitute (10) by

$$\begin{aligned} V_1 &= (-R - G + 2B)/2 \\ V_2 &= (R - G)\sqrt{3}/2, \end{aligned} \tag{13}$$

then the system is centered into the gray color, but the saturation is defined as a radius of a cylinder while the colors are defined in the cube. The saturation = 1 is not reachable inside the RGB gamut for the all hues.

The similar problem occurs in case of the TekHVC system [5], which coordinate chroma is derived from CIELUV color space by a similar way as the IHS saturation in the $V_1 - V_2$ space.

The HSI system is defined by the algorithm:

the intensity

$$I = (R + G + B)/3, \tag{14}$$

the hue

$$H = \cos^{-1}\left(\frac{\frac{1}{2}((R-G) + (R-B))}{((R-G)^2 + (R-B)(G-B))^{1/2}}\right). \tag{15}$$

If $B > G$, then $H := 360° - H$.

The saturation

$$S = 1 - \frac{3\min\{R, G, B\}}{R + G + B}. \tag{16}$$

The main disadvantage is the definition of the saturation in case of the high intensity. If just one of the RGB values is 1, then the saturation cannot be increased keeping the given brightness and hue, but S in this system is less than 1, e.g. $R = 1,\ G = 0.5,\ B = 0.5$:

$I = \frac{2}{3}$

$S = 1 - 3\min\{1, 0.5, 0.5\}/(1 + 0.5 + 0.5) = \frac{1}{4}$, but the color on the surface of the color cube should have the saturation 1.

The similar problem is in the HSV system. An example $V = \max\{R, G, B\} = 1$, $T = \min\{R, G, B\} = 0.5$ and $S = (V - T)/T = 0.5$, but it is a consistent model, we can decrease G and B to 0, the value V stays 1 and the saturation S increases to 1.

Recently, attempts to create a system overcoming these drawbacks has been described. Marcu and Abe [6] suggest Modified HSL space, where the definitions of the brightness (1) and (7) are substituted by

$$V = 0.3R + 0.59G + 0.11B \tag{17}$$

and the saturation (8) is substituted by

$$S = M_1 - M_2. \tag{18}$$

Unfortunately, this paper does not solve all problems with the saturation and the back transformation is not presented at all.

Levkowitz and Herman [7] suggest Generalized Lightness, Hue, and Saturation color model (GLHS), where the HSV, HLS and IHS models are included. The lightness function is defined as

$$\begin{aligned} L = w_{min}\min\{R, G, B\} &+ w_{mid}\operatorname{mid}\{R, G, B\} \\ &+ w_{max}\max\{R, G, B\}, \end{aligned} \tag{19}$$

where $\operatorname{mid}\{R, G, B\}$ means the middle value of R, G and B. The weights w_{min}, w_{mid} and w_{max} define the concrete color model. The GLHS includes the brightness of HSV ($w_{min} = w_{mid} = 0$, $w_{max} = 1$), HLS ($w_{min} = w_{max} = 1/2$, $w_{mid} = 0$) and IHS models ($w_{min} = w_{mid} = w_{max} = 1/3$). The alternative definition of the hue is used, but it is equivalent to that of the HSV space (5). The most important contribution of this model is the adequate definition of the saturation

$$S = \begin{cases} \dfrac{L - \min\{R, G, B\}}{L}, & L \le Q \\ \dfrac{\max\{R, G, B\} - L}{1 - L}, & L > Q, \end{cases} \tag{20}$$

where

$$Q = w_{mid}\frac{\operatorname{mid}\{R, G, B\} - \min\{R, G, B\}}{\max\{R, G, B\} - \min\{R, G, B\}} + w_{max}. \tag{21}$$

It is 1 just for the colors on the surface of the color cube. It is appropriate model particularly for $w_{min} = w_{mid} = w_{max} = 1/3$. Nevertheless, one could want to use a color space, where the brightness would be defined with weights independent of the order of the RGB values and/or the hue would be defined by the exact angle using an inverse goniometric function (e.g. tan^{-1}).

III. The YHS system

Our goal is to find a color space, which is suitable for the computations in the color cube, such as color specification, coordinate transformation, color manipulation or coding of multiparameter distributions into integrated displays. It should satisfy some demands as:
1. The brightness should be a linear combination of all three RGB components. At least, it must be continuous growing function of all of them.
2. The hue differences between the basic colors (red, green and blue) should be 120° and similarly between the complement colors (yellow, purple and cyan). The hue difference between a basic color and an adjacent complement one (e.g. red and yellow) should be 60°.
3. The saturation should be 1 for the colors on the surface of the RGB color cube, it means in case of one of the RGB components is 0 or 1 except black and white vertices and it is 0 in case of R=G=B.

In our opinion the best brightness, hue and saturation system consists of the brightness (17), the hue from the HSI system (15) and the saturation from the GLHS model (20). It can be discussed, if better hue is the exact angle (15) or its approximation (5). The both satisfy the second demand. The exact angle was chosen because of the slightly simpler computation.

The brightness can be generalized

$$Y = w_R R + w_G G + w_B B, \tag{22}$$

where $w_R, w_G, w_B > 0$ and $w_R + w_G + w_B = 1$. The usual choice is $w_R = 0.299$, $w_G = 0.587$ and $w_B = 0.114$.

The hue can be defined equivalently as

$$H = \tan^{-1}\left(\frac{\sqrt{3}(G-B)}{2R-G-B}\right). \tag{23}$$

It is supposed in the range from 0 to 360° according to the signs of the numerator and the denominator.

The definition of the saturation can be simplified

$$S = \max\left\{\frac{Y-R}{Y}, \frac{R-Y}{1-Y}, \frac{Y-G}{Y}, \frac{G-Y}{1-Y}, \frac{Y-B}{Y}, \frac{B-Y}{1-Y}\right\} \tag{24}$$

If $Y = 0$ or $Y = 1$ then $S = 0$.

Comment: The extreme seeking in the saturation computation means the seeking of the nearest surface of the RGB color cube. If the color lies on the surface, the saturation equals 1. The saturation can be expressed alternatively

$$\begin{aligned} S &= 1 - \min\left\{\frac{R}{Y}, \frac{G}{Y}, \frac{B}{Y}, \frac{1-R}{1-Y}, \frac{1-G}{1-Y}, \frac{1-B}{1-Y}\right\} \\ &= 1 - \min\left\{\frac{\min\{R,G,B\}}{Y}, \frac{1-\max\{R,G,B\}}{1-Y}\right\}. \end{aligned} \tag{25}$$

If one of the RGB components is 0, then $\min\{R,G,B\} = 0$ and $S = 1$, if one of the RGB components is 1, then $\max\{R,G,B\} = 1$, $\frac{1-\max\{R,G,B\}}{1-Y} = 0$ and $S = 1$. If the color is gray, R=G=B=Y and $\min\{R,G,B\} = \max\{R,G,B\} = Y$, then $S = 1 - \min\{\frac{Y}{Y}, \frac{1-Y}{1-Y}\} = 0$.

IV. The conversion from YHS to RGB

The inverse conversion is difficult, but can be solved:
If $S = 0$, then $R = Y,\ G = Y,\ B = Y$ else

$$k = \frac{(w_G - w_B)\tan(H) - (w_G + w_B)\sqrt{3}}{(2w_G + w_R)\tan(H) + w_R\sqrt{3}}, \tag{26}$$

$$g_k = -\frac{w_B + w_R k}{w_G}, \tag{27}$$

$$y_k = \frac{Y}{Y-1}, \tag{28}$$

the vector

$$p = \left[1, y_k, \frac{g_k}{k}, \frac{g_k y_k}{k}, \frac{1}{k}, \frac{y_k}{k}\right] \tag{29}$$

and the vector of the inverse values

$$\hat{p} = \left[1, \frac{1}{y_k}, \frac{k}{g_k}, \frac{k}{g_k y_k}, k, \frac{k}{y_k}\right]. \tag{30}$$

If $k = 0,\ k = \infty$ or $g_k = 0$, then a special definition of the vectors is needed. If $k = 0$, then $g_k = -\frac{w_B}{w_G}$ and

$$\begin{aligned} p &= [0, 0, g_k, g_k y_k, 1, y_k] \\ \hat{p} &= \left[0, 0, \tfrac{1}{g_k}, \tfrac{1}{g_k y_k}, 1, \tfrac{1}{y_k}\right]. \end{aligned} \tag{31}$$

If $k = \infty$ (the denominator of the k (26) is zero), then $g_k = -\frac{w_R}{w_G}$ and

$$\begin{aligned} p &= [1, y_k, g_k, g_k y_k, 0, 0] \\ \hat{p} &= \left[1, \tfrac{1}{y_k}, \tfrac{1}{g_k}, \tfrac{1}{g_k y_k}, 0, 0\right]. \end{aligned} \tag{32}$$

If $g_k = 0$, then

$$\begin{aligned} p &= \left[1, y_k, 0, 0, \tfrac{1}{k}, \tfrac{y_k}{k}\right] \\ \hat{p} &= \left[1, \tfrac{1}{y_k}, 0, 0, k, \tfrac{k}{y_k}\right]. \end{aligned} \tag{33}$$

Then it must be decided, if $R > Y$ or not. The limit occurs in the points, where

$$\tan(H) = \frac{w_G + w_B}{w_G - w_B}\sqrt{3}. \tag{34}$$

Let us denote the value between 0 and 180°

$$H_1 = \tan^{-1}\left(\frac{w_G + w_B}{w_G - w_B}\sqrt{3}\right). \tag{35}$$

An auxiliary value m is either the maximum of the negative values or the minimum of the positive values of $\hat{p}$

$$m = \begin{cases} \max\limits_{i=1,2,\ldots,6}\{\hat{p}_i; \hat{p}_i < 0\} & H_1 \le H < H_1 + 180° \\ \min\limits_{i=1,2,\ldots,6}\{\hat{p}_i; \hat{p}_i > 0\} & H < H_1 \text{ or } H \ge H_1 + 180° \end{cases} \tag{36}$$

The result is

$$\begin{aligned} R &= Y(1 - Sp_1 m), \\ G &= Y(1 - Sp_3 m), \\ B &= Y(1 - Sp_5 m). \end{aligned} \tag{37}$$

Comment: The coefficients $k = \frac{R-Y}{B-Y}$ and $g_k = \frac{G-Y}{B-Y}$ are ratios of the color difference components. The index of $\hat{p}_i$, where the extreme m was found, is the same as the index of the maximum during saturation computation, see (24). The relative brightness y_k is always negative (for $Y \in (0, 1)$), therefore the vector $\hat{p}$ includes at least one positive and one negative member and the definition (36) of m is correct.

V. Numerical Experiment

The YHS system is suitable for adaptation of images in remote sensing. The image can be converted into YHS, then each component, i.e. brightness, hue and saturation can be adapted separately. Finally, the image can be converted back to the RGB and/or another color coordinate system. For the experiments was used a LANDSAT TM satellite image of area in the north-east Bohemia. The original is in Fig. 1, composed by channels 1,2,3, which are the closest of the blue, green and red spectral bands, but do not yield precise colors. Therefore the hue was translated to the green color by 44°. It results the forests in top-left quarter of the image in dark green and meadows are in the rest of image in light green. The saturation was multiplied by two. The reason was to get more expressive colors. The brightness was slightly (contrast by 6%) enhanced to utilize the given range more perfectly. The result of the YHS application is in Fig. 2.

VI. Conclusion

The new YHS color coordinate system has some remarkable advantages in comparison with the existing systems. The brightness Y is the gray level version of the image, depending on all three RGB components linearly. The coordinate system is centered, there are regular distances between the hues of the basic colors. The saturation uses full range from 0 to 1 for all values of the hue and the brightness. It is 1, if some of the RGB components is 0 or 1 and 0 when R=G=B.

The results of our test with the multichannel remote sensing images are encouraging. Especially in displaying the proposed YHS system put an image nearer to the human perception of colors and objects. The color manipulation in context of the object shape and its essentiality seems to be very important.

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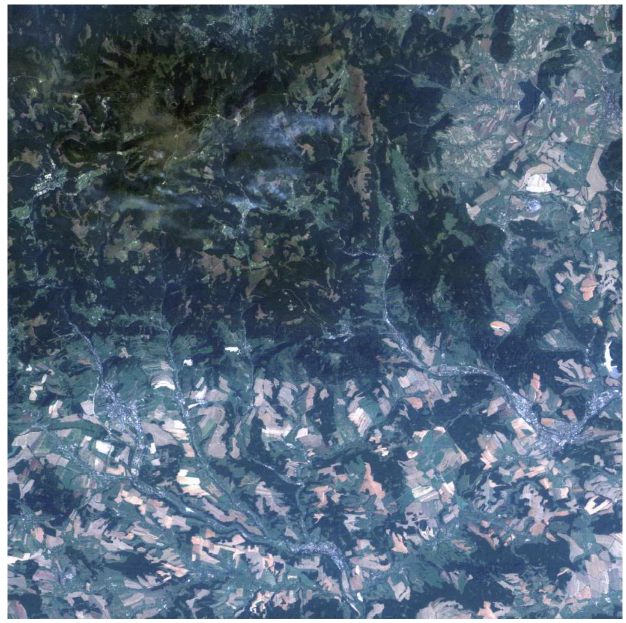

Fig. 1. The original image (LANDSAT TM, channels 1-3)

Fig. 2. The result