A NEW EQUATION OF SATURATION IN RGB-TO-HSI CONVERSION FOR MORE RAPIDITY OF COMPUTING

JIAN-FENG LI [a], KAUN-QUAN WANG [a], DAVID ZHANG [b]

[a] Dept. of Computer Science and Engineering, Harbin Institute of Technology, Harbin, China
[b] Department of Computing, Hong Kong Polytechnic University, Kowloon, Hong Kong
E-MAIL: lijeff @vip.sina.com, wangkq@hope.hit.edu.cn, csdzhang@comp.polyu.edu.hk

Abstract:

In this paper, a new equation of saturation in RGB-to-HSI conversion is proposed on the basis of HSI Color Space, aimed to provide more rapidity of computing in real-time control systems due to fewer operations needed. The theatrical validness of new conversion equation is studied and testified. Besides its significant advantages over traditional equation on temporal performance, better mapping performances is mathematically explained as a minor advantage. It is shown in illustrative experiments that average 30% time was saved in computing when using new saturation conversion equation instead of traditional one.

Keywords:

New saturation equation; RGB-to-HSI conversion; More rapidity in computing; Real-time control systems; Tongue image capture

1 Introduction

1.1 HSI Color Space

There exist several methods to specify a color quantitatively, among which most extensively used is RGB format. Although it would be easy for the RGB coordinate system to display color image by utilizing three different electron guns of red, green, and blue, color images are always perceived in terms of hue, saturation, and luminance in human visual system.

The HSI format (Hue, Saturation, and Intensity), one of the most widely-used color coordinate system in color image processing, was developed by Munsell and are compatible with the scheme human perceive color [1][2]. It is based on intuitive sensation of color, and closely simulates the behavior of human eyes. The coordinate of HSI format is cylindrical, as shown in figure1 [3].

In traditional HSI (Hue, Saturation, and Intensity) format, given the red, green and blue values of a pixel as R, G, B, the conversion equation from RGB space to HSI space was defined as [3]:

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

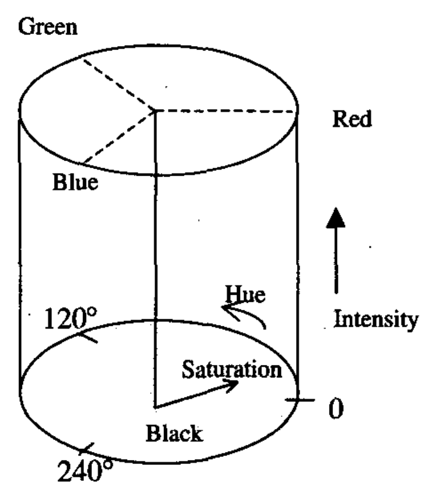

Fig.1. Cylindrical color space of HSI format

$$\theta = \cos^{-1}\left[\frac{\frac{1}{2}[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right] \qquad (2)$$

$$H = \begin{cases} \theta & G \geq B \\ 2\pi - \theta & G \leq B \end{cases} \qquad (3)$$

$$S = 1 - \frac{3\min(R,G,B)}{R+G+B} \qquad (4)$$

Hue le(H) represents which spectral wavelength a color preoccupies.

Saturation (S) evaluates the extent of purity of hue, and measures how much white light is added to a pure color.

Intensity (I) stands for brightness, or the average grey level.

It should be noticed that when R, G, B are equal, which represents a pure grey color, the saturation is 0 while the hue value doesn't exist.

0-7803-7508-4/02/$17.00 ©2002 IEEE

1.2 Real-time Tongue Image Capture Control System

Real-time control systems are characterized by execution of iterative tasks which are required to be finished timely and correctly within limitative time. In digital real-time control systems, the system performance behaves as a function of the sampling rate. Given fixed controller environment, higher sampling rate always induces improved control performance, if only not exceed tolerable limit of system.

Tongue Diagnosis, an important diagnostics part of Traditional Chinese Medicine, is a method of observing the changes of tongue body as well as tongue coating to analyze disease. Based on numerous doctors' experiences accumulated in medical practice of thousands years, the examining methods of tongue diagnosis has formed its own system [4]. The changes of tongue reflect inner visceral changes, which endowed Tongue Diagnosis System with significant importance in early diagnosis and health care [5]. Tongue Image Capture Control System is the foremost part of the entire Tongue Diagnosis System. A digital video camera is utilized to capture continuous tongue image frames when examinee stretches out his or her tongue. Under some circumstances, a large area of reflection patch of light source occurs on tongue surface due to specular reflection. The appearance of too many reflection points may cover up numerous valuable information patches thus undermines the subsequent part of tongue image analysis, therefore, must be detected and adjusted to proper illumination condition by real-time tongue image capture control system.

The reminder of this paper is organized as follows: In Section 2, a new conversion equation of saturation is proposed and its theatrical validness is studied and testified. Section 3 discussed advantages of new conversion equation over traditional equation thoroughly in two aspects: more rapidity in computing due to fewer operations needed, and better mapping performances as a minor advantage. Both theatrical and practical experiments are explained in Section 4.The paper concludes with Section 5.

2 New Conversion Equation and its Theatrical Validness

The new equation of saturation conversion we proposed is:

$$S' = \frac{\sqrt{R^2+G^2+B^2-RG-GB-RB}}{R+G+B} \quad (5)$$

Munsell's definition about Chroma, namely saturation are: 'It is that quality of colour by which we distinguish a strong colour from a weak one; the degree of departure of a colour sensation from that of a white or grey; the intensity of a distinctive hue; colour intensity. '[2]. Saturation is a measurement of how much white light has been merged into a specific color [6].

Suppose that RGB format of a color is represented by three vectors with 120° angle to each other, having the same start point, whose amplitudes are R, G, and B respectively. When the white component in a color increase, more equivalent value appears in each of R, G, B channel, the amplitude of the composition vector of R, G, B decreases. This characteristic satisfies the description of saturation in HSI color space which is mentioned above. The amplitude of the composition vector is $\sqrt{R^2+G^2+B^2-RG-GB-RB}$, which serve as the numerator of new conversion equation (5). When R, G, B are identical, the saturation should be smallest due to entire white component , the equation (5) equals 0. When one of R, G, B is zero, no white component exists, the saturation should be 1, which is obtained by the equation (5) under this circumstance.

3 Advantages of New Conversion Equation over Traditional Equation

There are two aspects of advantages in color and multispectral image processing of the new conversion equation (5), compared with the traditional equation (4), which are listed below.

3.1 Major advantage: more rapidity in computing due to less operations needed

In some real-time color image processing apparatus, rapidness of computing is highly appreciated. As far as new saturation conversion equation (5) is concerned, although it is true that when computing saturation solely, New S' equation spends more time than Traditional S equation (4). However, under certain circumstances of color image processing, such Tongue Diagnosis, the value of hue, saturation, and intensity of interested pixels are totally required to be calculated. To meet such needs, the New Equation S' (5) is more time-efficient because of less operations needed. The numerator of New Equation S' ($\sqrt{R^2+G^2+B^2-RG-GB-RB}$) is an indispensable part in calculating hue (2), and the denominator of S' ($R+G+B$) is an essential part in computing intensity (1). The result of New Equation S' (5) can be simply derived by conducting a division of these twos parts, sparing many operations including $\min(R,G,B)$ operation requested by the Traditional Equation S (4).

When calculating the value of hue, saturation, and intensity of a specific pixel, thorough computational operations comparison is listed in the Table 1:

Table 1. Computational Operations Comparison Table between Traditional S and New S' In Calculating Hue, Saturation, and Intensity

Computing Item	Add Minus	Multiply	Divide	Others
I	1	0	1	0

H	7	2	2	1square root 1arc cos
S (traditional)	1	1	1	1 $\min(R,G,B)$
S' (new)	0	0	1	0
Operation Spared by New Definition S	1 12.5% of total	1 33% of total	0	1 $\min(R,G,B)$

* $\min(R,G,B)$ means the operation computing the minimum of R,G,B.

It can be observed from the shaded items in Table 1 that, the new equation S' spared 1 add (minus) operation, 1 multiply operation, as well as 1 $\min(R,G,B)$ operation when computing the hue, saturation, and intensity of a specific pixel. One thing worthy of being mentioned is: $\min(R,G,B)$ operation is a relatively time-consuming operation in the process of computing, because this operation consists of branch reorientation in executing the program, which may undermine the pipelining of successive iterations of loops in computing [7]. Experiments were conducted to illustrate the time-saving characteristic of New Equation S'. Result shows that average 30% time was saved in computing when using new saturation conversion equation instead of traditional equation. Detailed explanations on experiments are written in Section 4.

3.2 Minor advantage: better mapping performances

From mathematical point of view, the saturation conversion equation is a mapping from RGB Cube, which is made up of 256^3 pixels, to continuous closed interval $[0,1]$. Every pixel in RGB Cube is projected to a value in $[0,1]$ by conversion equation. We compare mapping performances of two conversion equations from mathematical points of view in following three aspects:

3.2.1 Number of values on [0,1] being projected by RGB Cube

An ideal conversion equation will project pixels from source space, namely RGB Cube, to object space [0,1] EVENLY. Thus, more values in $[0,1]$ would be utilized, which will confer more distinguishability among pixels in the RGB Cube after they are projected into $[0,1]$. A poor conversion equation always project pixel in RGB Cube into limited number of values in $[0,1]$, making numerous pixels which are different in RGB Cube being projected into the same value, depriving much of distinguishability in object space.

Denote C as RGB 3-dimension Cube consisting 256^3 pixels, $I(u,v,w)$ as the image value of saturation conversion function corresponding to a specific pixel (u,v,w), $(u,v,w) \in C$.

Denote Q as the set of values in $[0,1]$ that were projected from C by $I(u,v,w)$:

$$Q = \{x \mid I(u,v,w) = x, (u,v,w) \in C, x \in [0,1]\} \quad (6)$$

What interests us is $|Q|$, the cardinal number of the set Q, which stands for the different values being projected by $I(u,v,w)$ in $[0,1]$.

When $I(u,v,w)$ represents image of Traditional S Equation, $|Q| = 39{,}583$

When $I(u,v,w)$ represents image of New S' Equation, $|Q'| = 1{,}544{,}616$

The values projected by C through the New S' Equation is 39.02 times to that of Traditional S Equation. The New S' Equation is more close to ideal from this aspect.

3.2.2 The number of pixels in RGB Cube being projected to the same value

In most circumstances, more than one pixels in RGB Cube were projected to the same value in $[0,1]$. We denote $N(a)$, $a \in [0,1]$ as the number of pixels being projected to value a, and denote the set of $N(a)$ as D.

$$N(a) = \left| \{(u,v,w) \mid (u,v,w) \in C, I(u,v,w) = a\} \right| \quad (7)$$

$$D = \{N(a) \mid a = I(u,v,w), (u,v,w) \in C, a \in [0,1]\} \quad (8)$$

The more evenly one conversion equation projects RGB Cube to $[0,1]$, the less will be the standard deviation of elements in D of that conversion equation. If a conversion equation projects too much pixels into a narrow range of values in $[0,1]$, the standard deviation of D would be huge. Results were listed in Table 2.

Table 2. Comparison of standard deviation, mean, maximum of D defined in (8)

	Standard deviation of D	Mean of D	Maximum of D
Traditional conversion equation S	948.259	422.186	$N(0.5) = 130048$
New conversion equation S'	9.884	10.861	$N(0.5) = 1728$

The standard deviation of D of New Conversion

Equation S' is only 1.04% of the traditional one. The result demonstrate that New Conversion Equation S' projects pixels more evenly.

3.2.3 Distance between two neighboring projected values

Probing into distances between two neighboring projected values in $[0,1]$ is a measurement of how evenly the values have been distributed in the closed interval $[0,1]$. For an ideally distributed sequence, distances between any two neighboring values should be very similar to each other. More evenly distributed sequence shows smaller standard deviation in distances between any two neighboring values.

On the basis of set Q mentioned in (6), we define non-descending ordered sequence $\overline{Q}$

$$\overline{Q} = \{q_n \mid q_n, q_{n+1} \in Q, q_n < q_{n+1}, n \in N\} \quad (9)$$

The set of distances between any two neighboring projected values is denoted as W.

$$W = \{x \mid x = q_{n+1} - q_n, q_n \in \overline{Q}, n \in N\} \quad (10)$$

Table 3. Comparison of standard deviation, mean, maximum of W defined in (10)

	Standard deviation of W	Mean of W	Maximum of W
Traditional conversion equation S	4.08×10^{-5}	2.52×10^{-5}	5.91×10^{-3}
New conversion equation S'	4.99×10^{-6}	6.44×10^{-7}	5.85×10^{-3}

The result shows that projected values in $[0,1]$ of new conversion equation distributes much more evenly than projected values of traditional conversion equation.

4 Experimental results

In order to show more rapidity of computing of new saturation conversion equation, we conducted both theatrical experiment and practical experiment.

4.1 Theatrical Experiment

We recorded the total time spent in calculating the value of hue, intensity, saturation of every pixel in RGB Cube, which includes 256^3 =16777144 pixels. The process is carried out for two times. In the first time, Traditional Saturation Equation (4) was exploited to calculate saturation, and in the second time, the New Saturation Equation (5) was applied. In order to obtain more universal result, such procedures were conducted by MATLAB 6 under different computing environments. Many differences in total time spent were exhibited by the result list in the Table 4.

Table 4. Comparison of Total Time Spent Between Two Equations Under Different Computing Environments

Comparing Items	PentiumIII600 WIN 98	Celeron 800 WIN2000	AMD 1600 WIN XP
Traditional S	1712.32 sec	1374.51 sec	541.89 sec
New S'	1203.85 sec	921.27 sec	378.42 sec
The percent of time spared	29.73%	32.97%	30.17%

Since the total amount of time include some fundamental basic operation such as controlling the loops which both programs inevitably spend, the time-saving improvement by the New Equation S' is more than the results shown above.

4.2 Illustrative Experiments on Real-time Tongue Image Capture Control System

In Real-time Tongue Image Capture Control System, reflection patches must be detected and adjusted to proper illumination condition. The differences between reflection points and normal points are: the intensity value of reflection point is higher than normal one; the saturation value of reflection point is lower than normal one. By investigating the intensity and saturation value of interested pixels, the real-time tongue image capture control system determine whether too much reflection occurs and give proper control instructions to examinee.

In our real tongue image capture control system, 0.228 second is needed to process one frame image using tradition saturation conversion equation; while only 0.181 second is needed using new saturation conversion equation. Utilizing new saturation conversion equation has reduced essential processing time to 79.3% of before; sampling rate has been improved 26.1%.

5 Conclusions

A new equation of saturation in RGB-to-HSI conversion on the basis of HSI format is proposed in the paper. The characteristic of new conversion equation faithfully agree with the description of saturation in HSI color space, and theatrical validness of new saturation equation is also testified. The results of comparison between two conversion equations demonstrates that new conversion equation has significant advantages over traditional conversion in two aspects: less operations needed in computing, and better mapping property from RGB Cube to closed interval $[0,1]$. Better temporal performance of new saturation equation was demonstrated by both theatrical and practical experiments: it can save averagely 30% time when employed in algorithm instead of traditional one under certain computing circumstances.

References

[1] A.H.Munsell, A Color Notation (8th ed.), Munsell Color Company, Boston, 1939.

[2] A.H.Munsell, A Grammar of Color, Van Nostrand-Reinhold, New York, 1969.

[3] Kenneth R.Castleman , "Digital Image Processing", Prentice Hall Inc., New Jersy, 1996,page550-554

[4] Naimin Li, "The great integrated of Chinese Tongue Diagnosis", Academic Press, Beijing, 1994

[5] David Zhang, "Automated Biometrics: technologies and systems", Kluwer Academic Publishers, page298-310

[6] Ledley,R.S.; Buas, M.; Golab, T.J.: "Fundamentals of true-color processing" Pattern Recognition, 1990, Proceedings. , 10th International Conference on, Volume I, 1990

[7] Kai Hwang, "Advanced Computer Architecture Parallelism, Scalability, Programmability", McGraw-Hill Company, 1993, page291-295