Systematic Processing of Color Images and Quantization Precision of ULCS

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Abstract

Images are an essential element in the growing domain of worldwide "Multimedia networking". Several image-related problems arise which apply to this domain. For instance, when one or more images is inserted in a document, adjustments of the tone of color, enhancement, halftoning, gauzying, transforming low key or high key images and removal of staircasing shaped distortion along contours will be necessary. Especially the staircasing shaped distortion should be more strictly removed in the display of rotating 3D objects.

In such complicated image processing as described above, it is necessary that humans perceive the deterioration of color directly, and consequently that image processing should be handled in a color space which directly represents the three attribute of human color perception: hue, value and chroma. It is also necessary that processing is monitored by the color difference or a function of color difference between the original and the processed image. The function of the color difference we define to be the "Picture Quality Scale" (PQS).

In order for the measured color difference to be proportional to the perceived color difference, we have introduced the ULCS (Uniform Lightness-Chromaticness Scale system)[1]. In ULCS a color difference is defined by the Euclidean distance in the color space. As a representative of ULCS we have selected the Munsell Renotation System [Figure 1]. The transformation from an RGB image to an HVC image in the Munsell Renotation System depends on the look up table and which have a corresponding mathematical formula as is shown in the L*a*b*. However we have developed a mathematical transformation from an R,G,B color to the corresponding H,V,C (Hue, Value, Chroma) color which closely approximates the color of the Munsell Renotation System. We have named the new mathematical transformation MTM (a Mathematical Transform to Munsell Renotation System)[2]. The maximum approximation error of the color space transformed by MTM to the Munsell Renotation System is 0.59 in National Bureau of Standards unit (NBS).

Using MTM we have shown the quantization precision; the quantization accuracy of R, G and B signals should be not less than 14, 16 and 12 bits for linear quantization and 10, 12 and 9 bits for non-linear quantization (gamma = 3.0) respectively in order to keep the color difference of quantization errors smaller than 1NBS unit. MTM is applicable to many kinds of color image processing and is especially effective in the discussion of device independent color image processing.

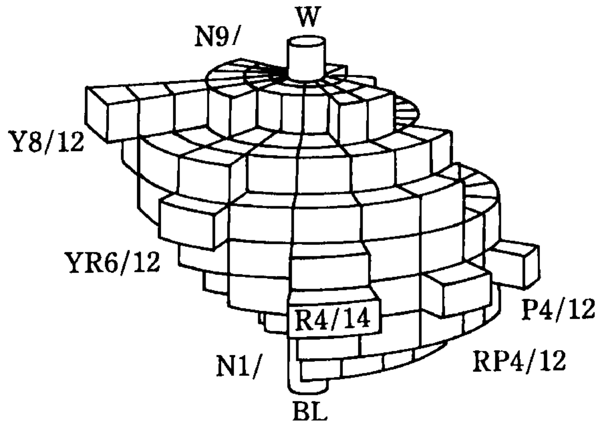

Figure 1. Munsell Color Solid

Systematic Image Coding[3]

Metric and objective Picture Quality Scale (PQS) not only clears up the defect in many of the subjective assessment tests, but also contributes to the field of image coding. Clearly, PQS provides a direct measure of the perceived error in compressed images, and therefore will help to develop a more systematic design for image coding. We want to define PQS which will represent MOS (Mean Opinion Score). Another merit of PQS is that a coding specialist who has no knowledge of the psychophysics on visual perception can develop image processing with the help of PQS measure in order to get perceptually better images.

"Systematic" means systematic design and systematic signal processing based on PQS. In order to define PQS, we must consider not only stochastic properties but also local features which are very important to human eyes. A PQS must be defined as a function of all kind of elementary deterioration of images including those occurring locally such as the deterioration of contours.

Definition of Fi by the Color Difference in the Munsell Color Space

$PQS = f(Fi)$; $i = 1 - n$

Fi: A disturbance to the image defined by a function of an error signal between the original and its processed image signal e(m,n) where (m,n) denotes an address of an image.

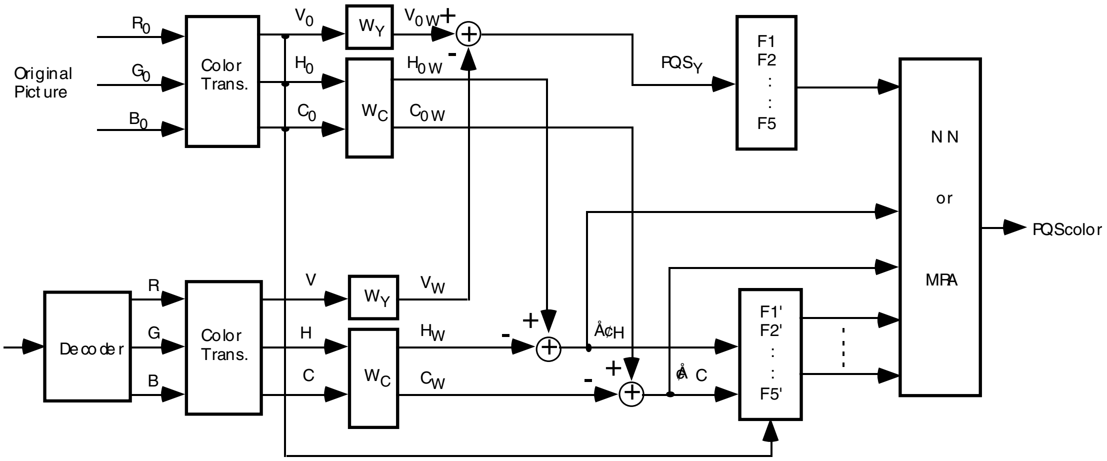

Figure 2. Block diagram leading to PQS

Fi = f(three color differences: ΔH, ΔV, ΔC in ULCS)

F1: Random noise weighted by the MTF (modulation transfer function) of human eyes.

F2: Autocorrelations of errors and blocking artifacts.

F3: Local errors along contours due to the masking (visibility function[4]).

F4: Local errors along contours due to the Vernier Acuity.

Procedure to Realize PQS

In order to obtain a reliable relationship between the MOS and PQS as the function of e(m,n), we shall first of all obtain the MOS of coded images by various coders (e.g., OTC, DPCM, VQ, etc.) at different bit-rates.

Principal components Z_k are calculated, and PQS is obtained by multi-regression analysis between the MOS already obtained and a linear combination of Z_k [Figure 2].

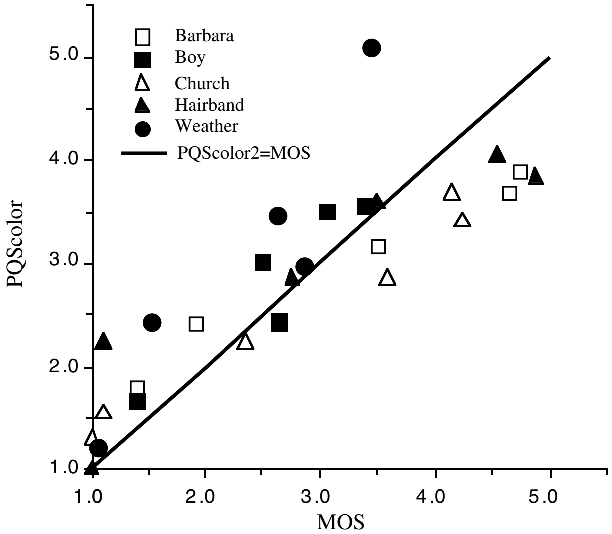

Figure 3. Obtained PQS vs. MOS

Further research on spatial masking of any one of three attributes with respect to another is necessary in order to include the perceptual correlation of images in the definition of the color of natural images. Also further research is necessary on the perceptual properties of the value compared to the hue and the chroma. Nevertheless, the procedure to realize PQS described above can cut the research described above if our purpose is only to obtain a reliable relationship between MOS and PQS [Figure 3]. For such purpose, the application of a neural network algorithm to PQS analysis has also been very effective.

Quantization Precision of Color Images[5]

A computer simulation is executed to observe the mapping and distribution of the discrete (R,G,B) colors in HVC color space. At first, RGB color space is sampled with linear quantization to 256 levels (8 bits) on each axis, giving 256*256*256 points distributed uniformly throughout the color space. Each (R,G,B) color is transformed to an (H,V,C) color by MTM and mapped to HVC color space.

The result shows that we scarcely find mapped data in the area of lower than 1/3 in the value axis and find coarse data distribution in the area of 1/3 - 1/2 in value axis in the HVC color space.

Discussion of Quantization Errors in 8 Bit Quantization

Table 1 shows the maximum value of color difference of each discrete color and its most adjacent color in several V-C planes when (R,G,B) signals are linearly quantized by 8 bits respectively where

(1) (R,G,B) signals are quantized linearly,
(2) Gamma-precorrected (R,G,B) signals are quantized linearly (gamma = 2.2),
(3) (R,G,B) signals are linearly quantized after a non-linear transformation (gamma = 3.0).

According to Table 1, the maximum color differences of adjacent colors is very large in the case of (1). In the case of (2) and (3), we can find more mapped color data than in the case of (1) in the lower area of value, but the color difference of adjacent colors is still larger than the "just perceptible color difference" ($\Delta E_{NBS} = 1$).

Table 1. Maximum Color Difference of Adjacent Colors in V-C Planes (NBS value)

Hue	ΔE_{NBS} MAX		
	(1)	(2)	(3)
5R	2.45	1.98	2.11
5YR	3.78	3.12	1.81
5Y	4.26	3.26	2.69
5GY	3.18	2.73	2.71
5G	4.18	3.17	2.98
5BG	5.25	4.23	3.43
5B	1.60	1.63	1.45
5PB	2.79	2.50	2.29
5P	3.86	2.84	2.42
5RP	2.48	1.90	1.92

Quantization: Quantization Error Less Than the Just Perceptible Color Difference

We have examined how many quantization levels are necessary to quantize (H,V,C) signals with the color difference of $\Delta E_{NBS} = 1$ as the maximum distortion[5]. The results are shown in Table 2 for H, V and C. According to the results, it is desired that the quantization be performed in HVC color space because a respective 8 bit quantization in H, V and C satisfies the condition: $\Delta E_{NBS} < 1$. However it is hard to maintain the stability of the hardware of non-linear processing and to realize the transformation of RGB <-> HVC with considerable precision. Therefore, we must quantize (R,G,B) signals uniformly before any processing. The procedure to get the quantization precision of (R,G,B) signals is as follows.

First, HVC color space is quantized into a small uniform solid. Second, after reverse transforming the (H,V,C) data of representative colors each solid into 8 bits RGB color space, the minimum distance between the representative colors along the R,G,B axes should be equivalent to the necessary uniform quantization interval of (R,G,B) colors. In order to satisfy the condition $\Delta E_{NBS} < 1$, the linear quantization should use the minimum interval as the quantizing interval in the entire range of RGB color space. To reduce the necessary quantizing accuracy of (R,G,B) signals, a simple non-linear quantization method (gamma = 3.0) is recommended. Results are summarized in Table 2.

Table 2. Necessary Quantization Accuracy under the Condition: $\Delta E_{NBS} < 1$

	Linear Input	Non-linear Input ($\gamma = 3$)
H	8C levels/pixel (2~8 bits/pixel)	
V	8 bits/pixel	
C	6 bits/pixel	
R	14 bits/pixel	10 bits/pixel
G	16 bits/pixel	12 bits/pixel
B	12 bits/pixel	9 bits/pixel

References

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