Color-Tone Similarity on Digital Images

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***Abstract*—A color-tone similarity index (CSIM) between two color images is presented and another index, picture similarity index (PSIM), is also given for a comprehensive similarity comparison between color images. CSIM is defined by a statistical analysis of cumulative histograms in a hue-oriented color space. It characterizes the color distributions, while the existing structural similarity index reflects the spatial structure involved with grayscale images. The behaviors of CSIM are checked by the comparisons of color code chips. Experimental results are given. The proposed indexes combined with SSIM are hopeful to provide a tool for color image quality analysis (IQA).**

I. Introduction

It is important to measure the similarity between color images for image quality analysis (IQA), the network control in broadcasting and wireless communications, and image/video retrieval systems.

Color information has been exploited in robot vision such as found in histogram intersection [1]. This is because the color histogram analysis can be simplified for the purpose of real-time processing. Since the object identification and tracking are the major concerns in robot vision, the distance between feature vectors is calculated [2], [3], [4], while the similarity between the entire bodies of color images is never taken into account.

On the other hand, the structural similarity index (SSIM) has been presented for a measure of similarity of grayscale images [5], [6]. It represents a degree of similarity on spatial structure between a pair of grayscale images. It is widely applied in full-reference IQA, because it fits in with the subjective impression of the human observers. As for color similarity, some works were reported [7], [8], although satisfactory results have been not yet obtained.

This paper presents a color-tone similarity index which is simple and is expected to agree with the perceptual impression.

II. A Preliminary Note

The color difference between a pair of color values is readily measured with the color difference formulas [9]. It is easy to define the color similarity, if just a couple of colors are present.

The situation changes completely, when one compares a pair of color images. There are many colors in an image. It is almost impossible to complete exhaustive comparisons of all possible combinations. Even if such a comparison is successfully completed, the result is doubtful whether it makes sense.

Let us imagine that a picture contains only two colors of red and green. If the color values on the image are averaged to obtain the average color value of the picture, one obtains a color value of yellow. It is completely different from the actual colors in the image. The arithmetic operation among color values causes color mixing. As a result, the averaged color value of a color image tends to approach an achromatic color, because many colors are contained in a natural image. It is desirable to exclude any spatially smoothing operations to avoid color mixing.

Also, the color similarity measure is desirable to be stable and robust against various operations including cutout, spatial processing, and color value quantization. To meet these requirements, any spatial information is never touched and a statistical analysis is developed.

III. Color-Tone Similarity and Picture Similarity Indexes

The proposed similarity indexes are computed in the system illustrated in Fig. 1. After RGB-to-HSY color space conversion, our attention is paid to dominant colors on which cumulative histograms are analyzed to define the color-tone similarity.

Colors are described by a set of three attributes in color perception: hue, saturation and brightness. They are favorably spread in many fields for color manipulations. A hue-oriented color space is thus selected for the analysis of color distribution. The color space conversion is a two-step procedure. Given RGB values are at first converted into a YCC system:

$$\begin{pmatrix} Y \\ C_1 \\ C_2 \end{pmatrix} = \begin{pmatrix} 0.2126 & 0.7152 & 0.0722 \\ 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}. \quad (1)$$

The luma component, Y, is one of the brightness representations which is close to the perceptual scale [10]. Since the basis vectors for the other components are orthogonal to the lightness axis described by $R = G = B$, hue and saturation are defined independently to the lightness. The hue and saturation

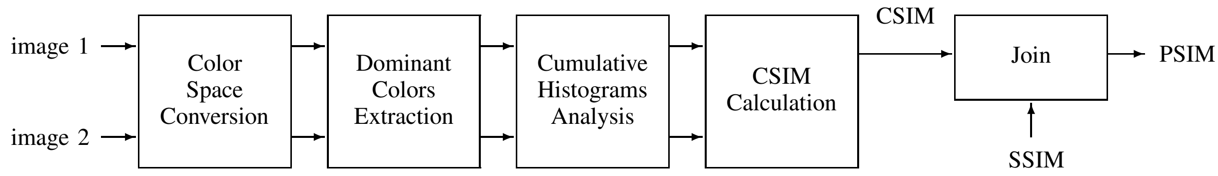

Fig. 1. A processing chain for computing CSIM and PSIM.

are defined as follows [3].

$$H = \begin{cases} h, & \text{for } C_2 \leq 0 \\ 2 - h, & \text{otherwise} \end{cases} \tag{2}$$

where

$$h = \frac{1}{\pi} \arccos \frac{C_1}{C}, \tag{3}$$

$$C = \sqrt{C_1^2 + C_2^2}, \tag{4}$$

and

$$S = \frac{2C}{\sqrt{3}} \sin \left\{ \frac{2}{3} - \mathrm{mod}\left(H, \frac{1}{3} \right) \right\} \pi. \tag{5}$$

As a result, the RGB color values are converted into the HSY color values.

As one ordinarily experiences, relatively bright areas in a color image affect the appearance of the image, if the color-tones are not very dull. Those colors are hence kept for image analysis and the others are neglected. A dominant color, D, is identified in the HSY color space, and is defined by

$$D = \{(H, S, Y) \mid S \geq S_t, \text{ and } Y \geq Y_t\}, \tag{6}$$

where S_t and Y_t are threshold values given in advance.

The dominant color distribution in HSY is analyzed by means of normalized cumulative histograms. It is reported that, for a given pair of color distributions, a cumulative histogram is superior to a histogram in the differentiation of color distributions [2]. The feature hue vector is defined by

$$\boldsymbol{H}_i = \{H_i(n)\}, \tag{7}$$

where

$$H_i(n) = \{H \mid c_i(H) = p_n\}, \tag{8}$$

where $c_i(H)$ is the normalized cumulative histogram of hue for image $i \in \{1, 2\}$. p_n is the nth element of a vector, $\boldsymbol{p}$, that accommodates cumulative occurrence probabilities. Explicitly it is given by

$$\boldsymbol{p} = (0.16,\ 0.33,\ 0.50,\ 0.67,\ 0.84,\ 0.995). \tag{9}$$

As illustrated in Fig. 2, a pair of cumulative histograms with respect to a color component in HSY are compared on the identical cumulative probability. Note that a *color value* here implies the value of H, S, or Y in HSY color space. If one may try to compare the cumulative probability on an identical color value, the bin for the color value can be empty, thus a comparison may end in failure. On the contrary, no such

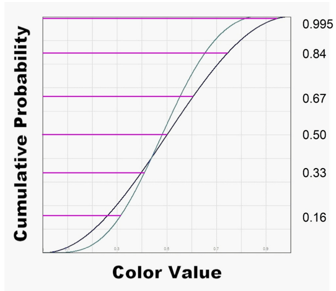

Fig. 2. Matching of two normalized cumulative histograms. They are matched on the cumulative probabilities to find the value differences in H, S, or Y.

a matching failure can occur in the case of matching along the cumulative probability. Furthermore, a cumulative histogram is monotonically increasing. As far as empty bins are skipped, one-to-one correspondence is valid on a cumulative histogram unlike on a histogram. In order to reduce the complexity, the cumulative probability is sampled on six points. The last sampling point of $p = 0.995$ gives an estimate of the last significant bin over which color values are absent.

The hue agreement between two feature hue vectors, $\boldsymbol{H}_1$ and $\boldsymbol{H}_2$, is defined by

$$A_H = \left(\prod_{n=1}^{6} 1 - d\left(H_1(n), H_2(n)\right) \right)^{1/6}, \tag{10}$$

where the distance function $d(x, y)$ is given by

$$d(x, y) = \begin{cases} \min\left(\left|x - y\right|,\ 2 - \left|x - y\right|\right), & \text{for } x, y \in H \\ \left|x - y\right|, & \text{for } x, y \in S \end{cases} \tag{11}$$

because H is periodic. The same calculation is applied to the saturation component to define the saturation agreement, A_S. According to Weber-Fechner's Law, the human sensation to the different light stimuli with respect to intensity behaves to be identical, if the intensity ratio of the stimuli is constant [9]. The luma agreement is thus defined by the form of a ratio instead of a difference as follows.

$$A_Y = \left(\prod_{n=1}^{6} \frac{\min\{Y_1(n),\ Y_2(n)\}}{\max\{Y_1(n),\ Y_2(n)\}} \right)^{1/6}, \tag{12}$$

where $Y_i(n)$ is calculated in the same manner as for H in Eq. (8).

The proposed color-tone similarity index is defined by

$$\mathrm{CSIM} = \sqrt[3]{A_H A_S A_Y}. \tag{13}$$

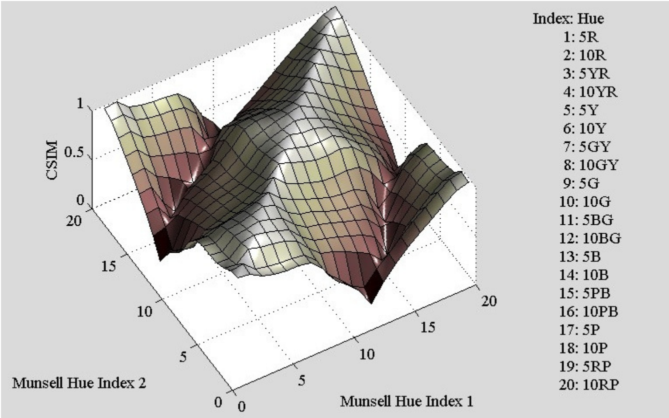

Fig. 3. Three-dimensional surface plot of CSIM dependency onto the Munsell hue under constant $V/C = 7/8$ in HV/C system.

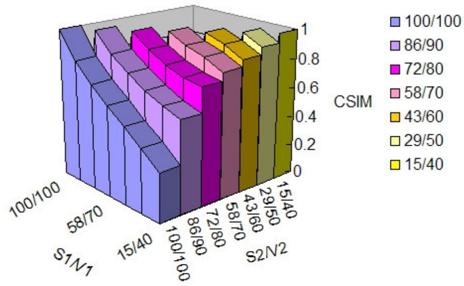

Fig. 4. CSIM dependency onto S and V under the constant hue at $282°$ in HSV system.

The histogram information for calculating CSIM is an at most 18-dimensional vector for each image.

Finally, CSIM is combined with the structural similarity index to obtain a comprehensive index for color image similarity. The picture similarity index is defined by

$$\mathrm{PSIM} = \mathrm{SSIM} \times \mathrm{CSIM}. \tag{14}$$

Note that the spatial structure is extracted by the correlation analysis of brightness in SSIM, while the information of color distributions is extracted in CSIM. They represent different information, and they are complementary.

IV. Experiments

The behavior of CSIM against the variations in hue, saturation, and intensity is checked by color code chips. The threshold values for dominant colors are $S_t = 1/16$ and $Y_t = 1/6$. The dependency of CSIM onto hue is shown as a 3-dimensional plot in Fig. 3, where 20 equi-spaced hues are set on the hue ring of Munsell color system [1][9]. For all color chips, it is common that $V/C = 7/8$. The horizontal and vertical axes are the indexes for Munsell hues, and their definitions are listed in the right-hand side. Two hues being compared are given by a crosspoint between two hue indexes. The CSIM value is read as the height. Two valleys are in parallel to the diagonal ridge and the spacing corresponds to a halfway of one period of hue. Inhomogeneous behaviors appeared as a plump ridge are observed around the hues of yellow and bluish green. This is because five basic colors are placed equi-distantly on the Munsell hue ring, whereas three primary colors are located equi-distantly on the hue ring in the other hue-oriented color spaces. As seen in the figure, the overall behavior is pretty fine.

The dependency of CSIM onto saturation and brightness is shown in Fig. 4. Since it is impossible to make equi-spaced values of V and C at a constant H in Munsell system due to the absence of some colors, HSV color space is selected for objective validations [11]. The hue is kept constant at $H = 282°$ in HSV. As observed in the figure, the value of CSIM decreases as the pair values of S and V are distant. For example, when a pair-wise value of $S = 15$ and $V = 40$ that belongs to the west-side axis seen at the front-most column is compared to the other pair-wise values along the east direction, the CSIM value monotonically increases.

From these verifications, the proposed CSIM is found to be satisfactory for the differentiation of colors. It is hopeful to differentiate color distributions in the sense of the human color perception rather than the sense of colorimetry.

As a preliminary experiment for IQA, pairs of images are compared. A part of them are shown in Fig. 5, and the values of SSIM, CSIM, and PSIM are listed in Table I. In part (a), it is evident that CSIM is insensitive to rotation. A pair of images in (b) are from the same video sequence but are different shots. The images in (c) share the same original image, but the resolutions and cutout regions are different, while the value of CSIM is as high as 0.94. The images in (d) were subjected to nonlinear tone-mapping. One of the images in (e) is a result of histogram matching to a different image. The values of CSIM seem to agree with the visual impression. The values of PSIM reflect both values of CSIM and SSIM.

Another demonstration is conducted with a part of test images in TID2008 [12]. The results are listed in Table II, and a few sample images are shown in Fig. 6. In the case of part (a), false colors are apparent and the value of CSIM takes 0.837 which is the lowest among the demonstrations. In part (b), less-saturated colors are lost on sails and water and CSIM is 0.864. In part (c), ghost effects are present, but the colors of two images are close, and the CSIM value is high. The values of CSIM and PSIM would be satisfactory for color IQA. Detailed experiments should be developed for the establishment of exact assessment technology.

V. Conclusions

A color-tone similarity index and a picture similarity index were presented to measure the picture-color similarity between two color images. CSIM is independent of the resolutions of two images being compared and is insensitive to spatial operations including translation, rotation, scaling, and segmentation.

[1] Colors are specified by hue, value, and chroma with notation of HV/C. R, Y, G, B and P stand for red, yellow, green, blue and purple, respectively. The hue value of 5 is reserved for the typical hues on those five colors. V is limited up to 10, but the excursion of C is unlimited. Munsell color system is the primary reference for perceptual color calibration.

(a) (b) (c) (d) (e)

Fig. 5. Samples of CSIM measurements.

It is possible to combine CSIM with SSIM into PSIM so that color image quality may be assessed. Experimental studies with subjective assessments are future works.

TABLE I
VALUES OF SSIM, CSIM, AND PSIM FOR THE CASES IN FIG. 5.

Fig. 5	SSIM	CSIM	PSIM
(a)	0.306	1.000	0.306
(b)	0.907	0.974	0.883
(c)	0.025	0.940	0.023
(d)	0.872	0.802	0.708
(e)	0.902	0.644	0.587

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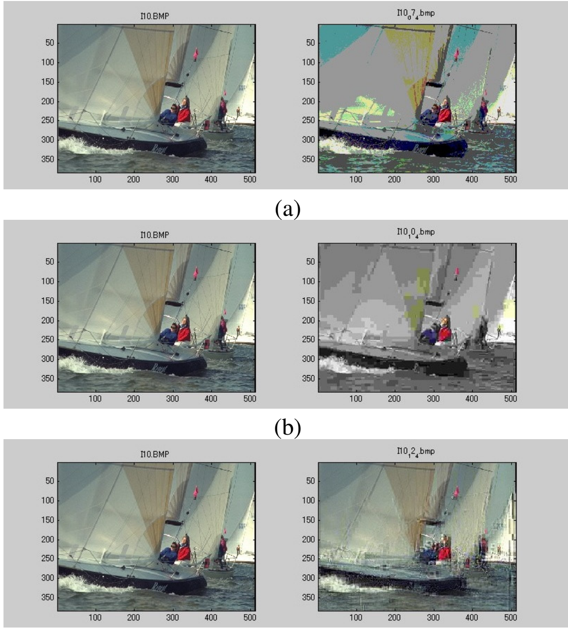

(a) (b) (c)

Fig. 6. IQA samples on a few test images in TID2008. On a pair of images, the left is the original and the right is a degraded image. The distortions are subjected to (a) additive noises differently in color components, (b) JPEG compression, and (c) JPEG transmission errors.

TABLE II
VALUES OF SSIM, CSIM, AND PSIM OF SOME TEST IMAGES IN TID2008 DATABASE.

Type of distortion	Fig. 6	Image	SSIM	CSIM	PSIM
Additive noise	—	I10-07-1	0.889	0.950	0.849
	—	I10-07-3	0.765	0.894	0.691
	(a)	I10-07-4	0.714	0.837	0.604
JPEG compression	—	I10-10-1	0.926	0.992	0.919
	(b)	I10-10-4	0.657	0.864	0.575
Transmission error	—	I10-12-1	0.913	0.992	0.906
	(c)	I10-12-4	0.521	0.987	0.515

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