Quantification of color motion picture quality considering human visual sensitivity

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Abstract

When a color video system with highly accurate color reproduction is designed, a good measure is required for evaluating the image quality including the color reproduction. There are some degradation sources in a total imaging system from image acquisition to image reproduction. Color random noise is one of major degradations which is often added in image capture phase. In this paper, we investigate the performance of the S-CIELAB (spatial CIELAB) and ST-CIELAB (spatiotemporal CIELAB) color difference as a quality measure in color motion picture degraded by random noise. In the experiment, we added a spatiotemporal noise to three kinds of still images and two kinds of motion pictures, performed the observer evaluation experiment, and found the noise level at which the noise is just noticeable. Color differences between images which correspond to just noticeable noise level by human observers were measured by CIELAB, S-CIELAB and ST-CIELAB space. In this paper, we report the performance of S-CIELAB and ST-CIELAB compared to CIELAB.

Introduction

When a color video system with highly accurate color reproduction is designed, a good measure for evaluating the image quality including the color reproduction is required. Though, for instance, MSE (mean square error) or PSNR (peak-signal to noise ratio) is a measure often used in the field of video compression, it does not necessarily correlate the subjective image evaluation by human observers [1]. Wang et al are proposing sophisticated methods taking advantages of known characteristics of the human visual system (HVS) [2]. However, those methods seem to be weighted on the luminance.

As a conventional measure for color difference, the difference in the CIELAB color space is used. However, in evaluating color difference between images the pixelwise color difference still does not correlate the subjective impression. Spatial CIELAB (S-CIELAB) [3] is a measure for calculating the color difference between images which taking spatial sensitivity characteristics of the HVS into account and therefore has better correlation with subjective evaluation by human observers. Furthermore, a spatio-temporal CIELAB (ST-CIELAB) [4] has been proposed for color difference evaluation for color motion picture.

In this paper, we investigated the performance of S-CIELAB and ST-CIELAB for the evaluation of noise degradation of color motion picture. As a preliminary experiment, images degraded by spatio-temporal random noise are evaluated by the above mentioned color differences. The random noise is added to each of the opponent color components and the just noticeable level of noise is subjectively evaluated. Then the color differences between those noisy images and the original images were calculated and how such measures depend on image contents and opponent color components noise-added were investigated.

Color difference in S-CIELAB and ST-CIELAB

The processing flow of calculation the color difference in S-CIELAB or ST-CIELAB is shown in Fig. 1. Original R, G, B images and noise-added R, G, B images are respectively transformed to the opponent color components, A, T, D. Then, the spatial frequency filtering in S-CIELAB and the spatio-temporal frequency filtering in ST-CIELAB are performed. Those filtered images are transformed to X, Y, Z colorimetric values and then L*, a*, b* values. Finally color difference is calculated pixel-by-pixel and then the mean value is calculated.

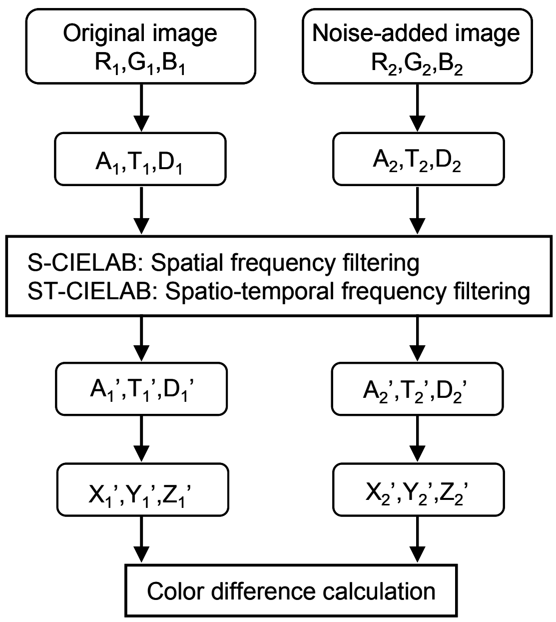


Fig. 1 Basic flow for calculation of color difference common to S-CIELAB and ST-CIELAB.

For S-CIELAB, we followed the original paper [3]. The detail parameters used in the S-CIELAB can be seen in [3]. On the other hand, for ST-CIELAB, a few modifications have been done from the original ST-CIELAB [4]. Spatiotemporal frequency sensitivity functions used in [4] is based on the researches by Kelly et al [5-8]. Firstly, in our processing, spatio-temporal sensitivity function is modeled by a separable function, namely the multiplication of a temporal sensitivity function and a spatial sensitivity function, while the original ST-CIELAB models the spatio-temporal sensitivity function of HVS by a more complicated function. Secondly, in our model, the spatial sensitivity function for two achromatic components, T and D, are modeled by the functions same as the ones used in

S-CIELAB, while the original ST-CIELAB approximately gives the common function common to T and D images based on [9].

The temporal frequency sensitivity functions used in our model are given below. For achromatic component A, the temporal sensitivity function is given

$$S_a(f_t) = K(f_{s2}, f_t), \tag{1}$$

and for the chromatic components, T and D, the temporal sensitivity function,

$$S_c(f_t) = [2T_E(f_t) - K(f_{s2}, f_t)] / C_C \tag{2}$$

Here,

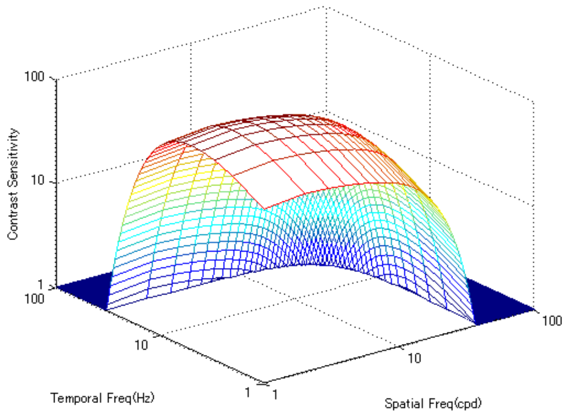
$$T_E(f_t) = \begin{cases} c_1 K(f_{s1}, f_t) & for \quad f_t \le f_{t1} \\ K(f_{s2}, f_t) & for \quad f_t > f_{t1} \end{cases} \tag{3}$$

$$c_1 = K(f_{s2}, f_{t1}) / K(f_{s1}, f_{t1}) \tag{4}$$

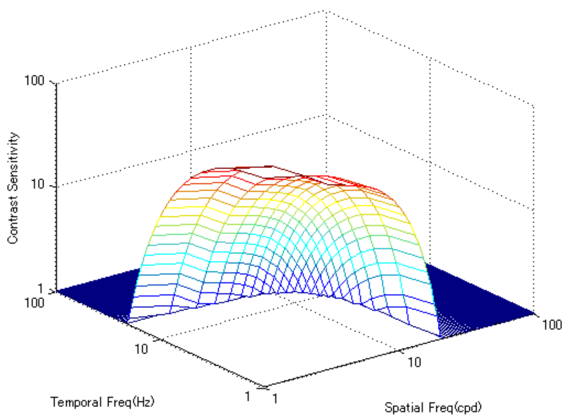
$$K(f_s, f_t) = (6.1 + 7.3 \,|\log_{10}(f_t / 3f_s)|^3) f_t (2\pi)^2 f_s \times \exp(-4\pi(f_t + 2f_s)/45.9) \tag{5}$$

$f_{s1} = 10[\text{cpd}], f_{s2} = 0.5[\text{cpd}], f_{t1} = 19[\text{Hz}], C_C = 30$.

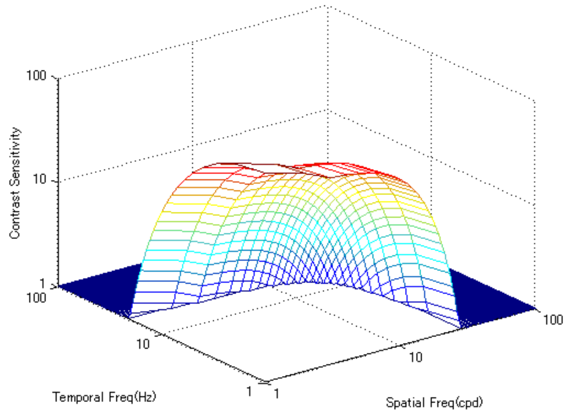
The spatio-temporal frequency filters for ST-CIELAB used in this paper is shown in Fig. 2. Achromatic component, A, has the widest bandwidth both temporally and spatially. Chromatic component T has a little wider bandwidth than component D in the spatial domain.



(a) A channel



(b) T channel



(c) D channel

Fig. 2 Contrast sensitivity functions used in this paper.

Evaluation experiment

Three still images and two motion pictures shown in Fig. 3 were used. Still image #1 is a photo of Macbeth color checker which includes many uniform color patches and is a colorful content. Still image #2 is a photo of flowers which is also a colorful and spatially complex image. Still image #3 is a general portrait. Motion picture #4 is that a woman is sitting with a wine glass where a camera is moving around her slowly. Motion picture #5 is that women wearing traditional costume are dancing outside in relatively fast motion.

Each still image has 752x752 pixels, while each motion picture has 720x540 pixels. Degraded images were generated by adding white noise with a normal distribution to any of A, T, or D channel image. Adding noise to A, T or D channel is done in order to directly observe the effectiveness of introducing the contrast sensitivity functions of HVS given in the opponent color space to the S-CIELAB and ST-CIELAB.

For still images, the thirty copies of an original still image were made and noises were added to each image. Those images form a one-second motion picture with 30 frame/second rate and are presented to observers repeatedly. Original motion pictures #4 and #5 respectively have 120 frames which make a four-second movie. White noise was added to those motion pictures to generate noisy motion pictures as well. Many motion pictures with different noise levels were generated.

Ten observers with normal vision participated in the experiment. In the evaluation experiment, an image with noise and an original image were sequentially presented to observers. The order of those images was at random and the observer was asked to select the image which he or she felt the noise was present. Observation time was not limited. For each noise level, the ratio that observers selected a correct image was calculated. For each degraded image, mean color differences measured by the CIELAB, S-CIELAB and ST-CIELAB metric are calculated. We defined the just noticeable noise level by 75% correctly answered ratio and calculated the corresponding color difference by the probit analysis.

A high-vision master monitor, HTM-1980 (Ikegami) with the resolution of 1920x1080 pixels, and non-compression video recorder, UDR-2E (Keisoku Giken) were used in the experiment.

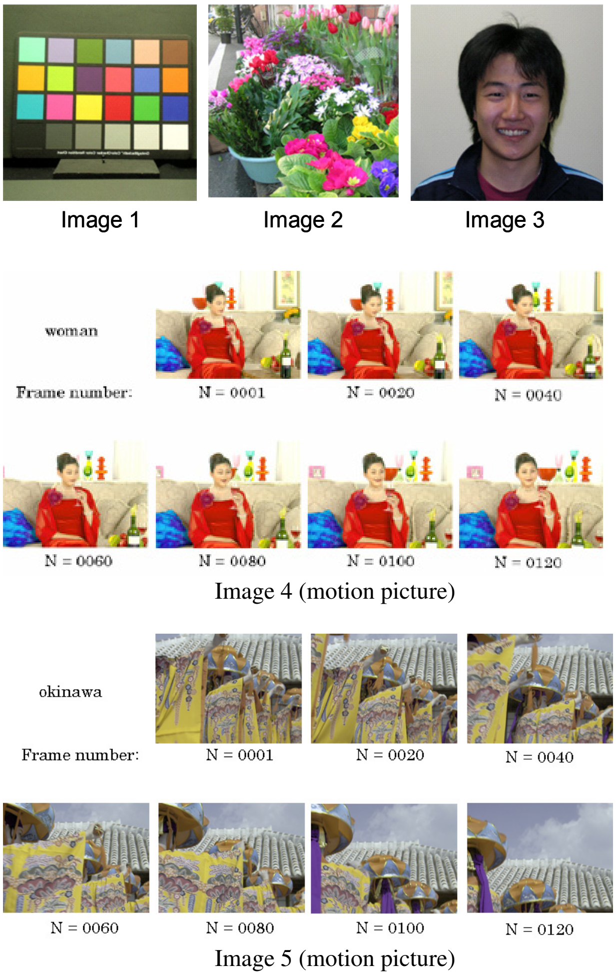


Fig. 3 Images including two motion pictures used in the evaluation experiment.

The mean color differences corresponding to just noticeable noise level calculated are listed in Table 1. Three metrics, CIELAB, S-CIELAB and ST-CIELAB are compared. For the purpose of visual observation of these data, bar graph representation of the same data is also presented in Fig. 4.

Table 1: Color difference corresponding to just noticeable noise level.

still or movie	image number	CIELAB			S-CIELAB			ST-CIELAB		
		A	T	D	A	T	D	A	T	D
still image	#1	0.40	3.32	4.02	0.12	0.69	0.88	0.10	0.46	0.75
	#2	0.47	2.10	4.37	0.16	0.48	1.01	0.12	0.35	0.88
	#3	0.66	1.33	3.30	0.34	0.45	0.84	0.31	0.38	0.73
motion picutre	#4	0.23	0.75	1.72	0.10	0.23	0.51	0.08	0.18	0.43
	#5	0.49	2.70	2.03	0.18	0.54	0.36	0.12	0.27	0.21

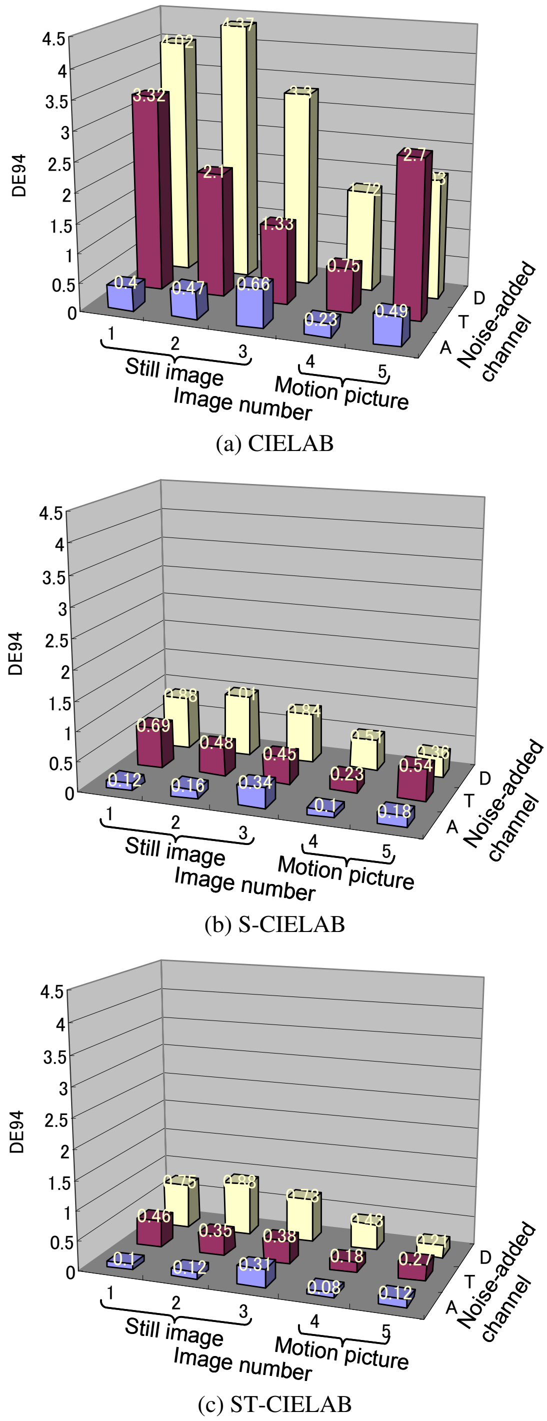


Fig. 4 Color differences corresponding to just noticeable noise level (graphical representation of table 1).

Discussion

In the case of the CIELAB, large variation between different components and different color images is observed. The just noticeable color difference for D component noise is the largest among three components. These large values are markedly weakened in the cases of both S-CIELAB and ST-CIELAB. This is because the low pass filtering in S-CIELAB and ST-CIELAB basically blurs images, then original and noise-added image look similar.

It is ideal that the color difference giving just noticeable noise level does neither depend on the component noise-added, nor image content. In order to evaluate this aspect, we take the variance of the color differences listed in Table 1 as a measure. However, the use of the absolute values is not fair because S-CIELAB and ST-CIELAB in general have smaller values than CIELAB because of its low pass filtering nature. So, the values are first normalized by the maximum value and then the standard deviation was calculated. The calculation was performed for the still image set and for the motion picture set, separately.

The result is listed in Table 2. For still images, S-CIELAB and ST-CIELAB show better performance than CIELAB, but there is no difference between S-CIELAB and ST-CIELAB. On the other hand, for motion pictures, ST-CIELAB shows the best performance. Especially, in image #5 including large motion, the color difference for the D component noise is greatly reduced in ST-CIELAB. However, at this stage, it is not possible to say if the ST-CIELAB is superior. Only two sets of motion pictures are too small to argue the effectiveness. The visual masking effect [10] should also be considered.

Basic researches on noise perception over uniform background [11] should also be referred or analyzed to construct a good model to evaluate the quality of the motion picture with noise.

Table 2: Standard deviation of the color differences giving just noticeable noise level.

Metric	Standard deviation	
	Still image	Motion picture
CIELAB	0.34	0.33
S-CIELAB	0.30	0.30
ST-CIELAB	0.30	0.26

Conclusions

We studied the performance of S-CIELAB and ST-CIELAB and the modification for in the evaluation of color motion picture. As a preliminary experiment, images degraded by spatio-temporal random noise were evaluated by those color differences. The random noise was added to each of opponent color component and the just noticeable level of noise was subjectively evaluated. We found that S-CIELAB and ST-CIELAB perform better than the conventional CIELAB color difference. However, further improvement of those metrics is required for practical use.

Acknowledgement

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Author Biography

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