Using Different Color Models to Test JPEG and Modified JPEG

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Abstract

In this paper, issues of storage and transmission of high quality color images were discussed. JPEG is the most robust algorithm being used for image compression. The cubic spline interpolation (CSI) has previously been used in JPEG1992 to improve its performance for medical images. In current work, CSI was amalgamated with JPEG 1992 standard for color image compression. In addition, different color models were also incorporated into JPEG to compare the performance of JPEG and modified JPEG named as CSI-JPEG. The JPEG was modified at two stages called color space conversion and down sampling stage and was tested by incorporating different color models. The results showed that CSI-JPEG algorithm provided about 30% more compression rate on average for same visual quality as compared to traditional JPEG algorithm. Moreover, CAM02-UCS was found to perform best in terms of compression rate and image quality for both of the algorithms. By statistical significance test, the performance of CAM02-UCS was proved significantly better comparing with non-uniform color spaces and the performance difference of CSI-JPEG and JPEG was also significant. This also implies that CAM02-UCS is a more visually uniform color space than CIELAB and CIELUV. Psychophysical experiments were also conducted that validated the test results.

Introduction

With the advent of technology, high resolution images can be captured, stored and transmitted. But because of high resolution image data to be saved requires more memory space and more time to transmit. Due to limitations of memory devices and communication systems, data needs to be compressed. The most commonly used industrial standard for image compression is JPEG, an algorithm proposed by joint photographic experts group (JPEG) [1]. JPEG is a low loss compression algorithm which can achieve desired degree of compression by allowing a selectable tradeoff between compression rate and quality of the compressed image. The latest version of JPEG is JPEG2000 standard [11]. It is an improvement over JPEG 1992 standard. The present work investigated the performance of JPEG by modifying it at two stages; color space conversion and sub-sampling, which are included in both 1992 and 2000 standards. JPEG 1992 standard was implemented and investigated here in order to compare the results with that of Chen et al [5-7] and Moroney et al [2].

Selection of a 'good' color space for image compression has become crucial due to properties of visual distortion prediction and compressibility. Enormous work has been done to investigate which color space best suits for image compression [2-4]. Moroney and Fairchild presented results for selection of best color space that should be incorporated for improvement of JPEG [2]. They found that uniform color spaces (CIELAB and CIELUV) performed best and device color space was the worst, while CIEXYZ and YIQ color spaces lie in between. Zhu and Luo, compared linear and non linear model's performance for different color image compression algorithms and concluded that all non-linear models perform better comparing with linear models [9]. Nadenau and Reichel, evaluated CIELAB, YCbCr and the pattern color separable opponent color space, on color image compression [3]. Using CIE XYZ tristimulus space, NTSC YCbCr and NTSC YIQ in image compression algorithms were suggested in [8]. CAM02-UCS is a uniform color space based on CIECAM02 which gave accurate prediction performance to all types of color discrimination data. Its property of compressibility has not been investigated before [12, 13]. It is believed that a more uniform color space close to visual perception should give better performance in image compression i.e. equal amount of compression in different color regions to give same amount of perceived color differences.

In cubic spline interpolation (CSI), the interpolant is a special type of piecewise polynomial called spline. It is preferred over other polynomial based interpolation techniques because it avoids instability being sufficiently smooth at knots and its robustness against so called Runge's phenomenon [14], i.e. the problem of oscillations at the edges of an interval that occurs while performing interpolation with high degree polynomials. Truong and Chen joint cubic spline interpolation with JPEG to compress medical images and concluded that performance of JPEG improves by about 30% in terms of compression rate [5]. Lin et al [6] proposed that medical image compression ratio can be increased 3 times by combining CSI with lossless JPEG algorithm (JPEG-LS). In [7], JPEG was modified using cubic spline interpolation with bit-plane compensation and improved 20-30% performance. In the present work, CSI-JPEG algorithm was developed for 3-channel color image compression that is amalgamation of baseline JPEG algorithm with cubic spline interpolation.

In the present work, six widely used and popular color spaces were investigated: device space RGB, CIE tristimulus space XYZ, color TV space YIQ, CIE non-linear and uniform color spaces LUV and LAB, and CAM02-UCS extended from CIECAM02, for color image compression, by incorporating them into standard JPEG and proposed CSI-JPEG algorithms. The CIEDE2000 color difference formula was used for performance analysis [15, 16].

Compression Algorithms

Two compression algorithms JPEG and proposed CSI-JPEG have been investigated in this work. Conventionally the image is first down-sampled and up-sampled before and after using standard baseline JPEG algorithm, which is the first algorithm investigated here and is depicted in **Fig. 1(a)**. Secondly, CSI-JPEG algorithm for color images was developed which is amalgamation of cubic spline interpolation and standard baseline JPEG algorithm, depicted in **Fig. 1(b)**.

In JPEG algorithm, image is down-sampled after color space transformation and standard JPEG encoder is then applied. Output of the JPEG encoder is the compressed image data which can be saved or transmitted over the network. To restore the compressed image, reverse process is done, which includes standard JPEG decoder, up-sampling and reverse color space transformation. JPEG encoder and decoder consist of three steps each, applied on 8x8 blocks of pixels for each channel. In JPEG encoder, 8x8 blocks of image are first transformed from spatial representation to frequency representation and are then quantized systematically. The quantized data is encoded using statistical encoding. These steps are repeated for each block of the entire image. At this point, the image can be stored or transmitted. While decoding the stored image, statistical decoding, dequantization and frequency to spatial domain transformation are performed. For decompression, the same steps are repeated in reverse.

The proposed compression algorithm CSI-JPEG is different than JPEG at the sampling stage. Where, forward cubic spline interpolation has been incorporated instead of using down-sampling and inverse cubic spline interpolation instead of up-sampling in the compression and decompression, respectively. To obtain maximum smoothness and to avoid distortions at the edges, the constraint of continuity of first two derivatives was employed on cubic spline interpolation . And smoothness at the edges is highly desired to avoid distortions, while sub-sampling the image data [5]. The CSI was employed in such a way that the image size reduced to 9/64 of the original. While in the case of down sampling the image size is reduced to 16/64 of the original image. That is why it increases the compression rate of JPEG by about 30%. After sampling stage, baseline JPEG algorithm has been used in the same way as described above.

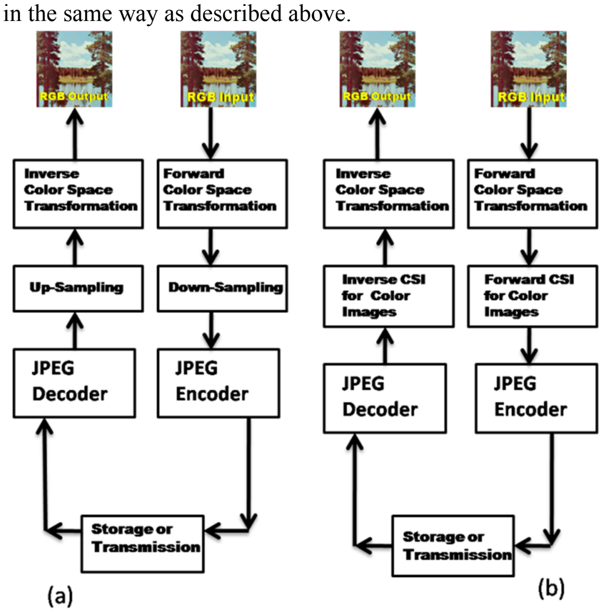

Figure 1. Basis flowchart for a) JPEG and b) CSI-JPEG

Experimental Color Spaces

As mentioned earlier, six different color spaces sRGB, YIQ, CIEXYZ, CIELAB, CIELUV and CAM02-UCS were tested in this work. CAM02-UCS will be designated as JAB space onwards in this paper. Each of YIQ, LAB, LUV, XYZ and JAB color spaces has one luminance and two chrominance channels. Luminance signal is represented by Y, J or L*. The RGB space is the only color space in which there is no single channel that represents only luminance or chrominance. Note that the display used here is calibrated to a sRGB display.

CIE Illuminant D65 and 1931 standard colorimetric observer were used as reference conditions for all color spaces. The RGB color space can be linearly transformed to XYZ using Eq.1. The transformation matrix used for RGB to YIQ conversion is given in Eq.2.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.298936 & 0.587043 & 0.114021 \\ 0.595946 & -0.274389 & -0.321557 \\ 0.211497 & -0.522911 & 0.311413 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2)$$

Three uniform color spaces selected were CIELAB, CIELUV and CAM02-UCS. Uniform color spaces are now frequently used to present colors. The goal is to have a color space which corresponds to visual perception. As these models are based on XYZ space, so they are device independent. The CIELAB and CIELUV can be calculated using Eqs.3-5 and Eqs. 3, 6 and 7, respectively.

$$L^* = 116\, f\left(\frac{Y}{Y_W}\right) - 16, \quad (3)$$

$$a^* = 500(f\left(\frac{X}{X_W}\right) - f\left(\frac{Y}{Y_W}\right), \quad (4)$$

$$b^* = 500(f\left(\frac{Y}{Y_W}\right) - f\left(\frac{Z}{Z_W}\right), \quad (5)$$

where

$$f(t) = \begin{cases} t^{\frac{1}{3}}, & t > \left(\frac{6}{29}\right)^3 \\ \frac{841}{108} t + \frac{16}{116}, & t \leq \left(\frac{6}{29}\right)^3 \end{cases}.$$

$$u^* = 13L^*(u' - u_w') , \quad (6)$$

$$v^* = 13L^*(v' - v_w'), \quad (7)$$

where

$$u' = \frac{4X}{X+15Y+3Z},$$

$$v' = \frac{9Y}{X+15Y+3Z},$$

and subscript '*w*' represents the reference white. For XYZ to JAB transformation in CAM02-UCS [13] which is an extension of CIECAM02 [12], Eqs.8-10 were used to compute J', a' and b' from CIECAM02 J, M and h.

$$J' = \frac{(1+100c_1)J}{1+c_1 J}, \quad (8)$$

$$a' = M' cos(h), \quad (9)$$

$$b' = M'\sin(h), \quad (10)$$

where

$$M' = (1/c_2)\ln(1 + c_2 M)$$

and J, M and h are CIECAM02 lightness, colorfulness and hue angle (degrees), respectively. Values used for constants c_1 and c_2 were 0.007 and 0.0228, respectively [13]. Average surround conditions were considered for CIECAM02 forward and reverse.

Testing Methods' Performance

Both the compression algorithms with each of six color space models using MATLAB were implemented. Four different test images were selected from an image set including over 100 test images, which gave more reliable results. Their contents include natural objects, human faces, animals, indoor and outdoor environment and natural scenes that include green grass and blue sky. The four selected color images were named as actress, ladies, horses, and fruits, respectively (see **Fig. 2**). They had sizes of 1536x1024, 512x1024, 1536x1536 and 1536x1024 pixels, respectively. Six measures for quantifying the performance of compressibility including compression rate (CR), bits per pixel (BPP), signal to noise ratio (SNR), peak signal to noise ratio (PSNR), mean squared error (MSE), CIELAB color difference measure (ΔE^*_{ab}) and CIEDE2000 color difference formula (ΔE_{00}), were used to examine the overall performance.

Two tests were performed for performance comparison of each of the six models for both algorithms. In first test, ΔE_{00} value was fixed to 4±0.1. And in the second test, compression rate (CR) was fixed to 8±0.1. To obtain the reliable results in both tests, the threshold values of ΔE_{00} and CR were chosen to meet the criteria of acceptability as found by Song et al [17]. These tests were designed to verify the methods' performance in order to find how much compression rate each model can give to achieve equal color difference, and how much color difference can be reached by adapting same compression rate, respectively.

The results of the first test were averaged over four images and are summarized in Table 1. From these results, the six color spaces according to their compressibility performance were ranked. Table 1 showed that for conventional JPEG algorithm, JAB performed the best, followed by LUV and LAB having almost similar performance, then YIQ and RGB apace was worst. Almost same ranking of the six color spaces may be observed for CSI-JPEG algorithm. However CSI-JPEG gave almost 30% extra compression rate as compared to JPEG algorithm. And JAB color space model showed its superiority. In conclusion, in the first test, CSI-JPEG algorithm with JAB color space model outperformed all other models in terms of compressibility. Moreover, for same ΔE_{00}, the values of SNR, PSNR, MSE and ΔE^*_{ab} were different for different models.

In the second test, compression rate was fixed (CR = 8±0.1) and all other measures were computed for both JPEG and CSI-JPEG algorithms. The results are summarized in Tables 2. These results verify that JAB color space is the best among all six color space models for image compression and performance of CSI-JPEG algorithm is better than JPEG in terms of color difference and signal to noise ratio when the compression rate is same. The other two uniform color spaces (LAB and LUV) did not perform very differently comparing with each other. The results also showed that SNR and PSNR indicate almost similar performance for three linear models (RGB, YIQ and XYZ), while the nonlinear models proved better.

Statistical significance test was also performed for the results of both tests shown in Tables 1 and 2. Pair comparison was done using two-tailed T-test. Over all analysis of variance (ANOVA) showed that performance of all models for both tests was significantly different. Subsequently, the models were compared pair wise for the two algorithms in both tests. The results showed that uniform color spaces CIELAB and CIELUV performed insignificantly better than non-uniform color spaces (RGB, XYZ and YIQ), Where as the performance of JAB was significantly better and insignificantly better in comparison with CIE uniform color spaces (LAB and LUV). Secondly, it was also proved that CSI-JPEG performed significantly better comparing with conventional JPEG algorithm in both tests.

Table.1: Test results for ΔE_{00}=4±0.1

Algo.	Model	CR	BPP	SNR	PSNR	MSE	ΔE^*_{ab}
JPEG	RGB	6.5	3.7	54.7	63.4	10.7	6.3
	XYZ	6.8	3.6	55.1	63.7	10.7	6.4
	YIQ	8.4	2.9	56.1	63.8	9.9	6.4
	LAB	9.8	2.4	56.0	67.4	9.5	6.2
	LUV	9.4	2.5	55.3	67.4	9.6	6.0
	JAB	10.6	2.2	57.8	69.0	9.4	6.0
CSI-JPEG	RGB	8.6	2.8	58.7	67.2	10.1	6.0
	XYZ	9.0	2.7	59.0	67.9	10.5	6.4
	YIQ	11.0	2.2	58.9	68.3	9.9	5.9
	LAB	12.7	1.9	62.9	74.3	9.8	5.9
	LUV	12.4	1.9	62.9	74.3	9.9	5.7
	JAB	13.9	1.7	64.3	76.3	9.5	6.0

Table.2: Test results for ΔE_{00}=4±0.1

Algo.	Model	SNR	PSNR	MSE	ΔE^*_{ab}	ΔE_{00}
JPEG	RGB	47.2	53.4	11.8	7.2	4.9
	XYZ	49.0	54.5	11.2	7.0	4.7
	YIQ	50.9	55.2	10.2	6.5	4.1
	LAB	55.7	62.0	8.5	5.7	3.5
	LUV	55.3	61.3	8.7	5.6	3.4
	JAB	58.7	64.7	7.2	5.1	3.0
CSI-JPEG	RGB	50.9	56.5	10.7	7.0	4.5
	XYZ	52.8	58.4	10.5	6.9	4.4
	YIQ	54.4	60.5	9.6	6.0	3.6
	LAB	59.2	67.0	7.9	5.6	3.1
	LUV	59.0	67.3	8.5	5.6	3.1
	JAB	62.8	71.2	7.0	4.5	2.7

Psychophysical Experiment

The results of second test were also quantified by performing psychophysical experiment. A wide-gamut Eizo Colour Edge CG243W display with resolution 1920x1200 was adopted in the experiment. The display was calibrated to have approximately linear relationship between digital counts and luminance. The peak white of the monitor was set at 6500K with a luminance value of 100cd/m^2. The grey background with L*=50 was set to display images. All colors were measured by a Specbos-1211(Jeti) spectrophotometer. Ten observers participated in the experiment. **Fig. 3** illustrates the viewing conditions used for psychophysical experiment.

Four original images and their corresponding restored images from each of the 12 models were processed for the experiment. The restored images from different models were compared pair wise by displaying randomly. Each pair of restored images was displayed keeping the original image in the middle i.e. three images were displayed at the same time. The observers were then asked to judge that which (left or right) image out of a pair is visually more close to the original one (middle). The overall appearance of the images was observed. Observers took approximately 15 seconds on average for each pair. There were 264 numbers of pairs in total. Each observer participated in two sessions. Each session took about 35 minutes.

The data were presented in Z-score [18] to represent how close the result of each model is to the original image. The raw data given by observers to each model were sorted out according to all possible combinations and probability of each model to be better than the other and the proportion matrix was computed from the sum matrix. The Z-score of each model was then calculated. The Z-score of each of selected six models for CSI-JPEG were then compared with JPEG as shown in Fig. 4. The visual results of both the algorithms, when JAB color space was incorporated, were very close to the original and it was hard for the observers to make decision. But for the other models, better visual performance of CSI-JPEG algorithm was observed in comparison with the JPEG. The 95% confidence interval was also calculated that indicates the reliability of the estimate and is shown in Fig. 4.

The correlation coefficients between Z-Score and the other five measures (SNR, PSNR, MSE, ΔE^*_{ab} and ΔE_{00}), were computed. The results are given in Table 5 in terms of correlation coefficient (R) and probability (P) for showing the statistical significance. For $P<0.05$, it can be considered to be significantly close to the visual data represented by Z-Score [19]. It can be seen that color difference formula CIEDE2000gave the best correlation with the visual results. This was followed by ΔE^*_{ab} *and* MSE and PSNR stood worst. This implies that a more robust model such as CAM02-UCS or CIEDE2000 can be reliably used to predict color difference for complex images.

Table.3: Correlation coefficients and P-values

Algorithms		SNR	PSNR	MSE	ΔE^*_{ab}	ΔE_{00}
JPEG	*R*	0.89	0.86	0.93	0.93	0.96
	P	0.02	0.029	0.006	0.008	0.003
CSI-JPEG	R	0.88	0.85	0.93	0.93	0.97
	P	0.02	0.034	0.006	0.007	0.001
Both	R	0.87	0.82	0.92	0.92	0.95
	P	2.1e -04	1e -03	1.7e -05	1.9e -05	2.6e -06

Figure 2. Selected test images

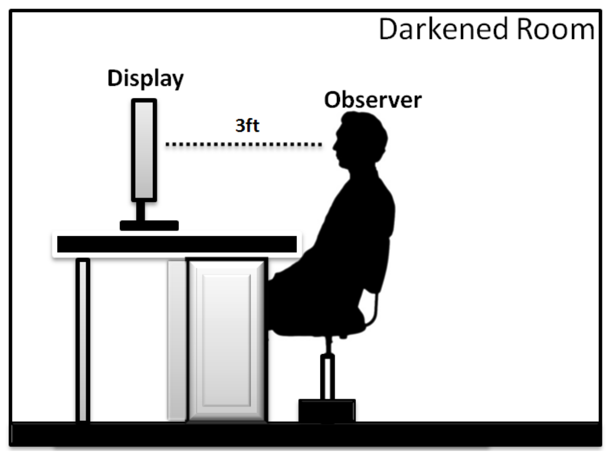

Figure 3. An illustration of experimental viewing conditions

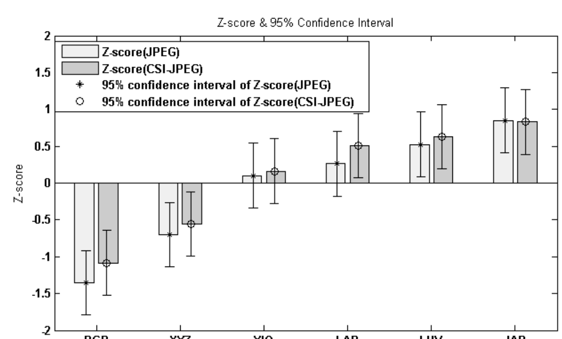

Figure 4. Experimental results (Z-score and its 95% confidence interval)

Conclusions

A new image compression algorithm named CSI-JPEG was developed for color images. It was compared with conventional JPEG algorithm by incorporating six different color spaces including RGB, XYZ, YIQ, LAB, LUV and JAB. Two different tests were conducted, by fixing ΔE_{00} and CR, respectively. The JPEG results were improved by 30% due to using CSI in the sampling stage and obtaining visual performance. And it was also concluded that compressibility of CAM02-UCS color space is best among the selected six color spaces. Ranking of different color models on the basis of their performance drawn previously by Moroney and Fairchild [2] was verified and the superiority of the newly developed color space CAM02-UCS was also established. Statistical significant test was also performed for the test results. The performance of CAM02-UCS was proved significantly better comparing with non-uniform color spaces, while LAB and LUV were insignificantly better. The performance difference of CSI-JPEG and JPEG was also significant.

A psychophysical experiment was also carried out which validated the test results. The results confirmed that the proposed CSI-JPEG algorithm gave smaller visual difference between the compressed and original images for the fixed value of CR. The uniform color space CAM02-UCS remained best among all the color spaces tested. Out of the five measures used, ΔE_{00} best correlated with the visual, while PSNR was proved worst. On the basis of these results, cubic spline interpolation and the uniform color space CAM02-UCS may be included in the future standards of JPEG.

References

[1] G. K. Wallace, "The JPEG Still Picture Compression Standard," Consumer Electronics, IEEE Transactions on 38(1), xviii-xxxiv, (1992).

[2] M. Moroney and D. Fairchild, “Color Space Selection for JPEG Image Compression,” Journal of Ele. Img., 4(4), 373-381, (1995).

[3] M. J. Nadenau and J. Reichel, “Opponent Color, Human Vision and Wavelets for Image Compression,” Proc. Color Imaging Conference, pg.237–242, (1999).

[4] M.J. Nadenau, J. Reichel, and M. Kunt. “Wavelet-based Color Image Compression: Exploiting the Contrast Sensitivity Function,” IEEE Transactions on Image Processing, 12(1), 58–70 (2003).

[5] T. K. Truong and S. H. Chen “Medical Image Compression Using Cubic Spline Interpolation for Low Bit-rate Telemedicine Applications,” Proc. of SPIE, pg.61450H-61450H. (2006).

[6] T. C. Lin, C. W. Chen, S. H. Chen and T. K. Truong, "Near lossless medical image compression using JPEG-LS and cubic spline interpolation," Optical Engineering Applications; International Society for Optics and Photonics, 70721G-70721G, (2008).

[7] T. K. Truong, S. H. Chen and T. C. Lin, "Medical image compression using cubic spline interpolation with bit-plane compensation," Proceedings of SPIE Vol. 6516, 65160D (2007).

[8] I. Ylakoski and H. Ronngren, CIE XYZ Colour Space used for Image Compression, Taga Proceedings, pg.139-151. (1992).

[9] S. Y. Zhu and M. R. Luo, “An Evaluation of Colour Models’ Performance using Image Compression Algorithms,” Proc. of Color Imaging Conference, pg.177-179. (1999).

[10] D. J. Granrath, “The Role of Human Visual Models in Image Processing,” Proc. of the IEEE, 69(5), pg.552-561. (1981).

[11] T. Acharya and P. S. Tsai, JPEG2000 standard for image compression: concepts, algorithms and VLSI architectures (John Wiley & Sons, 2005).

[12] N. Moroney, M.D. Fairchild, R.W.G. Hunt, C.J Li, M.R. Luo, and T. Newman, “The CIECAM02 Color Appearance Model,” IS&T/SID 10th Color Imaging Conference, Scottsdale, pg.23-27. (2002).

[13] M. R. Luo, C. Guihua and C. Li, “Uniform Colour Spaces Based on CIECAM02 Colour Appearance Model,” Col. Res. App., 31(4), 320-330 (2006).

[14] S. Chapra and R. Canale, Numerical Methods for Engineers (McGraw-Hill 2007), (5th ed.).

[15] M. R. Luo, G. Cui and B. Rigg, “The Development of CIE 2000 Color Difference Formula: CIEDE2000,” Color Res. App., 26(5), 340-350 (2001).

[16] G. Sharma, W. Wu and E. N. Dalal, “The CIEDE2000 Color-Difference Formula: Implementation Notes, Supplementary Test Data, and Mathematical Observations”, Color Res. App., 30(1), 21-30 (2005).

[17] T. Song and M. R. Luo, "Testing color-difference formulae on complex images using a CRT monitor," The eighth Color and Imaging Conference, IS &T and SID, Scottsdale, Arizona, pg.44-48. (2000).

[18] P. G. Engeldrum, Psychometric Scaling (Imcotek Press. Winchester, MA, 2000).

[19] S. Stigler, “Fisher and the 5% Level,” Chance, 21(4), 12 (2008).

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