ANALYSIS OF RELATIONSHIP BETWEEN IMAGE COMPRESSION AND GAMUT VARIATION

Tae-Yong Park, Kyung-Woo Ko, and Yeong-Ho Ha

School of Electrical Engineering and Computer Science
Kyungpook National University
Taegu, Korea
E-mail: yha@ee.knu.ac.kr

ABSTRACT

This paper investigates the relationship between the compression ratio and the gamut area for a reconstructed image when using JPEG and JPEG2000. Eighteen color samples from the Macbeth ColorChecker are initially used to analyze the relationship between the compression ratio and the color bleeding phenomenon, i.e. the hue and chroma shifts in the a^*b^* color plane. In addition, twelve natural color images, divided into two groups depending on four color attributes, are also used to investigate the relationship between the compression ratio and the variation in the gamut area. For each image group, the gamut area for the reconstructed image shows an overall tendency to increase when increasing the compression ratio, similar to the experimental results with the Macbeth ColorChecker samples. However, with a high compression ratio, the gamut area decreases due to the mixture of adjacent colors, resulting in more grey.

Keywords: JPEG, JPEG2000, gamut, compression ratio

1. INTRODUCTION

Image compression schemes, such as JPEG[1] and JPEG2000[2], degrade the quality of a reconstructed image due to their lossy characteristics. Among such degradation factors, color bleeding is particularly visible around colors between highly contrasting chrominance areas. This phenomenon is a result of the abrupt truncation of high-frequency components due to coarse quantization and subsampling of the chrominance channel, which appears as color smearing owing to spurious colored oscillations in the reconstructed image. Consequently, a change of color information, such as loss of the chrominance component and corresponding color smearing phenomenon, affects the gamut characteristic of the reconstructed image.

Many studies have already examined the image distortions related to JPEG and JPEG2000[3-5], and presented both quality metrics for measuring such artifacts and practical approaches for improving the perceptual quality of a decompressed image[3],[6],[7]. Nonethelss, in case of sacrificing large amounts of color information for effective data reduction, using the premise that the human visual system is less sensitive to the chrominance component, research on color artifacts has only recently been receiving attention[8-11]. At high compression ratios, a decompressed image suffers from color artifacts, which are caused by the subsampling of the chrominance channels in JPEG and multi-resolution nature of the wavelet transform in JPEG2000, along with the coarse quantization of the chrominance component in both algorithms. Color bleeding is particularly visible around colors between highly contrasting chrominance areas, and appears as color smearing due to spurious colored oscillations in the reconstructed image[8-11]. Thus, a change in the color information, such as a loss of the chrominance component in the compression process and corresponding color smearing, affects the image gamut characteristic. Hence, since the image gamut is related to the overall color richness of a given image, investigating the image gamut may be an effective metric for evaluating the perceptual quality fidelity of a decompressed image compared to the original image.

Accordingly, this paper investigates the relationship between the compression ratio and the gamut area for a decompressed image using JPEG and JPEG2000. To analyze the relationship the between compression ratio and the color bleeding phenomenon, i.e. the hue and chroma shift in the a^*b^* color plane, eighteen color samples from the Macbeth ColorChecker are initially used as representative colors for all colors due to their uniform distribution in CIELAB color space. Based on the color information shift for the representative color samples, twelve natural color images, classified into two groups depending on four color attributes, are also used to investigate the relationship between the level of compression and the variation in the gamut area for the reconstructed images. After determining the gamut areas for the decompressed images in relation to the compression ratio, the optimal least square method is applied to approximate the relationship for each image group. Finally, fitting curves are presented for an equation minimizing the error between the real data, the gamut area for the decompressed images, and its corresponding approximated values.

2. HUE AND CHROMA SHIFT FOR MACBETH COLOR SAMPLES

To examine the hue and chroma shift phenomenon of colors in relation to the compression ratio in the a^*b^* color plane, three synthetic test images using color samples from each row of the Macbeth ColorChecker were initially designed, as shown in Fig. 1. The test images were composed of a circular color bar so as to emphasize the

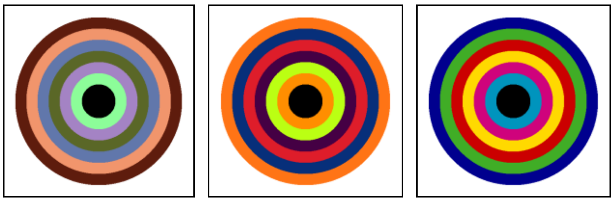
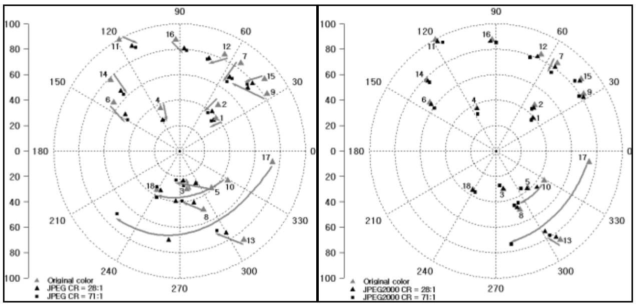


Fig. 1: Three synthetic circle bar images.



(a) (b)

Fig. 2: Average shift of hue angle and chroma for eighteen colors from Macbeth ColorChecker: (a) with JPEG and (b) with JPEG2000.

color shift after compression when using JPEG, which is based on a discrete cosine transform (DCT) of 8x8 pixel blocks, and JPEG2000, which is based on a discrete wavelet transform (DWT) of rectangular non-overlapping blocks (tiles)[11].

In this experiment, the compression ratios were set at 28 and 71 as the lower and higher compression ratio, respectively, corresponding to 0.86 bits per pixel (bpp) and 0.34 bpp, respectively. The color shift phenomenon in the reconstructed images is then apparent as color smearing between the original color and the two neighbor colors. As the compression ratio increases, most of the colors produced by color smearing from adjacent regions exhibited a loss of chroma, whereas some of the colors produced by spurious colored oscillations along a strong contrast colored edge exhibited an increased chroma. In addition, the hue of these colors was distributed along the direction connecting the adjacent two colors. The magnitude of the color shift increased as the compression ratio increased, and when comparing JPEG and JPEG2000, the color bleeding caused by JPEG was more obvious than that caused by JPEG2000.

Fig. 2 shows the average shift of the hue angle and chroma due to color bleeding in the eighteen color regions, where the numerals next to the original color (gray triangle) represent the order of the colors in the Macbeth ColorChecker from left to right and from top to bottom. The dark triangles and dark squares indicate the results corresponding to a compression ratio of 28 and 71, respectively, while the gray arrows indicate the locus of the color shift according to the increase in the compression ratio. Except for purple (number 10) and magenta (number 17), which were placed around the purple boundary in the xy chromaticity diagram, the rest of the colors exhibited a similar aspect in each graph.

(a)

(b)

Fig. 3: Classification of twelve natural test images: (a) group 1 and (b) group 2.

3. CLASSIFICATION OF NATURAL COLOR IMAGES

To investigate the gamut variation of reconstructed natural color images according to the level of compression, twelve natural color images were also tested. These images were divided into two groups depending on four color attributes, such as the image gamut size, colorfulness[12-13], spatial frequency of the chrominance channel Cb and Cr[14], and number of unique colors in RGB color space.

First, the gamut size of the original image was calculated as the area of the gamut boundary described by GBD in the a^*b^* color plane. Since GBD is obtained using the Segment Maxima Method that does not have a convexity limitation, it represents the image gamut almost accurately[15].

Second, it is generally well-known that the colorfulness of an image containing a lot of chromatic details is reduced at a higher compression ratio. The colorfulness M_c was calculated using a computationally more efficient approach in a simple opponent color system, defined as follows[12-13]:

$$\begin{aligned} rg &= R - G \\ by &= \frac{1}{2}(R+G) - B \\ M_c &= \sqrt{\sigma_{rg}^2 + \sigma_{by}^2} + 0.3 \times \sqrt{\mu_{rg}^2 + \mu_{by}^2} \end{aligned} \tag{1}$$

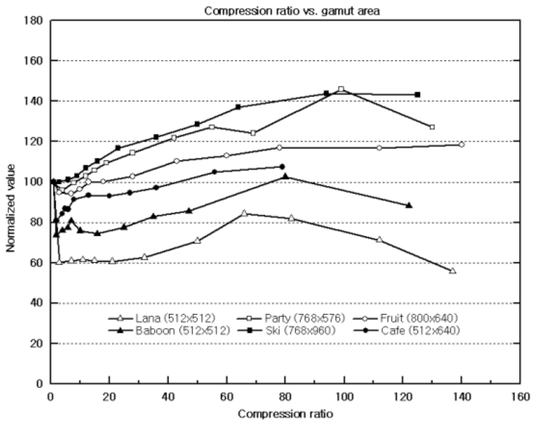
where, σ and μ are the standard deviation and mean of the pixel cloud along directions rg and by, respectively.

Third, natural images containing large spatial frequency areas in the chrominance channel experience large errors due to coarse quantization of the frequency coefficients, as well as the subsampling process, resulting in more color artifacts in the decompressed image. Therefore, the spatial frequency M_{sf} was also adopted as one of the metrics for classifying the natural test images, which was calculated as follows in the chrominance channel Cb and Cr[14]:

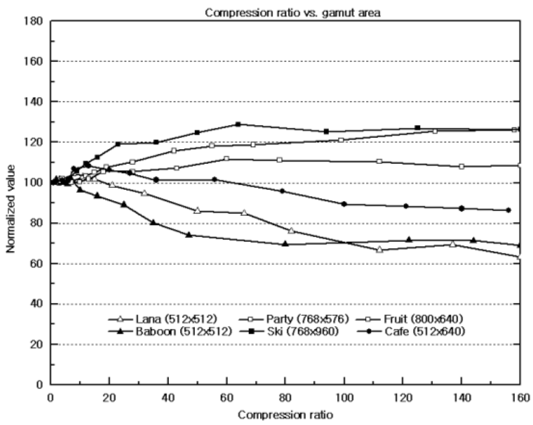
$$\begin{aligned} M_{sf} &= \sqrt{R^2 + C^2} \\ R^2 &= \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-2}\left(x_{i,j} - x_{i,j+1}\right)^2 \\ C^2 &= \frac{1}{MN}\sum_{i=0}^{M-2}\sum_{j=0}^{N-1}\left(x_{i,j} - x_{i+1,j}\right)^2 \end{aligned} \tag{2}$$

Table 1: Classification of natural test images according to four attributes.

Image \ attribute		Gamut area (a*b* plane)	Colorful-ness	Spatial frequency		Number of unique color
				Cb	*Cr*	
Group 1	Lena	9658.7	64.8	5.6	5.4	56.6%
	Baboon	20846.4	85.8	14.2	13.3	87.9%
	Party	19532.6	46.7	5.1	4.8	33.7%
	Ski	27398.7	92.5	8.0	9.1	40.4%
	Fruit	28664.8	104.4	6.5	7.5	47.4%
	Café	32606.8	95.8	17.7	15.3	61.6%
Group 2	Cap	9292.0	46.8	2.1	1.8	9.2%
	Girl	2955.8	50.1	1.3	2.9	8.1%
	House1	4434.8	37.0	2.2	2.5	13.9%
	House2	2468.9	25.0	2.2	2.3	12.3%
	Light house	5035.3	29.6	1.7	1.5	6.4%
	Motor cycle	11839.0	34.4	2.9	2.7	16.6%



(a)

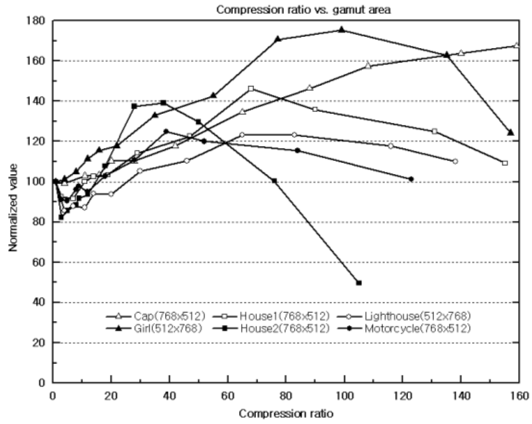


(b)

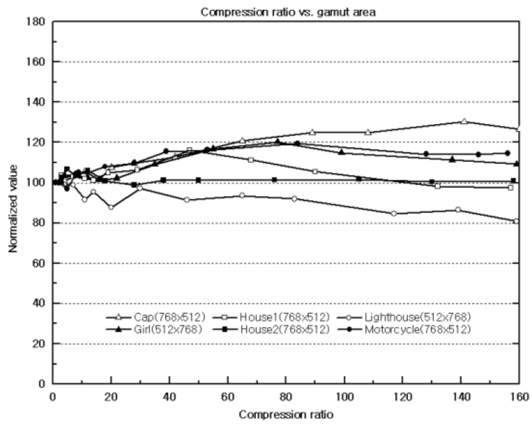
Fig. 4: Change in gamut size according to compression ratio for group 1 images: (a) with JPEG and (b) with JPEG2000.

where R and C are the spatial frequency along the row and column direction, respectively. $x_{i,j}$ denotes the spatial coordinates for the Cb and Cr image, and M and N are the numbers of pixels in the horizontal and vertical direction, respectively.

Finally, in this paper, a unique color was defined as a pixel with a mutually different R, G, and B value. Plus, the number of unique colors is related to the overall color richness of an image, which in this case was calculated as a percentage of the total number of pixels to remove the influence of the image size. The results after classifying the twelve natural color images according to the above-mentioned four attributes are shown in Fig. 3 and Table. 1. The test images belonging to group 1 had larger values those in group 2 with regard to all four attributes. Even though the Lena image had a slightly smaller gamut area than the Motorcycle image, it was still included in group 1 due to significant difference in the other three attributes.



(a)



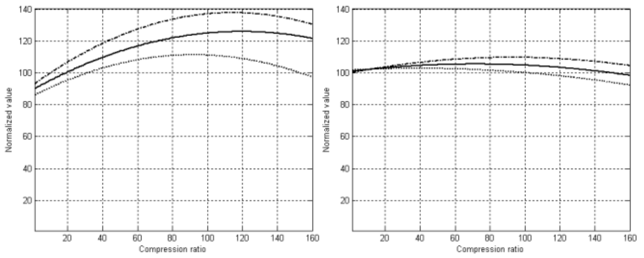
(b)

Fig. 5: Change in gamut size according to compression ratio for group 2 images: (a) with JPEG and (b) with JPEG2000.

4. RELATIONSHIP BETWEEN COMPRESSION RATIO AND IMAGE GAMUT

In this paper, the quality factor was specified on a scale between 1 and 100, where a factor of 100 represented the lowest compression rate and a factor of 1 was the highest. Meanwhile for JPEG2000, the compression level of an image can be controlled by the quantization step size. For each subband after DWT, the quantization step size is used to quantize all the coefficients in that subband, where the quantization step size is controlled by combining the dynamic range of that subband and two unsigned integers[16]. Therefore, in this paper, the compression ratio for JPEG2000 was specified on a scale between 1 and 160.

For the natural color images categorized into group 1 and



(a) (b)

Fig. 6: Fitting curves: (a) with JPEG and (b) with JPEG2000.

group 2, graphs showing the gamut areas for the decompressed images according to the compression ratio are displayed in Figs. 4 and 5, respectively. The vertical axes in all the graphs represent the normalized gamut area, which was calculated as a percentage of the gamut area for the original image for easy comparison. When compressed using JPEG, the gamut area for the reconstructed images more fluctuated, as shown in Figs. 4(a) and 5(a). In the case of the images with a large original gamut area, such as Café and Fruit in group 1, the change in the gamut area for the reconstructed image compared to that for the original image was relatively smaller than the change exhibited by the other images, even with an increase in the compression ratio, as shown in Fig. 4. Conversely, the images with a small original gamut area, such as House2 and Girl in group 2, exhibited a significant fluctuation in the gamut size of the reconstructed image when increasing the compression ratio, as shown in Fig. 5. These results also reflected the experimental results when using the color samples from the Macbeth ColorChecker, namely, when the chroma of the original color was high, the chroma increase caused by spurious colored oscillation was small.

The optimal least square method was also applied to approximate the relationship between the compression ratio and the change in the image gamut size. For each group of images, fitting curves for a second-order equation minimizing the error between the real data, the gamut area for the decompressed images, and its corresponding approximated value were deduced as follows:

$$\begin{aligned} y &= -0.0026x^2 + 0.61x + 89.5 && \textit{for all images in JPEG} \\ y &= -0.0030x^2 + 0.56x + 85.64 && \textit{for group1 images in JPEG} \\ y &= -0.0035x^2 + 0.79x + 92.4 && \textit{for group2 images in JPEG} \end{aligned} \quad (3)$$

$$\begin{aligned} y &= -0.0009x^2 + 0.13x + 100.88 && \textit{for all images in JPEG2000} \\ y &= -0.0007x^2 + 0.055x + 101.7 && \textit{for group1 images in JPEG2000} \\ y &= -0.0011x^2 + 0.21x + 99.99 && \textit{for group2 images in JPEG2000} \end{aligned} \quad (4)$$

In Eqs. (3) and (4), x was the compression ratio specified on a scale between 1 and 160, while y was the normalized gamut area for the reconstructed image, which was calculated as a percentage of the gamut area for the original image. Fig. 6 shows the fitting curves corresponding to Eqs. (3) and (4). Here, the solid line indicates the modeling graph for all twelve natural color images, the dotted line the six images contained in group 1, and the dash-dot line the six images belonging to group 2. The modeling graphs show that the image gamut size decreased after a gradual increase when increasing the compression ratio, and finally became smaller than the gamut size of the original image at a higher compression ratio. Thus, it would seem that the initial increase in the gamut size when changing from a lower to a medium compression ratio resulted from a chroma increase due to spurious colored oscillations in the reconstructed image, whereas the decrease in the gamut size with a higher compression ratio was caused by the mixture of colors from adjacent regions, resulting in more grey. When comparing JPEG and JPEG2000, the graphs had a similar appearance overall, although there was a difference in the slopes of the graphs. Namely, the variation of the gamut size with JPEG was more noticeable than that with JPEG2000 at a same compression ratio.

5. CONCLUSION

This paper investigated the relationship between the compression ratio and the gamut area for an image compressed using JPEG and JPEG2000. To examine the shift phenomenon of hue and chroma in relation to the compression ratio, three synthetic images based on eighteen color samples from the Macbeth ColorChecker were used in the experiments. Using the experimental results, twelve natural color images, classified into two groups depending on four color attributes, were then used to investigate the relationship between the level of compression and the variation in the gamut area for the reconstructed images. Finally, fitting curves were presented for an equation approximating the relationship between the compression ratio and the image gamut area. For each image group, the gamut area for the reconstructed image showed an overall tendency to increase when increasing the compression ratio, due to a chroma increase resulting from spurious colored oscillations. However, with a high compression ratio, the gamut area tended to decrease due to the mixture of adjacent colors, resulting in more grey.

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