QUANTITATIVE ANALYSIS OF IMAGE QUALITY OF LOSSY COMPRESSION IMAGES

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ABSTRACT:

High resolution images acquired by an aerial digital camera and high resolution satellite images are expected to become more powerful data source of GIS. Since the large data volume of a high resolution image brings difficulties in dealing with it, lossy image compression is going to be indispensable. Image quality of a reconstructed image after decompression is usually evaluated by visual inspection. Although some numerical measures such as RMSE or PSNR are used to compare various image compression techniques, numerical evaluation of quality of a reconstructed image is seldom conducted. Therefore, we decided to carry out an empirical investigation into the effects of lossy image compression on quality of color aerial images by using color and texture measures. From the experiment results, it can be concluded that color space conversion and downsampling in JPEG compression have an effect on quality of a reconstructed image. The results supported that lossy JPEG 2000 compression is superior to lossy JPEG compression in color features. However, lossy JPEG 2000 compression does not necessarily provide an image of good quality in texture features. Moreover, the results indicated that an image of finer texture features is less compressible, and quality of the reconstructed image is worse in both color and texture features. Finally, it was confirmed that it is difficult to set an appropriate the quality factor, because the optimal setting of the quality factor varies from one image to another.

1. INTRODUCTION

High resolution images acquired by an aerial digital camera and high resolution satellite images such as IKONOS images are expected to become more powerful data source of GIS. Resolution of images for urban GIS is usually desired to be as high as possible. The higher resolution of the image is, the larger its data volume is. The large data volume of a high resolution image brings difficulties in dealing with it. Therefore, image compression is going to be required. Since the compression ratio achieved by lossless image compression is unsatisfactory for this purpose, lossy image compression is indispensable.

Quality of a reconstructed image after decompression is usually evaluated by visual inspection. Although some numerical measures such as RMSE (root mean square error) and PSNR (peak signal to noise ratio) are used to compare various image compression techniques, numerical evaluation of quality of a reconstructed image is seldom conducted. Therefore, we carried out an empirical investigation into the effect of lossy compression on quality of a reconstructed image by using numerical measures of image quality.

2. LOSSY IMAGE COMPRESSION

2.1 JPEG Compression

From the point of view of interoperability, lossy JPEG compression and lossy JPEG 2000 compression are desirable compressions at the moment.

Lossy JPEG compression based on the discrete cosine transform (DCT) is the past and current still image compression standard. On the other hand, lossy JPEG 2000 compression based on the discrete wavelet transform (DWT) is the current and future still image compression standard. However, JPEG 2000 compression has not yet come into wide use. Accordingly, we decided that the main target of the study was lossy JPEG compression.

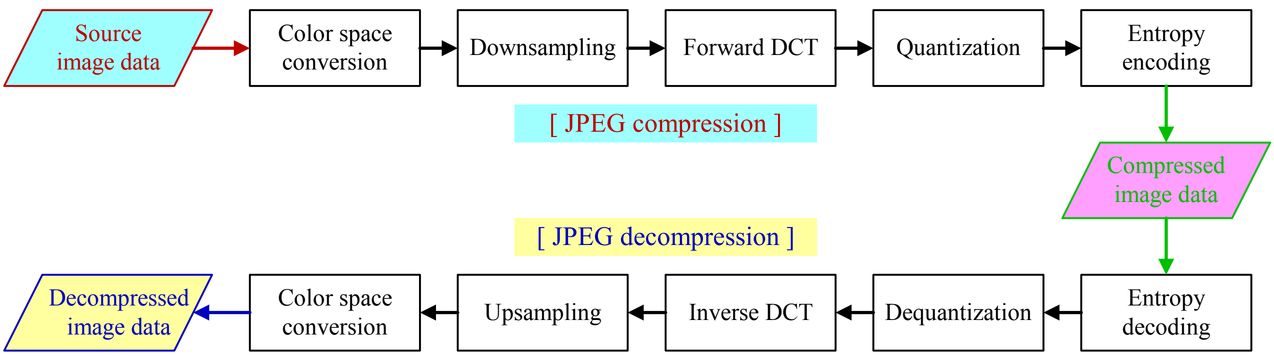

Figure 1. JPEG compression and decompression process flow

Figure 1 is a flow diagram of JPEG compression and decompression.

(1) Color space conversion

A source image represented in the RGB color space is converted into an image represented in the YCbCr color space in JPEG compression.

Inversely, the transformation from the YCbCr color space to the RGB color space is executed in JPEG decompression.

(2) Downsampling / Upsampling

Data reduction of chrominance components Cb and Cr is performed in JPEG compression as required. Most of pieces of JPEG compression software adopt the 4:1:1 sampling as the default setting. The 4:1:1 sampling means sampling four data of the luminance component Y and one data for each chrominance component Cb and Cr from two horizontal pixels by two vertical pixels. The 4:4:4 sampling is also used, which means no data reduction of chrominance components.

Restoration of chrominance components Cb and Cr to full size is performed in JPEG decompression if necessary.

(3) Forward DCT / Inverse DCT

The source image is transformed into the spatial frequency domain by DCT in JPEG compression.

The compressed image data in the spatial frequency domain is transformed into the image domain by inverse DCT in JPEG decompression.

(4) Quantization / Dequantization

DCT-coefficient data are quantized in JPEG compression. The quantization table used in this step controls the compression level of an image. The quantization stage is a lossy process.

Dequantization in JPEG decompression is performed by using the quantization table included in the compressed image data.

(5) Entropy encoding / Entropy decoding

Arithmetic entropy encoding is performed to further reduce compressed image data volume in JPEG compression. Huffman coding is a commonly used method.

Arithmetic entropy decoding is performed in JPEG decompression.

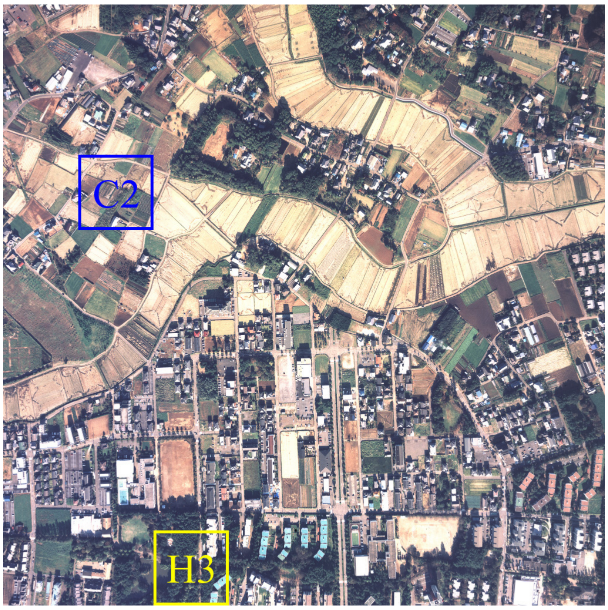

Figure 2. Test image (digitized color aerial photograph)

In JPEG compression, the compression level of an image can be controlled by a constant, which is generally called the quality factor (Q-factor). Q-factor sets the quantization table. A higher Q-factor gives higher compression. A lower Q-factor gives a better quality image, but a lower compression ratio. Therefore, variable compression can be achieved by simply scaling the Q-factor. An important property of the JPEG compression scheme is the adjustment of the Q-factor to balance the reducing image size and degraded image quality. In fact, different JPEG compression programs have different Q-factors

2.2 Evaluation of Image Quality of Reconstructed Images

RMSE and PSNR are usually used to compare various image compression techniques (Santa-Cruz *et al.*, 2000, Grgic *et al.*, 2001, Taubman *et al.*, 2002). Rountree *et al.* (2002, 2003) demonstrated the effectiveness of JPEG 2000 compression for remote sensing data by PSNR.

Fukue *et al.* (1998, 2000) evaluated the effects of lossy compression of a pair of stereo satellite images by the accuracy of surface measurement. Moreover Li *et al.* (2002) investigated the effects of lossy compression on the accuracy of photogrammetric point determination.

Numerical evaluation of quality of a reconstructed image after decompression is seldom conducted. Al-Otum (2003) reported the experiment on various numerical measures to determine a proper measure of image quality of a reconstructed image.

Since most of studies on assessment of lossy image compression utilized monochrome images and no texture measures for evaluation, results of the studies cannot be applied directly for GIS application. Therefore, we decided to carry out an empirical investigation into the effects of image compression on quality of color aerial images by using color and texture measures.

3. EXPERIMENT

3.1 Test Image

A color aerial photograph of a city taken at a scale of 1:7000 was digitized. Scanning resolution was 40 μm on the photograph, that is, 280 mm on the ground. Each color component (Red, Green and Blue) was quantized into 8 bits (256 levels). The test image of 4096 pixels by 4096 lines was extracted from the center part of the scanned image. Figure 2

Image size	4096 pixels × 4096 lines		
Gray level features	[R]	[G]	[B]
• mean	149.2	141.3	142.7
• standard deviation	75.1	63.4	48.0
Color features	[H]	[S]	[V]
• mean	110.6	55.5	162.3
• standard deviation	75.9	27.2	63.9
GLDV	[R]	[G]	[B]
• contrast	18.8	18.4	15.7
• angular second moment	0.220	0.158	0.154
• entropy	3.92	4.13	4.06
• mean	10.8	11.7	10.7
Fourier power spectrum	[R]	[G]	[B]
• mean spatial frequency	110.1	132.0	153.6

Table 1. Statistics of test image

Figure 3. Block C2

Figure 4. Block H3

Image size	512 pixels × 512 lines		
Gray level features	[R]	[G]	[B]
• mean	170.0	156.5	152.0
• standard deviation	65.1	52.1	38.4
Color features	[H]	[S]	[V]
• mean	94.9	48.5	177.9
• standard deviation	80.4	21.4	56.5
GLDV	[R]	[G]	[B]
• contrast	22.4	21.5	17.1
• angular second moment	0.188	0.125	0.136
• entropy	4.24	4.43	4.22
• mean	14.7	15.6	12.8
Fourier power spectrum	[R]	[G]	[B]
• mean spatial frequency	22.3	29.2	31.8

Table 2. Statistics of Block C2

Image size	512 pixels × 512 lines		
Gray level features	[R]	[G]	[B]
• mean	88.6	96.2	115.9
• standard deviation	55.6	54.5	45.2
Color features	[H]	[S]	[V]
• mean	145.1	76.9	118.2
• standard deviation	41.1	28.4	49.2
GLDV	[R]	[G]	[B]
• contrast	13.8	14.6	12.3
• angular second moment	0.216	0.185	0.176
• entropy	3.60	3.82	3.77
• mean	7.3	8.7	8.1
Fourier power spectrum	[R]	[G]	[B]
• mean spatial frequency	14.6	15.8	15.4

Table 3. Statistics of Block H3

shows the test image used in the experiment. Statistics of the test image are shown in Table 1.

We divided the test image into 8 by 8 blocks, so that each block was a square image of 512 pixels by 512 lines. 64 blocks were investigated in the same way as the whole test image. Block C2 located in the upper left of the test image was the least compressible block, in other words, compressed image data volume of Block C2 was the largest of all 64 blocks. On the other hand, Block H3 located in the lower left of the test image was the most compressible block. Locations of both Blocks C2 and H3 are shown in Figure 2. Figure 3 and Figure 4 show Blocks C2 and H3 respectively. Table 2 and Table 3 show statistics of Blocks C2 and H3 respectively as well. The texture of Block C2 is finer than that of Block H3.

3.2 Lossy Compression

Four compression types shown in Table 4 were investigated. Three Types S444, S411 and RGB adopted lossy JPEG compression technique, and the Type J2K adopted lossy JPEG 2000 compression technique.

We used Independent JPEG Group's free JPEG software for JPEG compression. The quality setting of the IJG's software scales quantization tables to adjust image quality. The IJG quality setting, which is opposite to the ordinary Q-factor, is 0 (worst) to 100 (best); default is 75 (Independent JPEG Group, 1999). The IJG quality setting lets one trade off compressed image data volume against image quality of the reconstructed image: the higher the IJG quality setting, the larger the JPEG file, and the closer the reconstructed image will be to the source image.

The test image was compressed at 21 various levels using IJG quality setting of every 5 from 100 to 0. In Types S444 and S411 color space conversion was performed. While Type 444 adopted the 4:4:4 sampling (no downsampling), Type S411

Type	Technique	Color space	Downsamplig
S444	JPEG	YCbCr	4:4:4
S411	JPEG	YCbCr	4:1:1
RGB	JPEG	RGB	4:4:4
J2K	JPEG 2000		

Table 4. Compression types

adopted the 4:1:1 sampling. In Type RGB the source image was separated into three color component (Red, Green and Blue) images, and each color component image was compressed and decompressed respectively. Evaluation of quality of the reconstructed image was executed after combining three decompressed color component images.

We used LuraWave SmartCompress 3.0 by Algo Vision LuraTech GmbH for JPEG 2000 compression. We prepared JPEG 2000 compressed image data of the same size of JPEG compressed image data of Type S444.

As for Blocks C2 and H3, only Type S444 was investigated.

3.3 Measures of Image Quality of Reconstructed Images

The following numerical image quality measures were examined.

(A) Gray level features
  a) PSNRs of RGB (Red, Green, Blue) components
(B) Color features
  a) PSNRs of HSV (Hue, Saturation, Value) components
  Each component of HSV color space has 256 levels (8 bits).
(C) Texture features
  a) Standard deviations of RGB components
  b) Grey level difference vector (GLDV) measures:

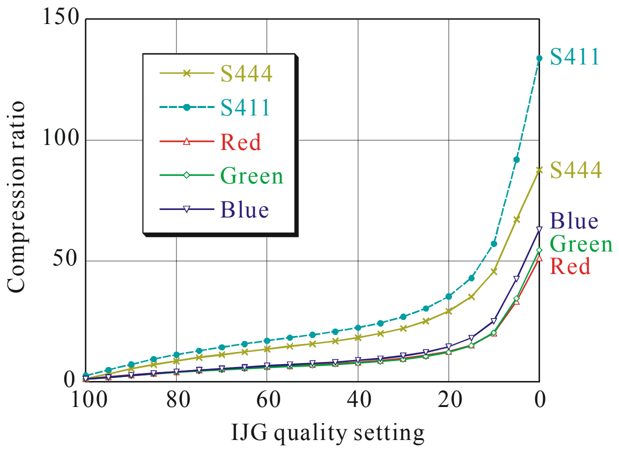

Figure 5. Compression ratio vs. IJG quality setting (IJG quality setting: 100 - 0)

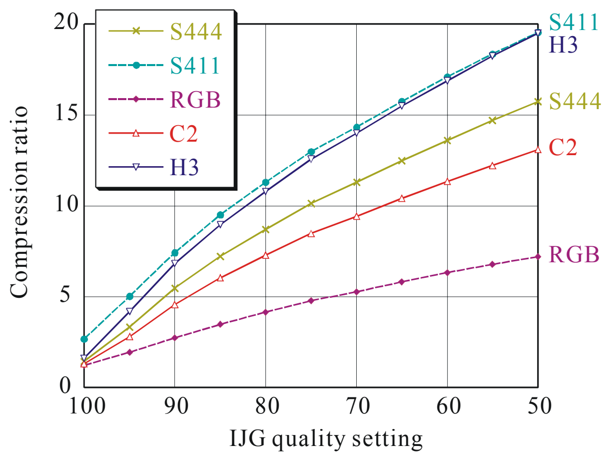

Figure 6. Compression ratio vs. IJG quality setting (IJG quality setting: 100 - 50)

Contrast, Angular second moment, Entropy, Mean
  c) Mean spatial frequency of Fourier power spectrum

An image of finer texture features has higher values of texture measures except GLDV Angular second moment and a lower value of GLDV Angular second moment.

3.4 Results

Since the effect of changing compression ratio on PSNR of each

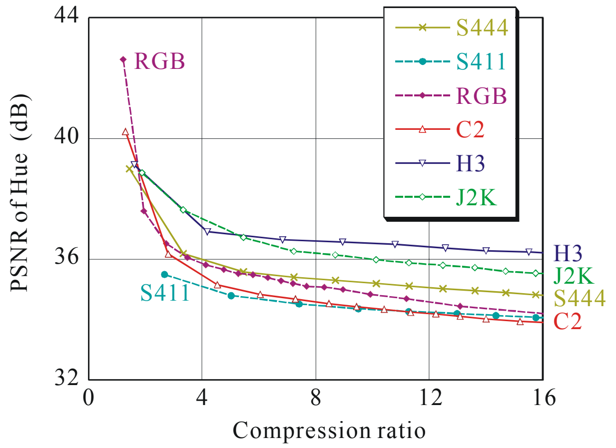

Figure 7. PSNR of Hue vs. compression ratio

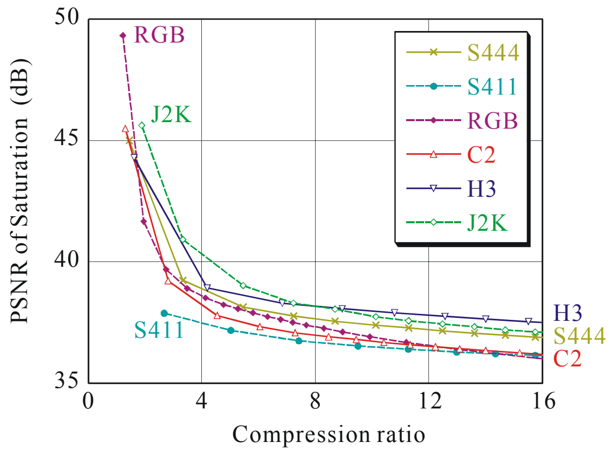

Figure 8. PSNR of Saturation vs. compression ratio

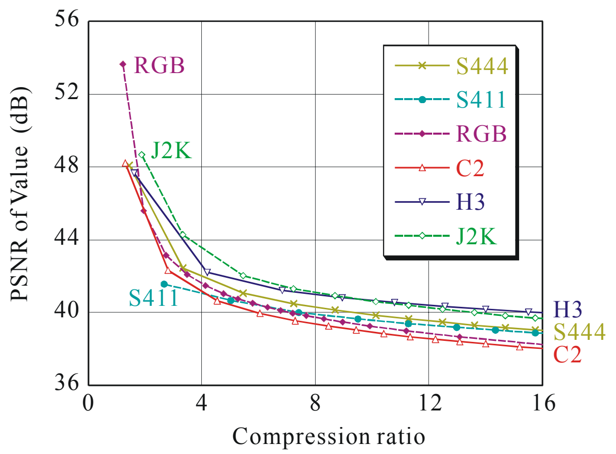

Figure 9. PSNR of Value vs. compression ratio

component of RGB color space was similar to that on PSNR of Value of HSV color space, we do not show graphs of PSNRs of RGB components.

Furthermore, graphs of the effect of changing compression ratio on image quality measures are illustrated in the compression ratio range from 1 to 16 in our judgment that highly compressed images, that is, low quality images are not suitable for most of GIS application.

(A) Figures 5 and 6 show the effect of changing the IJG quality setting on the compression ratio. The compression ratio is defined as the ratio of the number of bytes of the source image before compression to the number of bytes of the compressed image data.
The compression ratio of the compressed image data of each color component (Red, Green and Blue) in Type RGB is shown in Figure 5. Figure 6 shows the compression ratios of Blocks C2 and H3 as well.

(B) Figures 7, 8 and 9 show the effect of changing compression ratio on PSNRs of Hue, Saturation and Value of HSV color space respectively.

(C) There were no significant differences among the effects of changing compression ratio on the texture measures of Red, Green and Blue of RGB color space. We provide graphs of texture measures of Green against the compression ratio in Figures 10 to 13.
Each texture measure is illustrated in the ratio of the value of the reconstructed image to that of the source image. A ratio of a texture measure closer to 1.0 indicates that the reconstructed image is closer to the source image in texture feature.
Figure 10 shows the effect of changing compression ratio on standard deviation. Figures 11 and 12 show the effect of changing compression ratio on GLDV contrast and GLDV angular second moment respectively. Figure 13 shows the effect of changing compression ratio on mean spatial frequency of Fourier power spectrum.

3.5 Discussion

There were significant differences in the compression ratio against the IJG quality setting among three Types S444, S411 and RGB as shown in Figures 5 and 6. While Type S411 provided the most compressed image, Type RGB with no color space conversion had the least compression efficiency. Differences in the compression ratio among each color component (Red, Green and Blue) in Type RGB were rather small.

As the IJG quality setting decreases, differences in the compression ratio among Types S444, S411 and RGB increases. Furthermore, the compression ratios in all types increase rapidly with decreasing the IJG quality setting range above 20 as shown in Figure 5.

There are differences in the compression ratio among Type

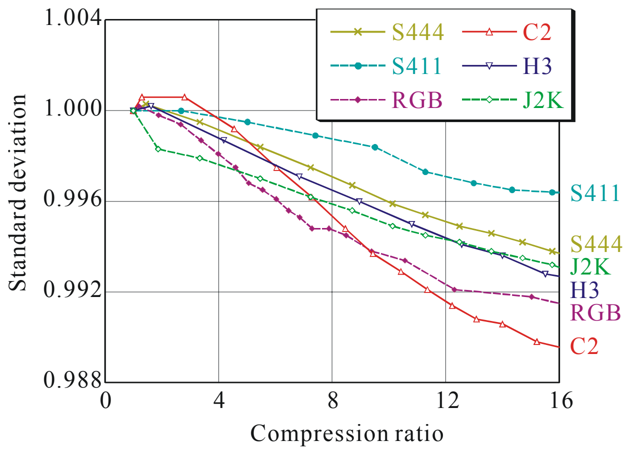

Figure 10. Standard deviation vs. compression ratio

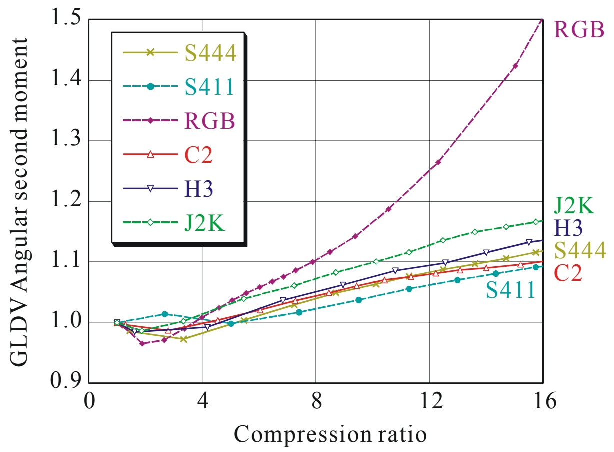

Figure 12. GLDV angular second moment vs. compression ratio

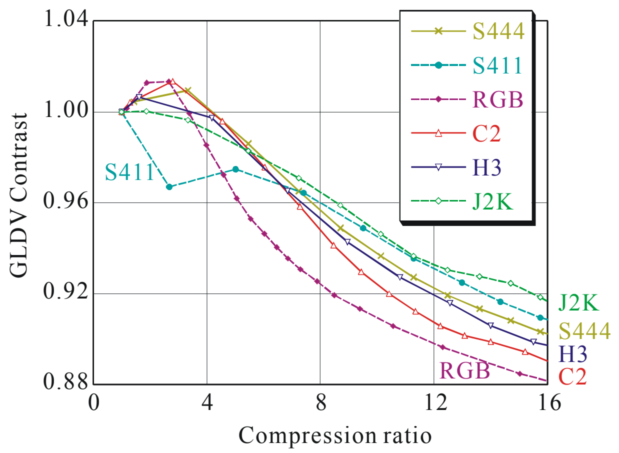

Figure 11. GLDV contrast vs. compression ratio

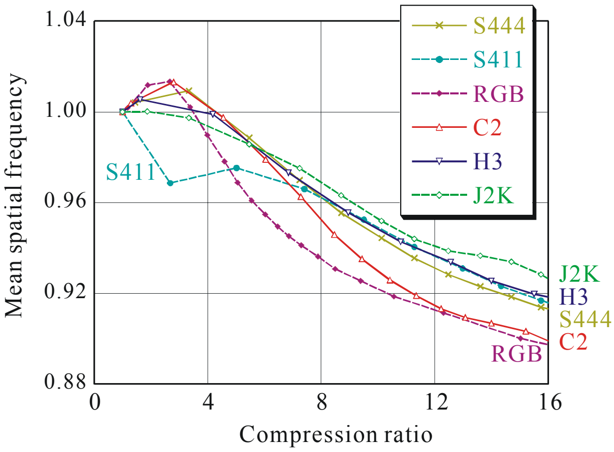

Figure 13. Mean spatial frequency vs. compression ratio

S444, Blocks C2 and H3. This fact indicates that it is difficult to estimate the compression ratio achieved by a certain value of the quality factor such as the IJG quality setting in JPEG compression.

Figures 7, 8 and 9 demonstrate that Type J2K provided the best quality images in color features. Type S444 is seen to be superior to both Types S411 and RGB in color features as well. However, the differences of PSNR of Saturation between Types J2k and S444, and the differences of PSNR of Value between Types S444 and S411 become smaller with an increase in the compression ratio as shown in Figures 8 and 9 respectively.

Figures 7, 8 and 9 present that the degradation of quality of the reconstructed images of Block H3 of coarse texture features is less than that of Block C3 of finer texture features in color features.

As for texture features shown in Figures 10 to 13, there are some discrepancies of the effect of image compression among various texture measures. The inclinations of the effect of image compression in the compression ratio below approximately 6 differ form those in the compression ratio range above approximately 6. Quality of reconstructed images of all types in texture features degrades with increasing the compression ratio range above approximately 6.

On the whole, Type RGB is inferior to the other types, and Type S411 is superior to Type S444 in the compression ratio range above approximately 6.

The degradation of quality of reconstructed images of Block H3 of coarse texture features can be said to be less than that of Block C3 of finer texture features in texture features as well as in color features.

4. CONCLUSION

From the experiment results, it may be concluded that color space conversion and downsampling in JPEG compression have an effect on quality of reconstructed images. While Type S444 with color space conversion and no downsampling may provide an image of good quality in color features, Type S411 with color space conversion and downsampling may provide an image of good quality in texture features.

As for comparison between lossy JPEG compression and lossy JPEG 2000 compression in performance, it was confirmed that lossy JPEG 2000 compression is superior to lossy JPEG compression in color features. However, lossy JPEG 2000 compression does not necessarily provide an image of good quality in texture features.

Moreover, comparison of the experiment results between Blocks C2 and H3 indicates that an image of finer texture features is less compressible, and quality of reconstructed images is worse in both color and texture features.

In JPEG compression, the compression ratio of an image is controlled by a constant (Q-factor) such as the IJG quality setting. The experiment results confirmed that it is difficult to set an appropriate Q-factor, because the optimal setting of Q-factor varies from one image to another.

We plan in the future to conduct further experiments by using another source images such as high resolution satellite images and images obtained by an aerial digital camera. Effects of land cover and ground resolution, and capabilities of various image quality measures are going to be investigated.

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