*Digitalization and Management Innovation*
*A.J. Tallón-Ballesteros and P. Santana-Morales (Eds.)*


*doi:10.3233/FAIA230063*

# Providing a Desired Compression Ratio for Better Portable Graphics Encoder of Color Images: Design and Analysis

Fangfang Li [a] and Vladimir Lukin[b,1]
[a]*Key Laboratory of Opto-Electronic information Science and Technology of Jiangxi Province, Nanchang Hangkong University,Nanchang, China*
[b] *National Aerospace University, Kharkiv, Ukraine*

**Abstract.** In this paper, we consider a task of providing a desired compression ratio (CR) in lossy compression of color images by better portable graphics (BPG) encoder. The problem consists in the fact that this encoder, on the one hand, produces certain benefits compared to other modern image compression techniques in the sense of better quality for the same CR, but, on the other hand, CR for a fixed value of a parameter that controls compression (PCC) in BPG can vary in very vast limits depending on image content. Since a recently proposed two-step method of providing a desired quality of compressed images based on average rate-distortion curves has recently demonstrated its high efficiency and accuracy acceptable for many practical applications, we analyze the applicability of this approach to providing a desired CR. It is shown that the accuracy of providing a desired CR characterized by variance for a set of test images improves radically after the second step compared to the first step parameters, which are determined by the average dependence of CR on Q. Variances of original (after the first step) and provided (after the second step) also depend on a desired CR and they are larger for the larger desired CR. The influence of residual errors in the provided CR on image quality is studied as well.

**Keywords.** lossy compression; color images; compression ratio; better portable graphics encoder

## 1. Introduction

Modern imaging systems produce an enormous amount of image data of different types. These can be standard consumer camera images, remote sensing data, medical and non-destructive testing images [1-3], etc. Acquired images have to be stored, transferred via communication lines, and disseminated [1, 2]. Due to the possible limited bandwidth of communication channels and memory for data saving, it is often needed to compress images [1-5]. Lossless compression techniques are often unable to provide a desired compression ratio (CR) [2, 4]. Then, lossy compression techniques have to be applied. Meanwhile, they introduce distortions inevitably where a larger CR is connected with larger losses.

[1] Corresponding Author, Vladimir Lukin, Department of Information-Communication Technologies National Aerospace University, Kharkiv, Ukraine; E-mail: v.lukin@khai.edu.

Depending upon the task at hand, requirements for lossy compression might have different priorities [2, 5, 6]. There are practical situations where it is extremely necessary to provide quality of compressed image, not worse than desired, although it is also desired to have as large CR as possible. On the contrary, it is also possible that it is extremely necessary to have a certain CR whilst quality has to be as high as possible. Just such a configuration of requirements has led to the design of JPEG2000 as a possible replacement for JPEG [7, 8]. One obvious advantage of JPEG2000 is that it is able to provide a desired CR or, equivalently, BPP – bits per pixel (another advantage is that JPEG2000 produces a better quality of compressed images for the same BPP compared to JPEG for large CR values).

JPEG2000, SPIHT [9], and some other wavelet-based encoders able to provide a desired CR were designed about 20 years ago. Since then, many other, more efficient lossy compression techniques have been designed [10-12]. In particular, better portable graphics (BPG) encoder has been designed and tested [3, 12-14]. It has been shown as a possible alternative to JPEG due to many useful features, such as considerably better rate-distortion characteristics [13, 14]. In addition, BPG supports most Web browsers, different chroma formats, and image data from 8 to 14 bits per channel [12].

Meanwhile, like other coders, BPG has certain drawbacks and limitations. A parameter that controls compressed image quality denoted by BPG authors as Q can be only an integer and varies from 1 to 51. Such a property of Q leads to the fact that peak signal-to-noise ratio (PSNR) can be provided with a limited accuracy characterized by error from -0.5 dB to 0.5 dB. Similarly, it is even potentially impossible to provide desired values of visual quality metrics without errors [14]. It is also impossible to provide a desired CR.

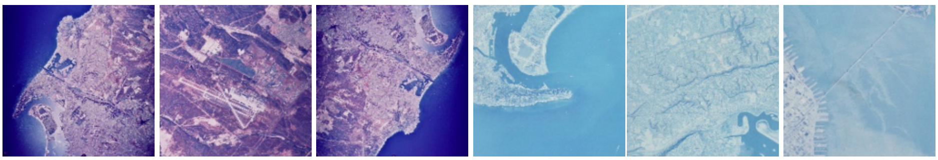
Note that the problem of reaching a desired CR is typical for many coders based on discrete cosine transform [6, 8, 14]. It stems from the fact that rate-distortion curves (e.g., dependences of PSNR on CR in general or on Q for the BPG encoder) are very individual and depend on image complexity [15]. Similarly, the dependences of CR on a parameter that controls compression (PCC), e.g., quantization step or Q, are individual as well (this will be shown below). The discussed problem can be solved by iterative procedures similar to those in [16], where an image is compressed with a certain PCC, then CR is determined and compared to a desired CR, PCC has changed accordingly, and the procedure is repeated until the desired CR is reached with pre-determined accuracy. However, such iterative procedures have several obvious drawbacks. The main of them is a priori unclear number of iterations that will be needed and considerable time and computational resources that might be needed for multiple compression.

Fortunately, simple and fast two-stage procedures have been proposed recently [6, 14]. They have been designed to provide a desired visual quality of compressed images according to a chosen metric (e.g., MDSI [17] in [14]). Meanwhile, we propose to use the same approach to reach a desired CR. To the best of our knowledge, this is the first attempt to solve the problem of attaining a desired CR in this manner.

To understand the applicability of the proposed approach in practice, it has to be studied for a set of test images. Because of this, we, first, give the description of the proposed approach and present the average dependence of CR on Q for color images. Then, the accuracy is analyzed for another group of test images that have not been employed in determining the average curve. The studies are performed for the 4:2:0 version of the BPG encoder, which is the default setting for color image compression in [12]. We suppose that originally the images are represented as PNG data.

## 2. Preliminary Analysis of Compression Characteristics

The two-step image compression procedures[6, 14] employ two sets of images that contain ten or more images. The first set is used to get an average curve, CR on Q in our case. Any set (both the first and the second) should be representative enough, i.e., contain typical (for a considered application) images of different complexity and content. Figure 1 shows small copies of remote sensing (RS) color (three-channel) images included in Set 1 (they have been taken from the database USC-SIPI[18]). As one can see, there are complex structures images as the test images RS1, RS5, and RS8, and images having a quite simple structure as the test images RS6, RS2, and RS3.



RS1 RS5 RS8 RS2 RS3 RS6

**Figure 1.** Test image examples for the basic image Set 1 (small copies).

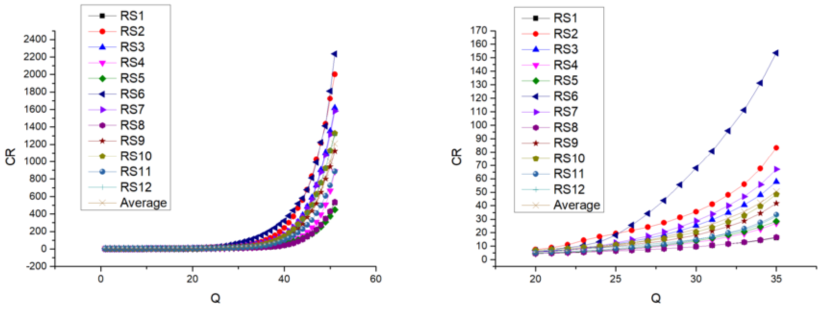
**Table 1.** CR(Q=25) and entropy values for the test images in Set1.

| Test image | $E_I$ | $E_A$ | CR |
|---|---|---|---|
| RS1 | 7.6175 | 7.3508 | 6.47 |
| RS2 | 5.7855 | 5.5155 | 19.31 |
| RS3 | 5.9331 | 5.6627 | 11.62 |
| RS4 | 6.6384 | 6.2906 | 7.22 |
| RS5 | 7.2326 | 7.0896 | 7.47 |
| RS6 | 5.5226 | 5.4199 | 18.11 |
| RS7 | 6.2038 | 5.9199 | 12.53 |
| RS8 | 7.6368 | 7.3612 | 6.46 |
| RS9 | 6.3657 | 5.9057 | 10.04 |
| RS10 | 6.2469 | 5.7667 | 11.25 |
| RS11 | 6.3521 | 6.0708 | 8.10 |
| RS12 | 6.4425 | 6.2128 | 9.59 |

Earlier [15], it has been shown that image complexity for noise-free images can be associated with their entropy where, for color images, entropy can be calculated in two ways: for intensity image (EI) and as mean of entropies for R, G, and B components (EA). To demonstrate that CR and entropy values are really correlated, let us present CR values for BPG that uses Q=25. They are presented in Table 1. Analysis of data confirms that CR is larger for images having the smaller EI and EA, whilst the smaller CR are observed for test images having complex structure and characterized by the larger values of entropies. One more observation is that, for the same Q, CR values differ by about three times. Even larger differences in CR values (by about ten times) take place for Q about the upper limit of this parameter variation.

The experiment was conducted for 12 remote sensing images, where Q is {1,...,51}, and the result are shown in Figure 2a. the average CR for each Q has also been calculated.

Note that we are not interested in too small Q values where CR is about 2 (it differs from unity because down sampling is applied to color components for the mode 4:2:0). We are also not very interested in Q values close to the upper limit Q=51 where annoying distortions can be introduced into compressed images[14]. The main area of our interest will be the range from CR about 10 (Q about 25 according to the average curve) to CR about 80 (Q about 45 according to the average curve). More detailed plots that approximately correspond to this range are represented in Figure 2b.It is seen here that for Q=35, the values of CR can differ by about ten times exceeding 100 for a simple structure test image. In other words, setting Q according to the average curve (average CR for Q=35 is equal to 50.5) leads to CR=153.6 for RS6 and 16.3 for RS1.




a b

**Figure 2.** Dependences of CR on Q for the BPG coder (4:2:0 mode) for 12 test color images and the average curve, the whole range (a), and in narrower limits (b).

## 3. Two-step Compression Method for Providing a Desire CR

For the two-step method, we will need parameters of the average curve, namely, its values for each Q as well as derivative values. For a discrete representation of a function, derivative values can be easily calculated from function values. Because of this, we present the average function values CRA for Q equal to 1, 3, 5, …51. They are given in Table 2. Since Q can be only an integer, even in the best case (of providing a desired CR with potential accuracy), maximal errors can be of the order dCR/2dQ, i.e., if one wants to provide CR≈10, a maximal error can be about 1.5, and its variance (under the assumption of uniform distribution) is about 0.2.

**Table 2.** Average CR values for BPG encoder.

| Q | CRA | Q | CRA | Q | CRA |
|---|---|---|---|---|---|
| 1 | 2.026 | 19 | 5.247 | 37 | 73.550 |
| 3 | 2.026 | 21 | 6.361 | 39 | 108.200 |
| 5 | 2.178 | 23 | 8.138 | 41 | 163.100 |
| 7 | 2.326 | 25 | 10.680 | 43 | 246.700 |
| 9 | 2.561 | 27 | 14.400 | 45 | 365.700 |
| 11 | 2.915 | 29 | 19.540 | 47 | 548.900 |
| 13 | 3.302 | 31 | 26.32 | 49 | 816.1 |
| 15 | 3.770 | 33 | 35.58 | 51 | 1207 |
| 17 | 4.425 | 35 | 50.48 | | |

In view of the success of the two-step compression method that has been applied in lossy compression for providing a desired visual quality, it is reasonable to transplant this method to provide a desired CR. The basic idea of the two-step method is the usage of the average rate/distortion curve, which is essential in the calculation of starting and corrected values of PCC, i.e., Q in our case.

The average CR curve (see Figure 2) is able to represent the monotonic and locally linear behavior of rate/distortion characteristics for all images in the set1; this makes it possible to control the CR in a certain accuracy range according to the average trend.

In this research, the parameter Q for a required CR is determined as follows: first, an initial Q is selected in terms of average CR curve and desired CR; second, the first stage compression is conducted with the initial Q and followed by the initial CR calculation; third, the Q is corrected according to the average CR curve and $CR_{des}$ and $CR_{init}$, For more detail see Eq. (1), where M' denotes the derivative corresponding to the $CR_{init}$ in the average curve; finally, the second stage compression is performed with the corrected Q.

$$Q_{cor} = Q_{init} + \frac{CR_{des} - CR_{init}}{M'} \tag{1}$$

Note that $Q_{cor}$ in (1) has to be rounded off to the nearest integer (within the limits from 1 to 51). The CR in the second stage is supposed to be closer to the desired CR through effective parameter correction. However, some experiments are needed verify our method.

## 4. Preliminary Experiments on Basic Images

Preliminary experiments were conducted on set1; the obtained statistical results are shown in Table 3. For analysis, we used four typical values of the desired CR: 10, 20, 40, and 80, respectively.

**Table 3.** Statistical results of the basic image set

| $CR_{des}$ | $VAR_{fir}$ | $VAR_{sec}$ | $MEAN_{sec}$ |
|---|---|---|---|
| 10 | 18.222 | 1.510 | 8.822 |
| 20 | 265.10 | 22.797 | 16.888 |
| 40 | $1.05\times10^3$ | 104.646 | 33.761 |
| 80 | $3.79\times10^3$ | 155.603 | 71.429 |

Let us consider the variances of the provided values of CR after the first step (denoted as $VAR_{fir}$) and the second step ($VAR_{sec}$). We have also determined the mean of the provided CR ($MEAN_{sec}$) for the final step. Analysis of the data in Table 3 demonstrates that, in general, the proposed two-step algorithm of CR providing performs well enough. Really, the variance after the second step has been reduced by more than 10 times. The mean is quite close to the desired value.

One observation that follows from the analysis of data in Table 3 is that both variances quickly increase if the desired CR increases. The relative errors are smaller for smaller desired CR. Such as $CR_{des}$=10 and 20, which correspond to visually lossless compression. However, variances become larger for larger values of CR, which correspond to visually noticeable distortions (CR=40 and 80). This means that it is harder to provide larger CR with appropriate accuracy.

More detailed data for the basic image set for $CR_{des}$=20 is shown in Figure 3. The provided CR values in the first step compression are marked by black squares and in the second step by red dots, respectively. CR values after the second step are sufficiently closer to $CR_{des}$ = 20 than the CR after the first step. Therefore, the accuracy is considerably improved.

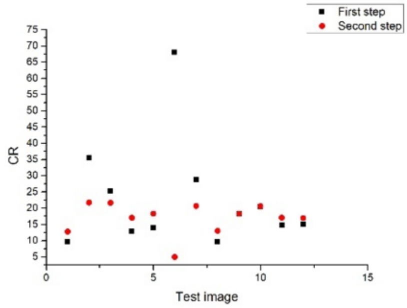



**Figure 3.**The result of basic images ($CR_{des}$= 20).

Meanwhile, the accuracy is still not good enough for some images, such as RS6. The reason is that the CR curve for the image RS6 considerably differs from the average CR curve (see Figure 2).This results in a limited parameter correction capability in the second step. According to the analysis in Section 2, it can be seen that an obvious feature of these images is their low complexity, which can be detected by entropy analysis at the image pre-processing stage.

## 5. Verification for SET2 Images and Discussion

It is also worth checking if one can use the average curve determined for the basic image set for other images. For this purpose, the other twelve remote sensing images denoted as RSI #13, …, RS #24 have been taken from the SPAQ database and processed. Table 4 presents the statistical results obtained for these images.

Analysis of data in Table 4 shows that the tendencies and the corresponding parameter values are close to those in Table 3. The provided CR is slightly biased – its values are mostly smaller than $CR_{des}$). Due to the second step, the accuracy is greatly improved. The average curve model obtained earlier occurs applicable. The detailed data for the images RSI #13,…,RS #24 for $CR_{des}$=20 are shown in Figure 4.

**Table 4.** Statistical results of the validation image set

| $CR_{des}$ | $VAR_{fir}$ | $VAR_{sec}$ | $MEAN_{sec}$ |
|---|---|---|---|
| 10 | 10.648 | 0.934 | 9.635 |
| 20 | 55.802 | 2.527 | 18.398 |
| 40 | 440.098 | 25.564 | 35.071 |

Similar to the results of the basic image set, the second step allows providing CR closer to $CR_{des}$ compared to the first step. So, the error is effectively decreased. Another observation from this example is that, due to the integer setting of Q, for some images (see RS ##16, 19, and 24 in Figure 4), one does not need the second step compression. However, for other images, the second step of compression is still necessary, and for some particular images, the residual error is still too large after the second step. Let us take image RS #17 as an example (Figure 5).

In opposite to the test image RS6, the image RS17 is of high complexity (EA=6.85). In the first step compression, Q is set as 30, and CR equals 12.433. Then, one needs to carry out the second step of compression. The Q value is corrected to 32, and CR after correction equals 17.721. Thus, it is considerably closer to $CR_{des}$ = 20.

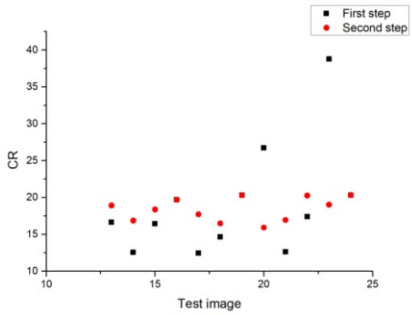
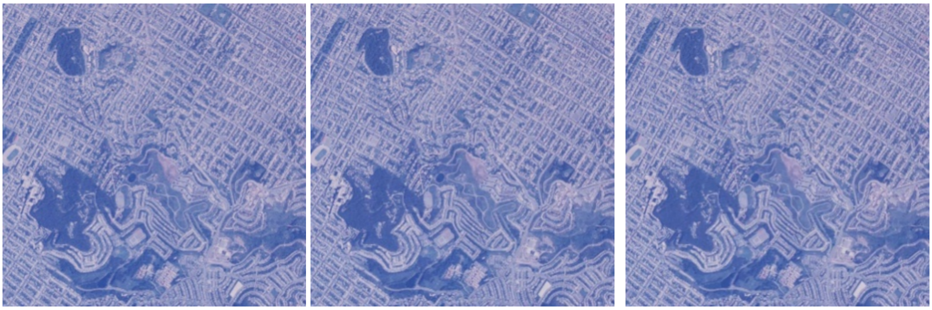



**Figure 4.** The results for validation images ($CR_{des}$= 20).



a b c

**Figure 5.** Compression example for the test image RS 17: Original image,size=2.12Mb (a), first step,Q=30, CR=12.433, PSNR=30.473dB (b); second step,Q=32, CR=17.721, PSNR=29.450dB (c).

Based on this example, some conclusions can be drawn as follows. Large errors after the first step might happen not only for simple structure images but also for high complexity ones. The reason is that we use linear interpolation while the curves are only locally linear. Another reason is that we use an average derivative while the derivative for each particular dependence of CR on Q can differ from the average, especially for very simple and very complex structure images. This leads to possible situations when the corrected Q is not the value that can provide the CR nearest to the desired CR.

## 6. Conclusions

We have analyzed the problem of providing a desired CR for color (three-channel) images compressed by the BPG encoder applied to PNG format images in 4:2:0 mode. It is shown that the problem arises due to two facts. First, for a given Q, CR varies in wide limits and, thus, to provide a given CR, Q has to be set adaptively (individually) depending on image complexity that can be characterized by entropy. Second, it is impossible to provide a desired CR very accurately since Q can be only an integer for the considered encoder.

The two-step procedure earlier developed for providing a desired visual quality can be quite effectively applied to improving the accuracy of CR provides. After the second step, the variance of residual errors of CR providing decreases by one order of magnitude for the wide range of possible values of the desired CR compared to the variance after the first step. Errors are larger for larger desired CR. Residual errors are larger for images with "extreme" complexity – either very simple or very complex.

We expect that the two-step procedure can be applied to images compressed by BPG in other modes. The task is to get average curves in advance. Also, note that the approach should work for images originally presented in PNG format. However, again, the corresponding average curves have to be obtained in advance.

## References

[1] Hussain AJ, Al-Fayadh A, and Radi N. Image compression techniques: A survey in lossless and lossy algorithms. Neurocomputing. 2018July; 300(26): 44-69.
[2] Blanes I, Magli E, and Serra-Sagrista J. A tutorial on image compression for optical space imaging systems. IEEE Geoscience Remote Sensing Magazine. 2014 Sep; 2(3):8-26.
[3] Yee D, Soltaninejad S, Hazarika D, Mbuyi G, Barnwal R, and Basu A. Medical image compression based on region of interest using better portable graphics (BPG).Proceedings of 2017 IEEE international conference on systems, man, and cybernetics (SMC);2017 Oct 05-08; Banff, AB.Piscataway(NJ): IEEE; p.216-221.
[4] Sayood K, Introduction to data compression. San Francisco: Morgan Kaufmann, 2017.700 p.
[5] Christophe E, Hyperspectral data compression tradeoff. In:Prasad S, Bruce LM, and Chanussot J, editor. Optical remote sensing, Berlin, Heidelberg: Springer; 2011, p. 9-29.
[6] Li F, Krivenko S, and Lukin V. Two-step providing of desird quality in lossy image compression by SPIHT.Radioelectronic and computer systems. 2020 Jan; 94(2):22-32.
[7] Oh H, Bilgin A, and Marcellin M. Visually lossless JPEG 2000 for remote image browsing. Information 2016 Sep; 7(3):45.
[8] Llinàs FA. Model-based JPEG2000 rate control methods. UniversitatAutònoma de Barcelona, 2007. 175 p.
[9] Chourasiya R and Shrivastava A. A Study of image compression based transmission algorithm Using SPIHT for low bit rate application. Advanced Computing: An International Journal (ACIJ).2012 Nov;3(6):47-54.
[10] Ponomarenko N, Lukin V, Egiazarian K, and Astola J. ADCTC: advanced DCT-based image coder. Proceedings of LNLA, Lausanne, Switzerland, 2008, p.1-6.
[11] Ginesu G, Pintus M, and Giusto DD. Objective assessment of the WebP image coding algorithm. Signal Processing: Image Communication, 2012 Jan; 27(8): 867-874.
[12] Bellard F. (2018, 2021.7.25). BPG Image format. Available: https://bellard.org/bpg/.
[13] Albalawi U, Mohanty SP, and Kougianos E. A hardware architecture for better portable graphics (BPG) compression encoder.Proceeding of 2015 IEEE International Symposium on Nanoelectronic and Information Systems, 2015 Dec 21-23; Indore,MP. Piscataway(NJ): IEEE; p. 291-296.
[14] Li F, Lukin V, Ieremeiev O, and Okarma K. Quality control for the BPG lossy compression of three-channel remote sensing images. Remote Sensing. 2022 Apr; 14(8): 1824.
[15] Lukin V, Krivenko S, Li F, Abramov S, and Makarichev V. On Image Complexity in Viewpoint of Image Processing Performance. Proceeding of the 3rd International Workshop on Intelligent Information Technologics and Systems of Information Security: 2022 Mar 23-25; Khmelnytskyi. Aachen(NR);RWTH Aachen. p.458-473.
[16] Zemliachenko A, Lukin V, Ponomarenko N, Egiazarian K, and Astola J. Still image/video frame lossy compression providing a desired visual quality. Multidimensional Systems & Signal Processing. 2016 Jul; 27(3): 697-718.
[17] Nafchi HZ, Shahkolaei A, Hedjam R, and Cheriet M. Mean deviation similarity index: Efficient and reliable full-reference image quality evaluator. IEEE Access. 2016 Aug; 4:5579 - 5590.
[18] USC-SIPI. (2021). The USC-SIPI image database. Available: http://sipi.usc.edu/database/database.php?volume=aerials.