JPEG and BPG visually lossless image compression via KonJND-1k database

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Abstract:

Introduction/purpose: This paper presents the results of the research on visually lossless image compression which is of particular interest because it achieves a high degree of compression, while the visual quality of the image is not impaired, i.e., end users are very satisfied with the image quality. The analysis was carried out using the publicly available large-scale picture-wise KonJND-1k database which contains the results of subjective tests on JPEG and BPG compressed images.

Methods: Thanks to the availability of images from the KonJND-1k database, the dependence of objective assessments of image quality on parameters that control the degree of compression of source signals (quality factor for JPEG and quantization parameter for BPG) is analyzed. The results of the visually lossless subjective tests are used for a deep analysis of the boundary and typical values of the parameters that control these two types of compression, as well as for the analysis of the corresponding values of the objective quality scores. Furthermore, reliable features for predicting the boundary between visually lossless and visually lossy compression have been identified. For that purpose, the degree of agreement between the predictions and the ground truth values of the peak *signal-to-noise ratio (PSNR) and image representation in bits per pixel (bpp) is used. The visually lossless compression ratio is used to compare JPEG and BPG techniques.*

Results: It is shown that the boundary between visually lossless and visually lossy image compression is found in a wide range of PSNR values (about 20 dB for JPEG and 15 dB for BPG). The corresponding JPEG image compression quality factor values at this threshold also range widely from 31 to 79, with concentration between 40 and 45. For the BPG encoder, the values of the quantization parameter are grouped around 30, and the boundary values are 25 and 34. Furthermore, it is shown that this boundary can be reliably determined based on simple features derived from the original uncompressed image. Gradient-based features known as spatial frequency and spatial information proved to be the best predictors. The degree of agreement between the predictions obtained from these features with the ground truth values of PSNR and bpp in both types of compression is greater than 85%. A comparative analysis has showed that, using BPG compression, it is possible, on the average, to achieve a twice larger compression ratio of visually lossless compression than for JPEG (80 versus 40).

Conclusion: Although a high degree of agreement is achieved between the predictions and the ground truth values of PSNR and bpp of the boundary between visually lossless and visually lossy compression, there is a need for the development of new prediction approaches, especially with the BPG technique, which through the compression ratio proved to be superior to the JPEG technique. The existing databases used for the analysis of visually lossless compression contain color images from the visible part of the electromagnetic spectrum. Considering the increasing use of images from the infrared part of the spectrum, there is a need to conduct similar tests in this spectral range.

Key words: BPG compression, JPEG compression, just noticeable difference (JND), peak signal-to-noise ratio (PSNR), visually lossless image compression.

Introduction

With the increasing use of images and videos in everyday life, compression of visual signals is gaining more and more importance. The compression process adapts the image/video to the bandwidth of the transmission system while the requirements for memory resources are reduced. It is well known that compression techniques can be divided into lossless compression and lossy compression (Bull & Zhang, 2021). In real applications, the degree of compression of lossless techniques is often not sufficient, while lossy compression techniques can achieve a significantly higher degree of compression, but at the expense of impairing the visual quality of the signal. As a compromise solution, visually lossless techniques have been increasingly used in recent years. Some researchers classify these techniques as the third type of compression, while some of them divide lossy compression techniques into visually lossless and visually lossy (Krivenko et al, 2018).

The just noticeable difference (JND) concept is very important within the visually lossless techniques, and it refers to the smallest degree of degradation that the observer is able to notice if the image is compressed with some compression process (Kovalenko & Lukin, 2023). The JND threshold can be defined for individual pixels (pixel-wise), at the region level (patch-wise), or at the level of the entire image (picture-wise) (Shen et al, 2021).

Thanks to the publicly available JND image databases with subjective test results, such as MCL-JCI (Jin et al, 2016), JND-Pano (Liu et al, 2018), JND-VVC (Shen et al, 2020), VLT (Mikhailiuk et al, 2021), KonJND-1k (Lin et al, 2022), researchers are enabled to analyze the JND concept in different types of compression. The JPEG compression type has been included in MCL-JCI and JND-Pano databases, JND-VVC database uses Versatile Video Coding (VVC) compression, VLT database contains JPEG and WebP compressed images, and the large-scale crowdsourced JND database KonJND-1k contains test results on JPEG and Better Portable Graphics (BPG) compressed images. The JPEG standard was developed more than 30 years ago and is still widely used, while the BPG coder is one of the promising lossy compression coders (Bellard, 2018; Kovalenko et al, 2022). The degree of JPEG compression is controlled using a quality factor (QF) that ranges from 1 to 100, where lower QF values provide a higher degree of compression. BPG compression uses a quantization parameter (QP) that ranges from 0 to 51, where lower values correspond to better visual quality (Lin et al, 2022). As BPG relies on the H.265/HEVC video compression standard, this dynamic range corresponds to the QP values used to adjust the quality of the H.265/HEVC compressed video signal. Recently introduced JND databases include subjective tests on a larger number of codecs (Testolina et al, 2023), and on a larger number of degradation types (Liu et al, 2023).

The boundary between visually lossless and visually lossy image compression (first JND point or JND #1) can be determined through QF/QP prediction, image representation prediction in bits per pixel (bpp) or through objective quality prediction using some of the measures such as PSNR (Saha & Vemuri, 2000), PSNR-HVS-M (Zemliachenko et al, 2016), SSIM (Cai et al, 2019), FSIM (Li et al, 2021), MDSI (Li et al, 2022), VIF (Fiorucci et al, 2012) and similar measures. The simple approach presented in (Bondžulić et al, 2021) to predict the PSNR of the first JND point of JPEG compressed images uses only one feature of the original uncompressed image (the mean gradient magnitude). The effectiveness and acceptable prediction error of the PSNR value of the first JND point of this approach inspired the authors in (Pavlović et al, 2023) to analyze the prediction based on other features, where it was shown that good predictors are spatial information, spatial frequency, contrast and degree of compression. Deep learning approaches (Fan et al, 2019; Lin et al, 2020; Liu et al, 2020) for the prediction of the position of the first JND point of JPEG compressed images provide a smaller PSNR prediction error and can be used for direct QF/QP prediction.

The proposed approaches, where the prediction of the position of the first JND point is carried out through bpp or objective measures, require that the desired bpp or objective quality be reached through an iterative way by changing QF/QP (Zemliachenko et al, 2016). In the literature, one can find approaches such as the two-step approach (Li et al, 2024) or the approach with linear interpolation of the rate distortion curve (Poth et al, 2020; Bondžulić et al, 2024) by which the process of achieving the desired quality is carried out in a few iterations. However, the error introduced by such approaches is superimposed on the prediction error of the position of the first JND point.

In this paper, the results of subjective tests of the KonJND-1k database are analyzed, as it is the largest JND database, which covers JPEG and BPG compressed images, and instead of tests in a laboratory environment, the authors used a crowdsourcing framework. The positions of the JND points in both types of compression are analyzed through the values of PSNR (Wang & Bovik, 2009), PSNR-HVS-M (Ponomarenko et al, 2007) and bpp. Dependences of objective quality measures on parameters that control the degree of compression are shown. The possibility of predicting objective quality scores of visually lossless compressions based on simple features derived from original uncompressed images is analyzed. Finally, the gain (compression ratio) that can be achieved with both types of compression at the JND threshold is given.

KonJND-1k database content analysis

KonJND-1k is a publicly available picture-wise JND image database (Lin et al, 2022). The database consists of 1008 source images and their JPEG and BPG compressed versions with dimensions of 640x480 pixels, together with the results of JND subjective tests. One half of the source images is compressed with JPEG, while the other half is compressed using the BPG encoder. The degree of compression of JPEG images is controlled by the quality factor (QF) which ranges from 1 to 100, so that for one original image there are 100 JPEG compressed images. The degree of compression of BPG images is controlled by the quantization parameter (QP) which is changed from 1 to 51, so that there are 51 BPG compressed images per one original image.

A total of 503 observers participated in the subjective tests, and an average of 42 opinions per original image were collected. Unlike the MCL-JCI (Jin et al, 2016) where the subjective results were collected using binary search comparison, in the KonJND-1k database the results were collected using slider adjustment and a flicker test to determine the position of the first JND point. In the flicker test, the original image and its compressed version alternate at a frequency of 8 Hz, whereby subjects drag the slider to the position corresponding to the smallest distortion level with a noticeable flicker effect. With the flicker approach, the duration of the subjective test can be reduced by 50% while doubling the perceptual sensitivity compared to the standard binary search approach, in which the compressed images are compared side by side with their original.

Figure 1 shows two original images from the KonJND-1k database, their JPEG and BPG compressed versions corresponding to the first JND points, and SSIM (Wang et al, 2004) maps of the structural similarity between the original and compressed version. From Figure 1, it is visually very difficult to find the differences between the original and its compressed versions. Furthermore, in Figure 1(e) and Figure 1(f), the regions with structural information degradation can be observed. For Figure 1(a), it is the lower part of the original image, while for Figure 1(b), it is the central part of the image. The differences in quality can be seen visually if parts of the images are enlarged, as shown in Figure 2, with 150x150 pixel patches. In Figure 2, a blocking effect is observed with the JPEG compressed image, while a blurring effect is observed with the BPG compressed image. In both cases, the SSIM image similarities are close to the maximum value, and the PSNR-HVS-M values are very high. The PSNR values are greater than 30 dB.

(a) image SRC0336.bmp (900 kB) (b) image SRC0845.bmp (900 kB)

(c) JPEG JND #1 image (QF=62, 32.2 kB) (d) BPG JND #1 image (QP=29, 19.5 kB)

(e) (f)

Figure 1 – (a) (b) original images, (c) JPEG JND #1 compressed image, (d) BPG JND #1 compressed image, (e) structural similarity map for JPEG image, and (f) structural similarity map for BPG image

(a) *(b)* *(c)* *(d)*

Figure 2 – Patches of: (a) original image SRC0336.bmp, (b) JPEG compressed image, (c) original image SRC0845.bmp and (d) BPG compressed image

Subjective tests conducted by (Alakuijala et al, 2020) showed that H.265/HEVC Intra and JPEG 2000 codecs, with a noticeable blurring effect, generally result in better rate distortion curves when compared to JPEG, with a dominant blocking effect. This means that by blurred (H.265/HEVC Intra and JPEG 2000) images, more visually pleasing images can be obtained.

The content of the source images of the KonJND-1k database is wide, including the categories of people, animals, plants, things, buildings and transport means. Spatial information (SI) and colorfulness (CF) are used as indicators of the complexity of images that need to be compressed. While the definition of colorfulness is unified, different approaches are used to determine spatial information. After determining the local values of image gradient magnitudes, the spatial information can be determined as their maximum value, mean value, root mean square value or as standard deviation of local scores. Although the ITU recommends using the maximum value, (Yu & Winkler, 2013) has showed that it is better to use the mean gradient magnitude (SI_{mean}) to estimate the complexity of the image in compression. Thus, Figure 3 shows scatterplots of SI_{mean} versus CF, along with the convex hulls for two subsets of original KonJND-1k database images. From Figure 3, it can be concluded that both subsets have approximately the same dynamic range of both indicators and that the contents are almost uniformly distributed within their convex hulls.

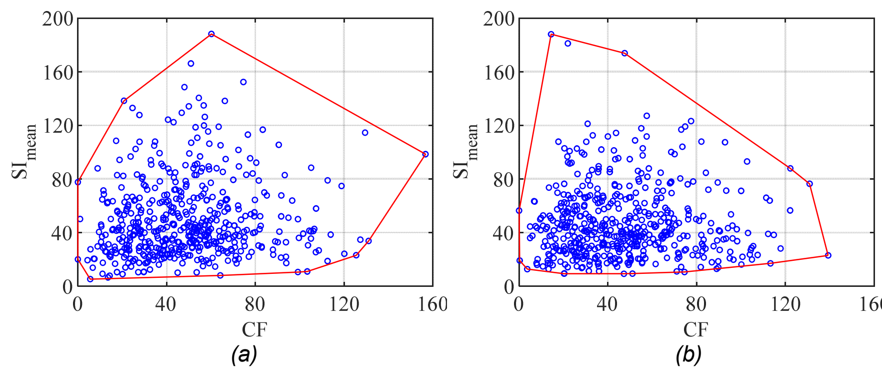


Figure 3 – Spatial information (SI_{mean}) versus colorfulness (CF) plots of the source images belonging to the: (a) JPEG and (b) BPG subsets

Visually lossless compression and objective quality assessment

Objective image quality assessment measures are often used with the aim of achieving the desired quality of the visually lossless compressed image. In some papers, visually lossless quality is defined using fixed thresholds of objective measures, and algorithms for predicting objective values on the boundary between visually lossless and visually lossy compression can also be used. Therefore, it is interesting to analyze the relationship between the objective quality scores and the parameters that control the compression, together with the positions of this boundary.

Figure 4 shows the dependences of PSNR, PSNR-HVS-M and bpp on the quality factor of JPEG compression (rate distortion curves, RDCs). A subset of the KonJND-1k images used for JPEG compression is utilized. Additionally, the positions of the first JND points obtained in the subjective tests (marked with x symbols) are shown.

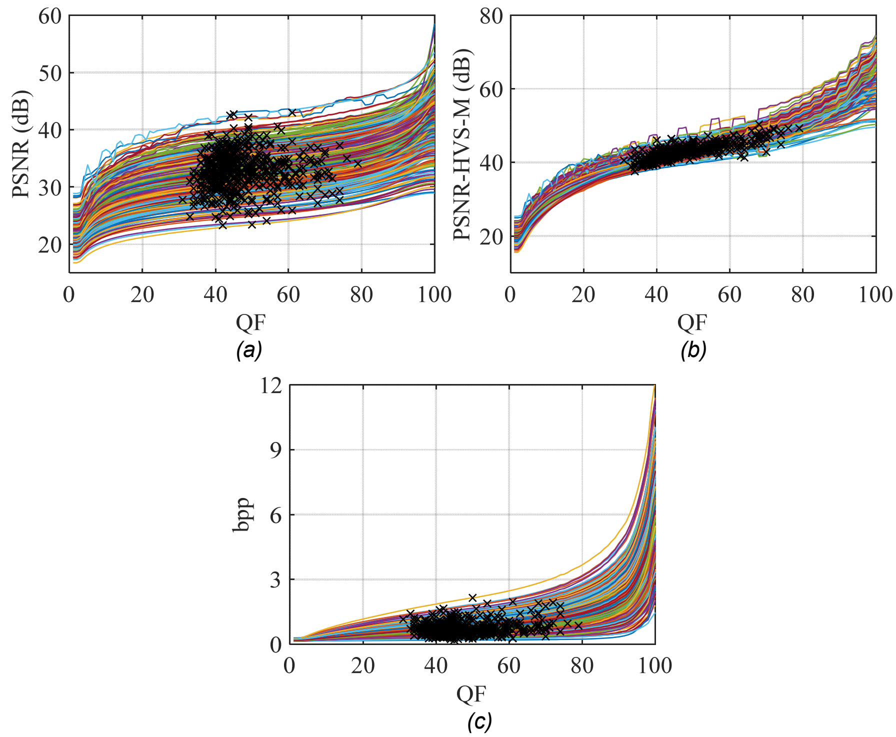


Figure 4 – RDCs PSNR, PSNR-HVS-M and bpp on QF, along with JND #1 points, for a subset of scene images taken from the KonJND-1k database and compressed by JPEG

From Figure 4, no relationship can be observed between the objective quality scores (PSNR, PSNR-HVS-M and bpp) and the QF values of the first JND points (visually lossless compression). It can be observed that the dynamic range of PSNR is significantly higher than the dynamic range of PSNR-HVS-M quality scores. Furthermore, some PSNR and PSNR-HVS-M rate distortion curves show a non-monotonous dependence on the quality factor, known as the strange effect (Bondžulić et al, 2022). This effect does not exist in bpp curves. Similarly, Figure 5 shows the RDCs, along with the positions of the first JND points on the subset of the KonJND-1k images that were used for BPG compression. In this case, the RDCs are monotonous so that the strange effect does not exist for BPG compressed images.

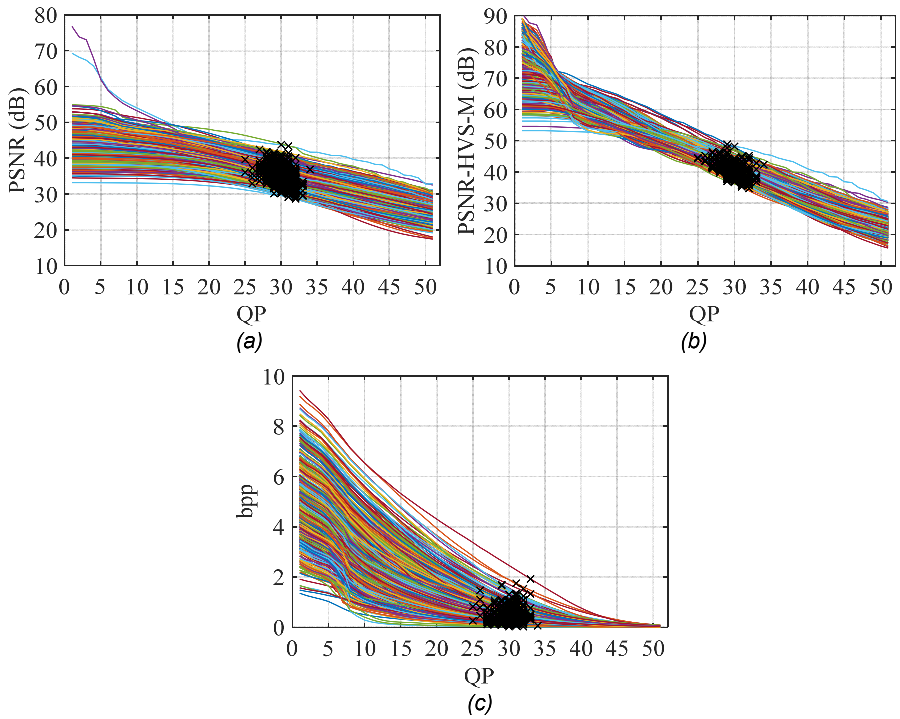


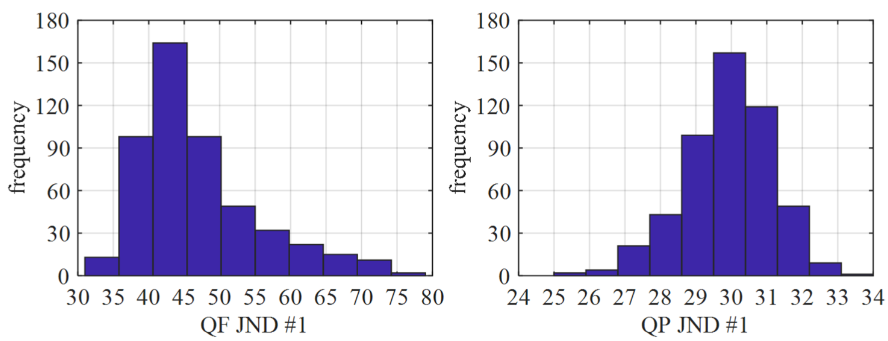
Figure 5 – RDCs PSNR, PSNR-HVS-M and bpp on QP, along with JND #1 points, for a subset of scene images taken from the KonJND-1k database and compressed by BPG

Table 1 provides the boundary values of QF/QP, bpp and objective quality scores for the first JND points of JPEG and BPG subsets. The positions of the first JND points are found in a wide range of PSNR quality values, of almost 20 dB for the JPEG subset, and about 15 dB for the BPG subset. According to PSNR-HVS-M, the range corresponding to the positions of the first JND points on both subsets is about 14 dB. If bpp is used as an indicator, it can be concluded that the positions of the first JND points can be reached by applying lower bpp values in BPG compressed images, which means that a higher degree of compression is achieved than in JPEG compressed images. Additionally, a wide range of QF factors is observed in JPEG compressed images (from 31 to 79). For BPG compressed images, the boundary values of the QP quantization parameter are 25 and 34.

Table 1 – Boundary values of PSNR, PSNR-HVS-M, QF/QP and bpp of the first JND points of the JPEG and BPG subsets

Subset		**JPEG**	**BPG**
PSNR	minimum	23.3149	28.6247
	maximum	42.9831	43.7344
PSNR-HVS-M	minimum	37.5680	34.7033
	maximum	50.3154	48.9101
QF/QP	minimum	31	25
	maximum	79	34
bpp	minimum	0.1841	0.0237
	maximum	2.1429	1.9232

With the histograms of QF/QP values, Figure 6, it can be concluded that the positions of the first JND points of JPEG compressed images are grouped between the QF values of 40 and 45, while in BPG compressed images, the QP values are grouped around 30.



(a) *(b)*

Figure 6 – Histograms of: (a) JND #1 JPEG quality factors, and (b) JND #1 BPG quantization parameters for the subsets of the KonJND-1k database

Identification of the features for visually lossless compression

In recent research (Pavlović et al, 2023), the relationship between simple features derived from the original uncompressed image and the position of the first JND point has been analyzed, with the aim of predicting the values of PSNR JND #1 or bpp JND #1. Here, the analysis is performed on both subsets of the KonJND-1k database, and for the first time on BPG compressed images. The linear correlation coefficient (LCC), the root mean square error (RMSE) and the sum of the squared error (SSE) are used in the analysis as quantitative indicators. These values are calculated between the bpp/PSNR JND #1 predictions obtained from the original image features and the ground truth bpp/PSNR values obtained in subjective tests. The second-order mapping law is used to map feature values into JND predictions.

To predict the boundary between visually lossless and visually lossy compression, simple features that have already been used in the literature as complexity measures or can be related to the complexity of the image are chosen. Only one of the adopted features uses color information, while the other features are calculated on grayscale versions of the original images. The following features have been adopted:

- Entropy, E_1; it quantifies the information content of the image and can be used to characterize the randomness of the original image intensity distribution.
- Standard Deviation, STD; it is a statistical measure of the pixel intensity values variability.
- Spatial Information, SI, and Spatial Frequency, SF; these are gradient-based features of the image, calculated on the basis of local gradient magnitudes obtained by applying Sobel spatial masks (SI), i.e., differences of pixel intensity values along rows and columns (SF) (Pavlović et al, 2023). The final values are calculated as their mean value (mean), the root mean square value (rms) and the standard deviation (std).
- Image Power Spectra Slope, IPSS; it is calculated as the slope of the fitted line in the log-log plot of radially averaged spectral power (Pavlović et al, 2023).
- Two-dimensional Entropy, E_2, Contrast, Correlation, Energy and Homogeneity; this feature set is calculated based on the gray level co-occurrence matrix (GLCM), known in image texture analysis and classification (Corchs et al, 2016). The frequencies of occurrence of pairs of gray levels at the positions (m,n) and (m+1,n+1) are used to determine the GLCM.
- Compression Ratio, CR_f; as a feature, here, it is calculated as the ratio of the size of the uncompressed image to the size of its JPEG compressed version with a quality factor of QF=100 (Corchs et al, 2016).
- Edge Density, ED; represents the percentage of edge pixels in relation to the dimensions of the image. The well-known Canny detector is used to determine edge pixels.

- Shape, α, and scaling, σ, parameters of the Generalized Gaussian Distribution (GGD), which models the distribution of Mean Subtracted Contrast Normalized (MSCN) coefficients. The MSCN coefficients distribution parameters are used in the literature to determine the type of degradation and image quality assessment (Mittal et al, 2012).
- Mean Percentage Intensity Uniformity, mPIU; it is determined based on the uniformity within 8x8 non-overlapping blocks of the original image (Goerner et al, 2013).
- Colorfulness, CF; can be used as an estimator of the variety and intensity of colors in an image. It is calculated based on the mean values and standard deviations within the planes obtained after the conversion of the RGB color image into the opponent color space (Hasler & Suesstrunk, 2003).

Tables 2 and 3 show the degree of agreement between the predictions and the ground truth PSNR and bpp values for both subsets of the KonJND-1k database.

Table 2 – Agreement between the predicted and ground truth PSNR (PSNR JND #1) for the KonJND-1k image subsets

	PSNR JND #1					
Subset	**JPEG**			**BPG**		
	LCC	***RMSE***	***SSE***	***LCC***	***RMSE***	***SSE***
Entropy, E_1	0.3943	3.049	4658	0.4663	2.389	2859
Standard Deviation, STD	0.3043	3.167	5024	0.2165	2.636	3482
Spatial Information, SI_{mean}	**0.9056**	**1.407**	**992.3**	**0.8585**	**1.385**	**960.7**
Spatial Information, SI_{rms}	0.8628	1.681	1415	0.7268	1.855	1723
Spatial Information, SI_{std}	0.7807	2.077	2162	0.6065	2.147	2309
Spatial Frequency, SF_{mean}	**0.9178**	**1.32**	**873**	**0.8662**	**1.349**	**912.3**
Spatial Frequency, SF_{rms}	0.9042	1.42	1010	0.7634	1.744	1524
Spatial Frequency, SF_{std}	0.8545	1.727	1495	0.6727	1.998	2000
Image Power Spectra Slope, PSS	0.7209	2.304	2660	0.5568	2.243	2521
Entropy, E_2	0.7353	2.253	2543	0.7475	1.794	1612
Contrast	0.8438	1.784	1595	0.7059	1.913	1833
Correlation	0.6867	2.412	2914	0.5763	2.207	2440
Energy	0.1043	3.306	5477	0.2319	2.627	3457

	PSNR JND #1					
Subset	**JPEG**			**BPG**		
	LCC	***RMSE***	***SSE***	***LCC***	***RMSE***	***SSE***
Homogeneity	0.7446	2.219	2468	0.7878	1.663	1385
Compression Ratio, CR_f	0.8246	1.881	1772	0.8508	1.419	1009
Edge Density, ED	0.7921	2.029	2063	0.8294	1.509	1140
GGD, shape α	0.4574	2.956	4378	0.4883	2.357	2782
GGD, scale σ	0.7706	2.119	2249	0.7597	1.756	1545
mPIU	0.7253	2.289	2624	0.5818	2.196	2416
Colorfulness, CF	0.3036	3.167	5026	0.2605	2.607	3405

Table 3 – Agreement between the predicted and ground truth bpp (bpp JND #1) for the KonJND-1k image subsets

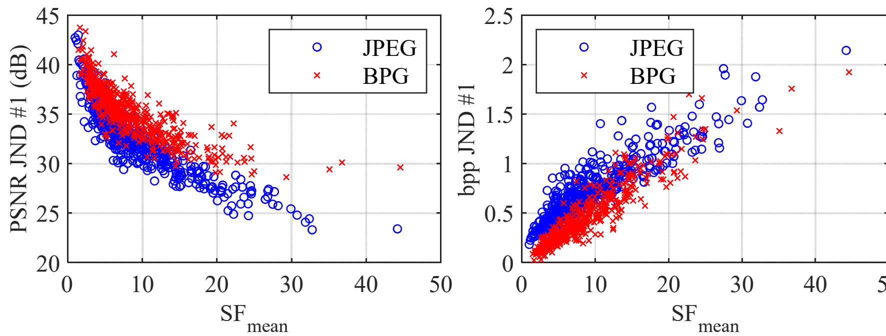
	bpp JND #1					
Subset	**JPEG**			**BPG**		
	LCC	***RMSE***	***SSE***	***LCC***	***RMSE***	***SSE***
Entropy, E_1	0.4620	0.2758	38.12	0.4422	0.2686	36.14
Standard Deviation, STD	0.2798	0.2986	44.67	0.2178	0.2923	42.79
Spatial Information, SI_{mean}	**0.9052**	**0.1322**	**8.759**	**0.9052**	**0.1273**	**8.116**
Spatial Information, SI_{rms}	0.8255	0.1755	15.43	0.7934	0.1823	16.65
Spatial Information, SI_{std}	0.6974	0.2229	24.89	0.6439	0.2291	26.3
Spatial Frequency, SF_{mean}	**0.9006**	**0.1352**	**9.153**	**0.9302**	**0.1099**	**6.054**
Spatial Frequency, SF_{rms}	0.8500	0.1638	13.44	0.8534	0.1561	12.21
Spatial Frequency, SF_{std}	0.7627	0.2012	20.27	0.7459	0.1994	19.93
Image Power Spectra Slope, PSS	0.6291	0.2418	29.28	0.6131	0.2366	28.04
Entropy, E_2	0.7926	0.1897	18.02	0.7824	0.1865	17.43
Contrast	0.8275	0.1746	15.28	0.8218	0.1706	14.58
Correlation	0.6753	0.2294	26.36	0.6859	0.2179	23.79
Energy	0.1703	0.3065	47.06	0.2034	0.2932	43.07
Homogeneity	0.7861	0.1922	18.51	0.7854	0.1854	17.22
Compression Ratio, CR_f	0.8131	0.181	16.42	0.8445	0.1604	12.89
Edge Density, ED	0.8061	0.1841	16.97	0.7975	0.1807	16.35
GGD, shape α	0.5479	0.2602	33.91	0.4924	0.2606	34.03
GGD, scale σ	0.7253	0.2141	22.97	0.7562	0.1959	19.23
mPIU	0.7670	0.1996	19.95	0.7415	0.2009	20.23
Colorfulness, CF	0.3430	0.2921	42.76	0.1247	0.2971	44.23

It can be concluded that gradient-based spatial information (SI) and spatial frequency (SF) are the two best features for prediction, with SF performing better. Additionally, the earlier observation that the mean gradient magnitude is a better predictor than the root mean square value or the standard deviation is confirmed (see SI_{mean}/SF_{mean} vs. SI_{rms}/SF_{rms} and SI_{std}/SF_{std}). If LCC is considered as a quantitative indicator, it can be concluded that the performance of these two most reliable prediction features is worse in predicting PSNR JND #1 within the BPG subset, and in contrast, the success in predicting bpp JND #1 is observed within the BPG subset.

Also, in earlier research related to JPEG compressed images, it has been concluded that it is better to predict PSNR than bpp, which is also confirmed here. However, it can be concluded here that, for BPG compressed images, it is better to use bpp predictions than PSNR. By predicting bpp based on SF_{mean}, the degree of agreement with the ground truth values is better than 90% for both subsets. Apart from the mentioned two features, contrast, edge density and a compression ratio stand out as good predictors.

As spatial frequency proved to be the best predictor, Figure 7 presents the relationship between SF_{mean} and the ground truth positions of JND #1 points. On both subsets, a linear relationship can be observed between the feature values and the ground truth bpp JND #1 positions, while the trends slightly deviate from the linear law at PSNR JND #1 points. In this way, it is confirmed that the second-order mapping law is a good choice in predicting the positions of JND #1 points.

Additionally, it can be observed that the positions of the first JND points can be reached with lower bpp values, i.e., with a higher degree of compression using BPG. In addition to a higher degree of compression, the PSNR objective quality of BPG compressed images is also better. Finally, it can be concluded that BPG compression at the JND threshold provides both a higher degree of compression and a better PSNR objective quality than JPEG compression.



(a) *(b)*

Figure 7 – Spatial frequency and: (a) PSNR and (b) bpp of the first JND points on the KonJND-1k image subsets

The optimal functions for mapping the SF_{mean} feature into PSNR JND #1 and bpp JND #1 predictions determined on the KonJND-1k image database results are given in Table 4. In this case, the second-order laws used to map SF_{mean} to PSNR JND #1 must be decreasing functions (see Fig. 7(a)) which remain constant after reaching the minimum values (25.4 dB with JPEG and 29.5 dB with BPG compression). Without this restriction, they would be U-shaped symmetric curves (parabolas). From the law of mapping SF_{mean} to bpp JND #1 of JPEG compressed images, it can be concluded that when SF_{mean} tends to zero, bpp JND #1 tends to 0.2504. For BPG compressed images, it is necessary to introduce a prediction limit (SF_{mean}=0.75) because without it bpp JND #1 values would be negative as SF_{mean} approaches zero (see Fig. 7(b)).

However, if the relationship between SF_{mean} and PSNR-HVS-M of the first JND points is analyzed, Figure 8, it can be concluded that the quality of JPEG compressed images is better. This quality inversion can be explained by the fact that PSNR is a simple measure that uses the difference of the amplitudes between individual pixels in the quality assessment, while PSNR-HVS-M additionally takes into account the characteristics of the human visual system. Thus, there is a decorrelation between SF_{mean} and PSNR-HVS-M values, so that instead of an orderly trend of scores there is a cloud of points in the 2D space SF_{mean} versus PSNR-HVS-M.

Table 4 – Optimal functions for mapping the SF_{mean} feature into PSNR JND #1 and bpp JND #1 predictions determined on the KonJND-1k subsets

	JPEG
PSNR	$PSNR(SF_{mean}) = \begin{cases} 0.01376SF_{mean}^2 - 0.8645SF_{mean} + 38.97, SF_{mean} \le 31 \\ 25.4, SF_{mean} > 31 \end{cases}$
bpp	$bpp(SF_{mean}) = -0.0003719SF_{mean}^2 + 0.05558SF_{mean} + 0.2504$
	BPG
PSNR	$PSNR(SF_{mean}) = \begin{cases} 0.01336SF_{mean}^2 - 0.7618SF_{mean} + 40.36, SF_{mean} \le 28 \\ 29.5, SF_{mean} > 28 \end{cases}$
bpp	$bpp(SF_{mean}) = \begin{cases} -0.0003425SF_{mean}^2 + 0.05989SF_{mean} - 0.02376, SF_{mean} \ge 0.75 \\ 0.0201, SF_{mean} < 0.75 \end{cases}$

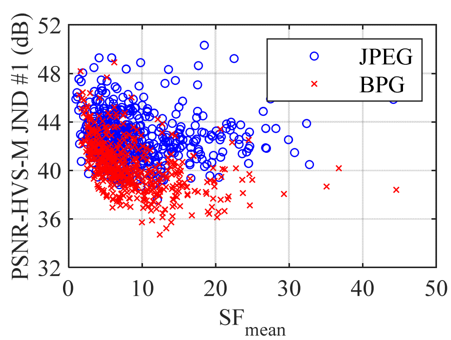
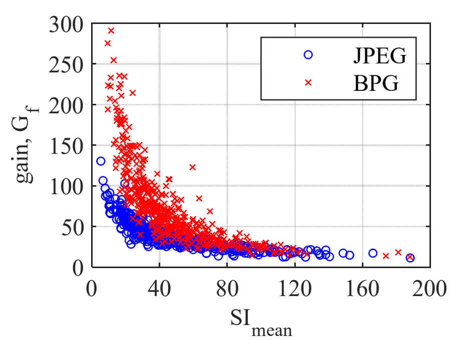


Figure 8 – Spatial frequency and PSNR-HVS-M of the first JND points on the KonJND-1k image subsets

JPEG and BPG visually lossless compression comparison

In several previous illustrations, it has been observed that, at the JND threshold, a higher degree of compression can be obtained if BPG compression is used instead of JPEG. This observation is further illustrated in Figure 9, where the relationship between the achieved gain (compression ratio, G_f) calculated as the ratio of the size of the uncompressed image and its visually lossless version and the SI/SF feature is shown. These scatter plots confirm the previous observation, whereby it can be additionally concluded that the degree of BPG compression is significantly higher than JPEG for lower values of SI/SF, i.e., with low complexity images (with large homogeneous and without textured regions). The degree of compression in both cases is approximately the same for images with higher SI/SF values (images rich in details). On the average, Table 5, the degree of compression at the JND threshold is two times higher if BPG is used instead of JPEG (80.5 vs. 39.4). From Table 5, in which the boundary values of compression are given, it can be concluded that the BPG compression ratio G_f goes over 1000 times (in Figure 9 it is not visible because the dynamic range is shown up to a value of 300) in images with uniform regions. The maximum compression ratio using JPEG is approximately 130. From Figure 9, it can be additionally concluded that SI and SF can be used for reliable prediction of the achieved gain. In this case, due to the large dynamic range and the slope of the dependence of G_f on the mentioned characteristics, it is desirable to use the mapping law of a higher order.



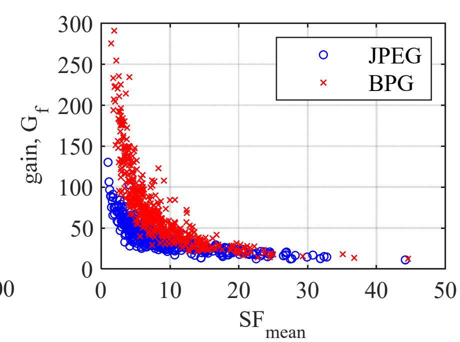


Figure 9 – The gain achieved by applying visually lossless compression versus: (a) spatial information and (b) spatial frequency

Table 5 – Gain boundary values of visually lossless compression for the KonJND-1k subsets

Subset		JPEG	BPG
gain, G_f	minimum	11.1996	12.4795
	maximum	130.3536	1012.7
	mean	39.3763	80.5105

Conclusion

The conducted analysis on visually lossless image compression using the KonJND-1k database confirmed some earlier observations about the prediction of the first JND point position of JPEG compressed images, but also brought new conclusions about the prediction of the first JND position of BPG compressed images.

It has been confirmed that the prediction of the first JND point position, as the boundary between visually lossless and visually lossy compression, in JPEG compression can be achieved using simple features derived from the original uncompressed image. The gradient-based features spatial information and spatial frequency are singled out as reliable features for prediction, where the degree of agreement with the results of subjective tests is greater than 90% for both indicators, PSNR and bits per pixel.

The analysis conducted on the prediction of the first JND point position of BPG compressed images has showed that spatial information and spatial frequency can also be used for reliable prediction. The degree of agreement between the predictions derived from these features and the results of subjective tests is greater than 90% if the representation is predicted in bits per pixel. If the PSNR of the first JND point is predicted, the degree of agreement is worse and is around 86%. In addition to these two features, good predictors are contrast, edge density and compression ratio.

A special contribution of the paper is the comparative analysis of the compression ratio on the boundary between visually lossless and visually lossy JPEG and BPG compression. The analysis has showed that the advantage in the degree of compression is on the side of BPG coding, where on average the degree of compression is twice as high compared to JPEG (80 versus 40). The degree of compression of BPG is significantly higher than JPEG for low complexity images (with homogeneous regions), slightly higher for medium complexity images, while for high complexity images with pronounced texture, the degree of compression is approximately the same for both codecs.

Due to the increasing use of images from the infrared part of the spectrum, visually lossless compression in this spectral band will be analyzed in further work. The goal is to conduct subjective tests and additional analyzes using objective image quality assessment measures.

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Compresión de imágenes JPEG y BPG sin pérdida visual a través de la base de datos KonJND-1k

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CAMPO: telecomunicación
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Este artículo presenta los resultados de la investigación sobre la compresión de imágenes sin pérdida visual, que es de particular interés porque logra un alto grado de compresión, mientras que la calidad visual de la imagen no se ve afectada, es decir, los usuarios finales están muy satisfechos con la calidad de la imagen. El análisis se llevó a cabo utilizando la base de datos KonJND-1k de *imágenes a gran escala disponible públicamente, que contiene los resultados de pruebas subjetivas en imágenes comprimidas JPEG y BPG.*

Métodos: Gracias a la disponibilidad de imágenes de la base de datos KonJND-1k, se analiza la dependencia de las evaluaciones objetivas de la calidad de la imagen en los parámetros que controlan el grado de compresión de las señales de origen (factor de calidad para JPEG y parámetro de cuantificación para BPG). Los resultados de las pruebas subjetivas sin pérdida visual se utilizan para un análisis profundo de los valores límite y típicos de los parámetros que controlan estos dos tipos de compresión, así como para el análisis de los valores correspondientes de las puntuaciones de calidad objetivas. Además, se han identificado características fiables para predecir el límite entre la compresión visual sin pérdida y la compresión visual con pérdida. Para ello, se utiliza el grado de acuerdo entre las predicciones y los valores de verdad fundamental de la relación señal-ruido (PSNR) de pico y la representación de la imagen en bits por píxel (bpp). La relación de compresión visual sin pérdida se utiliza para comparar las técnicas JPEG y BPG.

Resultados: Se muestra que el límite entre la compresión de imágenes visual sin pérdida y visual con pérdida se encuentra en un amplio rango de valores de PSNR (aproximadamente 20 dB para JPEG y 15 dB para BPG). Los valores del factor de calidad de compresión de imágenes JPEG correspondientes en este umbral también varían ampliamente de 31 a 79, con una concentración entre 40 y 45. Para el codificador BPG, los valores del parámetro de cuantificación se agrupan alrededor de 30, y los valores límite son 25 y 34. Además, se muestra que este límite se puede determinar de forma fiable basándose en características simples derivadas de la imagen original sin comprimir. Las características basadas en gradientes conocidas como frecuencia espacial e información espacial demostraron ser los mejores predictores. El grado de acuerdo entre las predicciones obtenidas a partir de estas características con los valores de verdad fundamental de PSNR y bpp en ambos tipos de compresión es superior al 85%. Un análisis comparativo ha demostrado que, utilizando la compresión BPG, es posible, en promedio, lograr una relación de compresión de compresión sin pérdida visual dos veces mayor que para JPEG (80 frente a 40).

Conclusión: Aunque se logra un alto grado de acuerdo entre las predicciones y los valores de verdad fundamental de PSNR y bpp del límite entre la compresión sin pérdida visual y la compresión con pérdida visual, existe la necesidad de desarrollar nuevos enfoques de predicción, especialmente con la técnica BPG, que a través de la relación de compresión demostró ser superior a la técnica JPEG. Las bases de datos existentes utilizadas para el análisis de la compresión sin pérdida visual contienen imágenes en color de la parte visible del espectro *electromagnético. Considerando el uso creciente de imágenes de la parte infrarroja del espectro, existe la necesidad de realizar pruebas similares en este rango espectral.*

Palabras claves: compresión BPG, compresión JPEG, diferencia apenas perceptible (JND), relación señal-ruido máxima (PSNR), compresión de imágenes sin pérdida visual.

Сжатие изображений JPEG и BPG без визуальных потерь с помощью базы данных KonJND-1k

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РУБРИКА ГРНТИ: 28.23.00 Искусственный интеллект;
28.23.15 Распознавание образов. Обработка изображений
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлены результаты исследований по сжатию изображений без визуальных потерь, которое представляет особый интерес, поскольку позволяет достичь высокой степени сжатия, при этом визуальное качество изображения не ухудшается, т.е. конечные пользователи очень довольны качеством изображения. Анализ проводился с использованием общедоступной крупномасштабной картинной базы данных KonJND-1k, содержащей результаты субъективных тестов изображений, сжатых в форматах JPEG и BPG.

Методы: Благодаря наличию изображений из базы данных KonJND-1k проанализирована зависимость объективных оценок качества изображения от параметров, управляющих степенью сжатия исходных сигналов (коэффициента качества для JPEG и параметра квантования для BPG). Результаты субъективных тестов без визуальных потерь используются для тщательного анализа граничных и типичных значений параметров, управляющих этими двумя типами сжатия, а также для анализа соответствующих значений объективных показателей качества. Кроме того, были идентифицированы надежные функции для прогнозирования границы между сжатием без визуальных потерь и сжатием с визуальными потерями. Для этой цели используется степень

согласия между прогнозируемыми и фактическими значениями пикового отношения сигнал/шум (PSNR) и представления изображения в битах на пиксель (bpp). Степень сжатия без визуальных потерь используется для сравнения методов JPEG и BPG.

Результаты: Показано, что граница между сжатием изображений без визуальных потерь и сжатием изображений с визуальными потерями находится в широком диапазоне значений PSNR (около 20 дБ для JPEG и 15 дБ для BPG). Соответствующие значения коэффициента качества сжатия изображения JPEG при этом пороге также широко варьируются от 31 до 79 с накоплением от 40 до 45. Значения параметра квантования группируются около 30, а граничные значения составляют 25 и 34. Показано, что эту границу можно надежно определить на основе простых признаков, полученных из исходного несжатого изображения. Градиентные характеристики, известные как пространственная частота и пространственная информация, оказались лучшими предикторами. Степень согласия между прогнозируемыми и фактическими значениями PSNR и bpp при обоих типах сжатия превышает 85%. Сравнительный анализ показал, что при использовании BPG сжатия в среднем можно добиться вдвое большей степени сжатия без визуальных потерь, чем при JPEG (80 против 40).

Выводы: Несмотря на достигнутую высокую степень согласия между прогнозируемыми и основными значениями PSNR и bpp на границе между сжатием без визуальных потерь и сжатием с визуальными потерями, существует необходимость в разработке новых подходов к прогнозированию, особенно с использованием метода BPG, который по коэффициенту сжатия превосходит метод JPEG. Современные базы данных, используемые для анализа сжатия без визуальных потерь, содержат цветные изображения видимой части электромагнитного спектра. Учитывая широкое использование изображений инфракрасной части спектра, возникает необходимость проведения аналогичных испытаний и в этом спектральном диапазоне.

Ключевые слова: сжатие BPG, сжатие JPEG, едва заметная разница (JND), пиковое соотношение сигнал/шум (PSNR), сжатие изображения без визуальных потерь.

Компресија JPEG и BPG без губитка визуелних информација на примеру базе KonJND-1k

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ОБЛАСТ: телекомуникације
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У овом раду представљени су резултати истраживања компресије без губитка визуелних информација. Она је од посебног значаја јер се њоме остварује висок степен компресије, при чему визуелни квалитет слике није нарушен, па су крајњи корисници веома задовољни. Анализа је спроведена коришћењем обимне, јавно доступне базе KonJND-1k, која садржи резултате субјективних тестова на компримованим сликама JPEG и BPG.

Методе: Захваљујући доступности слика базе KonJND-1k анализирана је зависност објективних мера процене квалитета слике од параметара којима се контролише степен компресије изворних сигнала (фактор квалитета код JPEG, односно параметар квантизације код BPG). Резултати субјективних тестова искоришћени су за детаљнију анализу граничних и типичних вредности параметара којима се контролишу ова два типа компресије, као и за анализу одговарајућих вредности објективних скорова квалитета. Такође, извршена је идентификација поузданих обележја за предикцију границе између компресије без и са губитком визуелних информација. У ту сврху коришћен је степен слагања између предикција и тачних вредности вршног односа сигнал/шум (PSNR) и репрезентације слике у битима по пикселу (bpp). Степен компресије остварен применом компресије без губитка визуелних информација искоришћен је за поређење техника JPEG и BPG.

Резултати: Показано је да се граница између компресије без и са губитком визуелних информација налази у широком опсегу вредности PSNR (око 20 dB код JPEG и 15 dB код BPG). Одговарајуће вредности фактора квалитета слика JPEG на овој граници се, такође, налазе у широком опсегу од 31 до 79, са груписањем између 40 и 45. Вредности параметра квантизације групишу се око 30, а граничне вредности су 25 и 34. Такође, потврђено је да се ова граница може поуздано одредити на основу једноставних обележја изведених из оригиналне некомпримоване слике. Показало се да су *најбољи предиктори градијентна обележја позната као просторна фреквенција и просторна информација. Степен слагања предикција добијених из ових обележја са тачним вредностима PSNR и bpp код оба типа компресије већи је од 85%. Компаративном анализом доказано је да се применом компресије BPG, у просеку, може остварити дупло већи степен компресије без губитка визуелних информација него применом компресије JPEG (80 насупрот 40).*

Закључак: Иако је остварен висок степен слагања између предикција и тачних вредности PSNR и bpp на граници између компресије без и са губитком визуелних информација, постоји потреба за развојем нових приступа предикције, нарочито код технике BPG која се кроз степен компресије показала супериорном у односу на технику JPEG. Постојеће базе које се користе за анализу компресије без губитка визуелних информација су са сликама из видљивог дела електромагнетног спектра. Имајући у виду све већу употребу слика из инфрацрвеног дела спектра, постоји потреба за спровођењем сличних тестова у овом спектралном опсегу.

Кључне речи: компресија BPG, компресија JPEG, једва уочљиве разлике (JND), вршни однос сигнал/шум (PSNR), компресија без губитка визуелних информација.

EDITORIAL NOTE: The first author of this article, Boban P. Bondžulić, is a current member of the Editorial Board of the Military Technical Courier. Therefore, the Editorial Team has ensured that the double blind reviewing process was even more transparent and more rigorous. The Team made additional effort to maintain the integrity of the review and to minimize any bias by having another associate editor handle the review procedure independently of the editor – author in a completely transparent process. The Editorial Team has taken special care that the referee did not recognize the author's identity, thus avoiding the conflict of interest.

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