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PREPROCESSING OF DIGITAL IMAGE FOR COMPRESSION

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Work is devoted to development of technique of preprocessing of digital image on the basis of replacement of left and right singular vectors corresponding to the maximum singular number in blocks of matrix by *n*-optimum vector to improve the quality of digital image compression (DI) while saving it in JPEG. The criteria of DI compression quality in this study are the volume of DI file after saving and the values of quantitative indicators of both whole and local digital image perception reliability. These quantitative indicators are used according to the previously developed by authors technique of quantitative assessment of digital image perception reliability. The results of computational experiments that confirm the effectiveness of proposed technique usage are shown.

Keywords: compression, digital image (DI), JPEG, preprocessing.

Introduction

With the development of computer technology and the extensive use of multimedia content more and more information is held in the form of digital image (DI). They are subject to stringent requirements regarding the volume of compressed data and recovered image quality with regard to computational complexity of the compression algorithms. In connection with this the problem of improvement of digital image compression algorithms is important.

The most widely used format for storing DI is JPEG, which provides high compression with acceptable levels of perception reliability of the compressed image. JPEG lossy compression method perfectly handles images with continuous tones, in which close pixels usually have similar colors. An important advantage of the JPEG method is a large number of configurable options that user can choose at his discretion, in particular, he can adjust the percentage of loss of information, and, hence, the compression ratio in a wide range [1].

In this paper the method of digital image preprocessing to reduce DI file size while JPEG compression is considered.

Images preprocessing usually contributes to the improvement of characteristics of compressed data (in this case — DI matrices), which in turn increases the final degree of compression.

As it is known [2], the singular values and singular vectors obtained by normal singular value decomposition uniquely and comprehensively characterize the DI matrix (matrices), and therefore can be considered as a complete set of DI parameters.

As a preprocessing in this paper it is considers the process of compression of digital images, based on the change of certain singular vectors obtained using the normal singular value decomposition [2] of the image matrix blocks.

Purpose of study and problem formulation

The *aim* of this work is to develop a method for digital images preprocessing to improve the quality of compression while saving DI in JPEG.

To achieve the aim it is necessary to:

1. Suggest the possibility of improving the DI compression quality based on the change of certain parameters of the complete set of DI parameters;
2. Formulate the basic steps of DI preprocessing method;
3. Select the criteria for assessing the quality of DI compression;
4. Carry out the computational experiments to assess the quality of the compression according to the selected criteria;
5. Carry out a comparative analysis of the JPEG compression algorithm with and without proposed DI preprocessing.

Main section

So, as the complete set of DI parameters it is proposed to use the singular values and singular vectors of DI matrix (matrices) obtained using the normal singular value decomposition. However, during the DI analysis or processing singular value decomposition is not accepted to apply to the entire DI matrix (matrices) virtue of its (their) high dimension. So to start the original image is divided into non-overlapping blocks B of size $n \times n$ pixels.

Singular value decomposition is applied to each block of the image.

Let B be $n \times n$ -matrix with elemants $b_{ij}, i, j = \overline{1,n}$. It is true singular value decomposition of B :

$$B = U \Sigma V^T, \tag{1}$$

where U, V are the orthogonal matrices of dimension $n \times n$ containing left $u_1,...,u_n$ and right $v_1,...,v_n$ singular vectors of matrix B accordingly;

$\Sigma = diag(\sigma_1,...,\sigma_n)$ is a diagonal matrix containing singular values $\sigma_i, i = \overline{1,n}$, $\sigma_1 \geq ... \geq \sigma_n \geq 0$.

Further let's assume that blocks B of DI matrices are non-degenerate and have pairwise distinct singular values $\sigma_i, i = \overline{1,n}$. Then it is possible to build a single normal singular value decomposition (1), in which the left (right) singular vector are lexicographically positive [3].

In [3] on the basis of the Frobenius theorem is shown that the singular vectors u_1, v_1 of DI matrices blocks corresponding to the largest singular values σ_1 are close to the n-optimal vector [4] of corresponding dimension, which is also confirmed by computational experiments.

As it is known, most DI compression algorithms, including JPEG, are based on reducing a variety of the values of certain parameters defining the images which leads to smaller and simpler method of encoding, which in its turn reduces the size of the DI file.

For example, in the process of compression according to JPEG the quantization of discrete cosine transform (DCT) coefficients of DI matrix blocks of 8×8 is used [1, 5]:

$$\overline{u_{ij}} = [u_{ij} / q_{ij}], \tag{2}$$

where $\overline{u_{ij}}$ is a value of DCT coefficient u_{ij} the next DI matrix block 8×8 after quantization, $u_{ij} \in R$, $\overline{u_{ij}} \in Z$, $i, j = \overline{1,8}$;

q_{ij} is a quantization coefficient corresponding to u_{ij}, $q_{ij} \in Z$,

$[\bullet]$ is an operation of rounding an argument to the nearest integer.

The process of quantization of DI DCT coefficients during JPEG compression is studied in detail in [5]. In the quantization of DCT coefficients (2) as a result of rounding their domain of definition from the set of real numbers goes into the set of integers. Moreover, due to the division of values u_{ij} by quantization coefficient q_{ij} the range of $\overline{u_{ij}}$ compared to u_{ij} reduces the q_{ij} time, which also reduces the number of possible taken values of $\overline{u_{ij}}$.

In connection with all aforesaid in this paper as a DI preprocessing for compression in JPEG it is proposed to replace singular vectors u_1, v_1 by n-optimal vector of the corresponding dimension in each block of DI.

It is assumed that such replacement of vectors u_1, v_1, at first, does not lead to significant distortion of DI, since the first singular vectors u_1, v_1 are near n -optimal vector [3]. Secondly, it is assumed that reduction the variety of values of the first singular vectors of DI matrix blocks (which corresponds to the general concept of compression algorithms constructing) will improve the quality of compression in JPEG.

In this paper, we propose to use two criteria of DI compression quality:

- size of DI file after saving;
- values of PSNR and PSNR4 in accordance with the previously developed by the authors method of assessment the digital image perception reliability [6].

The main steps of the method of DI preprocessing for compression:

1. Split the DI matrix into blocks B by $n \times n$ pixels;
2. Apply the normal singular value decomposition to each block B;
3. In each block B replace the left u_1 and the right v_1 vectors corresponding to the maximal singular value σ_1 by n-optimal vector of the corresponding dimension;
4. Change other vectors u_i and v_j $i, j = \overline{2,n}$ in each block, so that the matrices U, V (1) contained orthonormal singular vectors;
5. Obtain the image matrix;
6. Save DI in JPEG.

For color images represented by multiple matrices the proposed preprocessing can be carried out for one or several matrices.

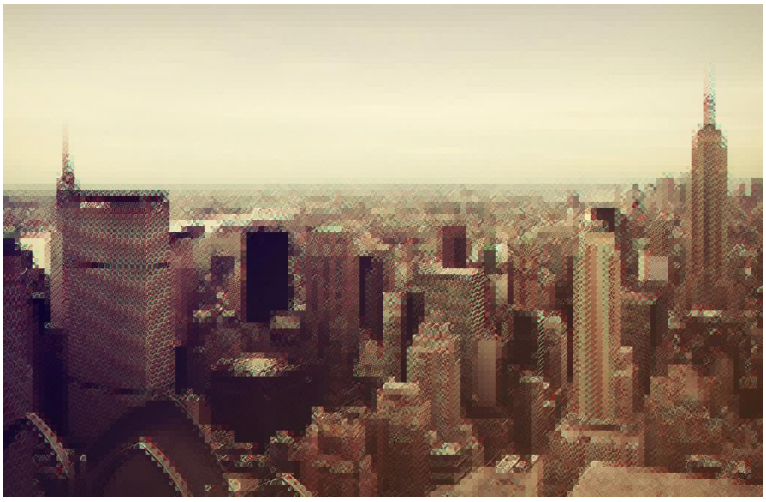
Results of computational experiment

To test the effectiveness of developed method the computational experiment is carried out with the participation of more than 100 DI. During the DI preprocessing in accordance with the developed method by using a variety of block B sizes $n = \{8,4,2\}$ are recorded the image file size and values of two parameters: PSNR to evaluate the perception reliability of DI in general and PSNR4 to estimate the local DI visual distortion [6].

Computational experiment shows that partitioning of the image matrix into blocks of size $n = \{8,4\}$ during the processing of all three RGB components the DI undergoes significant visual distortions, which can be seen both by values of PSNR, PSNR4 and expert assessment. An example of DI after preprocessing with different block sizes is shown on Figure 1.

An example of DI processing, shown on Fig. 1, except the violations of perception reliability is indicative from the point of the small (compared to the size of the original DI) file size reduction with increasing the size of the blocks $n \times n$. So, there is a significant deterioration of the perception reliability during the changing values from $n = 2$ to $n = 4$ and

$n = 8$, but significant reduction in file size is not happening. Obviously, the parameter n allows to adjust the compression quality of DI.



a

b

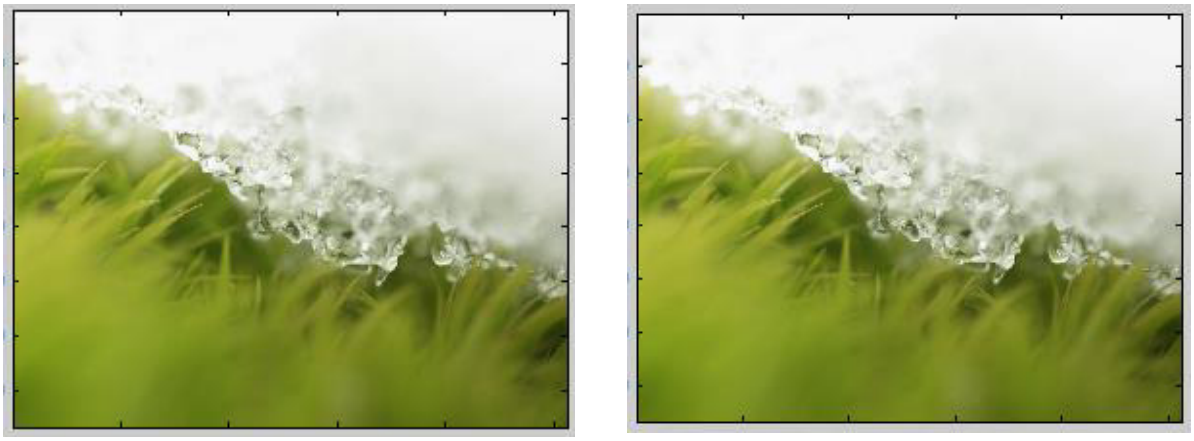
c

Fig. 1. Digital image (file size is 277.350 KB) after preprocessing with blocks of size: a - 8×8 pixels, file size is 91.639 KB; b - 4×4 pixels, file size is 101.850 KB; c - pixels, file size is 107.064 KB

During the computational experiment it is found that to maintain the DI perception reliability during preprocessing only the blue component of the image matrix should be changed with the blocks 2×2. Examples of DI after such preprocessing are shown on Fig. 2 and 3.

a **b**

Fig. 2. Digital image: a - without preprocessing, file size is 281.339 KB; b - after preprocessing with blocks of 2×2 pixels, file size is 103.224 KB, PSNR=37.11



a **b**

Fig. 3. Digital image: a - without preprocessing, file size is 80.863 KB; b - after preprocessing with blocks of 2×2 pixels, file size is 42.049 KB, PSNR=45.69

The experimental results in processing only the blue component of the image when $n = 2$ for fifteen randomly selected DI are shown in Table 1.

As can be seen from the results shown in Table 1, when values of perception reliability parameters PSNR and PSNR4 are acceptable the DI file size after processing by proposed method reduces on 35 — 50% as compared to DI before processing. At the same time high values of PSNR4 close to the PSNR value indicate a lack of local violations of DI perception reliability, which confirms a high image quality after compression.

Table 1.

Results of DI preprocessing with following saving in JPEG

N	DI file size before preprocessing, KB	DI file size after preprocessing, KB	PSNR value	PSNR4 value
1	767	296	39.6	37.6
2	152	76.5	40.6	38.6
3	281	103	35	33
4	277	114	33	29
5	166	66	38	36.9
6	817	309	41.6	41
7	391	184	30.6	28
8	80	42	44	42
9	429	220	36	33
10	630	224	39	38
11	336	199	39	37
12	845	439	37	34
13	781	294	36	33
14	204	112	45.6	42
15	457	244	34	33

When carrying out the computational experiments after replacing the first singular vectors the images are saved in JPEG format with the default settings. To evaluate the effectiveness of the work of developed method of DI preprocessing for compression the comparative analysis with the JPEG method as the most common modern analogue is conducted.

To be able to carry out such comparative analysis the DI is subjected to such two independent processing:

- saving in JPEG with low quality coefficient (usually with a value of 60%);
- preprocessing in accordance with the developed method with following saving in JPEG with the default settings.

The quality coefficient of 60%, while saving in JPEG leads to visual distortions, comparable to the violation of DI perception reliability during preprocessing in accordance with the developed method. Thus, one of the criteria for comparative assessing the quality of the two compression methods receives similar values, and comparative analysis can be carried out on the second criterion — the size of the DI file. Fig. 4 shows an example of DI, which participated in a comparative analysis.

According to the results of comparative analysis the developed method of DI preprocessing for compression no worse than JPEG compression according to values of selected criteria, however, does not exceed it considerably. At the same time the expert assessment of DI perception reliability after compression revealed some qualitative differences between results of compared methods.

Thus when compressing DI with low values of quality coefficient (JPEG) visual distortions can be seen in blurred contours and the appearance of «squares» in the background parts of image (for example, Fig. 5, *a*). When carrying out the preprocessing with developed method with the following saving in JPEG format with high quality coefficient there are no visible visual disturbances in the images (e.g., Fig. 5, *b*). At the same time the DI file sizes after processing with both compared methods are similar.

a **b**

Fig. 4. Digital image: a - after saving in JPEG, PSNR=35.828, file size is 25.497 KB; b - after preprocessing, PSNR=35.824, file size is 24.689 KB

a **b**

Fig. 5. Fragment of digital image: a - after saving in JPEG; b - after preprocessing and saving in JPEG

Conclusions

It is developed the method of preprocessing the digital image based on the replacement of the left and right singular vectors corresponding to the maximal singular value in blocks of matrices by the *n*-optimal vector which allows to:

- to achieve a smaller DI file sizes at high values of quality coefficient while saving in JPEG;
- maintain a high level of DI perception reliability, avoiding artifacts typical for JPEG at low values of quality coefficient.

The usage of developed method of digital image preprocessing for compression in JPEG may be recommended in cases where preservation of image contours is essential in decreasing the size of its file.

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ПЕРЕДОБРОБКА ЦИФРОВОГО ЗОБРАЖЕННЯ ДЛЯ СТИСНЕННЯ

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Робота присвячена розробці методу передобробки цифрового зображення на основі заміни лівого і правого сингулярних векторів, що відповідають максимальному сингулярному числу, в блоках матриці на *n*-оптимальний вектор для підвищення якості стиснення цифрового зображення (ЦЗ) при збереженні в форматі JPEG. Критеріями якості стиснення ЦЗ в даній роботі вважаються об'єм файла ЦЗ після збереження і значення кількісних показників для оцінки надійності сприйняття ЦЗ в цілому і його локальних візуальних спотворень у відповідності з розробленою авторами раніше методикою кількісної оцінки надійності сприйняття цифрового зображення. Наведені результати обчислювального експерименту, що підтверджують ефективність використання розробленого методу.
Ключові слова: стиснення, цифрове зображення, JPEG, передобробка.

ПРЕДОБРАБОТКА ЦИФРОВОГО ИЗОБРАЖЕНИЯ ДЛЯ СЖАТИЯ

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Работа посвящена разработке метода предобработки цифрового изображения на основании замены левого и правого сингулярных векторов, соответствующих максимальному сингулярному числу, в блоках матрицы на *n*-оптимальный вектор для улучшения качества сжатия цифрового изображения (ЦИ) при сохранении в формате JPEG. Критериями качества сжатия ЦИ в данной работе считаются объем файла ЦИ после сохранения и значения количественных показателей для оценки надежности восприятия ЦИ в целом и его локальных визуальных искажений в соответствии с разработанной авторами ранее методикой количественной оценки надежности восприятия цифрового изображения. Приведены результаты вычислительного эксперимента, подтверждающие эффективность использования разработанного метода.
Ключевые слова: сжатие, цифровое изображение, JPEG, предобработка.