UDC 004.932:004.627 **doi: 10.32620/reks.2019.1.03**

I. V. BRYSINA, V. O. MAKARICHEV

National Aerospace University "Kharkiv Aviation Institute", Ukraine

DISCRETE ATOMIC COMPRESSION OF DIGITAL IMAGES: ALMOST LOSSLESS COMPRESSION

In this paper, we consider the problem of digital image compression with high requirements to the quality of the result. Obviously, lossless compression algorithms can be applied. Since lossy compression provides a higher compression ratio and, hence, higher memory savings than lossless compression, we propose to use lossy algorithms with settings that provide the smallest loss of quality. The ***subject matter*** *of this paper is almost lossless compression of full color 24-bit digital images using the discrete atomic compression (DAC) that is an algorithm based on the discrete atomic transform. The* ***goal*** *is to investigate the compression ratio and the quality loss indicators such as uniform (U), root mean square (RMS) and peak signal to noise ratio (PSNR) metrics. We also study the distribution of the difference between pixels of the original image and the corresponding pixels of the reconstructed image. In this research, the classic test images and the classic aerial images are considered. U-metric, which is highly dependent on even minor local changes, is considered as the major metric of quality loss. We solve the following* ***tasks****: to evaluate memory savings and loss of quality for each test image. We use the* ***methods*** *of digital image processing, atomic function theory, and approximation theory. The computer program "Discrete Atomic Compression: User Kit" with the mode "Almost Lossless Compression" is used to obtain results of the DAC processing of test images. We obtain the following* ***results****: 1) the difference between the smallest and the largest loss of quality is minor; 2) loss of quality is quite stable and predictable; 3) the compression ratio depends on the smoothness of the color change (the smallest and the largest values are obtained when processing the test images with the largest and the smallest number of small details in the image, respectively); 4) DAC provides 59 percent of memory savings; 5) ZIP-compression of DAC-files, which contain images compressed by DAC, is efficient.* ***Conclusions:*** *1) the almost lossless compression mode of DAC provides sufficiently stable values of the considered quality loss metrics; 2) DAC provides relatively high compression ratio; 3) there is a possibility of further optimization of the DAC algorithm; 4) further research and development of this algorithm are promising.*

Keywords: *atomic functions; discrete atomic compression; discrete atomic transform; almost lossy image compression.*

Introduction

Digital image compression is a distinct branch of data compression. All existing methods of such processing can be classified according to various criteria. In general, image compression methods are divided into two types: lossless and lossy compression algorithms [1]. It is clear that the algorithm is called lossless if the original image can be exactly restored in the process of decompression. In other words, the original and decompressed images are exactly the same. In spite of this important feature, full-color digital images, such as digital photos are often compressed using lossy compression algorithms (we note that the JPEG algorithm is the most popular). In most cases, lossy compression provides a higher compression ratio and hence higher memory savings than lossless compression. Besides, loss of quality may be visually imperceptible or may not be perceived as significant. This explains the widespread use of lossy compression algorithms. However, some changes may not be acceptable in the future. Some local quality losses can be visually insignificant, but at the same time adversely affect the process of analysis and lead to incorrect results. In some cases, for example, when processing medical images, the consequences of such errors can be disastrous. One solution to this problem is to regulate the quality of selected areas of the image. Nevertheless, not all compression algorithms provide an implementation of this approach. Moreover, it can be inapplicable when processing the big data. Another solution is to use compressors with settings that minimize the quality loss of the entire image, and not just the selected areas.

In the paper [2], discrete atomic compression (DAC) of digital images was introduced. This algorithm is based on the application of so-called atomic functions [3]. DAC is an algorithm for lossy compression of full color 24-bit digital images. Also, it was shown in [2] that DAC is an effective image compression tool. In this paper, classic test images and classic aerial test images were used. It follows from the obtained results that DAC provides higher compression ratio than the JPEG

ISSN 1814-4225 (print).
ISSN 2663-2012 (online)

algorithm with the same quality of results. We used such modes of these algorithms that do not provide minimal loss of quality. Although, in each case, the differences between the original image and the corresponding decompressed image are invisible or hard to see.

The aim of this paper is to investigate the efficiency of DAC with settings that provide the maximal quality of the result.

1. Formulation of the problem

In the current research, we use the computer program "Discrete Atomic Compression: User Kit" with the mode "Almost Lossless Compression" [4]. Using this software, we compress the classic test images (Lena, baboon, peppers etc.) and the classic aerial images [5].

The main task of this paper is to evaluate memory savings and loss of quality for each test image.

To determine the effectiveness of the DAC algorithm, we use the compression ratio and metrics of quality loss. The compression ratio (CR) is defined by the formula

$$CR = \frac{\text{size of original image}}{\text{size of compressed image}}.$$

Using this value, we also can obtain a percentage of memory savings (PMS)

$$PMS = \left(1 - \frac{1}{CR}\right) \cdot 100\%.$$

We note that evaluation of the quality of the result is extremely subjective.

Further we use the following metrics of the difference between the source data $x = (x_1, x_2, ..., x_n)$ and the data $y = (y_1, y_2, ..., y_n)$ obtained during the processing:

1) the uniform metric (U-metric)

$$U = \max_{i=1,2,...,n} |x_i - y_i|;$$

2) the root mean square metric (RMS-metric)

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2};$$

3) peak-to-peak signal-to-noise ratio (PSNR-metric)

$$PSNR = 20 \cdot \log_{10} \frac{\max}{RMS}$$

(in the current research, max=255).

High dependence on even minor local changes is an important feature of the uniform metric U. It is obvious that if U is small, then all changes, which were obtained during the process of compression and decompression, are minor. For this reason, this measure is major in the study of the almost lossless compression. Two other metrics provide estimation of the average loss of quality.

A more comprehensive analysis of quality loss can be carried out by studying the distribution of difference between pixels of the original image and the corresponding pixels of the reconstructed image. Consider the function

$$f(k) = \frac{n(k)}{N},$$

where N is the total number of pixels and n(k) is the number of the reconstructed image pixels whose variation from the corresponding pixels of the original image equals k. This function in combination with the metrics U, RMS and PSNR is the main tool for analyzing loss of quality.

In the next sections, we present and discuss the results of compression of the test images.

2. Almost lossless compression using DAC

The DAC algorithm is based on atomic functions $up_s(x)$. The feasibility of this approach was shown in [6]. Further, in [7], discrete atomic transform (DAT), which is the core of DAC, was introduced. This procedure provides the implementation of all useful properties of atomic functions in data processing and especially in image compression.

DAT is an operator that associates the source data $d = (d_1, ..., d_n)$ to the set of values $\omega = (\omega_1, ..., \omega_n)$ called DAT-coefficients. Analysis and processing of the source data can be carried out by analyzing and processing the correspondent DAT-coefficients. All advantages of such an approach are presented in [7].

The figure 1 shows the main steps of DAC.

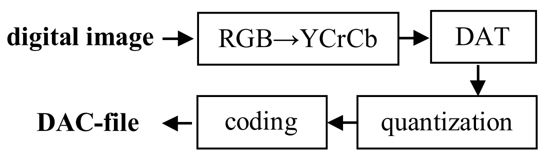

Fig. 1. Discrete atomic compression of digital image

As it can be seen, DAC is based on the classical scheme: preliminary processing → discrete transform → quantization → coding (this image compression model is well described in chapter 8 of [8]). This principle is used in the JPEG algorithm [9], which is the most popular algorithm for compression of digital photos, and the JPEG2000 algorithm [10]. Besides, it is applied to medical image compression [11] and chaotic image compression encryption technology [12].

The tables 1 and 2 show the results of processing of the test images using almost lossless mode of DAC.

More detailed analysis of quality loss is presented in the tables 3 – 6.

All files used in this study are available at https://drive.google.com/drive/folders/1yXjs2BHmKw6pRi-_me-r1F-ViNdY2dCJ?usp=sharing.

Table 1

Compression of the classic test images

No	**Original image**		**DAC "Almost Lossless Compression"**					
	name	size, kB	size, kB	CR	PMS, %	loss of quality		
						U	RMS	PSNR
1	baboon	769	735	1,046258503	4,42132639	8	1,21640	46,42927538
2	Barbara	1216	626	1,942492013	48,51973684	9	1,21546	46,43599019
3	boats	1330	513	2,592592593	61,42857143	8	1,17136	46,75699582
4	cablecar	721	344	2,095930233	52,28848821	7	1,17042	46,76396892
5	cornfield	721	406	1,775862069	43,68932039	10	1,18209	46,67779274
6	f16	769	333	2,309309309	56,69700910	8	1,19353	46,59413681
7	flowers	531	350	1,517142857	34,08662900	8	1,20695	46,49701803
8	fruits	721	343	2,102040816	52,42718447	9	1,21238	46,45802834
9	goldhill	1216	606	2,006600660	50,16447368	8	1,21398	46,44657297
10	Lena	769	379	2,029023747	50,71521456	8	1,22126	46,39464095
11	monarch	1153	400	2,882500000	65,30789245	9	1,14618	46,94574709
12	peppers	769	414	1,857487923	46,16384915	7	1,21311	46,45279995
13	sailboat	769	508	1,513779528	33,94018205	8	1,21890	46,41144207
14	splash	769	296	2,597972973	61,50845254	8	1,20767	46,49183805
15	Tiffany	769	378	2,034391534	50,84525358	8	1,16178	46,82832569
average				**2,020225651**	**47,48023892**	**8,2**	**1,19676**	**46,57230487**
min				**1,046258503**	**4,42132639**	**7**	**1,14618**	**46,39464095**
max				**2,882500000**	**65,30789245**	**10**	**1,22126**	**46,94574709**

Table 2

Compression of the classic aerial images

No	**Original image**		**DAC "Almost Lossless Compression"**					
	name	size, kB	size, kB	CR	PMS, %	loss of quality		
						U	RMS	PSNR
1	Earth	769	425	1,809323993	44,73342003	8	1,22213	46,38845551
2	Foster City	769	459	1,669928021	40,31209363	8	1,21846	46,41457808
3	Oakland	3073	1607	1,912321346	47,70582493	8	1,22066	46,39890934
4	San Diego 1	769	622	1,235643732	19,11573472	8	1,22670	46,35603630
5	San Diego 2	769	497	1,546529440	35,37061118	9	1,21915	46,40966075
6	San Diego 3	769	385	1,998922367	49,93498049	8	1,22224	46,38767376
7	San Diego 4	3073	2370	1,296329477	22,87666775	8	1,20916	46,48112817
8	San Diego 5	3073	1579	1,945743036	48,61698666	8	1,22066	46,39890934
9	San Diego 6	3073	2155	1,425615638	29,87308819	8	1,21977	46,40524465
10	San Francisco 1	769	405	1,896838145	47,33420026	7	1,21267	46,45595093
11	San Francisco 2	3073	1619	1,897806934	47,31532704	8	1,19967	46,54956764
12	San Francisco 3	3073	1777	1,729200335	42,17377156	8	1,20832	46,48716433
13	San Francisco 4	3073	2218	1,385301749	27,82297429	8	1,21806	46,41742998
14	San Francisco 5	3073	2141	1,435042274	30,32866905	8	1,22078	46,39805550
15	Stockton 1	3073	1816	1,692115786	40,90465343	8	1,21586	46,43313219
16	Stockton 2	3073	1824	1,684465804	40,64432151	8	1,21961	46,40638408
17	Stockton 3	3073	1808	1,699652806	41,16498536	8	1,22133	46,39414311
average				**1,662398875**	**38,60166530**	**8**	**1,21737**	**46,42249551**
min				**1,235643732**	**19,11573472**	**7**	**1,19967**	**46,35603630**
max				**1,998922367**	**49,93498049**	**9**	**1,22670**	**46,54956764**

ISSN 1814-4225 (print).
ISSN 2663-2012 (online)

Table 3

Loss of quality: the distribution of differences between pixels. The classic test images, part 1

k	f(k)							
	baboon	**Barbara**	**boats**	**cablecar**	**cornfield**	**f16**	**flowers**	**fruits**
0	0,04259110	0,04295670	0,05627250	0,05276290	0,04681400	0,04669190	0,04522100	0,04377850
1	0,48899800	0,49047800	0,50920300	0,52220900	0,51208900	0,50313900	0,49138100	0,49125600
2	0,35786400	0,35468500	0,33782300	0,32895500	0,34439300	0,34820200	0,35504400	0,35491500
3	0,09272770	0,09334730	0,08249950	0,08123780	0,08194580	0,08637620	0,09106080	0,09226890
4	0,01546860	0,01620610	0,01258960	0,01287430	0,01291500	0,01359940	0,01527620	0,01540930
5	0,00201035	0,00208333	0,00146698	0,00172933	0,00159912	0,00173569	0,00178453	0,00205485
6	0,00028229	0,00021701	0,00013236	0,00020345	0,00020345	0,00023270	0,00020995	0,00028483
7	5,34E-05	2,17E-05	1,10E-05	2,85E-05	2,85E-05	1,91E-05	1,10E-05	2,44E-05
8	3,81E-06	0	2,21E-06	0	8,14E-06	3,81E-06	1,10E-05	4,07E-06
9	0	4,82E-06	0	0	0	0	0	4,07E-06
10	0	0	0	0	4,07E-06	0	0	0
11	0	0	0	0	0	0	0	0
>11	0	0	0	0	0	0	0	0

Table 4

Loss of quality: the distribution of differences between pixels. The classic test images, part 2

k	f(k)						
	goldhill	**Lena**	**monarch**	**peppers**	**sailboat**	**splash**	**Tiffany**
0	0,04284820	0,04209900	0,05376180	0,04740910	0,04259870	0,04525380	0,06578450
1	0,49018600	0,48700700	0,53701300	0,48584700	0,48698400	0,49289700	0,49826000
2	0,35701200	0,35754000	0,32715400	0,35435900	0,35762800	0,35299700	0,33242800
3	0,09236830	0,09456250	0,07091270	0,09382250	0,09443660	0,09113310	0,08614730
4	0,01529220	0,01638030	0,00993856	0,01619720	0,01601410	0,01517490	0,01512910
5	0,00204716	0,00211716	0,00108846	0,00210571	0,00212860	0,00223541	0,00203705
6	0,00022666	0,00025559	0,00011190	0,00024414	0,00017929	0,00025940	0,00017166
7	1,45E-05	3,05E-05	1,53E-05	1,53E-05	2,29E-05	4,58E-05	3,43E-05
8	4,82E-06	7,63E-06	2,54E-06	0	7,63E-06	3,81E-06	7,63E-06
9	0	0	2,54E-06	0	0	0	0
10	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
>11	0	0	0	0	0	0	0

Table 5

Loss of quality: the distribution of differences between pixels. The classic aerial images, part 1

k	f(k)							
	Earth	**Foster city**	**Oakland**	**San Diego1**	**San Diego2**	**San Diego3**	**San Diego4**	**San Diego5**
0	0,04190440	0,04193500	0,04203220	0,04145810	0,04188920	0,04150770	0,04559900	0,04200360
1	0,48611800	0,48713700	0,48636000	0,48236500	0,48694600	0,48531700	0,48933200	0,48730100
2	0,35854700	0,35866200	0,35854100	0,36127500	0,35958900	0,35937500	0,35449600	0,35757800
3	0,09483340	0,09444050	0,09451960	0,09600450	0,09337230	0,09526440	0,09264370	0,09490110
4	0,01613240	0,01579280	0,01618100	0,01647950	0,01602550	0,01614000	0,01564790	0,01583580
5	0,00220108	0,00186920	0,00208187	0,00207901	0,00195313	0,00214767	0,00202656	0,00207520
6	0,00023651	0,00015259	0,00026035	0,00030899	0,00017929	0,00022125	0,00021935	0,00027084
7	2,29E-05	3,81E-06	2,00E-05	2,29E-05	3,43E-05	1,91E-05	3,15E-05	3,05E-05
8	3,81E-06	7,63E-06	4,77E-06	7,63E-06	7,63E-06	7,63E-06	3,81E-06	3,81E-06
9	0	0	0	0	3,81E-06	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
>11	0	0	0	0	0	0	0	0

Table 6

Loss of quality: the distribution of differences between pixels. The classic aerial images, part 2

k	f(k)								
	San Diego6	**San Fran-cisco1**	**San Fran-cisco2**	**San Fran-cisco3**	**San Fran-cisco4**	**San Fran-cisco5**	**Stock-ton1**	**Stock-ton2**	**Stock-ton3**
0	0,0421114	0,0442581	0,0442104	0,0429630	0,0421381	0,0422058	0,0424204	0,0421171	0,042406
1	0,4860550	0,4898410	0,4997080	0,4945230	0,4874360	0,4859630	0,4892440	0,4868580	0,486005
2	0,3595030	0,3557700	0,3524550	0,3553660	0,3583210	0,3587230	0,3572160	0,3584540	0,357903
3	0,0945873	0,0926285	0,0874720	0,0903444	0,0943747	0,0947676	0,0932684	0,0943613	0,095200
4	0,0155869	0,0153313	0,0142670	0,0148525	0,0154858	0,0160923	0,0156298	0,0159044	0,016183
5	0,0019149	0,0019111	0,0016698	0,0017366	0,0020237	0,0019989	0,0019769	0,0020303	0,002032
6	0,0002203	0,0002250	0,0001917	0,0001964	0,0001974	0,0002317	0,0002222	0,0002450	0,000240
7	1,91E-05	3,43E-05	2,29E-05	1,72E-05	2,10E-05	1,62E-05	1,91E-05	2,48E-05	2,67E-05
8	1,91E-06	0	2,86E-06	9,54E-07	1,91E-06	1,91E-06	3,81E-06	4,77E-06	2,86E-06
9	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
> 10	0	0	0	0	0	0	0	0	0

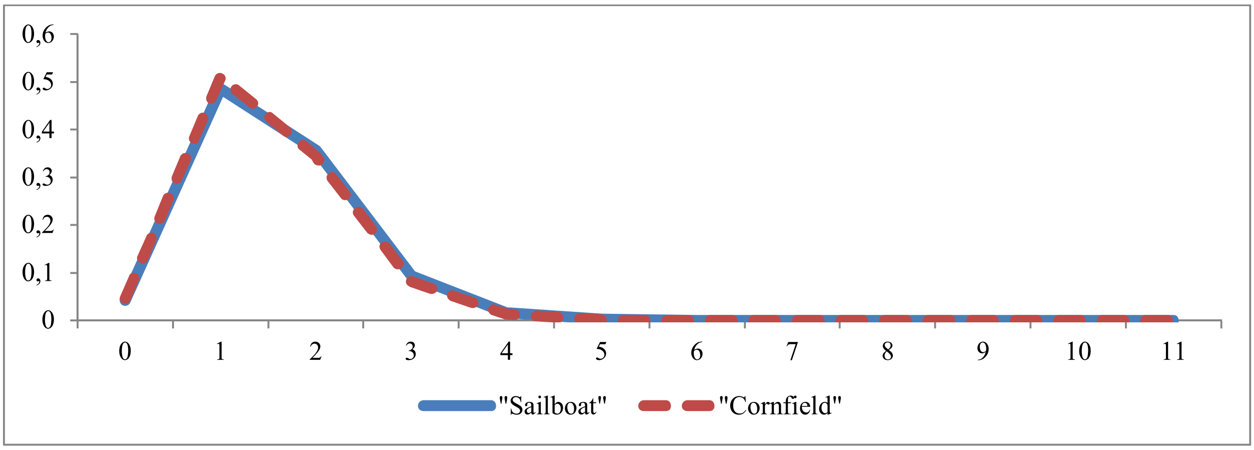

Fig. 2. Graphs of the distribution functions for the test images "Sailboat" and "Cornfield"

3. Discussion of the results

It follows that, in terms of U-metric and RMS-metric, loss of quality in the processing of the test images "Sailboat" and "Cornfield" are the smallest and the largest, respectively. However, if we compare the corresponding distribution functions, we see that the difference between the results is extremely minor (see figure 2). Hence, loss of quality is quite stable and, therefore, predictable.

The value of the compression ratio as well as the loss of quality significantly depends on the image. The smallest and the largest CR-values are obtained when processing the test images "Baboon" and "Monarch", respectively. First of all, this is due to the smoothness of the color change (see figures 3, 4). This feature is typical for algorithms based on the use of smooth functions (see [7] for more details). Nevertheless, application of DAC provides memory savings. Note that the total size of the source images is 51409 kB. The total size of DAC-files, which were obtained using almost lossless mode of DAC, equals 30338 kB. This means that approximately 40,98 percent of the memory has been saved.

Another useful feature of DAC-files is the possibility of their additional compression using the ZIP algorithm. Applying this algorithm, we get an archive of size 25870 kB. In other words, ZIP compression of DAC-files is efficient (fig. 5).

Conclusions

From the presented results, it follows that the almost lossless compression mode of DAC provides sufficiently stable values of quality loss metrics. Their values indicate small loss of quality. It is clear that the quality of the result and the size of the saved memory are inversely related. Despite the high quality, DAC

ISSN 1814-4225 (print).
ISSN 2663-2012 (online)

provides relatively high compression ratio. Since ZIP compression of DAC-files is useful, there exists a possibility of further optimization of the DAC algorithm. Hence, further research and development of this algorithm are promising.

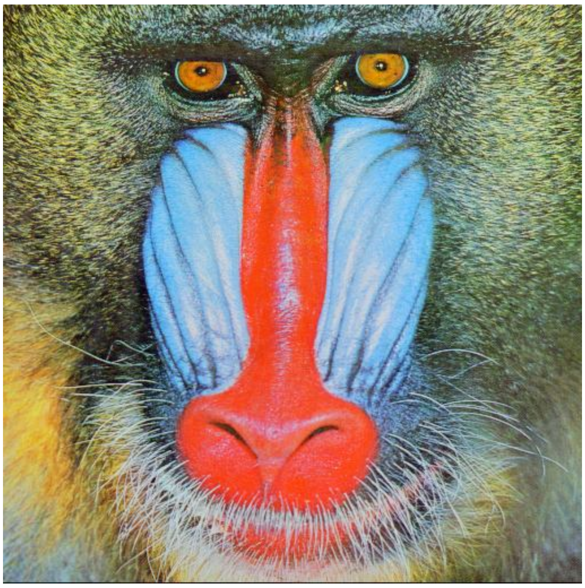

Fig. 3. The test image "Baboon". This image contains a huge number of sharp color changes

Fig. 4. The test image "Monarch". This image contains large areas with smooth color changes

It should be mentioned that the following problems are of interest:

1) compression of JPEG images using the DAC algorithm (this problem is of particular interest, since the JPEG algorithm is de facto the standard for compression of digital photos);

2) compression of special classes of digital images, such as medical images, using DAC;

3) development of algorithms for recognition of DAC-images;

4) watermarking of DAC images;

5) DAC-files protection;

6) application of the DAC algorithm to video compression.

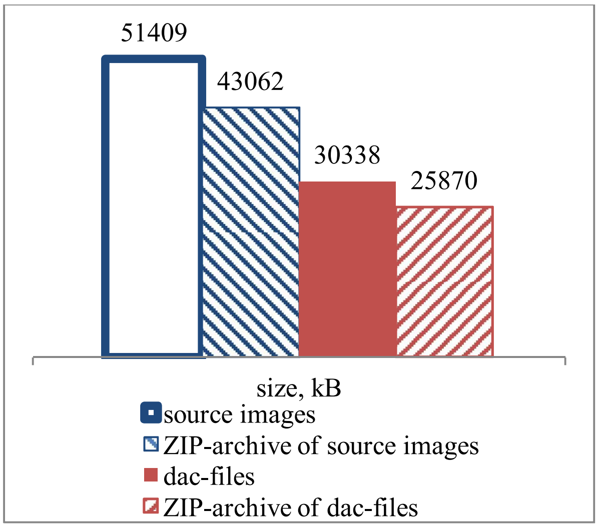

Fig. 5. Size of the test data and the processing results

It is clear that each of these problems is a separate direction for the further development of the technology presented in this article.

Acknowledgement. The authors are grateful to professor V. A. Rvachev for his attention to their research.

References (GOST 7.1:2006)

1. Sayood, K. Introduction to data compression [Text] / K. Sayood. – 5th edition. – Morgan Kaufman, 2017. – 790 p.

2. Brysina, I. V. Discrete atomic compression of digital images [Text] / I. V. Brysina, V. O. Makarichev // Radioelectronic and Computer Systems. – 2018. – No. 4 (88). – P. 17-33. Doi: 10.32620/reks.2018.4.02.

3. Rvachev, V. A. Compactly supported solutions of functional-differential equations and their ap plications [Text] / V. A. Rvachev // Russian Math. Surveys. – 1990. – Vol. 45, No. 1. – P. 87 – 120.

4. Свідоцтво про реєстрацію авторського права на твір № 83047. Комп'ютерна програма «Discrete Atomic Compression: User Kit» [Текст] / Макарічев В. О. – № 83954 ; заявл. 01.10.2018 ; реєстр. 23.11.2018.

5. The USC-SIPI image database [electronic resource]. – Access mode: http://sipi.usc.edu/database/. – 10.02.2019.

6. Makarichev, V. O. Application of atomic functions to lossy image compression [Text] / V. O. Makarichev // Theoretical and applied aspects of cybernetics. Proceedings of the 5th International scientific conference of students and young scientists. – Kyiv : Bukrek, 2015. – P. 166-175.

7. Brysina, I. V. Atomic functions and their generalizations in data processing: function theory approach

[Text] / I. V. Brysina, V. O. Makarichev // Radioelectronic and Computer Systems. – 2018. – No. 3 (87). – P. 4-10. Doi: 10.32620/reks.2018.3.01

8. Gonzalez, R. C. Digital image processing [Text] / R. C. Gonzalez, R. E. Woods. – 4th edition. – Paerson, 2017. – 1168 p.

9. Pennebaker, W. B. JPEG: Still image data compression standard [Text] / W. B. Pennebaker, J. L. Mitchell. – Springer, 1993. – 638 p.

10. Taubman, D. JPEG2000: image compression fundamentals, standards and practice [Text] / D. Taubman, M. Marcelin. – Springer, 2002. – 777 p.

11. Baraskar, T. The compression of digital imaging and communications in medicine images using wavelet coefficients thresholding and arithmetic encoding technique [Text] / T. Baraskar, V. Mankar // WSEAS Transactions on Signal Processing. – 2018. – Vol. 14. – P. 160-169.

12. Li, Z. Design and implementation in image compression encryption of digital chaos based on MATLAB [Text] / Z. Li, X. Sun, Q. Ding // Intelligent data analysis and its applications, Volume II. Advances in intelligent systems and computing / JS Pan, V. Snasel, E. Corchado, A. Abraham, SL. Wang (eds). – Springer, Cham, 2014. – Vol. 298. – P. 509-518.

References (BSI)

1. Sayood, K. *Introduction to data compression,* Morgan Kaufman, 5th edition, 2017. 790 p.

2. Brysina, I. V., Makarichev, V. A. Discrete atomic compression of digital images. *Radioelectronic and Computer Systems*, 2018, vol. 88, no. 4, pp. 17-33. doi: 10.32620/reks.2018.4.02.

3. Rvachev, V. A. Compactly supported solutions of functional-differential equations and their applications. *Russian Math. Surveys*, 1990, vol. 45, no. 1, pp. 87-120.

4. Makarichev, V. O. *Discrete Atomic Compression: User Kit.* The Certificate on official registration of the computer program copyright, no. 83047, 2018.

5. *The USC-SIPI image database*. Available at: http://sipi.usc.edu/database/. (accessed 10.02.2019).

6. Makarichev, V. O. Application of atomic functions to lossy image compression. *Theoretical and applied aspects of cybernetics. Proceedings of the 5th International scientific conference of students and young scientists.* Kyiv,"Bukrek" Publ., 2015, pp. 166-175.

7. Brysina, I. V., Makarichev, V. A. Atomic functions and their generalizations in data processing: function theory approach. *Radioelectronic and Computer Systems,* 2018, vol. 87, no. 3, pp. 4-10. doi: 10.32620/reks.2018.3.01.

8. Gonzalez, R. C., Woods, R. E. *Digital image processing,* Paerson, 4th edition, 2017. 1168 p.

9. Pennebaker, W. B., Mitchell, J. L. *JPEG: Still image data compression standard,* Springer, 1993. 638 p.

10. Taubman, D., Marcelin, M. *JPEG2000: image compression fundamentals, standards and practice*, Springer, 2002. 777 p.

11. Baraskar, T., Mankar, V. The compression of digital imaging and communications in medicine images using wavelet coefficients thresholding and arithmetic encoding technique. *WSEAS Transactions on Signal Processing*, 2018, vol. 14, pp. 160-169.

12. Li, Z., Sun, X., Ding, Q. Design and implementation in image compression encryption of digital chaos based on MATLAB. In: Pan JS., Snasel V., Corchado E., Abraham A., Wang SL. (eds) *Intelligent Data analysis and its Applications, Volume II. Advances in Intelligent Systems and Computing*. Springer, Cham, 2014, vol. 298, pp. 509-518.

Поступила в редакцию 10.01.2019, рассмотрена на редколлегии 15.03.2019

ДИСКРЕТНЕ АТОМАРНЕ СТИСНЕННЯ ЦИФРОВИХ ЗОБРАЖЕНЬ: СТИСНЕННЯ МАЙЖЕ БЕЗ ВТРАТ

І. В. Брисіна, В. О. Макарічев

У роботі розглянуто проблему стиснення цифрових зображень за умови наявності високих вимог до якості результату. Безумовно, у цьому випадку можна скористатися алгоритмами стиснення без втрат якості. Через те, що стиснення з втратами якості дозволяє отримати більш високий коефіцієнт стиснення та економію пам'яті, ніж алгоритми стиснення без втрат, ми пропонуємо використання алгоритмів з втратами з налаштуваннями, що гарантують найменші втрати якості. **Предметом** вивчення статті є стиснення майже без втрат якості кольорових 24-бітних цифрових зображень з використанням дискретного атомарного стиснення (ДАС), що є алгоритмом, основаним на використанні дискретного атомарного перетворення. **Метою** є дослідження коефіцієнту стиснення та показників втрат якості таких, як рівномірна (U) та середньоквадратична (RMS) метрики, а також відношення сигнал-шум (PSNR). Ми також досліджуємо розподіл відхилення пікселів вихідного зображення від відповідних пікселів відновленого зображення. У цьому дослідженні ми використовуємо класичні тестові зображення та класичні аерофотознімки. U-метрика, що значно залежить навіть від незначних локальних змін, розглядається у якості основного індикатору втрат якості. **Завдання**: оцінити економію пам'яті та втрати якості для кожного тестового зображення. У даній роботі ми використовуємо **методи** цифрової обробки зображень, теорії атомарних функцій та теорії наближень. У даному дослідженні використано комп'ютерну програму "Discrete Atomic Compression: User Kit" у режимі "Almost Lossless Compression". Отримано наступні **результати**: 1) різниця між найменшими та найбільшими втратами є незначною; 2) втрати якості є стійкими та передбачуваними; 3) коефіцієнт стиснення залежить від гладкості

ISSN 1814-4225 (print).
ISSN 2663-2012 (online)

змін кольору (найменше та найбільше значення було отримано при обробці тестових зображень відповідно з найбільшою та найменшою кількістю малих деталей на зображенні); 4) використання ДАС дає економію пам'яті у розмірі 59 відсотків; 5) ZIP-стиснення ДАС-файлів, що містять оброблені за допомогою ДАС зображення, є ефективним. **Висновки**: 1) стиснення майже без втрат за допомогою алгоритму ДАС забезпечує стійкі значення індикаторів втрат якості; 2) ДАС забезпечує достатньо високий коефіцієнт стиснення; 3) подальша оптимізація алгоритму ДАС є можливою; 4) подальший розвиток та дослідження ДАС є перспективними.

Ключові слова: атомарна функція; дискретне атомарне стиснення; дискретне атомарне перетворення; стиснення майже без втрат.

ДИСКРЕТНОЕ АТОМАРНОЕ СЖАТИЕ ЦИФРОВЫХ ИЗОБРАЖЕНИЙ: СЖАТИЕ ПОЧТИ БЕЗ ПОТЕРЬ

И. В. Брысина, В. А. Макаричев

В роботе рассмотрена проблема сжатия цифровых изображений при условии наличия высоких требований к качеству результата. Несомненно, в этом случае можно использовать алгоритмы сжатия без потерь качества. Так как сжатие с потерями качества позволяет получить более высокий коэффициент сжатия и экономию памяти, чем алгоритмы сжатия без потерь, мы предлагаем использовать сжатие с потерями с настройками, которые гарантируют получение минимальных потерь качества. **Предметом** изучения статьи является сжатие почти без потерь полноцветных 24-битных цифровых изображений с использованием дискретного атомарного сжатия (ДАС), которое является алгоритмом, основанным на применении дискретного атомарного преобразования. **Целью** является исследование коэффициента сжатия и таких показателей потерь качества, как равномерная (U) и среднеквадратическая (RMS) метрики, а также отношение сигнал-шум (PSNR). Мы также исследуем распределение отклонения пикселей исходного изображения от соответствующих пикселей восстановленного изображения. В данном исследовании мы используем классические тестовые изображения и классические аэрофотоснимки. U-метрика, которая в значительной мере зависит даже от незначительных локальных изменений, рассматривается как основной индикатор потерь качества. **Задание**: оценить экономию памяти и потерь качества для каждого тестового изображения. В данной работе мы используем **методы** цифровой обработки изображений, теории атомарных функций та теории приближений. В данном исследовании использована компьютерная программа "Discrete Atomic Compression: User Kit" в режиме "Almost Lossless Compression". Получены следующие **результаты**: 1) разница между наименьшими та наибольшими потерями является незначительной; 2) потери качества являются устойчивыми и предсказуемыми; 3) коэффициент сжатия зависит от гладкости изменения цвета (наименьшее и наибольшее значение было получено при обработке тестовых изображений соответственно с наибольшим и наименьшим числом мелких деталей на изображении); 4) применение ДАС дает экономию памяти в размере 59 процентов; 5) ZIP-сжатие ДАС-файлов, которые содержат обработанные с помощью ДАС изображения, является эффективным. **Выводы**: 1) сжатие почти без потерь с помощью алгоритма ДАС обеспечивает устойчивые значения индикаторов потерь качества; 2) ДАС обеспечивает достаточно высокий коэффициент сжатия; 3) дальнейшая оптимизация алгоритма ДАС является возможной; 4) дальнейшее развитие и исследование алгоритма ДАС является перспективным.

Ключевые слова: атомарная функция; дискретное атомарное сжатие; дискретное атомарное преобразование; сжатие почти без потерь.

Брысина Ирина Викторовна – канд. физ.-мат. наук, доцент, доцент кафедры высшей математики и системного анализа, Национальный аэрокосмический университет им. Н. Е. Жуковского «Харьковский авиационный институт», Харьков, Украина.

Макаричев Виктор Александрович – канд. физ.-мат. наук, доцент кафедры высшей математики и системного анализа, Национальный аэрокосмический университет им. Н. Е. Жуковского «Харьковский авиационный институт», Харьков, Украина.

Brysina Iryna Victorivna – PhD in Physics and Mathematics, Associate Professor of Higher Mathematics and System Analysis Chair, National Aerospace University "Kharkov Aviation Institute", Kharkov, Ukraine, e-mail: iryna.brysina@gmail.com.
Scopus Author ID: 6507678966, ZbMath ID: https://zbmath.org/authors/?q=ai%3Abrysina.iryna-v

Makarichev Victor Olexandrovych – PhD in Physics and Mathematics, Associate Professor of Higher Mathematics and System Analysis Chair, National Aerospace University "Kharkov Aviation Institute", Kharkov, Ukraine, e-mail: victor.makarichev@gmail.com.
Scopus Author ID: 41761910800, ZbMath ID: https://zbmath.org/authors/?q=ai%3Amakarichev.victor-a,
Orcid Author ID: 0000-0003-1481-9132.