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SIMPLE ALGORITHM OF WAVELET-COMPRESSION OF HALFTONE AND COLOUR IMAGES

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Simple algorithm of wavelet-compression allowing realizing inexpensive hardware and software platforms for closed circuits and processing systems of high definition television in real time has been developed.

Introduction

Standard of shrinking digital images JPEG2000 on the basis of wavelet transform is one of the most perspective ones. It consists of two extensive parts (JPEG2000 Part I, JPEG2000 Part II). In the range of the standard there is a majority of software implementations (ACDSee, LeadTools, Mjp2000, Jasper, Lurawave etc.) differed significantly in degree and rate of shrinking images [1, 2]. Implementation of JPEG2000 from ACDSee according to [1] possesses the best characteristics: rate of shrinking, degree of shrinking and quality of reconstructed image (further in the article at the mention of standard JPEG2000 implementation from ACDSee is considered). JPEG2000 gains obviously in 20...25 % as a reconstructed image by the metric PSNR [2, 3] (at equal shrinking ratio) relative to common JPEG. The main reason of restricted distribution of JPEG2000 is a complicity of software implementation and as a result low shrinking rate. Shrinking process duration is caused to a large extent by complicity of sampling stages, block coding and output stream arrangement occupying about 80 % of the total compression time [2]. Therefore, on the basis of the first and he second parts of the standard JPEG2000 (Part I, Part II) a simpler and quicker algorithm of wavelet compression QWC (Quick Wavelet Compress, authors name) possessing practically equal JPEG2000 quality of recovered image (at equal degree of shrinking) was developed.

Shrinking algorithm QWC

Algorithm QWC has shrinking diagram similar to the standard JPEG2000 (Fig. 1).

Stages of preprocessing and wavelet transform of the standard JPEG2000 and algorithm QWC coincide. According to the standard JPEG2000 input image preprocessing consists in adjustment of values of color component of RGB pixels relative to zero. Image preprocessing occurs only in the case if values of color component of RGB pixels are in the range of $[0,2^N-1]$ (where N is the capacity of color components bit of RGB or brightness of image pixels) then value of each color component of RGB pixels decreases by 2^{N-1}:

$$P_{i,j} = \begin{Bmatrix} P_{i,j},\ P_{i,j} \subset [-2^{N/2}, 2^{N/2}-1] \\ P_{i,j} - 2^{N-1},\ P_{i,j} \subset [0, 2^N - 1] \end{Bmatrix},$$

where $P_{i,j}$ is the value of one of color components of RGB or image pixel brightness, i,j are the coordinates of pixel in image matrix.

The next stage of algorithm is wavelet transform [2]. Standard establishes two possible variants of transformation according to the part I:

- integer transformation 5/3 used for lossless compression;
- irrational transformation 9/7 used for lossy compression.

In comparison with standard JPEG2000 where even scalar quantizer is used, in algorithm QWC sub-band scalar quantizer with different sampling coefficients for sub-bands (levels) of high-frequency wavelet coefficients is used. Application of uneven quantizer increases quality of reconstructed image at permanent degree of shrinking regardless of applied wavelet transform [4].

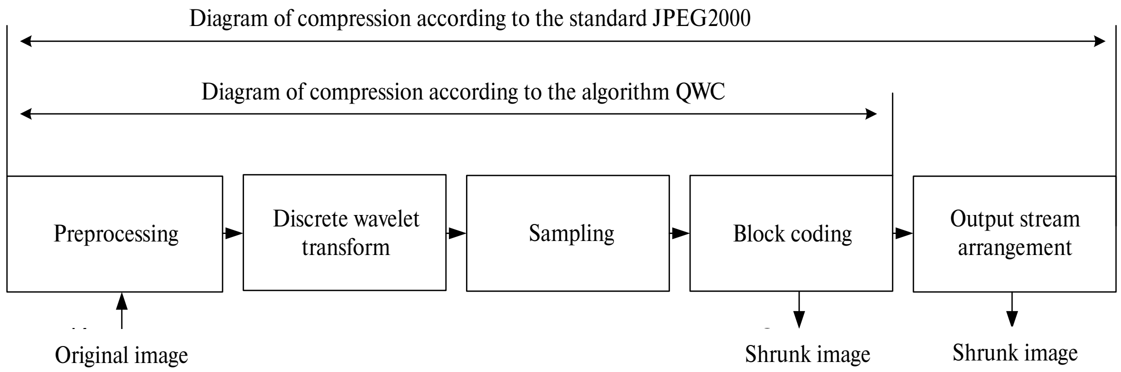

Fig. 1. *Diagram of image compression of the standard JPEG2000 and algorithm QWC*

On the basis of wavelet transform specification it is considered that energy of high-frequency (HF) sub-bands HL_1, HH_1, LH_1 (Fig. 2) describes the smallest details of image which are badly perceived by a man, therefore, the coefficient of scalar sampling for these sub-bands may be rather high, for example specified by a user [4, 5].

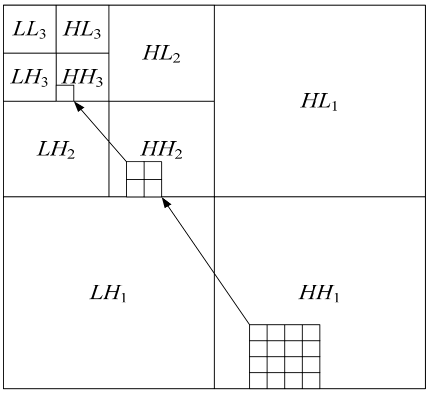

Fig. 2. *Shift of signal energy presented by the image per three steps of wavelet transform*

Sub-bands LH_2, HH_2, HL_2 describe larger details and possess higher energy value, therefore, sampling coefficient for these bands should be lower, otherwise, losses at image reconstruction are more significant than at previous levels HL_1, HH_1, LH_1. For sub-bands of higher level (HL_3, HH_3, LH_3 etc.) the process is similar:

$$Q_1 > Q_2 > Q_3 ... Q_n,$$

where Q is the sampling coefficient, n is the step of wavelet transform.

It should be noted that for the ranges $HH_1, HH_2 ... HH_n$ coefficient of scalar sampling may be considerably higher than for sub-bands $LH_1 ... LH_n$ and $HL_1 ... HL_n$ due to weak pixel correlation bias and coefficients of sub-band HH_1 may be zeroed without significant losses in quality [2, 4, 6].

The above mentioned interaction of energy distribution among HF sub-bands allows constructing sub-band scalar quantizer with irregular pitch of sampling coefficient and supporting image reconstruction more detailed than at application of quantizer with one sampling coefficient. Unfortunately, a question of dependence of sub-band energy or a way of obtaining sampling coefficients for sub-bands is rather complicated and not well covered at the moment in modern scientific literature. The only indication of dependence between sub-band coefficients in scientific literature is that energy growth from each (n–1) band to n band depends only on the band (n–1) for pyramidal expansion, Fig. 2. Then it is appropriate to suppose that dependence of sampling coefficients is similar that is coefficient for n sub-band is calculated of the coefficient of (n–1) sub-band [7]. It is obvious that sampling coefficient Q depends for each band not only on sampling coefficient of the previous sub-band but on a concrete shrunk image, therefore, for simplicity of implementation and high rate of sampling only the dependence between sampling coefficients was kept and correction coefficients L was introduced:

$$Q_i = L\, Q_{i-1},$$

where i is the level of coefficient expansion or wavelet transform.

In algorithm of shrinking QWC as well as in standard JPEG2000 the main parameter at shrinking which a user indicates is either compression ratio or a size of compressed file that is a user may indicate only one parameter for image shrinking – compression ratio K_c. But the compression ratio is not the only parameter participating in sampling and arithmetical shrinking the sampling coefficient Q and correcting coefficient L should be also specified. As the user specifies only the compression ratio (file size) then the dependence of sampling coefficient Q and correction coefficient L on compression coefficient K_c should be determined. Theoretical defining of coefficients Q and L is rather complicated process, therefore, to simplify obtaining coefficients K_c, Q and L the experiment was carried out.

Experiment

The aim of carrying out the experiment is to obtain four experimental dependences (value arrays) of coefficients к Q and L depending on K_c and giving the best quality of reconstructed image, that is, it is necessary to obtain two arrays of values of coefficients Q and L for halftone and color images.

Thus, for each value of compression ratio K_c it is necessary to determine experimentally an optimal pair of values of coefficients Q and L giving the best quality of reconstructed image.

The initial data for the experiment:

- five master images of a set of color images Calgary Corpus with color depth 24 bits per a pixel and five halftone images with depth of 8 bits per a pixel obtained by lossless conversion from original color ones 8 (images are selected subject to their reality);
- compression ratio interval for color images $K_c \in [8, 200]$, for halftone images $K_c \in [4, 200]$, step 1;
- interval of sampling coefficient Q for halftone and color images $Q \in [4, 60]$, step 1;
- interval of correction coefficient L for halftone and color images $L \in [10, 99]$, step 1;
- down-sampling coefficient for color components 1:8:8 (only for color images) [4].

Extreme values of coefficients K_c, Q and L intervals were preliminary obtained experimentally.

Quality of reconstructed image was determined by metric PSNR* [3]:

* Use of estimation method of PSNR quality is justified by the fact that application of more exact methods of estimation, for example, VQM [3] or SSIM [3] is complicated as the initial files or binary libraries of techniques are implemented for OS Windows(r) family and their use at TPU cluster is not possible, the cluster is controlled by OS Linux(r) SuSe(r) in console mode.

$$\mathrm{PSNR}(x,y) = 10\log_{10}\frac{255^2 nm}{\sum_{i=1,j=1}^{n,m}(x_{i,j}-y_{i,j})^2},$$

where n, m is the amount of signal samples, x are the samples of original, initial signal for compression, y are the samples of unpacked, regenerated signal.

Compression ratio K_c was determined by the formula:

$$K_c = \frac{S_o}{S_c},$$

where S_o and S_c are the volumes of initial and shrunk image.

To carry out the experiment and determine four arrays of values of coefficients Q and L the program defining the most optimal ratios of coefficients K_c, Q and L at a set of master images was developed for TPU «SKIF-Politekh». Use of TPU cluster is justified by a large volume of calculations and simplicity of computation parallelization, for example, for the experiment on halftone images the initial data are as follows:

- amount of master images 5 (halftone);
- interval of compression ratio $K_c \in [4, 200]$, step 1;
- interval of sampling coefficient $Q \in [4, 60]$, step 1;
- interval of correction coefficient $L \in [10, 99]$, step 1.

For the experiment on color images the initial data are:

- amount of master images 5 (color);
- interval of compression ratio $K_c \in [8, 200]$, step 1;
- interval of sampling coefficient $Q \in [4, 60]$, step 1;
- interval of correction coefficient $L \in [10, 99]$, step 1.

Thus, for each value K_c all combinations of values of coefficients Q and L are selected by the program that may give without optimization of result selection 6(200–4+1)(60–4+1)(99–10+1)=6063660 for halftone and 6(200–8+1)(60–4+1)(99–10+1)=5940540 for color shrunk and reconstructed images.

Maximal amount of parallel computing may be equal to a number of variants of values K_C, Q and L. Therefore, to decrease the amount of computing and further selection of optimal results the method of concessions was applied [8]. The method allows specifying a rate of concessions λ by quality increment (criterion) of each reconstructed image ensuring, thereby, that optimal vector of image quality increment and searched values Q and L is selected at maximal loss between values inside vector not more than λ, %. Therefore, maximal error at faulty selection of quality increment vector (and values Q and L for the given vector) does not exceed λ, %. Application of other methods, for example, additive or multiplicative ones of criteria check may result, in general case, in cancellation of special criteria and faulty selection of optimal vector.

Experiment results

The result of experimental program performance is 4 arrays of values of Q and L for color and halftone images specifying values of sampling coefficient Q and correction coefficient L for compression ratio K_c selected by a user. Because of low quality of image estimation by metric PSNR a part of values of arrays Q and L turned out to be inadequate; there are «gaps» (zero or start values) in coefficient values in value array. To correct the situation the arrays of values of coefficients Q and L for color and halftone images were sectionally approximated and smoothed (the example is in Fig. 3, 4).

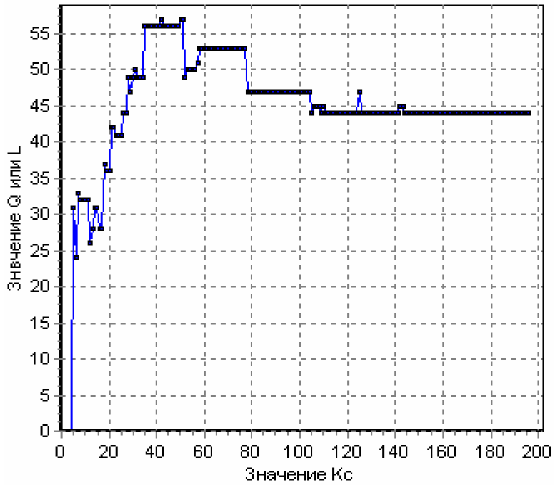

Fig. 3. *K_c – L initial curve for halftone images*

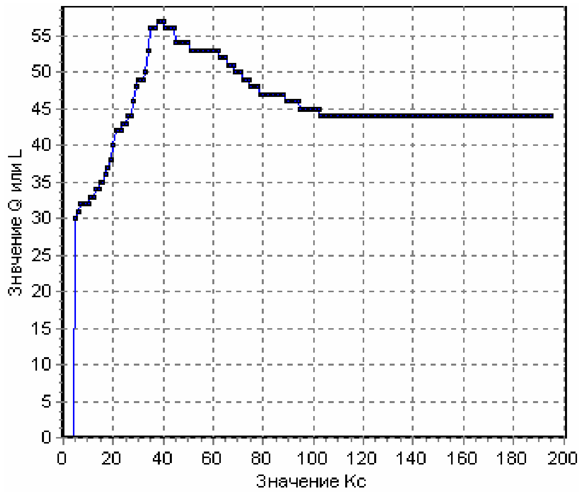

Fig. 4. *K_c – L approximated curve for halftone images*

The arrays of values of coefficients Q and L obtained after approximation and smoothing were included into quantizer of algorithm QWC.

The next stage of compression according to algorithm QWC is the stage of block coding (Fig. 1). The process of block coding of algorithm QWC in comparison with the process of block coding in the standard JPEG2000 was significantly simplified and accelerated (Table 1).

According to standard JPEG2000 HF wavelet coefficients are compressed by blocks. After compression of all HF wavelet coefficients by blocks the blocks are rearranged (according to location, value of bit planes) for being recorded into output stream buffer. In the suggested algorithm blocks are compressed in the required order therefore, the arrangement of output buffer is not required.

Table 1. *Stage of block coding of standard JPEG2000 and algorithm QWC*

Standard JPEG2000	Algorithm QWC
HF wavelet coefficients are divided into square blocks of a free size, often 32×32 or 64×64 but not more than 4096 coefficients.	HF wavelet coefficients are divided into blocks according to the levels of expansion of coefficient (conversion steps).
State of arithmetic coder is resetted.	Excluded
Block is presented in the form of 11 bit planes.	Excluded
For each bit plane the value of adjacent bits is forecasted; for each 8 bits in the plane the value of 9 bit is forecasted.	Excluded
Planes are packed in the form of bit cuts that, for example, for a block of 4096 coefficients can give from 1 to 11 passages (respectively, 1 passage at maximal compression and 11 passages at minimal one) or 4096·11=45056 searches of coefficients at minimal compression and not less than 4096 searches of coefficients at maximal one.	Only the values of coefficients themselves are packed that, for example, for block of 4096 coefficients always gives only 1 passage regardless of compression degree. On the average, the quantity of passages is 6...7 times less than for the standard JPEG2000.

The originals color image (image size 512×512 pixels, color depth 24 bits) compressed by the standard JPEG2000 (Fig. 5, *b*, PSNR=33,77; SSIM=0,89179; K_c=100) and algorithm QWC (Fig. 5, *c*, PSNR=30,71; SSIM=0,86779; K_c=100) is given in Fig. 5.

The results of comparative test of the standard JPEG2000 and algorithm QWC at mark images of a set Calgary Corpus (images were initial data in the experiment of obtaining arrays of values of coefficients *Q* and *L*) are given in Table. 2.

Table 2. *Comparison of quality of compression of standard JPEG2000 and algorithm QWC*

Master image of the set Calgary Corpus	Compression ratio	Index PSNR		Index SSIM		Difference in % in index for QWC relative to JPEG2000	
		JPEG2000	QWC	JPEG2000	QWC	PSNR	SSIM
lena.bmp	20	40,25906	33,88858	0,95792	0,95333	-18,79	-0,48
	50	36,84676	32,79163	0,92970	0,91856	-12,36	-1,21
	100	33,77797	30,71334	0,89179	0,86779	-9,97	-2,79
	150	32,07620	29,42957	0,86843	0,83540	-8,99	-3,95
	Mean value of difference by PSNR and SSIM					-12,53	-2,11
bat.bmp	20	43,94340	34,93433	0,98256	0,97225	-25,78	-1,06
	50	36,73378	31,91089	0,96110	0,95133	-15,11	-1,02
	100	32,25620	29,47235	0,92720	0,91092	-9,44	-1,78
	150	30,15820	27,39804	0,89842	0,87320	-10,07	-2,88
	Mean value of difference by PSNR and SSIM					-15,10	-1,68
papr.bmp	20	41,20751	34,94453	0,96824	0,95629	-17,92	-1,25
	50	37,36990	31,30622	0,93541	0,92038	-19,36	-1,63
	100	33,74086	28,04916	0,89790	0,87349	-20,29	-2,79
	150	31,64930	26,45925	0,85934	0,83862	-19,61	-2,47
	Mean value of difference by PSNR and SSIM					19,30	-2,04
serf.bmp	20	34,50090	29,93922	0,93553	0,88968	-14,11	-5,15
	50	29,66250	27,36494	0,82053	0,77156	-7,07	-6,34
	100	27,15076	25,78640	0,70902	0,65324	-4,40	-8,53
	150	26,05561	24,87761	0,63702	0,58829	-3,70	-8,28
	Mean value of difference by PSNR and SSIM					-7,32	-7,07
fl.bmp	20	39,26349	34,17872	0,96982	0,95998	-14,87	-1,02
	50	33,25353	31,44448	0,90210	0,90895	-5,75	+0,75
	100	30,00079	28,28929	0,83054	0,80631	-6,05	-3,01
	150	28,33185	26,63861	0,77671	0,74357	-6,36	-4,45
	Mean value of difference by PSNR and SSIM					-8,26	-1,93
Mean value of difference by PSNR and SSIM						**–12,5**	**–2,97**

According to the carried out test (Table 2) algorithm QWC loses to JPEG2000 on the average 3 % by metric SSIM, by metric PSNR – 12,5 %. Expert judgment shows that metric PSNR does not virtually give more or less adequate estimation of quality as images are weakly distinguishable visually.

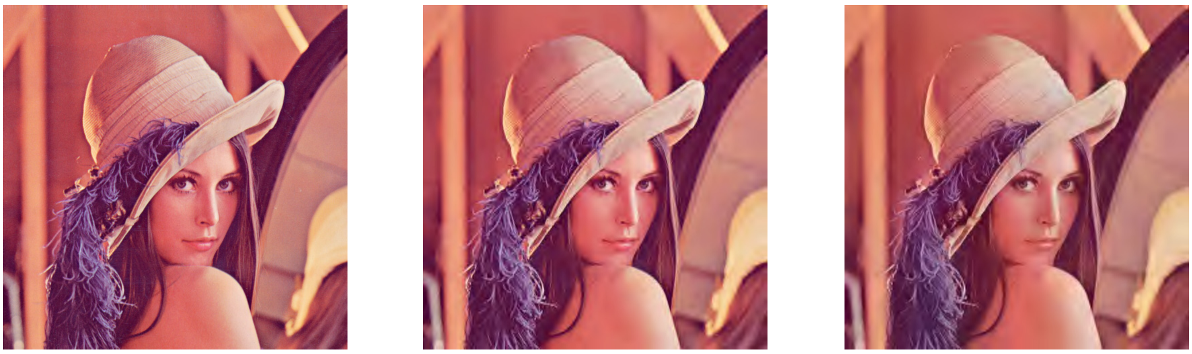

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Fig. 5. *Image: a) original; b) compressed by JPEG2000;c) compressed by QWC*

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Fig. 6. *Image area: a) original; b) shrunk by standard JPEG2000; c) shrunk by algorithm QWC*

The developed and implemented algorithm QWC shrinks efficiently the images not used in the experiment of forming arrays of values of coefficients *Q* and *L*. The area of free image (it did not take part in determining coefficients, image size 1600?1200 pixels, color depth is 24 bits) shrunk by the standard JPEG2000 (Fig. 6, *b*, SSIM=0,70929; K_c=60) and algorithm QWC (Fig. 6, *c*, SSIM=0,64978; K_c=60) is given as the example in Fig 6, *a*. Expert judgment prefers the image shrunk by QWC (Fig. 6, *c*) to JPEG2000 (Fig. 6, *b*) as algorithm QWC kept the structure of small details of image (grass stems) at shrinking.

Conclusion

A more rapid and simple algorithm of wavelet compression QWC with pyramidal diagram of sampling and coefficient keeping was developed. It possesses quality of reconstructed images (at equal degree of compression) almost equal to standard JPEG2000 and in some cases excels it. Algorithm QWC may be rather easily transferred on inexpensive hardware platform capable of processing HDTV video-flow in real time operation mode.

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