FACTA UNIVERSITATIS
Series:**Electronics and Energetics** Vol. 26, N° 2, August 2013, pp. 79 - 85
DOI: 10.2298/FUEE1302079S

ANALYSIS OF THE IMPACT OF THE QUANTIZER RANGE CHOICE ON COMPRESSION AND QUALITY OF THE RECONSTRUCTED IMAGE *

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Abstract. *In this paper an algorithm for grayscale image compression based on usage of three fixed uniform quantizers designed for discrete input samples is presented. The algorithm is based on the alternating use of these three quantizers. Number of quantization levels and quantizer range size increases from the first to the third quantizer. Experimental results show that choice of the quantizer range has an impact on system performance. While selecting a range of the first two quantizers (with a lower number of quantization levels) it is necessary to make a compromise between quality and bit rate (larger quantizer range leads to lower average bit rate but the quality of reconstructed image is also lower). It is shown that the range of the third quantizer should be set up to cover as many as possible high number of input samples making sure that the overload distortion does not become dominant.*

Key words: *uniform quantizer, algorithm for image compression, grayscale image*

1. INTRODUCTION

The main goal of image compression is to reduce redundancy and irrelevance of the image data in order to be able to store or transmit data in an efficient form. Data compression let us store more information in the same space, transfer it in shorter time or using narrower bandwidth. Image compression research aims at reducing the number of bits needed to represent an image by removing spatial and spectral redundancies as much as possible [1], [2].

Image compression is widely used in many widespread applications, such as video conferencing, video telephony, multimedia systems, processing and record keeping systems for the transmission of television images of standard and high definition, biomedicine, and other procedures. Moreover, their development is based on investing in new image compression methods research [3].

Received June 08, 2013
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***Acknowledgement**: The paper is a part of the research done within the project III 044006 supported by the Serbian Ministry of Science.

The best image quality at a given bit-rate is the finalobjective of image compression. The required quality of the reconstructed image and video is application dependent. As a measure of quality of the compressed image, *PSQNR* (peak signal-to-quantization-noise ratio) is used.

The basic idea behind digital data compression is to take the given representation of information and replace it with a different representation that takes up less space and from which the original information can later be recovered. If the recovered information is guaranteed to be identical to the original, the compression method is described as "lossless". If a certain amount of information loss is allowed, the compression method is described as "lossy".

A common feature of most images is that the adjacent pixels are correlated and thus contain redundant information. Consequently, algorithms for image compression are very often based on image dividing into blocks of pixels and each block is processed separately [4], [5], [6].

Digital signal transmission is the dominant mode of transmission in modern telecommunications. Even areas where the analog transmission was traditionally dominant, such as TV and radio, today are being digitized. A process in which the continuous range of values of an analog signal is sampled and divided into non-overlapping subranges, and a discrete, unique value is assigned to each subrange is called quantization.

Uniform quantization is the simplest, yet very popular quantization technique [7]. The design of a quantizer involves choosing the number of levels *N*, and selecting the values of decision levels and reconstruction levels (deciding where to locate them). Optimal design of quantizers was analyzed in the paper [8]. Since the signal variance (speech, audio, video) is not stationary (variance varies with time), adaptation should be applied to achieve good signal quality in a wide range of input variances. However, different combination of uniform quantizers can be applied as an alternative method (a kind ofsimple adaptation without transmiting information about variances).

In the rest of the paper there will be discussed a new method of grayscale image compression. Quantization process based on using a combination of three fixed uniform quantizers is presented in Section 2. Furthermore, the influence of quantizer range choice to the qulity of reconstructed images is considered in Section 3. Finally, the experiment is done, applying this algorithm on four standard grayscale images.

2. Application of Three Fixed Uniform Quantizers on the Grayscale Images

In this section schema and description of algorithm for image compression is given (Fig. 1). This algorithm is based on using three fixed uniform quantizers with 4, 8 and 32 boundary segments, respectively.

Quantizer deciding is defined with two thresholds T_{h1} and $T_{h2.}$. Also, these parameters define maximal pixel values for the first (N=4) and the second (N=8) quantizer that can be processed, respectively. The range of the third quantizer defines parameter T_{h3} (working area).

The algorithm is performed as follows. First, the image is divided intoa set of non-overlapping *mxm* blocks.After that, each block is being processed by sending data and decoding on the reception side.The algorithm is performed from left to right and from top to bottom. The mean pixel value of all pixels in a block (x_{av}) is calculated and quantized

$(\hat{x}_{av})$ with fixed uniform quantizer.In the coding process we use values which will be available to decoder, to minimize the reconstruction error.

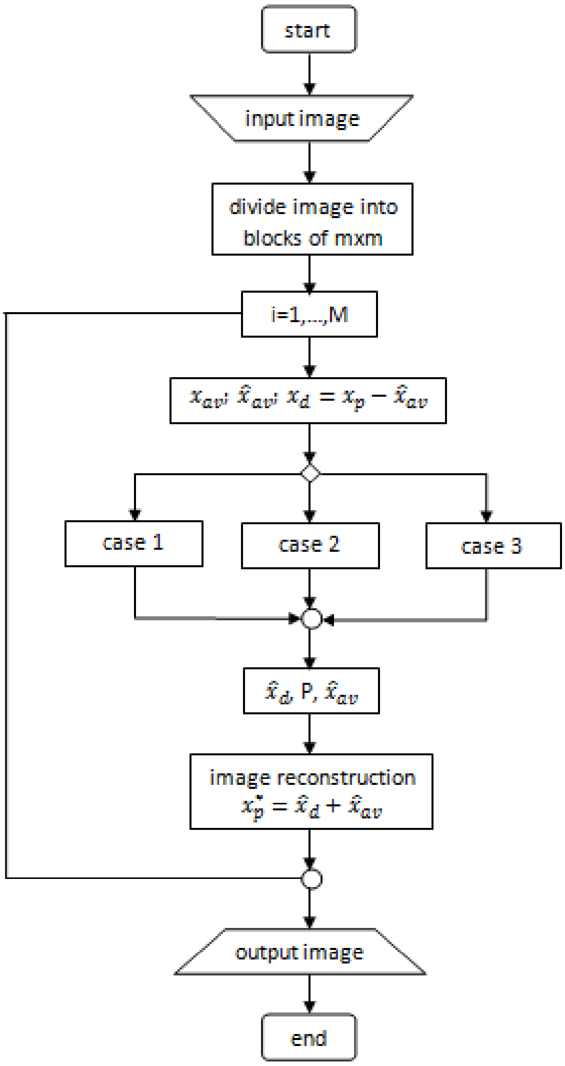

Fig. 1 Proposed algorithm for image compression

So, all pixel values x_p in a block are substituted with x_d that is defined as:

$$x_d = x_p - \hat{x}_{av} \quad (1)$$

In the next block of algorithm we define the process of quantizer selecting:

case 1: if all pixel values are lower than T_{h1}, quantizer Q_1 is used.
case 2: if at least one pixel has a value higher than T_{h1} and all values are lower than T_{h2}, quantizer Q_2 is used.
case 3: if at least one pixel value is higher than T_{h2}, quantizer Q_3 is used.

After the process of quantization, the quantized values $\hat{x}_{av}$ and $\hat{x}_d$ are transmitted to the receiver. In this step we also send extra bits P (notification bits) from the set {0,10,11} indicating which of the offered quantizers is used. The last step is image reconstruction. Reconstructed pixel value x_p^* is:

$$x_p^* = \hat{x}_d + \hat{x}_{av} \tag{2}$$

With ^ are denoted quantized values and with * are denoted reconstructed values available to decoder.

Compression quality of the reconstructed image will be described with the total average bit-rate that can be calculated according to the relation:

$$R_{av}[bpp] = [N_1(r_{av} + N_b r_1 + r_{p1}) + N_2(r_{av} + N_b r_2 + r_{p3}) + N_3(r_{av} + N_b r_3 + r_{p3})] / N_{pixels} \tag{3}$$

where *bpp* is an abbreviation for bits per pixel.

We introduced the following parameters (indices 1, 2 and 3 are related to the first, second and third quantizer): r_{av}, r_i and r_{pi} denote the number of bits that is used for transmission $\hat{x}_{av}$, $\hat{x}_d$ and P, respectively. In the end, N_i, N_b and N_{pixels} denote the total number of blocks used by a certain quantizer, total number of pixels in each block and total number of pixels in an image.

3. Experimental Results and Discussion

The quality of the reconstructed image is measured with *PSQNR*, which is defined with:

$$PSQNR = 10\log_{10}\left(\frac{x_{max}^2}{MSE}\right) \text{ [dB]} \tag{4}$$

where x_{max} is the maximal pixel value of the original image (for grayscale images x_{max} =255) and $MSE = (1/N_{pixels}) \cdot \Sigma(x_p - x_p^*)^2$ is the mean square error between the original and the reconstructed images, where summation is done for all pixels in the image.

In this section, experimental results obtained by applying algorithm from previous section on four standard test images of dimension 512x512pixels (N_{pixels})(Lena, Street, Jet and Boat) are given. Pixels of an image can take integer values from 0 to 255. Also, the mean value of each block can take values in the same range and it is coded with 64 levels (r_{av}=6). Since, the quantized value represents the difference between two aforementioned values, the maximal input range of quantizers is [-255,255]. As a result, the value of parameter T_{h3} is set to 255 in the beginning.The image is processed by blocks of 4x4 pixels (m=4). Parameters r_{pi} (i=1,2,3)can take values 1or 2, depending on the corresponding quantizer frequency occurance (a quantizer with the highest frequency occurance is marked with 1 bit, and other two quantizers with 2). Also, parameters r_i (i=1,2,3) can take values 2, 3 and 5, respectively.

From Table 1, we can see that the best results (in consideration is taken the ratio between compression quality and bit rate) achieved for T_{h1} and T_{h2} are (4, 20) and (6, 16).

In order to determine the best ratio between compression quality and bit rate it should be noted that *PSQNR* values increase/decrease for 5.5 dB by changingthe bit-rate for 1 bit [6]. The optimal values of T_{h1} and T_{h2} show that samples in the region around zero we need to cover with as many as possible high number of representational levels in order to reduce the quantization error. A single sample, in our case, is the difference between pixel value and the mean pixel value of all pixels in the observed block. This observation proves weighting function from paper [4] which gives extremely high probability occurrence for samples in the range around zero.

Table 1 Experimental results for the three fixed uniform quantizers T_{h3}=255

	T_{h1}	4	4	4	4	6	6
	T_{h2}	8	16	20	12	12	16
Lena	*PSQNR*[dB]	38.0986	40.1399	40.5517	39.4493	39.4200	40.1494
	R_{av}[bpp]	4.3998	3.9127	3.7984	4.0654	3.8542	3.7015
Street	*PSQNR*[dB]	36.4580	38.5828	39.3554	37.5173	37.5110	38.5852
	R_{av}[bpp]	5.0071	4.2921	4.0739	4.6077	4.5400	4.2244
Jet	*PSQNR*[dB]	38.8864	40.1069	40.3966	39.5793	39.5090	40.0550
	R_{av}[bpp]	3.8934	3.6354	3.5547	3.7436	3.5995	3.4912
Ship	*PSQNR*[dB]	38.8983	40.4841	40.8493	39.8172	39.7470	40.4369
	R_{av}[bpp]	3.9820	3.6252	3.5393	3.7618	3.6345	3.4979

Now we will take in consideration the influence of reducing maximal range of third quantizer on system performance. Results for T_{h3}=255, 159, 95 and 79 are shown in Table 2.

Experimental results show that system performance increasing with the decreasing value of parameter T_{h3}. Decreasing of T_{h3} make sense to a certain thresholdwhen the overload distortion of third quantizer becomes dominant that leads to decreasing performance of the whole system. Furthermore, experimental results show that optimal threshold value T_{h3} is about 90.

Such combined usage of three fixed uniform quantizers, the kind of simple adaptation, is considered. Experimental results show unexpectedly better performance (both in quality and at high average bit rate) compared to the previous solution in which the classic adaptation is done [6] (in the case of classic adaptation, information about variance must be transmitted). The obtained results show the gain compared to the results of the application of fixed piecewise uniform quantizer [4].

Table 2 Experimental results for the three fixed uniform quantizers using optimal values for T_{h1} and T_{h2} and for different values ofT_{h3}

	T_{h1}	4	6	4	6	4	6	4	6
	T_{h2}	20	16	20	16	20	16	20	16
	T_{h3}	79	79	95	95	159	159	255	255
Lena	*PSQNR*[dB]	44.716	45.716	45.016	45.891	43.571	43.734	40.551	40.149
	R_{av}[bpp]	3.7984	3.7015	3.7984	3.7015	3.7984	3.7015	3.7984	3.7015
Street	*PSQNR*[dB]	45.549	46.483	44.825	45.328	42.450	42.113	39.355	38.585
	R_{av}[bpp]	4.0739	4.2244	4.0739	4.2244	4.0739	4.2244	4.0739	4.2244
Jet	*PSQNR*[dB]	45.566	46.042	46.154	46.580	43.819	43.747	40.396	40.055
	R_{av}[bpp]	3.5547	3.4912	3.5547	3.4912	3.5547	3.4912	3.5547	3.4912
Ship	*PSQNR*[dB]	44.137	44.495	45.272	45.630	43.972	43.858	40.849	40.436
	R_{av}[bpp]	3.5393	3.4979	3.5393	3.4979	3.5393	3.4979	3.5393	3.4979

Three images from Fig. 2 after compression with described algorithm (T_{h1}=6, T_{h2}=16, T_{h3}=95) are shown in Fig. 3. The original and the reconstructed images almost have no visual difference.

Fig. 2 The grayscale images, size 512x512 pixels, a) Lena, b) Jet, c) Street

Fig 3 The grayscale images from Fig. 1 after compression with the described algorithm (T_{h1}=6, T_{h2}=16, T_{h3}=95)a) Lena, b) Jet, c) Street

4. CONCLUSION

This paper discussed the application of three fixed uniform quantizers in the algorithm for compression of grayscale images. System performance (*PSQNR* and *R*) is strongly influenced by the proper selection of the range of all three quantizers. The obtained optimal values for T_{h1} and T_{h2} (4, 20) and (6, 16) show that the region around zero needs to be covered with as many as possible high number of representation levels. T_{h3}=95 indicates that the range of the third quantizer must be much narrower than the possible range of input samples [-255, 255]. This value is optimal because it does not increase the overload distortion impact of the third quantizer on the system performance reduction. This simple adaptation gives better results compared to the previous research in which the classic adaptation is done.

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