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Quantizer design for multilevel BTC

Absract. *In this paper a novel image compression method based on Block Truncation Coding technique is presented. The essence of this method is the designing of both, fixed and adaptive, multilevel quantizers and their appliance for discrete input. Experimentaly obtained results show that usage of compression based on this method provide lower bit rate values comparing to the previosly BTC-based results, while attaining requested level of quality.*

Streszczenie. *Zapropnowano nową metodę kompresji obrazu bazująca na technice BTC. Ideą tej metody jest zaprojektowanie wielopoziomowych kwantyzerów stałych i adaptacyjnych. Eksperymenty potwierdziły, że uzyskano lepszą przepływność bez pogorszenia jakości. (**Projekt wielopoziomowego kwantyzera do kompresji obrazu**)*

Keywords: image compression, block truncation coding, multilevel BTC
Słowa kluczowe: kompresja obrazu, metoda BTC.

Introduction

The amount of data used to represent image is reduced to meet a bit rate requirement, while the quality of the reconstructed image satisfies a requirement for a certain application in a process called image compression. The complexity of computation involved can be applied for desired application properties.

The required quality of the reconstructed image and video is application dependent. In medical diagnosis and some scientific measurements, we may need the reconstructed image and video to mirror the original image and video. This type of compression is referred to as lossless compression. In application, such as motion picture and television (TV), a certain amount of information loss is allowed. This type of compression is called lossy compression.

There are several image compression methods applied in practice [1]. BTC is lossy compression method for graysacle images, introduced by Delp and Mitchell [2,3]. The method is based on attaining the statistical characteristics of pixels [4,5]. Many efficient compression methods are developed based on BTC later [6].

Originally with BTC an input image is first partitioned into non-overlapping pixel blocks, and then two-level quantizer is designed for quantizing each pixel block, while threshold and two representation levels are adopted to the local statistics. For each pixel in block, representation levels *a* and *b* are calculated as:

(1) $$a = \overline{x} - \overline{\sigma}\sqrt{\frac{q}{m-q}}$$

(2) $$b = \overline{x} + \overline{\sigma}\sqrt{\frac{m-q}{q}}$$

where $\overline{x}$ is mean value of pixel in block, $\overline{\sigma}$ is standard deviance of pixel in block, *q* is number of pixels with higher or equal values of $\overline{x}$ and *m* is total number of pixels in block

Lemma and Mitchel have provided the BTC approach called absolute moment BTC (AMBTC) [7]. With AMBTC block pixels are devided into two sets, one from pixels with greater values than $\overline{x}$ and the other from pixels with smaller values. The represents of these sets are x_H and x_L respectively.

(3) $$x_H = \frac{1}{k}\sum_{x_i \geq \overline{x}}^{n} x_i$$

(4) $$x_L = \frac{1}{n-k}\sum_{x_i < \overline{x}}^{n} x_i$$

k denote number of pixels with equal or greater values than $\overline{x}$

AMBTC [8] method have lower level of complexity and practical realization.

In this paper attention will be payed to the quantizer designing process and its adaptation according to the statistics of pixels [9]. The appliance of compression based on this method, provide significantly better results comparing to the previosly BTC-based methods.

First, related works on multilevele BTC are presented. After that, multilevel fixed quantizer appliance and its adaptation are presented. Obtainned experimental results are then discussed. Finaly conclusions are derived.

Related works on multilevel BTC

With AMBTC, mean $\overline{x}$ value and the the first absolute moment α of *nxn* (*m=nxn*) block are preserved. The first absolute moment is defined as:

(5) $$\alpha = \frac{1}{m}\sum_{i=1}^{m}|x_i - \overline{x}|$$

The reconstruction levels that preserve $\overline{x}$ and α are therefore:

(6) $$a = \overline{x} - \frac{m\alpha}{2(m-q)}$$

(7) $$b = \overline{x} + \frac{m\alpha}{2q}$$

Donson i DeWitte [10] used 2-level AMBTC output in order to define two tresholds for 3-level BTC. First, each block is quantized with respect to 2-level AMBTC algorithm. Then two tresholds t_1 and t_2 are defined as*:*

(8) $$t_1 = (3b_2 + a_2)/4$$

(9) $$t_2 = (3a_2 + b_2)/4$$

with a_2 and b_2 being the outputs of 2-level AMBTC (6) and (7). Finaly representation levels are given with a_3, $(a_3 + b_3)/2$, b_3 where

(10) a_3 = mean of pixels $\leq t_2$

(11) b_3 = mean of pixels $> t_1$

The advantage of this method is transmission of just two (a_3 and b_3) of three levels.

In paper [11] genethic algorithm is applied over previosly mentioned 3-level BTC. Also an optimal treshold determining procedure for obtaining minimal absolute error value is presented. Considering this fact, the following measurement is defined:

(12) $$MAE = \sum_{i=1}^{m-q-1}|x_i - a| + \sum_{i=m-q}^{m}|x_i - b|$$

However this procedure requires huge ammount of calculation so the practical implementation of it for multilevlel BTC is limited up to level four. In order to overcome this level number limitation, novel multi-level quantizer is proposed.

Applying of multilevel quantizer and its adaptation

The key item in our method is quantizer designing for discrete input [9]. Input samples of the quantizer Q can take N_0 discrete values, denoted with $X=\{x_1,..,x_{N_0}\}$. Probabilities of the discrete levels from the set X are $P(x_i)=p(x_i)\Delta_0=\left(\frac{1}{\sqrt{2}\sigma}\right)\exp\left(-\frac{\sqrt{2}|x_i|}{\sigma}\right)\Delta_0,, i=2,\dots N_0-1$ and $P(x_1)=P(x_{N_0})=\left(\frac{1}{2}\right)\exp\left(-\frac{\sqrt{2}x_{max}}{\sigma}\right)$. Output levels of the quantizer Q are denoted with $y_j, j=1,..,N$. It is valid that $N_0=NL$, where L is an integer. This means that L discrete input levels $X_j=\{x_{j1},\dots,x_{jL}\}\in X$ are mapped to one output level $y_j, j=1,\dots,N$.

Two quantizers Q_1 and Q_2 will be used. Q_1 is uniform quantizer with N_1 levels, while the maximal input amplitude is determined by the treshold T_h. Second quantizer Q_2 represents the union of two uniform quantizers, where their border line is determined by the treshold T_h. The first part of second quantizer has codebook size of N_1 levels while second part N_2.

The algorithm is performed from left to right and from top to bottom. The proposed algorithm has the following steps:

1. The image is divided into a set of non-overlapping *M*x*M* blocks (macroblocks).
2. The mean value of pixels in each macroblock (x_{av}^{macro}) is calculated, quantized ($\hat{x}_{av}^{macro}$) and transmitted to the receiver.
3. The macroblock M_B is divided into a set of non-overlapping mx*m* blocks $M_B=\bigcup_{i=1}^{s}M_{B_i}$ (microblocks) where *s* is the total number of microblocks within macroblock ($s=\frac{MxM}{mxm}$). The mean value of pixels in the microblock (x_{av}^{micro}) is calculated. Then, the difference between the mean value in the microblock and the quantized mean value of the macroblock is calculated,

$$x_{av}^{diff}=x_{av}^{micro}-\hat{x}_{av}^{macro} \quad (13)$$

After that, this difference is quantized ($\hat{x}_{av}^{diff}$) and transmitted to the receiver.

4. The pixel values in each individual microblock are substituted with x_{diff}, which is the difference between the pixel value x and the mean value of the microblock available in the receiver (i.e. in the decoder): $(x_{av}^{micro})^*=\hat{x}_{av}^{macro}+\hat{x}_{av}^{diff}$. Therefore, we have that

$$x_{diff}=x-(x_{av}^{micro})^*=x-\left(\hat{x}_{av}^{macro}+\hat{x}_{av}^{diff}\right) \quad (14)$$

5. If the relation $|x_{diff}|\le Th$ is valid for each pixel values from microblock then indicator bit "1" is assigned. Quantization of x_{diff} is done using quntizer Q_1 and quantized values ($\hat{x}_{diff}$) are transmitted to the receiver. Then step 7 is performed. If, for at least one from microblock values, the relation is not valid then step 6 is performed.
6. Indicator bit "0" is assigned. The relation $|x_{diff}|\le Th$ is questioned for each pixel values from microblok. If the condition is satisfied, then in corresponding bit plane " indicator bit "1" is assigned and quantization is performed by the first part of quantizer Q_2. On counter indicator bit "0" is assigned and quantization is performed by the second part of quantizer Q_2. Quantized values ($\hat{x}_{diff}$) are transmitted to the receiver.
7. Go to the step 3 until all microblocks are processed.
8. Go to the step 2 until all macroblocks are processed.

In the previous algorithm, with ^ are denoted quantized values and with * are denoted values available to decoder.

To summarize: $\hat{x}_{av}^{macro}$, $\hat{x}_{av}^{diff}$ and $\hat{x}_{diff}$ are transmitted to the receiver and these values are available to the decoder. Reconstructed pixel value on the output of the decoder is

$$x^*=\hat{x}_{av}^{macro}+\hat{x}_{av}^{diff}+\hat{x}_{diff}. \quad (15)$$

In (13) in the step 3, $\hat{x}_{av}^{makro}$ is used instead of x_{av}^{macro} since $\hat{x}_{av}^{macro}$ is available to decoder. In (14) in the step 4, $(x_{av}^{micro})^*$ is used instead of x_{av}^{micro} since $(x_{av}^{micro})^*$ is available to decoder. Therefore, in the coding process we use values which will be available to decoder, to minimize the reconstruction error (i.e. the difference between the original and the reconstructed images).

We introduced the following parameters: r_{macro}, r_{av} and r_{diff} denote the number of bits that is used for transmission of $\hat{x}_{av}^{macro}$, $\hat{x}_{av}^{diff}$ and $\hat{x}_{diff}$ respectively. N_{macro}, N_{micro} and N_{pixels} denote the total numbers of macroblocks, microblocks and pixels, respectively. The average bit rate per pixel R_{av} for fixed quantizer can be calculated according to the relation:

$$R_{av}=\frac{N_{macro}r_{macro}+N_{micro}(r_{av}+1)+N_{pixel}*r_{diff}}{N_{pixel}} \quad (16)$$

where:

$$r_{diff}=\begin{cases}2 & if\ (\forall x_{diff}\in M_{B_i})\Rightarrow|x_{diff}\le T_h| \\ 1+r_1 & if\ (\exists x_{diff}\in M_{B_i})\Rightarrow|x_{diff}>T_h|\end{cases} \quad (17)$$

for $i=1,\dots mxm$ and where:

$$r_1=\begin{cases}2, & |x_{diff}\le T_h| \\ 5, & |x_{diff}>T_h|\end{cases} \quad (18)$$

The maximal amplitude of the adaptive quantizer depends on the quantized standard deviation of the microblock $\hat{\sigma}$, i.e. $x_{max}^{adapt}=k\hat{\sigma}$, where *k* is a parameter of proportionality [9].

Step 4 of previosly described algorithm, is extended with new step 4.1.:

4.1. The standard deviation σ of such obtained values (x_{diff}) for the microblock is calculated. After that, this standard deviation is quantized ($\hat{\sigma}$) and transmitted to the receiver.

r_σ denotes the number of bits used for transmission of $\hat{\sigma}$. R_{av} for adaptive quantizer can be calculated according to the relation:

$$R_{av}=\frac{N_{macro}r_{macro}+N_{micro}(r_{av}+r_\sigma+1)}{N_{pixel}}+\frac{N_{pixel}*r_{diff}}{N_{pixel}} \quad (19)$$

where conditions (17) and (18) are still valid.

Based on qunatized standard deviation $\hat{\sigma}$ quantizers Q_1 and Q_2 are adopted in step 5 and 6.

Experimental results

The quality of the reconstructed image is measured with *PSQNR* (peak signal-to-quantization-noise ratio), which is defined as followed:

(20) $$PSQNR = 10\log_{10}(\frac{x_{max}^2}{MSE}) \quad [\text{dB}]$$

(for grayscale images $x_{max} = 255$) and $MSE = \sum(x - x^*)^2$ 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 we present experimental results, obtained by applying algorithm from previous section on three grayscale images (Lena, Airplane and Peppers), shown in Fig. 1. These images are 512x512 of pixel size and each pixel can take integer values from 0 to 255.

Based on few decisions, treshold T_h value is set on 15 (r_{macro}=6 bits and r_{av}=5 bits). In Table 2 results obtained for the proposed multilevel BTC with fixed quantizers Q_1 and Q_2 appliance are given.

Table 2. Results obtained by applying new multilevel BTC with fixed quantizers

Image	*PSQNR*	*R*
Lena	42	3.042
Airplane	42.11	3.11
Peppers	41.27	3.057

Performances of newly proposed method with adaptive quantizers Q_1 and Q_2 appliance are presented in Table 3. Presented results are compared with GA over 4-level BTC. It should be mentioned that the 4-level BTC rate for all images is R=3.5

Table 3. Results obtained by applinig new multilevel BTC with adaptive quantizers

Image	new multilevel BTC		multilevel BTC with GA	
	PSQNR	*R*	*PSQNR*	*R*
Lena	43.95	3.23	39.95	3.5
Airplane	44.83	3.3	39.72	3.5
Peppers	43.24	3.24	39.59	3.5

Conclusion

By applying newly proposed multilevel quantizer model for discrete input, *PSQNR* measurement of quality, has overachieved quality of multilevel BTC with GA for almost 4 dB. Comparing with multilevel BTC with GA transmission, we derive conclusion that not only we have achieved better quality, but also we can reach better compression for 0.25 bit. The main benefit of our algorithm is that we have reached this quality without using GA, so the practical implementation of our model is less complex, and is not limited up to given level number.

a) b) c)

Fig.1. The grayscale images, size 512x512 pixels, a) Lena, b) Airplane, c) Pepper

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