# Image Pre-processing for IDP efficiency enhancement

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*Abstract* - **In the paper is presented a new method aimed at image quality and compression ratio enhancement for images processed with IDP decomposition. For this is performed image contrast pre-processing based on segmentation of the areas, containing relatively high density of the image brightness elements. The problem is solved changing the brightness intervals of the obtained segments followed by equalization of the corresponding parts of the histogram. The idea is to smooth slightly the sharp transitions in the image, which will decrease the number of the calculated transform coefficients with big values, retaining the visual quality of the treated image. The method permits easy adaptation of the contrasting algorithm in accordance with the image contents. As a result, for same IDP parameters the compression ratio is higher and the restored image quality – better. The obtained experimental results prove the efficiency of the new method.**

*Keywords* - **Image Compression, Inverse Difference Pyramid Decomposition, Image Contrast Enhancement.**

## I. INTRODUCTION

The visual efficiency of an image compression technique depends directly on the amount of visually significant information it retains. One of the disadvantages of the image compression based on image decomposition with Inverse Difference Pyramid (IDP) (and of other compressing algorithms as well) is that for high compression ratios (more than 15) the restored image contains visible artifacts. By "visually significant" is usually meant information to which the human observer is most sensitive. The overall sensitivity depends on the image contrast, color, spatial frequency, etc [1,2,3]. One important aspect is the relationship between contrast sensitivity and spatial frequency, described by the contrast sensitivity function, which quantifies how well the Human Visual System (HVS) perceives the contrast at a given spatial frequency. As it is known, the HVS has nonlinear characteristics and is less sensitive for high frequencies [4,5]. This is particularly important point in the context of image compression: if in a compressed image strong artifacts are present, these artifacts are definitely far above the perception threshold. In order to improve the image quality is necessary to decrease the artifacts visibility to near-visibility-lossless rates.

One approach for solving the problem is to perform an image pre-processing, changing to some degree the image histogram in such a way, that to obtain restored images with better visual quality.

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The new method for image pre-processing is presented below. The paper is arranges as follows: section II contains the method for image pre-processing; section III is a brief presentation of the IDP decomposition; in section IV are given some of the obtained experimental results; section V is the conclusion.

## II. METHOD FOR IMAGE PRE-PROCESSING WITH ADAPTIVE CONTRAST ENHANCEMENT

The method is aimed at image pre-processing used to prepare the image contents for the IDP decomposition [6]. The offered method concerns adaptive image contrast enhancement, performed in two consecutive stages: (1) brightness segmentation based on image histogram analysis and (2) transformation of the pixels brightness in the so-defined segments in accordance with tables, defined using the segment histograms.

In the first stage is performed the image segmentation using the values $k_1$ and $k_2$, in result of which the image histogram is divided in three segments (A,B,C). It is supposed that the second segment (B) contains an image area in the brightness range ($k_2$-$k_1$), for which in the histogram exists clearly defined maximum. In case that there is more than one maximum with equal values, the range ($k_2$-$k_1$) corresponds to the one, closest to the dark (black) level. The objects, whose brightness values are in the range ($k_2$-$k_1$), have relatively low contrast and in order to increase it the sorresponding part of the histogram should be widened (stretched). Its limits $k_1$ and $k_2$ are calculated as follows:

- The maximum h(k) of the image histogram is identified:

$$h_{max} = \max\{h(k)\} \text{ for } k = 0, 1, 2, \ldots, k_{max}, \quad (1)$$

- The threshold value $t = \alpha\, h_{max}$, where $\alpha < 1$ (for example $\alpha = 0.9$) is defined;

- The end points of the segment $k_1$ and $k_2$ are defined in accordance with:

$$h(k) \le t \text{ for } k = 0, 1, 2, \ldots, k_1\text{-}1, \quad (2)$$

$$h(k) \ge t \text{ for } k = k_2+1, k_2+2, \ldots, k_{max}, \quad (3)$$

where $|k_2 - k_1| \ge \Delta$ ($\Delta$ – a value, set in advance).

In case, that the last condition is not satisfied the parameter $\alpha$ is decreased, for example to $\alpha$=0.8, and with the new threshold value $t=\alpha.h_{max}$ are defined the corresponding values of $k_1$ and $k_2$. If the requirement $|k_2–k_1| \ge \Delta$ is satisfied the calculation cycle is over, else it continues in the already described way.

In the second stage the brightness level k for every pixel in the three segments (A,B,C) is transformed in accordance with an individual table for every segment, as follows:

$$g(k)=\begin{cases} g_A(k) & \text{if} \quad 0\le k<k_1; \\ g_B(k) & \text{if} \quad k_1\le k\le k_2; \\ g_C(k) & \text{if} \quad k_2<k\le k_{max}. \end{cases} \quad (4)$$

Here $g_A(k)$, $g_B(k)$ and $g_C(k)$ are the corresponding tables for brightness transform in the segments A, B and C. In order to increase the contrast of the low-contrast areas, the segment B is widened, moving the points $k_1$, $k_2$ in new positions $(k_1-\delta_1)$ and $(k_2+\delta_2)$, and correspondingly the upper limit point of the segment A is moved down and the lower limit of the segment C – up. In this case $\delta_1$ and $\delta_2$ are parameters, which define the contrast enhancement of the objects in the segment B. Each table for brightness transform calculation is defined in accordance with the histogram equalization relation for the corresponding segment A, B or C with changed (stretched or skewed) brightness range:

$$g_A(k)=(k_1-\delta_1)\sum_{l=0}^{k} h_A(l), \quad (5)$$

$$g_B(k)=(k_2-k_1+\delta_1+\delta_2)\sum_{l=k_1-\delta_1}^{k} h_B(l)+(k_1-\delta_1), \quad (6)$$

$$g_C(k)=(k_{max}-k_2-\delta_2)\sum_{l=k_2+\delta_2}^{k} h_C(l)+(k_2+\delta_2). \quad (7)$$

In particular, when the histogram is uniform, i.e. for

$$h_A(k)=\frac{1}{k_1} \quad \text{for} \quad k=0,1,..,k_1-1; \quad (8)$$

$$h_B(k)=\frac{1}{k_2-k_1} \quad \text{for} \quad k=k_1,k_1+1,..,k_2; \quad (9)$$

$$h_C(k)=\frac{1}{k_{max}-k_2} \quad \text{for}\ k=k_2+1,k_2+2,..,k_{max}, \quad (10)$$

then the table for brightness transform calculation of the pixels in the segments is linear and defined with the relations:

$$g_A(k)=\left(\frac{k_1-\delta_1}{k_1}\right)k; \quad (11)$$

$$g_B(k)=\left(\frac{k_1-k_2-\delta_1-\delta_2}{k_1-k_2}\right)k+\left(\frac{\delta_2 k_1+\delta_1 k_2}{k_1-k_2}\right); \quad (12)$$

$$g_C(k)=\left(\frac{k_{max}-k_2-\delta_2}{k_{max}-k_2}\right)k+\left(\frac{\delta_2 k_{max}}{k_{max}-k_2}\right). \quad (13)$$

In this case the brightness levels in the range $(k_1, k_2)$ are stretched following linear relation and accordingly the levels in the intervals $(0, k_1-1)$ and $(k_2+1, k_{max})$ are skewed.

In the cases, when $k_1 = 1$ or $k_2 = k_{max}$ the image histogram is divided in two segments A и B only, which are processed with similar way as the already described one for three segments. In this case the dynamic range of the segment A, containing the low-contrast object is stretched, and correspondingly the second segment is skewed. The contrast enhancement of color images in R, G, B format is performed after their transformation in Y, Cr, Cb format, after which the Y component is treated in accordance with the already presented way. After that the three Y, Cr, Cb components are transformed back in R,G, B format.

## III. IMAGE COMPRESSION WITH TWO-LEVEL IDP

The essence of the method for grayscale image compression with two-level IDP decomposition is as follows. At first, the image matrix is divided in square sub-images. If every block is presented as a matrix [B(8)] with size 8x8, after lossy compression it is approximated with the matrix $[\hat{B}(8)]$ with same size, presented as:

$$[\hat{B}(8)]=[\hat{B}_0(8)]+[\hat{E}_0(8)], \quad (14)$$

where $[B_0(8)]$ and $[\hat{E}_0(8)]$ are matrices with size 8×8. The first matrix $[\hat{B}_0(8)]$ is the "zero" approximation of [B(8)], and the second one, $[\hat{E}_0(8)]$ is a difference matrix, representing the approximation error. The matrix $[\hat{B}_0(8)]$ for the "zero" IDP level is calculated using two-dimensional DCT transform:

$$[\hat{B}_0(8)]=[C(8)]^t[\hat{S}_0(8)][C(8)], \quad (15)$$

where [C(8)] is a DCT matrix with size 8x8 and coefficients:

$$c(i,j)=A(i)\cos[\tfrac{1}{16}(2j+1)]\, i\,\pi], \quad (16)$$

$$A(i)=\begin{cases}\sqrt{1/8} & \text{for} \quad i=0; \\ 1/2 & \text{for} \quad i=1,2,..,7.\end{cases} \quad (17)$$

$$\hat{s}_0(u,v)=m_0(u,v)s'_0(u,v) \quad \text{for}\ u,v=0,1,..,7 \quad (18)$$

are the coefficients of the truncated transform $[\hat{S}_0(8)]$, and

$$m_0(u,v)=\begin{cases}1 & \text{if} \quad (u,v)\in V_0; \\ 0\text{ - in other cases,}\end{cases} \quad (19)$$

are the elements of the binary matrix $[M_0(8)]$ with size 8×8, defining the area $V_0$ of the retained coefficients of the transform $[\hat{S}_0(8)]$.

In the relation (Eq.18) $s'_0(u,v)$ are the coefficients of the restored transform $[S'_0(8)]$, which is defined from the matrix [B(8)] of the original sub-block with two-dimensional direct DCT and quantization/dequantization of the obtained spectrum coefficients' values:

$$[S_0(8)]=[C(8)][B(8)][C(8)]^t, \quad (20)$$

$$s_{0,q}(u,v)=Q_0[s_0(u,v)],$$

$$s'_0(u,v)=Q_0^{-1}[s_{0,q}(u,v)], \quad (21)$$

Here $Q_0[\bullet]$ and $Q_0^{-1}[\bullet]$ are the corresponding operators for quantization/dequantization of the spectrum coefficients calculated for the sub-blocks in the "zero" IDP level.

The calculation of the matrix $[\hat{E}_0(8)]$ in the first IDP level starts with the calculation of the difference matrix:

$$[E_0(8)]=[B(8)]-[\hat{B}_0(8)]=\begin{bmatrix}[E_0^1(4)] & [E_0^2(4)] \\ [E_0^3(4)] & [E_0^4(4)]\end{bmatrix} \quad (22)$$

The matrix $[E_0(8)]$ is divided in four sub-matrices and for each is calculated the corresponding transform, using two-dimensional direct Wash-Hadamard transform:

$$[S_1^k(4)] = [H(4)][E_0^k(4)][H(4)] \text{ for } k = 1, 2, 3, 4. \quad (23)$$

Here $[H(4)]$ is a Wash-Hadamard matrix with size 4x4:

$$[H(4)] = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix}. \quad (24)$$

The coefficients of the truncated approximated transform are calculated in accordance with:

$$\hat{s}_1^k(u,v) = m_1(u,v)s_1'^k(u,v), \text{ for } u,v = 0,1,2,3, \quad (25)$$

where

$$m_1(u,v) = \begin{cases} 1 \text{ if } (u,v)\in V_1; \\ 0 \text{ - in other cases,} \end{cases} \quad (26)$$

are the elements of the binary matrix $[M_1(4)]$ with size $4\times 4$, defining the area $V_1$ of the retained coefficients in the $[\hat{S}_1^k(4)]$ transform.

In the relation (Eq.25) $s_1'^k(u.v)$ are the coefficients of the restored transform $[S_1'^k(4)]$, obtained after quantization and dequantization:

$$s_{1,q}^k(u,v) = Q_1[s_1^k(u,v)],$$

$$s_1'^k(u,v) = Q_1^{-1}[s_{1,q}^k(u,v)]. \quad (27)$$

Here $Q_1[\bullet]$ and $Q_1^{-1}[\bullet]$ are operators for quantization and dequantization of the spectrum coefficients in the first IDP level. From the transform $[S_1'^k(4)]$ with two-dimensional inverse Walsh-Hadamard transform is defined the matrix:

$$[\hat{E}_0^k(4)] = (1/16)[H(4)][S_1'^k(4)][H(4)]. \quad (28)$$

Then the matrix $[\hat{E}_0(8)]$ for level "one" of the decomposition (Eq.14) is obtained in accordance with (Eq.25) for k = 1, 2, 3, 4:

$$[\hat{E}_0(8)] = \begin{bmatrix} [\hat{E}_0^1(4)] & [\hat{E}_0^2(4)] \\ [\hat{E}_0^3(4)] & [\hat{E}_0^4(4)] \end{bmatrix}. \quad (29)$$

The values of the retained spectrum coefficients from same IDP levels for all sub-images are arranges in corresponding two-dimensional frequency bands:

- For the "zero" level each band with frequency (u,v) in the $V_0$ area is presented with the matrix $[S_{0,q}(u,v)]$, whose size m×n is defined in accordance with the sub-blocks number;
- For the level "one" each band (u,v) in the $V_1$ area is presented with the matrix with size m×n:

$$[S_{1,q}(u,v)] = \begin{bmatrix} [S_{1,q}^1(u,v)] & [S_{1,q}^2(u,v)] \\ [S_{1,q}^3(u,v)] & [S_{1,q}^4(u,v)] \end{bmatrix}, \quad (30)$$

where $[S_{1,q}^k(u,v)]$ for k = 1, 2, 3, 4 is sub-matrix with size (m/2)×(n/2).

The calculated spectrum coefficients from all bands in the two IDP levels build an inverse pyramid. The coefficients from each band are arranged sequentially in one-dimensional massif with length (4+64)×mn. The numbers in this massif are treated with adaptive RLE followed by modified Huffman coding and in result is obtained the compressed massif. The data is decompressed performing the already described operations in reverse order. The compression coefficients are controlled by the quantization coefficients set for every pyramid level and with the selected elements of the matrices $[M_0(8)]$ и $[M_1(8)]$.

## IV. EXPERIMENTAL RESULTS

The software implementation of the presented method confirmed its efficiency. The experiments were performed with significant number of test images. Here are presented the results, obtained for the test image "Lena" (512×512 pixels, 8bpp). The changes in the IDP performance are significant and they concern the compression ratio and the quality of the restored image. The parameters used for the histogram segmentation are as follows: $k_1$=16, $k_2$=24 and the corresponding segment was given the value 10, i.e. the segment length was stretched approximately with 7%. The visual image quality is unchanged. The results represent the change of the restored image quality and the increased compression ratio for same IDP quality factors. In Table 1 are presented the results obtained for the compression ratios in the range from 6 to 65. The mean CR increase for the image "Lena" is 0.92; for some images (for example – test image "Fruits" this change is 3,5 and for "Peppers" it is more than 5).

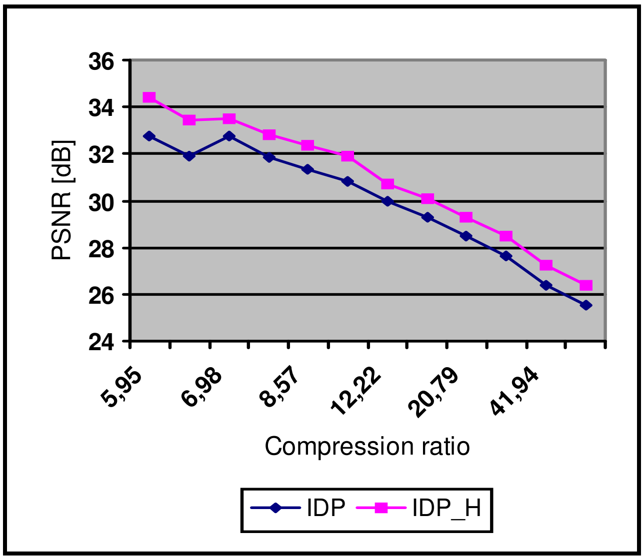


Fig. 1. Comparison of the obtained image quality for same compression ratios (Image "Lena")

For the research was used the 100-stage quality factor (QF) set used for the IDP decomposition research, defined by a number of parameters (QF1 is for best quality and smallest compression, QF100 – correspondingly for worst quality and highest compression ratio). This set of parameters comprises the number of pyramid levels, the approximation transform (DCT or WHT), the quantization values, the used transform coefficients (the binary matrices [$M_0(8)$] and [$M_1(4)$]), the scanning arrangement for same spatial frequencies, etc. In result of the histogram modification the quality of the restored images was improved in average with more than 1 dB. In Fig. 1 and 2 are presented the results obtained for same compression ratios and the improved quality for same quality factors. The characteristics of results, obtained for the other test images are similar with those for "Lena ". The test images « Lena » and « Fruits » are presented in Fig. 3.

TABLE 1. Influence of the Histogram Change on the CR.

| QF | CR | CR_HM | Δ CR |
|---|---|---|---|
| 40 | 5,95 | 6,39 | 0,44 |
| 45 | 6,35 | 6,77 | 0,44 |
| 50 | 6,98 | 7,46 | 0,48 |
| 55 | 7,82 | 8,29 | 0,47 |
| 60 | 8,57 | 9,03 | 0,46 |
| 65 | 9,23 | 9,72 | 0,49 |
| 70 | 12,22 | 12,68 | 0,46 |
| 75 | 16,21 | 16,74 | 0,53 |
| 80 | 20,79 | 21,58 | 0,79 |
| 85 | 30,43 | 31,17 | 0,74 |
| 90 | 41,94 | 43,39 | 1,45 |
| 95 | 65,26 | 68,00 | 2,75 |
| 100 | 78,16 | 80,66 | 2,50 |

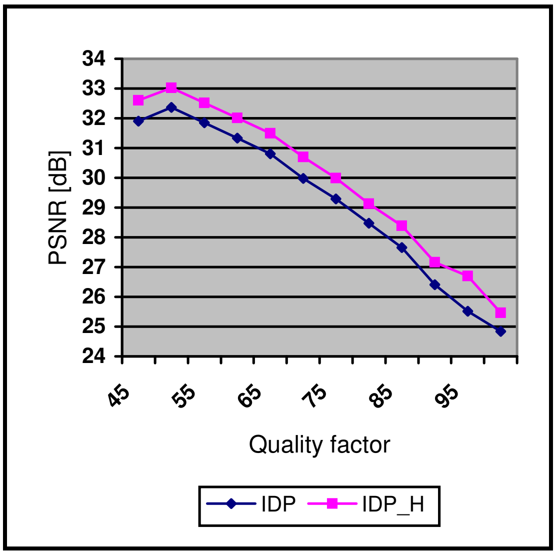


Fig.2. Influence of the histogram modification on the PSNR (Image "Lena").

Fig. 3. Test images "Lena" and "Fruits"

## V. CONCLUSION

The experimental results proved the efficiency of the proposed approach. In result of the performed research work the following conclusions are defined:

- The histogram modification influences the IDP compression in all range of the settled quality factor (QF) set;
- The compression ratio (CR) for all tested images was increased;
- The quality of the restored after IDP compression image is better;
- The dual influence (CR/image quality) practically moves the QF scale with more than 4 positions, i.e. for example, the performance for QF50 for the test image "Lena" in result of the pre-processing is equivalent to the performance of QF46 regarding the restored image quality and to the performance of QF54 regarding the CR. The results for other test images like "Fruits" and "Peppers" are similar;
- The new method proved its qualities for grayscale images. The results, obtained for color images are good too, but as it is known, the characteristics of the HVS for color images are different from those for grayscale ones and detailed research should be performed specially for such applications.
- The method for histogram modification accordingly the image contents could be used for better contours extraction.

## VI. ACKNOWLEDGEMENT

This paper was supported by NSF of Bulgarian Ministry of Education and Science (Contract ВУ-МИ-104).

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