Adaptive Fuzzy Filter for Reduction of Blocking Artifacts in Images Compressed with IDP Decomposition

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Abstract: In the paper is offered a new approach for blocking artifacts reduction in still images, processed with 2-level IDP Inverse Difference Pyramid (IDP) decomposition, based on DCT and Walsh-Hadamard orthogonal transforms. For this purpose was developed a two-dimensional fuzzy digital filter, whose performance changes in accordance with the image contents, framed by the filter window, and depending on the compression ratio and the maximum approximation error, obtained in result of the IDP decomposition. The experimental results show, that the block artifacts in the restored images are reduced without visual deterioration of the image sharpness. The main advantages of the new filter are its low computational complexity and the ability for adaptation in accordance with the image contents. In the paper are presented the results of the filter performance on JPEG-compressed images. The advantages of the new filter and its abilities for quality improvement of images with blocking artifacts are presented.

Keywords: Deblocking Filter, Two-dimensional Adaptive Fuzzy Filter (2DAFF), Image Compression, Inverse Difference Pyramid (IDP)

1. Introduction
The block-transformed techniques for image coding, based on orthogonal transforms, may generate significant distortions, called blocking artifacts [5,16] and this effect is accentuated at high compression ratios. These artifacts display themselves as artificial boundaries between adjacent blocks or around sharp transitions in the processed images. The distortions of the second kind, called ringing artifacts, are a result of the Gibbs effect and depend on the quantization of the used transform coefficients. In order to minimize the artifacts in the decompressed images are already developed significant number of methods for pre- and post – processing [2-13]. The methods in the second group could be classified as follows: Direct linear or non-linear smoothing techniques in the spatial domain [7-10]; Combined techniques employing both edge detection or segmentation for detail classification and spatial adaptive filtering [11]; Iterative techniques based on the theory of projections on to convex set (POCS) [6,12], and Soft threshold approaches in the wavelet domain [13]. The major issues existing in the current post-processing methods can be summarized as: limitation to a certain type of artifacts, concerning the methods in the first group, mentioned above, and such with high computational complexity – included in the remaining three groups.

In the paper is offered a relatively simple and effective technique for removing various blocking artifacts using a two-dimensional fuzzy digital filter, which is quite adequate for the processing of decompressed images, obtained using Inverse Difference Pyramid (IDP) decomposition, based on DCT and Walsh-Hadamard transform (WHT) and for decompressed JPEG images. In section 2 is presented the algorithm for fuzzy filtration, in section 3 is given a brief description of the method for still image compression with IDP, in section 4 is described the approach, used for the adaptation of the filter parameters in accordance with the IDP method peculiarities, in section 5 are presented the results of the investigation on the filter performance for test images compressed with software based on the IDP method and on the JPEG standard and in the conclusion are pointed the specific features of the filter, its advantages and future applications.
2. Fuzzy adaptive digital filter

The offered approach for post-processing of decompressed still images is based on the use of fuzzy digital filters [1,3], which became very popular recently due to their specific features. The algorithm, which describes the performance of the presented two-dimensional adaptive fuzzy filter (2DAFF), using a sliding window with size MxN pixels (M=2R+1 and N=2S+1) is as follows:

\[ x_f(i,j) = \sum_{r=-R}^{R} \sum_{s=-S}^{S} \mu(i+r,j+s)x(i+r,j+s) \]

for all cases, where \( \mu \) is a membership function with parameters \( \alpha \) and \( \beta \), which define the fuzziness area. The argument \( \Delta \) is the module of the difference between the central pixel \( x(i,j) \) in the filter window and the pixel \( x(i+r,j+s) \), which is at a distance \( (r, s) \) from this pixel:

\[ \Delta(i+r,j+s) = |x(i,j) - x(i+r,j+s)| \]

for all cases.

The values of the parameters \( \alpha \) and \( \beta \) are defined in accordance with the image contents and with the kind of the distortions, which should be corrected. In the case, when they are block artifacts, due to the high compression ratio, \( \alpha \) and \( \beta \) are defined in accordance with the compression strength and the kind of the used compression algorithm. In the presented research work the 2DAFF filter is applied on images, with block artifacts, due to lossy compression based on the IPD decomposition [14] and on the JPEG standard. The IDP method is presented in brief below provided as follows. At first, the digital image matrix is divided in square sub-blocks. Every block is presented as a matrix \( [B(8)] \) with size 8x8, and after lossy compression it is approximated with the matrix \( [\hat{B}(8)] \) with same size, presented with the decomposition:

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

where \( [B_0(8)] \) and \( [E_0(8)] \) are matrices with size 8x8. The first matrix \( [\hat{B}_0(8)] \) is the “zero” approximation of \( [B(8)] \), corresponding with the first level of the IDP decomposition, and the second one, \( [\hat{E}_0(8)] \) is the difference matrix, presenting the approximation error. The matrix \( [\hat{B}_0(8)] \) for the “zero” IDP level is defined with two-dimensional inverse DCT [16]:

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

where \( [C(8)] \) is the DCT matrix with size 8x8, \( \hat{m}_0(u,v) = m_0(u,v)s'_0(u,v) \)

for \( u, v = 0, 1, . . . , 7 \)

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

\[ m_0(u,v) = \begin{cases} 1 & \text{if } (u,v) \in V_0; \\ 0 & \text{in all other cases} \end{cases} \]

are the elements of the binary matrix \( [M_0(8)] \) with size 8x8, which defines the area \( V_0 \) of the retained coefficients in the transform \( [\hat{S}_0(8)] \). In the equation (6), \( s'_0(u,v) \) are the coefficients of the restored transform \( [S_0(8)] \). The last one is defined with the matrix \( [B(8)] \) of the original sub-block, using two-dimensional direct DCT and applying quantization and dequantization of the obtained spectrum coefficients’ values:

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

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

\[ s_0(u,v) = Q_0^t[s_{0,q}(u,v)], \]

Here \( Q_0^{[\cdot]} \) and \( Q_0^{t[\cdot]} \) are correspondingly the operators for quantization and dequantization of the values of spectrum coefficients, belonging to the sub-blocks in the “zero” IDP level.

In order to define the matrix \( [\hat{E}_0(8)] \) for the next (first) IDP level, at the beginning is calculated the difference matrix, representing the approximation error:
\[ [E_0(8)] = [B(8)] - [\hat{B}_0(8)] = \\
\begin{bmatrix}
[E_0^1(4)] & [E_0^2(4)] \\
[E_0^3(4)] & [E_0^4(4)]
\end{bmatrix}
\] (10)

The obtained matrix \([E_0(8)]\) is divided in four sub-matrices and for each is defined the corresponding transform, using two-dimensional direct Walsh-Hadamard transform (WHT) \[16\]:

\[ [S^k_t(4)] = [H(4)][E^k_0(4)][H(4)] \]

for \( k = 1, 2, 3, 4. \)

Here \([H(4)]\) is a WHT matrix with size \(4 \times 4\). The coefficients of the truncated approximated transform are calculated in accordance with:

\[ s^{k}_t(u,v) = m_t(u,v)s^{k}_t(u,v), \]

for \( u,v = 0,1,2,3, \)

where

\[ m_t(u,v) = \begin{cases} 1 & \text{if } (u,v) \in V_t; \\
0 & \text{in other cases}, \end{cases} \]

are the elements of the binary matrix \([M_t(4)]\) with size \(4 \times 4\), which defines the area \(V_t\) of the retained coefficients in the transform \([S^k_t(4)].\)

In the relation (12) \(s^{k}_t(u,v)\) are the coefficients of the restored transform \([S^k_t(4)]\), obtained after quantization/dequantization:

\[ s^{k}_t(u,v) = Q_t[s^{k}_t(u,v)], \]

\[ s^{k}_t(u,v) = Q^{-1}_t[s^{k}_t(u,v)]. \]

Here \(Q_t[x]\) and \(Q^{-1}_t[x]\) are the operators for quantization and dequantization of the spectrum coefficients obtained from the sub-blocks, comprising the first IDP level. Using two-dimensional inverse WHT, from the transform \([S^k_t(4)]\) is defined the matrix:

\[ [\hat{E}_0^4(4)] = (1/16)[H(4)][S^k_t(4)][H(4)]. \]

Then the matrix \([\hat{E}_0(8)]\) for the first level of the IDP decomposition (4) is obtained using the relation (15) for \( k = 1, 2, 3, 4: \)

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

The retained and quantized spectrum coefficients from all sub-images in the same IDP level are arranged in corresponding 2D bands:

- For the “zero” IDP level each band with frequency \((u,v)\) in the \(V_0\) area is represented with the matrix \([S_{0,q}(u,v)]\), whose size \(m \times n\) is defined with the number of blocks in the processed image;

- For the next, “first” IDP level each band with frequency \((u,v)\) in the \(V_1\) area is represented with a matrix with size \(m \times n: \)

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

where \([S^k_{1,q}(u,v)]\) for \( k = 1, 2, 3, 4\) is a sub-matrix with size \((m/2) \times (n/2).\)

The values of the spectrum coefficients from all bands in the two IDP levels comprise an inverse pyramid, i.e. the number of their values increases together with the pyramid level. All coefficients belonging to each spectrum band are arranged sequentially in one-dimensional sequence. The numbers in this sequence are processed with adaptive Run-Length Encoding and modified Huffman coding \[15\], and in result is obtained the compressed data massif \(\{v_t\}.\)

The decompression of the \(\{v_t\}\) data is performed applying the already described operations in reverse order. The compression ratio is controlled changing the elements of the matrices \([M_d(8)]\) and \([M_t(8)]\), and the values of the quantization coefficients, used for the processing of the participating spectrum coefficients in every IDP level.

4. Filter adaptation

In order to decrease the block artifacts obtained in the restored image (after performing the IDP compression/decompression), the values of the parameters \(\alpha\) and \(\beta\) of the 2DAFF filter are defined by the relations:

\[ \alpha = \delta - \varepsilon, \quad \beta = \delta + \varepsilon, \]

where \(\delta\) represents the center of filter fuzziness, for which the function \(\mu(\Delta) = 0.5\), and \(\varepsilon\) defines the boundaries of the deviation from \(\delta\). The value of the parameter \(\delta\) is defined in accordance with the relation:

\[ \delta = \frac{1}{2} \left| \hat{E}_0(i,j)_{\text{max}} \right|. \]

Here \(E_0(i,j)_{\text{max}}\) is a pixel from the matrix \([E_0]\), representing the approximation error, calculated in the second IDP level. The parameters \(\varepsilon\) and \(T\) of the 2DAFF filter are selected experimentally, depending on the image compression ratio and the noise level. For this was used the information obtained at the end of the image processing with IDP, in particular, the maximum difference between the original image and its approximation. The results are significant, when the PSNR of the restored image, compared with the original one, is less than 30 dB. In these cases, the influence of the filter on the image quality is visible and the calculated PSNR is increased with 0,5 dB up to more than 1 dB, depending on the image contents. The preferred filter width (window size) is 3, for images with PSNR between 25 to 30 dB, and 5 if the
PSNR is worse. The center of the filter fuzziness should be set at ½ of the calculated maximum difference between the original and its approximation. Advantage of the IDP method is, that in the process of the image processing all this information is obtained permanently, and the setting of the filter parameters is easy.

5. Experimental results
The research was done for test images compressed with software based on the already described IDP decomposition. The processing was performed for different quality factors (QF) defined, using the corresponding sets of the participating IDP parameters (number of pyramid levels, number of retained coefficients, the values of the quantization coefficients, the 2D approximation for every pyramid level, etc.). The experimental results show, that the filter influence is more significant when the compression ratio (CR) is higher and correspondingly – the restored image quality – worse. For the investigation was used filter window with width 3, 5 and 7 pixels (the window height is always 3 pixels), and the center of the filter fuzziness had been changed consecutively from 5 to 65. For the investigation were used more than 100 images. The values of the IDP parameters were used to define a 100-stage quality-factor (QF) scale. The best quality corresponds with QF1. As a rule, the filter parameters should not be too small so that the noisy edges can be sufficiently smoothed. Since different compression ratios lead to different noise levels, the parameters were optimized to achieve the best tradeoff, taking into account the sub-image size and the maximum difference between the original image and its approximation. The used values for the main IDP parameters were:

- pyramid levels 0 and 1, with sub-images with size 8x8 and 4x4 pixels correspondingly;
- approximation - for the lower level it was CHT and for the higher one –WHT;
- retained coefficients: 4 for the lower level and 3 for the higher one;
- global division (quantization) coefficient: 4;
- global threshold for the coefficients’ values: 2.

The influence of the filter width and of the center of fuzziness is presented in Fig.1. Here one unit of the PSNR change (vertical axis) corresponds to 0,01dB. The image quality improvement starts from CR higher than 10. In all these cases the PSNR after the processing was higher and the visual quality was significantly improved. Similar results were obtained for all test images. The filter width for the tests was 3, 5 and 7. The center of the filter fuzziness area was 65. For IDP QF from 40 to 90 best performance was obtained for filter window width 3. For QF in the range 90-100 the filter window width was 7.

![Fig. 1. Image “Fruits”: 2-level IDP, CR = 35, PSNR=31 dB; window width = 3, 5 and 7 pixels](image1)

![Fig. 2a. Fragment of the test image “Fruits” after treatment with 2-level IDP decomposition: compression ratio 46, PSNR = 29,80 dB](image2a)

![Fig. 2b. Fragment of the same test image “Fruits” after filtration: PSNR = 30,70 dB](image2b)
The influence of the filter with width 3 and center of the filter fuzziness changing from 5 to 65, for different test images (“Lena”, “Pepper” and “Fruit”), is presented graphically in Fig. 3. The initial restored image quality was: $\text{PSNR}_{\text{pepper}} = 29.41 \, \text{dB}$, $\text{CR}=29.5$; $\text{PSNR}_{\text{Lena}} = 28.0 \, \text{dB}$, $\text{CR}=23.73$; $\text{PSNR}_{\text{Fruit}} = 31.4 \, \text{dB}$ (CR=27.02). In the figure one unit of the PSNR change (vertical axis) corresponds to 0.01 dB. For all test images (more than 100) in result of the filtration the PSNR was significantly improved and the visual image quality became obviously better. The mean value of the PSNR improvement for all tested images obtained with the selected filter parameters for CR over 15 was more than 0.55 dB.

Fig. 3. Image quality change after filtration (filter fuzziness center 5 - 65, window size 3).

Very good results were obtained applying the new filter to still images, processed with JPEG. In order to adapt the filter parameters to the specific features of the JPEG compression the filter performance was investigated for the whole range of 100 positions of the QF scale of MS Photo Editor. The research proved that the filter is efficient when compression ratios are higher than 10. Each restored image was compared with the original and were calculated the PSNR and the maximum difference. The basic filter parameters were set as follows: filter fuzziness center equal to $\frac{1}{3}$ of the maximum difference and filter width 5 (experimentally the center of the filter fuzziness was set to be 65).

Fig. 4. Filter influence on the restored image “Lena”, after compression with JPEG (low QFs).

Visual example of the filter performance for JPEG coded image is presented below. In order to show the changes in the processed image better, there are used enlarged fragments of the test image “Lena” (Fig. 5): The visible blocking artifacts in the image on Fig. 5a are suppressed after the filtration (Fig. 5b).

Fig. 5a. Enlarged fragment of the test image “Lena”, treated with JPEG compression (MS Photo Editor, quality factor 10).

Fig. 5b. The same enlarged fragment of the test image “Lena”, after processing with the new filter. The results show that the investigation on the new filter, performed with IDP-processed images is quite suitable for JPEG images too. This is a consequence of the IDP structure, based on the processing of sub-images with size 8x8 and 4x4 pixels in the two consecutive pyramid levels, which correspond with the block artifacts in the JPEG-processed image (8x8 pixels). The mean value of the PSNR improvement for QF lower than 30 is 0.5 dB.
6. Conclusion
The basic results of the performed investigations are:
- The filter performance is best for cases, when the compression ratio (for IDP and JPEG) is higher than 10 - for such compressions the blocking artifacts become visible and the filtration is efficient;
- The filter width should not be greater than the number of pixels in the sub-image of the processed image (for IDP - the last decomposition level). In the presented examples for IDP (for sub-image in level “one” with size 4 pixels) this width is 3, and for the cases, when only one pyramid level is used and the sub-image size is 8 pixels, better performance is obtained for filter width equal to 7; for JPEG this parameter is 5.
- The center of the filter fuzziness should be half of the maximum difference, calculated between the original and its approximation in the last pyramid level (for JPEG it is set to be equal to 65).

Advantages:
- The computational complexity of the new filter is low and it could be easily integrated for real-time implementations;
- The filter has high flexibility, because its performance adapts depending on local and global parameters: the filter fuzziness center is calculated as a part of the maximum difference (global parameter) and it analyzes and changes the single pixels values (local parameters) framed by the filter window.
- The filter performance for color images processed with IDP or JPEG is good too, but additional investigation should be performed in order to achieve better results for the processing of the specific distortions in the image color components.

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References