Fingerprints Compression with IDP

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Abstract - **In this paper new algorithm for compression of grayscale fingerprint images is presented. The algorithm is based on the Inverse Difference Pyramid Decomposition, followed by lossless compression of the obtained data. For the lossless compression is used adaptive run-length coding. The results of the compression are compared with those, obtained with software, based on the wavelet decomposition.**

Keywords – **Image coding, grayscale fingerprints compression**.

I. Introduction

The problem of effective fingerprint images compression is an object of many research and application works [1,2,3,6,8,9]. The method Wavelet Scalar Quantization (WSQ) has been adopted by the Federal Bureau of Investigations (FBI) as its standard for fingerprint compression [1]. It involves three steps: a Discrete Wavelet Transform (DWT), adaptive scalar quantization of the wavelet coefficients and a two-pass Huffman coding. The still image compression standard JPEG2000 [4] ensures even better results for fingerprints compression.

The aim of this paper is the presentation of new efficient algorithm for lossless and visually lossless compression of grayscale fingerprint images. It is based on the Inverse Difference Pyramid (IDP) [5] method for image decomposition with Walsh-Hadamard Transform. The data, obtained in result, is processed with new adaptive run-length data coding and entropy coding. In Section II are presented the main steps of the algorithm, in Section III are given the results, compared with those, obtained with the FBI free software for fingerprints compression [6] and with methods based on the JPEG2000 standard [7] and are pointed some of the main advantages of the presented method, compared with the known ones**.** Section IV presents the main applications of the method and its future development.

II. Algorithm for Image Compression

The algorithm is developed on the basis of the two-level Inverse Difference Pyramid (IDP) method for image decomposition [5]. In correspondence with this decomposition each image block [B(8)] with size 8 x 8 pixels is described with the relation:

$$[B(8)] = [\tilde{B}_0(8)] + [E_0(8)] . \tag{1}$$

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Here $[\tilde{B}_0(8)]$ and $[E_0(8)]$ are matrices with size 8x8 elements each, which represent the first and the second component of the IDP decomposition for levels p = 0,1 respectively. The first one, $[\tilde{B}_0(8)]$ is approximation of the block [B(8)], and the second one $[E_0(8)]$ is a difference matrix, representing the approximation error.

The compression algorithm is described with the following steps:

1. The image matrix is divided in blocks [B(8)], with total number m×n.
2. The component $[\tilde{B}_0(8)]$ for the level p = 0 is calculated, using the two-dimensional inverse Walsh-Hadamard Transform [4].

$$[\tilde{B}_0(8)] = (1/64)[H_0(8)]^{-1}[\tilde{S}_0(8)][H_0(8)]^{-1}, \tag{2}$$

where $[H_0(8)]$ is Walsh-Hadamard matrix with size 8x8 elements,

$$\tilde{s}_0(u,v) = m_0(u,v)s_0(u,v)\,, \tag{3}$$

is a coefficient with frequency (u,v) in the transform $[\tilde{S}_0(8)]$ of the component $[\tilde{B}_0(8)]$, and

$$m_0(u,v) = \begin{cases} 1 \text{ if } (u,v) \in V_0; \\ 0 \text{ - in other cases,} \end{cases} \text{ for u,v=0,1, ... ,7} \tag{4}$$

is the element (u,v) of the binary matrix-mask $[M_0(8)]$ with size 8×8. This mask defines the area of the retained coefficients V_0 in the transform $[\tilde{S}_0(8)]$.

In relation (3) $s_0(u,v)$ are the elements of the transform matrix $[S_0(8)]$. It is defined with the direct two-dimensional Walsh-Hadamard Transform of the block [B(8)] in accordance with:

$$[S_0(8)] = [H_0(8)][B(8)][H_0(8)] \tag{5}$$

In particular, if $m_0(u,v)=1$ and for u,v = 0,1 the total number of the retained coefficients in the area V_0 is 4.

3. The component $[E_0(8)]$ is defined for the level p = 1 in accordance with the relation:

$$[E_0(8)] = [B(8)] - [\tilde{B}_0(8)] \tag{6}$$

4. The difference matrix $[E_0(8)]$ is divided in four sub-matrices for the level p = 1

$$[E_0(8)] = \begin{bmatrix} [E_0^1(4)] & [E_0^2(4)] \\ [E_0^3(4)] & [E_0^4(4)] \end{bmatrix}, \tag{7}$$

where each is defined as follows:

$$[E_0^k(4)] = (1/16)[H_1(4)]^{-1}[S_1^k(4)][H_1(4)]^{-1} \text{ for k =1,..,4} \quad (8)$$

Here $[H_1(4)]$ is a Walsh-Hadamard Matrix with size 4x4 elements, and

$$[S_1^k(4)] = [H_1(4)][E_0^k(4)][H_1(4)] = \\ = \begin{bmatrix} s_1^k(0,0) & s_1^k(1,0) & s_1^k(2,0) & s_1^k(3,0) \\ s_1^k(0,1) & s_1^k(1,1) & s_1^k(2,1) & s_1^k(3,1) \\ s_1^k(0,2) & s_1^k(1,2) & s_1^k(2,2) & s_1^k(3,2) \\ s_1^k(0,3) & s_1^k(1,3) & s_1^k(2,3) & s_1^k(3,3) \end{bmatrix} \quad (9)$$

is the transform of the sub-matrix $[E_0^{k_1}(4)]$ with size 4x4 elements, and $s_1^k(u,v)$

5. The coefficients $s_p(u,v)$ are defined for the corresponding IDP level p of each block, [B(8)], in correspondence with Table 1.

TABLE 1.
DEFINITION OF COEFFICIENTS

Level	Type of coefficients $s_p(u,v)$	Total number of coefficients Σ_p
p = 0	$s_0(u,v)$ for u,v = 0,1	$\Sigma_0 = \sum_{u=0}^{7}\sum_{v=0}^{7} m_0(u,v) = 4$
p = 1	$s_1^k(u,v)$ for u,v = 0,1,2,3 and k = 1, 2, 3, 4	$\Sigma_1 = 4\times16 = 64$

6. The coefficients $s_p(u,v)$ are arranged from the two-level IDP blocks in corresponding sub-bands.

- for p = 0 the corresponding sub-band with spatial frequency (u,v) is described with a matrix with size m×n:

$$[S_0(u,v)] = \begin{bmatrix} s_0^1(u,v) & s_0^2(u,v) & .. & s_0^m(u,v) \\ s_0^{m+1}(u,v) & s_0^{m+1}(u,v) & .. & s_0^{2m}(u,v) \\ .. & .. & .. & .. \\ s_0^{m(n-1)}(u,v) & s_0^{m(n-2)}(u,v) & .. & s_0^{mn}(u,v) \end{bmatrix} \quad (10)$$

u, v = 0,1;

- for p = 1 the corresponding sub-band with spatial frequency (u,v) is described with a matrix with size m×n:

$$[S_1(u,v)] = \begin{bmatrix} [S_1^1(u,v)] & [S_1^2(u,v)] \\ [S_1^3(u,v)] & [S_1^4(u,v)] \end{bmatrix}, \text{ u,v = 0,1,2,3,} \quad (11)$$

where:

$$[S_1^k(u,v)] = \begin{bmatrix} s_0^{k,1}(u,v) & s_0^{k,2}(u,v) & \dots & \dots & s_0^{k,m/2}(u,v) \\ s_0^{k,\frac{m}{2}+1}(u,v) & s_0^{k_1,\frac{m}{2}+2}(u,v) & \dots & \dots & s_0^{k,m}(u,v) \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ s_0^{k,\frac{m}{2}(\frac{n}{2}-1)}(u,v) & s_0^{k,\frac{m}{2}(\frac{n}{2}-2)}(u,v) & \dots & \dots & s_0^{k,\frac{mn}{4}}(u,v) \end{bmatrix} \quad (12)$$

is a sub-matrix with size (m/2)×(n/2) and number k = 1, .., 4.

7. Each sub-band (u,v) is processed using a “meander” scan in horizontal direction (Figure 1) correspondingly for levels p = 0,1 and the obtained coefficients α_I are arranged in one-dimensional massif $\{\alpha_I\}$ for i =1,2,..,(68×m×n).

8. The numbers from the massif $\{\alpha_I\}$ are processed with adaptive RLE:
   - The histogram $h(\alpha_I)$ of the numbers α_I is calculated;
   - The “free” intervals in the histogram are calculated, where $h(\alpha_I) = 0$ for i = s, s+1, . . , k;
   - The most frequent lengths $L_0(i)$ of sequential zero values in the massif $\{\alpha_I\}$ are represented with codes, which are defined with the values of i in the “free” intervals;
   - The lengths L(i) of the series of zeros, whose values are outside the “free” intervals of the histogram $h(\alpha_I)$, are coded in accordance with the usually used for the RLE way, with code words containing the zero value and the number of its consecutive appearances;

9. The sequence $\{\beta_I\}$, prepared after adaptive RLE of the one-dimensional massif $\{\alpha_I\}$, obtained in step 8 is coded with entropy coding [3]. The compressed sequence obtained in result is $\{\chi_I\}$.

10. Each sub-band (u,v) from levels p = 0,1 obtained at the end of step 6 is processed sequentially following “meander” scan in vertical direction. After that are preformed steps 8 and 9 and at the end of step 10 the corresponding compressed data is arranged in the sequence $\{\delta_I\}$.

11. The final combination of compressed data $\{\nu\}$ representing the processed image is selected in result of the comparison of the lengths of the two sequences $D\{\delta_I\}$ and $D\{\chi_I\}$. In case, that $D\{\delta_I\} \geq D\{\chi_I\}$ is accepted that $\{\nu\} \equiv \{\chi_I\}$, else - $\{\nu\} \equiv \{\delta_I\}$. The selected sub-band scan direction is notified with a special flag bit in the compressed data header.

The decompression is performed applying over $\{\chi_I\}$ the already described operations in inverse order.

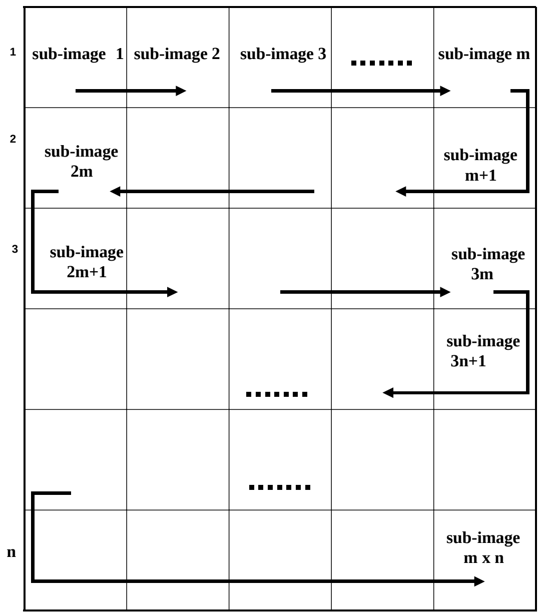

Figure.1. “Meander” scan of the sub-image blocks (horizontal direction).

III. RESULTS

The method efficiency was evaluated using the free FBI software for fingerprints compression (lossy compression) and Algovision LuraTech [7] (lossless compression). All IDP results are obtained with TKView, implementing the IDP method.

For the research were used several hundred grayscale fingerprints images with size 288x353 pixels. Example test images are shown in Figure 2.

Figure 2.a,b. Test images.

The fingerprint images have some peculiarities, which are important for their processing and compression. One of them is that their histograms differ from those of the natural pictures very much. This is shown in Figure 3. The main energy of the fingerprint histogram is concentrated in relatively small number of values, while for usual natural image this arrangement is more uniform. This helps to increase the run-length coding efficiency because there are "free" areas in the histogram. Another peculiarity is that the orientation of the lines in the image has higher correlation with some of the two-dimensional Walsh-Hadamard functions and the number of meaning and non-meaning coefficients varies depending on the direction of the sub-blocks' meander scan (in horizontal or vertical direction). In result, the compression ratio is higher when the proper direction was chosen. In order to increase the compression ratio, the scan was performed twice, and the better result was selected.

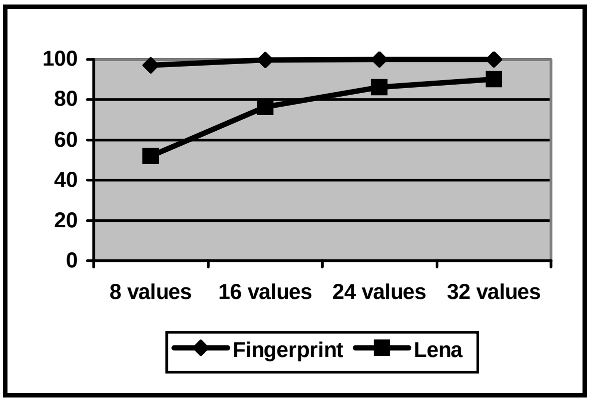

Figure 3. Parts of the cumulative histograms in % (first 32 values) for test image "Lena" and test fingerprint image from Fig.2.a.

Comparison with the FBI standard. The comparison results for visually lossless compression are presented in Figure 4.a,b.:

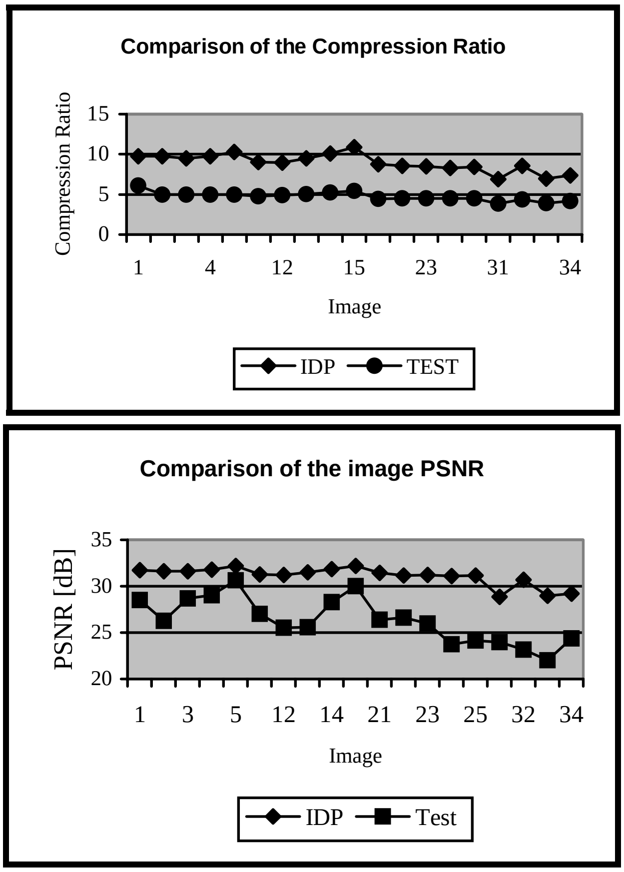

Figure 4.a,b. Comparison results for IDP and FBI standard.

The results in Figure 4 show that the compression ratio obtained with the IDP method is much higher than that with the FBI free software and together with this the quality of the restored IDP images is better (PSNR is higher).

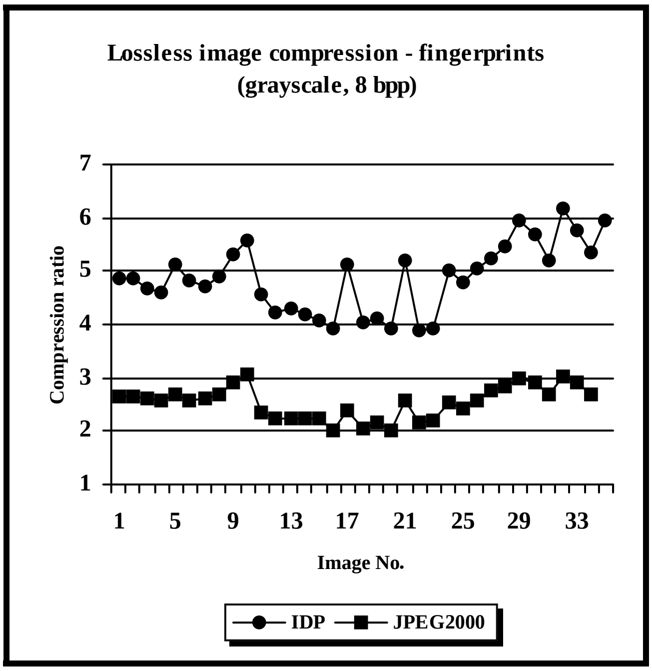

Figure 5. Graphic presentation of the compression results with IDP and JPEG2000

Comparison with Algovision LuraTech (JPEG2000). The results are shown in Table 1 and Figure 5.

TABLE 2.
LOSSLESS COMPRESSION RESULTS

No.	Image	IDP PSNR=∞	JPEG2000 PSNR=∞
1	01gs	4,88	2,64
2	02gs	4,88	2,65
3	03gs	4,66	2,63
4	04gs	4,59	2,59
5	05gs	5,11	2,70
6	11gs	4,84	2,58
7	12gs	4,70	2,61
8	13gs	4,89	2,69
9	14gs	5,33	2.93
10	15gs	5,56	3,08
11	21gs	4,56	2,34
12	22gs	4,22	2,25
13	23gs	4,29	2,23
14	24gs	4,19	2,24
15	25gs	4,07	2,24
16	31gs	3,91	2,02
17	32gs	5,13	2,40
18	33gs	4,03	2,06
19	34gs	4,11	2,17
20	35gs	3,94	2,01
21	41gs	5,21	2,56
22	42gs	3,89	2,18
23	43gs	3,94	2,19
24	44gs	5,03	2,54
25	45gs	4,80	2,43
26	51gs	5,04	2,57
27	52gs	5,25	2,75
28	53gs	5,48	2,82
29	54gs	5,96	2,99
30	55gs	5,67	2,91
31	61gs	5,21	2,70
32	62gs	6,16	3,03
33	63gs	5,75	2,92
34	64gs	5,35	2,67
35	65gs	5,95	2,97

For the comparison IDP-JPEG2000 was used *Algovision LuraTech* [7], based on the wavelet decomposition. The software offers the option “JPEG2000, lossless compression”. The obtained results show that the image quality in both cases is the same, but the compression ratio for IDP is higher.

The results of the investigation show that the IDP compression has certain advantages compared with the FBI standard and with the JPEG2000, as follows:

- The IDP method is more efficient for fingerprint images compression, due to the peculiarities in their coefficients' histograms.
- The results, concerning the image quality and the compression ratio, obtained with the IDP-based TKView are more consistent than those, obtained with the other test programs.
- The computational complexity of the IDP method (respectively - of TKView) is smaller than that of the other methods and corresponding test programs. This results from the fact that the IDP compression uses 2D Walsh-Hadamard transform, which is easier to implement than the wavelet transforms.

The same algorithm is implemented for color images as well. In this case the RGB image is presented as Y, Cr, Cb one and after that each component is processed independently. This approach is interesting for color fingerprint images.

IV. CONCLUSION

The comparison of the obtained results was made for lossless compression (JPEG2000) or for compression with very high quality (FBI test software) of the restored images. This approach was preferred because the image quality is of great importance for the selected class of images (fingerprints). As it is known, the fingerprints databases are increasing very quickly recently and the importance of their efficient compression grows as well.

The further development of the method will continue in following directions:

- Increasing the efficiency of the lossless coding of the coefficients values with arithmetic coding;
- Increasing the method efficiency with adaptive selection of the participating coefficients, retaining the restored image quality;
- Developing new algorithms for lossless compression of color fingerprint images.

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