EVALUATING REGIONS FOR DIGITAL WATERMARKING WITH PIXEL IMPACT FACTOR AND QUANTIZATION IN SPATIAL DOMAIN

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Abstract. In this article I propose a novel usage of Pixel Impact Factor model to estimate regions for embedding digital watermark in image. Watermarking is performed in spatial domain, with usage of quantization methods. Using different quantization levels allow me to introduce relationship of Pixel Impact Factor and watermark capacity.

Keywords: digital watermarking, pixel impact factor, invisible watermarks, watermark capacity

WYSZUKIWANIE REGIONÓW DO OSADZENIA ZNAKÓW WODNYCH Z WYKORZYSTANIEM 'PIXEL IMPACT FACTOR' ORAZ KWANTYZACJI W DZIEDZINIE PRZESTRZENNEJ

Streszczenie. W tym artykule proponuję nowe podejście do wyszukiwania regionów do osadzania znaku wodnego w obrazie. Osadzanie wykonywane jest w dziedzinie przestrzennej, z użyciem metod kwantyzacji. Użycie różnych poziomów kwantyzacji pozwala wskazać na związek pomiędzy współczynnikami 'Pixel Impact Factor' oraz pojemnością cyfrowych znaków wodnych.

Słowa kluczowe: cyfrowe znaki wodne, niewidoczne znaki wodne, pojemność cyfrowych znaków wodnych

Introduction

Digital watermarking [10] is a field of science being still under rapid development. The basic purpose of digital watermarks is to provide copyright protection for intellectual property that's in digital format. Digital watermarks can be measured and described by many parameters: effectiveness, fidelity, payload, redundancy, robustness, blindness of algorithm, capacity and security [1, 5]. In this work I will take into consideration only fidelity, robustness and capacity.

Fidelity [11] is one of the most important parameters for digital watermarking systems embedding invisible watermarks. This is when embedder does not want to interfere and distort original content. Fidelity is responsible for information how much difference is between copy and original image.

Robustness [2] is a parameter corresponding resistance to attacks on watermarked content. These attacks can be intended or unintended. For images these can be, for example, filtering, cropping, rotating, color changing and more. Higher robustness is better though it helps to extract watermark from attacked content.

Capacity [6] is a parameter telling how much information can we put as watermark. More information causes bigger distortion for watermarked content. But embedding more information could make robustness higher, for example using spread spectrum technic to replicate watermark inside watermarked content.

Watermarking systems parameters depends on each other. For example, less capacity means less information that we can use to watermark and it means that this watermark is less robust. These dependency can be presented as triangle (Fig. 1).
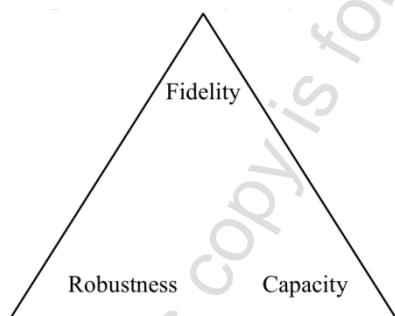

Fig. 1. Digital watermarking parameters dependency triangle

According to applications, watermarking systems balance between these parameters [7].

1.1. Background

In earlier work [12] authors proposed a Pixel Impact Factor method for improvement of fidelity measures.

Pixel Impact Factor is based on standard deviation calculated for block built around each pixel in image. Default block size is 9x9 pixels where subject pixel is in the center of block. The main idea is to use standard deviation as measure of importance of this actual pixel in fidelity measure. The highest Pixel Impact Factor (PIF) means the lowest impact on fidelity measure in this actual point of image [12] (Fig. 2).
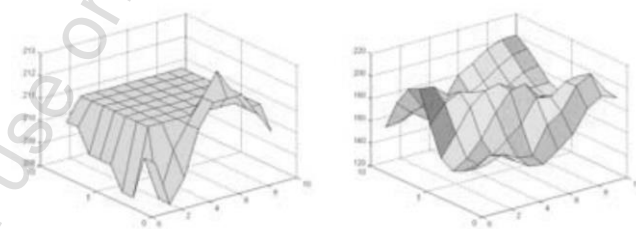

Fig. 2. Less (high Pixel Impact Factor, PIF = 1,131) and more (low Pixel Impact Factor, PIF = 0,059) distorted blocks with evaluated pixel in center

Pixel Impact Factor is prescribed as

$$PIF = \frac{1}{\sigma_{B(i,j)}} \qquad (1)$$

where $\sigma_{B(i,j)}$ is standard deviation of block B build around pixel with coordinates in image i,j. Standard deviation can be prescribed as

$$\sigma_{B(i,j)} = \sqrt{\frac{\sum_{x=1}^{M}\sum_{y=1}^{N}\left(x_{B(x,y)} - \mu_{B(i,j)}\right)^2}{(M*N)-1}} \qquad (2)$$

where: M, N – block dimensions in pixels, $x_{B(x,y)}$ – block pixel value, $\mu_{B(i,j)}$ – mean value of pixels in block, i, j – coordinates of pixel in image, x, y – coordinates of pixels in block. Mean value can be prescribed as

$$\mu_{B(i,j)} = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N} x_{(x,y)}}{M*N} \qquad (3)$$

1.2. Embedding watermark

Embedding watermark into image always distorts its structure [3] (Fig. 3). Digital watermark can be considered as a noise.
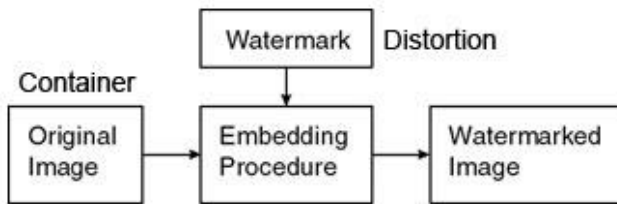
Fig. 3. Embedding watermark schema

It can be prescribed as

$$c_w = c_o + w \tag{4}$$

where: c_o – original image, w – watermark, c_w – watermarked image.

For embedding invisible watermark, the most important is to achieve very high fidelity of original and watermarked image.

$$similarity(c_o, c_w) \approx 1 \tag{5}$$

where *similarity* = 1 means that images are identical. Maximizing similarity is a goal author wants to achieve. At the same time author needs to keep reasonable capacity and robustness of watermark.

1.3. Watermarking domains

Four of the mostly used watermarking domains are [5]:

- spatial domain,
- wavelet transform domain,
- cosine transform domain,
- Fourier transform domain.

Watermarking in spatial domain means that we directly change pixels in image. One of the very first watermarking algorithms was changing least significant bit (LSB) in pixels of image [10]. Using transform domains means that transform coefficients are used to embed watermark [9]. Image is transformed, then specified coefficients are modified and transform is reversed. Using transforms domains does not allow to control direct place where watermark is embedded (opposite to spatial watermarking scheme) [4].

1.4. Perception of distortion

Considering Human Visual System (HVS) there is difference of perception of distortion inserted into the same image in different areas [1]. As an example author uses well known Lena image (Fig. 4).

Fig. 4. Comparison of distortion in different areas. Left image – highly visible distortion. Right image – hardly noticeable distortion

Both images are distorted with the same mask (100px by 100px randomly generated AWGN). Distortion on left image is much more visible than on the right [11]. Because it is the same distortion it can be treated as watermark with capacity parameter constant. So embedding the same watermark in different regions we can influence fidelity of watermarked image to original one.

$$capacity = \text{const.} \tag{6}$$

$$fidelity(c_o, c_w) = \text{maximum} \tag{7}$$

This leads to idea of finding the best region to embed watermark in terms of fidelity.

2. Assessing regions for digital watermark

Considering perception of distortion mentioned in 1.4 I propose a novel method to assess region for digital watermark embedding. This method is based on Pixel Impact Factor. Method consists of two steps:

1) Calculate PIF matrix for image,
2) Quantize PIF matrix.

Different quantization levels allows to use different strength for watermark embedding though it impacts capacity and fidelity. It is important to balance this parameters.

2.1. Calculate PIF matrix

Algorithm for calculation PIF matrix is designed as presented on diagram (Fig. 5).
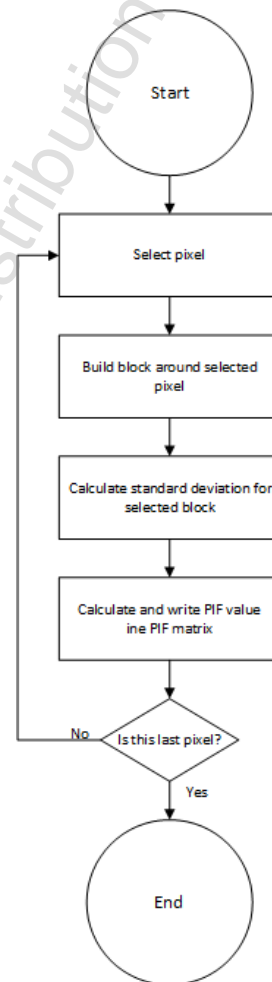

Fig. 5. Diagram calculating Pixel Impact Factor matrix

2.2. Quantize PIF matrix

As a result of calculations completed in previous step I receive a Pixel Impact Factor coefficients matrix. These values are $<0, 134.3968>$ so Pixel Impact Factor values are $<\infty, 0.0074>$. To achieve regions evaluation I use uniform quantization. This is achieved by mapping floating-point value to an integer value. Integer value is determined by quantization level value. The input range is divided into 2^n evenly spaced intervals, where n is quantization level. Input entries are first quantized according to subdivision of the input range, and then mapped to one of 2^n integers. Algorithm of quantization is presented on diagram (Fig. 6).

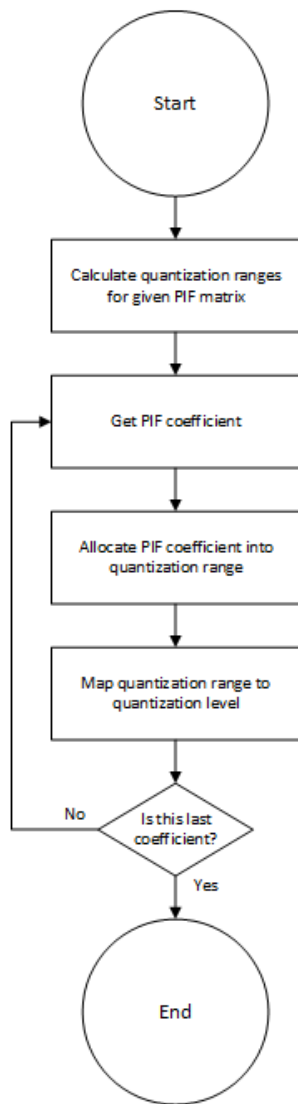Example of part of quantized matrix is presented on next figure (Fig. 7).

Fig. 6. Diagram quantize Pixel Impact Factor matrix

	1	2	3	4	5
239	16	31	31	31	31
240	16	30	27	26	29
241	16	27	27	26	28
242	16	23	26	26	25
243	16	25	30	31	27
244	16	25	30	31	27
245	16	26	31	31	28
246	16	25	31	31	27
247	16	24	28	28	25
248	16	25	31	31	26
249	17	24	28	28	25
250	17	26	29	31	31
251	17	31	31	31	31
252	17	31	31	31	30
253	17	25	27	31	31
254	17	30	31	31	31

Fig. 7. Part of quantized matrix with 2^5 quantization levels

2.3. Algorithms complexity

Time complexity of both algorithms is linear $O(n)$ and it depends on number of pixels in image. Considering colorful images the overall number of primitive calculations have to be multiplied accordingly. Because these calculations are independent, they can be done on many cores simultaneously. This trait makes use of GPU justified [8].

3. Results

I tested proposed method with well-known Lena image. As a result I managed to evaluate, through quantization matrix, regions to embed digital watermark. To better visualize, evaluated regions are presented as images (Fig. 8 – Fig. 12). Black color is used to present better regions to embed watermark, while white color opposite.

Fig. 8. Lena image quantized with quantization level 2

Fig. 9. Lena image quantized with quantization level 3

Fig. 10. Lena image quantized with quantization level 4

Fig. 11. Lena image quantized with quantization level 5

Fig. 12. Lena image quantized with quantization level 6

Changing quantization level for Pixel Impact Factor is affecting size of evaluated region. On next figure (Fig. 13) I present chart of dependency of quantization level and size of evaluated region.
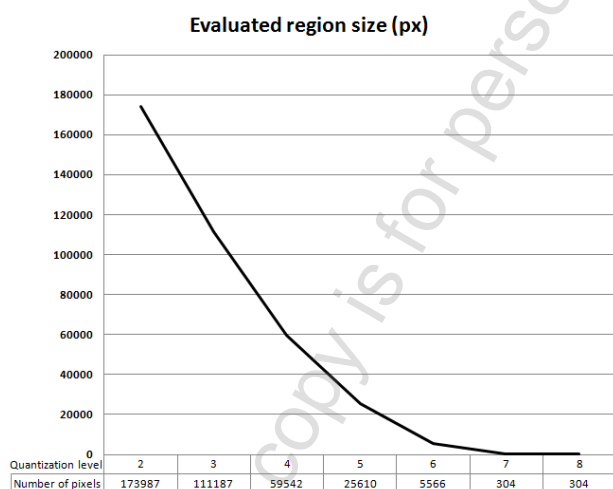

Evaluated region size (px)

Quantization level	2	3	4	5	6	7	8
Number of pixels	173987	111187	59542	25610	5566	304	304

Fig. 13. Chart of dependency of quantization level and size of evaluated region

4. Conclusions

Embedding invisible watermark is a very interesting technique in terms of protecting copyright laws. But embedding watermark is distorting image and it is very important to find regions where watermark embedding is maximally invisible.

In this article I propose novel method of evaluating regions for embedding digital watermark in spatial domain, especially for invisible digital watermarks. This method is based on calculating Pixel Impact Factor matrix and quantizing this matrix using uniform quantization. Also this method allows to associate watermark visibility and capacity. Higher level of quantization indicates lower quantity of pixels to embed watermark and higher level of invisibility, because of use lower values of Pixel Impact Factor.

5. Future Work

Using Pixel Impact Factor to evaluate regions for embedding invisible digital watermarks is a very promising method. In future work it is planned to compare Pixel Impact Factor model to different models using Human Visual System model. Comparing and extending Pixel Impact Factor model can improve usability of Pixel Impact Factor model for using in digital watermarking systems and other systems using digital signal processing.

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