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Standard Deviation-Based Image Fidelity Measure for Digital Watermarking

Abstract. *In this article we introduce new standard deviation-based image fidelity measure for digital watermarking . We demonstrate that this measure outperforms well-known image fidelity measures in terms of correlation with subjective assessment of a human. As a result it can complement well known image fidelity measures in digital watermarking.*

Streszczenie. *W tym artykule proponujemy rozszerzenie istniejących miar podobieństwa obrazów wykorzystywanych w cyfrowym znakowaniu wodnym w oparciu o miarę odchylenia standardowego. Pokazujemy również, że wyniki uzyskane przy pomocy poprawionych miar podobieństwa zachowują lepszą korelację z subiektywną oceną wskazaną przez człowieka. Poprawione miary nadają się do zastosowania w systemach cyfrowego znakowania wodnego.(**Miara podobieństwa obrazów oparta o odchylenie standardowe stosowana w cyfrowym znakowaniu wodnym**)*

Keywords: digital watermark, images similarity measures, image fidelity measures.
Słowa kluczowe: cyfrowe znaki wodne, miary podobieństwa obrazów, miary wierności obrazów

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Introduction

In today's digitalized world, the problem of protecting copyright law of electronic documents, such as images, becomes a vital challenge. Invisible digital image watermarking is one of the technologies that can solve it. In digital watermarking of images the assessment of image fidelity of watermarked image is an important, though still unsolved issue. Adding the watermark to an image affects its structure, and as a result the presence of the watermark can be noticed by incidental observer. Therefore measurement of watermarked image quality considered as distortion of original image is important topic. In invisible digital watermarking, image fidelity measures, should be designed in such a way that they reflect the subjective assessment of a human. Currently there are no standards, that consider fidelity between original and watermarked image. However, in the past many works have been presented, that dealt with signal similarity measures [1] [2] [3].

There are two approaches proposed by researchers: subjective and objective. In the first case the assessment is performed by the group of human observers. In the second one, objective mathematical measures are used [2].

Subjective measurement

Methodology of subjective measurements is based on human observation and comparison of two images. Number of observers score images similarity or quality. This method is expensive, time-consuming and inconvenient. And most important, it can't be easily implemented in automatic, real-time systems.

Objective measurement

Computer systems needed automated measures to compare two images. Objective methods are automated, mathematically defined algorithms that are designed to be independent from human observations [2]. Therefore, much effort has gone into the subject in recent years. Many algorithms consider similarity as a difference between two images [3]. Most of the tested measures are based on difference between pixel values in original and watermarked image but some are based on correlation value between pixels in original and watermarked image denoted as multiplication [3].

(1) $c_{(i,j)} = c_{o(i,j)} - c_{w(i,j)}$

(2) $c_{(i,j)} = c_{o(i,j)} * c_{w(i,j)}$

where: c – calculated difference, c_w – watermarked image, c_o - original image, i,j – pixel coordinates

For purpose of this article we will analyze and propose improvements of following (well-known) measures [4]:

- Mean Square Error (MSE):
- Peak Signal to Noise Ratio (PSNR)
- Maximum Difference (MD)
- Average Difference (AD)
- Correlation Quality (CQ)
- Image Fidelity (IF)
- Chi-square (CHI)
- Structural Similarity Index (SSIM)

Background

Digital image watermarking [5] is a method of embedding information (*w – watermark*) into image. Image, in this case, is treated as a container (*c - container*) for information. In spatial domain, a watermark is a difference between original and watermarked image. Embedding information into image introduces distortion to original content.

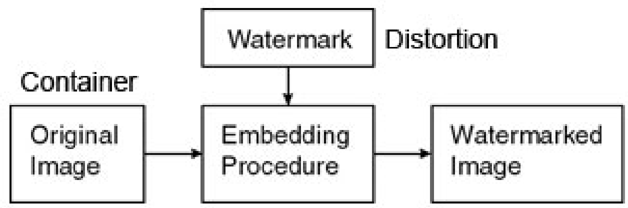

Fig. 1. Embedding watermark process

It can be prescribed as

(3) $c_w = c_o + w$

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

Considering visualization methods [6] we can use watermark to embed additional, important data, while not interfering with the container.

Proposed method

All above mentioned well-known fidelity measures base on pixel values difference or correlation [3]. Therefore, they work very well when the whole image is subjected to distortion. But they give unsatisfactory results when a part of the image is affected . Furthermore, they are insensitive to position where a watermark is applied.

To eliminate this drawback , we introduce Pixel Impact Factor (PIF) coefficient. This coefficient reflects the importance of each pixel according to its neighborhood.

Each pixel can be evaluated with pixels surrounding it. For purpose of tests we build blocks of size 9 x 9 pixels where evaluated pixel is located in the middle of the block. Example of two blocks, less and more distorted, are presented in Fig. 2.

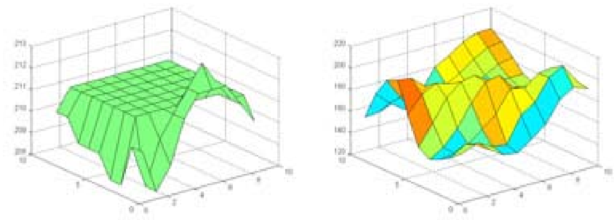

Fig. 2. Less (high Pixel Impact Factor, $\mathrm{PIF} = 1{,}131$) and more (low Pixel Impact Factor, $\mathrm{PIF} = 0{,}059$) distorted blocks with evaluated pixel in center.

PIF is calculated basing on standard deviation. Standard deviation is a statistic measure showing variation or dispersion from the expected value. Low standard deviation indicates that data points have very close values to the expected value. High standard deviation indicates much higher variation or dispersion of surrounding points of values in tested subset. If standard deviation is low, impact factor of this pixel's distortion on fidelity measure is high and if standard deviation is high, impact factor of this pixel's distortion is low, so Pixel Impact Factor is reversed standard deviation of each block.

Considering Human Visual System [7] , we know that image distortions introduced by watermarks are hardly noticeable when pixel variation and dispersion is high part and easily noticeable on flat plane [8]. Taking this into account we can conclude that pixels in blocks having higher standard deviation are a better place to embed watermark than blocks with lower standard deviation. This is reflected in our PIF measure.

Pixel Impact Factor can be prescribed as

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

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

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

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

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

For presented in Fig. 2 blocks Pixel Impact Factors are:

- left block $PIF_L=1,131$
- right block $PIF_R=0,059$

We modified every tested measure so that every pixel value form original image is multiplied by PIF. Modified equations (1) and (2) can be prescribed as

(7) $$c_{PIF(i,j)}=\left(c_{o(i,j)}-c_{w(i,j)}\right)*PIF_{(i,j)}$$

or

(8) $$c_{PIF(i,j)}=\left(c_{o(i,j)}*c_{w(i,j)}\right)*PIF_{(i,j)}$$

where: i,j – coordinates of pixel in image $c_{PIF(i,j)}$ – calculated modified value of pixel, $c_{o(i,j)}$ – original pixel value, $c_{w(i,j)}$ – watermarked (distorted) pixel value, $PIF_{(i,j)}$ – Pixel Impact Factor.

Pixel Impact Factor can be treated as a mask put on image to expose impact of each pixel on measures.

Comparison of PIF and well-known image fidelity measures

For purpose of comparison of PIF measure with well-known image fidelity measures we implemented all of the above mentioned objective well-known measures and compared with PIF. Tests were performed for 14 different images selected from the USC-SIPI Image Database [9]. Watermark was a square-shaped, 100x100 pixels window of white Gaussian noise (WGN) values. WGN values were drawn from the range of 0 to 255 (minimum and maximum signal values). In every image we have embedded a watermark in five positions: upper left corner, lower left corner, center of image, upper right corner and lower right corner. Each watermarked image has been compared to original image and the fidelity has been calculated using all measures. Sample results for image 'Lena' are presented in Table 1.

Table 1 Results of fidelity measures for image 'Lena'

	MSE	PSNR	MD	AD	CQ	IF	CHI	SSIM
upper left corner	5,827	40,477	21,000	0,407	142,926	1,000	0,048	0,999
lower left corner	5,827	40,477	21,000	0,407	142,855	1,000	0,074	0,999
center of image	5,827	40,477	21,000	0,407	142,902	1,000	0,063	0,999
upper right corner	5,827	40,477	21,000	0,407	142,850	1,000	0,073	0,999
lower right corner	5,827	40,477	21,000	0,407	142,888	1,000	0,056	0,999

For every image in tested set, measures values have been similar and expressed as standard deviation for all five positions of watermark. Results are presented in Table 2.

Table 2 Results of standard deviation of fidelity measures for watermarked images

	MSE	PSNR	MD	AD	CQ	IF	CHI	SSIM
F16	0,00	0,00	0,00	0,00	0,04	0,00	0,01	0,00
armored	0,00	0,00	0,00	0,00	0,09	0,00	0,02	0,00
baboon	0,00	0,00	0,00	0,00	0,04	0,00	0,01	0,00
desert	0,00	0,00	0,00	0,00	0,11	0,00	0,26	0,00
desert2	0,00	0,00	0,00	0,00	0,04	0,00	0,02	0,00
desert3	0,00	0,00	0,00	0,00	0,08	0,00	0,02	0,00
landscape	0,00	0,00	0,00	0,00	0,09	0,00	0,01	0,00
Lena	0,00	0,00	0,00	0,00	0,03	0,00	0,01	0,00
pepper	0,00	0,00	0,00	0,00	0,08	0,00	0,03	0,00
plane	0,00	0,00	0,00	0,00	0,05	0,00	0,01	0,00
tank	0,00	0,00	0,00	0,00	0,07	0,00	0,01	0,00
tank2	0,00	0,00	0,00	0,00	0,06	0,00	0,04	0,00
tank3	0,00	0,00	0,00	0,00	0,09	0,00	0,01	0,00
truck	0,00	0,00	0,00	0,00	0,09	0,00	0,02	0,00

Example graph for MSE measure, for every position of watermark inserted into 'Lena' image, is presented on Fig. 3

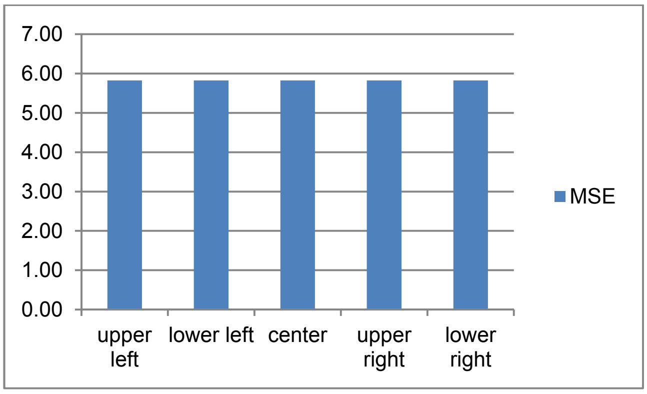

Fig. 3 MSE measure for 5 positions of watermark inserted into 'Lena' image.

Almost all tested fidelity measures are completely insensitive to the place where we embed a watermark. Only *Correlation Quality* and *Chi-square* are showing some sensitiveness for embedding watermark position.

Considering example image 'Lena' (Fig. 4 and Fig. 5) we can see that for a human observer, watermark localization strongly influences subjective fidelity

According to Human Visual System (HVS) [7] image presented on Fig. 4 should have similarity measure indicating more distortion while image presented on Fig. 5 should have similarity measure indicating less distortion.

Fig. 4. Watermark embedded in upper left corner.

Fig. 5. Watermark embedded in center of image.

Same tests as for well-known measures, above mentioned, were used to test PIF modified measures. Standard deviation values for modified image fidelity measures are presented in Table 3

Table 3 Standard deviations for modified fidelity measures

	MSE	PSNR	MD	AD	CQ	IF	CHI	SSIM
F16	7,62	0,08	0,00	0,22	0,02	0	0,05	0,001716660
armored	3,08	0,16	0,45	0,14	0,07	0	0,04	0,002113245
baboon	10,56	0,07	0,00	0,11	0,04	0	0,09	0,002905689
desert	1,43	0,05	0,89	0,09	0,09	0	0,14	0,000510514
desert2	0,85	0,01	0,00	0,04	0,04	0	0,01	0,000234118
desert3	1,54	0,02	0,00	0,04	0,07	0	0,02	0,000654672
landscape	3,41	0,03	0,00	0,14	0,07	0	0,03	0,000359143
Lena	4,67	0,07	0,00	0,14	0,03	0	0,06	0,001009316
pepper	2,55	0,03	0,00	0,09	0,06	0	0,05	0,000378491
plane	5,94	0,23	0,00	0,19	0,04	0	0,06	0,005048055
tank	3,24	0,12	0,00	0,12	0,06	0	0,04	0,001991032
tank2	4,06	0,09	0,45	0,09	0,04	0	0,14	0,003473094
tank3	4,57	0,11	0,00	0,12	0,08	0	0,05	0,001757819
truck	2,44	0,07	0,00	0,10	0,08	0	0,03	0,001422055

Results for ‚Lena' image with Pixel Impact Factor implemented are presented in Table 4.

Table 4 'Lena' image measures with Pixel Impact Factor

	MSE	PSNR	MD	AD	CQ	IF	CHI	SSIM
upper left corner	1,223	47,256	26,035	0,148	39,955	0,99993	0,009	0,21129
lower left corner	0,627	50,155	23,805	0,077	39,860	0,99996	0,009	0,21077
center of image	0,070	59,687	10,637	0,034	39,829	1,00000	0,001	0,21093
upper right corner	0,864	48,765	21,000	0,114	39,891	0,99995	0,010	0,21047
lower right corner	0,536	50,839	31,313	0,079	39,864	0,99997	0,006	0,21052

Example graph for MSE measure, for every position of watermark inserted into 'Lena' image, is presented on Fig. 6

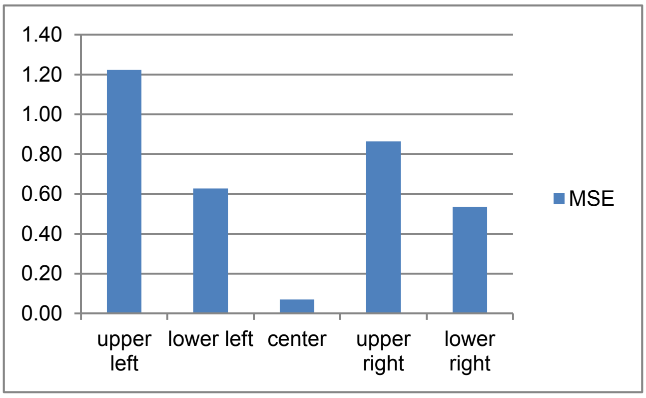

Fig. 6. Modified MSE measure for 5 positions of watermark inserted into 'Lena' image.

Fig. 6 clearly shows that MSE measure is much better for watermark inserted into center of image according to subjective assessment.

According to results presented in Table 3 and Table 4 all measures are having better results that reflects our subjective assessment against better fidelity for watermark embedded in center of Lena image.

Conclusions

Objective image fidelity measures play important role in digital watermarking systems. Many researchers have put a great effort in developing objective measures that can be implemented in computer and automated environment. Unfortunately, many of this measures, are insensitive to watermark location . In this paper we have introduced Pixel Impact Factor Measure which takes into consideration the localization of the distortion introduced by the watermark . Results shown in Table 3 and Table 4 indicate that the new measure is sensitive to the watermark location. As a result it is more suitable for the purpose of image watermarking systems, than other well-known fidelity measures.

Future work

The introduced PIF should be compared with subjective measures using large number of images with manually added watermarks in carefully selected areas in order to verify it's robustness in real life applications.

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